Boeing 737-200 Aloha, USA 1988

V. P. Rombakh

INTRODUCTION TO THE PHYSICS OF DESTRUCTION

Volgograd Bridge Russia 2010

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INTRODUCTION TO THE PHYSICS OF DESTRUCTION

In Memory of Victims of Man-made

Disasters is Dedicated

Fragments of the rail, which was destroyed during derailment, Hafield UK 2000
Four people were killed, seventy injured

Edmonds WA USA 2014

V. P. Rombach

Introduction to the physics of destruction

The basis of the physics of destruction is the hypothesis that the destruction is the result of breaking the bonds between atoms of the local group, due to the absorption of the energy of such a capacity in which the energy density of the external force exceeds the density of the binding energy. The source of this energy is a local group of atoms of the material, called the domain of destruction, in which the rate of accumulation exceeds the rate of energy dissipation. Accumulation of energy due to the transition of electrons to higher metastable atomic energy levels. Cracking or destruction becomes possible only when stimulated emission of excited atoms domain of destruction happened. The book contains the scientific and technical rationale for a more accurate experimental and theoretical evaluation of wear and residual life of structures and devices in order to prevent catastrophic destruction that based on the analysis of more than four thousand publications, of which 270 is cited. More than two hundred photographs of the results of experimental studies of materials at the nano-, meso- and macroregions, about a hundred graphs and charts used to substantiate the hypothesis. Method of assessing results of experimental research has been proposed. It is demonstrated for the destruction (including catastrophic) of aircraft fuselage, rail, bridge, pipeline, compressor disk, cable-fixing the roof. 180 graphs characterizing the process of accumulation of energy and its radiation in the riveted joints is given. A method for estimating the degree of wear, time of safe operation, and critical state of the elements of structures and devices has been suggested. It uses equation whose terms are the physical parameters of the material from which the element is made. These parameters are taken into account at designing, and changing them is controlled during operation. The method is multipurpose, as it considers all types of external influence, regardless of their destination and socheteny of the element. The book is intended for researchers concerned with strength, fracture, material scientists and technologists designed and operating structures and devises, teachers of universities and technical schools.

Vladimir Rombach
Introduction to the physics of destruction

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This book was written because of the daily care and support of my wife Berta and my sons Pavel and Oleg.

Foreword

The basis of the physics of destruction, that I have proposed, consists of the following ideas and theories.

1. The idea of J. C. Maxwell that the potential energy due to the deformation, the emission of which leads to destruction, can not be expressed only by the mechanical parameters of the material.

2. The Pauling idea about chemical bond oscillations and experimental confirmation in the coherent chemistry.

3. The theory of spontaneous and stimulated (induced) emission of light.

4. Quantum Electrodynamics.

5. The theory of dissipative structures.

6. Feynman's idea of the special behavior of the atoms in the nanoscale region

This book is a sequel to my book, "Atom Parameters and Metal Properties," which offered a new model of metal, based on two postulates.

1. A metal may consist of atoms of one element having different electron shell configurations, i.e., atoms with varying energy states may be present in the metal simultaneously. Such atoms exchange electrons and energy in the form of photons and phonons.

2. External excitation energy is distributed unevenly in the metal as a result of deformation wave interference caused by reflection from the boundaries of their heterogeneity.

3. Running and reflected strain waves form in the local area the standing waves, the impact of which on the atoms at the antinodes and nodes of the wave is different. Thus, the local region plays a role of a resonator. External influence on the atoms is particularly strong in the cavity, the dimensions of which do not exceed 137 nanometers.

This is due to the fact that at the nanoscale manifest the quantum properties of particles to describe the behavior of which can only be based on quantum theory.

These postulates are formulated on the basis of long-term studies of numerous articles, monographs, and scientific reviews.

Experimental studies refuting these postulates are found.

This allows us to give a definition of deformation waves:

Waves of deformation are an interconnected set of electromagnetic, acoustic, electronic, spin, and other kinds of waves.

In modern physics, it is established that all interactions are reduced to four types: nuclear (strong), electromagnetic, weak, and gravitational.

All processes that occur in a solid can be described on the basis of the electromagnetic interaction, using modern physical theories, of which the most accurate is quantum electrodynamics.

Hardening of a metal, and its destruction, arises at the nanoscale. In this regard, the problem of preventing man-made disasters can be solved only when accounting for changes in the interatomic interaction.

The conclusion that was made in the book runs:

1. The destruction is the result of stimulated photon radiation energy stored in local regions of the material as a result of transfer of electrons to higher metastable energy levels whose lifetime exceeds the period of external influences.

2. The formation of cracks or failure occurs when the density of the energy accumulated in the local area, exceeds the energy density in undeformed material.

3. High power radiation due to the fact that the stimulating signal is a photon, which propagates at the speed of light.

4. Strengthening of the material, its destruction emerges at the nanoscale. In connection with this the problem to prevent man-made disasters can be solved only in accounting the changes of the interatomic interaction.

Chapter I. The analysis of existing theories of strength and fracture of materials made fom the positions of modern physics; Maxwell's ideas about the problem of strength and fracture were presented; Feynman's analysis about Shuttle "Challenger" catastrophe considered; the shortcomings and mistakes of fracture mechanics were indicated.

Chapter II. Problems of strength and fracture of nanomaterials are considered; physical fundamentals of nanotechnology are formulated; electron-wave mechanism of hardening and destruction offered. The physical definition of a nanomaterial is given.

*Nanomaterial is a special dissipative quantum mechanical structure formed in the local area of the substance from three or more atoms or molecules, the ratio of surface to volume,of which is greater than 1/*137 $nm^{-1} \approx 7.297 \cdot 10^4$ cm^{-1}=9.04 eV.

Changing of the energy spectrum of the atoms, wherein the normal energy level is reduced to b times and/or zero energy level rises g times depending on the nature of the external impact takes place under the influence of the reflection electronic, electromagnetic, acoustic or other waves from the nanoregions boundary heterogeneity.

Chapter III is devoted to the nature and mechanisms of crack formation and destruction.

Considered:

1. The electron-photon interaction in a multicomponent system.

2. Features of impact fracture when: a) mechanical shock at subsonic speed; b) mechanical shock at supersonic velocity; c) mechanical shock with space velocity; d) electromagnetic shock; f) ions of hydrogen and helium implantation.

Chapter IV. The features of the aircraft fuselage damage have been studied;

Program evaluation of fatigue crack growth "NASGRO" Version 3.0 and an alternative solution to this problem was compared. Maxwell's idea about the distortion energy is realized in terms of modern physics. This energy is calculated using physical parameters of the material.

Calculations of energy cracking of fuselage riveted joints are used as an example of the application of one of the equations. Numerous graphs of the distortion energy change were built using data from experimental studies of the fuselage destruction.

CHAPTER V. A method of quantitative assessment the wear and residual life of structures and facilities is provided. It allows calculating the time for safe operation, the degree of wear, the critical state and residual life of structures and devices. It’s univesalen as it is based on accounting the changes of the interatomic interaction.

Chapter VI. The book shows that the main source of energy, the radiation of which leads to destruction, is a local field, called domains destruction. A theoretical and experimental justification of the model has been done. In this chapter invited 20 of the experimental methods for the detection and evaluation the domains of destruction and their energy.

Dear Reader!

This book is intended for professionals who design, build, spacecraft, vehicles, bridges and other structures. Each of these devices must be constructed in such a way that during its operation was not destruction happened, in which harm may be caused to human health or nature.

Service life of structures and devices should be determined with the maximum precision. To do this, it's necessary to determine the critical state, both theoretically and experimentally as precisely because any even unintended effects, lead to disaster.

Finding a reliable method of theoretical and experimental evaluation of the critical state became the goal of my research. It turned out that this is only possible at the level of modern physics, on the basis of which, lasers, computers and other electronic devices were developed and crated.

Each of you uses them without knowing how they work. However, the creators of these devices well known laws of physics, and even opened the unknown phenomena.

My presentations at scientific conferences, discussions with experts in the field of strength and fracture have shown that many of them are difficult to understand the evidence of a new method to assess the wear and residual life of equipment. These proofs are based on modern physical theories, for for understanding which requires special training. Check their validity or disprove can only such specialists.

Anyone who is interested in establishing and operating more reliable and durable equipment can read only the description of the method and help in its implementation.

I apologize for any difficulties or mistakes in the presentation and will be grateful for any comments.

Vladimir Rombakh

Introduction

The late twentieth and early twenty-first century have been marked not only by great scientific discoveries and advancements in technology, but also grand man-made disasters that carry away hundreds, sometimes thousands of lives. Mankind can not control the laws of nature to prevent natural disasters, but it can take them into account. In this paper, we will focus on the prevention of disasters involving those structures and devices that are man-made, and about the safety of their operation. The work is intended primarily for those who create and use these devices. This determined the choice of material as well as the character of its presentation.

Today each of them knows that these devices consist of atoms, and that all the properties of the material from which they are made are due to the interaction of these atoms; each also has an idea of developed scientific theories, used to make computers, and complex electronic controls. These devices are designed so that people working with them, do not necessarily know all the laws of physics on which they are based. Modern natural science is multifaceted; in each section it is so complex that years of study are required in order to learn the basics of one of its sections. It is paradoxical, but a fact, that science was simplified by the discovery of its fundamental laws.

The book by A. Einstein and L. Infeld, "The Evolution of Physics," has a second name: "The drama of ideas." It is a drama, not a triumph, because great ideas which explained physical phenomena proved wrong when new experimental facts are detected that refute them.

They were replaced by new ideas, some of which suffered the same fate. Only some of them were preserved, as new experimental findings confirm them. Some mathematical apparatus has been created and used to make forecasts which have found experimental confirmation.

Thus were discovered planets Neptune and Pluto. The reality of electromagnetic waves predicted by J.K Maxwell has been experimentally proved; the association between mass and energy confirmed, predicted by Einstein, through which nuclear energy was developed; a particle like an electron was discovered, but having a positive charge, as predicted by Dirac; and the existence of the mysterious particle called the Higgs boson, predicted by P. Higgs, has been experimentally confirmed.

Only experimental confirmation is necessary in order to make an idea (hypothesis) be recognized as a theory.

These facts indicate the enormous successes of modern physics, every theory of which sooner or later finds practical application, providing technical progress.

This book is a continuation of the author's book “Atom Parameters and Metal Properties”, which offered a new model of metal and justifies more accurate prediction of the technical condition and

residual life of structures and devices.

Analysis of modern theories of strength and fracture showed that, being limited by classical mechanics, they lagged behind modern physics by 50-60 years. The words "atom", "electron", and "photon" are practically absent in numerous publications on strength and fracture mechanics.

The development of Feynman's idea about special behavior of atoms in the volume of $10^{-9} \div 10^{-7}$ m, called a nanoregion, led to the creation of new methods of materials research in this area. Modern experimental techniques allow to study the physical processes that occurred as billions of years ago, as well 10^{-15} seconds ago, as in the space object whose mass prevshaet thousands of solar masses, as well in the nano-objects, containing a few atoms.

The Maxwell Scientific archive was published in 1937.

S. P. Timoshenko found that Maxwell, in an 1856 letter to W. Thomson, formulated the same idea of the distortion energy, which in the 20th century was called the fourth (energy) theory of strength. Timoshenko wrote about it in 1953. Maxwell's priority was recognized and the theory is sometimes called the Maxwell-Huber-Hencky-von Mises theory of failure.

However, the failure criterion proposed by Maxwell is fundamentally different from all of the criteria proposed before and after him.

This difference is the basis of a new method of estimating wear and residual life of structures and devices proposed in this book.

CHAPTER I. MECHANICAL STRENGTH AND DESTRUCTION FROM THE POINT OF MODERN PHYSICS

The word light concentrated the whole physics, and with it all the sciences

William Bragg

1.1. Fragments of the history of physics

On the first page of Einstein's and Infeld's book "The Evolution of Physics", L. Infeld wrote: "According to Einstein, there are only a few basic ideas in physics, and they can be expressed in words."

"No scientist thinks by formulas", Einstein often said, "it is a drama of ideas."

Why is it drama, not triumph?

Because the ideas on the development of which a scientist expends his life, perhaps even several generations of scientists, are suddenly refuted by new discoveries, new ideas, which often await the same fate. It may be that the ideas and conclusions presented in this study will be disproved. This would mean that perhaps the only experiment that is needed has been found, and that this experiment would help to prevent man-made disasters. Therefore, the goal will be achieved.

There is a legend, that Newton, watching apples fall, discovered the law of gravity. Apples, and not only apples, fell long before Newton, but the discovery was made only by him. Although Newton stated: "I do not invent hypotheses", at the beginning it was a hypothesis, well-established, but still a hypothesis, formulated on the basis of experimental data.

Newton, having calculated the ratio of the acceleration of falling bodies on Earth to the centripetal acceleration of the Moon, established that it is equal to the square of the radius of the orbit of the Moon to the Earth's radius. He drew attention to the fact that bodies fall perpendicular to the ground. Aware of the fact that the Earth is spherical, he suggests that the force of gravity depends on the mass of bodies. The formula given by Newton was recognized as a law in 1846, that is, after 164 years, when the planet Pluto predicted by Lavery was found by Halle.

Seventy years later, Einstein published the general theory of relativity (GTR), which indicated that the photon has mass, and a ray of light emitted by a star should deviate in passing by the Sun. According to this calculation a certain angle of deflection of the ray has been found. This phenomenon has been observed repeatedly during total solar eclipses. Based on experimental studies carried out in

1984, it was found that the angle of deflection of the ray was 1.75", with an accuracy of about 0.3%, which is fully consistent with general relativity. It is known that the force of gravity becomes lower as the distance from the Earth increases. As is stated in the general theory of relativity, the frequency of a photon moving away from the Earth will change.

An experimental study of the gravitational frequency shift was conducted in 1960 by R. Pound and G. Rebka. It was shown that with a change in height of 22.6 m the gravitational frequency shift of the photon is $\frac{\partial\mu}{\mu} = (2.57 \pm 0.26) \cdot 10^{-15}$. This means that the deviation from the theoretical composition is about 10%. Currently the gravitational frequency shift has been investigated up to an accuracy of 0.04%. The interaction of electromagnetic and gravitational fields leads to a slowing of time, which is taken into account in satellite navigation systems.

Newton studied optical phenomena in addition to mechanics. His experiments on the interference and dispersion of light played a huge role in the understanding of these processes, in spite of the fact that Newton believed that light travels in the form of corpuscles. Newton, observing the interference of light in the thin air gap between the plate and the lens, did not withdraw from the corpuscular model and advanced the idea of “easy and difficult” reflection of light. In discussions with Hooke, a supporter of the wave hypothesis of light, Newton speaks of "the depth and thickness" of the vibration, which can be taken as the wavelength.

Newton’s authority and his book on optics led to the fact that for 150 years the wave theory of light was not practically developed, but nothing new was discovered in favor of the emission theory either. Only in the early 19th century did the wave theory of light triumph.

Maxwell, exploring the phenomenon of electromagnetic induction, came to the conclusion that with a change in an electric field there must also be a change in the magnetic field. The two fields, electric and magnetic, changing one another, create an electromagnetic wave. This conclusion was based not only on logic, but also as a result of mathematical equations. The velocity of electromagnetic waves was close to the speed of light. From this it was concluded that the nature of light is electromagnetic.

Not only Maxwell but also his contemporaries doubted the practical application of electromagnetic waves, because it was necessary to prove or disprove their existence experimentally. Only 21 years later H. Hertz proved that electromagnetic waves are real. But new problems have arisen for physicists related to the behavior of light waves: the mysterious laws of the hydrogen spectrum, the emission of bodies and primarily black-body radiation, the photoelectric effect and the elasticity of the ether.

M. Planck, analyzing the problem of a black body, comes to the conclusion that light is emitted in

certain portions, called quanta. After five years, i.e. in 1905, Einstein explains the photoeffect on the basis of the quantum properties of light. In the same year, Einstein published his work, called the Special theory of relativity, which is based on two postulates. One of the postulates states that in Maxwell's electrodynamics the speed of electromagnetic waves propagation in a vacuum is independent of the speed of movement of the source and of the waves observer, and is equal to the speed of light. This speed is the maximum possible speed of the bodies. Attempts to refute this postulate lasted more than a hundred years, until the commissioning of the Large Hadron Collider. The sensational discovery that the speed of neutrinos is faster than the speed of light in vacuum was mistaken.

Particularly important for modern science is Einstein's formula $E = mc^2$, linking mass with energy and the speed of light. This formula has been confirmed experimentally, inclusive of nuclear power development. The absence of the rest mass of the photon is experimentally confirmed up to 22 decimal places, the absene of electrical charge confirmed up to 33. On these basis quantum electrodynamics was created, which describes the interaction of photons with matter.

Of the four types of interaction (nuclear, electromagnetic, weak, and gravitational) we consider the electromagnetic and gravitational, although for analysis of the interatomic interaction leading to hardening or destruction, we need use only the electromagnetic interaction -- in all cases not connected with nuclear power.

On this basis, in the modern physical picture of the world it is considered that matter exists in the form of substance with finite rest mass, and a field, the quantum rest mass of which is zero. The mutual transformation of matter in an electromagnetic field is confirmed experimentally, since the collision of an electron and a positron produces photons. On the other hand, a gamma-ray photon with energy of at least 1.05 MeV creates an electron-positron pair in the nucleus field. A similar phenomenon occurs when joining other particles with antiparticles

One of the manifestations of the electromagnetic interaction is a chemical bond. L. Pauling was able to explain the nature of the chemical bond and its mechanism only after the birth of wave quantum mechanics. Pauling’s first work on the atomic orbitals hybridization was published in 1928 following the work of W. Heitler and F. London, devoted to the covalent bond of the atoms in the hydrogen molecule.

In 1939 Pauling published a paper [1.1] about the nature of chemical bonds in molecules and crystals, in which he suggested oscillations (changes) of the chemical bond. In the preface to the third edition of Pauling’s book, published in 1960, he writes: "The theory of the chemical bond proposed in this

book is still far from perfect. Most of the principles that have been developed are crude, and only rarely can be used in making an accurate quantitative prediction. However, they are the best as yet, and I agree with Poincaré that "it is far better to predict even without certainty than not to predict at all”

Confirmation of the oscillation of the chemical bond was obtained in 1999, by A. Zewail, using a femtosecond laser [1.2]. These experiments laid the foundation of a coherent chemistry. It became clear that the oscillations occur at both the nano- and macroscopic levels. Richard Feynman, in his report which began the era of nanotechnology, in fact expressed the same idea, noting that the behavior of atoms in nanoareas differ from their behavior in a macroscopic area. These changes are possible only as a result of changes in both the nature of the interaction, which is carried by photons, and changes in the energy state of the atoms.

Cracking and failure occurs abruptly. It means that the deformation process is an accumulation of energy and its long-term storage. Thus, as a result of nonlinear deformation, a new equilibrium structure occurs, the potential energy of which exceeds the minimum potential energy of the unperturbed system. The formation of these structures, called dissipative, was described in Prigogine's theory, [1.3] developed to explain the processes that result in the formation of Bénard cells, the oscillatory Belousov-Zhabotinsky reaction, and turbulence [1.4].

The destruction of metals, as well as other ordered systems, is accompanied by an increase in entropy. Schrödinger, one of the founders of quantum mechanics, gave a series of lectures in 1943 devoted to the problem of the physical processes in the cell of a living organism. These lectures formed the basis of his book "What is life? The Physical Aspect of the Living Cell" [1.5] and marked the beginning of the study of biological objects from the perspective of quantum mechanics. Schrödinger showed that the second law of thermodynamics is not violated in biological systems, in spite of the fact that a strictly regulated system occurs with a small number of molecules, which Schrödinger called an aperiodic crystal that contained genetic information in its configuration of covalent chemical bonds.

The formation of such crystal is due to the fact that the entropy of the cells does not increase, but decreases with light energy. The idea of an aperiodic crystal formed the basis of the explanation of quasicrystals and is used by the author [1.6] to explain the formation of dissipative structures in a deformation process.

The intermittent nature of crack formation and sudden destruction, like a bomb explosion, shows stimulated emission of stored energy. The theory of spontaneous and stimulated emission of energy was developed by Einstein and found practical application in lasers

1.2. Modern physical picture of the world

The modern physical picture of the world is formed on the basis of experimental studies of the physical processes that occur both in an individual molecule, and in distant galaxies. This means that the physical theory of spatial interval is from 10^{-12} m to 10^{10} light years and the time interval is from 10^{-15} seconds up to 10^{10} years. The saying of the English physicist William Bragg, who was one of the founders of X-ray research methods of crystals and inorganic molecules structure, taken as the epigraph, was made before the formulation of the principles of quantum mechanics by Schrödinger and Heisenberg. It is given here in order to show the important role that photons played in physical processes, including our lives. Without an understanding of the role of photons, which are due to the interatomic interaction, it is impossible to show the shortcomings and mistakes that have been committed in strength and fracture mechanics.

Connections between the research in heavenly bodies and nanostructures can be shown by example.

Figure 1.1

The photograph in figure 1 was made with the Hubble Space Telescope, showing outflow of gas from a black hole in the galaxy M86, located at the bottom of the photo. Close to the black hole, the gas temperature is increasing, as evidenced by the blue color. The black hole mass exceeds the mass of our Sun by a factor of billions. The photon cannot overcome the force of gravity, because of the great mass of the black hole. Neutron stars and black holes are formed by the close approach of atoms, in which the electron cloud of an atom, pushed away from the electron cloud of other atoms, approaches the nucleus and is captured by it. A nuclear reaction takes place, $p + e^- \rightarrow n + \nu_e + \gamma$, as a result of which the proton interacts with the electron, and the proton is converted into a neutron. According to the laws of energy and momentum conservation, gamma photons and neutrinos are emitted. In the analysis of the physical processes occurring in stars, quasars, and black holes, all types of interaction must be considered: the nuclear is taken to be 1, the electromagnetic, the value of which is 1/137 and the gravitational ~ 10-40.

There are four examples of nuclear reaction below called K-capture or electron capture by a nucleus.

1. $^{7}_{4}Be + e^- \rightarrow ^{7}_{3}Li + \nu_e + \gamma$; 2. $^{26}_{13}Al + e^- \rightarrow ^{26}_{12}Mg + \nu_e + \gamma$; 3. $^{40}_{19}K + e^- \rightarrow ^{40}_{18}Ar + \nu_e + \gamma$;

4. $^{59}_{28}Ni + e^- \rightarrow ^{59}_{27}Co + e^- + \nu_e + \gamma$.

Such reactions occur spontaneously on Earth and other planets of the solar system. The phenomenon

is not rare, as about two hundred of these reactions with various nuclei are known starting from beryllium. During electron capture from a near electron orbit other electrons are transferred from more distant orbits to the lower. As a result of this transition a gamma photon is emitted whose energy depends on the atomic number of the nucleus, and can reach hundreds of thousands of electron volts.

Let us look at atomic reaction #3, which is due to the formation of an argon isotope. This isotope is 99.6% of argon in the earth. Thus, the industry has argon at its disposal, whose stocks are replenished by the nuclear reaction of electron capture by the nucleus.

Рис.2

Naturally, the question arises: why does fracture analysis begin with space objects whose dimensions vary by billions of light years, not the earth, in which, excluding nuclear reactions, the gravitational interaction can be disregarded?

In December 2012 it was reported that a group of astrophysicists [1.7] has determined the value of the ratio of the electron and the proton, having studied the spectrum of emissions from the quasar PKS 1830-211, flying through an ancient galaxy in the constellation Sagittarius, located 7 billion years away. Photons passing through the galaxy "remember traces" of the molecules with which they interact.

These molecules were methanol, CH_3OH. Based on the study of the spectrum the ratio of the proton mass and an electron was measured, which is one of the constants of general relativity. Up to seven places the ratio coincided with those measured on Earth. Consequently, the nature of physical laws has not changed across 7 billion years.

Thus, the mechanism of external influence on the atom is the same both in space and on Earth, but differs only quantitatively.

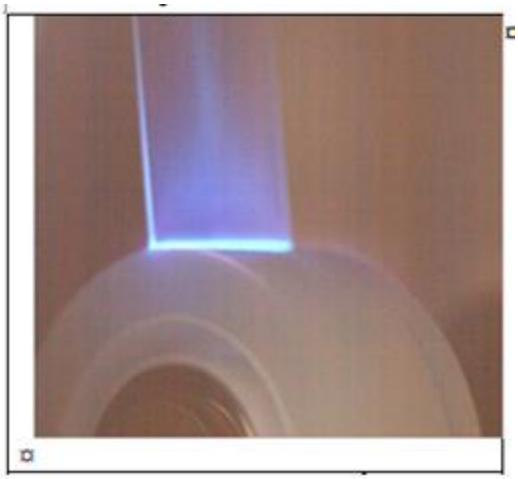

Figure 1.2 [1.8]

The photograph in Figure 1.2 shows a blue glow from scotch tape, observed as it was exfoliated [1.8]. This shows that the energy of the emitted photons exceeded 3.7 eV. Such radiation is emitted when an electron in an atom moves from a higher energy level to a lower, but before another electron to be removed from this lower level. Such electron transfer occurs upon absorption of energy from the external source.

Particularly important to note that, besides the visible light and *X-ray radiation was observed also*!

Note that the X-ray emission was observed in the Derjagin laboratory under destruction of the adhesive layer 55 years before that. [1.9].

Hence the tape or glue consists mostly of carbon atoms; we assume that the X-ray emission is due to the carbon atoms or an organic adhesive. The electronic configuration of the carbon atom is $1s^2 2s^2 2p^2$. This means that for the first shell, called the *K*-shell, there are two electrons, on the second (*L* -electron shell)-four. These four are the valence electron and the transition is due to only the visible or ultraviolet radiation, and they realize the chemical bond. Therefore, X-rays are only possible by separation of electrons from the *K*-electron shell. The energy required for this ionization is 392 eV. If it is assumed that the X-ray emission is caused by atoms having a higher atomic number, then the energy of the X-rays will be much greater.

1.3. J. C. Maxwell and Feynman's ideas about strength and fracture

The strength of a solid body is understood as its ability to resist destruction (cutting in pieces) and irreversible change in shape due to external loads. This means that the problem of preventing man-made disasters is closely linked to the strength of the material from which an element of the structure or device is made. The strength, from the position of physics, is due to the forces of atoms or ions.

Crack formation or destruction is the result of breaking the bond between a certain numbers of atoms, due to the fact that the energy absorbed by the atoms was greater than the binding energy. As the formation of cracks or destruction is stepwise, so between external excitation and bond breakage there is specific time interval Δt, during which there is an accumulated energy that is enough to break the bond. This interval depends both on the binding energy, and the power absorbed by the atoms.

The specific quantum mechanical properties of atoms in solids play an extremely important role in the accumulation of energy and its prolonged storage, leading to the mutual influence of atoms. Under non-linear deformations arise metastable levels whose lifetime increases rapidly.

However, during the time Δt, not only accumulation of energy occurs but its dissipation takes place. Thus, with equal power accumulation and dissipation of energy the crack is not formed and destruction does not occur, i.e. there is elastic (linear) strain. The excess accumulation of power over energy dissipation that occurs under a non-linear deformation indicates the formation of a local area in which the energy savings are due to the changing interaction between atoms. This means that the nature of the chemical bond has changed and there is a new dissipative structure with a higher energy density is formed.

In strength and fracture mechanics such an area is called the residual mechanical stress. However, the

form of potential energy, the radiation of which can cause crack formulation or destruction, is different from the elastic energy.

In this regard, we consider one of the theories of strength, known in the scientific and educational literature theory as the highest specific potential energy of deformation. According to this theory, a critical state is reached when the specific potential energy reaches a value corresponding to the yield stress in simple tension.

A large number of reviews on the strength of the various theories have been published. In this regard, we will limit ourselves to some of them that are published up to the 21st century.

The J. C. Maxwell archive was published in 1937. S.P. Timoshenko [1.10 p368] found a letter from Maxwell to W. Thomson [1.11], dated 1856. He quotes a fragment of this letter, commenting on it: «Maxwell suggested that the use of the expression for strain energy in determining the critical values can be resolved into two parts: (1) the strain energy of uniform tension or compression and (2) the strain energy of distortion. Considering now the strain energy of distortion, Maxwell makes the statement: “I have strong reason for believing that when [the strain energy of destruction] reaches certain limits than the element will begin give way.” Further on Timoshenko states: “This is the first time that I have written on this subject. I have never seen any investigation of the question, ‘Given the mechanical strain in three directions on the element, when will it give way?’ ”We see that Maxwell already had the theory of yielding which we now call maximum distortion energy theory. But he never came back again to this question. »

The quote from Timoshenko’s book played a major role in the recognition of Maxwell's priority. However, during the 60 years since its publication, numerous articles devoted to the strength problem cite not the primary source but Timoshenko. For example, Mao-hong Yu [1.12] quotes as written by Timoshenko. But Christensen [1.13] reduces the quote: "In a letter to Lord Kelvin in 1856, Maxwell foresaw what we now know as Mises criterion, saying," “I have strong reasons for believing that when the strain energy of distortion reaches a certain limit then the element will begin to give way” (Timoshenko (1953)). Much later Guang-Lian Liu [1.14] writes about Maxwell, but doesn't even refer to Timoshenko, but Christensen reduces it to the limit: "Maxwell first, in 1856, suggested energy as a parameter predicting the destruction of the material."

Osakada [1.15], citing Timoshenko, "complements" his formula, which is neither Timoshenko's nor Maxwell's.

It is given in such a context that the reader may think that the formula belongs to Maxwell. As can be seen, the formula contains an egregious blunder.

Such disregard to the scientific legacy of a brilliant scientist is unacceptable.

The work of Newton, Maxwell and Einstein form the basis of the modern science.

The reader may get the mistaken notion that the criterion proposed by von Mises is identical to the criterion of Maxwell. However, the difference is a distinction of kind as shown below. Moreover, it is unacceptable to reduce the great merits of Maxwell's theory of strength only to the fact that he "suggested that energy as a parameter predicting the destruction of the material". This idea was formulated earlier in the works to which Maxwell refers, including by Cauchy and Stokes.

In fact, Maxwell did a serious experimental study on strength, using the interference of polarized rays, and wrote a theoretical work that is still relevant. Moreover, these studies are particularly important for training purposes.

The current situation, in our opinion, is due to the fact that, first, this area of interest is not adequately reflected in Maxwell's biographical sketches, and secondly, Tymoshenko cites only a small fragment of one of the four sections of the letters on this problem. In the three previous sections is a study of deformation by interference of polarized beams, which formed the basis of a method based on a phenomenon called photoelasticity. As is known, this method is one of the most common for the calculation of stress intensity factors.

There is a long-felt need to talk about the results of Maxwell's study of the problem of solids elasticity to restore historical justice. We restrict ourselves to a brief statement of the result of more accurate reading of the letter and the analysis of Maxwell dedicated to the equilibrium of elastic solids [1.16]. "THERE are few parts of mechanics in which theory has differed more from exsperiment than in theory of elastic solids,"

Elasticity theory, proposed by him, more accurately describes the relationship between the strain and the interference of polarized rays than the theory, published in the 20th century. Maxwell has not yet formulated the idea of electromagnetism, did not have that amount of experimental evidence which are disposed theorists 20-21 centuries. This mainly relates to the physics of the atom. Theoretical conclusions made by Maxwell on the basis of experimental studies; proposed equations are confirmed experimentally.

Maxwell offers the equations relating the displacement α, β, γ with strains P_1, P_2, P_3, expressing this relationship through compression. $\frac{\delta\alpha}{\alpha}, \frac{\delta\beta}{\beta}, \frac{\delta\gamma}{\gamma}$:

$$\text{I}\ (P_1 + P_2 + P_3) = 3\mu\left(\frac{\delta\alpha}{\alpha} + \frac{\delta\beta}{\beta} + \frac{\delta\gamma}{\gamma}\right)$$

$$\text{II}\begin{cases}(P_1 - P_2) = m\left(\dfrac{\delta\alpha}{\alpha} - \dfrac{\delta\beta}{\beta}\right)\\ (P_2 - P_3) = m\left(\dfrac{\delta\beta}{\beta} - \dfrac{\delta\gamma}{\gamma}\right)\\ (P_3 - P_1) = m\left(\dfrac{\delta\gamma}{\gamma} - \dfrac{\delta\alpha}{\alpha}\right)\end{cases}$$

Here μ is cubic coefficient and m is linear coefficient of plasticity.

The relationship between these coefficients Maxwell expressed by equation:

$$\mu = \frac{Em}{9m - 6E}\ ,$$

noting that the "*Numerical value E can be obtained by an experiment using a wire or rod of the materia*l." (Emphasis mine).

This phrase shows the main difference between a study conducted by Maxwell from similar studies carried out after him.

Maxwell uses mathematical apparatus in order to show how to calculate the coefficients μ and m on the basis of the experiment. He shows how to associate the pressure inside the sample on example of deformation of the rod, a hollow cylinder, parallel plate, hollow sphere. He analyzes relationship between the interference of polarized beams and deformation caused by compression, rotation, and change in temperature.

“The fundamental equations of this paper differ from those of Navier Poisson, &c, only in not assuming an invariable ratio between the linear and cubical elasticity; but since I have not attempted to deduce them from the laws of molecular action, *some other reasons must be given for adopting them*.” (Emphasis mine).

This study is completed by the hypothesis “that the quantity ω (which shows a relationship between the pressure in a solid and index of birefringence) is *probably a function of m,* the determination of these quantities for different substanties might lead to more *complete theory of double refraction*, and extend our knowledge of the laws of optics.”

Maxwell's brilliant prediction, expressed in 1850, justified. Today it is not hypothesis, but a theory based on the fact that as a result of deformation of the solid body there arises anisotropy in which the phase difference of the ordinary and extraordinary rays of light depends on the direction.

Birefringence does not occur only under the deformation, but also under the influence of electric and

magnetic fields. The mechanism of all these phenomena is explained in quantum mechanics.

The fragment of the letter given by Timoshenko does not reflect the importance of the findings of Maxwell. A full copy of this letter is given in Appendix 1. We mention that part of it which represents fundamental importance for understanding the nature of Maxwell's ideas of strength and fracture of solids.

Letter to William Thomson

18 December1856

Here is my present notion about plasticity of homogenous amorphous solids. Let α β γ be the 3 principal strains at any point P Q R, the principal stresses connected with α β γ by symmetrical linear equations the same for all axes. Then the whole work done by P Q R in developing α β γ may be written as

$$U = A(\alpha^2 + \beta^2 + \gamma^2) + B(\beta\gamma + \gamma\alpha + \alpha\beta) \quad (1.1)$$

where A & B are coeffits, the nature of which is foreign to our inquiry. Now we may write $U = U_1 + U_2$ where U_1 is due to symmetrical compression, $\alpha_1 = \beta_1 = \gamma_1$, and U_2, to distortion withoutcompression, $(\alpha_2 + \beta_2 + \gamma_2 = 0)$, $\alpha = \alpha_1 + \alpha_2$, $\beta = \beta_1 + \beta_2$, and $\gamma = \gamma_1 + \gamma_2$. It follows that

$$U_1 = \frac{1}{3}(A + B)(\alpha + \beta + \gamma)^2 \quad (1.2),$$

$$U_2 = \frac{2A - B}{3}[(\alpha^2 + \beta^2 + \gamma^2) - (\beta\gamma + \gamma\alpha + \alpha\beta)] \quad (1.3)$$

«Now my *opinion* is, that these two parts may be considered as independent, U_1 being the work done in condensation and U_2 that done in distortion. Now I would use the old word ‘Resilience’ to denote the work necessary to be done on a body to overcome its elastic forces.

The cubical resilience R_1 is a measure of the work necessary to be expended in compression in order to increase the density permanently. This must increase rapidly as the body is condensed, whether it be wood or lead or iron.

The resilience of rigidity R_2 (which is the converse of plasticity) is the work required to be expended in pure distortion in order to produce a permanent change of form in the element. If the body is tough the disfigurement will go on till this function U_2 (which truly represents the work which the element would do in recovering its form) has diminished to R by an alteration of the permanent dimension…(Italics Maxwell's)

I have strong reasons for believing that when

$$\alpha^2 + \beta^2 + \gamma^2 - \beta\gamma - \gamma\alpha - \alpha\beta \quad (1.4)$$

reaches a certain limit=R_2 then the element will begin to give way. I think this notion will bear working out into a mathemat theory of plasticity when I have time to compare with experiment, when I know the right experiments to make.

Condition of not yielding

$$\alpha^2 + \beta^2 + \gamma^2 - \beta\gamma - \gamma\alpha - \alpha\beta < R_2 \quad (1.5)." \text{ (End of citation)}$$

We have presented part of the text of Maxwell's letters to Thomson to show the main idea that is still relevant today.

1) The relationship between the radiated potential energy which leads to destruction and mechanical stress cannot be expressed in terms of mechanical properties.

2) The two types of potential energy are independent, but the rate of change U_1 and U_2 are different. Only under certain conditions does the difference reach a certain value at which failure occurs.

3) The final sentence in the letter written by Maxwell to Thomson demonstrates that Maxwell suggested mathematical solution to the problem only after confirmation by experiment.

Today we have to express our regret that all those who deal with the problems of strength of solids after 1953, did not return to Maxwell. The elasticity theory proposed by Maxwell [1.16] is based on experimental studies of double light refraction. It is not from continuum mechanics, but from intermolecular interaction. The mathematical apparatus used by Maxwell exceeds that used by many authors of theories proposed in the 20th and early 21st century.

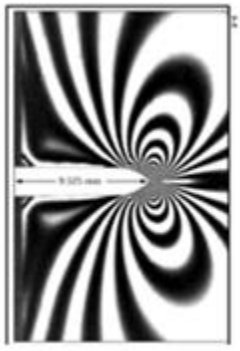

Figure 1.3 [1.17]

Let us demonstrate this by an example.

Photoelasticity is one of the most effective methods for studying the distribution of stresses in engineering structures on transparent isotropic materials. Under tension an isotropic material becomes anisotropic, resulting in birefringence. Due to the interference of polarized light on a screen or a photographic plate a picture is created, based on which a conclusion is made on the distribution of stresses.

Figure 1.3 shows one of these pictures. White and dark areas characterize changes in mechanical stress. If we take the tip of a crack at the beginning of the polar coordinates, in the plane of the picture the stress will be a function of distance and angle. The following is a fragment of the intermediate calculation of stress intensity factors (SIF) used in work [1.18].

$$\left(\frac{N f \sigma}{t}\right)^2 = \frac{K_I}{2\sqrt{\pi a}}\left\{\left(\frac{r}{2a}\right)^{-1/2}\cos\frac{\theta}{2}\left(2\sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right)+3\left(\frac{r}{2a}\right)^{1/2}\cos^3\frac{\theta}{2}-3\left(\frac{r}{2a}\right)^{1/2}\cos\frac{\theta}{2}+\sum_{n=1}^{\infty}\left(\frac{r}{2a}\right)^{n+\frac{1}{2}}C_n\left[2\left(n+\frac{1}{2}\right)\sin\theta\sin\left(n-\frac{1}{2}\right)\theta\right]\right\}$$

$$+\frac{K_{II}}{2\sqrt{\pi a}}\left\{\left(\frac{r}{2a}\right)^{-1/2}\left(2\sin\frac{\theta}{2}\cos\frac{\theta}{2}\cos\frac{3\theta}{2}\right)+\left(\frac{r}{2a}\right)^{-1/2}2\sin\frac{\theta}{2}-\frac{3}{2}\left(\frac{r}{2a}\right)^{\frac{1}{2}}2\sin\frac{\theta}{2}\cos^2\frac{\theta}{2}-\frac{3}{2}\left(\frac{r}{2a}\right)^{1/2}2\sin\frac{\theta}{2}\right.$$

$$\left.-\sum_{n=1}^{\infty}\left(\frac{r}{2a}\right)^{n+\frac{1}{2}}C_n\left[2\sin\left(n-\frac{1}{2}\right)\theta\right]-\sigma_{0x}\right\}^2+\frac{K_I}{2\sqrt{\pi a}}\left\{\left(\frac{r}{2a}\right)^{-1/2}\sin\frac{\theta}{2}\cos\frac{\theta}{2}\cos\frac{3\theta}{2}-\frac{3}{2}\left(\frac{r}{2a}\right)^{1/2}\sin\frac{\theta}{2}\cos^2\frac{\theta}{2}\right.$$

$$\left.-\sum_{n=1}^{\infty}\left(\frac{r}{2a}\right)^{n+1/2}C_n\left(n+\frac{1}{2}\right)\sin\theta\cos\left(n-\frac{1}{2}\right)\theta\right\}+\frac{K_{II}}{2\sqrt{\pi a}}\left\{\left(\frac{r}{2a}\right)^{-1/2}\cos\frac{\theta}{2}\left(1-\sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right)\right.$$

$$\left.+\frac{3}{2}\left(\frac{r}{2a}\right)^{1/2}\cos\frac{\theta}{2}\left(1+\sin^2\frac{\theta}{2}\right)+\sum_{n=1}^{\infty}\left(\frac{r}{2a}\right)^{n+\frac{1}{2}}C_n\left[\cos\left(n+\frac{1}{2}\right)\theta-\left(n+\frac{1}{2}\right)\sin\theta\sin\left(n-\frac{1}{2}\right)\theta\right]\right\} \qquad (6)$$

The analysis of these publications shows that none of the cited works no attempts were made to explain what are the two areas which Maxwell wrote about, what is the mechanism of accumulation of energy. Theory of strength, ductility and strength is considered new if it proposes a new combination of principal or shear stresses, the elastic modulus, Poisson's ratio and bias, but there are no new physical ideas.

Since the position of the maxima and minima of the interference depends on the wavelength, the picture is in color. In this regard, the most accurate measurements can be obtained with a high degree of polarization and monochromaticity light. It is best used for this purpose in the laser radiation. Photoelasticity method is widely used for study of the formation of cracks and the calculation of stress intensity factors. In this pattern is symmetric about the direction of the crack.

We note that on the right side of the equation there are no parameters to be measured on the material whose technical state is being graded except σ_{0x}, which is included only in the second term. The authors do not indicate how such a complex mathematical equation was obtained, but it does not matter, as this term has one dimensional and three dimensionless quantities. Therefore, the entire expression is incorrect. Stress σ on the left side of the equation is similar for all points located in front of the crack, but its distribution is determined.

Thus, we see that with the complexity of the calculations the forecast of the specific device technical condition cannot be done.

Figure 1.4 [1.19] shows another method for calculating the stress intensity factor and the formula is below.

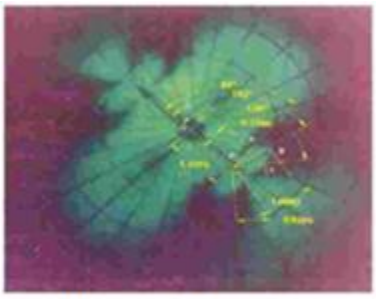

Figure 1.4 [1.19]

$$K_I = \frac{K}{\sqrt{\sin^2(\theta_m)\left[1+F(\theta_m)^2\right]+4F(\theta_m)\cos(\theta_m)\left[F(\theta_m)\cos(\theta_m)+\sin(\theta_m)\right]}}$$

$$K_{II} = F(\theta_m)K_I$$

Numerous such examples could be given. It is impossible to

assess which one is more accurate. The complexity of this or another formula is not the major danger in judging the residual life of technical facilities at the modern level of computing technology.

Formulas for the flight of vehicles to the Moon are not less complicated. However, corrections of their parameters may be introduced during the flight. In fracture mechanics, such a procedure is not possible, because in the final formula there are no measured physical parameters.

An analysis of computer programs designed to calculate the SIF is carried out in [1.19].

Maxwell was unable to photograph the chromatogram and quantify the distribution of intensity in it. However, plotting the location of the maxima and minima of the interference of polarized rays on the basis of experiment, he solved a problem which has not lost its scientific and practical value. Moreover, it can serve as an excellent illustration of ingenious solutions using simple but rigorous scientific methods.

P. L. Kapitsa, in an article on the memoirs of Rutherford [1.20], quoted original 18th century Ukrainian Philosopher H. Skovoroda, to emphasize the brilliant simplicity of his solutions: "We should be thankful to God that he has created the world so that all that is simple is true, and the entire complex is not true."

The review article by Mao-homg Yu [1.12], is devoted to the 20th century's success in the development of the theory of strength of materials under complex loading. He notes that in the 20th century about a hundred of theories of strength were proposed, which he divided into three categories according to the number of parameters. He shows tens of strength criteria, including for different materials, and cited Timoshenko's statement about Maxwell.

A review [1.21] on the problem of steel fluidity was published in 2010. It presented 29 criteria of

fluidity. Some authors or groups of authors suggested up to five different criteria; they publish them every 2-3 years. A review of K. Osakada [1.15] was published in the same (2010) year.

The analysis of these publications shows that none of the cited works attempted to explain what are the two areas which Maxwell wrote about, which is the mechanism of accumulation of energy. The theory of strength, ductility and fluidity is considered new if it proposes a new combination of principal or shear stresses, the elastic modulus, Poisson's ratio and bias, but there are no new physical ideas.

So Maxwell, exploring of the character of formation of the interference pattern of polarized rays, concludes that the nature of the the potential energy formation uder mechanical and thermal of solid bodies deformation is not due to mechanical, and not even thermal, reacting of molecules.

Such a brilliant prediction was made before the electron has been discovered, developed the electronic theory of solids, quantum-mechanical nature of the bond of atoms and molecules established. Moreover, Maxwell had not yet formulated the equations of electrodynamics.

It makes no sense to blame Maxwell that his prediction did not become the subject of careful study.

1.4. Richard Feynman and the shuttle "Challenger" disaster

Nanotechnology is one of the most important areas of technological progress of the 21st century. It originated through the work of theoretical physicist Richard Feynman. Realization of his ideas about how to manage the behavior of individual atoms in a small volume has been made possible thanks to the fact that, firstly, the hypothesis was based on a thorough understanding of the laws of nature; secondly, it has been confirmed experimentally.

Feynman, of course, knew about Maxwell's research, in particular in establishing the foundations of electrodynamics. This is evidenced not only by the fact that he was one of the authors of quantum electrodynamics, but also the simplicity of exposition of this section in "The Feynman Lectures on Physics." The simplicity of exposition, however, did not reduce the scientific level. Moreover, the Feynman lectures initiated a change in the traditional exposition of high school physics courses.

The first lecture [1.22], does not begin with mechanics as it was made before Feynman, but with the physical picture of the world. Feynman points out that the basis of the modern physical picture of the world makes the atomic hypothesis "... (You can call it not a hypothesis, but a fact, but it does not change anything): *all bodies are composed of atoms of small particles, which are in constant motion, drawn at a short distance, but are repelled, if one is held tightly to the other*. This sentence, as you have seen, contains an incredible amount of information about the world, if only to make it a little bit of imagination and ideas." (Emphasis added by Feynman).

This lecture was delivered by Feynman little more than year after the lecture "Downstairs there is still a lot of room," in which he laid the foundation of nanotechnology. Feynman, as well as Maxwell, being a theoretical physicist, preferred experience. "The principle of science is almost its definition, it is in the following: *the touchstone of all our knowledge is experience*. Experience, Experiment is *the only judge* of scientific "truth." (Emphasis added by Feynman).

Although the works of Feynman do not cover such a wide range of problems in physics as the works of Maxwell, he was one of those who had to solve technical problems related to the creation of the atomic bomb, and took part in the commission investigating the causes of the space shuttle "Challenger" disaster, which happened on January 28, 1986 after 73 seconds into the flight, which led to the death of all seven crew members.

Invitation to participate in the commision to investigate the causes of shuttle “Challenger” disaster was unexpected for him, because he never has been engaged in similar problems, including problems of strength and fracture mechanics. But precisely Feynman found the cause of the disaster, although he never built a rocket and was not engaged in their operation.

In this regard, a careful study of his research is particularly important. Just as in the behavior of a few atoms Feynman saw all this in common, that led to the creation of a new branch of engineering he demonstrated in this example that the total that must be taken into account when investigating the causes of any disaster. He never wrote about atoms, the laws of physics, but based on the knowledge of these laws.

He shows that search for solutions to security problems should be based on an analysis of the physical processes that lead to disaster.

The next section is devoted to the problem of the human factor, which occur as a result of man-made disasters. Analysis of the causes of the disaster must be only objective, but this often prevents the human factor. Feynman understood this like no other.

It is important to note a very important detail: Feynman to participate in the Commission invited the head of NASA Mr.V. R. Graham, previously listened to his lectures. The invitation was made by Feynman, despite the fact that the Commission has already had three physics, space-related activities. This indicates that the head of NASA was interested in an objective assessment of the causes of the disaster.

Feynman was already world-renowned scientist, Nobel laureate when he took part in a commission to investigate the causes of the of the shuttle "Challenger" disaster. Commission headed by a prominent politician William P. Rogers, who was formerly the Attorney-General, then U.S. Secretary of State.

Between Feynman and Rogers disagreement arose as the commission's report. Feynman's report was included in the commission's report only as an application. Feynman wrote that the majority of the committee members do not read it. These differences determined for the different approaches to the problem.

Search for truth was for Feynman goal of his life, while Rogers remained a politician. For him it was important, even in this case, to save the honour of the regiment. I quote of Feynman to my charge will be not unfounded.

«While I'm in the middle on my list, a secretary comes in with a letter for Rogers to sign. In the interim, when I've just been shut up and I'm waiting to come back, various other commission members offer to work with me. Then Mr. Rogers looks up again to continue the meeting, but he calls on somebody else- as if he's absentminded and forgot I'd be interrupted. So I have get the floor again, but when I start my stuff again another "accident happens.

In fact, Mr. Rogers brought the meeting to a close whele I was in midstream! He reppited his worry that we'll never realy figure out whot happened to the shuttle.

This was extremely discouraging. It's hard to understand now, because NASA has been taking at least two years to put the shittle back on track. But at the time, I throught it would be a matter of days.

I went over to Mr. Rogers and said, "We're going to Florida next Thursday. That means we've got nothing to do *for Jive days:* what'll do for five days?"

"Well, what would you have done if you hadn't been on the commission?"

"I was gouing to Boston to consult, but I canceled it in order to work 100 percent."

"Well, why don't you go to Boston for five days?"

I couldn't take that. I thought, I'm dead already! The goddamn thing isn't working right." I went to my hotel, devastated.

Then I thought of Bill Graham, and called him up.

"Listen, Bill," I said." You got me into this; now you've gotta save me: I'm completely depressed; I can't stand it."

He says, "What is the matter?"

"I want to do something! I want to go around and talk to some engineers!"

He says, "Sure! Why not? I'll arrange a tripp for you, you can go wherever you want: you could go to Johnson, you could go to Marshall, or you could go to Kennedy…"

Every self-respecting professor of physics at the University necessarily recommend to his students to read the work of Feynman "Surely You're Joking, Mr. Feynman!" The final part of this book is a study

of the Challenger disaster, which he called "What Do You Care What Other People Think?”

But physicists are rarely interested in the problems of disasters, while specialists occupying the problems of strength and fracture have not been paying attention to this Feynman’s investigation.

Feynman's report on his work to determine the causes of the space shuttle disaster is an excellent tool for all those involved in the problem of disasters. By his example, he showed the importance of understanding the physical processes in order to prevent a catastrophe. The main cause of the accident was a gas leak, due to the change of elasticity of a rubber seal at lower temperatures. To confirm this conclusion, at a meeting of the Commission Feynman demonstrated a simple experiment, dropping a piece of rubber seal in a glass with ice.

Modern theorists do not conduct physical experiments, as did Newton and Maxwell. Quantum electrodynamics, one of the founders of which was Feynman, nanotechnology, him predicted, and this simple experiment suggest uncommon potential of Feynman, as a scientist, plans to "correct one experiment", mentioned by Maxwell.

Spacecraft is unthinkable without computers. Of course, that modern computers are greatly exceed those that control the flight of the shuttle "Challenger". But today there are spacecraft accidents. Consequently, the analysis of the flight control computers shuttle Challenger conducted Feynman, remains relevant.

NASA chief was not mistaken, drawing Feynman to investigate the causes of the space shuttle "Challenger" disaster. Feynman was not only found the cause of the disaster, but also pointed out the mistakes that allowed both the design and analyzing the causes of the disaster.

Feynman wrote: "Mr. Weeks showed me pictures on previous flights-what the engineeres called “blowby,” a blackening behind an O-ring where hot gas leaked theough, and what they colled “erosion,” where O-ring had burned a little bit. There was a chart showing all the flighrs, and how serious the blowby and erosion were on each one. We went through the whole history up to *the* flight, 51-L.

I said, “Where does it say they were ever discussing the problem-how it’s going along, or whether there’s some progress?”

The only place was in the “flight readiness reviews”-between flights there was no discussion of the seals problem!

We looked at the summary report. Everything was behind little bullers, as usual. The top line says:

- The lack of a good secondary seal in the field joint is most critical and ways to reduce joint rotation sould be incorporated as soon as possible to redice criticality.

And then, near the bottom, it says:

- Analysis of exsiting data indicates that it is safe to continue flying existing design as long as all joints leak checked with 200 psig stabilization…

I was strack by the contradiction: "If it's 'most critical,'how could it be 'safe to continue flight'? What's the logic of this?" …

We went back trough the report and fouhd the analysis. It was some kind of competer model with various assumptions that were not right. *You know the danger of computer, it is called GIGO: garbidge in, garbidge out*! The analysis concluded that a little unpredicatible leakage here and here could be toleranted, even though it wosn't part of the original design." (Italics supplied).

Information about the behavior of atoms, including at the nanoscale, which we have 26 years after the Feynman's publication, allows us to make an extremely important conclusion.

Computer software designed to monitor physical processes and managing will be correct only if as input and output data used those physical parameters, the relationship between them is expressed by the equations arising from the laws of conservation of energy, momentum, angular momentum, and electric charge.

The next section, which is given by Feynman, reads as follows: "If *all* the seals had leaked, it would have been obvious even to NASA that the problem was serious. But only a few of the seals leaked of only some of the flights. So NASA had developed a peculiar kind of attitude: if one of the seals leaks a little and the flight is successful, the problem isn't so serious. Tray playing Russian roulette hat way: you pull the trigger and the gun doesn't go off, it must be safe to pull the trigger again…"

Feynman could clearly see the difference between random and patterns of physical phenomena. In this phrase, he warned about the dangers of mathematical extrapolation.

He writes: "It appears that there are enormous differences of opinion as to the probability of a failure with loss of vehicle and of human life. The estimates range from roughly 1 in 100 to 1 in 100,000. The higher figures come from working engineers, and the very low figures come from management. What are the causes and consequences of this lack of agreement? Since 1 part in 100,000 would imply that one could launch a shuttle each day for 300 years expecting to lose only one, we could properly ask, "What is the cause of management's fantastic faith in the machinery?"

Perfectly be able to use mathematical apparatus Feynman warned that "A mathematical model for calculating the erosion was not based on the physical sense, but on empirical curve approximation.

He wrote: "I am constantly asked not to show me the mathematical equation, but to explain the

physical meaning."

Let me draw attention to one feature of the analysis of experimental data about which Feynman wrote: "A mathematical model was made to calculate erosion. *This was a model based not on physical understanding but on empirical curve fitting.* To be more detailed, it was supposed a stream of hot gas impinged on the O-ring material, and the heat was determined at the point of stagnation (so far, with reasonable physical, thermodynamic laws). But to determine how much rubber eroded it was assumed this depended only on this heat by a formula suggested by data on a similar material. A logarithmic plot suggested a straight line, so it was supposed that the erosion varied as the .58 power of the heat, the .58 being determined by a nearest fit. At any rate, adjusting some other numbers, it was determined that the model agreed with the erosion (to depth of one-third the radius of the ring). *There is nothing much so wrong with this as believing the answer! Uncertainties appear everywhere*. How strong the gas stream might be unpredictable, it depended on holes formed in the putty. Blowby showed that the ring might fail even though it was only partially eroded. The empirical formula was known to be uncertain, for it did not go directly through the very data points by which it was determined. There was a cloud of points some twice above, and some twice below the fitted curve, so erosions twice predicted were reasonable from that cause alone. Similar uncertainties surrounded the other constants in the formula, etc., etc. *When using a mathematical model careful attention must be given to uncertainties in the model."* (Italics supplied).

"I went to Professor Bacher and told him about our success, and he said, "Yes, you come out and say that the neutron-proton coupling is V instead of T. Everybody used to think it was T. Where is the fundamental experiment that says it's T? Why don't you look at the early experiments and find out what was wrong with them?"

I went out and found the original article on the experiment that said the neutron-proton coupling is T, and I was shocked by something. I remembered reading that article once before (back in the days when I read every article in the Physical Review-it was small enough). And I remembered, when I saw this article again, looking at that curve and thinking, *"That doesn't prove anything!"*

You see, it depended on one or two points at the very edge of the range of the data, and there's a principle that a point on the edge of the range of the data-the last point- isn't very good, because if it was, they'd have another point further along. And I had realized that the whole idea that neutron-proton coupling is T was based on the last point, which wasn't very good, and therefore it's not proved. I remember noticing that!"

Crack formation and destruction occur as a result of stimulated emission. Emission time is much

less time to accumulate energy. This is the ‘last point’, which can be fixed only in the femtosecond range. But precisely this point which characterizes the crack tip is a key element of fracture mechanics. Let us agree with Feynman that *"That doesn't prove anything."*

The problem of reliability of any element of the structure or device is important in both the design and operation. Particular attention should be given to those elements whose destruction leads to disaster. Feynman has repeatedly analyzed it as in the main part of his research, as well as in Appendix F: Personal Observations on the Reliability of the Shuttle.

“This is a strange use of the engineer’s term ‘safety factor.’ If a bridge is built to withstand a certain load without the beams permanently deforming, cracking, breaking, it may be designed for the materials used to actually stand up under three times the load. This ‘safety factor’ is to allow uncertain excesses of load, or unknown exstra loads, or weakensses in the material that might have unexpected flaws, et cetera. But if the expected load comes on the new and crack appears in beam, this is a failure of the design. There was no safety factor at all, even through the bridge did not actually collapce because the crack only went one-third of the way through the beam. The O-rings of the solid rocket boosters were not designed to erode. *Erosion was a clue that something is wrong. Erosion was not something from which safety could be inferred.*

There was no way, without full understanding, that one could have confidence those conditions the next time might not produce erosion three times more severe that the time before. Nevertheless, officials fooled themselves into thinking thay had such understanding and confidence, in spite of the peculiar variations from case to cace.”

The conclusion drawn by Feynman, highlighted by me. It is particularly important to determine the causes and precursors of disaster, which will be discussed below.

Conclusions have been made about the disaster, ends with the words: “Let us make recommendations to ensure NASA officials deal in world of reality, understanding technological weaknesses and imperfections well enough to be actively thying to eliminate them. They must live in a world of reality in clmparing the costs and utility of the shuttle to other metods of entering space. And they must be realistic in makimg contracts and in estimating the costs and difficulties of each project. Only realistic flight schedules should be proposed-schediles that have a reconable chance of beeng met. If in this way the government would not support NASA, then to be it. NASA ownes it to the sitizens from whom it asks support to be frank, honest, and informative, so that these sitizen can make the wisest decisions for the use of their limited resources.

For a successful technology, realiy must take precedence over public relations, for Nature cannt be

fooled." (Italics supplied).

Ivestigation of the causes of the shuttle disaster, made by Feynman, is particularly important. It is due, firstly, that Feynman, like Newton, Maxwell and Einstein, perfectly be able to use mathematical apparatus favored physics of the process, without understanding that formula or computer program is meaningless. Secondly, the mathematical model can only help to control the process and properly manage them when the formula used in it, experimentally proved, used in them only the physical parameters and the results do not contradict the laws of conservation. Third, the mathematical extrapolation or interpolation must take into account the qualitative change in the properties of objects with composition and structure change.

Ideas of Maxwell and of Feynman created by them theories form the basis of modern physics, and hence of modern science and technology.

Currently was published a great number of textbooks devoted to the problem of strength. However, one gets the impression that the works of Maxwell and Feynman on this problem remained unknown to authors of these benefits. Currently was published a great number of textbooks devoted to the problem of safety. However, the impression arose that the works of Maxwell and Feynman on this problem remained unknown to authors of these learning aids.

We consider the well-known book by Landau and Lifshitz [1.24] and the work of Han [1.25], designed for engineers, experts in the theory of elasticity and students of universities and colleges for a brief analysis.

The analysis of Maxwell's studies devoted to the problem of elasticity, is limited in [1.24] to mentioning the idea of the Maxwell relaxation time. A great place it is paid to the basic equation of elasticity, however the equation proposed by Maxwell, it is not considered.

The difference between the basic equation of elasticity proposed by Maxwell, from equations suggested earlier, fully described Maxwell himself.

"The investigations of Leibnitz, Bernoulli, Euler, Varignon, Young, La Hire, and Lagrange, are confined to the equilibrium of bent rods; but those of Navier, Poisson, Lam and Clapeyron, Cauchy, Stokes, and Wertheim, are principally directed to the formation and application of the general equations....

I have found no account of any experiments on the relation between the doubly refracting power communicated to glass and other elastic solids by compression, and the pressure which produces it; but the phenomena of bent glass seem to prove, that, in homogeneous singly-refracting substances exposed to pressures, the principal axes of pressure coincide with the principal axes of double

refraction; and that the difference of pressures in any two axes is proportional to the difference of the velocities of the oppositely polarized rays whose directions are parallel to the third axis. On this principle I have calculated the phenomena seen by polarised light in the cases where the solid is bounded by parallel planes.

In the following pages I have endeavored to apply a theory identical with that of Stokes to the solution of problems which have been selected on account of the possibility of fulfilling the conditions. I have not attempted to extend the theory to the case of imperfectly elastic bodies, or to the laws of permanent bending and breaking. The solids here considered are supposed not to be compressed beyond the limits of perfect elasticity."

Analysis of Maxwell's works indicates that in the study of strength he went much further than his predecessors. Moreover, he used the equation to solve problems such as the effect of temperature, deflection and rotation. Unfortunately, do not know that not only students but scientists also.

Make a few remarks about the work [1.25].

In it also does not mention works of Maxwell, cited above.

Han writes that: "The physical content of the theory will always be placed on the front and not darkened by mathematical formalism." However, he immediately rejects this approach to address the problems of strengthby claiming: "Description of deformed solids and liquids is a purely geometrical problem and does not depend from the behavior of the material. He further clarifies that ... the character of the forces generated in the deformed body does not depend on the material properties."

As is known, the number of laws of classical mechanics, where ares built the basis of solid state theory is small. At the same time, we read: "Since there are so many different materials, it is thinkable many physical laws that can describe a particular behavior of materials under a variety of conditions. Although it would be desirable, however, to establish a universal physical law, which could be uniformly describe the mechanical behavior of materials, it is impossible."

This study is intended in order to refute such conclusion.

1.6 The human factor and the laws of nature

The well-known researcher of natural and man-made disasters Lee Davis, believes that the main cause of man-made disasters is the human factor, caused by stupidity, carelessness, greed. Manifestation of the human factor can be summarized as a disregard for the objective laws of nature. But there is a fourth factor, lack of knowledge of the laws of nature, which leads to errors in the design of engineering structures and devices, their operation, technical condition assessment the wear and prediction the

remaining life. Only in strict accounting laws of nature, leading to the destruction of man-made disasters, the catastrophe can be prevented.

It was found that even when such laws are disclosed, the human factor is not reduced. It manifests itself in an effort to maintain personal or corporate interests, or to evade responsibility for the rules of design or operation of engineering structure or devices violation.

In any state a man has no right to violate the laws of that state, citing their lack of knowledge. These laws are not objective, because they take people. They can be canceled or changed. Objective laws of nature can neither be changed nor canceled. However, not all the laws of nature are known to mankind. A person may not take into account the factors that are unknown to science. A striking example is the lightning. Millennium lightning killed people and animals, destroy buildings, set fire to forests and fields, causing fear. The man was helpless before it, considering it a divine punishment. But an American politician and public figure, Benjamin Franklin, not knowing that he was risking with his life launched a kite in a thunderstorm cloud and pulled an electric spark from the filament. Russian scientist Richman, repeating his experience, was killed.

Franklin invented the lightning rod, which save humanity from lightning strikes. But the main opponent of the lightning rod was the Catholic Church, although most lightning struck the cathedrals and churches. Over 33 years in the 18th century in Germany were burned or destroyed 400 bell towers, killing 120 bell ringers. Bell tower restored, but lightning destroyed them twice and even three times. Only after that the decision was made to equip churches, cathedrals, bell towers with lightning rods.

It is well known that on October 31, 1992, Pope Johannes Paul II after 359 years has publicly acknowledged that the court of inquisition in the case of Galileo Galilei was a mistake and restored its status as a true son of the Catholic Church. This act is of historic importance for both religion and science. This is meant the recognition of the church that the human factor should not prevail over the objective laws that are open, but had not previously been known to mankind. Newton, Maxwell, like Galilei, sought to move away from religious dogma, but did not break with the idea of God. Einstein sought to create a unified field theory, but did not reject the idea of the Creator.

The decision of the Pope Johann Paul II has recognized that the objective laws of nature are ordained by the Creator before they became known to man.

This allows the Catholic Church to use all the discoveries of science; in addition, it shows the danger of manifestations of the human factor called esprit de corps (defense of the honor of his uniform).

This factor is shown on the stage of investigating the causes of the disaster in order to conceal the true cause and the real perpetrators.

We have already told about the Feynman investigation of the causes of the space shuttle “Challenger” disaster.

Here is another example.

April 26, 1986 Chernobyl disaster occurred, the cause of which has been the human factor. Gross violations of operating rules were committed. There was a destruction of the reactor, in which one person died. But the Ukrainian government has hidden the scale of the disaster and the danger of its consequences. More than a day the town Pripyat population is at increased radiation exposure. First of May, a demonstration was held in Kiev, which by tens of thousands of people was demonstrated who do not know about the dangers of, and subject their children to radiation. In the first two months after the accident died from radiation sickness 28 people. Total radiation sickness killed more than 5000 people.

Another manifestation of the human factor is conservatism, fear of the new.

According to the figurative expression of the great French mathematician, theoretical physicist, engineer, and a philosopher of science Henri Poincare, "every idea is destined to only a moment of triumph from infinity when it is considered impossible to infinity, when it is considered trivial."

Idea becomes trivial when the hypothesis, even fantastic, finds convincing experimental confirmation. Often, new ideas, even experimentally validated, highly promising, met stiff resistance to their introduction. T.A. Edison patented more than a thousand inventions, considers AC dangerous invention, strongly hindering its implementation in industry. N. Tesla invented the high-frequency generator, showed himself to safety by electrical discharges that exceed meter. Only after that AC began its triumphal march.

There are many examples of great ideas, the most striking of which is the atomic hypothesis, which was experimentally confirmed after two millenniums. Feynman considered this hypothesis as the most important discovery of mankind. His idea of the possibility of controlling individual atoms was experimentally confirmed in thirty years. From this experiment begins nanotechnology.

The problem of more accurate assessment of the technical condition and remaining life of structures and devices, with all urgency to prevent man-made disasters can be solved not only in the scientific recognition of good ideas or methods, but with the financial support of major financial corporations, state, multiple states simultaneously. But to do this, first of all it is necessary that it has the desire and political will, in fact, the adoption of appropriate laws.

In almost all states, on the death of one person criminal proceedings are instituted. This means that the death of one person is recognized as man-made disaster.

1.6. Sources of energy and failure criterias

1.6.1. Photoelasticity and energy absorption

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The problem of the energy source, the mechanism of its accumulation and radiation is the key to any physical theory, including the theory of strength and fracture.
As shown above, Maxwell considers two types of potential energy (1.2), (1.3) and the failure criterion (1.4). In this case, we recall that the nature of accumulation of energy is due to the transformation of energy from external stresses into some other non-mechanical form of energy, which was unknown to him. Of course, Maxwell did not know about the energy due to the transition of electrons in the atom. He did not know about the Bauschinger effect, which was discovered later.

Birefringence, i.e. refractive index due to anisotropy, he associated with deformation, including the residual stress. It can be assumed that he knew of the Bouguer-Beer-Lambetra law, but the relationship between the absorption of light and its refraction was established in the electronic dispersion theory, which Maxwell could not know. However, we're not speaking of the year 1880, when articles by G. A. Lorentz [1.27] and L. Lorenz [1.28] were published, but about the 21st century. Note that these works have become a link between Maxwell's theory and the quantum theory of light dispersion.

In this connection it is necessary to say that birefringence is determined by anisotropy, while at the same time serving as the basis for the conclusion about the distribution of stresses, *including residual stress; whereas the accumulation of energy is determined by its absorbence.*

To show the difference between these two phenomena, we restrict ourselves to the electron theory of dielectric dispersion. Note that the absorption of electromagnetic waves by metals is different.

According to the electron theory of dispersion the refractive index $n=n'-in''$, where i-is an imaginary unit, $n'=Ren$ is the real part, which is called the real refractive index, $n''=Imn$ is an imaginary part, describing the attenuation of electromagnetic waves, including their absorption. Parameter ω_p, determined by the properties of the material, has the dimensions of frequency and is called formally plasma frequency. ω_0 is the natural frequency of an electron in an atom, ω is the frequency of the incident electromagnetic wave, and the parameter γ describes the damping, since the electron emits the energy and vibrations are damped.

Content authors often use the same letter designation of different parameters. We follow the authors' versions of the formulas, explaining them every time.

The behavior of electrons in an atom or a solid can only be described by quantum mechanics. In fact,

an electron after absorbing energy jumps on a different orbit. Only in a certain case, the energy radiated is equal to the energy that is absorbed. Such radiation is called the resonance fluorescence. Most often, an electron is transferred to an intermediate orbit, where it can stay from a fraction of a second to several years. This state of an atom is called metastable. These atoms determine the accumulation of energy, the radiation of which leads to the heating and rupture of bonds.

Thus, the study of photoelasticity gives only a qualitative understanding of where and how much energy is accumulated.

1.6.2. Surface energy and the Griffith criterion

The birth of fracture mechanics, admittedly, is Griffith's work, published in 1921 [1.29]. Hundreds of books, dozens, perhaps hundreds of thousands of articles, reports, and manuals have been devoted to this issue. There is no point in writing about the progress that has been achieved. However, his proposed energy criterion of destruction of a cracked body needs to be revised.

An extremely brief overview of progress of development of ideas of quantum mechanics is needed in order to demonstrate the main drawback of fracture mechanics (FM): attempts to describe the behavior of atoms causing cracking and collapse only with the help of classical mechanics.

The condition of the crack is represented by Griffith with the equation

$$\frac{\partial}{\partial l}(W - U) = 0 \quad (1.6),$$

where W is the strain energy, U is the potential energy of the surface with a crack, per unit of thickness, and l is the crack half-length. In accordance with this

$$U = 4l\gamma \quad (1.7),$$

where γ is the specific surface energy of fracture (in Griffith this is the surface tension).

The external stress σ, causing the formation of a crack, is connected with its length l, Young's modulus E, Poisson's ratio μ and γ by the following formula:

$$\sigma = \sqrt{\frac{2E\gamma}{\pi\mu l}} \quad (1.8).$$

Equation (6) can be written as:

$$\frac{\partial W}{\partial l} = \frac{\partial U}{\partial l} \quad (9),$$

where it follows that the crack will grow only in the case when

$$\frac{\partial W}{\partial l} > \frac{\partial U}{\partial l} \quad (10),$$

i. e. the rate of absorption of elastic energy at the crack tip must exceed the growth rate of the surface energy.

According to Griffiths, this situation occurs only at a certain (critical) crack length. Cracks whose length is less than the critical value does not lead to destruction.

Let's point out some peculiarities of this work

1. Griffiths considers crack formation as a break between the molecules, assuming that the potential energy accumulated in the deformation process exceeds the energy which is necessary to form the two surfaces.

Considering that the interaction of molecules on opposite sides of the crack is small, except for its end, Griffiths believes that the mathematical theory of elasticity allows the accurate determination of stress in all areas of the body beyond the surface of the crack, which are considered to be free.

2. Surface energy due to the surface tension per unit area of the material is taken to be constant. As a basis of research, Griffiths accepted a molecular theory of strength and the C. Inglis work, devoted to the problem of stress concentration near the crack.

3. There is a sub-critical crack size at the end of which there is no energy input. For some external stress σ, elastic energy reaches a level at which it arrives at the end of the crack.

4. There is no doubt that this work, which examined the fracture energy, significantly changed the understanding of the physical processes of destruction.

5. Work was done before the works of Heisenberg and Schrödinger, before the principles of quantum mechanics were formulated. Griffiths does not use the already-known hypotheses related to the problem of resistance, relying on intuition. However, the energy parameters introduced by him are largely rejected in modern physical theories. Of course, the energy of the surface is not related to surface tension, but it is constant for the material, as conditioned by the atomic binding energy.

6. As an energy source of destruction, Griffiths considers the elastic energy of the deformed body. This idea is generally accepted in FM so far, and we shall return to it below.

1.6.3. Disadvantages and mistakes of fracture mechanics

Fracture mechanics is based on the concept of a continuous medium, limited to 10-6 m. This has led to the fact that the successes of modern physics and experimental techniques are used insufficiently or not at all. Note that in recent years there has been great interest in the formation of cracks in nanoobjects. We'll consider these works separately.

From the point of view of the modern picture of the physical world, matter is the only continuous medium that exists in the form of a substance or field. The difference between them is due to the fact that the rest mass of the particles that form substance is non-zero, while the rest mass of the particles that form a field is theoretically zero. The quantum particle of the electromagnetic field is the photon.

It is experimentally established up to 22 decimal places that the rest mass of photon is zero. The absence of a charge in a photon is confirmed experimentally up to 33 places. A fundamental law of physics is the relationship between mass and energy. The interaction of photons and atoms is described by quantum electrodynamics, which is recognized as the most accurate theory.

Physics has always been the basis of technology. An analysis of the current situation showed that fracture mechanics, on which we base our methods of predicting technical condition and assessment of remaining life span, is 50 years behind in its development. It does not use the scientific potential associated with new physical theories: quantum electrodynamics, coherent chemistry, and quantum electronics. The bases of modern physics are four laws of conservation and four fundamental interactions. We confine ourselves to the law of conservation of energy and the electromagnetic interaction. To describe the mechanism of metal hardening and its destruction, four particles are enough: the ion, electron, photon and phonon, which have quantum properties.

Unfortunately, neither in science nor in the technical literature on the problems of security, are there words like atom, ion, electron, and the electromagnetic interaction.

As mentioned above, the main problem of any physical theory is the problem of the source of energy. FM comes from the fact that the main source of energy, which may be sufficient for crack formation or damage, is elastic energy due to the stress state.

Let us analyze the possibility of energy concentration of a stressed state.

The problem of destruction is closely linked to the problem of strength. We confine ourselves to the fourth energy theory of strength, the theory of the maximal specific potential of energy forming. Distortion energy is expressed through the main σ_x, σ_y, σ_z and shear stresses τ_x, τ_y, τ_z by the formula:

$$U_f = \frac{1+\mu}{6E}[(\sigma_x - \sigma_y)^2 + (\sigma_x - \sigma_z)^2 + (\sigma_y - \sigma_z)^2] + \frac{1}{2G}(\tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2) \quad (1.11),$$

where E isYoung's modulus, G is theshear modulus and μ is Poisson's ratio.

An increase in potential energy and its long-term storage is possible, if the nonlinear deformation of the position of the atoms is changed so that the repulsive forces are increased.

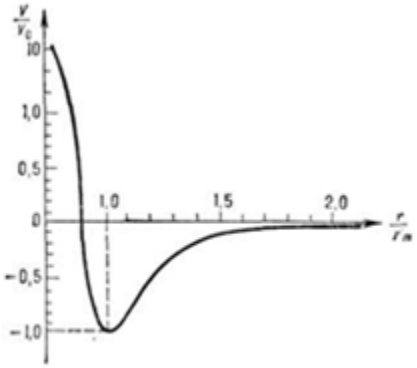


Figure 1.5

The interaction between two atoms is described by the potential curve shown in Figure 1, at which point 1.0 on the axis of the relative distance between the atoms corresponds to equilibrium between the forces of repulsion and attraction. The repulsive forces are increasing much faster than the attractive forces if, under the influence of external forces, the distance between atoms decreases. At present there are several formulas for the determination of the interaction potential. One of the most common formulas proposed by Lennard-Jones is

$$U = 4\varepsilon\left[\left(\frac{\sigma}{r}\right)^{12} - \left(\frac{\sigma}{r}\right)^{6}\right] \quad (12).$$

Where the force of interaction is from

$$F = = -\frac{dU}{dr} = 24\frac{\varepsilon}{r}\left[2\left(\frac{\sigma}{r}\right)^{13} - \left(\frac{\sigma}{r}\right)^{7}\right] \quad (13).$$

where r is the the distance between the centers of the particles, ε is the potential well depth, and σ is the distance at which the interaction energy is zero. The first term $\left(\frac{\sigma}{r}\right)^{12}$ describes the repulsive force; the second term $\left(\frac{\sigma}{r}\right)^{6}$ describes the attractive force.

According to this formula, the repulsive force increases in the thirteenth degree, while the attractive force only in the seventh and the balance must be broken. But this does not happen. Consequently, for some reason the attractive force has risen. In fracture mechanics there is no explanation of this fact because there is no conception of the interatomic bonding nature.

In contrast, such a representation exists in quantum mechanics. Heitler and London developed a theory of the covalent bond in 1927. F. London publishes in 1930 the theory of dispersion forces. The interaction energy of atoms or molecules he expressed by the formula

В 1930 Ф. Лондон публикует теорию дисперсионных сил, согласно которой энергия взаимодействия атомов или молекул U выражается через расстояние между ними r, потенциалы ионизации I_1, I_2, поляризуемости α_1, α_2 формулой:

$$U = \frac{3I_1I_2\alpha_1\alpha_2}{2r^6(I_1 + I_2)}. \quad (1.14)$$

where r is the distance between atoms or molecules, I_1 and I_2 is the ionization potential and α_1, α_2 is

polarizability.

This means that the new equilibrium state, corresponding to a higher potential energy, is due to some changes in the interaction of atoms (ions).

The energy state of an atom is due to the number of electrons in its shell and their location. A change in the energy state of the atom occurs upon absorption or emission of a photon, in which an electron moves from one energy level to another. The maximum change in the energy state is due to the additional ionization of an atom or ion-electron recombination.

Thus, with decreasing distance between the atoms there is an increase of the potential energy of two types: 1) the elastic energy, which can be considered analogous to the change in volume, 2) a change in the energy state of the atoms. To determine if this energy can be attributed to the energy

It is known that atoms (ions, molecules) vibrate and their energy is determined by temperature. It does not depend on whether a given area is in a state of stress or not.

During operation, chemical reactions (corrosion) may occur between the chemical elements of a material or with environmental elements, in which energy is emitted.

Therefore, the energy of all types of external influence will be distributed between the four types of energy in the solid.

Let us estimate the energy ratio between them.

1) It was established experimentally [1.30] that under thorough compression at a stress of 700 MPa the elastic energy stored in 1 m^3 of spring steel (7800 kg), containing $8.50 \cdot 10^{28}$ atoms, is $1 \cdot 10^6$ J = $1.60 \cdot 10^{25}$ eV. Consequently, there is $1.18 \cdot 10^{-23}$ J/atom or $1.88 \cdot 10^{-4}$ eV/atom.

2) It was established experimentally [1.31-1.34] that two peaks of light radiation with energy 1.7 and 2.14 eV were observed during spalling destruction of the crack surface of copper. But in silver spalling photons with energy of 4.08 eV was observed.

This means that crack formation happened with the participation of the energy of the excited atoms. Indeed, during the second breakaway the brightness of luminescence increased by 2-3 orders of magnitude. A similar phenomenon occurs in previously deformed metal.

3) The energy of thermal atomic vibrations k_{BT} at T=300 K is $1.3 \cdot 10^{-2}$ eV/atom.

4) The energy of Fe_2O_3 formation (corrosion) is 8.83 eV/atom, Al_2O_3 is 17.36 eV/atom.

Let's us summarize. 1) Elastic energy is minimal. It is an order of magnitude lower than the energy of vibrational motion at room temperature. When the temperature is lowered the ratio changes, and this leads to embrittlement. But the elastic energy of a single atom is much less than the binding energy between the atoms.

For example, the iron binding energy of atoms is 4.29 eV. So the binding energy is four orders higher than the elastic energy: (4.29:1.88 10^{-4}=22,819). This means that to break one of the interatomic bonds the energy of tens of thousands of atoms should be focused at the same time between the two elemental cells. The mechanism of this phenomenon is absent in nature, whereas the radiation of energy by excited atoms can be spontaneous or stimulated. This is the basis on which a laser works.

The thermal vibrations of atoms, including fluctuations, cannot lead to cracking or fracture, as they are spontaneous, incoherent, randomly assigned. The mechanism of energy concentration of the chaotic undirected thermal radiation in Nature is absent.

The maximum energy of the photons is emitted during metal corrosion, however it does not accumulate but damages the metal, weakening it. The corrosion process is slow. Destruction may occur as a result of depressurization, leakage of gas or explosive substance.

Thus, the main source of energy of crack formation or fracture are groups of atoms, where in the case of nonlinear deformation there is a transition of electrons to higher metastable energy levels.

These groups of atoms are called the domain of destruction. The state of stress is a consequence of of the domains of destruction formation. After the radiation energy of the domain's atoms, due to the transition of electrons to lower levels, the stress state disappears.

1.6.4. Analysis of the number of man-made disasters from a position of fracture mechanics

Let us consider the specific examples of evaluation and testing of a catastrophic failure of structures or devices. Figure 1.6 shows the pipeline API 5L X46 (Argentina), where in 1998 after 20 years of operation there appeared a crack whose length was 4.8 m [1.35]. Two windows were cut for the study. Theoretical study of the experimental results are analyzed with

Figure 1.6 [1.35]

the Paris-Erdogan formula $\frac{da}{dN} = C\Delta K^m$ (1.15)[1],

where a is the crack length (m), N is the number of cycles of exposure, C is the factor of proportionality (m/cycle), m is the index, $\Delta K = K_{max}$-K_{min} is the change of stress intensity factor (SIF). As a result of these calculations the following values were obtained:

1. Material: Base, m=6, C=3.818·10^{-15} m/cycle,
2. Material: Weld Salitral, m=5.29, C=3.327·10^{-14} m/cycle,

[1] In the scientific and technical literature, there is no uniformity in the designation of the physical parameters: the same parameters in different studies are indicated by different letters or different parameters denoted of the same letter. Designation of each parameter in the equation or formula is explained in order to avoid misunderstandings.

3. Material: Weld Alen, m= 5.27, C=$4.7\cdot10^{-14}$ m/cycle.

In this article, we are facing the same mindless extrapolation which Feynman wrote about. Remember that the size of an atomic nucleus is ~ 10^{-15} m, the shortest distance between the iron atoms is 2.48 Å=$2.48\cdot10^{-10}$ m.

Modern experimental methods allow manipulating by individual atoms, to determine the distance between them to a fraction of an angstrom. In connection with this, it is pointless to write about a crack that is smaller than the size of the atom and is commensurate with the size of the atomic nucleus. The number $3.818\cdot10^{-15}$ m does not mean that the measurements were carried out with such precision. The resolution of modern tunneling electron and atomic force microscopes does not exceed a few hundredths of an angstrom, i.e. ~10^{-12} m. To obtain the value of $3.818 \cdot 10^{-15}$ m, under measurements it is necessary that the resolution of the atomic force microscope has been 4-5 orders of magnitude higher.

The fallacy of such calculations is that the behavior of atoms in nanoregions can only be described on the basis of quantum mechanics.

Let me to pay attention to Paris-Erdogan equation (1.15).

The dimension of the left side is meter, but the coefficient C has the same dimension. Consequently, $\Delta K = K_{max}-K_{min}$ is dimensionless. The materials used in structures and devices are different; significantly different are their service conditions. However, in the stress intensity factors, these features are not taken into account. Thus, the use of SIF has no meaning. At the same time, Irvine, offering a new parameter, proposed by the formula ΔK = MPa m ½, where m has the dimension of meters. Hence, the dimension of SIF is Pa m½. Thus, these two formulas contradict each other, but the formula of Irwin has no physical meaning, since it also has no parameters characterizing the properties of the material and the conditions of its operation.

As we know, materials science proceeds from the triad: composition-structure-properties. Use of mathematical equations that do not have a physical meaning to evaluate the technical condition and remaining life of structures and devices in order to ensure their safe use is, at least, devoid of common sense.

The rail at the 35 meter section was destroyed by fragments of more than 300 as shown in Figure 1.7 a.

Figure 1.7 a [1.37]

Here are the main features of this disaster, in which four people died, 70 have been injured.

1. The rail was manufactured in 1995. Mass of the rail was 56 kg/m.

2. Maintenance of the rail was investigated in February 1998 and January 2000, including using ultrasound. Additional studies were carried out, if necessary, replacement or reconstruction.

3. Intensive spalling took place prior to the disaster. This is evidenced by the fact that cleavage in this case was as fresh and covered in rust. Fragments of the surface due to spalling, with sizes ranging between 20 to 35 inches (500 ÷ 900 mm). One of the fragments had the dimensions: length 100 mm, width 30 mm, depth 3 mm. (See Figure 1.7 b).

4. The cleaved surface has been bright or dark. It is assumed that bright surface is produced by brittle fracture caused by the martensitic transformation. Nature of the black surface was not analyzed

5. The surface which previously was black sustained intensive corrosion six years later, whereas the bright surface did not change, as shown in Figure 1.7c.

. This disaster has been the subject of a number of studies, including by the leading research laboratories in England. However, analysis of the causes of this destruction was done only within the framework of mechanics.

Figure 55 General rail head condition

Figure 56 A typical region of spalling

Figure 65 One of the fractures at 325m with the polished area showing

Figure 1.7 b [1.37]

In the work [1.6] attention has already been paid to the fact that this phenomenon is due to the difference in the energy structure of atoms forming the fault surface. Atoms on a bright surface are more highly ionized, or their ionization potential is higher, while the opposite surface have the less ionized atoms, with higher electron affinity, and easily react with oxygen or other non-metals.

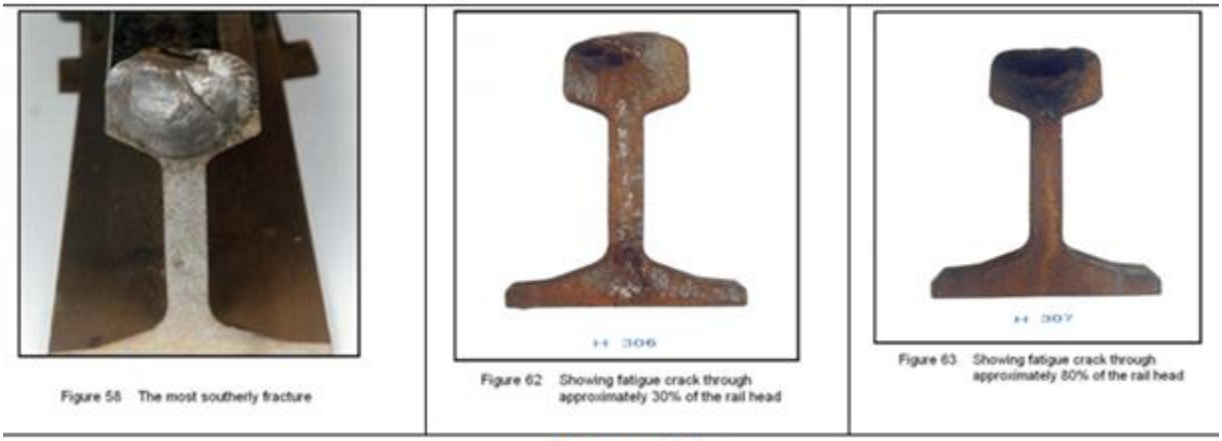


Figure 58 The most southerly fracture

Figure 62 Showing fatigue crack through approximately 30% of the rail head

Figure 63 Showing fatigue crack through approximately 80% of the rail head

Figure 1.7 c

The catastrophic failure of the I-35 W Bridge, which happened on August 1, 2007 on the Mississippi River (USA), shows that this phenomenon is not accidental. The I-35 W Bridge accident and the location of the rupture are shown on a Figure1.8.

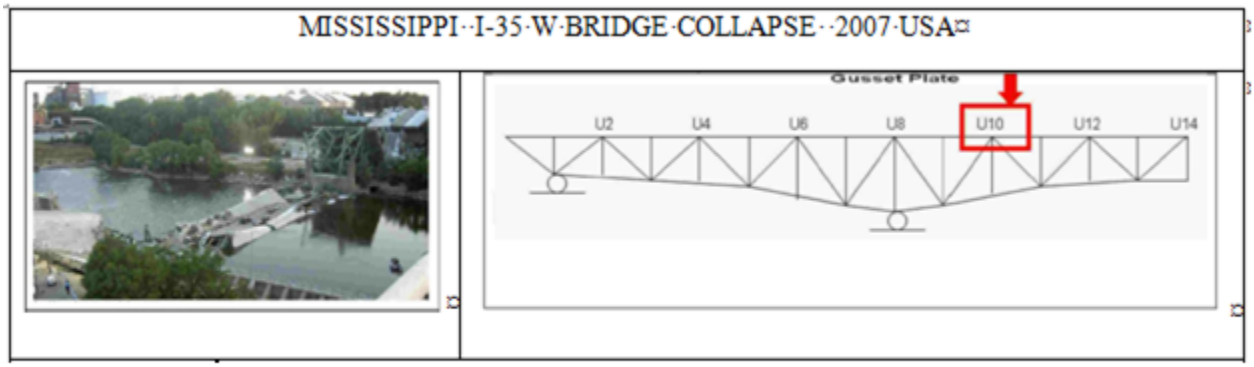


Figure 1.8 National Transportation Safety Board Highway Accident Report NTSB/HAR-03/03. Washington, DC. Published November 2008.

The analysis of the causes of destruction, as it follows from the report of the state commission made by the finite element method. Correctly identifying the cause of the accident, using only the methods of mechanics, is impossible.

The finite element method is a mathematical program that is done by computer. Here it is appropriate to recall Feynman's warning that a computer program is not always correct. In this case, first, it is based on the fact that the main source of energy is a state of stress. Second, it is designed to calculate the stress distribution in a design element. It is assumed that failure occurs at the point where the stress is highest. However, this assumption is refuted by experiment. For example, in a fish-eye type of destruction the stress distribution depends on the ratio of the strength of the alloy and the defect that has resulted from the deformation.

Features of the interaction of the defect with the matrix of the alloy are investigated in the work [1.39]. “In early studies the main reason why the TiN inclusions were detrimental was believed to be due to high stress concentration because of their cubic shape. Recent research, however, has shown that the elastic modulus of the TiN inclusion also plays an important role. When the surfaces of the TiN matrix are weakly connected, in the majority of cases the crack is created in TiN before the initiation of a rest crack. When the inclusions are tightly bonded to the matrix, the stress state around the inclusions depends on the difference in the elastic modulus between the inclusion and the matrix.”

The mechanism of influence in non-metallic inclusions in alloys depends not only on the ratio of the elastic modules, but also on the energy that is emitted during the defect formation. Let us compare the effects of Al_2O_3 and TiN inclusions on the properties of the corresponding alloy. The ratio of the elastic modules of the compound to the modulus of elasticity of the metal, (GPa) are: TiN/Ti=520/120=4.33, Al2O3/Al=353/70.6=5.0, i.e. the difference is about 15%. However, the ratio of the energy of the photons emitted during compound formation to the binding energy are TiN/Ti=3.46/4.855=0.71; Al_2O_3/Al=17.36/3.34=5.2 or the energy required to melt one cell is TiN/Ti=3.46/6.23=0.56;

$Al_2O_3/Al=17.36/0.7=24.8$. This leads to the fact that around the Al2O3 inclusion is formed not a stress state, but a heavily damaged area, since the density of Al_2O_3 is 1.46 times higher than the density of aluminum.

Such features of the properties of alloys play an important role in cracks and destruction formation, but are absolutely ignored in the finite element method.

There is an opinion that the rest cracks in titanium alloys are due to the expansion of titanium nitride, but as we can see, this is false.

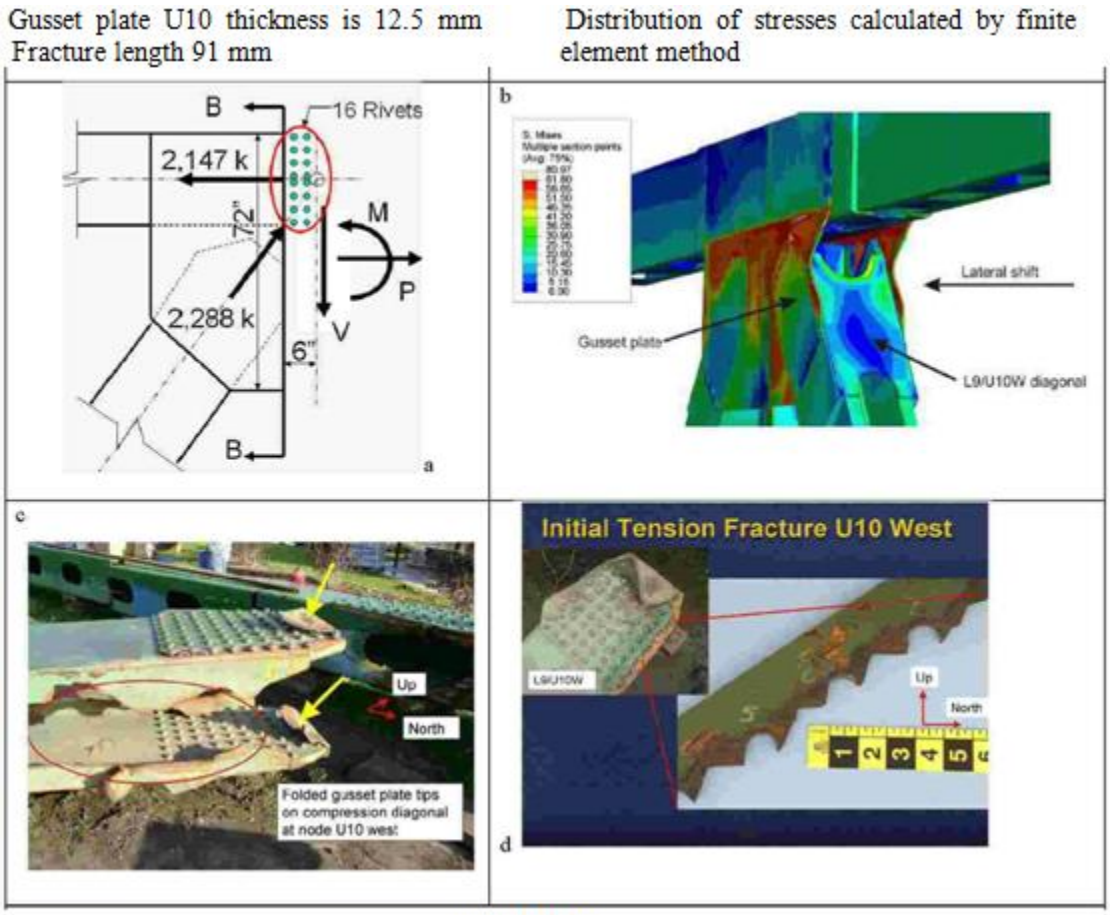


Figure 1.9

Bridge disaster occurred due to rupture of riveted joint (16 Rivets), shown in Figure.1.9a. Fracture behavior in greater detail shown in the pictures 1.9c and 1.9d. Figure.1.9b shows a fragment of the analysis result causes destruction made using the finite element method.

The report, which is dedicated to the causes of the I-35 W bridge accident, indicates that cracks and corrosion were not observed in the area where the destruction started. A number of possible scenarios were considered based on the redistribution of stresses. Of course, in such an important matter all options should be reviewed, but for some reason in the report the fragment, “Initial Tension Fracture

U10" was not included. Why?

Let's turn our attention to it. Only 8 rivet holes have been broken, but the bridge collapsed and killed 13 people. It is necessary to answer these questions: why is the character of the break and corrosion in even and odd holes different? Is it randomness or natural laws? Regular alternation of the properties observed under the deformation of metal and its destruction is very often observed. However, no significance is given to this fact in fracture mechanics, and the mechanism is not explained. We will return to this problem in the next chapter.

It should be noted that one of the causes of the bridge crash was the poor quality control of its condition. We studied "Fracture critical Bridge Inspection In-Depth report" from 1994 to 2006. In the process of inspection, damage was revealed and recommendations were made for their elimination. The major damages were fractures, corrosion, and screws self-unfastening and falling out. The emergences of dangerous cracks were not observed. Gusset Plates were not considered dangerous. The fact that bolts were falling out was also of no concern. For example, it was noted that in 1997, 11 bolts fell out of a single element of the bridge.

Let us note that the same deficiencies were noted for several years in a row. It especially characterized the five years (2002-2006) before the catastrophe. One example is taken from the section "Immediate Maintenance Recommendations".

The first of four recommendations: "Four-stringer connection bolts, all in the NBL, need replacement. At panel point #8, stringer #2 has 2 loose bolts, and the bearing block has rotated. This will likely require jacking the superstructure. Stringer bolts also need replacement at panel point #8, stringer #4, south side, and at panel #11, stringer #3." It is repeated unchanged in the "Inspection of bridges" in all reports from 2002 to 2006. Moreover, photos of stringers number 2 and number 4 are published invariably all these years. From this can be seen the characteristic signs of corrosion, the form of which has not changed.

A similar situation occurs with the second recommendation, which appears in the reports of 2004, 2005 and 2006, which is not given for the sake of brevity, such as repetition in other sections.

It is impossible to suppose that the state commission did not become familiar with these reports. Consequently, the final report of the commission cannot be regarded as objective.

The reliability and durability of riveted joints is especially important for aircraft. In this regard, chapter IV is dedicated to this problem. Here we concern ourselves with the general problems of fracture mechanics, using some examples.

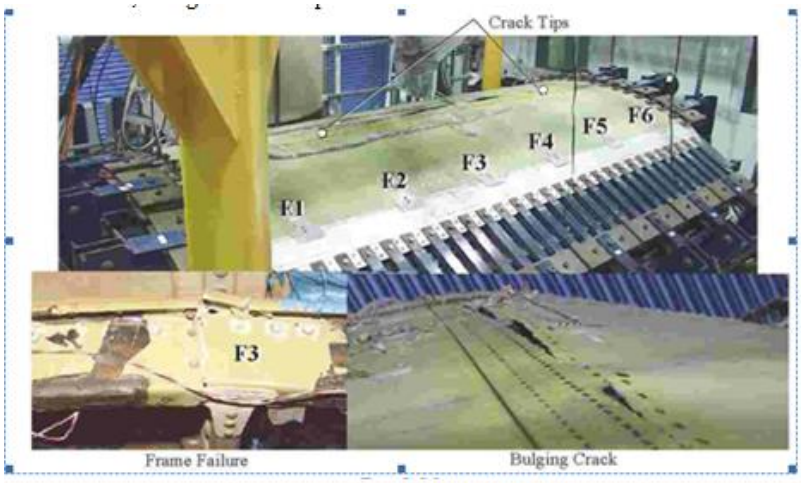


Figure 1.10 [1.40]

Figure 1.10 [1.40] shows a photograph of an experimental setup designed for studying crack formation and riveted joint fracture. The experimental results obtained in this study are of great interest and will be discussed below. However, the mathematical tools with which conclusions are drawn, does not hold up to criticism.

Let us consider five formulas.

$$\Delta K_{flat} = \left(\frac{\exp(A\ln(a) - B}{C} \right)^{-n} (1^*),$$

$$\frac{da}{dN} = \exp\left(A\ln(a) - B\right) \ (2^*),$$

$$\frac{da}{dN} = C\Delta K^n \ (3^*),$$

$$\Delta K_{curved} = \beta \Delta K_{flet} \ (4^*).$$

$$K_{eff} = \sqrt{E\left(\left(\frac{K_I^2}{E}\right) + \left(\frac{K_{II}^2}{E}\right) + \left(\frac{1+\nu}{3+\nu}\right)\left(\frac{\pi k_I^2}{3E}\right) + \left(\frac{1+\nu}{3+\nu}\right)\left(\frac{\pi k_{II}^2}{3E}\right)\right)} \ (5^*).$$

In (1*) and (2*) the dimension of the left and right is not the same; formula (3*), was examined earlier. The introduction of Young's modulus of the radical expression does not make sense since it is included in the numerator and denominator simultaneously; the link between Keff and K_I, K_{II}, k_I, k_{II} has not been experimentally confirmed.

Thus, the above formulas cannot be used to assess the results of the experiment.

It is known that the P.I. Baranov Central Institute of Aviation Motors development (Russia) has acquired a high-speed (up to 100 Hz) universal servo-hydraulic loading system NANO-PLUG and PLAY, intended for research methods appropriate to standards of Russia: GOST 25.506-85, OST 192127-90, OST 190268-78, OST 190215-78 with USA Standards ASTM: E647, E399, E813, E1152, E1290, E1820.

Creation and use of modern methods of monitoring the technical condition of elements structures and

devices, including in aircraft engine, driven by the need to prevent accidents that occur due to a failure or as fracture energy devices and their fastenings.

As these standards are based on the methods of fracture mechanics, we evaluate their effectiveness in terms of modern physics. As an example, we use the USA Standards ASTM NASGRO, which has been widely used not only in aeronautical engineering, but also in other sectors to estimate the rate of crack propagation.

ASTM·E647·USA·NASGRO·STANDARD¤	ASTM·E647·FCG·TESTING·STANDARD·¤
$\frac{da}{dN} = C\left[\left(\frac{1-f}{1-R}\right)\Delta K\right]^{n} \frac{\left(1-\frac{\Delta K_{th}}{\Delta K}\right)^{p}}{\left(1-\frac{K_{max}}{K_{crit}}\right)^{q}}$ ¶ where·*a*-crack·length,·*N*-number·of·cycles·of·exposure,·*R*-ratio·of·mechanical·stresses,·ΔK_{th}·SIF·threshold,·i.e.·Minimum·ΔK·at·which·value·a·crack·begins·to·spread,·K_{max}·the·maximum·value·of·SIF,·*C,·m,·p*·and·*q*·are·experimental·coefficients.·¶ The·most·important·parameter·is·*f*,·characterizing·the·crack·opening.·ΔK_{th}·is·a·complex·function·of·*a,·f,·R,*·and·other·new·parameters.¶ ·¤	Environmental·Conditions¶ *·AL-2-22:·19-21·June·06/3·days·duration¶ USAFA·TR·2006-10¶ a.·Temperature-26°C¶ b.·Humidity-24%¶ "*·AL-2-29:·22-23·June·06/2·days·duration¶ a.·Temperature-26*C¶ b.·Humidity-24%¶ "*·AL-2-30:·26-27·June·06/2·days·duration¶ a.·Temperature-260·C¶ b.·Humidity-24%¶ "*·AL-7-32:·17-18·May·05/2·days·duration¶ a.·Temperature-28*C¶ b.·Humidity-15%¶ "*·AL-7-33:·18-19·May·05/2·days·duration¶ a.·Temperature-29°C¶ b.·Humidity-16%¶ "*·AL-7-34:·23-24·May·05/2·days·duration¤

Understanding that the rate of crack formation depends on the temperature and humidity of the environment, the standard ASTM E647 was supplemented with ASTM E647 FCG TESTING. However, during its life a material is subjected to a complex environmental exposure and varying loads that cannot be taken into account.

The problem of describing the mechanism of opening and closing of cracks is important in fracture mechanics. To solve it, a range of mathematical models is offered, which includes a large number of additional parameters. The formula used in ASTM E647 includes four types of SIF ($\Delta K, \Delta K_{th}, \Delta K_{\max}, \Delta K_{crit}$) and five dimensionless coefficients (*f, R, m, p, q*), for which diverse mathematical procedures are offered to calculate. For this, the authors introduce new parameters.

Let me demonstrate one of these methods, for example [1.41, 1.42].

$$\Delta K_{th} = \left(\Delta K_1 \frac{a}{a + a_0} \right)^{1/2} \frac{[1-R]^{(1+RC_{th})}}{(1-A_0)^{(1-R)C_{th}}},$$

Where a_0-structural crack length, depending on the grain size of the material, C_{th}-correction factor, which depends on R, ΔK_1-the threshold value as $R \to 1$, f- Newman's function, describing the closing of cracks, equal $f = A_0 + A_1 R + A_2 R^2 + A_3 R^3$, when R $\geqslant$ 0;

$f = A_0 + A_1 R$ when R <0, where $A_0 = (0.825 - 0.34\alpha + 0.05\alpha^2)\left[\cos\left(\pi F(a) \frac{S_{\max}}{\sigma_o}\right) \right]^{1/\alpha}$,

$$A_1 = (0.45 - 0.071\alpha) \frac{F(a) S_{\max}}{\sigma_0},$$

$$A_2 = 1 - A_0 - A_1 - A_3,$$

$$A_3 = 2A_0 + A_1 - 1.$$

Here α is a limiting factor; the function F (a) is a correction factor that characterizes the crack and its border; $\frac{S_{\max}}{\sigma_0}$ is Newman's empirical coefficient.

Today there are large numbers of published papers in which similar mathematical method have been used. All of them have the same disadvantages. First, the chain of mathematical formulas with any experiments is not connected. For example, in [1.42] 36 parameters used, but only three of them (the length of the crack, the external stresses and the thickness of the specimen) can be measured, and the number of cycles can be counted, but the physical law that binds them, is not specified. Secondly, it is impossible on the basis of such methods to reveal the mechanism of formation of cracks, especially predict the technical condition of the sample. Third, they have no new physical ideas that complement the ideas expressed by Maxwall and Feynman. Moreover, they ignored Feynman'swarnings of discussed earlier.

Equation (6 *) is reduced to equation $\frac{dl}{dN} = C[\alpha \Delta K]^m \cdot \beta = C_1[\Delta K]^m$ (7 *), as the exponential quantity *m, p, q* and mathematical expressions in parentheses are dimensionless. Therefore, we came to to the Paris-Erdogan equation.

1.6.5. The main disadvantages of fracture mechanics:

1. Fracture mechanics of solids is the classical theory, which builds on the idea of a continuous medium, the theory of elasticity, and the theory of plasticity. Items that are less than 10^{-6} meters are

not used, including nanoscale inclusions. This lead to the fact that none of the scientific and technical achievements associated with nanotechnology are used.

2. The main source of energy in fracture mechanics is the elastic energy of the stress state, which is due to changes in the geometric arrangement of the atoms or molecules caused by deformation.

3. Energy radiation which leads to cracking and failure is considered in fracture mechanics as spontaneous.

4. Residual life assessment in fracture mechanics is based on: a) the stress intensity factor (SIF) *K*, b) the change ΔK, c) crack growth rate Δa/ΔN, d) formulas, for example, the Paris-Erdogan law, Forman Equation - Wheeler Model Crack Retardation, ASTM E647 USA NASGRO standard, e) methods of mathematical processing of data, such as finite element, f) computer programs, for example, AFGROW.

5. The formulas of Fracture mechanics do not contain the physical parameters of the material, which eliminates the possibility of monitoring the technical condition of the structure or device during its operation.

6. Mathematical procedures for calculation, including computer programs, do not contain energy parameters, without which the prediction of residual life is impossible.

7. One of the most common methods for determining the SIF is to study the chromatographic patterns obtained by photoelasticity on transparent samples. Photoelasticity is due to the interference of polarized light, in which the transmission of light depends on the difference between the ordinary and extraordinary rays, arising from birefringence. The response of the metal atoms to external mechanical impact is significantly different from the response to light. In this regard, the distribution of stress in the metal is different from that observed in photoelasticity. This leads to the fact that, first, the formulas used to estimate the remaining life contain multiple SIF, which are not related to the parameters of the material, and secondly, three to nine correction coefficients for each input case are used in the formulas simultaneously.

8. The formulas do not take into account the simultaneous impact on the object of several factors, such as mechanical, chemical (corrosion), the effect of stray currents on pipelines and railway track, radiation for aircraft, etc.

9. Physical methods of nondestructive testing (ultrasound, X-ray, eddy current, thermograph) are limited to the study of defects that are larger than 10^{-6} m.

10. For final conclusions on the technical state of the object it is necessary to build the

nomogram and complex computer models. All this leads to higher costs, does not guarantee reliable assessment, and makes continuous monitoring of extremely dangerous structures and device elements impossible.

REFERENCES TO CHAPTER I

1.1. L. Pauling, *The Nature of the Chemical Bond and the Structure of Molecules and Crystals: An Introduction to Modern Structural Chemistry*, Cornell University Press, 1960 - Science pp. 644.

1.2. A. Zewail: *Femtochemistry: Recent Progress in Studies of Dynamics and Control of Reactions and Their Transition States*, J. Phys. Chem. 1996, 100, 12701-12724

1.3. Prigogine, Ilya; Stengers, Isabelle (1984). *Order out of Chaos: Man's new dialogue with nature*. Flamingo. ISBN 0-00-654115-1.

1.4. Б. П. Белоусов, *Периодически действующая реакция и её механизм*. Сб.: Автоволновые процессы в системах с диффузией. — Горький: Изд-во ГГУ, 1951, с.76

1.5. А. М. Жаботинский, *Концентрационные колебания*. М.: Наука, 1974, 179 с.

1.6. V.P. Rombakh: *Atom Parameters and Metal Properties*. Logistics Capital Inc., Edmonds, WA 2008, P.313

1.7. Alcohol constrains physical constant in the early universe, http://tech.groups.yahoo.com/group/physical_sciences/message/7455

1.8. Carlos G. Camara, Juan V. Escobar, Jonathan R. Hird, Seth J. Putterman: *Correlation between nanosecond X-ray flashes and stick–slip friction in peeling tape Nature,* 2008 *455* (7216), 1089-1092.

1.9. V.V. Karasev, N.A. Krotova and B.W. Deryagin, "*Study of electronic emission during the stripping of a layer of high polymer from glass in a vacuum*," Dokl. Akad. Nauk. SSR, 1953, **88**, 777-780.

1.10. S.P Timoshenko, *History of Strength of Materials: With a Brief Account of the History of Theory of Elasticity and Theory of Structures* 1953, pp 452. (p 368 about [1.11], pp 269-274 about [1.16]).

1.11. J.C. Maxwell Letter to William Thomson, 18 December 1856, The Scientific Letters &Papers of James Clerk Maxwell, v.1, 1846-1862, 487-491.

1.12. Mao-hong Yu, *Advances in strength theories for materials under complex stress state in the 20th Century,* Appl Mech Rev vol 55, no 3, 2002, 196-246.

1.13. R. M. Christensen A Two Property Yield, Failure (Fracture) Criterion for Homogeneous, Isotropic Materials, http://www.failurecriteria.com/Media/Two_Property_Yield_Failure_Fracture_Criterion_for_Homogeneous_Isotropic_Materials.pdf

1.14. LIU Guang-lian*, A novel limiting strain energy strength theory*, Trans. Nonferrous Met.Soc. China, 19 (2009)1651-1662

1.15. K. Osakada, History of plasticity and metal forming analysis, Journal of Materials Processing Technology 210 (2010) 1436–1454

1.16. J.C. Maxwell, III. *On the Equilibrium of Elastic Solids,* pp.31-74, The Scientific Papers of James Clerk Maxwell, Edited by W. D. NIVEN, M.A., F.R.S. Two Volumes Bound As One. Dover Publication Inc. N.Y.

1.17. V. K. Singh and P.C. Gope: Photoelastic *Determination of Mixed Mode Stress Intensity Factors*, J. of Solid Mechanics, 1, No3, 2009, 233-244.

1.18. E. F. Finlayson: *Stress Intensity Factor Distribution in Bimaterial System-A three-dimensional photoelastic investigation*, Thesises, The Virginia Polytechnic Institute and State University 1998, pp.145

1.19. C. de Oliveira Miranda, M. A. Meggiolaro, L. F. Martha, J. T. Pinho de Castro, *Stress intensity factor predictions: Comparison and round-off error,* Computational Materials Science 53 (2012) 354–358

1.20. П.Л. Капица, *Научная деятельность Э. Резерфорда*, Эксперимент, теория, практика, М: «Наука», 1977, 211-242.

1.21. D. Banabic, Sheet Metal Forming Processes, Chapter 2 Plastic Behaviour of Sheet Metal «DOI 10.1007/978-3-540-88113-1_2, 27 Springer-Verlag Berlin Heidelberg 2010, pp.115.

1.22. R. P. Feynman, R.B. Lighton, M. Sands, *The Feynman Lectures on Physics*, v. 1, 1963, pp. 439 Eddison-Wesley Publiching

1.23. R. Feynman, *"What Do You Care What Other People Think?"* Amazon,1988

1.24. Л. Д. Ландау, Е.М. Лифшиц, Теория упругости, 1987. М.: Наука 248 с.

1.25. Х.Хан, *Теория упругости, Основы линейной теории и ее применения*. М: Наука, 1969, С.344.

1.26. П.Л. Капица, *Научная деятельность Вениамина Франклина*, Эксперимент, теория, практика, М: «Наука», 1977, 273-286.

1.27. L. Lorenz, *Über die Refraction constant*, Ann. Phys. 1880, v.11 70-103

1.28. H. A. Lorentz, *Über die Beziehung zwischen der Fortpflanzungsgeschwindigkeit des Lichtes und der Körperdichte*. Ann. Phys. 1880. V. 9, 641—665.A.

1.29. A.A. Griffith: *The phenomena of rupture and flow in solids*", Philosophical Transactions of the Royal Society of London, A 1921, **221**: 163–198.

1.30. J.E. Gordon: *The New Science of Strong Materials or Why You Don't Fall Through the Floor* Princeton University Press 2006 pp.328К.Б.

1.31. Абрамова, А.Б.Пахомов, Б.П. Перегуд, Д.Н. Перунов, В.А. Рейнгольд ,И.П. Щербаков: *Спектр излучения, сопровождающего разрушение медных, алюминиевых и серебряных проводников током большой плотности*. Оптика и спектроскопия, 1985, т.58, .809-814.

1.32. К.Б. Абрамова, А.Б.Пахомов, Б.П. Перегуд, И.П. Щербаков: *Механолюминесценция стали,* ЖТФ, 1986, **56**, 978-981

1.33. К.Б. Абрамова, А.Б. Пахомов, Б.П.Перегуд, И.П.Щербаков: Письма в ЖТФ, **9**, 769 (1983); ЖТФ, **56**, 978 (1986); ЖТФ, **58**, 817 (1988);).

1.34. К.Б. Абрамова, А.Б. Пахомов, Б.П.Перегуд, И.П.Щербаков. *Излучение света при динамическом разрушении титана.* - ЖТФ, 1990 **60**, 80-85.

1.35. M.D. Chapetti, J.L. Otegui, j. Motylici: *Fetugue Assessment of an Electrical Resistance Welded Pipeline*, Int. J. of Fetigue, 2002, **24**, 21-28.

1.36. Train Derailment at Hatfield: A Final Report by the Independent Investigation Board, 2006, pp 245.

1.37. Highway Accident Report Collapse of I-35W Highway Bridge Minneapolis, Minnesota August 1, 2007, National Transportation Safety Board.

1.38. NTSB Bridge Description and Collapse by Jim Wildey, http://www.ntsb.gov/news/events/2008/minneapolis_mn/presentations/2_Board_Presentation_Wildey_Graphic.pdf

1.39. Y. Furuya, S. Matsuoka, and T. Abe, *Inclusion-Controlled Fatigue Properties of 1800 MPA-Class Spring Steels*, Metallurgical and Mater. Trans.2004, 35A, 3737-3743.

1.40. J. G. Bakuckas, Jr, C. A. Bigelow, and Paul W. Tan: *Characteruzation of Fatigue Behavior of Aircraft Fuselage Structures, ICAF 2003 – Fatigue of Aeronautical Structures as an Engineering Chalenges* pp.18

1.41. S. Kłysz and A. Leski, *Good Practice for Fatigue Crack Growth Curves Description*, http://dx.doi.org/10.5772/52794.

1.42. Y. C. Tong, W. Hu, D. Mongru, *A Crack Growth Rate Conversion Module: Theory, Development, User Guide and Examples*, 2007, Air Vehicles Division Defence Science and Technology Organisation, DSTO-TR-2050, pp. 61.

CHAPTER II. STRENGTH AND DESTRUCTION OF NANOMATERIALS

Atoms on a small scale behave like nothing on a large scale, for they satisfy the ***laws of quantum mechanics****. So, as we go down and fiddle around with the atoms down there, we are* ***working with different laws****, and we can expect to* ***do different things****. We can manufacture in* different ways*. We can use, not just circuits, but some systems involving* ***the quantized*** *energy levels, or the interactions of* ***quantized spins****, etc*.

Richard Feynman

2.1. Physical fundamentals of nanotechnology

On December 29, 1959, Mr. Richard Feynman gave a talk, a fragment of which is shown above as an epigraph. We have identified in this passage 11 words that underpin the essence of Feynman's idea, the implementation of which gave rise to of an area of engineering which is called nanotechnology. Feynman, in a brief paragraph, twice repeated that we're speaking not about random events, but about regular phenomena; he repeated three times that these phenomena are due to the quantum properties of atoms. He noted that new materials will be obtained by different means using quantum energy levels or the interaction of the spins, and pointed the way for the implementation of the proposed ideas.

A founder of quantum electrodynamics, well-versed in advanced mathematics, he used only simple arithmetic calculations to justify his proposed ideas. Supposing that one letter could be written with 5 atoms, he found that all the world's literature could be written in a cube whose edges measured 0.1 mm, with a volume less than a speck lodged in the eye. It was found that an ordered arrangement of atoms in that amount does not contradict physical laws and is therefore feasible.

Today, humanity has seen the breakthrough called nanotechnology. Feynman's prediction came true about the "new use cases" that exceed any fiction. His "new patterns and effects, which have no analogues in the macroscopic scale" are now real.

Although formally development of Feynman’s idea continued on in the scientific and technological fields, in fact technology outstrips its scientific rationale. The number of publications devoted to fundamental problems is many times less than the technology ones, despite the fact that after the first successful experiments, it was necessary to explain the nature and mechanism of the observed phenomena on the basis of the ideas that were formulated by Feynman. One can put forward various hypotheses on why Feynman did not propose a mathematical theory. The distinctive feature of Feynman, like Maxwell, is the fact that theory is based on experiment. As is well known, Feynman

formulated the quantum principle of least action. In this regard, it seems most likely that until 1988, Feynman did not yet have enough experimental data to highlight the phenomena caused by the interaction of atoms in nanoobjects.

Feynman, of course, was well aware of the nature of waves and atomic interaction, but suggested the idea of manipulating atoms, as if it were not associated with the electron-wave processes. Is this accidental?

To answer this question, we call attention to the fact that he knew perfectly the works of the founders of quantum mechanics. Einstein's role in physics can not be overstated. Each of the scientific areas he developed is considered to be fundamental and served as a basis of modern physics. They can stay guides for many years or even centuries

M. Planck, the founder of quantum theory, analyzing the dynamic and statistical laws, writes: "... a statistical type of law that controls large-scale events is made up of dynamic laws that seem to govern the events of the small scale, the interaction of individual atoms and molecules. "

Einstein, like Planck, Schrodinger, and Louis de Broglie, stands opposed to the statistical interpretation of quantum mechanics by Bohr and Heisenberg. His protest: "*I will never believe that God plays dice with the universe," and "They've abandoned reason!"* particularly accurately describes the need to establish cause-and-effect relationships.

E. Schrödinger, analyzing the problem of heredity, comes to a conclusion about the inapplicability of the second law of thermodynamics to organic objects, in which "order is based on order" and the development processes do not occur with an increase in entropy, and its decrease is compensated by the absorption of light energy. He agrees with Planck's statement regarding statistical and dynamical laws.

Unfortunately, most theoretical studies of nanoobjects use only those methods that are designed for macroscopic objects. We restrict ourselves to self-organization and the dislocation model.

2.1.1. Self-organization and nanotechnology

The idea of self-organization was proposed by René Descartes (Renatus Cartesius). Each time it revives when the cause of a phenomenon remains unclear. However, in the case of nanotechnology self-organization contradicts Feynman's ideas.

Feynman, as noted above, has paid special attention to the fact that the laws of physics in the field of nanoscale appear differently than abroad. This means that there is a cause-and-effect relationship. In the interaction of two atoms only a linear structure is possible, in the interaction of three atoms only a

planar structure, while the interaction of four or more atoms can form even a spatial nanoobject. Such nano-objects were shown in [1.6]. The ordered structure of these objects suggests that there are distinct patterns of interaction between the atoms.

A series of lectures under the title “Fundamentals of Nanotechnology” is given in the Moscow State Unuversity by famous scientists since 2009. They are regularly published on the Internet. The lectures are a review and are certainly interesting for those who are interested nanotechnologies. But in the four years (2009-2013) nanotechnology bases were not determined, except for the definition given Goodilin about what is self-organization. “Self-organization can be used as a mechanism for creating complex templates, processes and structures at a higher hierarchical level of organization, than that observed in the original system at the expense of the many and multi-choice component interactions at low levels, which has its own, local, interaction laws other than the collective laws of behavior of self-ordering systems. The processes of self-organization are characterized by differences in scale of the interaction energies, as well as the existence of a limited degree of freedom of the system at several different levels of organization”.

Thus, Gudilin examines self-organization as a technological method; its mechanism is not described, and local and collective laws at various hierarchical levels are not formulated. Hence self-organization can not be considered as the fundamental basis of nanotechnology.

However, in several papers it is approved or tacitly accepted that the basis of nanotechnology is the self-organization or self-assembly of disordered systems. This conclusion is based on the synergetic paradigm Haken [2.1].

To solve the problem, we restrict ourselves to some of the conclusions of Prigogine’s theory of dissipative systems, and Haken’s Synergetics to match them with the ideas of the founders of quantum mechanics, and on this basis to clarify the nature and mechanism of the origin and development of the “new patterns and effects”, prompted by Nature.

In this regard, we consider:

1. Formation of long-range order in crystals;
2. The formation of clouds and dunes
3. The Belousov-Zhabotinsky reaction;
4. Formation of the laser pulse;
5. Formation of nano-objects.

2.1.2. Formation of long-range order in crystals

It is known that in a homogeneous medium the crystallization from liquid or gaseous phase is extremely difficult. This is caused under subcooling and lowering of the freezing point by tens or even hundreds of degrees (Fe-500˚, Ni-480˚, Co-470˚ [2.4]). However, only one foreign particle, electromagnetic or acoustic pulse is enough to start intensive crystallization, long-range order formation.

It has been shown, [2.2], that the formation of ordered structures in a disordered system is possible only on the condition that the influence has a fixed spatial and temporal periodicity. This condition is satisfied only by standing waves in which the effects on the atoms in the nodes and antinodes differ. Therefore, it is formulated and shown that the formation of standing waves in a limited region is a necessary and sufficient condition for formation of a crystalline structure.

2.1.3. The formation of clouds and dunes

As an example of self-organization Haken shows two photographs of clouds from the book [2.5]. One of them is shown in Figure 2.1. Haken does not comment on the photos and does not explain the nature of the phenomenon. A.R. Scorer [2.5] also did not express any hypotheses about the nature and mechanism of such a clear order. At the same time, we note that in studingy lightning, Tesla found the formation of standing electromagnetic waves in the atmosphere. It is known that the condensation of water vapor occurs by impurities. However, the fluctuations of the neutral impurities caused by the flow of air, impede the creation such a strict ordering of the clouds. One of the most effective condensation centers are ions. Ionization of gas molecules occurs mainly under the effect of solar radiation.

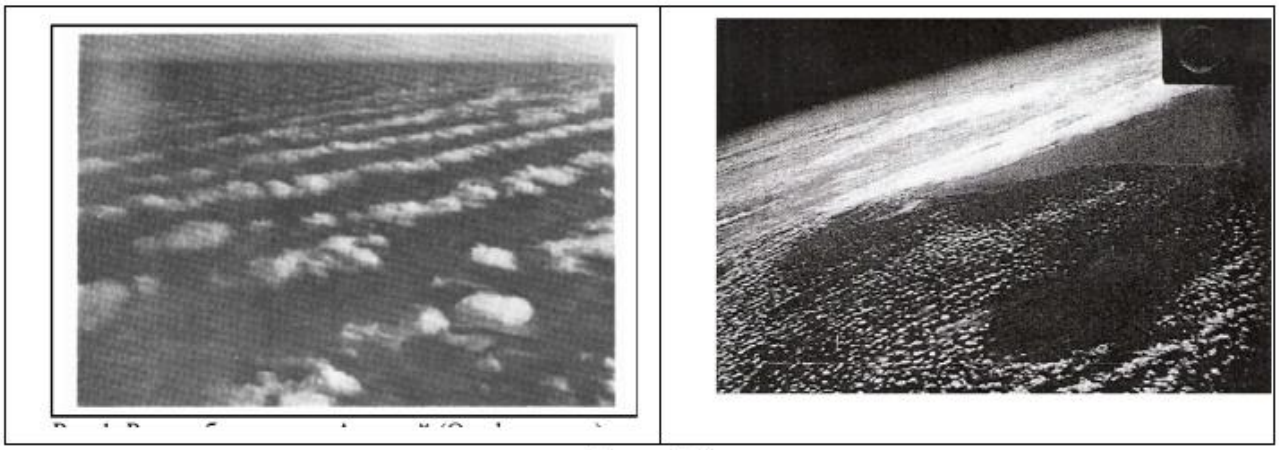


Figure 2.2

In the nodes and antinodes of the standing waves the degree of ionization is different. The impact of electromagnetic fields on the ions in the antinodes is much stronger than at the nodes. This leads to the fact that the intensity of condensation is higher there.

Figure 2.2, taken from the same work, show the formation of clouds over Lake Okeechobee, USA, Florida. Rows of clouds are located towards the wind, which blows from the west towards the Atlantic Ocean. It would seem that the clouds over the lake should be denser because of the lower dew point and intense evaporation, but they are virtually absent. Consequently, the pairs above the lake are located in a supercooled state because of the lack of condensation centers, in which ions play a decisive role.

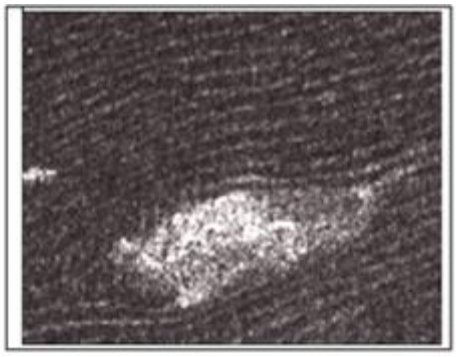


Figure 2.3.

It is known that the most efficient impurities in the atmosphere, through which ions formed are ethers, with maximum quantity produced above forests.

Figure. 2.3 shows the sand dunes formed on Saturn's satellite Titan. The height of the dunes is 100m, length 150 km, the total width 1,500 km. Discovered with the Cassini probe by the team of R. Lorenz, University of Tucson, Arizona, USA (2008).

For their formation, condensation nuclei are required. As is visible, the lines of dunes do not have discontinuities such as clouds.

It can be assumed that the magnetic field of the Earth, directed perpendicular to the rows, plays a role in the formation of the series. It is possible that the formation of the ordered structure of clouds is influenced by the Coriolis force associated with the rotation of the Earth.

2.1.4. Belousov-Zhabotinsky reaction BZ

This reaction was discovered in 1951 by B.P. Belousov [2.6]. A more detailed study was made by A.M. Zhabotinsky [27]. However, particular interest to the reaction appeared only after the publication of the works of I. Prigogine [2.8], in which he cited it as one example of order in a chaotic system due to nonlinear effects and dissipation.

Based on the reaction Prigogine reached the following conclusions:

1. The second law of thermodynamics is not contrary to the dynamics, but it can not be deduced from it.

2. At the the Belousov- Zhabotinsky reaction nonequilibrium processes occur.

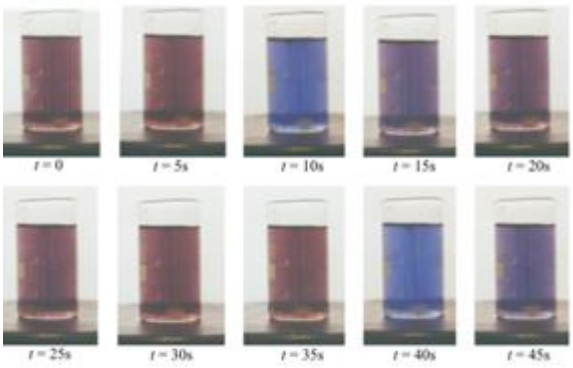


Figure 2.4

3. The Belousov-Zhabotinsky reaction occurs at an exchange of energy with the environment, i.e. such a system must be open.

4. In the non-equilibrium system, during exchange of energy with the environment, order may arise from disorder.

5. The reaction is autocatalytic oscillatory. The color of the solution changes periodically therein, as is shown in Figure 2.4. In this regard, this phenomenon is called chemical clock.

A huge number of publications devoted to the BZ reaction. Haken uses this response as an example of self-organization. In his paper Haken allocated 6 steps in this reaction, whereas in various papers their number ranges as high as 80.

One of the varieties of the Belousov-Zhabotinsky reaction in a solution of sulfuric acid H_2SO_4, malonate $CH(COOH)_2$, cerium sulfate $Ce_2(SO_4)_3$ and potassium bromate $KBrO_3$. Thus, the redistribution of the electrons involved bromine ions, oxygen, hydrogen, and more complex structures. For example, we show only two reactions.

In order to monitor the progress of the redox reaction by change of color, an indicator is added to the solution, for example feronin.

When describing the reaction, the basic accent is on the quantum transition $Ce^{3+} \leftrightarrow Ce^{4+}$. But this description is incomplete, since the reactions involve electrons and photons. In this regard, we present them in the form of: $Ce^{3+} + h\nu \rightarrow Ce^{4+} + e^{-}$ (1), $Ce^{4+} + e^{-} \rightarrow Ce^{3+} + h\nu_1$ (2).

It should be noted that the photon absorbed by ionization (1) and that emitted during recombination (2) are the same only at the resonance fluorescence. In other cases, they are different, as shown by S. I. Vavilov [2.9]. This is due to various factors, including the emission of a photon from a metastable state, whose lifetime is much longer than the excited state. These processes are non-linear, which in nanoobjects is stronger than in macroscopic ones.

This implies that the nature of the reaction depends on the energy of the absorbed photon hν. It was shown [2.10] that an electromagnetic field accelerates the Belousov-Zhabotinsky reaction. Based on this redox reaction during transitions $Fe^{2+} \leftrightarrow Fe^{3+}$ energy is supplied to living organisms. Changing the nature of the reaction can lead to severe pathological consequences Fig.2.5.

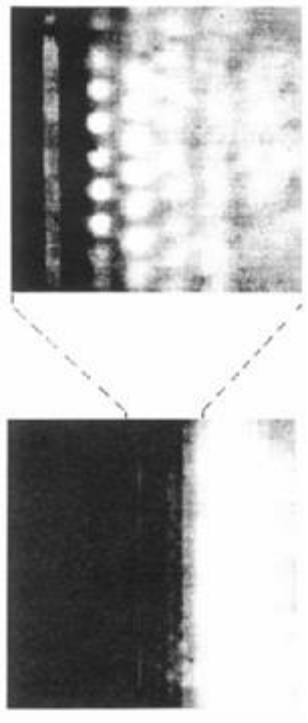


Figure 2.5 [2.11]

As has been shown, [2.2], atoms of one element may be present in a metal simultaneously with a different configuration of the electron shell. In iron atoms Fe0 even Fe- were observed experimentally. Such pathological atoms are called morbid, not able to implement redox reactions, and may even leave the erythrocytes that lead to leukemia.

The formation of waves, including standing waves, in the Belousov - Zhabotinsky reaction was described in numerous publications, and even textbooks. In this regard, we confine ourselves to a demonstration of photographs (Figure 2.5), taken from the work of Nicolis [2.11] dealing with chemical chaos and self-organization.

As we see, bright spots (places of photon emission) are arranged orderly in two directions. Moreover, they have different brightness. All this suggests that the recombination of electrons and ions in the solution took place at a specific location in accordance with the arrangement of nodes and antinodes of the standing waves. Let us quote a fragment from the book of Haken [2.1]. "In a number of chemical reactions occur spatial, temporal or spatio-temporal pattern. As an example, the Belousov-Zhabotinsky ... The resulting mixture was placed in a test tube in which there is a temporary oscillation immediately. The color of the solution changes periodically from red to indicate Ce^{3+}, to blue, indicating Ce^{4+}. Since the reaction takes place in a closed vessel the system eventually approaches stable equilibrium."(Emphasis added.)

So we see that Haken speaks about a resonator, in which there are standing waves.

Another example, on the basis of which Haken introduces Synergetics, is the formation of a laser pulse. Recall that the theory of spontaneous and stimulated emission was developed by Einstein. The main elements of a laser are: a lamp pumping the active medium, and mirrors (set off the Fabry-Perot interferometer). Haken compares the radiation of the lamp (spontaneous), the coherence length of which is 3 meters, with laser light (coherent), the coherence length of which is 300,000 km! He asks the question: “What demon provides this behavior of atoms?” On page 233 we read: “This analysis can be applied quite strictly to numerous modes, and shows that in a laser only one mode predominates, which is close to resonant.”

Haken did not pay attention to the fact that, by recognizing the presence of the resonator, he rejects the idea of self-organization. This example Haken refutes the idea of self-organization, recognizing the existence of resonator. For example, in a ruby laser the lifetime of a chromium atom at the

metastable level is 10^{-3} s, while at the excited level it is 10^{-8} s. The radiation power increases in the hundreds of thousands of times due to the fact that the light has time to go through the core thousands of times, stimulating the emission of atoms at the metastable level. At the start of the laser activation, at the same time and independently there are a lot of waves. Reflected from the resonator mirror, the waves that follow a condition of standing wave creation, i.e. an even number of half wavelengths fit the length of the resonator, are predominantly enhanced. All other frequencies will be suppressed and the radiation becomes coherent.

J. I. Alferov [2.12] concluded that at the p-n-transition in a semiconductor having a homogenous structure a continuous generation can not arise, but it is possible when the p-n-transition is created at the boundary of different chemical composition of the semiconductors (heterostructures).

H. Kreomer, who shared the Nobel Prize with Alferov, said [2.13], "Heterostructure can be defined as a non-homogeneous semiconducting structure created from two or more different materials, so that the transitional layer or the border between the two materials plays an important role in any process being conducted. Thus, the semiconductor laser can only be made on a heterostructure."

In this way in the presence of the resonator, in which the formation of standing waves occurs, the randomly distributed streams of light become a strictly ordered polarized monochromatic beam.

The quantum mirage, as one of the nano-objects, was discussed in Chapter I. It is considered in more detail in [2.2].

The fundamental difference between quantum mechanics and classical is that in the force field the particle energy has a discrete (quantized) value. The quantization of energy and momentum is a physical phenomenon due to the quantum wave nature of particles. A particle in a potential well is repeatedly reflected by the potential barriers, becoming enclosed in it. From the point of view of the wave between the walls two de Broglie waves move in opposite directions. Such waves are coherent and form a standing wave. However, there is some probability that a particle can leave the potential well due to the tunneling effect. This probability is higher, the lower the potential barrier, and is less than its width. There is no analogue of such a phenomenon in classical mechanics.

In this connection, a description the behavior of nanoparticles or nano-objects is only possible using quantum mechanics. Therefore, speaking about nanoobjects, by definition, we know that their formation is due to standing waves.

These examples allow us to formulate the physical basis of nanotechnology.

The bases of nanotechnology are the fundamental laws of physics, laws of conservation: energy, momentum, angular momentum, electric charge. The behavior of individual atoms obeys the laws of

quantum mechanics, according to which in a confined space (a resonator) containing more than two atoms, created standing waves are caused by the boundary conditions that lead to ordered (coherent) behavior of atoms of a nanoobject.

Conclusion:

Understanding that the order is due not to statistically processes, but to standing waves, allows advance planning of nanotechnological processes and their purposeful management.

2.2 Dislocations: reality or phantom?

The concept of dislocation was introduced in 1934 by Orovan, Polanyi and Taylor. Since then such a large number of theoretical and experimental studies have been published, that such a question will undoubtedly astonish. And yet, we will try to match the idea of dislocation with the experimental facts, for only they can answer that question.

The dislocation idea was proposed to explain the abnormally low values of the shear stress as compared with the theoretical. Only after the creation of the electron microscope was dislocation shown to be a reality, especially for explaining the processes of hardening and destruction of metal, although other phenomena could serve as indirect evidence, such as the change in conductivity, internal friction, the speed of sound and so on. But these changes are possible for other reasons not related to dislocation.

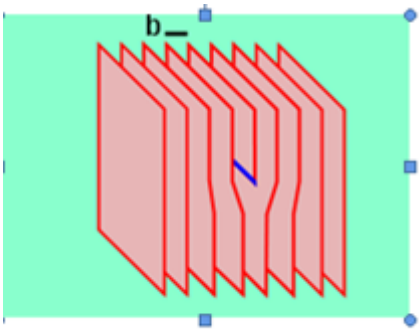


Figure 2.6 ¶

At each experimental discovery of previously unknown properties of metal, dislocation had to be supplemented with new properties or parameters. Naturally, this raised serious doubts as to its reality, even for Kontorova [2.13], whose works played an important role in understanding the atomic interactions on which the movement of dislocations is based.

Problems of metal aging and fatigue, leading to destruction, sometimes unexpected, and hence catastrophic, forces one to ponder: does the dislocation representation correctly forecast the state of the metal and its remaining life? There are cases when a technical structure is destroyed, resulting in loss of life, despite previously being carefully checked with all the modern methods of monitoring.

Therefore, the main problem is not the degree of physical reality of the phenomenon of dislocation, but rather whether

this model explains the actual processes and is able to predict an impending disaster?

Linear (edge) dislocation and its properties

By dislocation is meant a linear defect in the crystal lattice, causing the alternation of atomic planes. Fig. 2.6 gives a visual representation of the dislocation, similar to those outlined in both the scientific and educational literature. In this regard, a number of questions arise.

Are all the atoms in the selected area of pure metal identical, i.e. do they all have the same spatial and energy characteristics?

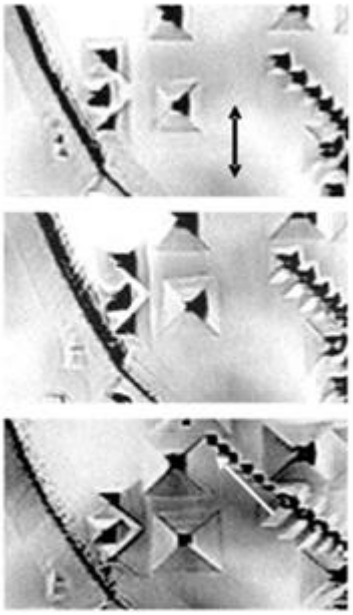


Figure 2.7 [2.16]

By default, it is assumed that all the pure metal atoms are identical, except for those which are on the surface and on the boundary extracted plane. These atoms have broken bonds. It is assumed that the atoms at the boundary of the extra-plane capture the conduction electrons or lose them, forming broken bonds. Thus, this ion defect differs from neighboring ions. This immediately implies that these atoms have a lower or higher valence.

Bonding between atoms on either side of the missing half plane is lessened, and, of course, the property of the entire area is something different from the regular filled areas and this should affect the metal's properties.

Fig. 2.7.

Figure 2.7 shows three photographs from R.B. Morgunov's work [2.16], devoted to the new direction in the theory of plasticity, called Spin micromechanics. The name itself indicates that it is the influence of the magnetic field on the ductility and consequently the strength of metals. We will not go into detail on the magnetoplastic effect, and moreover these photos are applicable for an insulator, but not metal. Dislocations were obtained by etching: the upper dislocation after the first etching, the middle after the second, and the lower after the third, respectively.

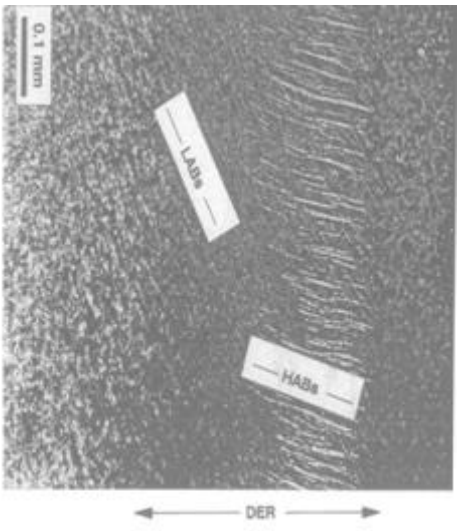


Figure 2.8 [2.17]

The sensitivity of the dislocations to the magnetic field is clearly visible from a comparison of the images. As one can see, a photograph taken after the second etching is a little different from a photograph taken after the first etching, but under the influence of a magnetic field there were

significant changes, which can be seen in the third picture.

It is found that the behavior of dislocations is very sensitive not only to permanent, but also to an alternating magnetic field, and is investigated by electron paramagnetic resonance, which means that they interact with electromagnetic waves.

It is known that the velocity and absorption of sound waves depends on the deformation of the metal. Thus, we can conclude that dislocations interact with electronic, electromagnetic, acoustic, and spin waves.

Let us pay attention to the size of the area revealed by etching. The wavelength of diffracted electron waves is less than the size of the atom and the dislocation created by one extra-plane can not be determined. Here we are talking about the whole complex of atoms, which is sometimes treated as a cluster of dislocations which are parallel. The question then becomes: what are these atoms?

Formation of etch pits indicates that the atoms of the sample react with the atoms of the etchant and are removed. For metal atoms such a reaction is possible only in the case where the metal atoms pass their electrons to a nonmetal atom. The less ionized the metal atom, the more easily it will react. This means that atoms located at the boundary of the extracted plane will enter into reaction before the others.

It was established experimentally that the effect of the etchant is not limited by dislocation.

Let us illustrate this. Consider the photograph (Fig. 2.8) of the study of cage ball bearings taken from AP Voskamp and EJ Mittemey's work [2.17]. On the etched surface, we see low-angle black stripes (LABs) and high angle bands (HABs) forming defects, which are called dark etching region (DER). We draw attention to some features of this phenomenon. First, the resolution in this case is higher than in Fig. 2.7, although the observation is carried out at optical wavelengths, and secondly, the direction of the bands is approximately 30° relative to the direction of movement (DER).

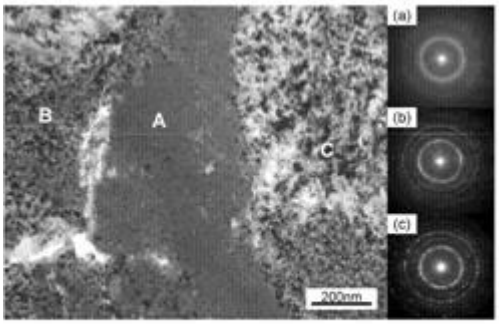


Figure 2.9 [2.18]

In Figure 2.9 shows a photograph of electron microscopic studies bearing steel [2.18]. It highlighted three areas. The grain structure is observed in the areas B and C, while the region

A is amorphous. It has been found that plastic deformation occurs in the region spheroidized carbide formation, whereas shear deformation accompanied by the formation of grains. Such processes are caused by radiation energy during the formation a chemical compound and residual austenite-

martensite phase transition.

It is known that segregation of bismuth in the bismuth-copper alloy leads to embrittlement, and to a sharp decrease in the shear modulus. As has been established [2.19], the cause is the formation of an amorphous phase, such liquid resulting from the diffusion of bismuth. We draw attention to this paradox. The atomic mass of bismuth is 3.3 times higher than that of copper, but the diffusion coefficient is 100 times higher. It would seem that it should be lower, since the maximum valence of the free atoms of Cu is 1, but of Bi is 5.

This fact can be explained by only because the bismuth atom is weakly ionized, perhaps even has zero valences. That zero-valent metal atoms exist is not only experimentally confirmed, but a technical application is found for zero-valence iron. At the same time in some publications it is concluded that in alloys 3*d*-4*s* hybridization occurs in which the *d*-electrons transfer to the conduction band.

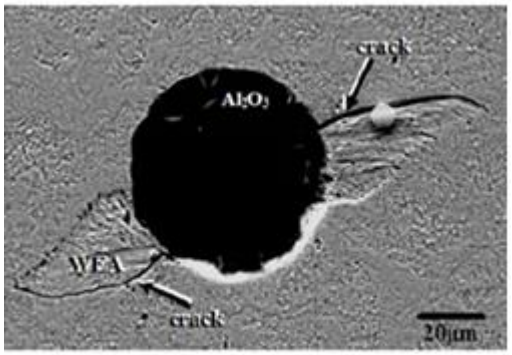


Figure 2.10 [2.20]

The aim of this work was to provide a state- of-the-art distribution of the damage processes preceding crack initiation under rolling contact fatigue condition, including criteria for crack initiation, microstructure changes in the steel matrix as well as the mechanism of crack growth.

"Butterfly Wings", called White Etching Area, and a crack in one of them are clearly visible thanks to the high resolution of the scanning electron microscope. One such defect is illustrated in Figure 2.10. This defect (actually corrosion) is especially dangerous for aluminum alloys, including the fuselage and wings of aircraft. A characteristic feature of these defects is that fact that cracks "follow" from them, indicating the direction of energy flows. This issue is considered in the next chapter. Here we confine ourselves to the fact that Grabulov [2.20], describes in detail the processes that lead to the formation of cracks, only from the standpoint of mechanics, saying nothing about the energy that is emitted in the process.

Of course, an attempt to describe the mechanism of crack formation without accounting for energy is impossible. However, it is important to note that the formation of defects leads to a weakened solid, the destruction of which requires less energy.

It is particularly important to note that during the operation of the structure or device in a solid two processes occur simultaneously: accumulation of damage and energy. Exactly these two factors predetermine the state of a solid, which is called fatigue.

Neglect of either one or the other factor leads to a catastrophe.

Often the role of dislocation in plasticity formation is compared with the role of electrons in the current formation. In this respect, the simultaneous study of deformation and conductivity that were started in the twenties of the last century on bulk samples is extremely interesting. A.F. Ioffe found that deformation and conductivity jumps may coincide in time but may occur separately. The abrupt change in the conductivity and deformation was observed on nanowires and nano-chains. It is senseless to speak about dislocations in the wire, the thickness of which is equal to the total diameter of the two atoms and, moreover, one-atom discussed in our paper [2.2].

However, the theoretical papers on nanomaterial often try to explain their strength from the position of the dislocation model.

Review [2.21] is devoted to ultra-strength materials. The goal that the authors set themselves is formulated as follows: *"For widespread adaptation of elastic strain engineering, four major scientific challenges need to be overcome: (a) how to synthesize material systems that can potentially sustain ultra-high elastic strain, (b) how to experimentally control the loads and measure the strain/stress using advanced, miniaturized instrumentation, (c) how to measure, understand and predict the dependencies of physi-chemical properties (electronic, magnetic, optical, phononic, thermoelectric, catalytic, etc.) on elastic strain, and (d) how to understand the different mechanisms by which stored elastic strain energy can relax from the material component, so ultra-strength can be reliably achieved and designed for different temperatures, sizes and expected service lifetimes*."

To investigate nanostructured materials, nanoparticles, nanowhiskers, and nanotubes were used. However, analysis of the possible solutions of the problems is based on traditional methods of mechanics. The authors of the review searched for solutions to problems based on the study of nanomaterials by conventional methods of mechanics, including using the dislocation model. However, to solve these problems without taking into account the interatomic interaction is not possible, but the atomic interaction is not considered.

For solving the problem (d) a formula

$$\nu = N\nu_0 \exp\left(-\frac{Q(\tau,T)}{k_B T}\right)$$

was proposed, where ν is transformation–rate, τ is shear stress, T is given temperature, ν_0 is the physical trial frequency, N is the number of equivalent sites of transformation, $k_B T$ is the thermal energy, and Q is the activation free energy whose magnitude is controlled by the local shear stress τ along with the temperature.

We note that the above formula is similar to the Zhurkov formula, which was published almost 50 years earlier, but the authors do not refer to it. Since the analysis of Zhurkov's formula will be conducted, here we confine ourselves to the remark that the Zhurkov formula has been confirmed by numerous experiments, whereas the function Q(τ, T) is not disclosed.

The conclusions drawn at the end of the review indicate that this objective has not been achieved since the mechanism of energy conversion, storage, and radiation is not disclosed.

Only at the conclusion the authors referred to the work of Frost and Ashby [1.22], who set a goal to reveal the mechanism of deformation on the basis of atomic processes

Frost and Ashby shared mechanisms of deformations into five groups, which are briefly mentioned: 1) Collapse at the ideal strength (flow when the ideal shear strength is exceeded). 2) Low-temperature plasticity by dislocation glide. 3) Low-temperature by twinning. 4) Power-law creep by dislocation glide, or glide-plus-climb. 5) Diffusion flow.

Each group includes several subgroups. It is noted that the simultaneous presence of several mechanisms is possible.

The authors believe that the plastic flow of fully-dense solids is caused by the shearing or deviating part of the stress field, σ_s, which is expressed through the principal stresses $\sigma_1, \sigma_2, \sigma_3$ by the equation:

It is assumed that defects are carriers of strain similarly as electrons and ions are carriers of charge. Taking as a major strain rate $\dot{\varepsilon}_1, \dot{\varepsilon}_2, \dot{\varepsilon}_3$, Frost and Ashby proposed a formula for determining the rate of shear deformation $\dot{\gamma}$:

The authors write: “To simplify the following discussion, we shall choose the strain-rate $\dot{\gamma}$ as an independent variable. Then each mechanism of deformation can be described by a rate equation which relates $\dot{\gamma}$ to the stress σ_s, temperature T, and the structure of the material at the instant:

As already stated, the set of *i* quantities *S*i are the state variables which describe the current microstructural state of the materials. The set of *j* quantities *P*j are the material properties: lattice parameter, atomic volume, bond energies, moduli, diffusion coefficients, etc., these can be regarded as constant except when the plastic properties of different materials are to be compared. The state variables *S*i generally change as deformation progresses. A second set of equations describes their rate

of change, one for each state variable: $\frac{dS_i}{dt} = g_i(\sigma_s, T, S_i, P_j)$ It should be noted that the research program proposed by the authors corresponds to the criteria that have been predetermined by Maxwell. Unfortunately, this work is of critical importance, but has not attracted enough attention and development, and is rarely cited. In this study, we can not analyze it in detail, noting only its features. 1) The theory suggests the equations that relate the mechanical properties of a solid with the physical parameters for virtually all five groups. 2) The relationship between energy and the atomic parameters is exponential.

However, the authors also did not refer to Zhurkov's work. 3) The stress intensity factor is not mentioned in it. 4) The authors have not abandoned the dislocation model. 5) Use of these equations to predict the technical condition is not possible, because it does not define the criteria of destruction and does not disclose the mechanisms of accumulation and radiation of energy

In the last decade, the results of studies have been published in which the problem of strength and fracture is also seen at the nanoscale, but they are much inferior to Frost and Ashby's research, though 25 years have passed.

A theoretical study (S. Huang et al [1.23]) is made of the nanocrack formation problem. Crystalline silicon was chosen as an object for research. Three aspects of the problem were investigated: fracture, dislocation emission, and amorphization. As usual, the authors note in the abstract the most important results of the study. We quote it in full, in view of its brevity.

"Understanding the nanoscale fracture mechanisms is critical for tailoring the mechanical properties of materials at small length scales. We perform an atomistic study to characterize the formation and extension of nano-sized cracks. By using atomistic reaction pathway calculations, we determine the energy governing the brittle and ductile responses of an atomically sharp crack in silicon, involving the competing processes of cleavage bond breaking, dislocation emission, and amorphization by the formation of five-and seven-membered rings. We show that the nanoscale fracture process depends sensitively on the system size and loading method. Our results offer new perspectives on the brittle-to-ductile transition of fracture at the nanoscale."

It is known that the authors of publications tend to talk in the abstract about the most important results obtained by them in the study. In the preceding annotation it is made only in the third sentence, while in the other sentences there is no useful information. However, the phrase contained in the third sentence, "atomistic reaction pathway calculations" is meaningless.

There is sense only in the nature of atomic reactions that occur as a result of the exchange of atoms by electrons and photons, but in the article, such reactions are not provided. The phrase "energy

governing the brittle and ductile responses." is devoid of sense. The term "cleavage bond breaking" is used in cases when it comes to the silicon compounds in which a binary Si = Si bond is cleaved into two single-Si-. But in the article crystalline silicon is studied, in which the double bond between the silicon atoms is missing.

The authors use Griffith's formula for calculating energy. This formula was proposed before the advent of quantum mechanics of the atom, especially to quantum chemistry and the quantum theory of solids. It makes no sense to speak about the surface energy quantization. The authors provide no formulas, or even calculations on the basis of which the conclusion of amorphization, dislocation emission and fracture were made.

Feynman's talk quoted above mentions circuits consisting of seven atoms, but Feynman draws attention to the fact that the interaction between them is due to quantum laws. The authors disregard this when they write about the rings, consisting of five to seven members (in this case atoms).

The authors of the above-cited reviews on the problems of strength and destruction analyzed in total more than four thousand publications. Analysis of these publications again confirms the conclusion drawn by Maxwell that solving these problems while limited to classical mechanics is impossible.

Thirty-nine authors of scientific papers [2.24] have expressed their opinion on the possibility of describing the behavior of atoms in a mesoscopic field in terms of dislocations:

"The modern theory of dislocation in crystals allows us to qualitatively explain many laws of the behavior of solids under different loading conditions. At first that seemed enough to overcome the purely mathematical difficulties of complex behavior of dislocation ensembles at the micro level to theoretically calculate the macroscopic characteristics of the deformed body.

However, to calculate the stress-strain curve based only on the microscopic representation of dislocation theory has failed so far. All attempts to direct transition from the micro-approach to the mechanics of the macro approach have proved unsuccessful.

In the past two decades it has become clear that such attempts in principle are doomed to failure.

A non-traditional approach is needed."

Maxwell's conclusion about the strength of the solution to the problem of solids and their destruction being beyond mechanics and optics has been forgotten. Feynman's Note that the behavior of atoms in a nanomaterial is different from their behavior in the macro-material is often ignored.

Attempts to explain the processes of cracking from the position of changes of the interatomic interaction with the quantum-mechanical models were made repeatedly. The listed works [2-18 2.22-2.39] are only a small part of the publications devoted to these issues. In all these studies, either the

dislocation model or SIF is used, often both. It must be acknowledged that the main disadvantage of these and similar publications is their failure to develop practical methods for assessing the technical condition and remaining life of structures and devices.

The creation of nanomaterials has stimulated studies which analyze their role in the origin of cracks. It is noted [6, 14, 17, 2.31, 2.39, 2.42] that crack nucleation occurs in the nanomaterial. Today, this conclusion is widely recognized. However, the nanomaterial is a quantum mechanical object and neither by the dislocation hypothesis nor by using the stress intensity factors in the behavior of atoms, is it possible to explain.

As noted by Einstein, in order to refute a theory, one experimental fact suffices. Following Einstein, we give at least one experimental fact that is contrary to the models offered in fracture mechanics.

Describing the necessary and sufficient condition for strength V. V. Novozhylov [20, 21, 2.43, 2.44] writes: "... the principal interpretation of crack formation in the atomic lattice has been given long ago: a crack arises as a result of the loss of stability of the trivial equilibrium shape deformation (corresponding to the"continuous"body) and the transition to a non-trivial equilibrium shape (corresponding to the body with a crack-cavity) separated from the initial state of the energy barrier. "(Emphasis added).

"Trivial" or "non-trivial" equilibrium is a relative concept. What is important is which of them corresponds to a lower minimum of the potential energy. Such transitions due to nonlinear strain occur not only in the formation of cracks, leading to weakening, but the formation of other imperfections that lead to weakening or hardening. According to Prigogine, such states are dissipative; their formation is possible not only in an ordered system, but chaotic also.

"In general terms, the formation of the initial crack is governed by two factors (with other conditions fixed): averaged stresses that determine the minimum energy barrier, after the overcoming of which a crack may arise, and the stored energy of a microstrain, an area of concentration which should be sufficient to overcome this barrier."

Firstly, the energy barrier necessary to overcome for crack formation, is not determined by micro-stresses, but the force between the atoms. Second, micro-stress is a consequence of changes in the force due to local regions of the material. Third, as noted above, the density of the energy radiated, for example in the creation of metal-nonmetal compounds (corrosion), is 2-3 orders of magnitude greater than the density of the elastic energy

[2.31, 2.33, 2.43] Further growth of the crack is made easier because it creates a stress concentration at its edges, not only under tension, but in compression of the body. (Emphasis added).

As is known, cracks are formed by both plastic and brittle deformation. The elastic-plastic nature of the cracking is now contradicted by no one. However, the mechanism of this phenomenon is associated with only dislocation. [2.31, 2.33, 2.43]

The aim set by the authors of [2.29] was to reveal the mechanism of the formation of cracks in nanoobjects. This evaluated a minimum value of the stress intensity factor. In this case the interval for the promotion of dislocation was assumed to be the lattice constant. The authors believe that the generation of a pair of dislocations at the tip of a crack occurs at the quantized values of the external stresses.

Indeed, there is no quantization of stress, but quantization of energy. It is well known that the formation of cracks is intermittent in nature. The length of the jump (the number of broken bonds) is due to the energy that has accumulated as a result of deformation and was absorbed by the crystal. The rate of accumulation of energy depends not only on the applied stress but also on the properties of the material, which are not considered.

In [2.23], the calculation of energy is made at an interval of 0.33 nm. Note that the silicon lattice constant is a=0.54307 nm. This means that the interval chosen for the calculations is less than the lattice constant, the experimental value of which is determined up to five decimal places. Modern experimental methods allow us to investigate the distribution of electron density. The band structure of silicon is calculated and these calculations are used in semiconductor technology. However, in the work on strength and fracture mechanics all these achievements are not taken into account. [4, 9, 12-19, 2.26, 2.34-2.41] discuss the breaks between the atoms of neighboring cells. Although this term appears in many publications, the mechanism can be described only in terms of quantum mechanics. All mechanical processes, including destruction, are caused by the electromagnetic interaction, the quantum of which is the photon. Of course, without taking into account the influence of the photon on the process of energy accumulation, and its emission and absorption of the crystal atoms, predicting the technical condition of a structure or device is very approximate, and often leads to mistakes and disasters.

The experimental techniques associated with the use of the properties of the photon, for example, the Mossbauer effect, the pump-probe, allow us to study changes in the properties of the material up to sixteen digits, in the time interval to within femtoseconds (10-15 seconds). Modern nanotechnology is unthinkable without the tunneling and atomic force microscopes, not to mention the high-resolution electron microscope.

It should be noted that quantization is not a mathematical method, but a physical phenomenon. The

energy state of an atom is described by the main quantum number, orbital, magnetic, and spin quantum numbers. The energy associated with its momentum, angular momentum, magnetic moment and spin, by their nature have discrete values. The quantum unit of electrical resistance is known and corresponds to electrical conductivity. The introduction of some other quantum numbers (quantum stress) must be justified; moreover, to explain the mechanical process is not necessary.

To explain the mechanism of all mechanical processes due to the interatomic interaction, it is necessary and sufficient to have photons, phonons, electrons, ions and a model that is not refuted by experiment.

2.4. The size effect

It is well known that the size effect is most clearly evident in nanoregions. It was established experimentally that when reducing the size of the sample below a certain value, its properties change, despite the fact that the structure and composition remain unaltered.

The properties of nanoparticles, nanowhiskers, and nanowires have been previously considered by the author in [2.2]. Additional study of this problem is due to the need for a more accurate understanding of the processes that lead to cracking and failure.

From the huge number of papers devoted to the size effect, we favor Batsanov's review [2.45] based on numerous experimental studies published from 1989 to 2010.

Of particular interest in the report due to the fact that it addresses the physical and chemical aspects, which are extremely important for understanding the mechanism of failure, are the following: the change of the coordinate numbers of atoms in the crystal splitting, bond lengths and volumes of unit cells in the macro-and nano-sized material; the change in the rigidity of the crystals in the transition to the nano-sized material; the change in atomic structure of nanophase, dependence of the phase transition pressure from crystal size, change in the melting point under the transition to nanophase, change in the band structure under dispersion of crystals, and the size effect in dielectric permeability. The review compares the properties of macro-and nanophase of metals, semiconductors, and insulators.

It is recognized that the size effect is due to ratio of the object surface to its volume. Table 1 shows the approximate influence on the properties of the surface atoms of nano-objects depending on the size, expressed as a percentage.

Table 1. Influence of surface atoms on the properties of nano-objects (percentage)

Shape	Parameter	Formula	Size					
			nm	100	68.5	10	5	2
Ball	Radius, r	3/r	%	3	4.4	30	60	~100
Cylinder	Radius, r	2/r		2	2.9	20	40	~100
Film	Thickness, h	2/h		2	2.9	20	40	~100

Fig. 2.11 As we can see from the table, reducing the size of the nanoobject entails almost parabolic growth in the influence of surface atoms. The influence of the atoms at the surface of the object, one of the dimensions of which is less than two nanometers, is so large that describing its properties by the theory developed for larger objects is impossible. New theory of interatomic interaction should be developed only on the basis of special experimental studies. As written by Kreomer, it actually is the case that the surface itself becomes the instrument. A new theory of atomic interaction should be developed only on the basis of specific experimental studies.

In this regard, we consider the results of some studies that suggest that the relationship between the geometric dimensions and physical properties of nano-objects has a nonlinear, complicated character.

In [2.46] the formation of gold film on glass has been investigated. Nanolayer formation may be delayed and all steps can be studied more carefully than under destruction, which even at low stress occurs abruptly. Because the aim of research, though, is the destruction, we will compare both the experimental results obtained in this study and those of other processes.

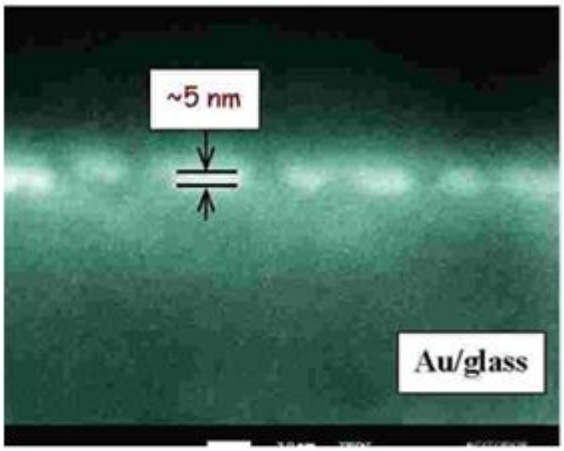


Figure 2.11 [2.46]

The authors note that the formation of nano-films, deposited for 20 seconds, occurs in the form of clusters as shown in Figure 2.11. During this time there was a change from an amorphous substance, which is a wide-band semiconductor, to metal. Some islands have a spherical shape.

Figure 2.12 [2.46] shows the transmittance spectra of gold films deposited on glass, according to their thickness. The first experimental value is given for a

layer thickness of 2.4 nm. Transmission minimum (maximum absorption) is weak. With increasing thickness of the nano-films, the absorption maximum is shifted to longer wavelengths and at a thickness of 19.5 nm, transmittance decreased from 90 to 10%, with a corresponding increase in light absorption.

The band gap may be determined by the boundary of fundamental light absorption. In metals it is zero. Changing the band gap of the nanolayer, with a change inthickness, is shown in Figure 2.13. Thus, the conclusion made in the work is experimentally justified: "It has been shown that in a wide temperature range, nanolayers of gold (<10 nm) exhibit both metallic and semiconducting properties." Thus, when the size of the nanoparticles is up to 2.4 nm the gold is in the amorphous state, in which the band gap is absent. But it does not melt.

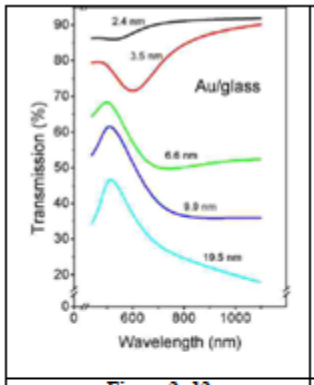


Figure 2 .12

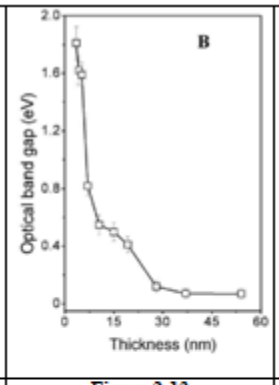


Figure 2.13

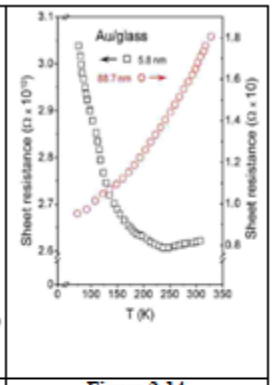


Figure 2.14

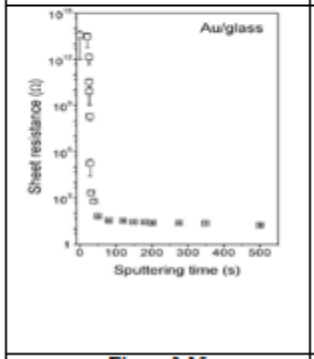


Figure 2.15

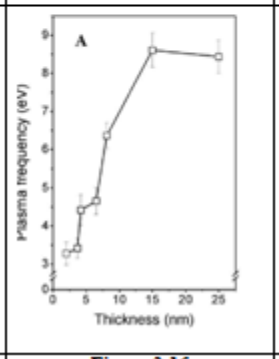


Figure 2.16

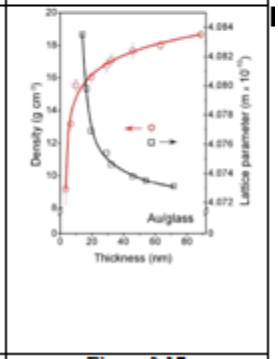


Figure 2.17

Figure. 2.14 shows the dependence of gold film resistance versus temperature for two samples. For a sample whose thickness is 5.8 nm, the resistance decreases with increasing temperature, like Fig. 2.13 semiconductors, whereas for the sample thickness of 88.7 nm it increased, though complete coincidence with the metal is not yet achieved. Figure 2.15. shows the change in electrical resistance as a function of deposition time. As we see in the beginning of the deposition, the film resistance was typical for a dielectric. At a certain film thickness, its resistance decreased by 11-12 orders of magnitude.

Of particular interest is the study of the optical properties of the nanofilm. Figure 2.16 show the frequency (energy) plasmons with increasing film thickness.

Figure 2.17 shows the change in density (from 9 to 19.62 cm-3, i.e. 2.18 times), with the lattice constant (from 4.072 to 4.084 Å, i.e. 0.29%).

The authors wrote, “...that the lattice parameter of metals prepared in the form of a thin layer by a

physical deposition is not a material constant but depends strongly on the layer thickness”

Note that the feature of the nanoclusters consists of that their properties depend on the number of atoms. At the same number of atoms, may be neutral, anionic and cationic cluster whose structure is different, different electron affinity and ionization potential. While as macroscopic samples of gold are chemically inactive, nano samples consisting of one or two atomic layers possess catalytic properties. Melting of gold nanoparticles depends on the size of the cluster and decreases to room temperature at a reduction the number of atoms in them.

Mechanism of the processes, which are due to the properties of nano-objects, in the cited works not considered. Meanwhile, the results are important for understanding the changes in the interatomic interaction, which are due to specific properties of nano-objects.

The high catalytic activity of gold nanoparticles has attracted special attention today. As established experimentally [2.47], it depends on the size of nanolayer, reaching a maximum value in the range 2 <d<7 nm. Conventionally we called it gamma-layer, γ-L. Depending on the catalytic activity of the substrate material can vary considerably. Conventional [2.45, 2.48-2.50] it is due to the coordination number of atoms, rising at its decrease. However, the mechanism of the phenomenon is not disclosed.

It is observed [2.50, 2.51] that the catalytic activity of gold is shown from a single atomic layer, the appearance of the second layer leads to a change in catalytic activity. Moreover, it is shown that the γ-L is an anionic cluster Au-δ. So, we pick out those most characteristic features that are inherent γ-L.

Feynman’s prevision that the behavior of atoms "below" obeys quantum laws, different from those that are "up", is experimentally confirmed. Formation of γ-L begins with two atoms forming on the surface of the nanostructure, for example, Au_2 dimer [2.50]. Nanoclusters may have both positive and negative excess charge.

The catalytic activity of Au nanoparticles has been investigated in [2.52]. For studies were used nanoparticles d ≈ 3.6, 5.7, 16.2 nm. Found that the rate of oxidation depends on the size of the particles and proportional to the d^{-3}.

One of the oxidation reactions designated R1: $CO + N_2O \rightarrow CO_2 + N_2$

($\Delta H^0 \approx -200.9 kJ \cdot mol^{-1}$), such that is shown as an example. There is important for us the fact that a similar reaction takes place with the participation of electrons, ions, photons and phonons. Au atoms accelerate the exchange of electrons and photons.

In connection with this we will consider the results of other experimental studies.

Figure 2.18 shows: 1) X-ray diffraction of silver wires and nanoparticles formed as a result of electrical explosion, 2) X-ray diffraction of iron wires and nanoparticles formed as a result of electrical explosion, 3) the spectrum of light absorption and luminescence of iron nanoparticles formed as a result of iron wires electric explosion in water and water containing polymer. [2.53].

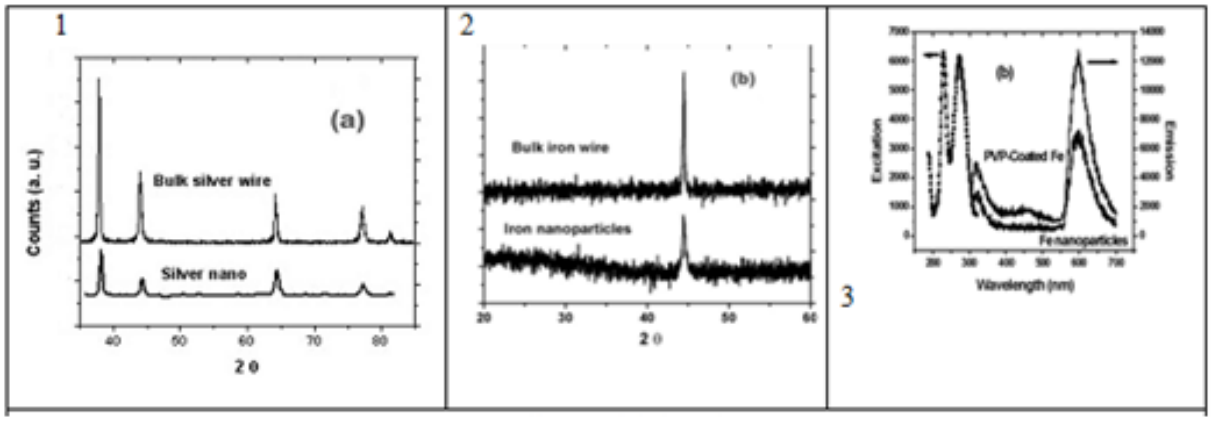


Figure 2.18 [2.53]

The coincidence of the diffraction spectra of the starting material and nanoparticles demonstrates that the crystalline structure is not changed. This is confirmed by the fact that the ascending part of the magnetization curve is also not changed. Full hysteresis loop in the works is not given. Selective light absorption in the ultraviolet and visible region, and a clearly defined maximum of luminescence indicate that the nanoparticle properties differ significantly from the starting material. This fact has extremely important scientific value, based on which it can be concluded that the energy-band structure of nanoparticles changed, but the crystal structure remains the same.

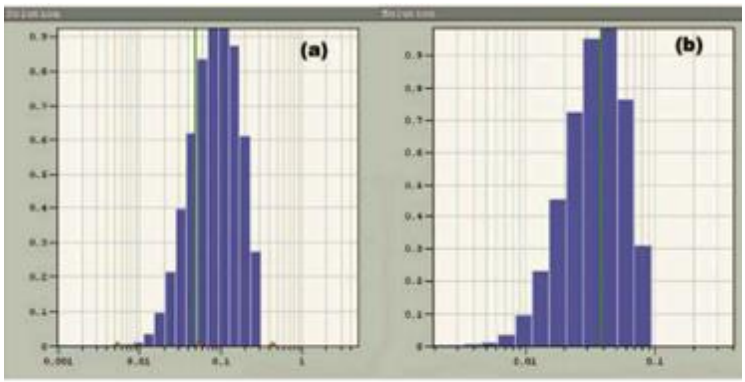


Figure 2.19 [2.53]

Note that the authors write about fluorescence, albeit without presenting any data on the duration of the afterglow.

Comparative analysis of the formation of nano-objects with a slow deposition and explosion acquires importance due to the fact that the explosion occurs nanowires at high current density and short duration. During this time, the energy dissipation don't occurs and almost all of it goes to destruction. In this regard, the nature of the destruction caused mainly by the geometry of the sample. This number indicates the

distribution of iron and silver nanoparticles by size as shown in Fig. 2.19.

"Particle size distributions have been made using dynamic light scattering where He – Ne laser light (633 nm) is passed through diluted nanoparticle solutions. The size distributions of silver and iron nanoparticles are shown in figure 2.19 (a and b) respectively. The X-axis shows the particle size in μm with logarithmic scale. Silver nanoparticle sizes ranging from 10 nm to 120 nm with distribution around 70 to 100 nm were obtained, while iron nanoparticles ranged from 3 to 90 nm with mean size of 40 nm."

As we have seen, the distribution of silver nanoparticles and iron is approximately the same, despite the fact that the properties of the metals are substantially different.

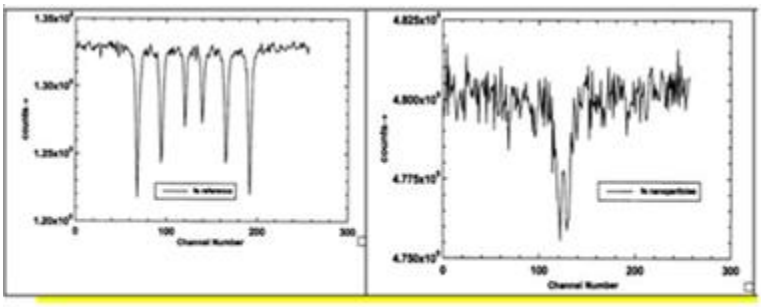


Figure 2.20 [2.54]

The Mössbauer spectra of the sample macroscopic and nanoscale iron produced by electrical explosion of wires are shown in Fig. 2.20 [2.54]. It is known that gamma-resonance is very sensitive to changes in the energy states of the atoms. These changes are clearly visible in the figure above. In addition, the energy transitions which caused the Mössbauer effect are extremely sensitive to various changes in the condition of a solid under the influence of temperature, pressure, phase transitions and other processes that lead to changes in the phonon spectrum of the crystal. Several theoretical studies suggest that the sensitivity of the Mössbauer effect on nanoobjects is greatly reduced. However, experimental studies refute such assumptions.

In addition, energy transitions, which is due to the Mossbauer effect, extremely susceptible to various changes in the condition of a rigid body under the influence of temperature, pressure, phase transitions and other processes leading to changes in the phonon spectrum of the crystal.

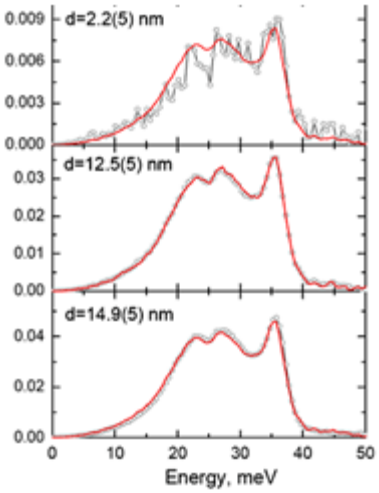


Figure 2.21 [2.55]

Research of density phonon states of the alloy nanoparticles using Mössbauer spectroscopy were performed in [2.55]. The authors note: "Since the elastic properties are tightly related to the lattice dynamics, clear understanding of the atomic vibrations in nanocrystalline materials is important. A key characteristic of atomic dynamics is the density of phonon states (DOS), which gives a frequency spectrum of atomic vibrations and provides a complete description of the elastic and thermodynamic properties. The experimentally-determined DOS of nanocrystalline systems reveals striking anomalies such as broadening of the phonon peaks and enhancement of the phonon states at low and high energies. These anomalies are generally believed to result from atoms at the nanograin surface, which can amount to ~65% of the volume for a grain of 2 nm in size.

Contrary to the general believes, we found [1] that the atomic vibrations in nanograins are actually identical to those in the bulk even for extremely small grain sizes d (Fig.1). The anomalous dynamics of nanocrystalline materials arises in fact from the atomic vibrations in the disordered interfaces". (Italics supplied).

2.3. Nanomaterial

All the foregoing permits a more precise physical, but not geometric, definition of nanomaterials. Note that it was first suggested by the author at the 4th International Conference on "Deformation and Fracture of Materials and Nanomaterials" held in Moscow October 25, 2011.

One of the most important constants of quantum electrodynamics is the fine structure constant $\alpha = \frac{e^2}{2\varepsilon_0 hc} = \frac{1}{137}$, calculated to the nearest tenth decimal place on the basis of the e electron charge, h Planck's constant, ε_0 the dielectric constant and the speed of light c.

Feynman hypothesis that the behavior of atoms, "down there" obeys the laws of quantum mechanics, but they are different from the behavior of atoms outside the area which is named nanoregions indicate

that there are some changes in the boundary conditions of interaction of the electron-photon-proton[2]. There is no doubt that Feynman did not connect them with the uncertainty relation. Based on this it is logical to assume that it does not exceed 137 nm. In this case, the ratio of the surface of the film S to the volume V of the magnitude is

$$\frac{S}{V} \le \frac{1}{137nm} \approx 72993cm^{-1} \approx 9.049eV$$

It is difficult to predict to what extent the quantum unit characterizes the energy variation of nanomaterials without serious theoretical studies and experiments. Introducing it, we proceed from the fact that the conductivity of metallic nanowires under tension changes abruptly by an amount equal to the quantum of conductance: $G_o = \frac{e^2}{2m}$. Here, e is the electron charge, m it's mass. Similar are the presently used used quantum resistance $R_K = \frac{1}{2\alpha}\sqrt{\frac{\mu_0}{\varepsilon_0}}$ and quantum thermal conductivity $G_{To} = \frac{\pi^2 k_B^2}{3h}$. Here μ_0 is the magnetic constant, ε_0 the electrostatic constant, and k_B is Boltzmann's constant.

In connection with the above, I propose the following definition of nanomaterial.

• *A nanomaterial is a special quantum mechanical dissipation structure formed in a local region of a material of three or more atoms or molecules, the ratio of surface to volume of which is greater than 1/137 nm ≈ 7.3·10⁴ cm⁻¹.*

Reflection of electronic, electromagnetic, acoustic and other types of waves at a nonuniform grain boundary accompanied by the formation of standing waves, under influence of which a change in the energy spectrum of atoms occur, which brings to the transition of electrons at higher or lower metastable levels.

• Below are phenomena that may be explained only by the change of the energy states of atoms or molecules forming a nanomaterial.

1. High strength;
2. Low melting point;
3. Significant change in the electrical, thermal and magnetic properties, both of the nanomaterials themselves and inclusions therein;

---

[2] Feynman exclaimed: "It's **one** of the **greatest** damn **mysteries** of **physics**: a **magic number** that **comes** to **us** with **no understanding** by **man**. You might say the "hand of God" wrote that".

4. Reduction of the ionization potential of nanoclusters and increase in the electron affinity with increasing number of atoms in them;

5. Existence of neutral, anionic and cationic clusters containing the same number of atoms;

6. Deformation emission of electrons and ions;

7. Reduction in work function under the influence of deformation;

8. Deformation luminescence in a wide spectral range from infrared to X-ray radiation;

9. The continued existence of a metastable state when changing the geometrical arrangement of the atoms, resulting from non-linear deformation;

10. Stimulated emission of photons, which leads to cracking and fracture

.

2.4. Electron-wave mechanism of strengthening and fracture

2.4.1. Terms and definitions

The strength of nanowhiskers, nanowires, nanoclusters has been considered in [2.2].

Here we limit ourselves to a small supplement.

Deformation waves are an interrelated set of electromagnetic, acoustic, electronic and other types of waves.

Interference is a fundamental property of waves.

The quantum of energy of electromagnetic waves is the photon, the quantum of acoustic energy is the phonon.

An element of a structure or device is the region limited by the boundary of the inhomogeneity on which a reflection and transmission of deformation waves and/or electrons occurs.

Disruption or cracking (*violation of the integrity of the element*) is the result of the *collective response of atoms of an element* to an external action, in which a group of atoms is removed from each other at such a distance that the force of attraction is not enough to restore the previous state of equilibrium.

Axiom 1. The equilibrium condition is caused by the dynamic equality of the binding energy between the atoms ε_b and the energy of thermal fluctuations $k_B T$ ($\varepsilon_b = k_B T$).

Axiom 2. Bond breaking becomes possible when the energy of external influence ε is more than the binding energy ($\varepsilon > \varepsilon_b$).

Axiom 3. Hardening or weakening of the element due to a change of the energy states of the atoms that make it.

Postulate 1. Accumulation of energy radiation which leads to the formation of cracks or destruction is due to a change in the energy state of the local groups of atoms, called the domain of destruction.

These changes occur as a result of the transfer of electrons to higher energy levels in the metastable atoms or energy zones. The maximum accumulation of energy occurs under additional ionization of atoms.

Postulate 2. The formation of cracks or fracture occurs only under stimulated (induced) emission energy. The maximum energy is emitted during the recombination of ions and electrons.

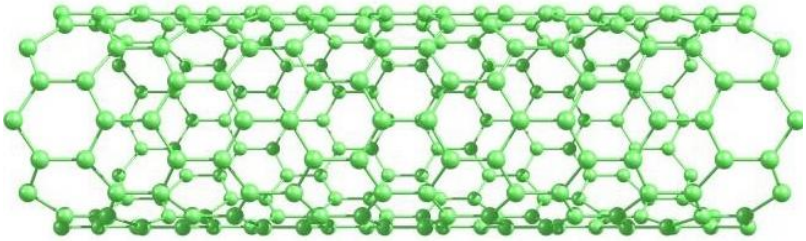
Element fatigue is caused by two factors: a) the weakening of atomic binding in the defects and b) the accumulation of energy in the domains of destruction.

Critical condition (critical fatigue) is a state of the element in which any spontaneous effect is capable to cause stimulated emission of energy and destruction.

2.4.3. Ideal material

An ideal material is one that has maximum strength combined with maximum ductility. Closed carbon nanotubes satisfy this criterion better than other nanomaterials.

To what do we attribute their unique properties?



Such nanotubes consist of carbon atoms arranged at the corners of hexagons. The bond length is 1.40 Å, the binding energy is 7 eV/atom. The maximum valence of carbon is four.

Each atom is bonded to three neighboring atoms in a binary relationship. All atoms are identical. The fourth electron is in communication with the other elements, both outside and inside the nanotube. Thus, the nanotube is a homogeneous environment in which the energy of the external impact is distributed among all the atoms more evenly than in the substance of an inhomogeneous structure. On the borders of any inhomogeneity a partial reflection of the deformation wave occurs. In such a localized area a domain of destruction forms more quickly.

Fullerene molecules, for example, C_{60}, also are closed structures, but in contrast to the closed nanotubes are composed of hexagons and pentagons. Each hexagon is bordered by three pentagons and three hexagons, while each pentagon is bordered only hexagon. The hexagon-pentagon bond length is 1.44 Å (single, binding energy is lower than that of the nanotube) and the pentagon-pentagon bond length is1.39 Å (double, the binding energy is somewhat higher than in the nanotube). However, the strength of the fullerene nanotubes closed lower strength due to the uneven distribution of the strain energy

Thus, the more homogeneous the element, and the more transparent its boundary for the deformation waves and electrons (potential barriers below), the stronger the material.

2.4.4. The influence of grains on the mechanical properties of metals.

The influence of grain size on the mechanical properties of metals and alloys has great practical and scientific interest. The strength of metals and their destruction are inseparably linked. A consideration of destruction without strength is meaningless, as is the opposite. However, strength is not the only criterion for safe operation of structures and facilities. As already mentioned, the safety criterion is the correlation of forces of the bonds between atoms by which the strength is determined, and the energy that is absorbed by atoms.

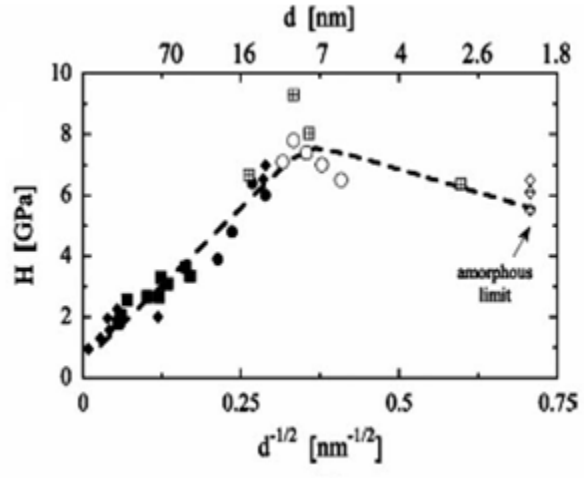


Figure 2.22 [2.56]

It is well known that by decreasing the grain size the metal hardens and becomes more pliable. Figure 2.22 shows the variation of grain nickel microhardness (open figures), and Ni-P alloy when changing grain size [2.56]. Such a dependence is called the Hall-Petch effect. It holds for the yield point. As follows from the graph, the normal Hall-Petch effect with decreasing grain diameter less than 7 nm is reversed, i.e. microhardness decreases to such an extent that when d ~ 2 nm, an amorphous phase forms, which was mentioned above as the γ-layer, wherein the shear modulus is significantly reduced.

The Hall-Petch effect is widely discussed in the mechanics of strength from the standpoint of the dislocation model. However, the generation of a positive ion, as a dislocation forms, is accompanied by the emission of an electron. Indeed, if the emitted electrons remain inside the grain, the electron density increases, increase the binding force between the ions and electrons. This leads to an increase in strength with decreasing grain size.

However, an unlimited decrease in grain size is not possible, because we must come to the conclusion that the highest strength will come when the grains are composed of a single atom. Experiment refutes such a mechanism. What, then, can explain the result of the experiment without controversy?

With decreasing grain size, the role of the surface due to increased surface contact between the grains rises. This leads to an increase in transparency to the exchange of electrons and photons of grains in which there is a more uniform energy distribution.

Consequently, at any volume the grain will reach a breaking point. This limit is due to the fact that at a certain number of atoms the long-range order vanishes and the grain de facto becomes amorphous, like liquid. This is due to slackening of tension. Thus, the nature of atomic binding of the layer cannot be considered metallic. Naturally, the question arises: why did the break come at 80-70 Å, but the amorphous state appears at 20 Å?

We call attention to the fact that the volume of a nickel nanograin at maximum strength is 180-270 nm^3. Nickel has a face-centered cubic lattice with a period of a=0.35238 nm. Hence the grain contains 16000-25000 atoms. Such a grain is a cluster whose properties vary not only with the number of atoms changing, but also on the density of the electron cloud. It makes no sense to talk about the density of dislocations, as the transition of a single electron from one grain to another substantially changes their properties, turning neutral clusters anionic and cationic. It was established experimentally that such clusters have different melting heat and melting temperature. For us it is important that the mechanical properties of the cationic and anionic clusters with the same number of atoms are different, as shown in Figure 2.23 [2.57] for the aluminum clusters containing from 30 to 70 atoms. Black dots are the experimental results and theoretical are red. The authors note that for some clusters the changing latent heat of melting is accompanied by a change in the electronic structure.

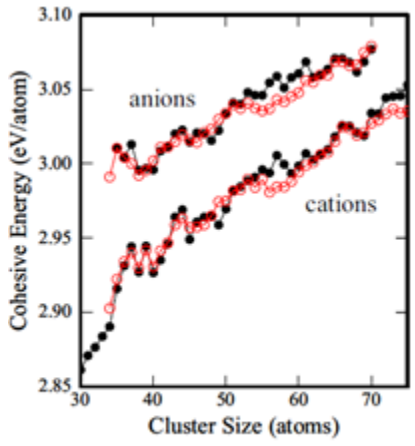


Figure 2.23 [2.57]

In turn, we note that all the processes that lead to the formation of cracks and destruction are caused by change of the electronic structure.

The nanoscale grain boundary, as we have already noted, plays a special role in the redistribution of energy absorbed during deformation. The acoustic wave velocity in aluminum is 6000 m/s. Standing waves that appear in the 2 nm grain have a frequency of about 10^{12} Hz, which corresponds to hyper-sound.

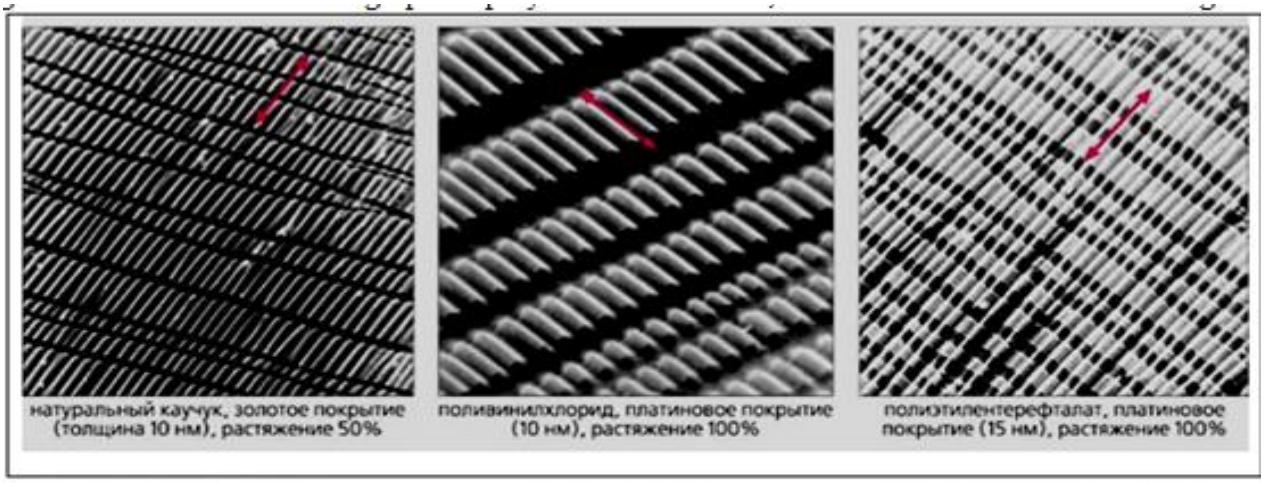
The role of solar radiation in plant photosynthesis (e.g., conversion of carbon contained in carbon dioxide into cellulose) is well known. However, the role of solar radiation in the destruction of solid bodies, especially metals, is almost ignored, limited by heating.

Meanwhile, electromagnetic radiation having a frequency above a certain value (higher than the frequency of the plasmons) passes into the metal. The energy of the plasmons in the metal exceeds the binding energy between the atoms and can not be ignored. The problem is to what extent it should be

taken into account in mechanical processes. But for this it is necessary to understand the mechanism of bond breaking, present it like a Born-Haber cycle and find the quantum mechanical equations that describe it.

Discovery of the laws, which caused the connection between the processes of energy accumulation and surface plasmons, as well as other collective phenomena, will fundamentally change the problem of assessing of wear and aging solid body during its operation.

2.5. Cracks in a nanomaterial



Substrate:	Lump rubber,	Polivenilhlorid	Polyethylene terephthalate
Film:	Au	Pt	Pt
Thickness:	10 nm	10 nm	15 nm
Elongation %	50	100	100
Zoom:	350x	1100x	1750x

Figure 2.24 [2.58]

We have considered above the formation of nano-films of metal and changes in its properties under changing thickness. Let us now consider the process of breaking the metal nano-films as described by A. L. Volynskii and S.L Bazhenov [2.58] and the works of Volynskii [2.59, 2.60].

Figure 2.24 shows three micrographs a polymer film in relief, coated with metal after stretching.

Volinskii writes: “The light stripes are pieces of decay ed coverage and the dark-are the formed cracks, i.e. bared polymer surface. It can be seen that the coating is divided into many highly elongated islands, bands of the same size, oriented perpendicular to the direction of extension, and at the same time on these fragments *a regularly undulating relief* is visible... During the stretching, tension in all fragments grows and at some point in the exact center reaches the limit of strength. There is a further breakdown of the coating, with surprising regularity: each island is divided into two equal parts.” [2.60]. (Emphasis added).

In the first of the aforementioned work [2.58], the authors found that the film breaks are similar to

the crust of the ocean floor off the west coast of Africa, (Figure 2.25, First Photo left). This allows simulating the processes of destruction of the earth's crust.

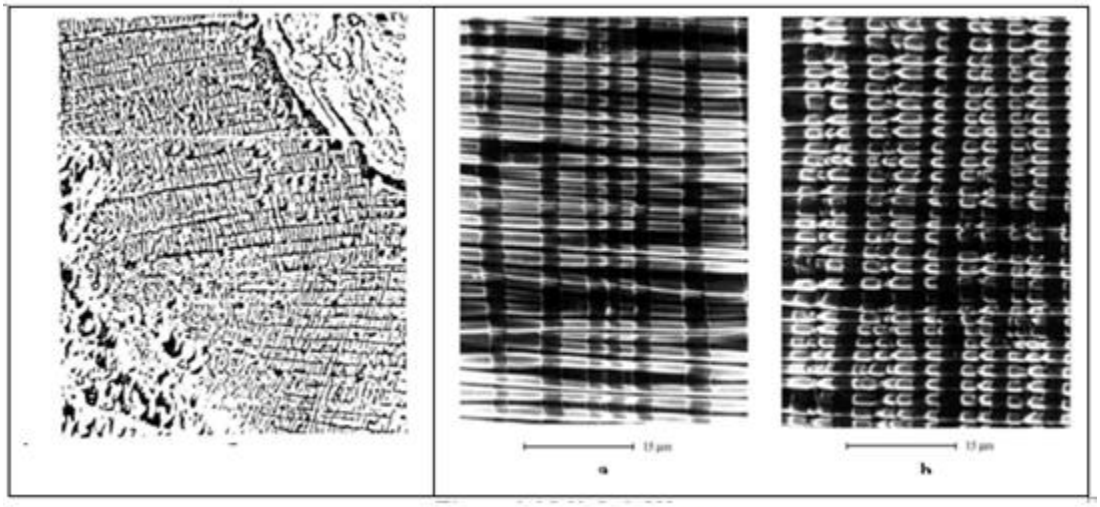


Figure 2.25 [2.58, 2.59]

Figure 2.25. Photos of the polymer film with a platinum coating (4 nm), (a) stretched 100% at 100 ° C, (b) after the additional tension at the higher mechanical stress. Zoom 2500^{x} [2.59].

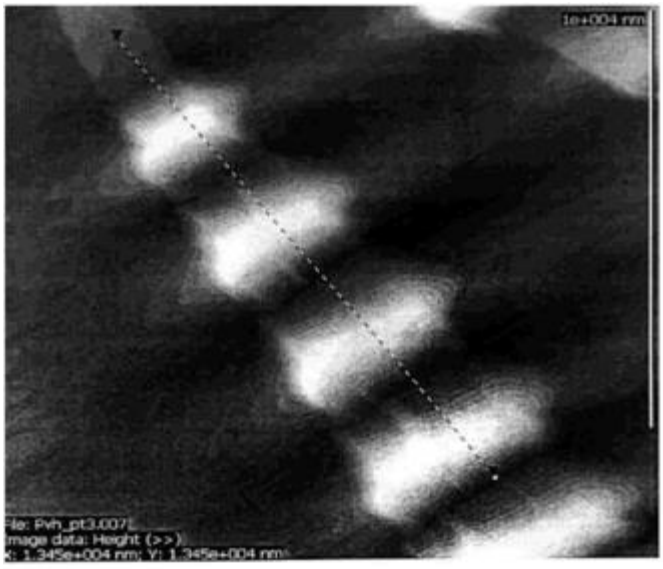


Figure 2.26 shows a photograph of the platinum film with a thickness of 20 nm on the surface of polyvinyl chloride after 100% stretching at 90° C. On the left side of the "islands" of platinum and perpendicular to the tension line occurs halo, similar to magnetic field lines, which demonstrated using iron powder. So regular destruction cannot be as accidental. It cannot be explained in terms of the mechanic models that have been proposed, including the works of [2.58-2.60].

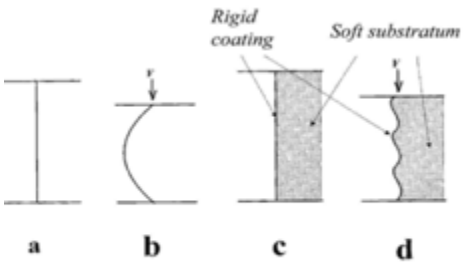


Figure 2.27 [2.58]

Figure 2.27 a, b, c, d shows the circuit with which the authors of [2.58] attempt to explain the mechanism of the observed phenomenon. They believe that the damage is the loss of stability that occurs for solid rods, the basic theories of which were laid by Euler.

In this paper, as well as other publications of Volynnsky and colleagues, there is no explanation of how the solid metallic coating suddenly was divided into almost equal, logically arranged fragments.

In this regard, we make a number of observations, without going into a detailed analysis of the problems of loss of stability in classical mechanics.

First, failure occurred in a nanoobject, to which classical mechanics is not applicable, and secondly, the loss of stability discontinuities is perpendicular to the applied force, whereas in this case there is a periodicity in two directions, and thirdly, the pattern observed in the Fig. 2.24-2.27, is characteristic of wave interference in a resonator. In this regard, consider the experimental results of two studies.

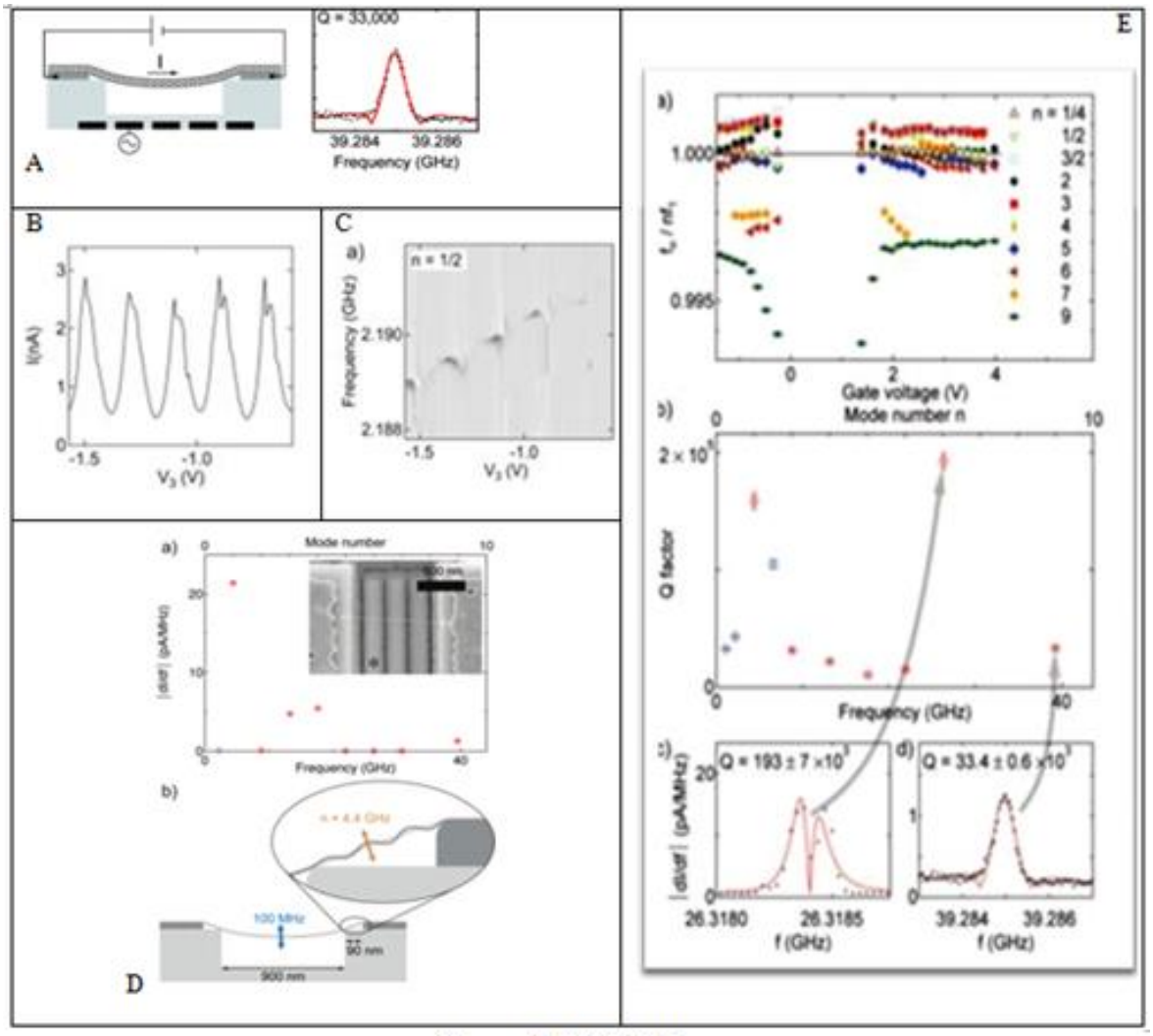


Figure 2.28 [2.61]

2.6. Resonance in nanoobjects

One of the first resonance phenomena observed in nano-objects, was the quantum mirage whicn considered in [2.2]. Physical fundamentals of nanotechnology discussed in section 2.1. Since

amplification at resonance oscillation occurs at a certain frequency and/or in the local area, the difference in energy absorbed by individual atoms can cause tearing in the connection area of the nanoobject.

Figure. 2.28 A [2.61] shows the experimental setup with the carbon nanotube in which the mechanical resonance has been observed. Phenomenon of resonances is characteristic of waves of any nature. Feature of this experiment is that the absorbed energy must exceed the energy of thermal fluctuations, i.e. $h\nu_f > k_B T$ phonon energy. In connection with this experiment was carried out at temperatures close to absolute zero.

As noted above, the quantization of physical quantities is an objective law of nature. It is due to features of the quantum wave properties of particles that form a particular material object: the nucleons in the nucleus of the atom, the electrons and nuclei in atoms, the atoms in the molecule, etc. The potential well becomes a resonator due to the reflection of electron waves from its walls. Only for the quantum mechanical object tunneling effect is possible.

In a macroscopic sample the effects of some ions on others is most pronounced in the range of local

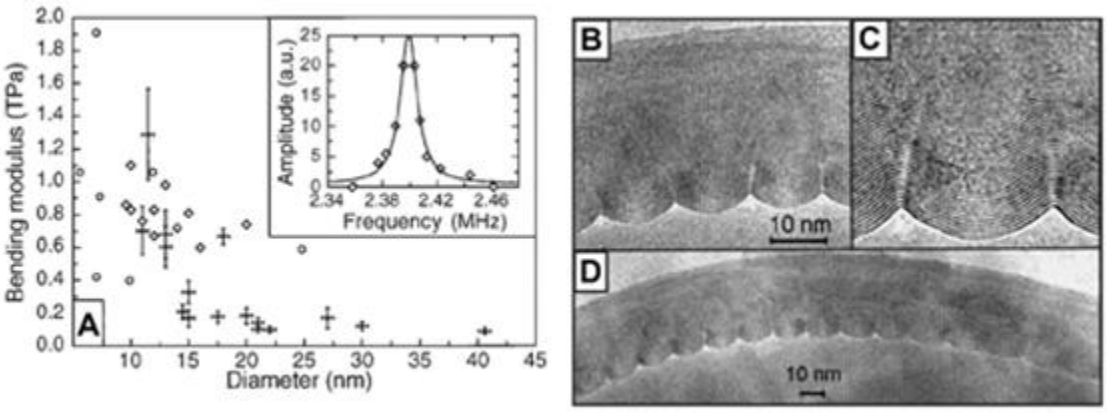


Figure 2.29 [2.62]

areas. In polymers such areas are much larger area than in pure metals and alloys. This leads to the fact that a polymer film under tension, without macroscopic gaps, can elongate more than one hundred percent. For metals, even plastic, this is impossible; the metal breaks if the adhesion between the metal atoms and the film is higher than that between the metal atoms.

Consequently, the properties of the film have a significant impact on the process of the destruction of the metal. This effect is due to two factors. First, in the deformation of the film photons are emitted with energies higher than the binding energy between the atoms of the metal. Waves with a frequency higher than the frequency of plasmons penetrate into the metal. Resonance occurs when the frequency

of the photons emitted by the film are equal to the frequency of plasmons.

This is due to the fact that the injuries are formed primarily on the metal surface. In nanofilms two metal surfaces are so close that the photons emitted by the substrate reach the outer surface. Secondly, the velocity of sound in a film is approximately two times lower than in metal. This leads to the intense reflection of acoustic waves from the metal-substrate border and metal-vacuum border, resulting in the formation of standing waves.

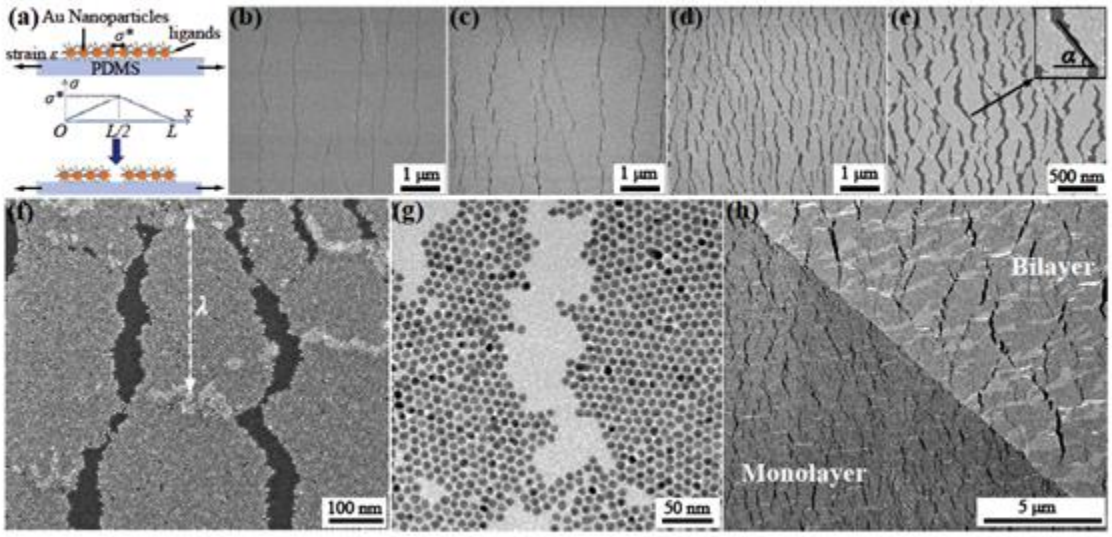


Figure 2.30 [63]

One of the characteristics of a polymer film is that nonuniformity appears in it as shown in Figure 2.31a [2.65]. This photo of the film surface is obtained with an optical microscope. Figure. 2.33b shows the dependence of wavelength on the film thickness. The observed phenomenon is called buckling, the period of irregularities in which the wavelength is determined. This name can not be considered valid, since the wave is periodic both in time and in space.

A.L. Volinskii et al. [2.66], investigating platinum and gold film on the surface of isoprene rubber or polyethylene, called these irregularities "similar waves". Similar studies were conducted by S. P. Lacour et al. [2.67]. Photographs obtained using scanning electron microscopes are shown in Fig. 2.34

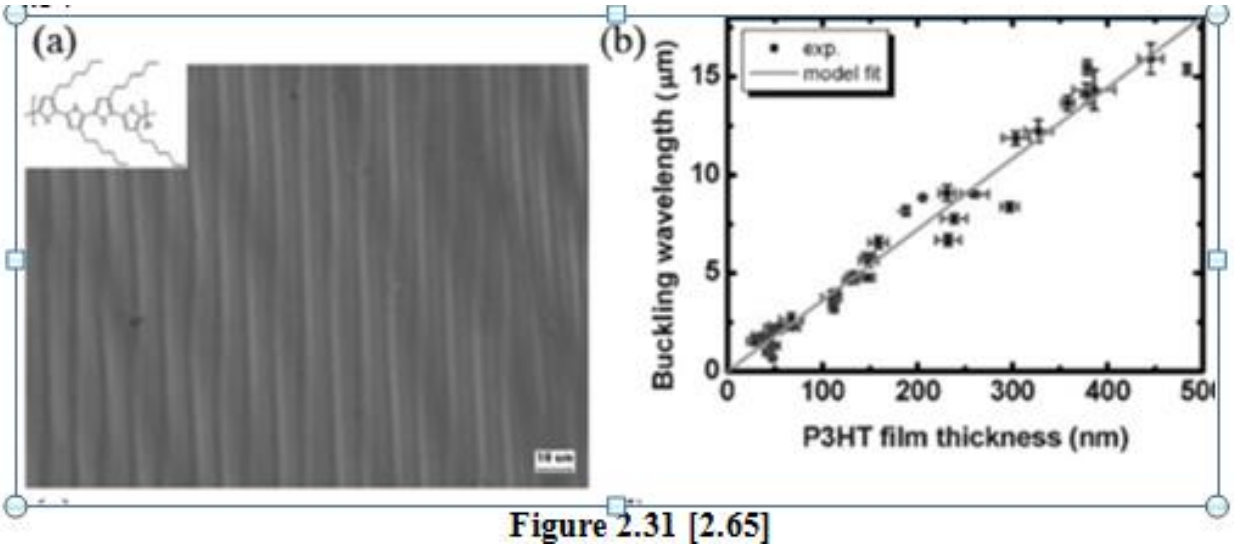


Figure 2.31 [2.65]

The authors of work [2.68] connect the buckling of nanofilms with surface acoustic waves, whose

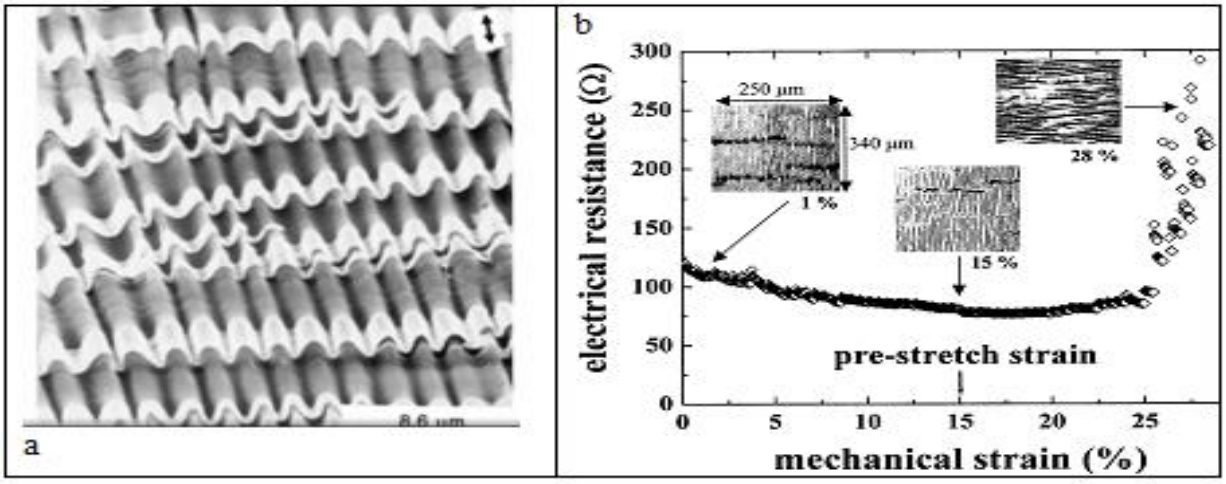


Рис. 2 32 a [2.66] **Рис. 2.32 b [2.67]**

wavelength is~ 8.4 μm and amplitude is~1.2 μm. However, it was found that one of the factors that has a significant influence on the buckling is the time of stress exposure. This fact clearly shows the comparison of the distribution of cracks in nano-films shown in Fig. 2.33 *a* and *b*. The parameter $< d >= \frac{2h_f \sigma^*}{E_s \bar{\varepsilon}}$ has been proposed to estimate the distribution of cracks in the deformed nano-films.

Here h_f is film thickness, E_s is Young's modulus of the substrate, σ* is calculated value of critical stress, σ_0^* is critical stress of unprocessed film, and $\bar{\varepsilon}$ is an expansion that matches the beginning of a

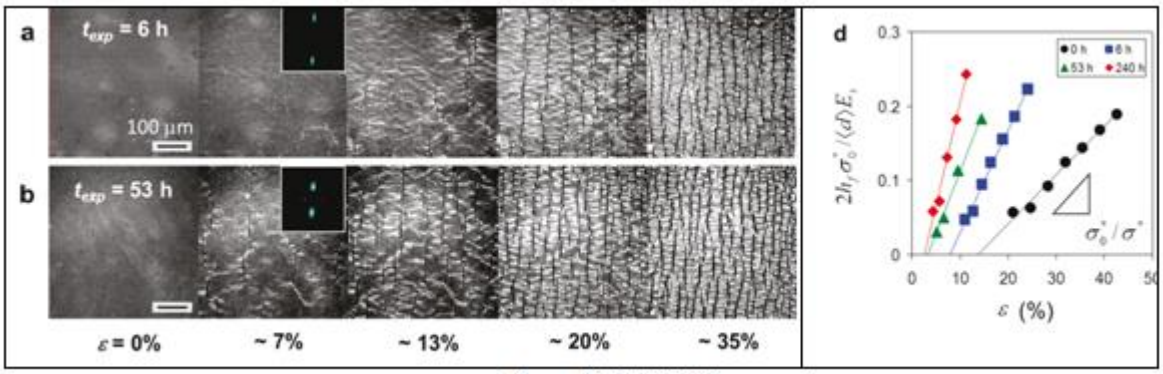


Рис. 2.39 [2.68]

crack.

It is well known that the thin film oxide Al_2O_3 (Young's modulus of 370 GPa) on the surface of Al (Young's modulus of 69 GPa) protects the aluminum from further oxidation. In [2.69], the influence of the film on the mechanical properties of aluminum was experimentally investigated. It was found that the change in Young's modulus is related not only to the thickness of the oxide, but to its wavy shape also. In the case when the roughness is of the same order as the film thickness, the effect of the oxide on the mechanical properties of aluminum is negligible. The authors believe that on the surface of aluminum composite Al + Al_2O_3 is formed and propose a model in which the properties of the film are described from the standpoint of surface waviness.

Theoretical studies of the nature of buckling and failure mechanism based on the account of changes of interatomic interactions have not been identified. In this regard, we shall restrict ourselves to just two works [2.70, 2.71], one of which was published in 2013.

2.7. Zhurkov's formula and its interpretation

On the basis of experimental studies, S.N. Zhurkov proposed the formula

$$\tau = \tau_0 e^{\frac{U_0 - \gamma\sigma}{k_B T}} \quad (2.1),$$

which bears his name, [2.72, 2.73]. Here τ is lifetime, σ is the stress, the constant τ_0 is essentially the reciprocal of the natural oscillation frequency of atoms in a solid, U_0 is the binding energy on the atomic scale, and γ is proportional to the disorientation of the molecular structure, k_B is Boltzmann's constant, T is temperature.

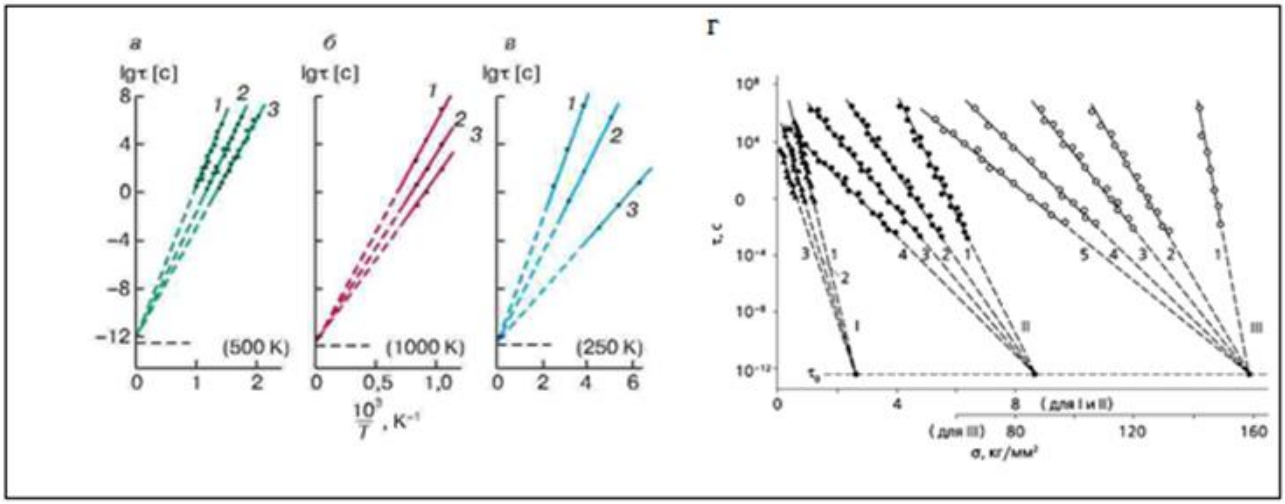


Figure 2.40 [2.74, 2.75]

Figure 2.40 (*а, б, в*) scows the logarithm of the durability *vs*. the temperature for nickel, germanium, nylon with increasing mechanical stress [2.72], The dependence of durability (I), aluminum (II) and nylon (III) *vs.* mechanical stress with temperature increase. (The graphs corresponding to the lowest temperature is indicated 1-5. In fact, the only variable parameter is γσ. A large number of studies have been devoted to the physical meaning of this magnitude. Particular interest the Zhukov formula caused in connection with the idea that the destruction caused by thermal fluctuations. We confine ourselves to some of the articles published during the period of 50 years that analyze the Zhurkov formula and provide these graphs [2.74-2.79].

Attempts to improve it, to suggest an alternative option or otherwise interpret it have been made repeatedly. Such examples were given earlier. A distinctive feature of the Zhurkov's formula was and still is the fact that it is offered on the basis of experiments and repeatedly confirmed by them.

In this connection there was a need for more carefully reading the original in order to understand why this formula is not used to estimate the remaining life of structures and devices. The kinetic concept of the strength of solids was described by Zhurkov in [2.72]. The work consists of two parts: the thermo fluctuation mechanism of solid-state destruction, and kinetics of the destruction of polymers from the position of the electron paramagnetic resonance.

Let me quote some of the fragments, and comment on them.

"In this report we shall consider the problem of the strength of solids on the basis of the kinetic concept of the mechanism of fracture. Within this concept, the fracture of solids is considered as a *time process whose rate is determined by mechanical stress and temperature*. From this stand-point the investigation of the time and temperature factors becomes very important for the understanding of the

mechanism of the phenomenon. In this connection, systematical studies of the relationship between the *life-time* of solids under load and magnitude of the *tensile stress and temperature* have been carried out". (Italics supplied).

So Zhurkov regards the destruction process using the term *lifetime*, not *longevity*, which began to be used later. This brought a certain amount of confusion in determining the cause and effect. The lifetime in atomic physics is understood as that period of time during which the energy state of an atom is not changed, whereas durability characterizes the time during which there was no formation of a crack or fracture, despite the changes that occur in the solid. Zhurkov uses the term *rate of the process*, but does not use it in the formula.

Note that Zhurkov, describing the formula $\tau = \tau_0 \exp[(U_0 - \gamma\sigma)/k_B T]$ (2.1) writes, "The constant τ_0 is essentially the reciprocal of the natural oscillation frequency of atoms in the solid, U_0 is the binding energy on the atomic scale, and γ is proportional to the disorientation of the molecular structure."

This coincidence of the atomic binding energy with the constant U_0 is not accidental. We are of the opinion that it indicates the existence of a direct connection between the kinetics of fracture of solids under the action of mechanical stress and the rupture of interatomic bonds, and permits us to consider the mechanism of fracture of solids as a kinetic process described by Eq. (2.1)

Zhurkov transformed the equation (2.1) in equation $k_B T \ln(\tau/\tau_0) = U_0 - \gamma\sigma$ (2.2). In this regard, he writes. "In this sense the fracture of solids is determined by thermal motion which *plays the major role*. In a stressed body, chemical bonds are broken *by thermal fluctuations*, the possibility of this process depending strongly on the magnitude of tensile stress." (Italics supplied).

Indeed, the left-hand side of equation (2.2), which characterizes the energy of thermal motion, is equal to the energy difference between U_0 and γσ, where U_0 is approximately equal to the binding energy of the group of atoms between which the bond breaking occurs. Thermal fluctuation depends mainly on the temperature of the body and reaches a maximum at the boiling point. But at the melting temperature, rather than bond breaking, a violation of long-range order occurs. A phase transition may take place at a lower temperature than the melting point, leading to a change in structure. Thermal fluctuations play a certain role in the rupture of the bond, but not the main role.

Any model on which long-term forecasts are based related to security, must give the most comprehensive understanding of processes that lead to destruction. However, studies devoted to thermal fluctuations (TF) have no response to numerous questions. Here are just a few of them.

Why palladium saturated with hydrogen, crumbles to dust? Why does white tin, by cooling to below -13.2°C, turn to gray and disintegrate? Why does a piece of ice on the surface of tin accelerate its

breakup in the same way that surface damage leads to a reduction of the shear stress? The discontinuous crack formation is accompanied by a jump in resistance. These jumps can occur either simultaneously or sequentially. How can this be explained by thermal fluctuations, if the effect of the electrons on the processes of destruction is not taking into account?

The literature on TF strongly supports the idea that “The main active factor is not the mechanical force, but the thermal motion that generates energy fluctuations.” “Fracture energy is drawn largely from the supply of heat, and not only from the work of external forces.” “The external force acts as a valve by facilitating and directing the destructive effect of thermal fluctuations.”

Such conclusions are refuted by experiment. We restrict ourselves to the results of experimental investigations: the deformation luminescence (DL), the deformation electron emission (DEE), the photoelectric effect in alkali-halide crystals [2.78], and ion emission in polymer films [2.79]. To characterize the processes, we cite the authors of the work “The spectrum of the DL was obtained for LiF crystal at room temperature. The spectrum is similar to X-ray luminescence, and contains two bands $\lambda_{min1}\approx 280$ and $\lambda_{min2}\approx 400$ nm

The short-wavelength band is due to recombination of the F-center with movable V_{K^-} (or V_{F^-}) center. A strained NaF selective photoelectric effect was observed due to the appearance of the samples *F*-centers (color centers). In addition, the thermally stimulated electron emission was observed due to thermal damage arising in the case of plastic deformation of the color centers. The experimental data show that under plastic deformation color centers are formed, similar to those formed by the action of ionizing radiation. On the other hand, the data obtained imply that *DEE* and *DL cannot occur due to cracks*.” (Italics supplied).

Thus, electron and ion emission, the emission of photons from the infrared to X-ray range, and the formation of vacancies (color centers) are possible in solids under strain not leading to destruction. The emission of a photon of ultraviolet light ($\lambda_{min1}\approx 280$ nm) by an LiF crystal is only possible when the absorbed energy exceeds 6.24 eV. This energy corresponds to the thermal energy at a temperature of 7000 K, at which the crystal will evaporate.

Emission of sound, ultrasound, hypersound and even long-wavelength infrared radiation is due to thermal vibrations*, but the optical radiation, especially X-rays, the photoelectric effect and the thermally stimulated emission phenomena that is caused by the quantum properties of matter*.

These events are a wonderful confirmation of Maxwell's prediction that the nature of energy accumulation due to mechanical action can not be explained within the boundaries of mechanics and those optical effects, in which the interference of polarized beams in strained material occurs.

This means that the interpretation of the structure-sensitive component in Zhurkov's formula should be sought only at the quantum mechanical level.

References to Chapter II

2.1. H. Haken, *Synergetics-An Introduction*, Second Edition, Springer-Verlag, 1978, pp 355.

2.2. В.П. Ромбах, *Фундаментальные законы физики: Проблемы нанотехнологий*, В сб. Материалы 15 Международного симпозиума «Динамические и технологические проблемы механики конструкций и сплошных сред», Москва, Федеральное Агентство по образованию, МАИ, 2009, 133

2.3. В. П. Ромбах: *Физические основы нанотехнологий*, Технология металлов, 2010, № 4, 25-32.

2.4. Д.И. Овсиенко, О влиянии структуры жидких металлов на склонность их к переохлаждению, *Металлофизика и Новейшие Технологии*, 1999, **21**, 31-41.

2.5. A.R. Scorer, *Clouds in the World*, Lothian Publ. Co., Melburne 1972, 166 pp

2.6. Б. П. Белоусов, Периодически действующая реакция и её механизм. Сб.: Автоволновые процессы в системах с диффузией. — Горький: Изд-во ГГУ, 1951, с.76.

2.7. А. М. Жаботинский, Концентрационные колебания. М.: Наука, 1974, С.179.

2.8. И. Пригожин, И. Стенгерс, *Порядок из хаоса: Новый диалог человека с природой*. М.: Прогресс, 1986.— С.432

2.9. С.И. Вавилов, *Микроструктура света*, М:, Изд. АН СССР, 1950, С.199

2.10. Blank, M., and Soo, L. *Electromagnetic acceleration of Belousov-Zhabotinski reaction*. Bioelectrochemistry 2003, **61**: 93-97.

2.11. Nicolis, *J. Phys.: Chemical chaos and self-organization*, Condens. Matter 1990, 2SA47-SA62.

2.12. Ж. И. Алфёров, *Двойные гетероструктуры: концепция и применения в физике, электронике и технологии*, *УФН*, 2002, **172**:9 1068–1086.

2.13. Г. Крёмер, *Квазиэлектрическое поле и разрывы зон. Обучение электронов новым фокусам*, *УФН*, 2002. **172**, 1087–1101.

2.14 В.П. Ромбах, *Дислокации реальность или призрак*; В. П. Ромбах, Г.П. Фетисов, *Нанонаука и дислокациии*, в Сб. Всероссийской научно-технической конференции «Нанотехнология и наноматериалы», Волгоград, 2009, 400.

2.15. М.В. Классен-Неклюдова, Т.А. Конторова, *По поводу дислокационной гипотезы пластичности* УФН, 1954, **46**,143-151 ().

2.16. Р.Б. Моргунов, *Спиновая микромеханика в физике пластичности*,УФН, 2004,**174,** 131-153.

2.17. A.P. Voskamp and E.J. Mittemeijer, *Crystallographic preferred orientation induced by cyclic rolling contact loading* Materials and Materials Transactions 1996, **27A**, 3445-3465.

2.18. H. Harada, T. Mikami, M. Shibata, D. Sokai, A. Yamamoto, and H. Tsubakino, *Microstructural changes and crack initiation with white etching area formation under rolling/sliding contact in bearing steel,* ISIJ International 2005, **45,** 1897-1902.

2.19. Alber, U., H. Müllejans, and M. Rühle, *Bismuth segregation at copper grain boundaries*, Acta Mater., 1999, **47**, 4047-4060.

2.20. A. Grabulov, *Fundamentals of Rolling Contacts Fatigue*, PhD Thesis, University of Belgrade, Serbia, 2010 pp.155.

2.21. T. Zhu, J. Li, *Ultra-strength materials,* Progress in Materials Science 55 (2010) 710–757.

2.22. H.J. Frost and M.F. Ashby, *Deformation –Mechanism Maps*. The Plasticity and Creep of Metals and ceramics, Pergamon Press, Oxford, N.Y., Toronto, Sydney, Paris, Franfurct,1982, pp.50.

2.23. S. Huang, S. Zhang, T. Belytschko, S. S. Terdalkar, T. Zhu, *Mechanics of nanocrack: Fracture, dislocation emission, and amorphization*, Journal of the Mechanics and Physics of Solids 2009, **57** 840–850.

2.24. *Поверхностные слои и внутренние границы раздела гетерогенных материалов*, под редакцией В.И. Панина- Новосибирск Изд.-во СО РАН 2006. С. 520

2.25. R. Peierls, *The Size of Dislocation*, Proc. Phys. Soc. London. 1940, **52**, 34-37.

2.26. F.R. Nabarro: *Dislocations in a Simple Cubic Lattice*, Proc. Phys. Soc., 1947, **59**, 256-272

2.27. H. Wei1, Y. Xiang, and P. Ming, *A generalized Peierls-Nabarro model for curved dislocations using discrete Fourier transform*, Global Science Preprint, http://www.global-sci.com

2.28. М. И. Каганов, В. Я. Кравченко, В. Д. Нацик: *Электронное торможение дислокаций в металлах.* УФН, 1973, **111,** 655-682.

2.29. G. P. Cherepanov, A. Richter, V. E. Verijenko, S. Adali, and V. Sutyrin, *Dislocation generation and crack growth under monotonic loading,* J. Appl. Phys. 1995, **78**, 6249.

2.30. B. Joós, M. S. Duesbery, *The Peierls Stress of Dislocations: An Analytic Formula.* Phys. Rev. Lett. 1997, **78**, No 2, 266-269.

2.31. L. I. Slepyan: *Wave Radiation in Lattice Fracture*. Acoustical Physics. 2010, **56**, No. 6, 962–971.

2.32. A. S. Bakankin, A.D. Izotov: *Ultimate strength and brittleness of crystal solids*. Revisia Mexicana de Física, 1995, **41**, No 2,147-180.

2.33. A. S. Bakankin, *Quantum-statistical approach to dynamic problems of solid mechanics*. Revisia Mexicana de Física, 1995, No. 6, 783-790.

2.34. N. M. Pugno and R.S. Ruoff: *Quantized fracture mechanics*, Philosophical Magazine, 2004, **84**, No. 27, 2829–2845.

2.35. N. Pugno: *New quantized failure criteria: application to nanotubes and nanowires*. Int J Fract. 2006, 141:313–323.

2.36. N.M. Pugno and E.C. Aifantis: *A Note on the Transition from Nano- to Mega-Mechanics: The Role of the Stress Quantization*, Journal of the Mechanical Behavior of Materials, 2009, **19**, No.1.

2.37. L.I. Slepyan, A.B. Movchan, G. S. Mishuris: *Crack in a lattice waveguide*. Int J Fract 2010, 162:91–106.

2.38. L.I. Slepyan, *Wave Radiation in Lattice Fracture,* Acoustical Physics, 2010, Vol. 56, No. 6, 962–971.

2.39. N.F. Morozov, I.A. Ovid'ko, Yu.V. Petrov and A.G. Sheinerman: *Generation and Converence of Nanocracks in Nanocrystalline materials Deformed by Grain Boundary Sliding*. Rev. Adv. Mater. 2009,**19**, 63-72

2.40. M. Ippolito, A. Mattoni, L. Colombo, N. Pugno: *Role of lattice discreteness on brittle fracture: Atomistic simulations versus analytical models*. J.Phys. Rev. 2006, **B 73**, 104111.

2.41. А. В. Андреев, В.М. Коренев. Ю.В. Тихомиров: *Отрыв атомных связей в вершине трещины. Потеря устойчивости участка цепочки атомов*. Изв. РАН Механика твердого тела, 1993,№ 5, 135-146.

2.42. A. C. O. Miranda, M. A. Meggiolaro, L. F. Martha, J. T. P. Castro, *Stress intensity factor predictions: Comparison and round-off error*, Computational Materials Science 2012, **53**, 354–358.

2.43. В. В. Новожилов, *О необходимом и достаточном критерии хрупкой прочности.* Проблемы математики и механики, 1969, **33**, в. 2, 212-222.

2.44. В. В. Новожилов, Л. И. Слепян: *Некоторые проблемы и достижения механики разрушения*. Вестник АН СССР. 1987, № 9. С.96-111.

2.45. С.С. Бацанов: *Размерный эффект в строении и свойствах конденсированных веществ*. Журнал структурной химии, 2011, **52**, 618-630.

2.46. Siegel, O. Lyutakov, V. Rybka, Z. Kolská, V. Švorčík: *Properties of gold nanostructures sputtered on glass.* Nanoscale Research Letters, 2011, 6:96. *NANO EXPRESS Open Access* http://www.biomedcentral.com/content/pdf/1556-276X-6-96.pdf

2.47. B. Hvolbæk, T. V. W. Janssens, H. Clausen, C. H. Christensen, and J. K. Nørskov, *Catalytic Activity of Au Nanoparticles*, Nanotoday 2007 2, 14-18.

2.48. M. Chen, Y. Cai, Z.Yan, and D. W. Goodman: *On the Origin of the Unique Properties of Supported Au Nanoparticles,* JACS article, Published on Web 04/25/2006

2.49. Dottoranda: Dr. Laura Bianchettin: *Electronic structure and chemical reactivity at solid surfaces: the role of under-coordinated atoms and bimetallic alloys,* UNIVERSITÀ DEGLI STUDI DI TRIESTE, A.A. 2006-2007, http://www.tasc.infm.it/research/amd/theses/Bianchettin.pdf

2.50. M.F. Camellone, P. M. Kowalski, and D. Marx: *Ideal, Defective, and Gold–Promoted Rutile TiO2(110) Surfaces: Structures, Energies,Dynamics, and Thermodynamics from PBE+U,* 2011, arXiv.org > cond-mat > arXiv:1107.0840v1

2.51. Н.А. Матвеевская, В.П. Семиноженко, Н.О. Мчедлов-Петросян, А.В. Толмачев, Н.И. Шевцов: *Получение, структура и свойства гетеронаночастиц SiO_2/Au*. Доповіді Національної Академії Наук, 2007, № 2, 101-107.

2.52. G. Walther, D.J. Mowbraya, T. Jianga, G. Jonesa, S. Jensen, U.J. Quaade, S. Horch, *Oxidation of CO and H_2 by O_2 and N_2O on Au/TiO_2 catalysts in microreactors*

2.53. 1) A. Alqudami and S. Annapoorni: *Fluorescence from metallic silver and iron nanoparticles prepared by exploding technique*, University of Delhi India, http://arxiv.org/ftp/cond-mat/papers/0609/0609369.pdf pp.16/ 2) A. Alqudami and S. Annapoorni *Magnetic properties of iron nanoparticles prepared by exploding wire technique* http_arxiv_org 0609_0609370, pp 17

2.54. P. Sen, J. Ghosh, A. Abdullah, P. R. Kumar and Vandana: *Preparation of Cu, Ag, Fe and Al nanoparticles by the exploding wire technique.* 2003, Proc. Indian Acad. Sci. (Chem. Sci.), Vol. 115, No 5 & 6, 499–508.

2.55. S. Stankov, Y.Z. Yue, M. Miglierini, B. Sepiol, I. Sergueev, A.I. Chumakov: *Легенды и мифы нанотрехнологий: чем на самом деле определяются упругие свойства нанокристаллитов*? XI Международная конференция "Эффект Мёссбауэра и его применение", Екатеринбург (2009); S. Stankov, Y.Z. Yue, M. Miglierini, B. Sepiol, I. Sergueev, A.I. Chumakov, L. Hu, P. Svec, and R. Rüffer, *The Legends and Myths of Nanotechnologies: what is a Real Nature of Elastic Properties of Nanocrystallites*, Phys. Rev. Lett., 2008, **100**, 235503.

2.56. M.A. Meyers, A. Mishra, D.J. Benson: *Mechanical properties of nanocrystalline materials,* Progress in Materials Science 2006, **51**, 427-556.

2.57. A. K. Starace, C. M. Neal, B. Cao, M. F. Jarrold, A. Aguado, and J. M. López*, Electronic effects on melting: Comparison of aluminum cluster anions and cations,* J. Chem. Phys. 2009, **131**, 044307 pp.11.

2.58. A. L. Volynskii and S.L. S.L Bazhenov: *Folding instabilities* and *of the thin coating on a soft polymer substrate as a model of oceanic crust*. Geofisika Internationale, 2001, **40**, No 2, 87-95.

2.59. А.Л. Волынский: *Удивительные свойства упаковочной пленки,* Природа, 2005, № 5

2.60. А.Л. Волынский: *Зависит ли прочность твердого тела от его размеров*? 2007, Природа № 9.

2.61. L.A. Laird, F. Pai, W. Tang, G.A. Steele, L.P. Konwenhoven: *A High Quality Factor Carbon Nanotube Mechanical Resonator at 39 GHz*, Nano Lett. 2011, DOI**:** 10.1021/nl203279v

2.62. P. Ponchard, Z.L. Wang, D. Ugarte, V.A. de Heer: *Electrostatic Deflection and Electromechanical Resonance of Carbon Nanotube,* Science, 1999, 283, 1513-1516

2.63. Y. Wang, P. Kanjanaboos, E. Barry, S. Mcbride, X.-M. Lin, and H. M. Jaeger, *Fracture and Failure of Nanoparticle Monolayers and Multilayers,* (Dated: May 20, 2013), Department of Physics, The University of Chicago, James Franck Institute, The University of Chicago, Center for Nanoscale Materials, Argonne National Laboratory, pp.5, http://jfi.uchicago.edu/~jaeger/group/JaegerGroupPapers/nanocrystals/Nanoparticle%20Fracture.pdf

2.64. S. L. Bazhenov, A. L. Volynskii, V. M. Alexandrov, N. F. Bakeev, *Two mechanisms of the fragmentation of thin coatings on rubber substrates,* Journal of Polymer Science Part B: Polymer Physics 2002, 40, 10-18.

2.65. Si-W. Hahm, H.-S. Hwang, D. Kim, and D.-Y. Khang, *Buckling-Based Measurements of Mechanical Moduli of Thin Films, Electronic Materials Letters, Vol. 5, No. 4 (2009), pp. 157-168*

2.66. A. L. Volynskii, S. L. Bazhenov, O.L. lebedeva, N. F. Bakeev, Mechanical buckling instability of thin coatings deposited on soft polymer substrates, J. of Material Science 2000, **35**, 547-554.

2.67. S. P. Lacour, J. Jones, Z. Suo, and S. Wagner*, Design and Performance of Thin Metal Film Interconnects for Skin-Like Electronic Circuits*, IEEE, Electron Device Lett., 2004, **25**, NO. 4, 179-181.

2.68. J. Y. Chung, J.-H. Lee, K. L. Beers, and C. M. Stafford, *Stiffness, Strength, and Ductility of Nanoscale Thin Films and Membranes: A Combined WrinklingCracking Methodology,* Nano Lett. 2011, 11, 3361-3365

2.69. M. T. A. Saif, S. Zhang, A. Haque, and K. J. Hsia, *Effect of native Al2O3 on the elastic response of nanoscale Al films,* Mechanical and Industrial Engineering, Theoretical and Applied Mechanics University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA

2.70. J. Song and S. Wang, *Theory for Stretchable Interconnection,* Stretchable Electronics, Fifst Edition. Edited by T. Someya. Published 2013 by Wiley-VCH Verlag GmbH & Co. KGaA pp 1-29.

2.71. A. L. Volynskii, D. A. Panchuk, S. V. Moiseeva, A. S. Kechek´yan, A. I. Dement´ev, L. M. Yarysheva, and N. F. Bakeev, *Reviews, New approach to evaluation of the stress_strain properties of nanolayers of solid materials,* Russ.Chem.Bull., Int.Ed., 2009, **58**, No. 5, 865-882.

2.72. С**.**Н Журков**,** *Проблема прочности твердых тел*, ***Вестник*** АН СССР, ***1957,*** № ***1, 78***– 82.

2.73. S.N. Zhurkov, Kinetic Concept of the Strength of Solids, Int. J. of Fracture Mechanics, 1965, **1**, No. 4, 311-322.

2.74. В. Р. Регель, А. И. Слуцкер, *Структурно-динамическая гетерогенность-основа разрушения твердых тел, Соросовский образовательный журнал*, 8, №1, 86-92 (2004).

2.74.

2.75. В.Р. Регель, А.И. Слуцкер, Е.Е. Томашевский, *Кинетическая природа прочности твердых тел*. М., 1974.

2.76. А. И. Слуцкер, А.И.Мехайлин, А. И. Слуцкер, *Микроскопика флуктуаций энергии в твердых телах*, УФН, 1994, **164,** 357-366.

2.77. А.И. Слуцкер, *Характеристики элементарных актов в кинетике разрушения металлов*. Физика твердого тела 2004,**46**, 1606-1619.

2.78. Л.Б. Потапова, В.П. Ярцев, *Механика материалов при сложном напряженном состоянии. Как прогнозируют предельные напряжения?* Москва, Изательство Машиностроение-1 (2005) С.372.

2.79. И. Д. Ибатуллин**,** *Новые методы и приборы для экспрессной оценки энергетических параметров усталостной повреждаемости и разрушения поверхностных слоев*, Автореферат

диссертации на соискание ученой степени доктора физико-математических наук, Тольятти 2010

2.80. В.А. Закревский, А.В. Шульдинер, *Электронные возбуждения, возникающие вследствие пластического деформирования ионных кристаллов*, Физика твердого тела, 1999, **41**, №5 900-903.

2.81. В.А. Закревский, В.А. Пахотин, *Эмиссия отрицательных и положительных ионов при разрыве полимеров,* Физика твердого тела, 2010, **52**, 1083-1089.

CHAPTER III. NATURE AND MECHANISMS OF CRACKING

We must strive to explain the phenomena of nature. And what does explain mean? It means reduce *to something simpler. And there's nothing wrong with that, it all comes down to the physical laws. This is the ideal for which to strive*.

A.A. Markov (Jr.) mathematics

3.1. Rupture of the interatomic bond

Any crack begins with breakage of the bond between the atoms. In connection with this understanding of the mechanism of this process is the key to solving the problem of preventing catastrophic destruction. The carbon cycle in nature was explained in a small piece [of Feynman's lectures] dedicated to fire. Carbon and oxygen atoms, repulsing each other, cannot form a molecule, just as a stone cannot be rolled into a hole at the summit of a mountain. However, with enough of a push, it will be there for a long time. So impulse is the energy released during the formation of a carbon monoxide molecule to start the chain reaction that ends with the formation of carbon dioxide. Plants separate oxygen by photosynthesis from CO_2. We will not examine in detail the process of photosynthesis, mentioning only one important step, the formation of molecular oxygen

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_8 + 6O_2 .$$

A water molecule dissociates under the influence of solar radiation and the hydrogen reacts with carbon to form glucose.

Thus, in this chemical reaction, absorption of electromagnetic energy and destruction of H_2O and CO_2 molecules occur, but other two molecules $C_6H_{12}O_8$ and O_2 are formed. In a living organism there is a reverse reaction as a result of which the body does work, heat, but a CO_2 forms. Such oxidation-reduction reaction proceeds with iron ions, electrons and photons $Fe^{2+} + h\nu - e^- \leftrightarrow Fe^{3+} + e^- - h\nu$, just as happens in the Belousov Zhabotinskii reaction with cerium ions. The change in iconicity of iron leads to pathology, energy balance disturbance and even death of the organismRemoving Ag from AgCl molecules occurs as a result of photon absorption. This is the basis of film photography. The chloride ion Cl-, absorbing a photon, loses an electron which is trapped by Ag+. As a result, two neutral atoms are formed, and the relationship between them is weakened so that a gaseous chlorine atom is removed from an atom of silver or leaves the emulsion.

In engineering structures subject to external influences, work is performed, at which there are changes not only in the position of the atoms, but also their energy state. Disturbance of the energy balance leads to damage and destruction.

The interaction of individual atoms with each other in both technical constructions and living organisms is subject to the same laws of physics. In this connection, destruction and hardening should be regarded as a chemical reaction which is caused by the exchange of electrons and photons between atoms

3.2. Electron-photon interaction in a multicomponent system

Protein molecules, amino acids and other organic compounds are the most complex compounds in nature. Despite the large number of atoms forming a molecule, it remains a definite structure that provides its strength and functionality. Moreover, a change in the energy state of a small group of atoms leads to pathology or even death of the organism. But it turns out that all the communication channels are due to the same electron-photon exchange.

Humanity in its development has come a long way from the use of natural materials to create multi-component systems. Probably the most complex inorganic systems developed in the 20th century, were high-temperature superconductors. The phenomenon of superconductivity is beyond the scope of this study. However, the material shows such amazing properties that to explanain them we had to repeatedly abandon the existing theoretical understanding of the behavior of atoms. In this regard, we look briefly at the problem, to better understand the processes that lead to the destruction of the material.

The mechanical properties of superconductors are of practical interest only to the technical field in which they are applied. But the destruction of superconductivity causes a magnetic field that changes the trajectory of electrons, the interaction of the spins. However, the behavior of electrons and ions is of great interest to solve the problem of destruction of $Tl_{2-x}Bi_xBa_{2-y}Pb_yCa_2Cu_3O_{10\pm\delta}$ size 3·3·1 mm^3 of high temperature superconductor (HTS) with a transition temperature 123 K, were obtained in 1989, by me, V. A. Gritskikh, and V.A Korotun in the Industry Research Laboratory (ONIL) which I chaired, at the Ministry of Electronics Industry of the USSR. The interest in this class of high-temperature superconductors in the whole scientific world was huge in relation to the expected prospects for their practical application.

The distinctive feature of these compounds is variable valence.

We demonstrate it through the example of compounds of thallium, which in some compounds is a monovalent, in others trivalent. It was found that the crystal structure of the compound TlSe is such that it contains Tl^{1+} ions and Tl^{3+} ions, occupying different positions. This meant that the compound is not binary and ternary. It was found that the variable valency of atoms in the compound is the rule rather than the exception. Such a conclusion was made in the twentieth century by founders of quantum

chemistry L. Pauling [3.1, 3.2], F. London [3.3], and V. M. Goldschmidt [3.4].

The bipolar transistor was invented in 1947 by Shockley, Bardeen and Brattain. Progress in semiconductor technology required the creation of new materials with a wide range of physical and physico-chemical properties due to the heterovalent atoms. These were compounds A^3B^5 and $A^2B^4C_2^5$ Goryunova's work [3.5, 3.6] played an important role in the understanding of physical and chemical processes in complex compounds. This has created favorable conditions for the creation (synthesis and crystal growth) of many complex diamond-like compounds with a wide range of properties.

Ternary thallium compounds such as, Tl_3VS_4, Tl_3VSe_4, Tl_3TaS_4, Tl_3TaSe_4, Tl_3NbS_4, Tl_3NbSe_4 were first synthesized by C. Crevecoeur [3.7] using solid-phase. With the compound Tl_3VS_4 we discovered a switching effect, known as the "Ovshinsky effect" [3.8], but on a crystalline sample, the size of which was $1 \cdot 1 \cdot 1 mm^3$. The results of our research have been published in [3.9], which was used as the prototype of a patent [3.10], since in these materials a pronounced piezoelectric effect was found, the high rate of electromechanical coefficient and high acousto-optical Q-factor.

As illustrated by the example of carbon, synthesis of the compound may help to understand the way in which failure occurs. A disadvantage of solid phase synthesis of compound Tl_3VS_4 is that the initial temperature of the components varies greatly: S-113°C, Tl-304° C, V-1910° C. In this regard, the reaction should be carried out for a long time due to the increased vapor pressure of sulfur and the risk of explosion, which results in pollution of the environment by highly toxic compounds.

To reduce the time of synthesis and improve safety, the synthesis was carried out in two stages. The first stage synthesized phase $Tl_3 - S_4$, at the second stage vanadium was added. At this stage Tl acts as a thallium-promoted catalyst, which reduces the synthesis of large masses and makes the reaction intrinsically safe.

This example is to show that the destruction is determined by stimulated emission of energy and certain chemical elements accelerate it, cutting the safe operation time. The impact of some atoms on the behavior of others in alloys and composite materials is well known and widely used in materials science. But in nature there is only one mechanism that canexplain this phenomenon: the exchange of atoms with electrons and energy. It is a mistake to believe that the formation of cracks or destruction is caused only by a change in the geometric arrangement of the atoms.

The influence of atoms of one material on the properties other materials will be shown by some examples. Interatomic interaction can be traced best at the nanoscale.

1). A method of controlled growth of carbon nanotubes in another nanotube was proposed in [3.12].

Growth was carried out using an electric current I ~ 20 mA, the electric field strength of which was $\left|\vec{E}\right| \approx 1.3 \cdot 10^{-4}\, V/nm$. Cobalt ions emitted during its melting, used as a catalyst.

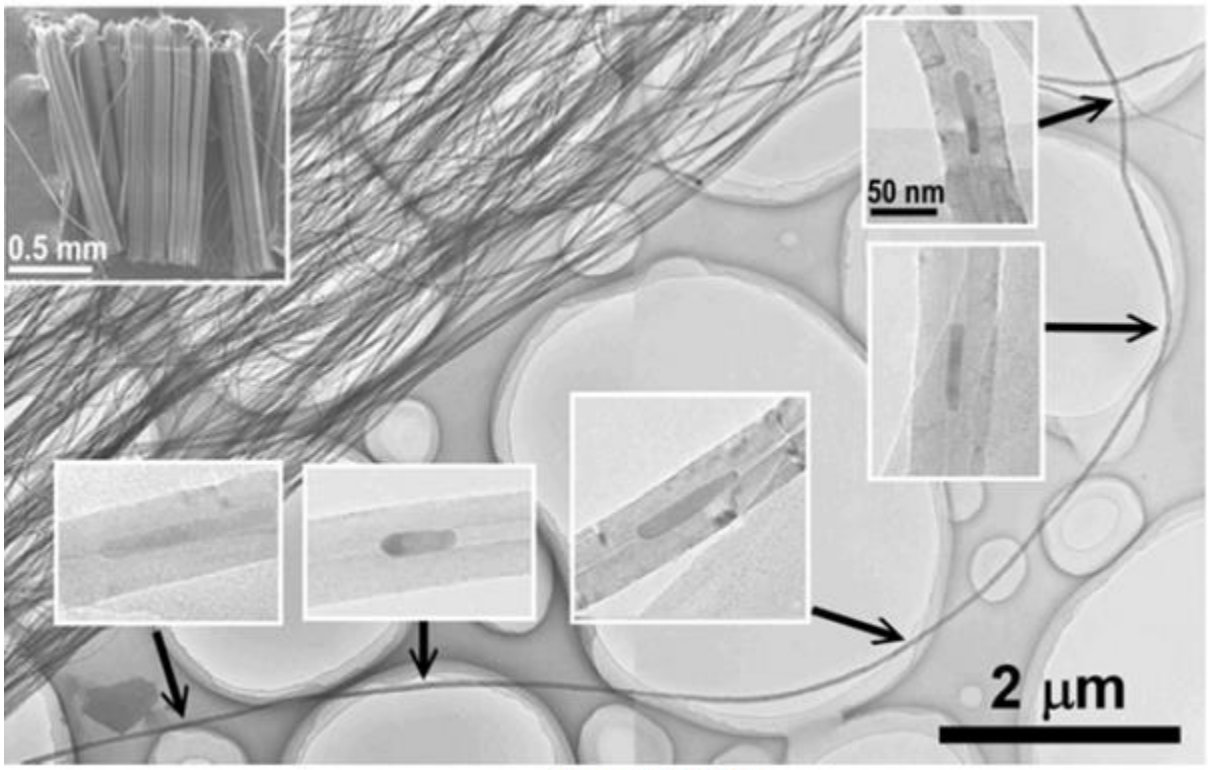


Рис. 3.1 [3.13]

Fig. 3.1. Characterization of CNTs and encapsulated catalyst particles. (top-left inset) SEM image of an as-grown 1.5 mm array of CNTs by sequentially feeding nickelocene and ferrocene each for 30 minutes. Five small TEM insets show catalyst particles following the length of a CNT (all at the same magnification) [3.13].

Changes in the structure of CNTs as well as in a catalyst are shown in Fig. 3.2.

Tracing the distribution of catalysts in the process of nanotube growth. (a)-top and (b): using nickelocene $\{Ni(C_5H_5)_2\}$; (a)-the lower part and (c): using ferrocene $\{Fe(C_5H_5)_2\}$[3.13].

We consider only the results of radiographic studies, without going into details of the technology. The catalyst $Ni(C_5H_5)_2$ contained Fe and Cu impurities. Let us pay attention to the two peaks in Ni and Cu. XRD pattern of the catalyst suggests that in this case, a maximum of two of iron and copper was observed. The presence of two peaks means that in the catalytic process, heterovalent ions of nickel, iron and copper were involved.

The structure of ferrocene is shown in Figure 3.3. Each carbon atom is bonded to two atoms of carbon, hydrogen and iron atoms. Thus, all valence electrons of the hydrogen and carbon atoms are

involved in the covalent bond. This is due to the name of the organometallic compounds (zehn is ten in German).

The iron atom is associated with ten carbon atoms. This is also a covalent bond. The electronic structure of the atom Fe is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^8 4s^2$. The minimum energy required to ionize an

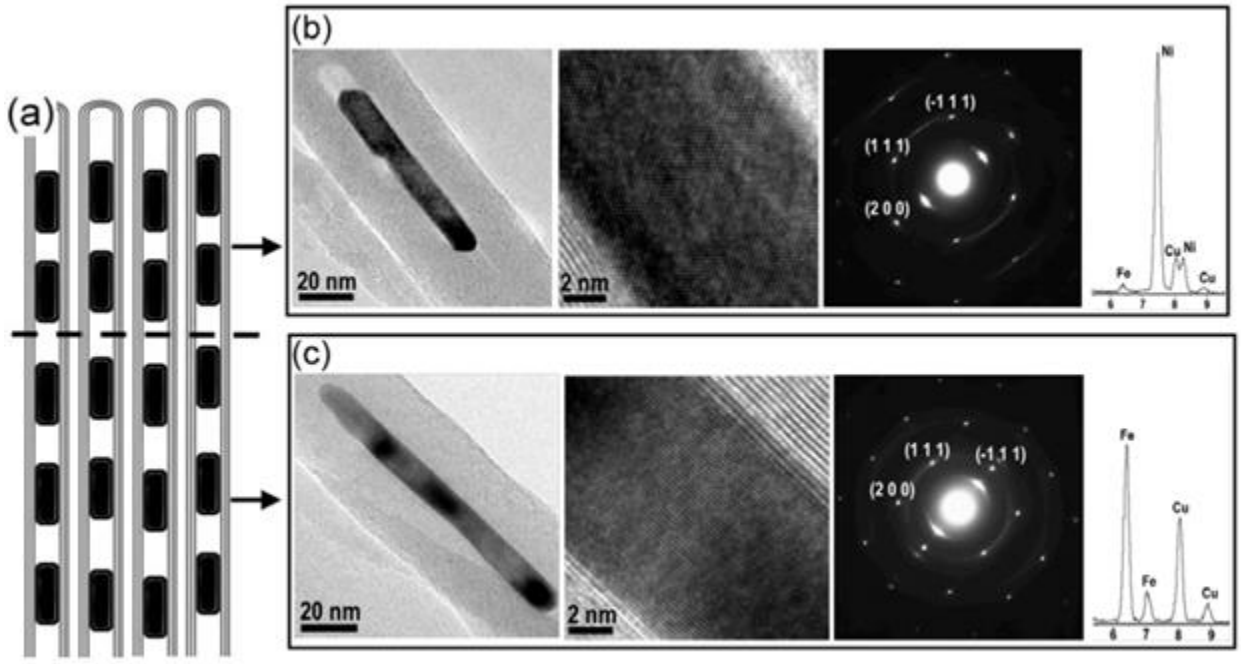


Рис. 3.2 [3.13]

atom of iron, involves the removal of electrons from the 4s shell. In this regard, a metal atom in the metallocene is ionized most easily to M2+. However, the length of each C-C bond length is 1,40 - 1,41 Å, the Fe-C bond length is 2,04 Å. This testifies to strict conservation of the electron cloud distribution in the molecule. Equality of the C-C bond lengths, as well as Fe-C bond length, means the absence of double bonds Electronic structure of atoms: H-1s1, C-1s22s22p2. Consequently, the interatomic interaction in the molecule is due to the ten-covalent bonds (C-H), ten covalent bonds (C-C) and ten bonds (Fe-C). These 30 bonds between 21 atoms is due to the exchange of 52 electrons (H-$1s^1$)=10, (C-$2s2^2p^2$)=40, (Fe-$4s^2$)=2.

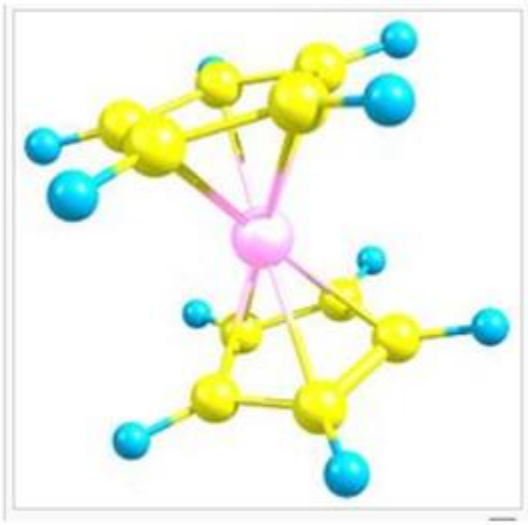


Рис. 3.3

The presence of heterovalent iron, noted above, testifies to the Fe-C bond oscillations from covalent to metallic. The probability of s-p or s-d hybridization increases with increasing temperature. Thus, the number of electrons is greater than the number of bonds and metallocene serves as a catalyst of synthesis and an inhibitor for detonation.

3) The influence of Cu, Ni, Pt atoms on the mechanical properties of CNT-type armchair (10, 10) was investigated in [3.14]. Figure 3.4A shows the dependence of the elastic energy under deformation of empty nanotubes and nanotubes filled with metal atoms.

Comparative analysis shows that the difference between the elastic energy of empty nanotubes and tubes filled with metal atoms occurs after a certain tension. The contribution of the metal atoms to the total energy increases with the number of them, and at 354 nickel atoms composes ~ 100%.

The presence of metal atoms in the carbon nanotubes results in a change of the energy distribution along the tube, as shown in Fig. 3.4 B. The character of deformation CNT d, e, f differs from the deformation of nanotubes a, b, c. The authors note that when the number of atoms exceeds 50, a cluster is formed and the critical buckling stress depends on the number of metal atoms therein.

Unfortunately, no hypothesis about the nature of the phenomenon and mechanism are offered in the cited paper. However, the results show that at a certain ratio of the number of metal atoms to carbon, energy density accumulated in the nanotube practically doubled, but failure did not occur.

This fact is of great importance for materials science. It is well known that the impurity of an element plays an important role in the wear, aging, and hardening of alloy or composite, even when a material contains it in a small amount. However, consideration of the effect of the impurity is based on empirical recipes, methods and formulas. The carbon-metal interaction predetermines the properties of a vast number of materials used in industry.

This fact can be explained using only the change in the energy states of the atoms that form a cluster of a certain size. The mechanism of the phenomenon can only be described by quantum mechanics and quantum (coherent) chemistry.

4) We show by the following example [3.15] the influence of atoms of one metal on the nature of the interaction between other metal atoms in a macroscopic sample.

Monocrystalline Zn rods 0.5 mm in diameter, coated with a Sn layer 2-5 μ thick, at 400 ° C burst under mechanical stress 8-10 times smaller than uncoated rods.

The nature of the rupture changed from plastic to brittle under a layer of Sn. The mechanical properties of Zn rods, coated by Pb, under the same conditions did not change, but the influence of the alloy 20%Sn+80%Pb was the same as that of pure tin. Diffusion of tin in zinc was practically nonexistent. The authors write: "An interesting result was obtained when a single zinc crystal, coated with a film of liquid tin, stood for a sufficiently long time without tension at 400° C and then a single crystal of zinc was put in liquid lead at the same temperature. Then, after a sufficient time in liquid lead the effect disappears completely and restores the normal strength of single crystals."

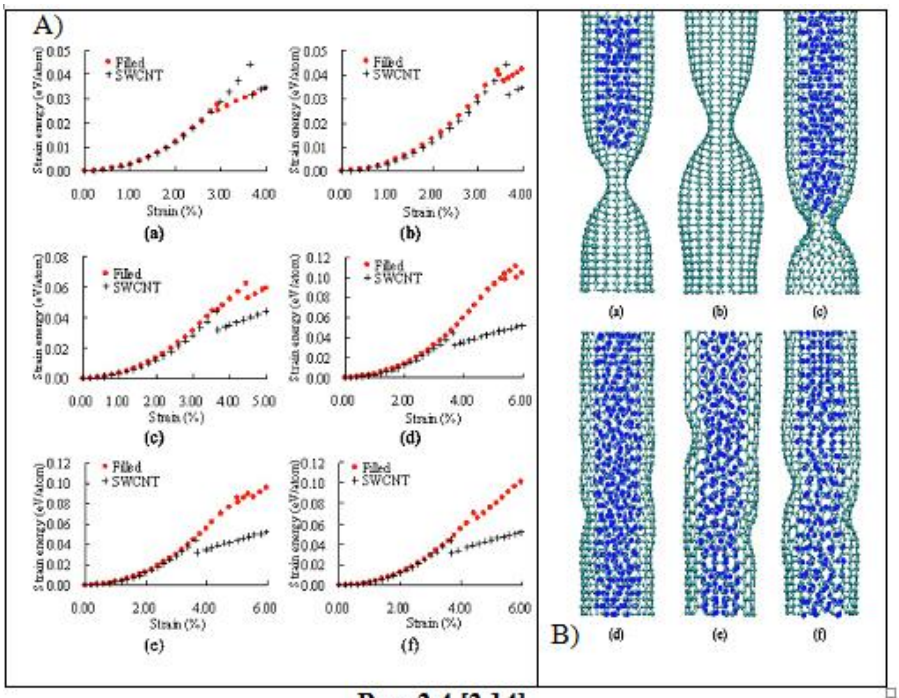


Рис. 3.4 [3.14]

Thus, reduction in strength of single crystals of zinc and the transition from ductile to brittle fracture is due to tin atoms which are in a different energy state, but not the surface quality. Mercury atoms produce the same response as tin atoms

Let us to pay special attention to the fact that there is a collective response of all zinc atoms on the energy state of the tin atoms, not only on the nearest neighboring atoms. Such a response is only possible thanks to the proliferation of strain waves representing an interconnected set of electromagnetic, acoustic, electronic and other types of waves.

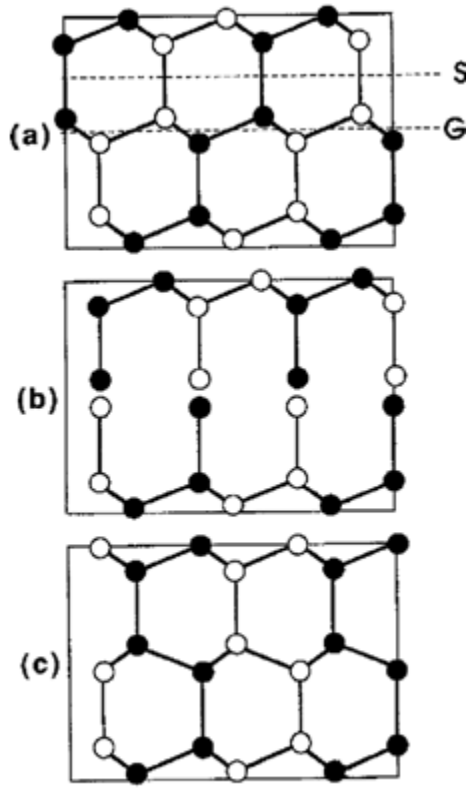


Рис. 3.5 [3.19]

A similar response occurs in a material susceptible to surface hardening. New properties of the hardened material are preserved for as long as the unchanged metastable state of the atoms remains, which arose during quenching.

3.3. Atoms on the surface of the crack

The analysis of experimental results presented above allows us to more deeply understand the mechanism of the processes that lead to the formation of cracks and destruction, and to give a more accurate description. The vast experimental material used in the dislocation model can be interpreted differently in the model proposed by this paper.

The work of G. E. Beltz and J.R. Rice [3.16] on the problem of the relationship between the formation of cracks and dislocations, as well as earlier works [3.17, 3.18], has caused great interest. Currently many papers are published on generalized stacking fault energy. Since these works are mainly theoretical, in this study we confine ourselves to only those results which help to understand the mechanism of cracking and fracture on the basis of changes of the interatomic interaction. The idea of the generalized stacking fault energy is introduced by means of a thought experiment. For this an incision in the crystal is made along a chosen crystallographic direction and one part moves relative to the other by a vector f parallel to the plane of the cutting plane. The cutting plane is called the γ-surface. The energy difference between the crystallite, both defective and not, is the energy matching the f-vector of the generalized stacking fault energy. This procedure is shown in Pic 3.5 [3.19] for two kinds of the section, designated G and S (a). The result is shown at Pictures (b) and (c). The properties of the γ-surfaces are the main subject of numerous studies. To describe them, a wonderful mathematical apparatus is designed which is based on the Frenkel-Kontorova models, barriers of Payrls, and the Payrls-Nabarro equation. But we shall not analyze these works, in which there are no major figures of the destruction process: photons, electrons, ions and phonons. We are not interested in the mathematical and physical properties of the

surface.

Experimental evidence suggests that the atoms forming the two surfaces are separated from each other as shown at Fig. 22 b, or shifted (c), and they differ from the previous ones.

It is important to note that this difference occurred before the formation of the gap, as a result of which there was a division. As long as it is a thought experiment, we imagine that Pic. 22 shows the crystal lattice of a monovalent metal, such as gold, and the atoms above the line G, (which we denote by γ1) with photons rejected by the electron, which were captured by atoms located below the line of G (denoted as γ_2). In this case, the atoms γ_1 form a defect, which is called a linear dislocation. Repulsive forces between the atoms γ_1 and free electrons are increasing, whereas those between atoms γ_2, which became neutral and free electrons, will weaken. Now atoms γ_1 and γ_2 can be removed from each other, as it shown at Fig. 3.5b.

Are there any experimental facts proving the possibility of such a process? Yes, there are. They are described in [1.6, 3.20]. We limit ourselves to one of them.

The surface of spalling luminesces. The afterglow duration is 10^{-3}-10^{-4} s. Note that the lifetime of the metastable state of an atom in a ruby laser has the same magnitude, although this may be a random coincidence.

In copper at spall two peaks are observed, whose energy coincides with the energy of self-diffusion of two isotopes (maybe that's a coincidence). The character of emission (intensity, duration, location, etc.) depends on the speed of impact of deformation of the metal, etc.

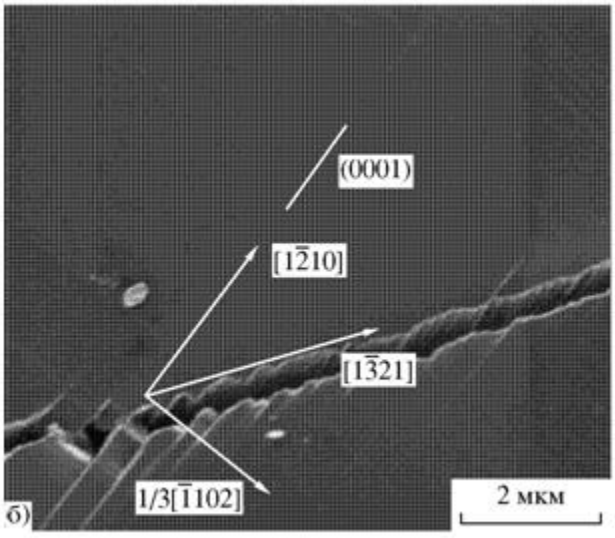


Рис. 3.6 [3.21]

Atomic properties are such that they absorb and emit photons of certain energy only. The band of absorption and emission of an atom in a solid is wider than that of the free atom. But in this case the radiation is similar to that observed in the nanoparticles formed by the explosion of thin wires. The local nature of the sites of radiation means that there is a localized nanomaterial in the bulk metal.

Fig. 3.6 shows a crack in a monocrystal Ti3Al [3.21].

The number of atoms forming a crack portion, and the degree of ionization, depends on the power absorbed by them, their energy state, and the presence of other defects. This leads to the fact

that the γ-surface under shear takes the form of a zigzag from one crystallographic direction, as shown at Pic 3.6. [3.21] So we have come to the conclusion that the formation of cracks in removing or shifting surface atoms γ_1 to surface γ_2 is preceded by a change in the energy states of the atoms that form these surfaces.

Let us now consider the mechanism of formation of the state of stress in compression. It is well known that under hydrostatic compression, fractures are formed and destruction does not occur. However, the phase transition occurs, both the melting temperature and electrical resistance change, and superconductivity appears. The brightness of luminescence of the previously compressed metal increases during spall fracture. Therefore, the electronic structure of atoms changes along with the interaction between them. These facts are confirmed so that no one is in doubt. It is also known that metal, pre-compressed, is torn at a stress lower than that which is not subject to compression (Bauschinger effect). In fracture mechanics this is explained by the appearance of dislocations caused by residual stress. It is meaningless to deny the existence of residual stress, because it is an experimental fact. At the same time, we know that with the converging of the atoms from their equilibrium position, the repulsive forces are increasing much faster than gravity. The question is: why does the removal of the external voltage at the repulsive forces not always return the atoms to the equilibrium position, and they remain in this new state with energy above the minimum potential energy, like a stone stranded on the side of the mountain? For electrons in an atom this energy level is called a metastable level. Consequently, on a graph of potential energy versus the distance between atoms, there are both the primary minimum and additional ones. The emergence of such minima is due to a change in the chemical bond, which was predicted by L. Pauling in the first edition of his book published in 1939. In the preface to the third edition Pauling wrote, “I agree with Poincare, it is better to predict, not being completely sure, then not to predict at all” [3.22]. Experimentally, this prediction was confirmed by Zewail more than 30 years later [3.23, 3.24].

Figure 3.7 shows graphs that characterize the transition from ionic to covalent compound NaI, and the abrupt change in the ionic bond to covalent bond after convergence of the atoms at a distance of less than 6.9 Å. The NaI bond length is 2.739 Å. According to Pauling, none of the links in its pure form are shown. In this regard, he introduced the idea of the ionic character of communication. For Nal it is 41% [3.25]. This assessment is confirmed by the depth of the potential well, corresponding to the minimum of potential energy.

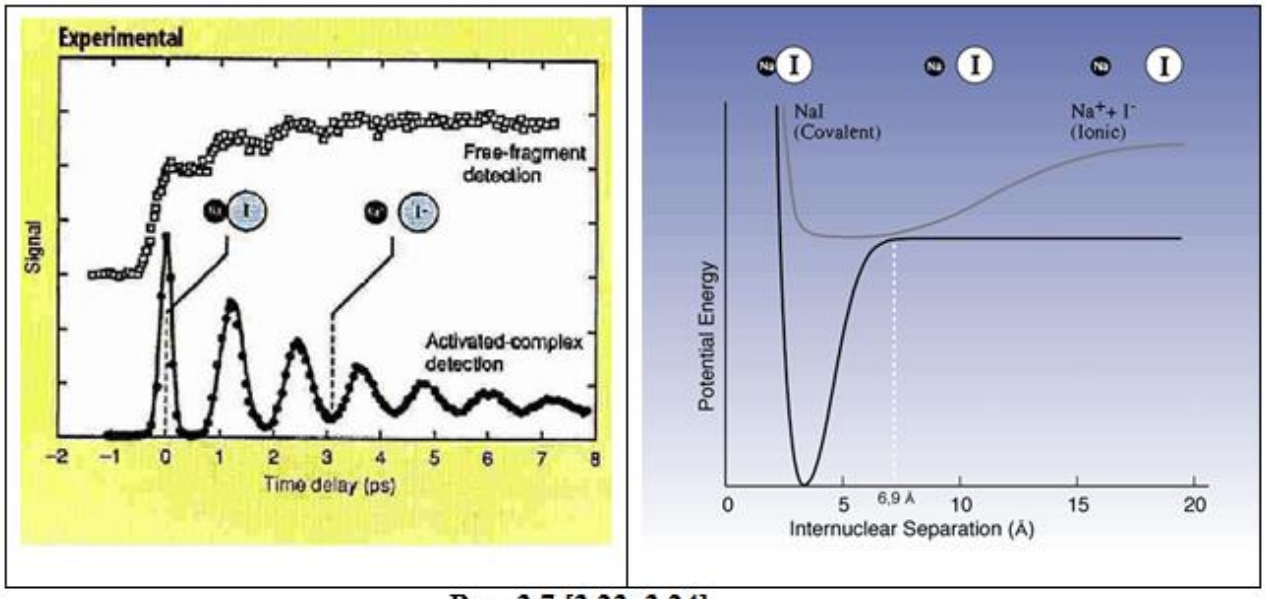


Рис. 3.7 [3.23, 3.24]

Thus, we see that the oscillation of the chemical bond occurs in the nanomaterial, which is due to the complexity of the processes taking place in the planes γ_1 and γ_2. An ion located in the plane γ_2, having absorbed an electron, emits a photon which in turn can be absorbed by other atoms. The smaller the size of nano areas, the more clearly its quantum properties are manifested, the narrower are the spectral lines of absorption and emission of energy. As a result, the atom absorbs only a photon whose energy corresponds to the transition of an electron from one level to another. If the energy of the photons emitted from the surface of γ_2 does not correspond to the transition of an electron in a certain atom, it is spent to increase the amplitude of vibration of the atoms, i.e., the photon-phonon interaction occurs.

Indeed, writing down all the formulas of physics from Newton's second law F=ma to the de Broglie formula $\lambda=h/mv$, including Einstein's formula $E=mc^2$, we will be convinced of their simplicity. The simplicity of Zhurkov's formula, a straight crack line occurring at impact, Einstein's confidence in the fact that the evolution of physics is the evolution of the ideas required to find the physical phenomenon which, figuratively speaking, is a control agent of all the processes of formation of the conditions for the emergence of the crack and its growth.

All the properties of a solid are due to the interaction of electrons and ions; as a link of this interaction are photons, the unique features of which are related to their frequency, amplitude, polarization, individual and collective action with the maximum possible speed in nature.

Let us illustrate this with examples of cracking under impact.

Figure 3.8 [3.26] shows six stages of crack formation. Let us pay attention to how little has changed in the form of figures characterizing the distribution of stresses in 100 microseconds. Note

that the chemical reaction time is 10^{10} times less.

The speed of the crack was 275 m/s. Over 100 microseconds, its length increased by 27.5 mm, i.e., on the macroscopic scale. This means that the sequence of atomic reactions leading to the cleavage of the bonds remained deterministic for a macroscopic interval. This phenomenon cannot be explained in fracture mechanics, since it is due to the lifetime of the metastable states of the atoms, but it is well known in optics. The nature and mechanism of phosphorescence is fully explained in quantum mechanics.

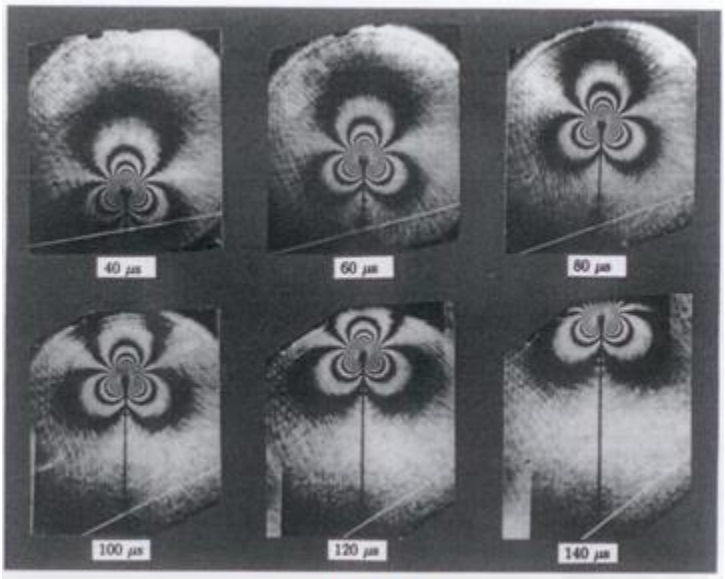


Рис. 3.8 [3.26]

Consequently, the transition from nano-to macrosizes did not affect the the decisive factor that controls all the processes.

The transfer of electrons to the metastable level is due to the absorption of energy. Today we know two types of luminescence, which is caused by mechanical influence: tribo luminescence and metal luminescence.

3.4. Impact fracture features

Shock destruction was and remains a relevant technical and scientific problem. It is considered in this study, as physical processes take place faster. As noted above, we assume that all the processes leading to the destruction of a solid body can be described on the basis of the electromagnetic interaction. Mechanical or thermal shock can be reduced, eventually, to electromagnetic shock. This will be shown below.

The physical processes leading to metal luminescence allow us to understand and more accurately describe the mechanism of crack formation and destruction.

This phenomenon has been investigated in detail by the author [1.6] on the example of scabbing. Fourteen points are highlighted, in which the features of luminescence were examined. Here we look at the most important ones.

1. The spalling surface emits light over a wide spectral range from infrared to ultraviolet. X-ray studies were not carried out.

2. Duration of the afterglow was 10^{-4}-10^{-3} seconds, which is 4-5 orders of magnitude longer than the lifetime of the excited state. The duration of luminescence is two orders of magnitude longer than the duration of the fracture process.

3. The radiation has a local character. The brightness of flashes increased by several orders of magnitude under increasing impact velocity of 1.5 times.

4. The brightness of flashes and their duration increased by 2-3 orders of magnitude during the second scabbing or preliminary deformation the samples. This means that some of the atoms remain in a metastable state which has accumulated energy. The lifetime of this state has not been investigated.

5. If a portion of the sample was removed to a depth of 0.5 mm after the first spalling, the brightness, and its character during the second spalling was the same as in the first.

These experimental facts suggest that the metals and alloys form local regions in which the atoms are in a metastable state with an energy greater than the minimum potential energy.

Luminescence of metals excited by laser pulses is of particular interest to understand the processes of cracking and fracture.

We confined ourselves to two studies [3.33, 3.34] in which an experimental study of the luminescence of metals by laser radiation was conducted. The objects of study were metal plates and film, as the radiation source used pulsed Nd: YAG laser with a pulse duration of 1.4 ms. Light luminescence was observed from the back side of the samples. Figure 3.9 [3.33] shows the oscillograms of the excitation signal (1) and luminescence signals (2). The film thickness was 2 micrometers for Cu, Ti, and Al, and 1 micrometer for Mo.

As we can see, the delay of the luminescence signal reached 15-16 ms=1.5÷1.6)$\cdot 10^{-2}$ s. This means that the number of metastable levels is greater than one in the atoms of each of the investigated elements, whereas the lifetime of the excited state of the luminescence is about 10^{-8} s.

It is dangerous to draw serious conclusions on the basis of four exsamples, but it can be assumed that the number of metastable levels is associated with a maximum valence of the atom. Particularly indicative in this regard is aluminum.

Figure 3.10 shows the structure formed on the silicon surface under pulsed light exposure. A.F. Banishev interprets the mechanism of formation of these structures from the perspective of the dislocation model. The main conclusion drawn in [3.33] is shown below. It coincides with the conclusion made by the applicant [3.34].

“Non-thermal luminescence (mechanoluminescence) of brittle refractory metals tungsten and molybdenum is excited by pulsed laser thermal deformation. Features of the structure of these

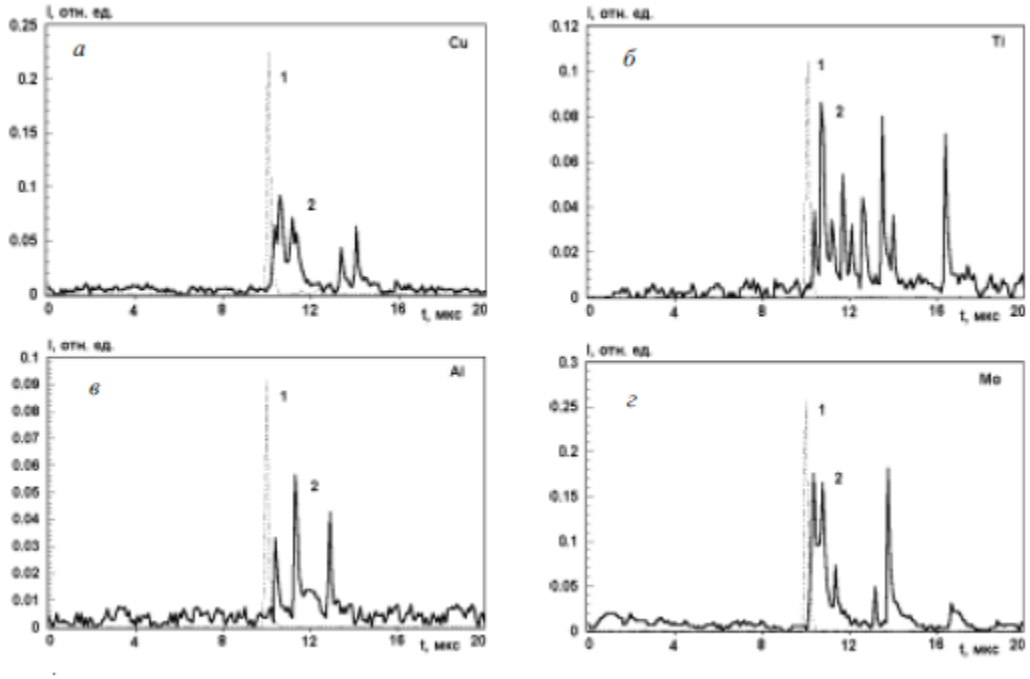


Рис. 3.9 [3.35]

materials: the small size of dislocation cells (sub-grains), the absence of dislocations within the cells and developed structure of the boundaries of sub-grains, suggest that the deformation of these materials to a large extent due to the intergranular slip. The glow is caused by activation reactions grain boundary dislocations with each other and with impurity atoms. It is shown that there is a tendency to increase the thresholds by reducing thermal stresses sample thickness."

Quantum theory fully explains all the phenomena of spontaneous and stimulated emission of light. It is senseless to speak about the "activation reactions of grain boundary dislocations with each other and with impurity atoms" using the laser for excitation of stimulated emission of atoms.

Quantum theory fully explains all the phenomena of spontaneous and stimulated emission of light. It is senseless to speak about the "activation reactions of grain boundary dislocations with each other and with impurity atoms" using the laser for excitation of stimulated emission of atoms.

The Nd^{3+} ion is an impurity atom in a matrix of yttrium aluminum garnet. The laser radiation is due to the transition of an electron in an ion from the metastable level to normal. Oscillograms shown in Figure 3.9 indicate that the luminescence of metals is also due to the transition of electrons from the metastable levels.

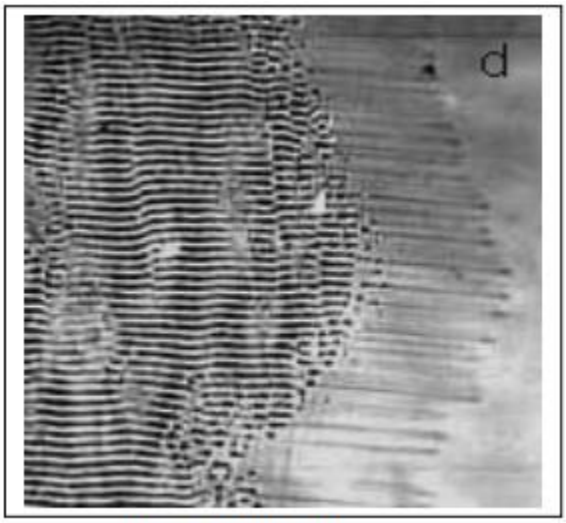


Рис. 3.10 [3.34]

The photo shown in Figure 3.10 is obtained using an optical microscope with a magnification M=250. Banishev writes that it is a "grating whose period ($d\approx3\div3.5\mu$) does not depend on the wavelength of the laser radiation. It was formed by the merging of local melting wells."

In his opinion the mechanism of formation of such a structure is due to the formation of dislocations: "It is shown that at the intersection of dislocation lines under $8.5\leq E_л<35$ J/cm^2 begins the local melting of the surface and the formation of an ordered cellular structure. The increase in the density of the cells and their merging leads to the formation of periodic structures (arrays) of nonuniform melting of the surface with a constant period $d_1\approx3\div3.5\mu$ and orientation determined by the relative orientation of the vector E of the laser radiation and the crystallographic axes of silicon.

A further increase in $E_л>$ 35 J/cm^2 leads to the formation of the lattice period and whose orientation is determined by the parameters of the laser radiation (И-lattice). As a result, on the surface there is a *superposition of gratings both dependent and independent of the laser wavelength period*. For large E, the И-grids dominate." (Emphasis added).

The above quotes show the difficulties that have arisen for the author of [3.34], who tried to interpret the experimental results, but still from the position of the dislocation model. We will try to get out of this maze.

First, the phrase "crossing the dislocation lines" is devoid of physical meaning, as in this case there is the response of a group of atoms that has undergone polarized monochromatic electromagnetic interference. The energy absorbed by an atom is due to the electric field $E\perp X$.

Secondly, the phrase "the superposition of gratings" also lacks physical meaning. There is a physical meaning for the superposition of waves, which leads to interference. The interference of waves caused the periodic structure which is observed in Figure 3.10, which is characteristic of the multiple reflection of light from the boundaries of thin films with highly monochromatic beams.

In this regard, we slightly modify the description of the observed phenomena.

It is shown that in areas of maximum interference at $8.5 \leq E_л < 35$ J/cm^2, local melting of the surface and the formation of ordered cellular structure begin. The cell density increases and duration of exposure is due to the merger or increasing of the laser pulse power $E_л > 35$ J/cm^2. This leads to the formation of the periodic structure of the surface at a constant period and the orientation due to the wavelength, the relative orientation of the vector E of the laser radiation, and the crystallographic axes of the silicon, as well as the geometrical and physical parameters of the material.

3.4.2 Electromagnetic punching of a solid

Figure 3.11 shows a pulsing mode, by which a stainless steel plate was punched: a) with power density $I=2.5\cdot10^5$ W/cm^2, b) with power density $I=4\cdot10^5$ W/cm^2. Curve 1 shows the laser pulse, curve the intensity of the laser radiation at the time of plate punching [3.34].

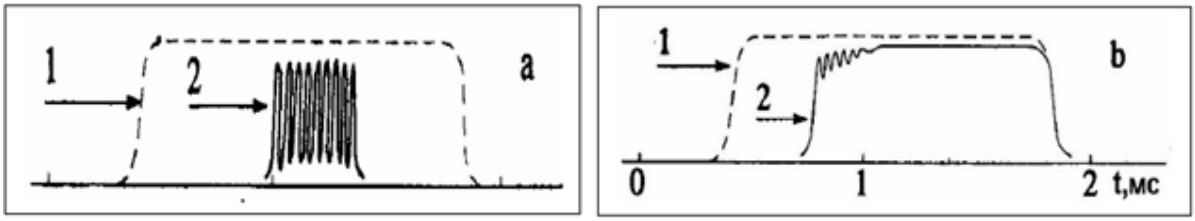


Рис. 3.11 [3.34]

Unfortunately, the observed phenomenon is not discussed either in this work or in other work known to me. The difference in the nature of punching at differing power levels is so significant that explanation is needed.

Of course, the laser beam passes completely through the hole after it is punctured. Pulsations of intensity are observed when the thickness of the material changes so that its value becomes comparable with the wavelength of the laser. In this case the observed oscillations under light transmittance and reflection are typical of interference. The evaporation of metal at $I=2.5\cdot10^5$ W/cm^2 is slower than when $I=4\cdot10^5$ W/cm^2. This led to the fact that the oscillations in the case of b were transient in low light absorption.

The superposition of waves is always present, but the spatial and temporal distribution of maxima and minima is conditioned by an interval in which the phase difference of the waves remains unchanged. The laser beam is coherent, monochromatic and polarized, which creates favorable conditions for observing this phenomenon. It is known that the distance between the peaks at MPI depends on the plate thickness and wavelength.

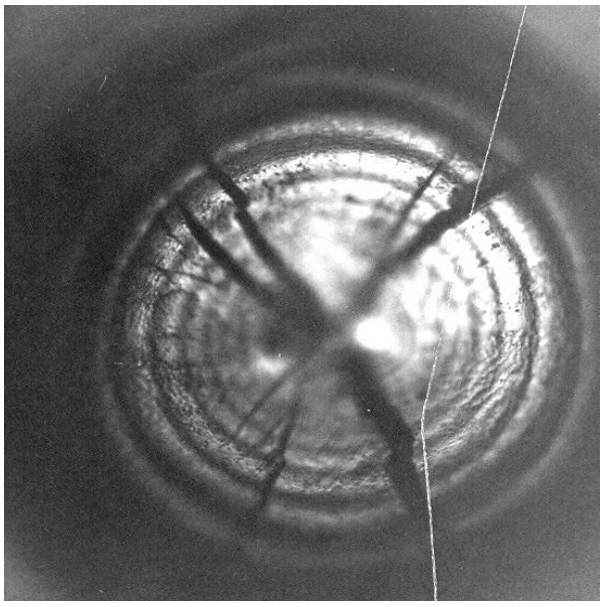
A.F. Banishev writes of just this, commenting on figure 3.12 b: “It is established that, along with

large-scale structures, small-scale periodic structures form on the channel walls. They have a period of d ~ 1-3 microns (the period varying with depth) and an orientation tangential to the channel walls. Such structures are likely to *make a significant contribution to the absorption of laser radiation*. Small-scale structures and the nature of the interference for "flat" geometry are well studied. " (Emphasis mine).

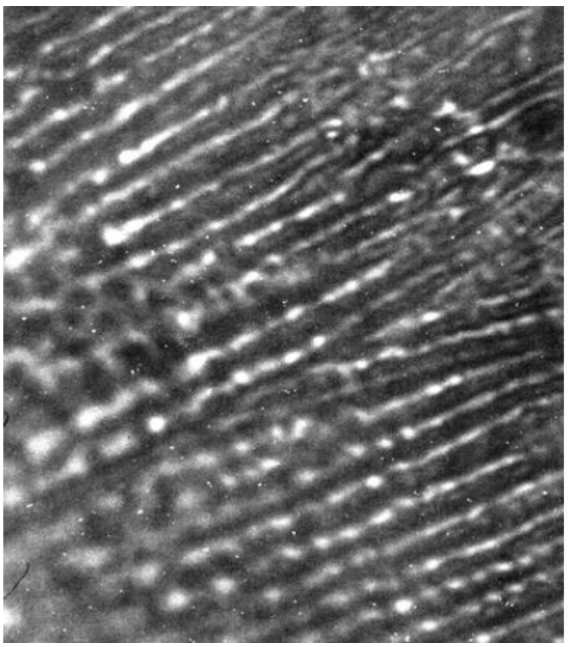
Note that the observed phenomenon is responsible for all the signs of wave interference, in which energy absorbed by the metal in the intensity maximums is significantly greater than the energy absorbed in the minimums. Exactly this leads to the formation of ordered structures.

All conditions, including the seemingly anomalous, can be explained by quantum optics. Such a task is the subject of a separate study. We limit ourselves to three remarks.

The anomalous scattering of light due to the influence of laser radiation is of interest, but the



a



b

3.12.

proposed mechanism based on the dislocation model invites serious objection also.

First, silicon is a semiconductor, the band gap of which E_g =1.12 eV. Photons emitted from a He-Ne laser (λ=632.8 nm) have energy (1.96 eV) greater than the band gap. These photons are intensively absorbed by the crystal, especially when the crystal contains impurities.

Secondly, the impact of photons emitted by a neodymium laser not only leads to a change in geometry of the surface, but to the redistribution of defects also, including impurity concentrations, which is caused by heating.

Thirdly, the use of an etchant leading to surface texturing, wherein reflectance is reduced and the absorption increases. As is known, this method is used to enhance the efficiency of silicon solar receivers.

The spectra of the diffuse reflection of light by crystalline semiconductor materials have been investigated by the author [3.37, 3.38] for the determination of the band gap. It was shown that the diffuse reflection of light is reduced sharply in intense absorption by a single crystal.

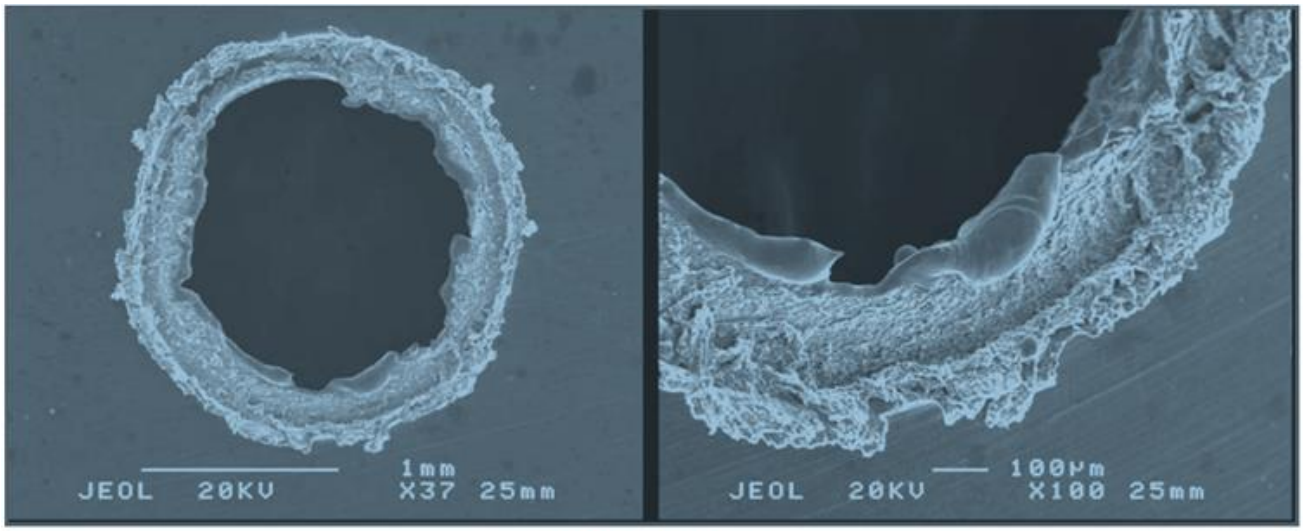


Figure 3.14 [3.39]

Here is another quote from [3.35, p.86]: "We have already noted that the increase in the scattering of the silicon surface in vacuum begins to occur only with multiple *laser pulses, when the size of the dislocations is comparable to the wavelength of the probe laser.*" (Italics mine)

Since the silicon lattice constant, a=0.54307 nm, the nanoobject covers 632.8:0.54307 ≈1,165 cells in the crystal, in which the absorption of photons, accumulation of energy, and radiation occur. With all the variety of properties that are attributed to dislocation, to explain the processes in such nano-objects is only possible on the basis of quantum optics.

Figure 3.14 shows scanning electron microscope photographs of holes punched by laser pulse in aluminum plate having a thickness of 200 microns [3.39].

The power density of the pulse (3 ns) laser is I=2.6 TW/cm^2. The deformation rate reaches $10^7 \div 10^8$ s^{-1}. The authors have placed thick gel over the back of the sample at a distance of 2 cm to trap breakaway fragments. It is possible to determine the velocity of the fragments and their size.

The size of some of the fragments reached 1 millimeter, their speed was 3500 m/s. The distribution of the fragments in the gel is shown in Figure 3.15. Some of the fragments had a spherical shape, the shape of the others was irregular. It is noted that the fracture behavior of tin and aluminum differ significantly.

Note that an attempt to describe the mechanism of failure of tin with a mechanical model was made in [3.40], published two years before this article. However, in this paper, this model is not used and the authors of the article end with the phrase, “Further work is needed to better understand the evolution of the process from the macro to the micro-cracking of the various structural metals”

Published by a large group of authors, [3.41] notes the importance of the study of space-time changes in materials subject to impact. Indeed, modern experimental techniques allow exploration of physical processes in a wide time range, down to femtoseconds and the spatial scale of an angstrom.

The article's abstract ends with the phrase: “In this article, we describe some of our studies which exploit existing and new generation ultrabright, ultrafast X-ray sources and large scale molecular dynamics simulations to investigate the real-time physical phenomena that control the dynamic response of shocked materials.”

The authors analyze the response of the unit cell to an external influence, modeled on the example of its individual atoms, but do not mention anywhere that the interaction between them can be explained only on the basis of quantum mechanics.

“Further work is needed to better understand the evolution of this process from spalling to microspalling in a variety of structural metals.”

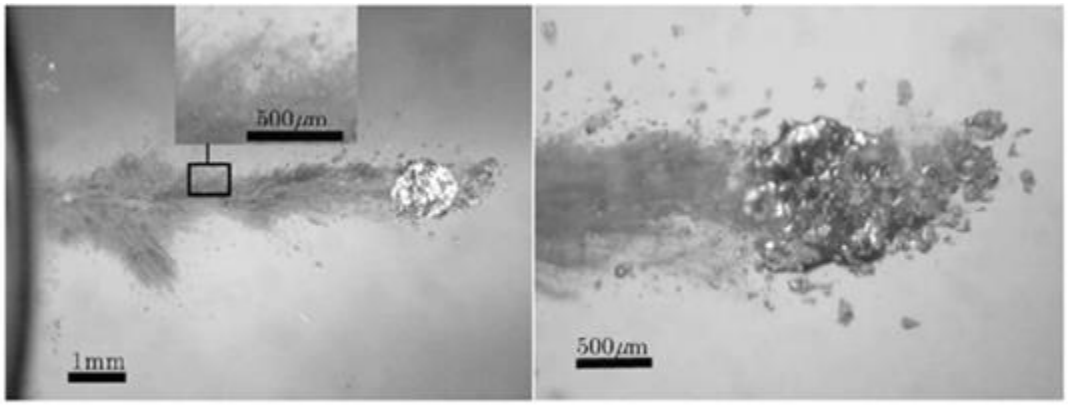


Figure 3.15 [3.39]

The experimental results obtained in [3.40] help to better understand the mechanism of destruction through nuclear reactions induced by photons. As we have seen (Figure 3.14), the shape of the edge of the hole is different in different places: the melt and destruction alternate. This indicates that the pulse energy is unevenly distributed. As a result, the structure was modified such that in some places the binding forces between the atoms was reduced and the metal melted, whereas in other places the binding force increased. Small fragments were separated completely, just as happens in the explosion of thin wires or mechanical shock.

We call attention to the chute in the form of a perfect circle, in which there is no melting or

cracking. The surface of the chute and its depth of are evidence of evaporation of material towards the incident photons. Fragments found in the gel were coming off from both the liquid phase and the solid. All this testifies to the complex, but law-governed process of energy distribution in the contact beam and metal.

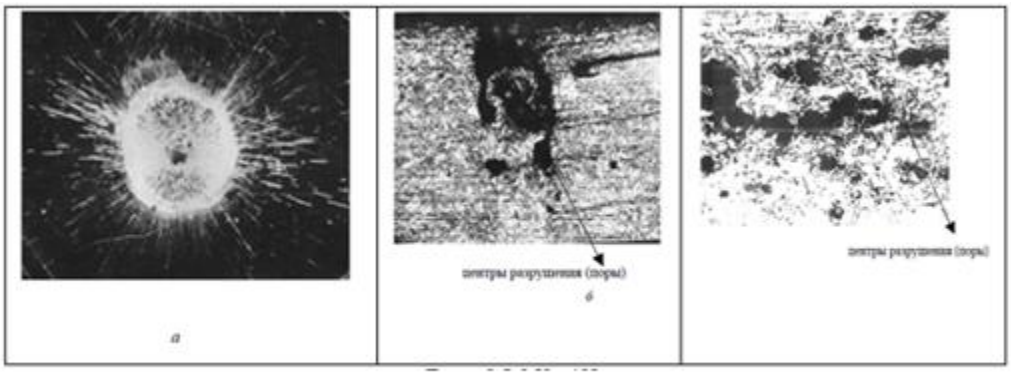


Figure 3.16 [3.42]

Unfortunately, there is no data in the work on the structure of the fragments and the solidified metal. Features of dynamic fracture of metals under the action of thermal shock caused by pulses of penetrating radiation and powerful laser pulses are discussed in [3.42, 3.43].

Two fragments, cited below, sufficiently characterize the basic ideas that guide the authors of these works. 1. "... metals in the state of dynamic fracture show universal properties which are caused by *self-organization* and instabilities in *dissipative structures* (cascades of the centers of destruction) that underlie the body's resistance to external influence. " 2. "The reaction of metal to external physical-mechanical treatment is defined as its thermodynamic state and characteristics of the loading process. *Waves of compression and expansion* occur in the exposed environment: for example, a flat layer expands in both directions, which is equivalent to the wave propagation inside depression heated material." (Emphasis added).

Thus, the authors attempted to reduce the problem, an electromagnetic, electronic and ion impact to mechanical response, while it is well known that electromagnetic interference can not be explained in mechanics.

Of particular interest are cascading centers of destruction.

Samples of copper and their cross-sections after laser irradiation are shown in Figure 3.16 a, b. A thin section of the sample of copper after exposure to intense beams of relativistic electrons is shown in Figure 3.16 c. The centers of destruction are marked by an arrow.

The authors of [3.44] suggest that the pores are the sphere of influence of the centers of destruction and on this basis propose a model of cluster volumetric destruction which is shown in

Figure 3.17. The authors write, “We consider the problem of random nodes, which corresponds to the process of multiple fractures. Random nodes are points (in this case fracture points) randomly distributed in space.”

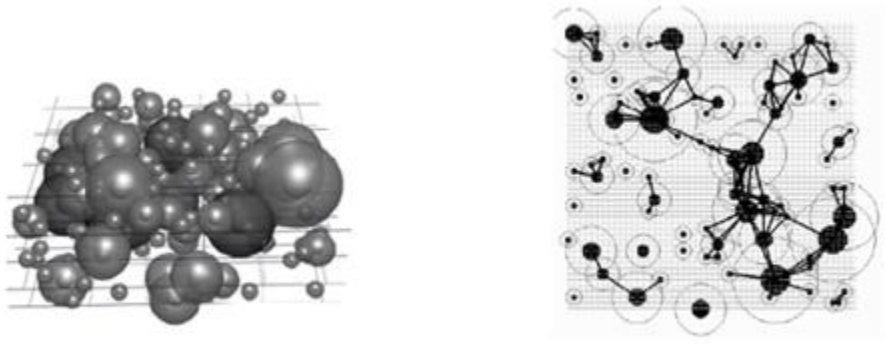


Figure 3.17 [3.44]

The proposed mechanism is untenable, since it is disproved experimentally, including objective laws, shown in Figure 3.14. Random processes lead to the spontaneous emission of energy, in which the power is not enough to break.

The problem of spall fracture caused by X-rays of a nuclear explosion is addressed in [3.45]. A.M. Molitvin considers such effects as thermal shock due to the rapid supply of energy, in which the material does not have time to expand. He writes, “The critical specific fracture energy increases with the increase in time of the tensile stresses. The necessity of taking into account the geometrical factor that can reduce the damage threshold and increase the degree of destruction of the object subjected to thermal shock has been shown....

The material expands both in the direction of impact and against it for stress relief. At the closing of expansion waves tensile stresses occur which can cause spall fracture ... The results of the experimental data on the spall fracture of copper with heat shock, initiated by the X-ray radiation of a nuclear explosion, are shown in Figure 3.18. "(Emphasis added Fig. 3.18 shows the time dependence of the spall strength of copper on heat shock (I) and impact loading (II): 1, no visible damage, 2-birth spalling (the beginning of the visible damage), 3-spalling or complete destruction.

1. Pictures like that shown in Figure 3.13a are repeatedly observed during mechanical deformation. As with mechanical and electromagnetic effects, they are similar to the conoscopic figures that appear in a deformed body as a result of the interference of polarized rays.

Of course, there are certain features of the energy distribution associated with the behavior of free electrons in metals. In this regard, the light interference pattern in the deformed metal may differ from the interference of light in a dielectric.

2. The results of experimental studies of silicon surface destruction under the influence of electromagnetic radiation, published in [3.33-3.36], are of great interest, but the interpretation in terms of a dislocation model invites serious objection.

Dislocation, as previously noted, is a defect in the crystal structure formed of atoms, the energy state of which is different from the energy states of the neighboring atoms. Photons emitted by neodymium atoms interact with atoms of the sample irrespective of whether they are included in the defect or not. This interaction may be a photon-electron or photon-phonon.

All the processes in which a photon can be absorbed by the atom, or scattered, occur in strict accordance with the laws of conservation. Destruction, as is well known, is jumplike in nature. For this a certain energy must accumulate. This means that in some of the sample atoms, photons are absorbed, and there is a change in the energy state, just as happened previously with neodymium atoms, absorbing photons emitted by the pumped lamp.

If the excited atom emits a photon (luminescence) or phonon (thermal radiation), this atom, figuratively speaking, is not involved in the destruction, no matter in which of the defects that happens. Just as the destruction requires a certain energy, the conclusion: "The competition of growth and relaxation of dislocation ultimately determines the destruction of the surface", made in the work, is at least not correct. In fact, the destruction is predetermined by a competition of accumulation and dissipation of energy. Let us make a few comments related to the peculiarities of heat stroke caused by nuclear radiation. First, the energy of the photons emitted by nuclear fission is many times greater than the energy of X-rays when the electron goes to the lower energy levels of the atom. In this regard, an X-ray photon interacts not only with atoms on the surface, but in the interior of the sample, causing ionization of the atoms and the displacement from the crystal lattice node or an increase in the amplitude of vibration of the atom.

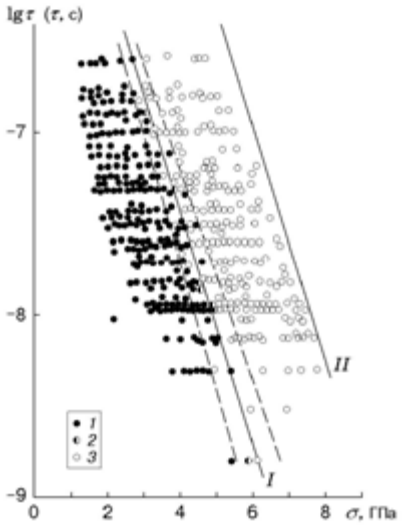


Figure 3.18 [3.45]

Secondly, the impact caused by X-rays differs substantially from the thermal shock caused by a temperature gradient. Temperature gradients arise when X-ray irradiation is practically throughout the region in which photons penetrate. As is known, the energy of thermal fluctuations at 300 K is 0.013 eV, the fifth ionization potential of Cu is equal to 82.7 eV. Such a photon absorbed by an atom, figuratively speaking, increases the temperature of the atom by 1.9 million kelvins. This happens in $10^{-9} \div 10^{-12}$ seconds. Expansion of the metal during this time will not happen, but the transfer of electrons to that level from higher levels is possible.

This leads to emission of photons throughout the material. Thus, the failure mechanism proposed by

Molitvin is untenable. It is refuted by the experimental results presented in [3.29-3.26]. Furthermore, hundreds experimental data shown in Figure 3.18 also refute it, since the same $\lg \tau$ value corresponds to different values of σ.

Statistical characteristics of multiple fractures of metallic targets under dynamic loading at a speed of 100-650 m/s, and their relationship with the mechanical parameters of the materials, were investigated in [3.46]. The main conclusion is formulated as follows: "The process of damage accumulation in a dynamic spall is generally not a self-modelling3 process that may be associated with simultaneous initiation of a large number of centers of defect origination." (Emphasis added).

Common to these two works, like many others, is that the processes caused by a mechanical shock and electromagnetic pulse are considered without any regard to the interaction of waves and atoms. If the study of processes in solids caused by mechanical shock, for this approach to the problem can only regret that the electromagnetic radiation, especially caused by a nuclear explosion is impossible to make serious conclusions.

3.4.3. The electromagnetic interaction of photons and atoms

We consider the interaction of photons and atoms in an alloy.

It is well known that all calculations in mechanics are performed using the laws of conservation of energy, momentum, angular momentum, and charge. The photon, like any other particle, has not only the energy εp, but the momentum ε_p/c, where c is the speed of light. An atom can absorb or scatter a photon in collisions with it.

Above the surface of a metal there is an electron cloud caused by the emission of electrons from the metal. Metal, emitting electrons, is positively charged. Thus, the metal and the cloud of electrons form a charged capacitor; the distance between the electrodes is 10÷20 Å. The electric field strength in this region reaches $10^6 \div 10^8$ V/m ≈ 10^{-3} V/Å. This phenomenon is used in vacuum photocells.

The interaction of photons with metal leads to a number of effects, which is not limited by heating and thermal shock. High light intensity leads to a nonlinear response of the material in which the properties are changing and multiple atoms absorb photons, which is equivalent to an increase in frequency. First of all photons start to interact with the electron cloud changing electric field over metal. These changes occur in ~ 10^{-18} s.

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3 By self-modelled means a process in which the distribution of defects in size at different times is obtained one from the other by a similar transformation.

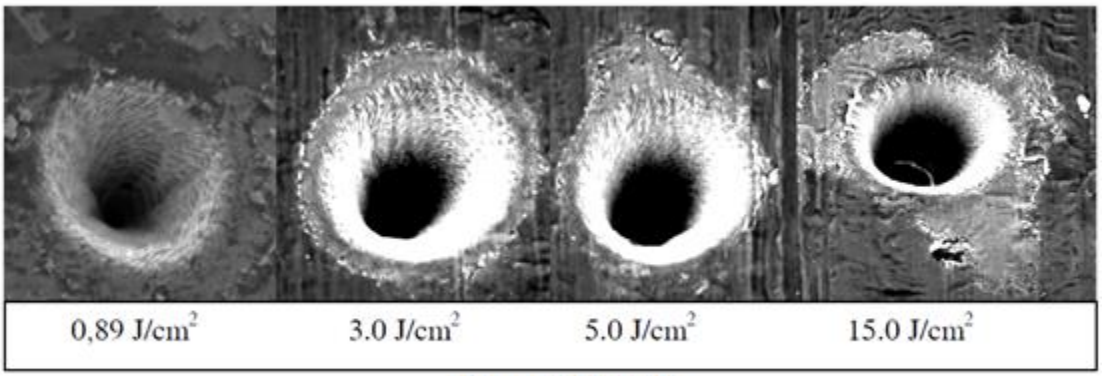

Figure 3.19 [3.47]

The bias current density depends on the electric field rate $j_b = \frac{dE}{dt}$. As is known, the thermal effect of the bias currents is equal to zero, but they create a magnetic field, which compresses the stream of ions, or electrons. The photons, colliding with electrons of the cloud, pass them energy and momentum, bringing the electrons closer to the surface. Photons that reach the surface, are not only heated, but also pull out electrons from the metal, especially effectively when the photon energy is higher than the electron work function.

The positive potential of the surface increases due to the photoelectric effect. This leads to the fact that between the exposed and unexposed areas of the target, a potential difference occurs and an electric current is caused by the movement of electrons, as the depth of the sample to the exposed surface and along it.

Let us pay special attention to the fact that all these processes are set at the rate of electromagnetic waves. Heat shock occurs as a result of two processes: the current pulse and the recombination of electrons and ions. An area in which the recombination occurs is the most powerful source of energy, which is sufficient for destruction. However, under high-intensity irradiation, which is achieved in a femtosecond laser, the nonlinear effects are so significant that the number of photons absorbed by the atom simultaneously varies.

The total energy absorbed by the atom can reach such a magnitude that the excitation of atoms is associated with the transition of electrons from deep levels located below the valence levels.

Recombination of these ions is accompanied X-rays. Electromagnetic waves reflected from the lower and upper boundaries of the sample interfere to form standing waves in the antinodes with intense

radiation of energy.

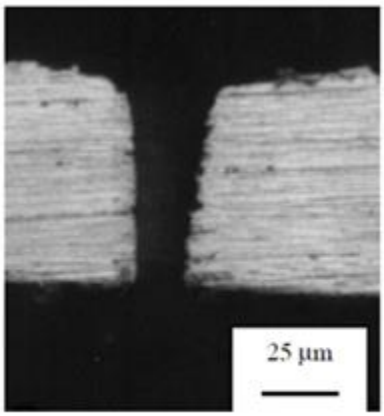

Figure 3.20 [3.47]

An important role is played by the resonant interaction of photons and plasmons. All this leads to the fact that intensive ablation occurs in which the metal does not crack. The distance between the maxima of the standing waves decreases with metal evaporation The characteristic feature of the interaction of photons with atoms of the material is easy to trace in a comparative analysis of photos shown in Figures 3.12, 3.14, 3.16, 3.18.

Figure 3.19 shows holes punched in stainless steel plate with thickness of 50 microns, in vacuum, using pulse radiation from a femtosecond laser. The number of pulses is 2000, the beam diameter is 12 microns. Increased output leads not only to increased diameter of the holes, but also to a change in the structure of the metal around it.

Unfortunately, such studies were probably not carried through, since the aim of the work was to demonstrate the possibilities of the method. We can judge them by the color and shape of the material around the openings, the form of which is shown in Figure 3.20 for the energy density of 15 J/cm2.

Two areas, including intact metal having a different structure, are visible at the energy density 0.89 J/cm2. Increasing energy density to 3 J/cm^2 leads to another almost symmetrical zone. The symmetry of these zones is broken at a 5 J/cm^2 "breakthrough" in one direction, but at 15 J/cm^2 disorders are particularly significant. The actual structure of the material around the holes can only be determined experimentally. We can only guess at how they are formed.

The pulse duration was less than 120 fs=1.2×10^{-13}s, the diameter of the crater was 4÷15 μm, the speed of the acoustic waves 6 10^3 m/s. During the pulse time, acoustic waves propagate a distance of 6 $10^3\cdot1.2\cdot10^{-13}$ =$7.2\cdot10^{-10}$ (m). This means that acoustic waves have time to communicate only with the atoms situated in the two unit cells, whereas photons pass a distance equal to $3\cdot10^8\times1.2\cdot10^{-13}$ =3.6 10^{-5} (m).

Laser wavelength is 760 ÷ 820 nm. The energy of the photons (1.5 ÷ 1.6 eV) is not sufficient to break the bond or excite luminescence in the alloy, but doubling of the frequency leads to sufficient energy density.

The authors note that in all cases, except for F <0.4J/cm^2, the holes have a symmetrical shape and the walls of the holes are free from debris. Around each hole there is a layer of melt. Ablation, like a fountain, is observed at an energy density greater than 20 J/cm^2.

As we can see, the nature of the interaction of photons with atoms of a semiconductor is different from the interaction with metal. There is no doubt that one of the reasons for this difference is the presence the free electrons in metals.

The experimental results lead to the conclusion that photons played a particularly important role in the processes that lead to destruction.

3.4.3. Electromagnetic interaction of atoms at mechanical shock

The mechanism of destruction due to mechanical shock is of great scientific and practical interest for material scientists and astrophysicists. A large number of papers have been devoted to this problem, but we restrict ourselves to only two, using them as an introduction to this section.

In [3.48], devoted to the problem the collision of celestial bodies, an experimental study about a projectile hitting a target has been carried out. The projectiles used were lead bullets weighing 4.1 grams and aluminum balls weighing 0.65 g, accelerated to a speed of 1000 m/s, and iron and aluminum balls weighing 1.06 and 0.04 g, respectively, accelerated to a speed of 1700-6500 m/s. As a target, blocks weighing 23-30 kg of Pb, Al, Fe, steel and basalt were used. The studies were conducted at a pressure of 5 mm of mercury column.

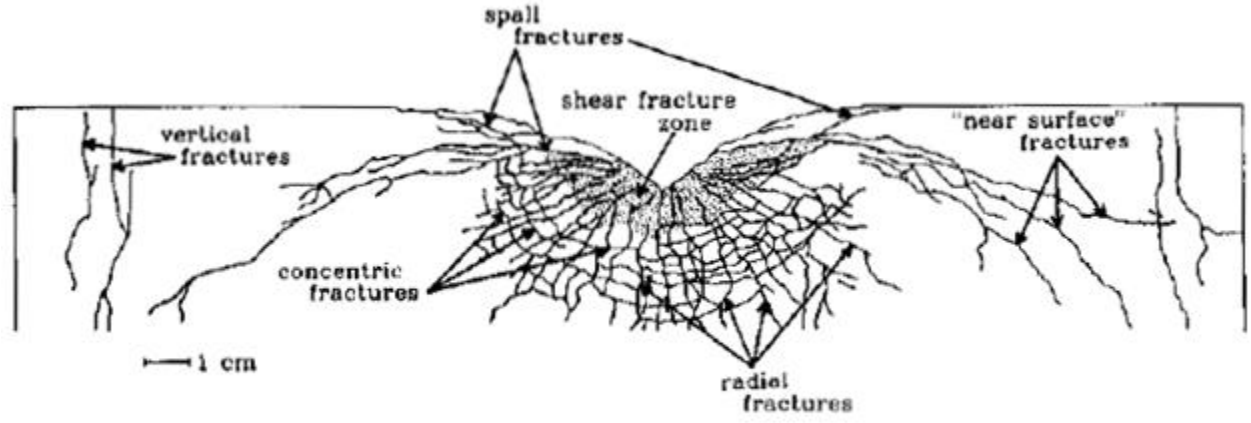

Figure 3.22 [3.48]

It was found that debris flew mainly in the opposite direction at a speed of impact of 0.5 to 27.4 m / s. Size and mass of the fragments were measured, and the volume of the crater. The total mass of the fragments ranged from 39 to 67 percent of the total mass lost by the target In all 22 experiments at the crater two zones have been observed. The central area was strongly damaged and contained only the crushed fragments, while surrounding this broad but shallow zone is a relatively fresh surface, which the authors consider as cleavage. The number of cracks extending deep into the material increases with increasing velocity of the projectile as shown in Figure 3.22. The authors note that the mechanism of

this phenomenon is not clear, but the mechanism proposed by other researchers is confirmed only at low impact velocities. Naturally, the question arises: where has almost 50% of the mass of the crater disappeared to?

Minimum mass of the crater was 1.4 g, the maximum -103 g, the minimum kinetic energy of impact was 138 joules, the maximum-22500 joules. A second question arises: why does this impact energy cause such severe damage?

Metal destruction as a result of a body colliding at a high speed is considered in [3.49]. The authors proposed an original mechanism of metal and meteorite destruction. Since the authors are members of well-known universities in the world (Moscow State Technical University named N. Bauman, and the University of California at Berkeley), it was necessary to comment on this mechanism. We restrict ourselves to a single quote to understand the original idea: "The action of mechanical force on the free electrons has been noticed for a long time. Most known is the experience of Tolman and Stewart (R.C Tolman and, T.D. Stewart., 1916) wherein a coil of copper wire has been untwisted like a spinning top, to a linear speed of 19÷56.4 m/s, then braked with a negative acceleration 39.6÷282 m/s2. It has appeared enough that the free electrons flying by inertia overshoot the braced ions ejected from the copper to an external circuit and are recorded as a galvanometer pulse of electric current. The current, however, was so weak that it did not cause any changes in the metal. Speed and acceleration of meteorites and shells are much higher, so when braking, there is a new phenomenon".(Italics supplied)

In this small fragment are at least three egregious errors. 1) Tolman and Stewart's experiment was performed in a closed loop conductor. This means that the number of electrons leaving the coil equals the number of electrons which have entered into it. 2) The drift velocity of electrons in the metal is millimeters per second, which is extremely small compared to the speed of random motion, but when braking in the coil occurred a potential difference was created, which resulted in the external circuit current recorded by the galvanometer. 3) The key to this phenomenon, known from any high school physics course, is the fact that when the electric field in the coil changes, the magnetic field changes also, and this electromagnetic pulse raced at light speed along the wire and "made" all the conduction electrons move in one direction.

Thus, further analysis of this paper does not make sense Two studies [3.45] and [3.46] having different scientific value, are shown at the same time in order to show that the first one looks only at the consequences of impact on the target, while in the second, only in the projectile. However, we have seen that an aluminum ball with a mass 750,000 times smaller than the mass of the target can produce serious damage. This means that for a mechanical shock it is necessary to consider the processes

occurring in the target and the projectile. Similarly, in a meteorite collision with the Earth, we are interested not only in those processes taking place with the meteorite, but also with the earth, in spite of the mass ratio.

The mechanism of fracture of solids in a collision, including that of a meteorite with the Earth, can be examined only taking into account all of those features of the interatomic interactions which have been discussed above.

Features of the destruction caused by mechanical and electromagnetic shock discussed above allow us to offer an alternative mechanism of destruction of in collision of solids due to the electromagnetic interaction of atoms.

Offering such a mechanism, we will start from the fact that it does not conflict with the fundamental laws of physics, despite the fact that it may seem fantastic.

The proposed mechanism must explain how the accumulation of energy occurs, the radiation of which leads to an explosion of the meteorite, its destruction before the collision with the Earth; how and why the object is destroyed.

. Let us consider the physical processes occurring in the meteorite, moving in near-Earth space. For simplicity, we assume that the meteorite represents an iron cube with sides l and it is constantly facing one facet toward the Sun. The face irradiated by the Sun is positively charged due to the photoelectric effect and thermal emission.

The maximum potential difference between the irradiated and non-irradiated surfaces is due to the electron work function. Therefore, our task is reduced to the motion of the dipole. However, the position of the meteorite relative to the Sun changes, changing the dipole moment and the conduction current generation, the density of which is $j_c = \frac{\varphi}{\rho l}$.

The varying electric field results in a change in the magnetic field distribution in the surrounding electromagnetic waves. Conduction current density in the meteorite is $j_c = \frac{\varphi}{\rho l}$. The bias current density and frequency at slow elecric field changes will be small. Conduction current density depends on the energy absorbed by the meteorite, and the parameters of the metal, and it can be estimated. For iron, $\varphi = 4.31$ eV, ρ=9.8 10-8 Ohm·m, therefore, jc ≈ 4.4·103 A/cm2. This current density is reasonable for iron and will not lead to destruction.

But for us what is important on its own account is the fact of the phenomenon by which processes occur in inorganic material as in photosynthesis of plants. The existence of heterovalent ions of the same element in the metal are confirmed by numerous experiments. Cosmic bodies, devoid of

atmosphere, undergo intense radiation exposure to X-ray and gamma-rays, bombarded by hydrogen and helium ions, which increases the probability of formation of metastable highly ionized atoms, for example: ${}_{1}^{1}H^{+}$, ${}_{1}^{2}H^{+}$, ${}_{1}^{3}H^{+}$, ${}_{2}^{3}He^{2+}$, ${}_{2}^{3}He^{1+}$, ${}_{2}^{4}He^{2+}$ ${}_{2}^{4}He^{1+}$, Fe3+ or higher.

Note that hydrogen and helium ions penetrating the meteorite have high ionization potentials: 13.6 eV hydrogen, 24.5 and 54.4 eV helium.

. Meteorites reaching the Earth's atmosphere have a speed from 1.1 106 to 7.2·106 m/s. Braking of the meteorite leads to a significant change of the electromagnetic interaction in it. It is believed that the resulting friction heats the metal and it burns. Heating due to friction really does take place, but this energy is not enough to melt and vaporize the metal, especially in the top layers of the atmosphere.

. Meteorites of small size are burned before they reach the Earth's surface. Large meteorites do not have time to break down in the upper atmosphere and are braked in its denser layers especially strongly. This leads to the fact that the density of the electron cloud in the head part rapidly increases, as do the temperature gradients. The potential difference between the head and tail is increased, the current density between them rises, which leads not only to heat but also to further ionization within the meteorite.

The changing electric field is accompanied by a changing magnetic field and an increase in the density of the bias currents. Thus, the meteorite is transformed into an electromagnetic wave generator. The thermal effect of bias currents is zero, but the mangnetic field generated by them compresses the current channel, just as happens in magnetized plasma.

The meteorite deceleration at the final stage is due not only to the resistance of air, but to the interaction of the electric field, and possibly the magnetic field of the meteorite and the Earth also. In some cases, it is noted that the horizontal component of the meteorite velocity is reduced to zero.

A sharp decrease in the speed leads to the fact that the bias current density increases sharply at first, but then rapidly falls. The decrease in the magnetic field leads to the expansion of the channel conduction current, intense stimulated recombination of ions and electrons, electromagnetic radiation of such power that failure occurs.

. All this leads to high power energy radiation throughout the entire volume meteorite, then fracture into small fragments, until evaporation.

We applied a physical hypothesis for the ideal case. Clarification of the mechanism of the destruction of the meteorite, as well as any other hypothesis requires experimental verification. Important roles in such a study are played by the spectrum of the explosion, the content of hydrogen, deuterium, tritium, helium isotopes and other elements. A real meteorite or meteor is not a conductor, but it contains both

metals and carbon, which are good conductors of heat and current. Only experiment can determine the extent to which these inclusions will play the role of destruction channels.

The density of bias currents in mechanical shock in two bodies, whose speeds are considerably lower than those of astronomical bodies, sharply increases only at the interaction of the electron cloud of the projectile with a target electron cloud extending 10÷20 Å at their surface. Although the electromagnetic processes take place with the speed of light and the resulting photons repeatedly pass through the target and the projectile, heat shock does not take place and the bodies have time to get closer to a distance equal to the lattice constant.

Changes of electromagnetic fields in the projectile and target are different, since they are caused by braking (negative acceleration), which is absolute and independent of the mass.

A projectile, flying in the atmosphere at supersonic speed, begins to decelerate and radiate electromagnetic waves immediately after the start. The velocity of the projectile is not sufficient for the rapid oxidation and the maximum variation of the electromagnetic field starting from the moment of interaction between the electron cloud of the projectile with the electron cloud of the target.

As we have noted, the electric field in this region is 10-3 V/Å. Collision of the surfaces of the projectile and the target will occur in $\Delta t = L : v$ where L is the thickness of the electron layer between the two metals and v is is the speed of approach the projectile and the target.

The created system is similar to an electric circuit consisting of two conductors (projectile and target), a condenser (the gap between the projectile and target), the plates of which are charges of different quantity and dielectric connecting the backs of the projectile and target. The total current density in this circuit is $j = j_c + j_b$, wherein jc is the conduction current density, $j_b = \frac{\Delta E}{\Delta t}$ is the bias current density, and E is the electric field strength.

Let us estimate the bias current density for the projectile velocity 1.6 km/s=1.6·103 m/s and electron cloud thickness L=20 Å=2·10-9 m.

At the moment when the distance between the target and the projectile ions becomes equal to the lattice constant the electrons from the electron cloud and moving projectile pass into the target. It is experimentally determined [3.50], that under shock not only electrons but also ions, such as carbon and iron, are transferred from the projectile to the target.

Electron density at the surface of the target increases dramatically, which leads not only to the formation of a conduction current in the target, but also to the intense recombination in narrow channels, as shown in Figure 3.22. These channels are formed in areas in which the recombination

preceded additional ionization due to interference of electromagnetic waves.

Similar processes occur in the projectile and the only difference is that the conduction current is reversed. The photons emitted by the recombination not only heat the metal, but ionize new atoms. All of these processes occur during sudden changes in the magnetic field within nano-or pico-seconds due to the high speed of photons.

The magnetic field is so large that the flow of conduction electrons is compressed to such an extent that a plasma filament with high conductivity forms in a narrow channel4. The calculated value of the conduction current density is comparable to the current density at which there is electric explosion of thin wires and plates. In this connection, destruction in the target is such that the projectile "burns" the target.

The main difficulty of the other models is the fact that the energy required to break may be greater than the kinetic energy of the projectile. The authors of this model realize that such a mechanism is not possible and offer options that are refuted by experiment.

The mechanism proposed above does not have this disadvantage. Of course, that energy is not "drawn out of the blue." It is stored in the atoms that emit it. The existence of metal atoms or clusters that have different ionization degree, have been confirmed by numerous experiments. Consequently, during the recombination stimulated by photons, especially when the metal is evaporated, the degree of ionization can be below that in the solid body.

The energy radiated by recombination may be commensurate with the kinetic energy of the projectile, but the pulse is so small that the power of the recombination radiation can exceed the absorption capacity of the kinetic energy. The shortening of the pulse leads to the fact that the number of atoms absorbing it decreases, and the structure of particulate material sprayed during the explosion, differs from the structure of metal, as the energy of the atoms in the nanoparticle was below what they had in the bulk sample (see Fig. 2.19).

As shown above, the laser radiation generated forms areas in the target, the destruction of which is

4 Such a conclusion may seem fantastic, but there is a possibility of the formation of Cooper pairs in such a plasma, as in this case violated the laws of conservation and the condition that the magnetic field produced by the current in the superconducting channel, just enough to maintain the current that creates it (see [3.51]).

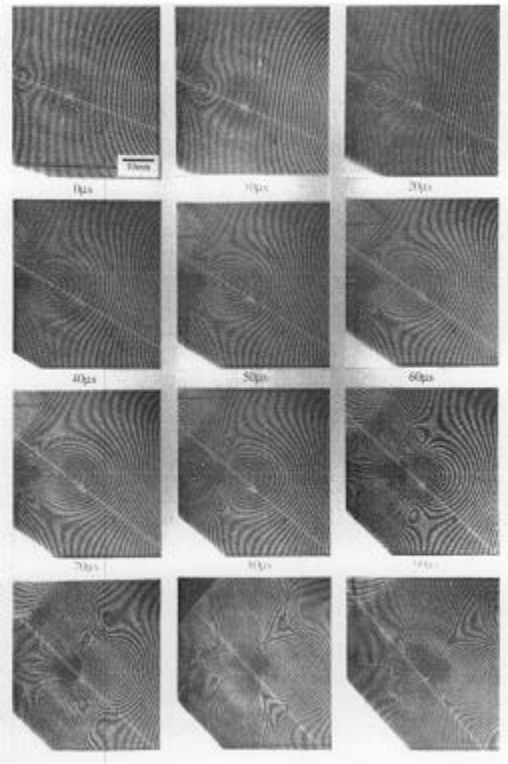

Figure 3.23 [3.52]

greater than the other. The energy distribution in the target during mechanical shock is expressed more clearly. Therefore, in one and the other case local regions are formed with higher power radiation energy. Such regions are called the domain of destruction As we have seen, photons are involved in all the processes that accompany a slow exfoliation of tape, and the most rapid effect of the femtosecond laser.

Figure 3.23 shows photographs of chromatograms, performed every 10 microseconds [3.52]. In the first photo, chosen as the reference point, we can see two groups of waves moving in the direction of impact, and in the opposite direction. While the traveling waves are almost flat, the reflected ones are spherical. They are not coherent and do not interfere. The tenth, eleventh and twelfth picture suggest that a crack does not form.

The question arises: how was the backward wave formed when the traveling one has not yet reached the border on which it may be reflected? Using the fact that the reflected wave is spherical, you can find the location of the wave source, which is outside the frame. It follows that the velocity of the reflected wave is higher than that of the traveling one. Thus, the nature of these waves is different. At the moment of impact there are not only the acoustic waves, but also the electromagnetic, the speed of which is many times higher than the velocity of acoustic waves. Reflected from the boundary, they form the acoustic wave. In turn, sound waves cause the appearance of electromagnetic ones. But in this case the specimen did not become a resonator, and no crack formed because the accumulated energy was not enough to break bonds Picture 3.24 [3.53].

The 14 pictures presented at Pic. 3.24 show the formation of the reflected acoustic waves from the

opposite verge to the arrival of a traveling wave.

However, in this case, the traveling waves are spherical, while the reflected are flat, as can be seen in the second frame. The third frame clearly shows the emergence of the figure, which is presented in Fig. 25-27. We draw attention to the fact that it is formed at the tip of the crack, which is not from the point of impact, but from the place of wave reflection. In 100 microseconds, at the tip of the crack stress distribution, like a torch, reaches a limiting value and at 445 microseconds the "torch" is moving to the opposite side of the point of impact. Without going into details, it can be concluded that in the formation of cracks all the atoms in the area are involved, on the borders of which the reflected wave deformation occurs. All photographs presented in Pic. 1.3, 1.4, 3.8, 3.23, were obtained in an isotropic material. In a metal with a complex structure, the presence of many borders of inhomogeneities, at which the reflection of strain waves occurs, the nature of crack formation is substantially changed.

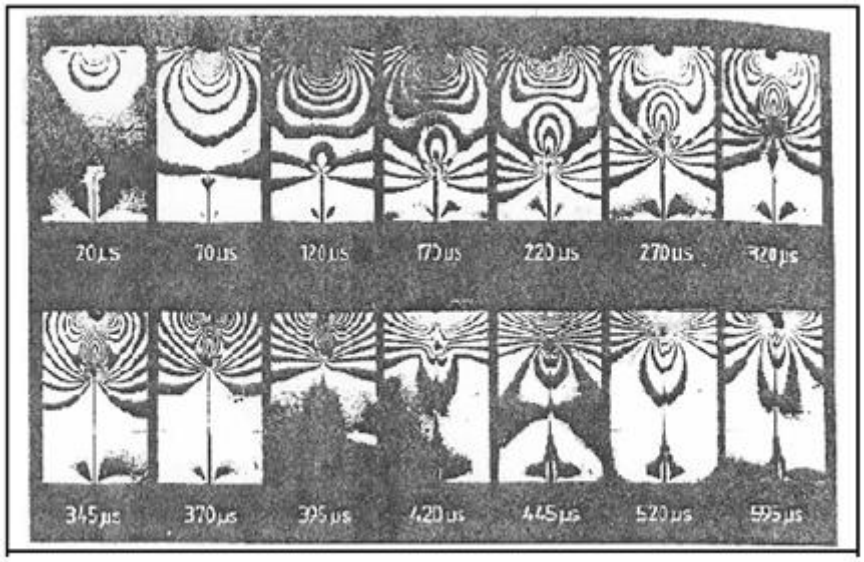

Figure 3.24 [3.53]

Fig. 3.25 [3.54]

All chromatograms, which were shown by several authors, except Maxwell, were intended to calculate the stress intensity factor, or to be used in models based only on the fracture mechanics. Creating a laser allowed the use of interference polarized beams to produce holograms, whose information capability is considerably higher than that of the chromatograms

"High-speed holographic microscopy is applied to take photographs of rapidly bifurcating cracks in PMMA with high spatial resolution. When a crack is propagating at a speed more than 600m/s, it bifurcates into two cracks near the center of the specimen. Three successive photographs are taken at the instant of the crack bifurcation. The frame interval is about 5 μs, and the spatial resolution is more than 180 lines/mm. Crack opening displacement (COD) of the two branch cracks and the mother crack

are measured from the photographs. The photographs and the measurement results show that two branch cracks propagate at the same speed even if they have different CODs. Also, some photographs clearly show that there sometimes exist small cracks that are not connected with other cracks on the surface of a specimen. The fact means that the rapid bifurcation process is not a two-dimensional but three-dimensional phenomenon."

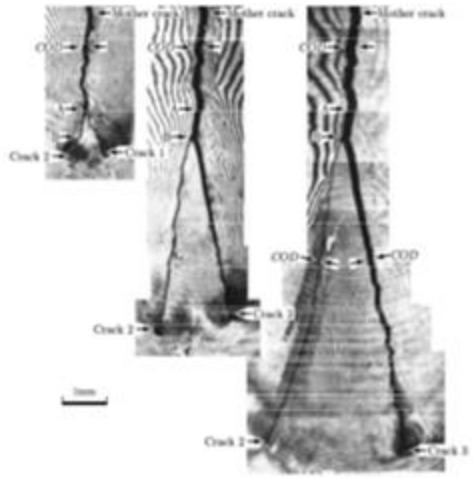

Figure 3.25 [3.54]

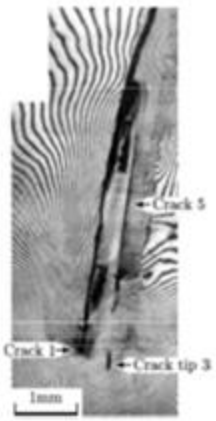

Figure 3.26 [3.54]

The use of holograms to study fracture processes is of great interest, but we limit ourselves to calling attention to the change in the interference pattern in the formation of cracks. The second frame shows bands of interference in the form of a circle whose radius is equal to the length of the crack from the branch point. In the third frame, these bands are preserved, but there are additional bands similar to them, as would be emitted from different sources. Indeed, on another sample, the picture shown in Figure 3.26, there was a crack (crack tip 3) going from the depths of the sample.

An attempt to calculate the stress intensity factor based on experimental studies of crack formation was made in [3.55]. The studies used quartz glass plates and were carried out using an atomic force microscope, the field of view which was 200x200 nm. As the authors note, the instrument allows for measurement at a distance of 10 nm from the crack tip. The measurements were processed using a Digital Image Correlation technique. A special mathematical model was developed in order to calculate the stress intensity factor on the basis of correlated data. The calculations obtained $K_1 = (0.39 \pm 004) MPa \cdot m^{1/2}$, which the authors believe is consistent with the values of the stress intensity factor for macroscopic samples.

We make three remarks.

1. Nanoregions studied in [3.55] contain about 10,000 cells. The behavior of atoms in it can not be described by the formulas proposed in the cited work, since they do not have quantized physical parameters.

2. A mathematical model for describing physical phenomena will be correct only if the functional relationship between the physical parameters is confirmed experimentally. Mathematical software designed to process information obtained from interaction of a cantilever (probe) AFM with the

surface of the sample plays an important role. This interaction is due both to the binding forces between atoms and interaction with the cantilever. But only a change in the binding forces between the atoms in the formation of cracks is the subject of the study. The stress intensity factor is not connected with any parameters of glass, so the parameter m can not be calculated.

. As shown experimentally, the same physical phenomena (eg, the quantum Hall effect, the Hall-Petch effect) in nanoregions occur differently. In this regard the coincidence of the values of K1 and the macroscopic region is doubtful.

Conclusion: Experimental studies performed with the use of equipment whose operation is based on the quantum mechanical properties of atoms or molecules and/or nanoscale materials can be correctly interpreted only on the basis of quantum mechanical models.

Cracking in nano-scale objects through ion implantation is of particular interest. Fig. 37 (a) shows a photograph of a defect in a crystal formed by implanting ions of helium, called He-plate. The picture shows one He-plate which was formed on a disc of Si by irradiating it with He+ ions and subsequent annealing. It is assumed that there was a crack in the expansion due to the increased pressure caused by the expansion of the gas. Fig. 3.27 (b) shows the spectrum of electron scattering. In this regard, the ratio of pressure to the shear modulus p/μ was proposed as a parameter.

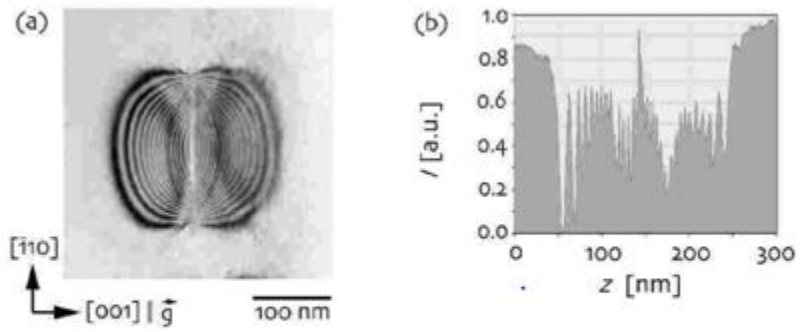

Figure 3.27 [3.56]

Fig. 3.28 shows the relationship between the radius r and p/μ.

On the basis of this graph the authors concluded $\frac{p}{\mu} \infty \frac{1}{\sqrt{r}}$

The photographs shown in Pic. 3.27 refute such a conclusion because, first, there were formed one large crack and a series of narrow ones, located on either side of it, and secondly, it is questionable whether the formation of cracks is due only to the reason, for which the pressure is taken.

To understand the mechanism of the formation of cracks in this action, we consider one similar study [89], in which the defect HeP, created at a certain depth in the Si, was subjected to additional exposure of ion. As the authors note, a thorough study of crack-causing hydrogen implantation was conducted in connection with layered transfer technology. This process is crucial in creating the semiconductor-on-insulator material SOI. Ions in this method control the processes of crack propagation on the surface, as a result of which one layer appears connected to the other. Thus, the investigation of the effects of hydrogen ions helps to elucidate the mechanism of cleavage.

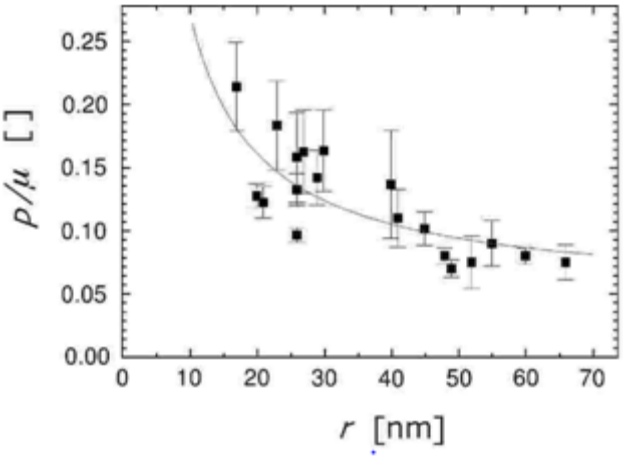

Figure 3.28 [3.56]

Indeed, the emergence of two He-plate defects led to the structure of the entire surface changing, as follows from Fig. 3.29.

The formation of two He-plates was brought about with the following experimental conditions: He ions accelerated by a potential difference U=45 kV, and an irradiated surface, the surface density of ions which was 1 · 1016 cm-2. The sample was annealed at 350 º C for 900 seconds.

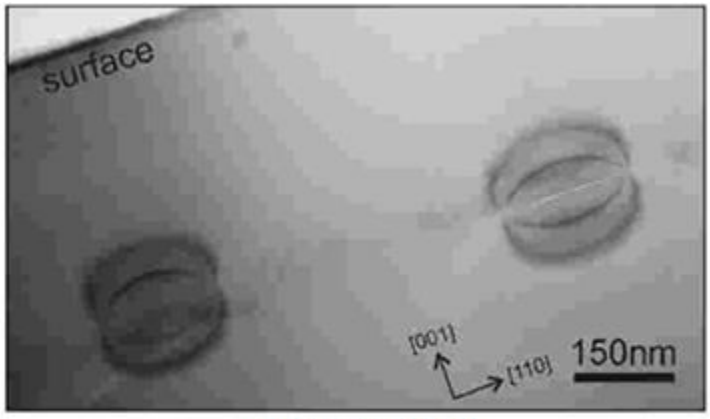

Figure 3.29 [3.57]

Ion implantation was carried out at 200º C under a voltage of 30 kV, the surface density of ions was 0.5·1016 cm-2, annealing was carried out for 900 seconds at a temperature of 300º C. HeP-defects were located at a depth of 200 nm. The effect of hydrogen was observed at a depth of ~ 400 nm. The result of joint action of the ions of hydrogen and helium is shown in Pic. 3.30.

The analysis of the results obtained was based on the SIF. The cause of the destruction was considered to be the thermal expansion of gases. The additional pressure arising in this case, according to the authors, was 200 MPa.

Let us analyze the results of the experiment in detail.

By comparing the HeP, shown in Fig. 3.28 (a) and Fig 3.29, it can be easily discovered that in the first case, the fracture energy is concentrated in a local volume of the defect, in which the main crack was formed along the direction [110] and side defects, in which, according to Fig. 3.28 (b), some cracks are made. From Fig. 3.29 it follows that transparency of HeP borders was considerably higher and the energy (or ions) dissipated, leading to the sawtooth line formation. The boundary of the HeP-defects in the second case is blurred In the left HeP no crack is formed. This indicates that its formation is a final, and not an initial stage of HeP formation.

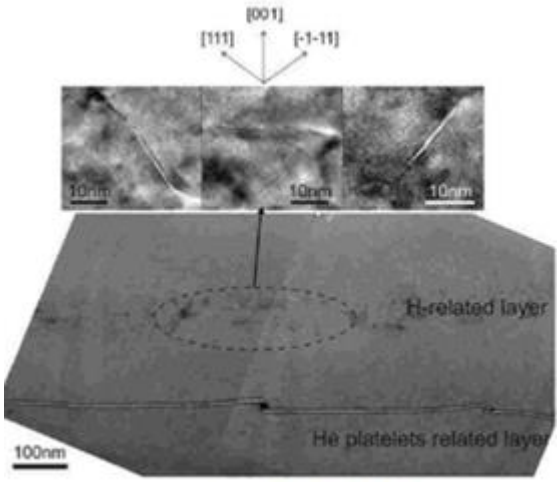

Figure 3.30 [3.57]

To explain all the features of HeP formation only by the thermal expansion is impossible, but not because of the variety of forms. When implanting, ions form point defects, which are accompanied by not only the waves, but the ionization appearance of electrons. Strict orientation of cracks indicates the direction of movement and energy of the electrons, while the thermal expansion is isotropic. Considering that the formation of defects is caused only by the work of gas, another source, the power and energy density of which is many times higher than the power of expansion, is ignored. The ionization potential of helium is 24.59 eV. In the case when the implantation of such a defect is formed, in which the electron is emitted, there is a possibility of recombination with the emission of a photon with this energy. Photons absorbed by the crystal heat it, weakening the bond between the atoms. The binding energy of atoms in Si is equal to 4.64 eV. In the case when the photon energy is reduced to this value, the rupture of the bond will occur. However, these processes are spontaneous and lead to the formation of randomly distributed defects.

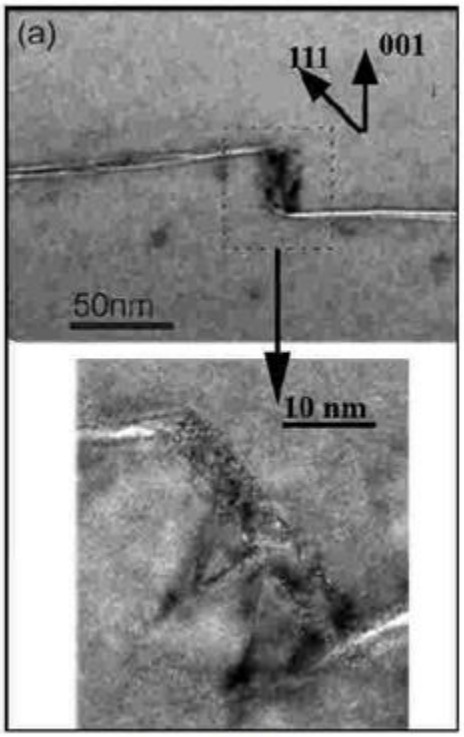

Figure 3.31 [3.57]

As noted above, the surface density of He+ ions was $1 \cdot 10^{16}$ cm^{-2}. The crystal lattice constant of silicon is equal to 5.43 Å. Consequently, a single square centimeter of surface contains $\sim 3 \cdot 10^{15}$ facets of the unit cells. This means that on average, there is one ion He+ on each facet. In the study of HeP a recombination with more intense emission of photons occurs with the help of electrons. In the direction [110] the recombination turns out to be stimulated and the radiation power is sufficient for the formation of cracks These processes are enhanced after the implantation of molecular hydrogen ions. In the recombination of $H_2^+ + e^- \rightarrow H_2 + h\nu$ (15.43 eV) a neutral molecule is formed and a photon is emitted. By this radiation, however, the effect of hydrogen is not limited. Upon annealing and under the influence of electrons, the molecule dissociates into atoms. In the presence of oxygen, the positive hydrogen ions may form water in which energy is released. All this leads to the fact that the crack growth is accelerating. Cracks formed from two HeP, can get close enough that there is an interaction between them, as shown in Fig. 3.31. The photo clearly shows the interaction of atoms of one end of a crack with the beginning of another crack.

The area in which this process occurs is similar to the breakdown of the dielectric between two thin electrodes. Not meaningless is the idea, expressed in the author's work [3.58], about the similarities of charge accumulation, leading to destruction and lightning.

Sclerometry is one of the hardness measuring methods. In this case, a scratch is applied on the surface of the body under study. The hardness is judged by the width of the scratch with a constant load or the load magnitude at a constant width of the scratch. It was found out that during the motion of the indenter in the forward and the opposite direction, we obtain different values. From the standpoint of crystallography, direct and opposite directions are invariant. However, the growth of two cracks from HeP-defects, as with sclerometry, suggests that in the formation of a defect caused by chemical reaction, a certain polarity occurs.

Fragments of the Si surface, irradiated with $He^+ + H^+$, at the surface density of $2 \cdot 10^{16}$ cm^{-2} (a), $6 \cdot 10^{16}$ cm^{-2} (b) and $10 \cdot 10^{16}$ cm^{-2} (c), presented at the photographs, indicate that nanocracks are focused in the direction [110]. The reason for such an orientation is unknown. Special experiments are required

to determine it. Identification of the mechanism of this phenomenon will undoubtedly lead to the creation of more durable material. The same characteristics of the material are caused by the fact that both cracks, formed by the HeP-defect, grow in one direction.

Fig. 3.33 shows four photographs of a crack in glass, into which sodium ions [92] have been implanted. A crack formation in a humid atmosphere was followed by oxidation of sodium (corrosion). The photos were taken with a help of an atomic force microscope.

The values of the stress intensity factor and speed are shown under each photo. Based on the data that are available in the article, I have evaluated the time during which the experiment was conducted. The voltage shown in the second photo, at which the crack appeared, decreased by 0.5%, and the rate was reduced by 36%. Accordingly, the further reduction of one percentage point reduced the rate by 47%. But the most interesting is the fourth image: at a load of 0.38 MPa, the rate dropped to 0.5 nm/s. This means that almost one bond breaks in a second. However, the corrosion continues.

The foregoing experiment allows us to answer the question: why is stress corrosion cracking, SCC, the most dangerous type of fracture?

Corrosion is a chemical reaction in which a metal-nonmetal compound is formed. Such a reaction is accompanied by the emission of photons. For example, in the formation of one molecule of Al_2O_3 the photon energy is 17.36 eV. This energy, absorbed by the metal, is sufficient to raise the temperature of five cells to the melting point. In turn, during the formation of cracks, bonds are broken; electrons are released, which are more readily captured by the nonmetallic atoms.

Thus there arises a positive feedback loop in which the corrosion reduces bonds, and the mechanical stress accelerates corrosion. In the fourth photo the corrosion has acquired the nature of an attack.

Conclusions.

The destruction process is due to the accumulation of energy in local areas of a material, divided by a border at which electromagnetic, acoustic, electronic, and other types of waves are reflected.

Accumulation of energy is due to a change of the energy states of the atoms that make these areas.

The increase in the energy density in some areas is due to decrease of energy density in other areas.

Under stimulated emission of radiation of energy, the radiation power may be sufficient to alter the integrity and removal of atoms at such a distance that the restoration of integrity due to the forces of attraction of atoms becomes impossible.

Description of the mechanism of these changes is possible only within the framework of modern quantum mechanical theories. This will allow more accurate assessment of the technical condition and remaining life of structures and devices.

References to Chapter III

3.1. L. Pauling, *The Theoretical Prediction of the Physical Properties of Many-Electron Atoms and Ions. Mole Refraction, Diamagnetic Susceptibility, and Extension in Space,* Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences **114** (767): 181–211.

3.2. L. Pauling, *The principles determining the structure of complex ionic crystals*". Journal of the American Chemical Society 1929, **51** (4): 1010–1026

3.3. Ф. Лондон, *Теория квантов и химическая связь*, УФН, 1929, (2) 1-25.

3.4. В.М. Гольдшмидт, *Строение кристаллов и химический состав,* УФН 1929 (6), 811-858.

3.5. Н.А. Горюнова, *Химия алмазоподобных полупроводников*. Изд-во ЛГУ, 1963 С.242.

3.6. Н.А. Горюнова, Сложные алмазоподобные полупроводники «Советское радио» 1968 , С. 265

3.7. C. Crevecoeur, *Some ternary thallium chalcogenides*, Acta. Crys. 1964, **17,** 757

3.8. S.P. Ovshinsky, *Symmetrical Current Controlling Device*, US Patent 3271591, 1966

3.9. Л.Н. Антипова, Б.В. Беляев, В.А. Горьков, В.П. Ромбах, *Эффект переключения на кристаллическом Tl_3VS_4*, Физика и техника полупроводников, 1972, 6, 2397-2398.

3.10. T.J. Isaacs and M.R. Daniel, *Acoustic Surface Wave Device using Single Crystal Tl_3VS_4 or Tl_3NbS_4,* US Patent 3991330, 1974.

3.11. Б.В. Беляев, В.П. Ромбах, *О переходе Мотта в системе Tl-B^V-C^{VI}*, Химическая связь в кристаллах и их физическик свойства, 1976, **1**, 179-183, Издательство «Наука и техника».

3.12. K. Jensen, W. Mickelson, W. Han, and A. Zettl, *Current-controlled nanotube growth and zone refinement,* Appl. Phys. Lett. 2005, **86**, 173107-3

3.13. R. Xiang, G. Luo, W. Qian，Q. Zhang, Y. Wang, F. Wei, *Encapsulation, compensation, and substitution of catalyst particles during continuous growth of carbon nanotubes,* Department of Chemical Engineering, Tsinghua University, China; Department of Mechanical Engineering, The University of Tokyo; http://arxiv.org/ftp/arxiv/papers/0707/0707.2759.pdf

3.14. L. Wang, H. W. Zhang, Z. Q. Zhang, Y. G. Zheng, and J. B. Wang, *Buckling behaviors of single-walled carbon nanotubes filled with metal atoms.* Appl. Phys. Lett. 2007, **91**, 051122-3.

3.15. В.И.Лихтман, Е.Д. Щукин, Физико-химические явления при деформации металлов. УФН, 1958, **66**, 213-245.

3.16. G. E. Beltz and J.R. Rice: 1991, *Dislocation Nucleation Versus Cleavage Decohesion at Crack Tips*, Modeling the Deformation of Crystalline Solids: Physical Theory, Applications and Experimental Comparisons, edited by T. C. Lowe, A.D. Rollett, P.S. Follansbee, and G.S. Dehn, The

Minerals, Metals and Materials Society, 1991, 457-480.

3.17. R. Peierls, *The Size of Dislocation*, Proc. Phys. Soc. London. 1940, **52**, 34-37.

3.18. F.R. Nabarro: *Dislocations in a Simple Cubic Lattice*, Proc. Phys. Soc., 1947, **59**, 256-272

3.19. Y.-M. Juan and E. Kaxiras, *Generalized Cracking Fault Energy Surface and Dislocation Properties of selicon: a First Principles Theoretical Study*, Philosophical Mag. A, 1996 **74**, 1367-1384.

3.20. В.П. Ромбах: *Почему не рухнул Волгоградский мост и как не допустить катастрофы*, Вестник ВолгГУ. 2011, Серия 10, № 5, 42-50.

3.21. Л.И. Яковенкова, Л.Е. Карькина: *Теоретическое и экспериментальное изучение процессов деформации и разрушения монокристаллов Ti_3Al при базисном скольжении*, Физика металлов и металловедение, 2007 103, №6, 563-587.

3.22. L. Pauling: *The nature of the chemical bond and the structure of molecules and crystals: an introduction to modern structural chemistry* Ithaca, N.Y. : Cornell University Press, 1960.

3.23. A. Zewail: *Femtochemistry: Recent Progress in Studies of Dynamics and Control of Reactions and Their Transition States,* J. Phys. Chem. 1996, 100, 12701-12724.

3.24. A. Zewail: *Press Release,* The Nobel Prize in Chemistry, 12 October 1999

3.25. С. С. Бацанов: *Структурная рефрактометрия*. Учебное пособие для вузов. Москва, «Высшая школа», 1976 С. 303.

3.26. H.V, Tipper, S. Krishnaswami and A.J. Rosakis: *Optical mapping crack tip deformations using the methods of transmission and reflection coherent gradient sensing: a study of crack tip K-dominance,* Int J. of Fracture, 1991, **52**, 91-117.

3.27. S.V. Pottl, K.Ravi –Chandar: *On the dominance of the singular dynamic crack tip stress field under high rate loading*, Int. J. of Fracture, 1992, 56, 41-59.

3.28. W. Schmitt, W. Böhme: *Impact loading and crack arrest,* Mechanical Engineering, Edited by L.H. Larsson, London, 1989, 402-427.

3.29. К.Б. Абрамова, А.Б.Пахомов, Б.П. Перегуд, Д.Н. Перунов , В.А. Рейнгольд ,И.П. Щербаков: *Спектр излучения, сопровождающего разрушение медных, алюминиевых и серебряных проводников током большой плотности*. - Оптика и спектроскопия, 1985, т.58, .809-814.

3.30. К.Б. Абрамова, А.Б.Пахомов, Б.П. Перегуд, И.П. Щербаков: *Механолюминесценция стали,* ЖТФ, 1986, **56**, 978-981

3.31. К.Б. Абрамова, А.Б. Пахомов, Б.П.Перегуд, И.П.Щербаков, Письма в ЖТФ, **9**, 769 (1983); ЖТФ, **56**, 978 (1986); ЖТФ, **58**, 817 (1988);).

3.32. К.Б. Абрамова, А.Б. Пахомов, Б.П.Перегуд, И.П.Щербаков. *Излучение света при динамическом разрушении титана.* - ЖТФ, 1990 **60**, 80-85.

3.33. А.Ф. Банишев, В.Я. Панченко, Ф.В. Шишков, *Люминесценция тонких металлических пластин и пленок возбуждаемая пластическими деформациями при воздействии лазерных импульсов,* Современные лазерно-информационные и лазерные технологии. Сборник трудов ИПЛИТ РАН, 2005, 91-102

3.34. А.Ф. Банишев, *Лазерно-стимулированные макроструктурные процессы в конденсированных средах*, Автореферат диссертации на соискание ученой степени доктора физико-математических наук, Москва, 2004,

3.35. А.Ф. Банишев, В.С. Голубев, А.Ю. Кремнев, *Разрушение поверхности кремния при воздействии лазеными импульсами,* Современные лазерно-информационные и лазерные технологии. Сборник трудов ИПЛИТ РАН, 2005, 78-90.

3.36. А.Ф. Банишев, *Лазерно-стимулированные процессы генерации и взаимодействия нано-микроструктур дефектов в конденсированных средах,* 30 лет Институту проблем лазерных и информационных технологий Российской академии наук (ИПЛИТ РАН**)**

3.37. В.П. Ромбах, *О границе фундаментального поглощения света окислами щелочно-земельных металлов*, Оптика и спектроскопия, 1960, 9, 258-259.

3.38. В.П. Ромбах, *О границе фундаментального поглощения света халькогенидами щелочно-земельных металлов*, Оптика и спектроскопия, 1961, 10 258-259.

3.39. T. De Resseguier, D. Loison, E. Lescoute, L. Signor, A. Dragon, *Dynamic Fragmentation Laser Shock- Melted Metals: Some Experimental Advances*, J. of Theoretical and Applied Mechanics 2010, **48**, 4, 957-972.

3.40. L. Singor, A. Dragon, G. Roy, T. De Resseguier, F. Llorca, *Dynamic fragmentation of melted metals upon intense shock, wave loading. Some modelling issues applied to a tin target*, Arch. Mech., 2008, **60**, 4, pp. 323–343.

3.41. H. Lorenzana, J. F. Belak, K. S. Bradley, E. M. Bringa, K. S. Budil, J. U. Cazamias, B. El-Dasher, K. Kadau, D. H. Kalantar, J. A. Hawreliak, J. Hessler, J. M. McNaney, D. Milathianaki, K. Rosolankova, D. C. Swift, M. Taravillo, T. W. Van Buuren, J. S. Wark, T. Diaz

De La Rubia, Shocked *Materials at the Intersection of Experiment and Simulation*, Lawrence Livermore National Laboratory, 2008, LLNL-JRNL-406569 pp.43

3.42. А.Я. Учаев, В.Т. Пунин, А.П. Моровов, В.В. Жмайло, А.С. Конкин, И.К. Розгачева, Н.И. Сельченкова, Е.В. Кошелева, Л.А. Платонова, Н.А. Юкина, *Особенности процесса динимического разрушения металлов при воздействии теплового удара, вызванного импульсами проникающих излучений и мощных импульсов лазерного излучения*, Российский федеральный ядерный центр, Всероссийский НИИ экспериментальной физики, Саров, Россия, http://www.vniitf.ru/rig/konfer/7zst/reports/s5/5-23.pdf

3.43. А.Я. Учаев, И.Т. Пунин, Н.И. Завада, Е.В. Кошелева, С.А. Новиков, Л.А. Платонова, Н.И. Сельченкова, Н.А. Юкина, *О количественных характеристиках процесса динамического разрушения металлов, диэлектриков, взрывчатых веществ***,** Российский федеральный ядерный центр, Всероссийский НИИ экспериментальной физики, Саров, Россия http://www.vniitf.ru/rig/konfer/6zst/dokl/sec5/22.pdf

3.44. А.Я. Учаев, Н.И. Завада, Е.В. Кошелева, С.А. Новиков, Л.А. Платонова, Н.И. Сельченкова, Н.А. Юкина, *Универсальные свойства металлов в явлении динамического разрушения,* Российский федеральный ядерный центр, Всероссийский НИИ экспериментальной физики, Саров, Россия http://www.vniitf.ru/rig/konfer/6zst/dokl/sec5/23.pdf

3.45. А.М. Молитвин: *Прочность и удельная энергия металлов при тепловом ударе*, Прикладная механика и техническая физика, 2003, **44**, 163-169.

3.46. Б.К. Барахтин, Ю.И. Мещеряков, Г.Г. Савченков : *Статистические характеристики множественного разрушения мишеней при динамическом нагружении и их связь с механическими параметрами материала,* Журнал технической физики, 2010, **8**, 79-84.

3.47. M. Meunier, B. Fisette, A. Houle, A. V. Kabashin, S. V. Broude P. Miller, *Processing of metals and semiconductors by femtosecond laser-based microfabrication system,* SPIE USE, 2003, 11, 4978-32, pp. 11.

3.48. C. A. Polanky and T. J. Ahres, *Impact Spallation Exsperiment: Fracture Patterns and Spall Velocities*, ICARUS, 1990, 87, 140-155.

3.49. М. Марахтанов, А. Марахтанов, *Металл взрывается*! Наука и жизнь, 2002, №4 С.5.

3.50. В. В. Немошкаленко, В.Ф. Мазанко, В.В. Арсенюк, Д. С.Герцрикен, *Особенности взаимодействия железа с углеродом в уловиях ударного сжатия*, Доповіді Національної академії наук України, 2001, № 3, 110-116

3.51. V. F. Weisskopf, *The Formation of Cooper Pairs and the Nature of Superconducting Currents*, Contemp. Phys., 1981, **22**, pp. 375—395. Имеется русский перевод: В. Вайскопф, *Образование куперовских пар и природа сверхпроводящих токов*, УФН, 1983, **140**, 117-135.

3.52. S.V. Pottl, K.Ravi –Chandar: *On the dominance of the singular dynamic crack tip stress field under high rate loading*, Int. J. of Fracture, 1992, 56, 41-59.

3.53. W. Schmitt, W. Böhme: *Impact loading and crack arrest,* Mechanical Engineering, Edited by L.H. Larsson, London, 1989, 402-427.

3.54. S. Suzuki and K. Sakaue, *High-speed High Resolution Photography of Rapidly Bifurcating Cracks,*Toyohashi University of Technology, 1-1 Tempaku-cho, Toyohashi, Aichi, JAPAN,
http://sem-proceedings.com/04s/sem.org-SEM-X-Int-Cong-s095p01-High-speed-High-Resolution-Photography-Rapidly-Bifurcating-Cracks.pdf pp.6.

3.55. K. Han, M. Ciccotti and S. Roux: *Measuring Nanoscale Stress Intensity Factors with an Atomic Force Microscope*; hal-00454092, version 1 - 7 Feb 2010. pp.5.

3.56. N. Hüging, K. Tillmann, H. Trinkaus, K. Urban, B. Holländer, S. Mantl, P. Fitchner and M. Luysberg: *Quantitative TEM Analysis on the Pressure of Helium Filled Nano-cracks in Inplamented Selicon*, ICEM-15 DURBAN 2002, 99-100.

3.57. S. Reboh, J. F. Barbot, M. F. Baufort and P.F.P Fitchner: *Propogation and interaction of cracks in Si induced by H supply into He filled clracks,* J. of Physics: Conference Series, 2001, **281**, 012022, P7.

3.58. В. П. Ромбах: *Трещины в металле и молнии в облаках*

3.59. S. Reboh, F. Schauruch, A. Declemy, J. F. Barbot, M. F. Baufort, N. Cherkashin, P.F.P Fitchner: *On the microstructure of Si compared with H and He ions at moderate energies*, J. Appl. Physics 2010, 108, Issue 2, 023502 P.6

3.60. M. Ciccoty: *Stress-corrosion mechanisms in silicate glasses J. Phys. D: Appl. Phys*. 2009, **42** 214006

3.61. R.S. Piascik and S.A. Willard: *The Growth of Small Corrosion Fatigue Cracks in Alloy 2024,* Fatigue Fracture Engineering Materials Structures, 1994, **17**, No.11, 1247-1259.

3.62.

3.63. E. Gordon: *The New Science of Strong Materials or Why You Don't Fall Through the Floor* Princeton University Press 2006 pp.328.

4. *

5. V.P. Rombakh: *Fundamentals of Metal Fracture Physics*, IV Международная конференция «Деформация и разрушение материалов и наноматериалов» Москва, ИМЕТ РАН 25-28 октября 2011, http://imetran.ru 83-85*.

5.17.

3. Обсуждаются возмо

4. http://books.google.com/books?id=lzlRAAAAYAAJ&printsec=frontcover&dq=the+scientific+letters+and+papers+of+james+clerk+maxwell+volume+ii+william+robert+grove&hl=ru&sa=X&ei=SMtcUuKGMoTZigLVgoHACw&ved=0CDcQ6AEwAQ#v=onepage&q&f=false

It is not by discoveries only and the registration of them by learned scientists that science is advanced. The true science is not in the volume of Transactions, but in the living mind, and the advancement consists in the direction of the men's minds into a scientific channel;

whether this is done by announcement of a discovery, the assertion of a paradox, the invention of a scientific phrase or the exposition of a system of doctrine. It is for the historian of science to determine the magnitude and direction of the impulse communicated by either of these means to human thought.

But what we require at any given epoch for the advancement of science is not merely to set men thinking, but to produce a concentration of thought in a part of the field of science which at that particular season ought to be cultivated.

Не только открытия и регистрации их учеными движет науку. Истинная наука не в объеме научных трудов, а в живом уме, и ее улучшение заключается в том, чтобы направить человеческую мысль в научный форватер. Это осуществляется сообщением об открытии, защитой парадоксальной идеи, изложением научного определения или системы доктрины. Задача историка науки –определить величину и направленность импульса, переданного человеческому мышлению одним из этих методов. Однако для развития науки в каждую эпоху требуется не то, чтобы люди мыслили вообще, а чтобы концентрировали свои мысли в той области науки, которая в данное время требует развития.

http://conf.sfu-kras.ru/sites/mn2013/thesis/s112/s112-026.pdf

http://www.nasa.gov/mission_pages/asteroids/news/asteroid20130215.html

http://www. metioritsics.ru/forum/viewtopic.php?t=31

1. *Поверхностные слои и внутренние границы раздела гетерогенных материалов*, под редакцией В.И. Панина- Новосибирск Изд.-во СО РАН 2006. С. 520

Литература

Литература

1.H. C. Manoharan, C. P. Lutz & D. M. Eigler, *Quantum mirages formed by coherent projection of electronic structure,* Nature 403, 512-515 (3 February 2000) | doi:10.1038/35000508;

2.Э. Шрёдингер. *Что такое жизнь? С точки зрения физика*.М: Атомиздат, (1972)-88 с

3.A. Zewail, *Nobel Lecture. Femtochemistry: Atomic-Scale Dynamics of the Chemical Bond Using Ultrafast Lasers* (1999)

4.И. Пригожин, И. Стенгерс, *Порядок из хаоса: Новый диалог человека с природой*. М.: Прогресс, 1986.—432 с.

5.H. Haken, *Synergetics-An Introduction*, Second Edition, Springer-Verlag, 1978 355 pp.

6.Д.И. Овсиенко, *О влиянии структуры жидких металлов на склонность их к переохлаждению*, Металлофизика и Новейшие Технологии, **21**, 31 (1999)

7.V.P. Rombarh, *Atom Parameters and Metal Properties,* Logistics Capital, Inc, Edmonds, WA (2008).- pp 311.

8.A.R. Scorer, *Clouds in the World,* Lothian Publ. Co., Melburne (1972)- pp. 166

9.С.И. Вавилов, *Микроструктура света*, М:, Изд. АН СССР (1950)-199 с

10. M. Blank, L. Soo, *Electromagnetic acceleration of Belousov-Zhabotinski reaction*. Bioelectrochemistry, 2003, **61**, 93-97.

11. G. Nicolis, C*hemical Chaos and self-organization*, J. Phys.: Condens. Matter 2 SA47-SA62, (1990).

12. L.Z. Yao, C.H.Ye, C.M. Mo, Y. .Zhang, L.D. Zhang*, Quantum points, Chinese Chem. Letters*, **11,** 627 (2000)

G. Nicolas, J. Phys: Condens. Matter 2SA47-SA62, (1990)

***

М.В. Классен-Неклюдова, Т.А. Конторова, *По поводу дислокационной гипотезы пластичности* УФН, **46**,143 (1954).

Осипьян Ю.А., Бредихин С.И., Кведер В.В. и др. Электронные свойства дислокаций в

полупроводниках / Под ред. Ю.А. Осипьяна. М., (2000).

Р.Б. Моргунов, *Спиновая микромеханика в физике пластичности*,УФН,**174,** 131-153, (2004).

1. A.P. Voskamp and E.J. Mittemeijer, Materials and Materials Transactions 27A, 3445 (1996).
2. H. Harada, T. Mikami, M. Shibata, D.Sokai, A. Yamamoto, and H. Tsubakino, ISIJ International **45,** 1897 (2005).
3. L. Alber, H. Müllejans, and M. Rühle, *Acta mater*. **47,** 4047(1999).
4. NOVFAC (Naval Facilities Engineering Command), Contract Report GR-05-007 ENV (2005).
5. Y. Murakami, N.N. Youkoyama, and Nagata, *Fatigue Fract. Engng. Mater. Struct*. **25**, 735 (2002).
6. К.Б. Абрамова, Б.П. Перегуд, И.П. Щербаков, ЖТФ, **60,** 187 (1990).
7. Y. Murakami, *Comprehensive Structural Integrity- Fracture of Materials from Nano to Macro, Cyclic Loading and Fatigue*, Elsiver, **4**, 41 (2003).
8. A.I. Yanson, R.G.R. Bollinger, H.E. van den Brom, N. Agraït, and J.M. Ruitenbeek, *arXiv: cond-mar/9811093 v1 6 Nov 1998.*
9. B. An, L. Zhang, S. Fukuyama, and K.Yokogawa, Japan. J. Appl. Phys. **46**, 5586 (2007).
10. Е.А. Шур, Разрушение рельсового путию М: Транспорт (1971)
11. S-i. Nishida, K. Sugino, C.Ukashima and H. Masumoto. *Bulletin of JSME*, **28**, No 243, 1819 (1985).
12. .E. Stanzl-Tschegg, H. Mayer, and A. Stich, *Fatigue Fract. Engng. Mater. Struct*. **25**, 887 (2002).
13. *Train Derailmant at Hatfield: A Finsh Report by the Independent Investigation Board*, Office of Rail Regulation, July (2006).
14. K. Svensson, H. Olin, and E, Olsson, *Phys. Rev. Lett*. **93**, 145901 (2004).

Необходимо обратить особое внимание на отмеченное Фейнманом различие поведения атомов в тех объектах, которые сегодня называются наноматериалами, от мезо- и макроматериалов.

1. T. Zhu, J. Li, *Ultra-strength materials,* Progress in Materials Science 55 (2010) 710–757.

2. H.J. Frost and M.F. Ashby, Deformation –Mechanism Maps. The Plasticity and Creep of Metals and ceramics, Pergamon Press, Oxford,N.Y. Toronto, Sydney, Paris, Franfurct,1982, pp.50.

3. S. Huang, S. Zhang, T. Belytschko, S.S.Terdalkar, T. Zhu, *Mechanics of nanocrack: Fracture, dislocation emission, and amorphization*, Journal of the Mechanics and Physics of Solids 57 (2009) 840–850.

Zdeněk P. Bažant1, Jia-Liang Le1, Martin Z. Bazant2

1Northwestern University, IL, USA; 2Stanford University, CA, Atomistic Fracture and Nano-Macro Transition for Strength

and Lifetime Statistics of Quasibrittle Structures

3.1. L. Pauling*, The Theoretical Prediction of the Physical Properties of Many-Electron Atoms and Ions. Mole Refraction, Diamagnetic Susceptibility, and Extension in Space,* Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences **114** (767): 181–211.

3.2. L. Pauling, *The principles determining the structure of complex ionic crystals*". Journal of the American Chemical Society 1929, **51** (4): 1010–1026

3.3. Ф. Лондон, *Теория квантов и химическая связь*, УФН, 1929, (2) 1-25.

3.4. В.М. Гольдшмидт, *Строение кристаллов и химический состав,* УФН 1929 (6), 811-858.

3.5. Н.А. Горюнова, *Химия алмазоподобных полупроводников*. Изд-во ЛГУ, 1963 С.242.

3.6. Н.А. Горюнова, Сложные алмазоподобные полупроводники «Советское радио» 1968 , С. 265

3.7. C. Crevecoeur, *Some ternary thallium chalcogenides*, Acta. Crys. 1964, **17,** 757

3.8. S.P. Ovshinsky, *Symmetrical Current Controlling Device*, US Patent 3271591, 1966

3.9. Л.Н. Антипова, Б.В. Беляев, В.А. Горьков, В.П. Ромбах, *Эффект переключения на кристаллическом Tl_3VS_4*, Физика и техника полупроводников, 1972, 6, 2397-2398.

3.10. T.J. Isaacs and M.R. Daniel, *Acoustic Surface Wave Device using Single Crystal Tl_3VS_4 or Tl_3NbS_4,* US Patent 3991330, 1974.

3.11. Б.В. Беляев, В.П. Ромбах, *О переходе Мотта в системе Tl-B^V-C^{VI}*, Химическая связь в кристаллах и их физическик свойства, 1976, **1**, 179-183, Издательство «Наука и техника».

3.12. K. Jensen, W. Mickelson, W. Han, and A. Zettl, *Current-controlled nanotube growth and zone*

refinement, Appl. Phys. Lett. 2005, **86**, 173107-3

3.13. R. Xiang, G. Luo, W. Qian，Q. Zhang, Y. Wang, F. Wei, *Encapsulation, compensation, and substitution of catalyst particles during continuous growth of carbon nanotubes,* Department of Chemical Engineering, Tsinghua University, China; Department of Mechanical Engineering, The University of Tokyo; http://arxiv.org/ftp/arxiv/papers/0707/0707.2759.pdf

3.14. L. Wang, H. W. Zhang, Z. Q. Zhang, Y. G. Zheng, and J. B. Wang, *Buckling behaviors of single-walled carbon nanotubes filled with metal atoms.* Appl. Phys. Lett. 2007, **91**, 051122-3.

3.15. В.И.Лихтман, Е.Д. Щукин, Физико-химические явления при деформации металлов. УФН, 1958, **66**, 213-245.

3.16. G. E. Beltz and J.R. Rice: 1991, *Dislocation Nucleation Versus Cleavage Decohesion at Crack Tips*, Modeling the Deformation of Crystalline Solids: Physical Theory, Applications and Experimental Comparisons, edited by T. C. Lowe, A.D. Rollett, P.S. Follansbee, and G.S. Dehn, The Minerals, Metals and Materials Society, 1991, 457-480.

5.18. R. Peierls, *The Size of Dislocation*, Proc. Phys. Soc. London. 1940, **52**, 34-37.

5.19. F.R. Nabarro: *Dislocations in a Simple Cubic Lattice*, Proc. Phys. Soc., 1947, **59**, 256-272

5.20. Y.-M. Juan and E. Kaxiras, *Generalized Cracking Fault Energy Surface and Dislocation Properties of selicon: a First Principles Theoretical Study*, Philosophical Mag. A, 1996 **74**, 1367-1384.

5.21. В.П. Ромбах: *Почему не рухнул Волгоградский мост и как не допустить катастрофы*, Вестник ВолгГУ. 2011, Серия 10, № 5, 42-50.

5.22. Л.И. Яковенкова, Л.Е. Карькина: *Теоретическое и экспериментальное изучение процессов деформации и разрушения монокристаллов Ti_3Al при базисном скольжении*, Физика металлов и металловедение, 2007 103, №6, 563-587.

5.23. L. Pauling: *The nature of the chemical bond and the structure of molecules and crystals: an introduction to modern structural chemistry* Ithaca, N.Y. : Cornell University Press, 1960.

5.24. A. Zewail: *Femtochemistry: Recent Progress in Studies of Dynamics and Control of Reactions and Their Transition States,* J. Phys. Chem. 1996, 100, 12701-12724.

5.25. A. Zewail: *Press Release,* The Nobel Prize in Chemistry, 12 October 1999

5.26. С. С. Бацанов: *Структурная рефрактометрия*. Учебное пособие для вузов. Москва, «Высшая школа», 1976 С. 303.

5.27. H.V, Tipper, S. Krishnaswami and A.J. Rosakis: *Optical mapping crack tip deformations using the methods of transmission and reflection coherent gradient sensing: a study of crack tip K-dominance,* Int J. of Fracture, 1991, **52**, 91-117.

5.28. S.V. Pottl, K.Ravi –Chandar: *On the dominance of the singular dynamic crack tip stress field under high rate loading*, Int. J. of Fracture, 1992, 56, 41-59.

5.29. W. Schmitt, W. Böhme: *Impact loading and crack arrest,* Mechanical Engineering, Edited by L.H. Larsson, London, 1989, 402-427.

5.30. К.Б. Абрамова, А.Б.Пахомов, Б.П. Перегуд, Д.Н. Перунов , В.А. Рейнгольд ,И.П. Щербаков: *Спектр излучения, сопровождающего разрушение медных, алюминиевых и серебряных проводников током большой плотности*. - Оптика и спектроскопия, 1985, т.58, .809-814.

5.31. К.Б. Абрамова, А.Б.Пахомов, Б.П. Перегуд, И.П. Щербаков: *Механолюминесценция стали,* ЖТФ, 1986, **56**, 978-981

5.32. К.Б. Абрамова, А.Б. Пахомов, Б.П.Перегуд, И.П.Щербаков, Письма в ЖТФ, **9**, 769 (1983); ЖТФ, **56**, 978 (1986); ЖТФ, **58**, 817 (1988);).

5.33. К.Б. Абрамова, А.Б. Пахомов, Б.П.Перегуд, И.П.Щербаков. *Излучение света при динамическом разрушении титана.* - ЖТФ, 1990 **60**, 80-85.

5.34. А.Ф. Банишев, В.Я. Панченко, Ф.В. Шишков, *Люминесценция тонких металлических пластин и пленок возбуждаемая пластическими деформациями при воздействии лазерных импульсов,* Современные лазерно-информационные и лазерные технологии. Сборник трудов ИПЛИТ РАН, 2005, 91-102

5.35. А.Ф. Банишев, *Лазерно-стимулированные макроструктурные процессы в конденсированных средах*, Автореферат диссертации на соискание ученой степени доктора физико-математических наук, Москва, 2004,

5.36. А.Ф. Банишев, В.С. Голубев, А.Ю. Кремнев, *Разрушение поверхности кремния при воздействии лазеными импульсами,* Современные лазерно-информационные и лазерные технологии. Сборник трудов ИПЛИТ РАН, 2005, 78-90.

5.37. А.Ф. Банишев, *Лазерно-стимулированные процессы генерации и взаимодействия нано-микроструктур дефектов в конденсированных средах,* 30 лет Институту проблем лазерных и информационных технологий Российской академии наук (ИПЛИТ РАН**)**

5.38. В.П. Ромбах, *О границе фундаментального поглощения света окислами щелочно-земельных металлов*, Оптика и спектроскопия, 1960, 9, 258-259.

5.39. В.П. Ромбах, *О границе фундаментального поглощения света халькогенидами щелочно-земельных металлов*, Оптика и спектроскопия, 1961, 10 258-259.

5.40. T. De Resseguier, D. Loison, E. Lescoute, L. Signor, A. Dragon, *Dynamic Fragmentation Laser Shock- Melted Metals: Some Experimental Advances*, J. of Theoretical and Applied Mechanics 2010, **48**, 4, 957-972.

5.41. L. Singor, A. Dragon, G. Roy, T. De Resseguier, F. Llorca, *Dynamic fragmentation of melted metals upon intense shock, wave loading. Some modelling issues applied to a tin target*, Arch. Mech., 2008, **60**, 4, pp. 323–343.

5.42. H. Lorenzana, J. F. Belak, K. S. Bradley, E. M. Bringa, K. S. Budil, J. U. Cazamias, B. El-Dasher, K. Kadau, D. H. Kalantar, J. A. Hawreliak, J. Hessler, J. M. McNaney, D. Milathianaki, K. Rosolankova, D. C. Swift, M. Taravillo, T. W. Van Buuren, J. S. Wark, T. Diaz De La Rubia, Shocked *Materials at the Intersection of Experiment and Simulation*, Lawrence Livermore National Laboratory, 2008, LLNL-JRNL-406569 pp.43

5.43. А.Я. Учаев, В.Т. Пунин, А.П. Моровов, В.В. Жмайло, А.С. Конкин, И.К. Розгачева, Н.И. Сельченкова, Е.В. Кошелева, Л.А. Платонова, Н.А. Юкина, *Особенности процесса динимического разрушения металлов при воздействии теплового удара, вызванного импульсами проникающих излучений и мощных импульсов лазерного излучения*, Российский федеральный ядерный центр, Всероссийский НИИ экспериментальной физики, Саров, Россия, http://www.vniitf.ru/rig/konfer/7zst/reports/s5/5-23.pdf

5.44. А.Я. Учаев, И.Т. Пунин, Н.И. Завада, Е.В. Кошелева, С.А. Новиков, Л.А. Платонова, Н.И. Сельченкова, Н.А. Юкина, *О количественных характеристиках процесса динамического разрушения металлов, диэлектриков, взрывчатых веществ***,** Российский федеральный ядерный центр, Всероссийский НИИ экспериментальной физики, Саров, Россия http://www.vniitf.ru/rig/konfer/6zst/dokl/sec5/22.pdf

5.45. M. Meunier, B. Fisette, A. Houle, A. V. Kabashin, S. V. Broude P. Miller, *Processing of metals and semiconductors by femtosecond laser-based microfabrication system,* SPIE USE, 2003, 11, 4978-32, pp. 11.

5.46. C. A. Polanky and T. J. Ahres, *Impact Spallation Exsperiment: Fracture Patterns and Spall Velocities*, ICARUS, 1990, 87, 140-155.

5.47. М. Марахтанов, А. Марахтанов, *Металл взрывается*! Наука и жизнь, 2002, №4 С.5.

5.48. V. F. Weisskopf, *The Formation of Cooper Pairs and the Nature of Superconducting Currents*, Contemp. Phys., 1981, **22**, pp. 375—395. Имеется русский перевод: В. Вайскопф, *Образование куперовских пар и природа сверхпроводящих токов*, УФН, 1983, **140**, 117-135.

5.49. E. Gordon: *The New Science of Strong Materials or Why You Don't Fall Through the Floor* Princeton University Press 2006 pp.328.

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5. Обсуждаются возмо

CHAPTER IV. FEATURES OF DAMAGES AIRCRAFT FUSELAGE

As if not were great difficulties associated with the discovery of new truths in the study of nature, even greater difficulties standing in the way of recognition.

J. B. Lamarck

4.1. Program of fatigue crack growth evaluation "NASGRO" Version 3.0 and an alternative solution of this problem

As noted above, the main purpose of this research is to establish the possibility of more accurate prediction of the technical condition and remaining life of structures and devices.

Certainly every technical structure and device has its own characteristics. Moreover, this also applies to its individual elements.

For the example of the fuselage, we consider the shortcomings of existing methods and their possible solutions.

A crack 18 feet (5.4 m) long was formed in a Boeing 737-297 fuselage during a 1988 flight at an altitude of 7300 m, as shown at Fig. 4.1 [4.1].

].

Рис. 4.1 [4.1]

After almost a quarter of century, the problem of giant crack formation in fuselages remains a central one for research.

In the final report of the government program of NASA, called: NAG-1-1184 "Crack Growth Prediction for Multiple-Site Damage" [4.2], according to its authors, the case of the Boeing 737-297 has revolutionized the aerospace community. Actually, a large number of papers were devoted to this problem, and new parameters and estimation methods were proposed. As one of these parameters of thin metal layers the authors proposed the use of the crack tip opening angle, CTOA [4.2÷4.4].

A large number of works, including at NASA, were devoted to tolerance to damage, but judging from the study published in the press, no revolution has occurred. New methods of assessment, like the previous ones, are based on a mechanical approach to the problem, and all scientific and technical discoveries in nanoscience and nanotechnology have gone unheeded. Thus in [4.5], for a number of alloys, graphs of crack growth rate when changing the stress intensity factor calculated by the equations of NASGRO, Walker or cubic spline are given. One example of the calculation of crack formation rate is made using the equations of NASGRO, shown at Fig. 4.2 [4.5]. This method was discussed in more detail in Chapter 1.

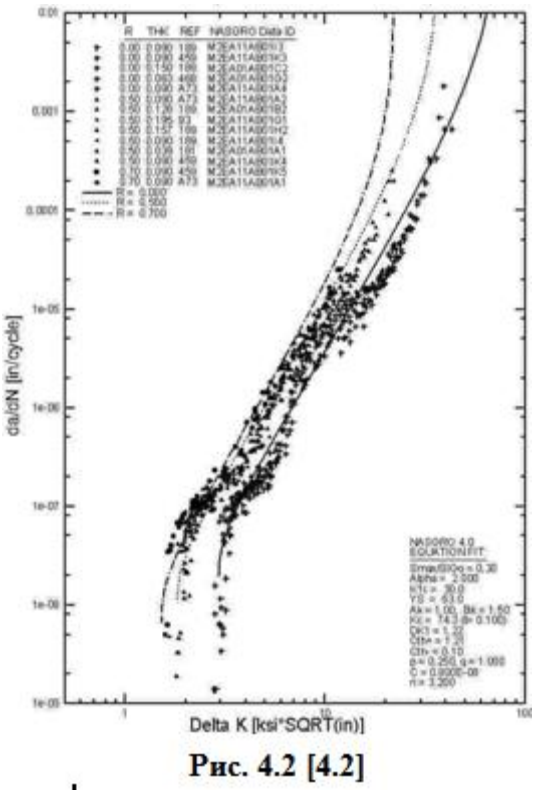


Рис. 4.2 [4.2]

Despite all the complexity and labor intensity of the calculations, the proposed methods do not guarantee the reliability of prediction. The NASGRO equation is an officially recognized U.S. Standard, although it does not contain any material parameters whose change leads to destruction.

Let us pay attention to one important feature in the construction of graphs, as described at Fig. 4.1. They appear in numerous works. As we see, the minimum speed of crack formation is taken as 10^{-9} inches/cycle=0.254 Å/cycle. The length of this "crack" is ten times less than the length of the interatomic bond?!

Through mathematical averaging we come to the absurd, because this crack is devoid of physical meaning. Moreover, even for bond dissociation, a certain energy (quantum) is required, for the accumulation of which many cycles may be needed. However, even when the stored energy is sufficient to break the bonds, more light is required, stimulating its radiation.

As noted above, the main purpose of this research is justification for the possibility of more accurate prediction the technical condition and remaining life of structures and devices.

Of course, that every technical structure and the device has its own characteristics. Moreover, this also applies to its individual elements. Currently, for monitoring the technical condition of each type of plant or even its elements proposed various methods related to the physical, structural features and operating conditions.

However, analysis of changes in the energy state of the atomic groups, accumulation of energy, whose radiation is the main cause of destruction, allows using a united method to assess the wear and forecasting residual resource.

We demonstrate it on the example of the results of experimental studies of plane riveted joints cracking, using the energy of destruction, but not the stress intensity factors.

Let us note the main physical characteristics of the fuselage.

1. The fuselage has the highest surface area to volume ratio in the device.
2. Overpressure intended from the inside, reaches one hundred kPa.
3. The temperature difference reaches 70 degrees.
4. It is subjected to intensive electromagnetic (up to gamma) radiation, and exposure to electrons, protons, and cosmic rays, when flying in the upper atmosphere.
5. The greatest danger for a fuselage is represented by the cracks, formed along the riveted joints, although any loss of containment is dangerous, especially in flight.
6. The chemical reactions (corrosion), accompanied by the emission of energy, not only violates the integrity of the fuselage, but also reduces its strength and durability.

4.2. Forming energy, suggested by Maxwell, from the position of modern physics

At present a rich experience has been accumulated in research on fuselage technical condition. We confine ourselves only to the necessary minimum, on the basis of which we will show the advantage of physics of destruction compared with the methods of fracture mechanics.

The investigation of fuselage fragments containing rivets was conducted through a system of analysis SPATE [Stress' Pattern Analysis by Measuring Thermal Emission], and based on SMAAC [Structural Maintenance of Aging Aircraft] technology. It has been shown that this method allows us to observe the cracks in the aluminum alloy 2024-T3 to a depth of

1.2 mm [4.5].

In the study of fragments of a Daimler-Benz Aerospace Airbus fuselage it was established that 80 to 96% of cracks are hidden [4.6, 4.7].

It has been established experimentally that during the operation of the fuselage there are two types of

cracks in it: along the row of rivets and perpendicular to them.

The metallic coating of a fuselage containing rows of rivets is a diffraction grating for those waves whose wavelength is comparable to the distance between the studs. As a result of diffraction, the wave energy is uneven and much of it is concentrated in the main maximum, located in the center. The more riveting "involved" in the formation of the diffraction pattern, rather than the clearance between them, the higher the peaks, especially the principal maximum. Only diffraction waves can explain the distribution of cracks, as shown in Figure 4.3.

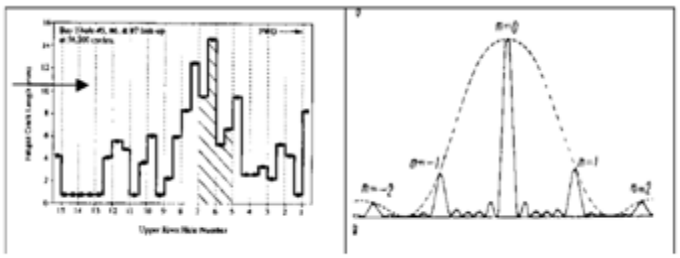


Figure 4.3

Figure. 4.3 (left part), taken from [4.7] shows the length of cracks in a fragment of a Boeing 727 fuselage. On the right is a graph of the diffraction spectrum, with 15 gaps, designed by the author [1.6]. Such an analogy cannot be considered accidental.

In this case, another very important factor that has a huge impact on the process of destruction should be considered. It comes to corrosion.

Simultaneous effect of these two factors is crucial.

To evaluate the technical condition and remaining life it is necessary to take into account both mechanical and chemical stress.

However, in fracture mechanics, these two factors are considered separately.

Let us consider the results of several studies breaking riveted joints made under the fatigue crack growth program "NASGRO" Version 3.0.

Six pieces of fuselage, with thickness of 0.05 and 0.063 inches (1.27 and 1.6 mm) of the aluminum alloy 2024-T3 2014-T6, containing rivets were tested on an experimental setup shown in Figure 1.11 [4.9]. Survey methodology is described in [4.10].

The pattern of destruction is shown in Figure 4.4. The first crack was detected at some distance to the right of the rivet A23 after 72,000 cycles (a) and spread to the right (b, c); over 16,430 cycles cracks were shown on the left and right of the rivet A22 (f). On this basis, the authors concluded that the crack propagates both right and left, meeting at some point between the rivets A22 and A23 (g).

However, the merger of cracks, known in fracture mechanics as a transition from small to big leaps, is not as simple as it seens from geometrical considerations. First, the process of merging is similar to that observed at the confluence of cracks shown in Figure. 3.31 Secondly, the crack width at the

junction increased. Of particular interest are the merge cracks which are near to rivets A24 (h). Third, significant changes have also taken place with the rivets.

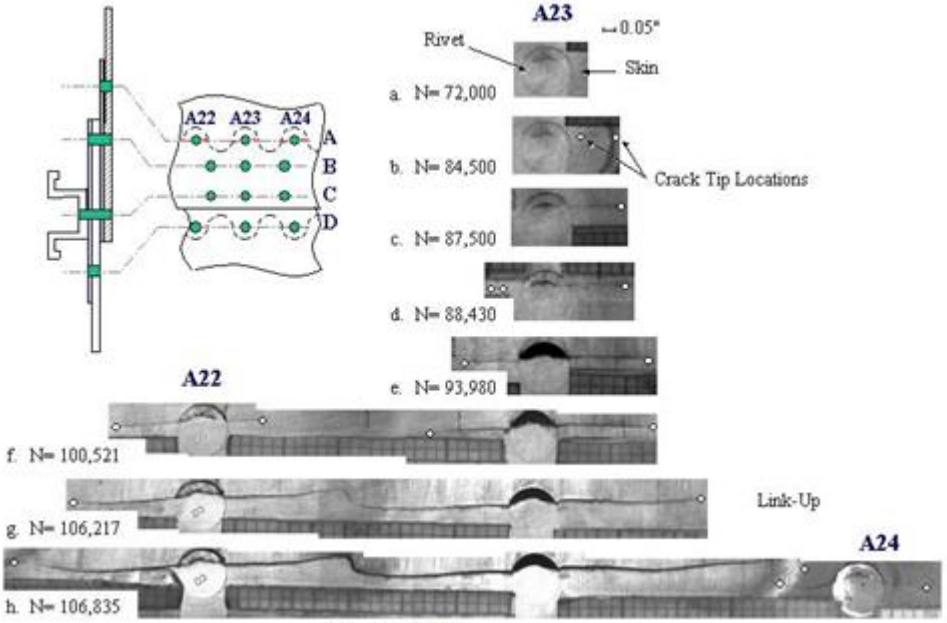


Рис. 4.4 [4.8]

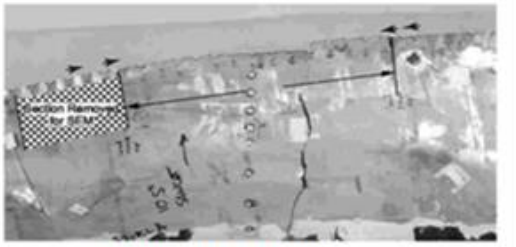


Figure 4.4 a [4.10]

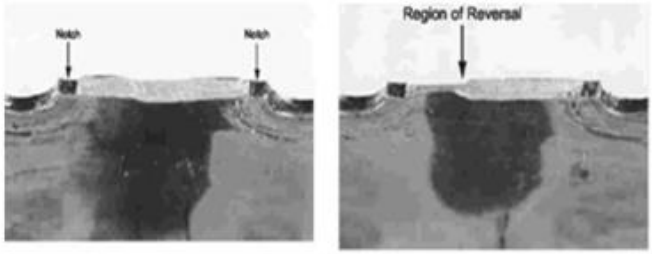


Figure 4.4 b [4.10]

The authors of the work [4.10] drew attention to another very important feature of the formation cracks along the rivets, shown in Figures 4.4 a and 4.4 b. Those places where, according to the authors, there was a change of cracks direction marked by arrows. The fragment, designated "Section removed for SEM", was removed and examined with a scanning electron microscope (SEM).

The analysis of physical processes in [4.8] is made from the viewpoint of fracture mechanics, as noted in Chapter I.

Figure 4.5 shows a diagram of crack growth adopted in fracture mechanics. The three models proposed to describe the mechanism are not confirmed experimentally.

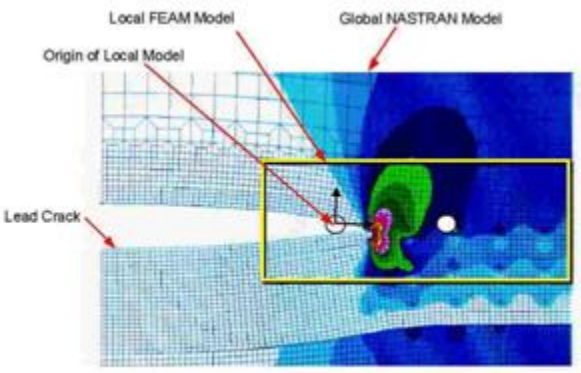


Figure 4.5 [4.9]

The results of numerous experimental studies have confirmed the legitimacy of Maxwell's ideas about the nature of distortion energy, which plays an important role in the destruction of the solid. But we confine ourselves to the works [4.11-4.13]. Timoshenko, as noted in Chapter I, did not pay attention to the brilliant prediction, which should be the basis of the theory of strength and ductility. Fracture criterion proposed by Maxwell, is fundamentally different from all the many criteria that are used in modern theories.

We distinguish two major fragment of a letter from Maxwell to Thomson and try to understand the logic that he was cited: "Here is my present notion about plasticity of homogenous amorphous solids.

"Let α β γ be the 3 principal strains at any point P Q R, the principal stresses connected with α β γ by symmetrical linear equations the same for all axes. Then the whole work done by P Q R in developing α β γ may be written as

$$U = A(\alpha^2 + \beta^2 + \gamma^2) + B(\beta\gamma + \gamma\alpha + \alpha\beta)\ 5\ (4.1)$$

where A & B are coeffits, the nature of which is foreign to our inquiry".

Equations similar to equation (4.1) form the basis of all modern theories of strength, but they are instead of α, β and γ use the principal stresses σ_1, σ_2, σ_3. Right and left sides of a mathematical equation, which describes the physical phenomena, must have the same dimension. To do this, the right side of equations similar to equation (4.1) is divided by the elastic modulus or shear. In this case, the dimension of the right-hand side is the specific energy or energy per unit volume. In addition to this Poisson's ratios or a combination of some dimensionless quantities are used.

Maxwell was familiar with the work of Young and Poisson, he writes about them in a long article published in 1850, [4.14], a pilot study of interference of polarized beams that form the basis of the method of photoelasticity, and even opens an unknown phenomenon called Maxwell effect, but represents the coefficients simple by letters A and B. Why?

Maxwell, ending the letter draws the conclusion: "I have strong reasons for believing that when

$$U_2 = \frac{2A - B}{3}[(\alpha^2 + \beta^2 + \gamma^2) - (\beta\gamma + \gamma\alpha + \alpha\beta)]\ (4.2)$$

reaches a certain limit=R_2 then the element will begin to give way. I think this notion will bear working out into a mathemat theory of plasticity when I have time to compare with experiment, when

[5] The numbering of equations is mine

I know the right experiments to make.

Condition of not yielding

$$(\alpha^2 + \beta^2 + \gamma^2 - \beta\gamma - \gamma\alpha - \alpha\beta < R_2 \ 4.3).$$

Equations similar to equation (4.1) form the basis of all modern theories of strength, but they are instead of α, β and γ use the principal stresses σ_1, σ_2, σ_3. Right and left sides of a mathematical equation, which describes the physical phenomena, must have the same dimension. To do this, the right side of equations similar to equation (4.1) is divided by the elastic modulus or shear. In this case, the dimension of the right-hand side is the specific energy or energy per unit volume. In addition to this Poisson's ratios or a combination of some dimensionless quantities are used.

Maxwell knew of Young's and Poisson's works. He wrote about them in an article published in 1850, [4.14], carries out experimental studies of interference of polarized beams that form the basis of the method of photoelasticity, and even opens an unknown phenomenon called Maxwell effect.

Maxwell was convinced that the potential energy (4.2) performs the work of destruction, but not notes about the cracks. The cofactor

$$(\alpha^2 + \beta^2 + \gamma^2) - (\beta\gamma + \gamma\alpha + \alpha\beta) \quad (4.3)$$

has the area dimension, therefore, the coefficients A and B should have a dimension of surface energy density. Maxwell perfectly understood it, but represents the coefficients simple by letters A and B. Why?

Several articles confirm this conclusion.

For example, in the work [The Dynamical Theory of Gases (1868)] Maxwell writes: "If we suppose the molecules to the bodies, or system of bodies, capable of rotation internal vibration or any form energy, other than simple motion of translation, this result will be modified".

We note that at this time, Maxwell had already formulated the idea of the electromagnetic nature of light [On a Method of Making a Direct Comparison of Electrostatic with Electromagnetic Force; with a Note on the Electromagnetic Theory of Light (1868)].

Maxwell highly appreciated the idea of V.R. Grove on the relationship of physical forces. He writes: Thus the "Physical Forces," whose correlation is discussed in the essay before us, are Motion, Heat, Electricity, Light, Magnetism, Chemical Affinity, and "other modes of force" [Grove's "Correlation of Physical Forces"].

In paper [On the Mathematical Classification of Physical Quantities (1871)], he analyzes the ratio of vector and scalar parameters that characterize the energy using the formula dimensions of energy $\frac{ML^2}{T^2}$

; work [On Reciprocal Figures, Frames, and Diagrams of Forces (1870).] is devoted to the forces and stresses in the solid.

Timoshenko was wrong when he wrote that Maxwell "to this problem did not come back." In fact, he returned to it repeatedly in solving various problems, as we see.

We draw attention to one very important detail.

Maxwell's equation (4.2) can be written as $U_2 = \frac{2A-B}{3}\alpha^2$ or $U_2 = \frac{k\alpha^2}{2}$, when $\beta = \gamma = 0$. Potential energy U_2 in this case is the energy of the deformed body. The coefficients A and B can be easily linked to the coefficient k, called rigidity. But Maxwell did not do that, because he believed that the destruction caused by a violation of Hooke's law.

I have not found in Maxwell's the works of such direct statements, but it follows from the fact that the nature of the destruction caused not by mechanical interaction, but somehow different.

Today it is installed and is called the quantum mechanical.

There is no doubt that Maxwell was always looking for "the right one experiment," on which he could develop a mathematical theory of strength.

This is evidenced by his statements, for example, in a letter to W. R. Grove [Experiment in Magneto-Electric Induction IN A LETTER TO W. R. GROVE, F.R.S. 8, Palace Gardens Terrace, W. March 27, 1868.]: "Since our conversation yesterday of your experiment on magneto-electric induction, I have considered it mathematically, and now send you the result… The machine produces in the primary wire an alternating electromagnetic force, which we may compare to a mechanical force alternately pushing and pulling at a body." (Italic supplied).

This example shows the genius for Maxwell, through which he, having the experimental data for one day wrote a mathematical theory of the phenomenon.

Maxwell's interest to experimentally established facts was extremely high. He opened on them especially the ones that were the subject of research and practical application of even the twentieth, but twenty-first centuries.

He writes: "Now we find by experiment that there is no difference between the phenomena in one part of the liquid and those in another part except in a region close to the surface and not *more than a thousandth or perhaps a millionth of a millimetre thick*. In the vapour also, everything is the same, except perhaps in a very thin stratum close to the surface. The change in the value of the energy takes place *in the very narrow region between water and vapour*." [Plateau on Soap-Bubble (1873)]. (Italic supplied).

Phrase highlighted by me indicates that Maxwell in 1873 came to the conclusion that in the $10^{-6} \div 10^{-9}$ m (nanoregion) emission occurs energy, the nature of which is different from that which takes place in the macro area. The conclusion drawn by Maxwell suggests that the mathematical theory he considered correct only if it is confirmed by the corresponding experiment. Theoretical foundations of electrodynamics were formulated them a decade later, but right experiment, confirming the actual existence of electromagnetic waves was made by H. Hertz, when Maxwell was no longer alive.

All experimental facts that necessary to create a mathematical theory of strength, based on the fact that the energy accumulation which necessary and sufficient to fracture occurs as a result of the electromagnetic interaction, were known in 1953, when Timoshenko published his review. But he confining mechanics did not appreciate the value of the two fragments, cited above, for further development of the theory of strength, and all those who developed new theory, do not bother read the works of Maxwell. Scientific direction associated with the use of stress intensity factors and mathematical models that do not have physical parameters proved to be false.

4.3. Method of analysis of experimental data on the basis of the account of the energy stored during deformation

Distortion energy can be calculated in all cases in which obtain quantitative values of external action energy, geometric and structural changes of the object and the physical parameters of the material.

We will demonstrate this limiting by two dissertations. Formation of cracks in the fuselage riveted joints of Boeing 727, which the flight time reached 66412 has been investigated in the thesis [4.11]. Experimental study was conducted in accordance with the program FAA FASTER (the Full-Scale Aircraft Structural Test Evaluation and Research) facility located at the Federal Aviation Administration William J. Hughes Technical Center).

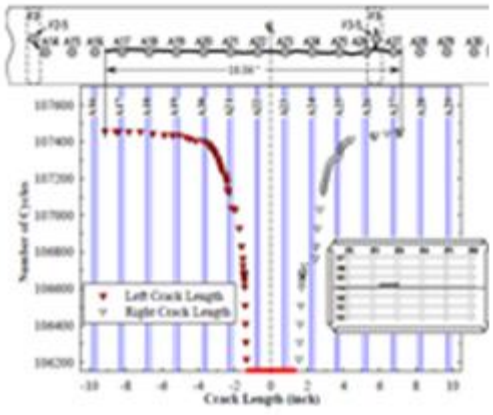


Figure 4.5 a [4.11]

To investigate the cracks used modern equipment, allowed to determine dimensions of the cracks to 0.000039 "(1.0 μm). Maximum crack length 75.80" (1.925 m) formed at a pressure of 17.83 psi (122.93kPa). Research results hundreds of cracks presented in the form of graphs, tables and images, are of tremendous significance.

But the theoretical analysis was made on the basis of stress intensity factors. The applicant has not

been able to explain the observed phenomenon, suggest new ideas for understanding the mechanism of failure and methods of forecasting.

It was found that the nucleation of cracks in the fuselage riveted joint began between A22, A23 rivets, as it have been observed previously in the same research center as [4.9, 4.10].

The formation of cracks in length 16.04 "(407.416 mm) A. Ahmed illustrates using the graph shown in Figure 4.6a. As we can see, the crack length varies nonlinearly but smoothly. Graphs relating the rate of crack growth with its length, for example,

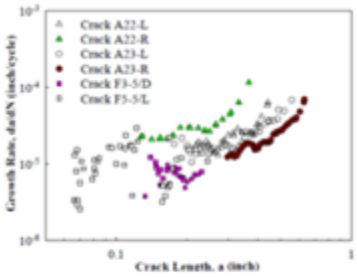


Figure 4.6 [4.11]

Fig.4.6, show that the crack growth rate is not so smoothly changing, but do any serious implications of these changes is not possible. We will proceed from the fact that the main source of energy of crack formation and destruction are the domains of destruction.

Through crack of length *l* can be formed only when the energy absorbed by the atoms in a in a given volume exceeds the binding energy $U_2 > \frac{h\varepsilon_b l}{a^2}$, where *h*-thickness of the material, *a*-lattice constant, ε_b-binding energy between the atoms.

As a first approximation, we assume that the lattice constant, binding energy and the thickness of the metal does not change. In this case the change in crack length indicates the changes of energy absorbed by the material and we can write $\Delta U_2 = \eta \frac{h\varepsilon_b \Delta l}{a^2}$ (4.4), where η is dimensional coefficient of proportionality, U_2 is the distortion energy, suggested by Maxwell (1.2). Dimension of $\alpha^2 + \beta^2 + \gamma^2 - \beta\gamma - \gamma\alpha - \alpha\beta$ is the same as the dimension of the product of $h\Delta l$.

Consequently, the dimension of coefficients A and B is the same as the fractions $\frac{\varepsilon_b}{a^2}$. This means that the proportionality factors in the Maxwell's equations had the dimension of the surface energy density.

Thus, long before Griffith, Maxwell came to this conclusion. But Maxwell formulated his ideas only if he could make the correct experience. He was not known to those experimental data that could know Griffiths, especially need to know all those who in the 20th century proposed the energy theory of strength.

Today we must recognize that the theory of forming, suggested by Maxwell, is not identical to other theories of strength. It is based on a deep understanding of the phenomenon. Equation proposed by them, contain the physical parameters which can be measured. It offers great opportunities for further

development the theory of strength on the basis of modern physics.

So as to understand the mechanism of formation and growth of cracks is important to know the ratio of energy at every stage of its growth In this case, we can establish that the limiting value of $U_2 = R_2$, at which the destruction occurs, using η changes.

Operation of facilities or devices under real-life environment is carried out by changing the material properties and the character of external influence. This means that all parameters of the right-hand side of equation 4.4, changes during operation. These changes without special experimental studies cannot be taken into account. In this regard, we simplify the problem as much as possible.

We assume in the first approximation, that a, h and ε_b not change and crack length increase depends only on changes in the number of cycles. In this case we can write

$$\Delta U_2 = \frac{h\varepsilon_b}{a^2} \cdot \frac{\Delta l}{\Delta N} \quad (4.5).$$

It may seem that the use of crack velocity $\frac{\Delta l}{\Delta N}$ in equation (4.5) is fundamentally does not change anything in the understanding of the destruction nature and of its mechanism, but this is misleading. As it was shown in Chapter I, the fraction in the fracture mechanics cannot be regarded as a physical parameter which characterizes the process of destruction, because to a certain point no cracks are formed. But this does not mean that change in the deformation process does not occur and the energy of external influence completely dissipated. If we replace the equation (4.5) by

$$\frac{\Delta l}{\Delta N} = \frac{a^2}{h\varepsilon_b} \Delta U_2 \, (4.6),$$

we obtain the equation loos like the Peris-Erdogan equation.

When $\Delta l < a$ the equation (4.6) becomes the inequality

$$\frac{a^2}{h\varepsilon_b} \Delta U_2 > \frac{\Delta l}{\Delta N} \quad (4.7).$$

The concept of "crack" in this case loses its meaning, because we should not use the classical, but quantum representations, considering the Heisenberg uncertainty relations:

$$\Delta E \cdot \Delta t \geq \frac{\hbar}{2}, \; \Delta p_x \cdot \Delta x \geq \frac{\hbar}{2}, \; \Delta p_y \cdot \Delta y \geq \frac{\hbar}{2}, \; \Delta p_z \cdot \Delta z \geq \frac{\hbar}{2},$$

where $\hbar = \frac{h}{2\pi}$ is the Dirac constant.

Inequality (4.7) has for physics of destruction of crucial importance. We represent it as

$$\frac{a^2}{h\varepsilon_b}\Delta U_2 > \frac{\Delta l^*}{\Delta N} \quad (4.8),$$

where Δl^* characterizes the region of the electromagnetic field, in which the accumulation of energy occurs. Catastrophic destruction, as discussed in chapter I, and the explosion of multi-ton meteorite suggests that in such areas hold enormous energy, despite the quantum nature of its accumulation.

Equation (4.5), in contrast to the equations of mechanics describes the energy change in the object due to external effects. Assume that the nanocrack formation whose length exceeds the lattice constant required dN cycles. Then the time of energy accumulation is $dt = \Theta dN$, where Θ is the period of cyclic influences. Thus, we can calculate the energy storage power and to compare it with the power of the radiation.

We'll show it at the specific examples.

Table changes in crack length under cyclic loading, suggested by A. Ahmet allowed us to establish a functional link between external action and the response of the metal, using the equation

For aluminum, studied in [4.11], we have taken the values:

h=1.6·10^{-3} m,

a= 4.05·10^{-20} m,

ε_b=5.34·10^{-19} J,

ν=0.04 Hz,

Crack Δl_1=4.074·10^{-1} m, formed at a pressure of p_1=1.103·10^5 Pa and the number of cycles ΔN_1=174,458; crack $\Delta l2$=1.925 m was formed by the pressure p_2=1.12293·10^5 Pa. The exact number of cycles is not specified, so we take it equal ΔN_2= 175,000.

So, $U_2 = \frac{1.6\cdot 10^{-3}\cdot 1.0\cdot 10^{-3}\cdot 5.34\cdot 10^{-19}}{4.05^2\cdot 10^{-20}}\cdot\frac{\Delta l}{\Delta N} = 5209\cdot 10^{-9}\frac{\Delta l}{\Delta N}$ (J) for h=1.6 mm or $U_2 = 3308\cdot 10^{-9}\frac{\Delta l}{\Delta N}$ (J) for h=1 mm.

In this regard, as the unit of energy used nanojoules.

Instead of tables for cracks, published in [4.11-4.13], are the new tables, which assess the functional relation $\Delta U_2 = F\left(\frac{\Delta l}{\Delta N}\right)$ (4.6), shown in the corresponding graphs.

A distinctive feature of these graphs is that in they $\frac{\Delta l}{\Delta N}$ are an argument but not a function. The energy required for the cracks formation, accumulates, emitted and absorbed by atoms.

Break bonds between atoms occurs only when the energy absorbed by the atoms exceeds the binding

energy. In this case, the interval between the absorption and bond rupture (the appearance of cracks or destruction) is much shorter than the period of exposure, when it is not a mechanical or electromagnetic impact. Energy radiation, its absorption and a crack appears, in this case, an increase in U_2, while the accumulation of its decline.

Since each cycle lasts a certain time, so $\frac{\Delta U_2}{\Delta t} = P$ is the power of external influence

4.4. Features of Energy crack formation in the fuselage

An alternative method for the analysis of experimental research results, based on the account of stored energy is discussed below.

Table 4.1. The energy of cracking near rivet hole A24-R

N	ΔU_2 (1)	N	ΔU_2 (1)	N	ΔU_2 (1)	ΔU_2(2)
36680						
37680	35.723*	61680	21.169	84680	17.200*	64.831
38680	55.569	62680	30.431	85680	23.816*	39.693
39680	15.877*	63680	29.108*	86680	33.077*	35.723*
40680	7.983*	64680	44.985	87680	13.231*	21.169
41680	13.238	65680	5.292	88680	23.816*	31.754
42680	25.139*	66680	22.493*	89680	18.523*	30.431
43680	30.431	67680	19.846*	90680	23.816*	35.723*
44680	3.969	68680	21.169	91680	23.816*	37.046
45680	33.078*	69680	14.554	92680	29.108*	43.662
46680	43.669	70680	13.231*	93680	29.108*	37.754
47680	7.983*	71680	27.785	94680	35.723*	47.631
48680	33.078*	72680	17.200	95680	44.985	46.308*
49680	23.816*	73680	19.863	96680	26.462	46.308*
50680	25.139*	74680	22.493	97680	64.831	54.246
51680	22.492*	75680	7.939	98680	52.923	66.14
52680	43.662	76680	13.231*	99680	60.862	63.862
53680	17.200*	77680	19.849*	100680	75.416	72.770
54680	10.585	76808	13.231*	101680	82.031	84.678
55680	19.846*	79680	11.908*	102680	95.262	92.262
56680	9.262	80680	29.108*	103680	112.462	113.785
57680	25.139*	81680	18.523*	104680	130.00	119.078
58680	25.139*	82680	15.877*	105680	260.00	
59680	11.908*	83680	23.816*			
60680	26.462					

We consider it using the example of cracks in the fuselage and riveted joints near the open holes formatting.

Peculiarities of fatigue cracks in the fuselage have been investigated in [4.11, 4.12]. The results are shown in the form of graphs, images, and tables. New tables and charts describing the energy accumulation and radiation, which results in the formation of cracks, calculated by me on the basis of the tables published in [4.11-4.12]. Let me to pay attention to very important difference between the analysis of experimental data from the standpoint of classical mechanics and quantum mechanics.

Energy absorbed and emitted by atom is quantized. This means that the individual atom absorbs and emits energy only in discrete portions, quanta. Emission spectrum of diluted gases is a line. The width of spectral lines increases due to the impact of some atoms on the other. In this regard, in the solid there is a broader absorption and emission energy spectrum formed. However, to break the bond

between two atoms a certain portion of energy is needed. One of the tables to calculate the energy required for the formation of cracks in the fuselage, cited as an example. Here ΔU_2 (1) and ΔU_2 (2) the cracking energy on two different surfaces in accordance with the table Crack A24-R [4.11].

Spasmodic character of crack formation is clearly visible by comparing energy for various numbers of cycles. For example, when N=36,680, ΔU_2=55.569 nJ, while for N = 40 680, ΔU_2 = 7.983 nJ, i.e. energy of formation of cracks dropped 7 times. Of particular interest are the energy values marked with an asterisk *. These portions are several times repeated 2, 3, 4 or even 6 times (23.816 nJ). Such coincidences are typical only for nano-objects. Description the mechanism of physical processes in nano-objects, using the methods of classical mechanics is wrong.

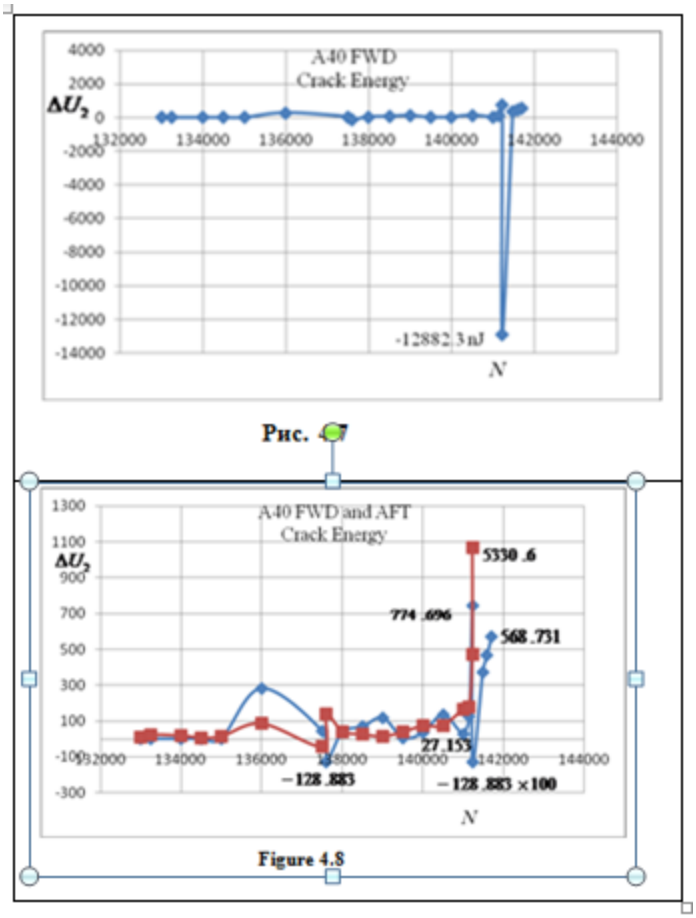


Рис. 4.7

Figure 4.8

In the next chapter we will estimate minimal geometrical dimensions of two areas in which energy absorption 3.696 and 260 nJ has caused cracking.

Other tables using which were built graphs, for brevity are not shown.

We confine ourselves brief comments to them.

I limited myself to brief commentaries.

The graph A40 FWD Crack Energy, characterizing fracture energy for fracture mechanics is a paradox, because it shows the kind of negative energy, indicating the formation of a crack.

In reality, there is no paradox.

Typically it is observed that the crack length upon subsequent exposure more than in the previous one. In this case $\Delta l = l_2 - l_1 > 0$. Hence, under $l_2 = l_1$, Δl=0.

Crack length near rivets A40 remained at 0.1881" (4.7777 mm) when the impact increase from 130,000 to 135,000 cycles, while at N = 137,500 increased to 0.3070" (7.7978 mm), but fell at N=137,600 to 2903" (7.3736 mm).

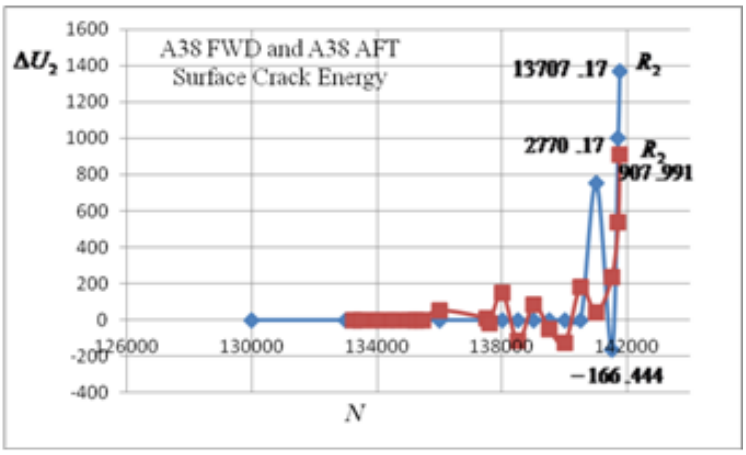


Figure 4.9

This means that energy is accumulated to a certain time, radiated, but then accumulates again, and this was reflected in the chart. Minimum energy was so deep that the maxima on the background hardly visible.

These changes are clearly visible on the same graph, where the depth of this minimum is reduced to a hundred times. Now clearly visible four minimums energy that precede four maximums. Two maxima 774,696 nJ and 568,731 nJ require explanation. The first maximum indicates that the destruction occurred after the accumulated energy and emit relatively small portions until the formation of a minimum of 27,153 nJ.

Energy radiation occurred in a short time, after which a deep minimum-12888.3 nJ is formed. Energy radiated in the maximum 568,731 nJ is less than 5% of the energy accumulated in the minimum. Therefore, at each stage of small cracks formation accumulation of energy occurs, radiation of which at some point may be sufficient for the giant cracks formation, as it happened in 1988, when in the Boeing 737 fuselage a five-meter crack was formed. Two energy minima differ from each other a hundred times, but with such precision that the coincidence may seem random. But coincidences that seem impossible, so many, that we have to take them regularities.

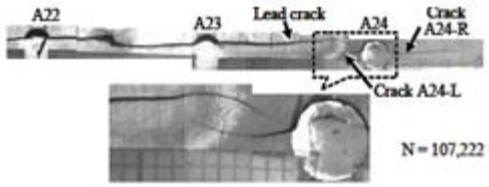
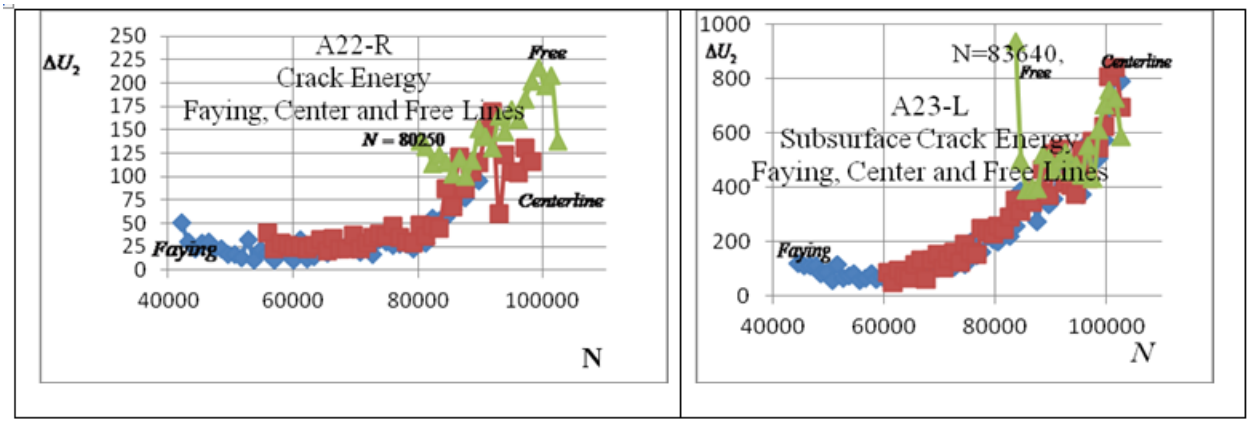


Figure 4.10 [4.11]

The ratio of accumulated (128,833 nJ) and radiated (568.731 nJ) energy is 226.5:1. This means that the area of the metal in which is accumulated and stored long-term excess energy can become a source of destructive energy.

As we can see, the energy radiated for cracking greatly exceeds that which is accumulated: 82.34:1 22.21:1 for FWD and for AFT. Consequently, the extra energy came from another source, possibly from rivets A40. It is the redistribution of energy from the donor to the acceptor due to the processes that are scraping to destruction.



Figures: **4.11** **4.12**

This means, first, that the area of the metal in which the excess energy is accumulated and stored for a long time, can become a source of destructive energy, and secondly, that the power source spatially removed from the crack It has been noted above that the nucleation of cracks occurred between rivets A23 and A22, as shown in Figure 4.10. The first crack was discovered after cycle N=80,550.

It was noted above that the nucleation of cracks occurred between rivets A23 and A22, as shown in Figure 4.10.

Diagrams shown in Fig. 4.11 and Fig. 4.12, allow us to understand the energy of cracks formation. The first maximum of the radiation energy on the Free surface detected near the A22-R after N=80,250. As we can see, the maximum radiation energy precedes detectable cracks. A long crack (N = 83,640, U2 = 936 nJ), stimulated by emission arose to the left from the A23 on the same surface.

More accurate representation of the processes occurring between rivets A23 and A22, can be obtained by comparing the graphs in one figure, as shown Figure 4.13.

Crack extending from A23 to A24, Ahmed believes that the main, since its parameters it surpasses the crack (Crack 24-L), marked by an arrow. Ahmed drew attention to the fact that crack A24-L and A24 R, growing faster than the crack between the rivets A23 and A22.

However, the energy at the maximum A24-R, indicated by $R_2 = 390.31$, is lower than the maximum $R_2 = 936.164$. Consequently, the energy radiated from the right rivets A24, has no significant effect on the processes occurring between the A23 and A22.

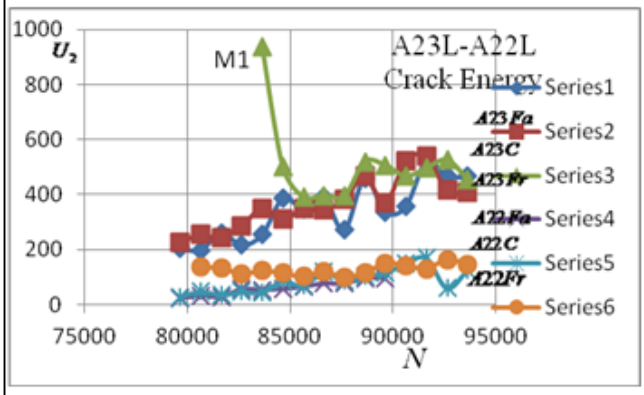


Figure 4.13

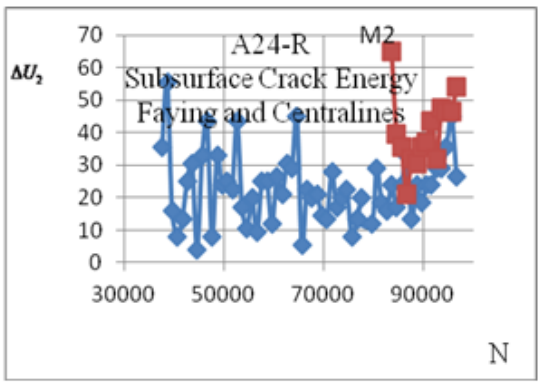


Figure 4.14

Crack extending from A23 to A24, Ahmed believes that the main, since its parameters it surpasses crack (Crack 24-L), marked by an arrow.

Formation of cracks shown in Figure 4.15, published in [4.11] is identical with the formation of cracks as described for four years before in [4.9], despite the fact that the test frequency has decreased five times. Experimental data presented in two papers do not differ by more than 0.5%. This indicates the existence of strict regularity of the observed phenomenon.

It has been established that the crack shown in figure 4.15 (a), growing to the left and right. It reaches the rivet holes for N =85250 (b); new crack like the previous one, was observed left at N=88390 (c). Inextricable crack is shown in Figure 16 (e). This phenomenon has been observed previously, but A. Ahmed carefully measured the distance of such cracks to the rivet holes (Uncracked ligament) during its growth, and published in the dissertation.

Higher (Figure 4.16) shows a portion of the crack growth table A23-L to the moment when the crack reaches the rivet hole. This happens when N=91840, l= 0.2089 ", d = 0 (Uncracked ligament). $\Delta l = 0.2089 - 0.1542 = 0.0547$("), while $\Delta d = 0.0965$" i.e. $\Delta d - \Delta l = 0.0965 - 0.0547 = 0.0418$(").

Consequently, the crack not only grows in the direction to the rivet hole A23, but also there is crack healing from the A22 side. A similar situation holds for crack A22-R, for which, $\Delta d = 0.0592$ and $\Delta l = 0.0348$", i.e. $\Delta d - \Delta l = 0.0244$". But cracks A22-L fracture length change is $\Delta l = 0.0893$", whereas $\Delta d = 0.0802$", i.e. elongation of cracks occurred in the direction A21, equal to 0.0091" It is difficult to assume that A. Ahmed twice mistaken in measurements. *Therefore, there is made an important discovery that cannot be explained on the basis of fracture mechanics as Maxwell warned about this, but understandable from the standpoint of the interatomic interaction*.

In Figure 4.17 shown that for the formation of cracks A24L accomplished work N = 106765,

$R_2 = 67{,}434nJ$ which is 152 times higher than the maximum N = 106160 (Figure 4.18). We can imagine the hurricane that rush aside rivet A23 along the crack, which was formed by 605 cycles earlier.

Recall that this is the energy that is emitted by atoms at the transition of electrons from higher energy levels.

Further growth of cracks in the side of A22 began after it reaches the hole A23. This contact with N = 90480 was accompanied by radiation of energy, marked with a maximum energy of 334.24 nJ, which is visible on the left side of the graph. Energy source declined to the minimum 3.39 nJ for N = 91340.

Accumulation of energy accompanied by periodic radiation, as evidenced by nine equidistant maxima and minima, as seen in Figure 4.18.

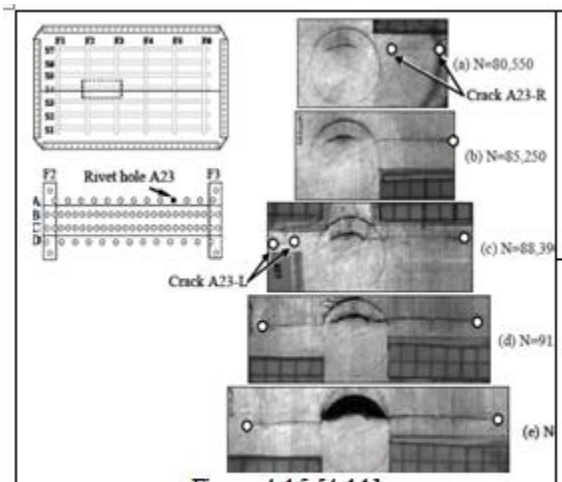


Figure 4.15 [4.11]

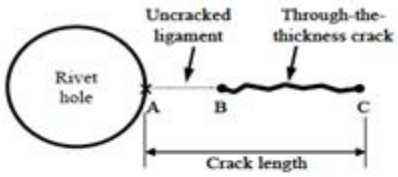


Figure 4.16 [4.11]

N	*l*	*d*
88390	0.1542	0.0965
89450	0.1692	0.0886
89810	0.1772	0.0863
90310	0.1842	0.0774
90810	0.2	0.0753
90840	0.2077	0.0567
91340	0.2064	0.475
91840	0.2089	0

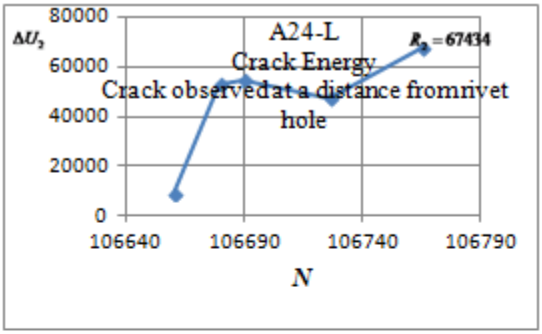


Рис.17

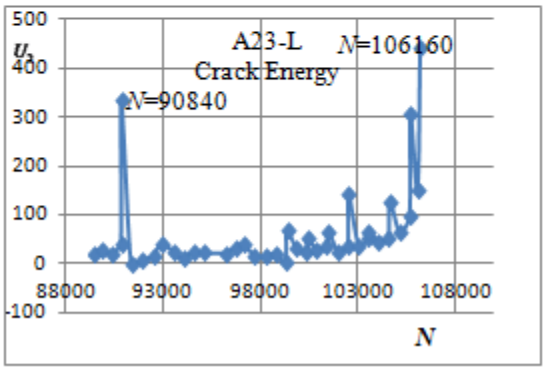


Рис.18

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Accumulation of energy accompanied by periodic radiation, as evidenced by nine periodic maxima and minima, as seen in Figure 4.18

The periodic structure shown in Fig. 4.19, named four- six- or ten-group markers. These groups are shown in the photographs (Fig. 4.19 a). The number of bands depends on the applied stress and the number of cycles. The mutual arrangement of the bands has strict laws.

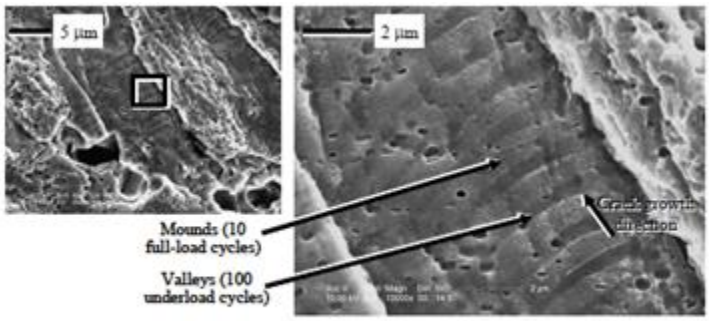


Рис. 4.19 [4.11]

The coincidence of the number of periodic energy minima and maxima with a periodic structure of the crack surface, shown in Figures 4.19 and 4.19 a may seem random. But both of patterns are due to the accumulation of energy and radiation. "Hills" and "valleys" occur as a result of abrupt crack formation. The distance between the strations increases with the crack increase as seen in the photograph (Figure 4.19). This corresponds to an increase in radiated energy, as seen in Fig. 4.20, Fig. 4.21. The periodic structure of destruction occurs under metal thin film tension at the same time in a direction perpendicular to the applied force, as well as parallel to it.

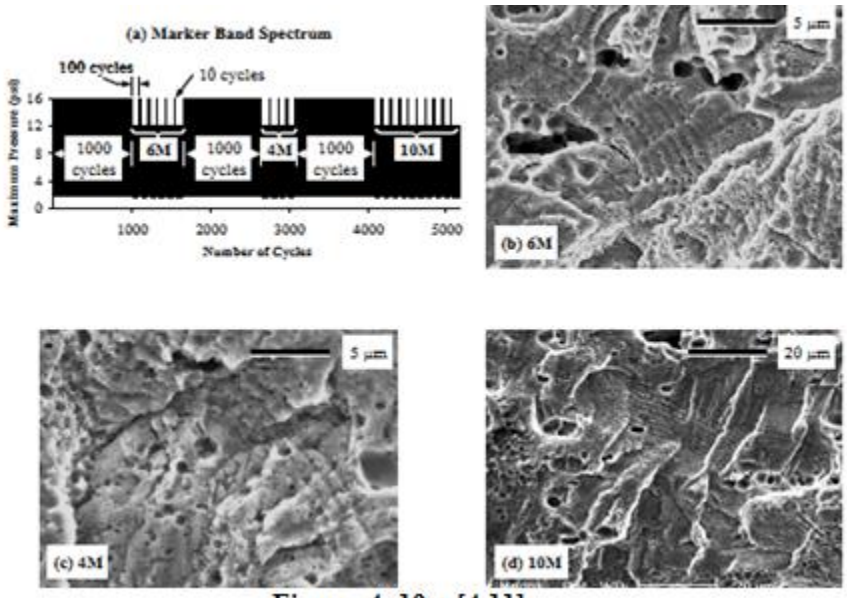


Figure 4. 19 a [4.11]

Images of a well-defined 10M marker band group on the left side of rivet hole A23 sowing hills and valleys corresponding to full-load underload cycles, respectively. Individual fatigue striations are visible on the hills [4.11].

The energy required for the formation of a crack length 407.4 mm, is 2.12 106 nJ. The rapid growth of cracks between 22 and 18, 24 and 27 due to the accumulation of energy rivets in these areas. 107,458th cycle was the signal inducing emission of excited atoms of domain destruction, as well as it happens in laser. This is clearly seen in Figures 4.20 and 4.21. Nearly vertical line charts indicate a high power output.

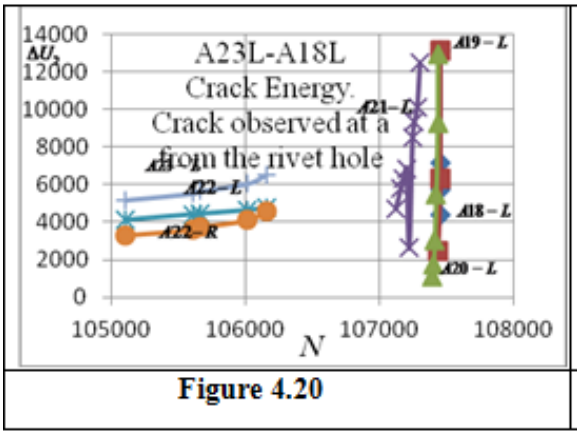


Figure 4.20

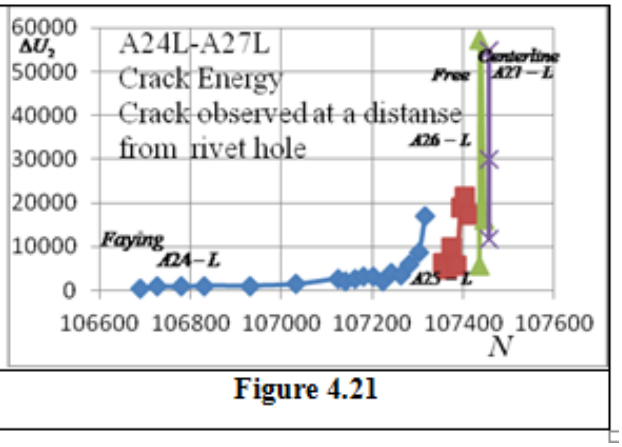


Figure 4.21

SIF solutions for unsymmetrical corner cracks at a straight shank hole subject to tension, bending,

and bearing have been calculated by S.A. Fawaz et al. [4.13]. All structurally significant crack shapes were considered; crack depth to crack length ratios (a/c) of 0.1 to 10.0, crack depth to sheet thickness ratios (a/t) of 0.1 to 0.99, and hole radius to sheet thickness ratios (r/t) of 0.1 to 10.0. As a result, a new fatigue crack growth analysis procedure was suggested which considers propagating the crack at 32 points along the crack front.

As the authors note: "A mathematical splitting method was used to efficiently and reliably calculate the 5,672,700 stress intensity factor solutions."

Wide experimental and analytical investigation of the same problem has been performed by J.J. Rijck [4.14].

Let me cite just one piece of this work, without going into the details:

"5***.3.5 Convergence study***

A convergence study was performed on the mesh generation procedure describes in Section 5.3.2. The results for one crack with crack properties a/c_1=1.00, b/t=0.25 and r/t=1.00 are shown in Figure 5-23. The baseline finite element mesh contains 68,640 elements, three other finite element meshes are generates having 35,350, 52,000 and 84,600 elements. In sequence of element size the meshes have 915,510, 1,341,750, 1,767,990 and 2,180,910 degrees of freedom. The smallest finite element mesh differs 1.51 % from the baseline model. The largest mesh produces results-0.27% from the baseline model. From this result, and small gain that can be achieved by increasing the number of elements and thus the degree of freedom with respect to the baseline mesh the *K* solutions produced by this route are converged."

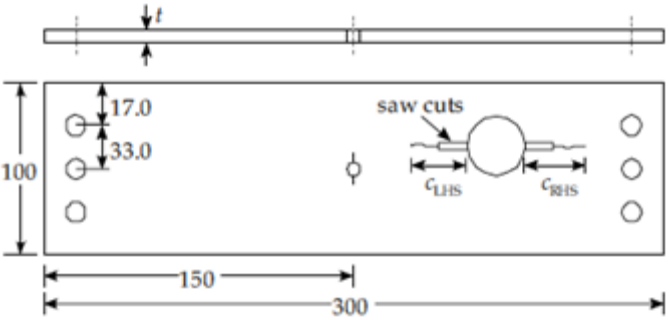


Figure 4.22 [4.14]

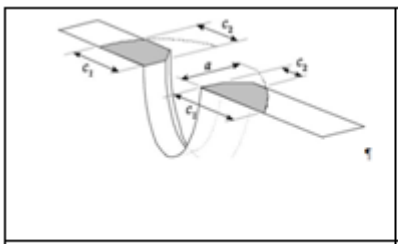


Figure 4.22 a

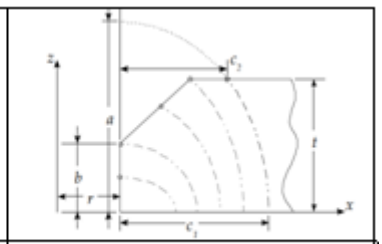


Figure 4.22 b

Experimental studies of the formation of cracks near the open holes thoroughly investigated in J.J.M. Rijck [4.14]. Numerous tables contain the data of length of cracks occurring both in tension and bending

Shape of the sample is shown in Fig. 4.22. Left and right cuts were made in different lengths. Tests were conducted at the maximum load of 100 MPa at a frequency of 15 Hz.

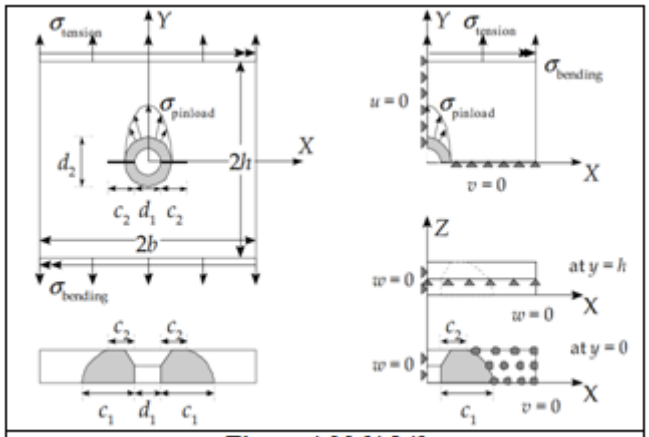


Figure 4.23 [4.14]

102 tables provided in Appendix to [4.14] contains the length of cracks occurring both in tension and bending. The tables presented in [4.14], grouped by category: B-6 tables, C-51 table, D-45 tables. It was measured the length of three types of cracks a, c_1, c_2, shown in Figures 4.22, 4.23. Measurements were taken for cracks occurring to the right of the holes as well as on the left.

Maximum interests are the table of the D group, since the crack length measurements accompanied in this case by a scanning electron microscope investigation of the structure.

The quote that characterizes the analysis of the results is given below.

"**Finite element generation**

Considering the number of crack parameters shape and load cases, a very large number of finite element models must be created. To do this manually, one by one, is a horrendous task that will take too much time and can easily lead to discretization errors. Thus an automated process was developed.

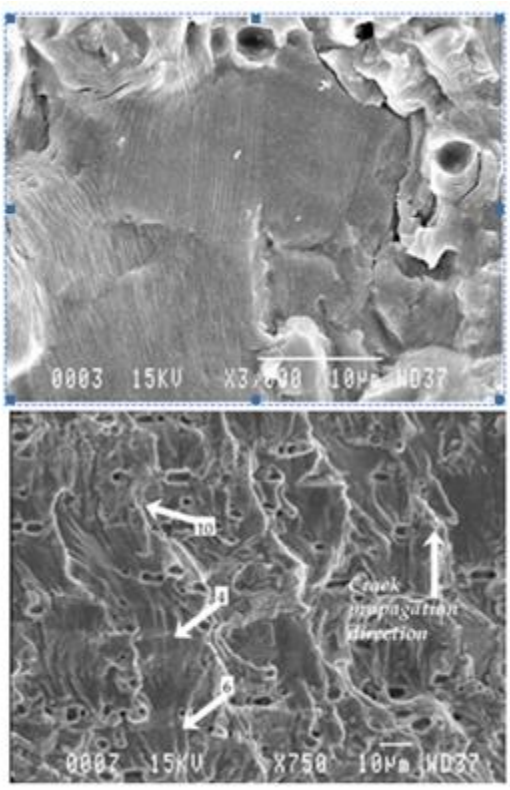


Figure 4.23 a [4.14]

The process is automated in such a manner that the steps most prone to error have been eliminated and only limited manual input is required. The first step in the process is generating a 2-dimensional FEM on the entire crack region. This model is constructed in such a manner that the 2D model contains a complete crack trajectory, meaning that K's can be calculated for multiple crack shapes in one model by simple changing the crack plane boundary condition."

So we see that the automation of the method has not made any fundamental changes in the assessment of the nature and mechanism of the observed phenomenon. Parameters on the basis of which the calculations are crack sizes and the amount of load.

At the same time paper presents the pictures Fig.23 a made using a scanning electron microscope, such as those which are shown in Figure 4.19 and Figure 4.19a.

Four-, six-, ten-, and striation structure were observed in this case also. These groups of striations are taken as the marker, using them for determining crack growth rate. We note that the markers are arranged perpendicular to the direction of crack growth, as can be seen from the photograph Fig. 4.19 and along this, as shown in Fig. 23 a.

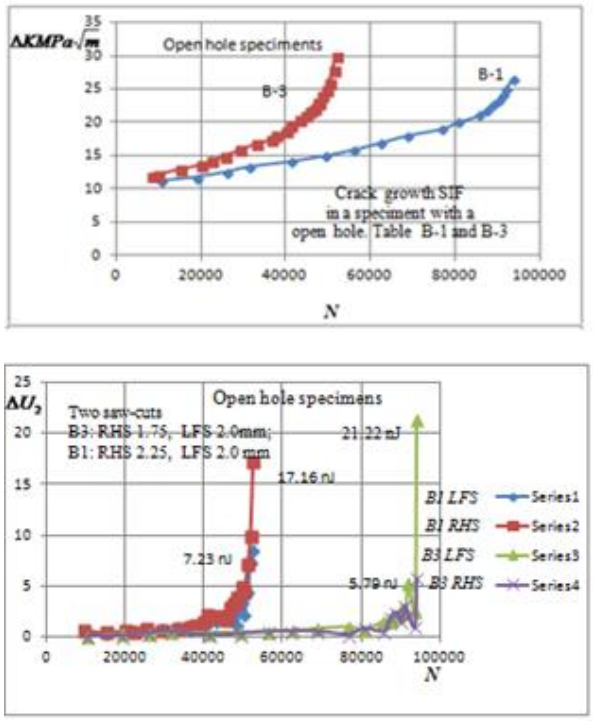
This means that the failure mechanism of the metal coating of the fuselage is similar to rupture of the metal thin film on the polymer surface. However, the metal coating of fuselage is not a nanoobject. This leads to the fact that the electron-wave processes are complicated and the interference pattern is not as clearly expressed. Additional complexity of the interference pattern due that between rivet not only coherent wave interacts but the waves of deformation that radiate by incoherent sources.

The experimental results obtained in [4.13, 4.14], as in [4.10-4.12], studies are of great scientific interest, despite the fact that neither the nature of the phenomenon, nor is the mechanism in them are not disclosed. However, for practical applications we need a method which allows predict when and where there will crack happened, as the first unpredicted crack may result in accidents and loss of life.

The results of studies presented in [4.14] as tables allowed me to perform the analysis of nucleation and growth of cracks from energy positions. The results of my calculations are presented in the form of new tables and graph are shown in the form of new tables and graphs for four (the length of the cracks on the left a_{LFS} and right a_{RHS} sides of the holes on the front and back of the specimen) or nine (a_{LFS}, a_{RHS}, a for three different surfaces) species of cracks.

These charts and tables are provided with brief comments.

The graphs shown in Figures A and 4.24, allow us to compare the method which utilizes the stress intensity factors (4.24 A), with the energy method proposed by me (4.24 B).



Figures 24 A and B

Two samples B-1 and B-3 were selected as the size of the cutout to the left $LFS_1 = LFS_3 = 2mm$, whereas $RHS_1 = 1.28RHS_3$. However, the work done to produce the maximum crack is not consistent with this relationship. Indeed, $w_{LFS1} = 7.23nJ$, $w_{LFS3} = 2.32nJ$, i.e. $w_{LFS1} : w_{LFS3} = 3.05$; $w_{RHS1} = 17.16nJ$, $w_{RHS3} = 5.79nJ$, i.e. $w_{RHS1} : w_{RHS3} = 2.96$.

Of course, that useful information about the cracks get under SIF impossible since for two cracks of each sample is given a graph showing some averaged crack, which is unacceptable.

Graphs of the function *SIF = f (N)*, characterizing the connection between the SIF and the number of cycles to fracture in the samples B-2, B-4, B-5, B-6, are shown in Figure 4.24C. Character of action on samples B-1 - B-2 and B-3 -B-6 varies. These changes resulted from the fact that the graphics for the B-1 and B-2 have a steep climb. The length of the notches in the samples B-3 -B-6 differ at 4-34%, but these differences are mirrored by SIF changes slightly, despite the fact that they are very important, as is seen in Figures 4.26-4.28.

However, the main difference is that instead *of eight graph is shown four*.

502 tables given in [4.14], but I have selected only 130 of them, to demonstrate the distinctive features of the energy method. I draw attention to the fact that Microsoft Offise Exel 2007 Program enough for their construction.

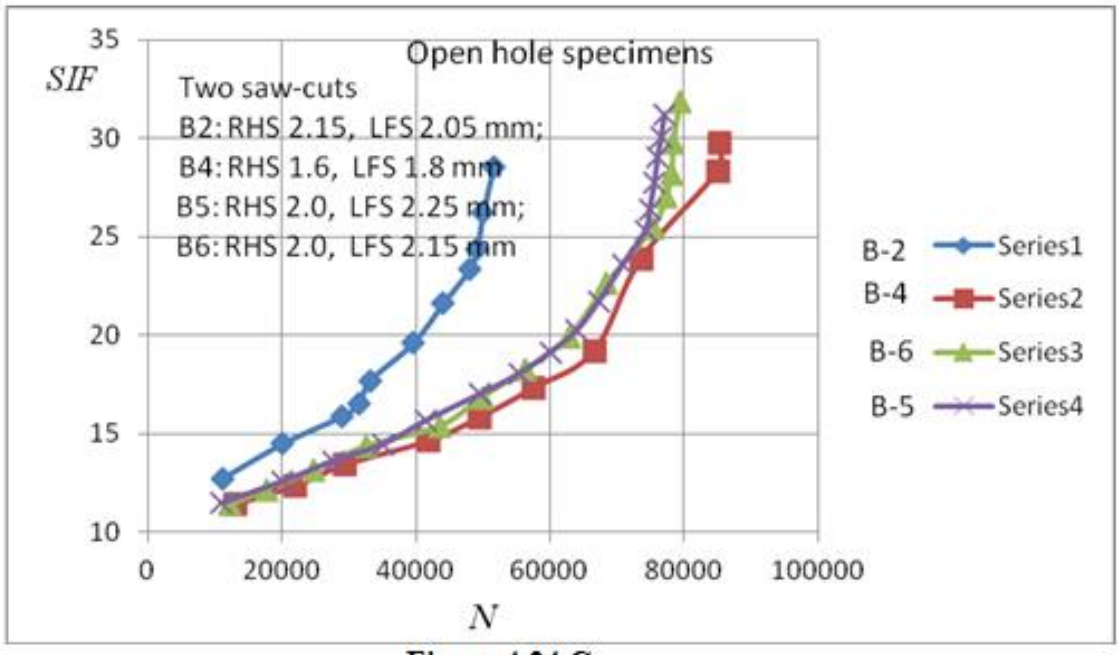


Figure 4.24 C

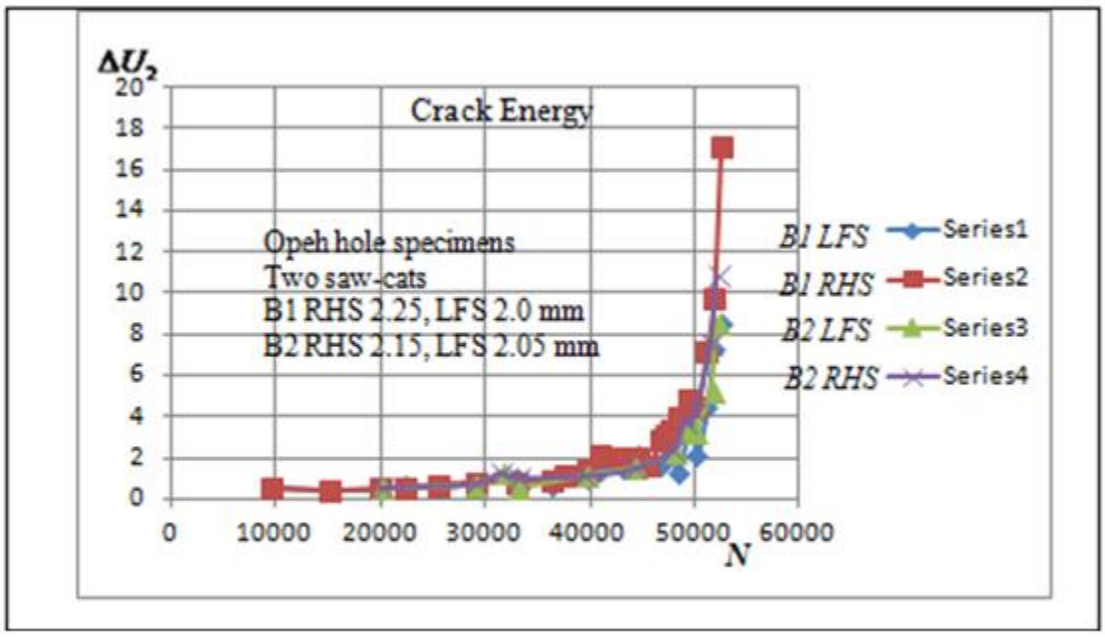


Figure 4.25

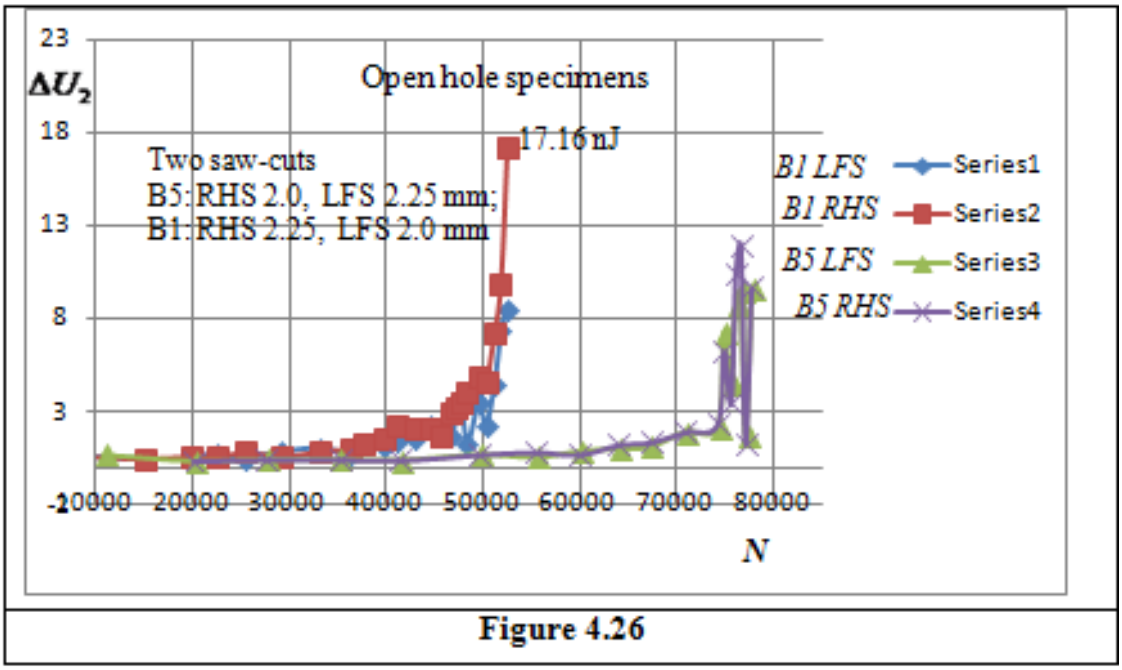


Figure 4.26

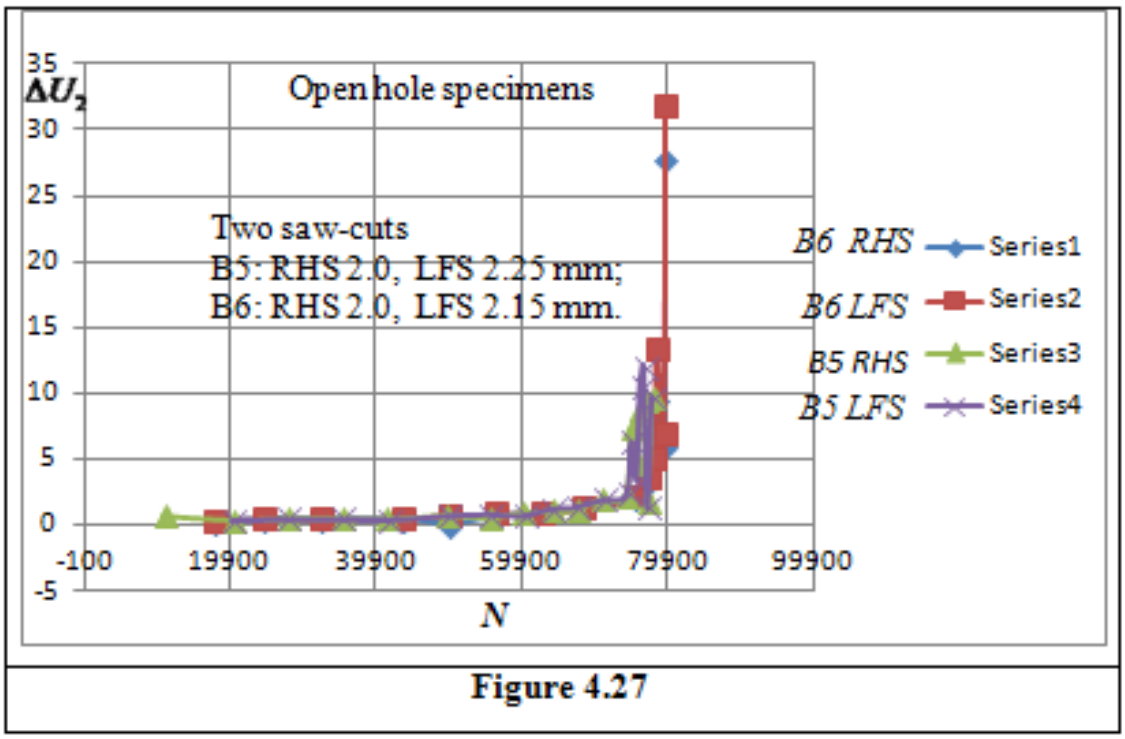


Figure 4.27

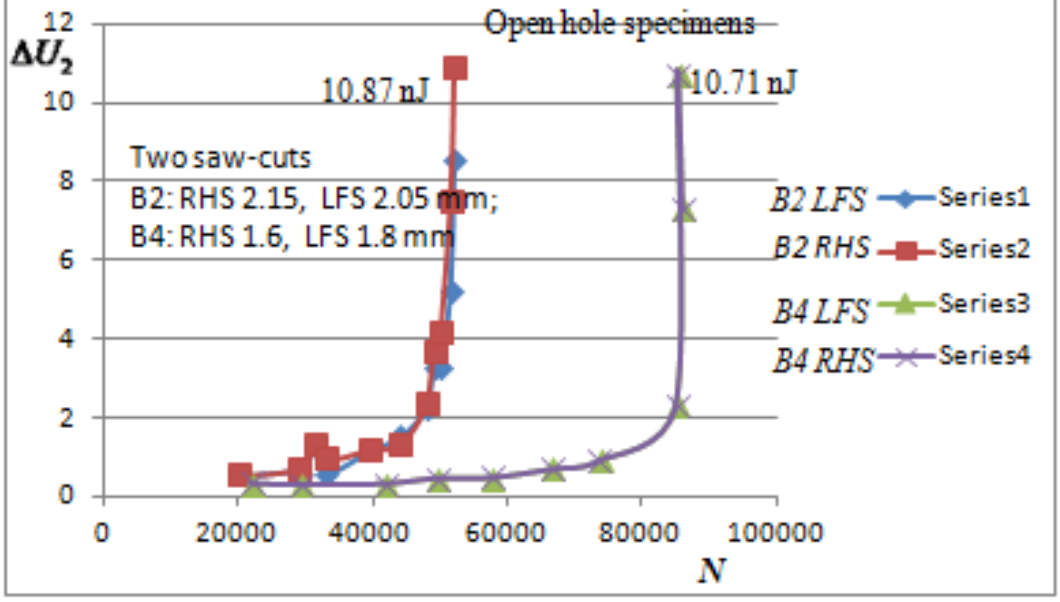
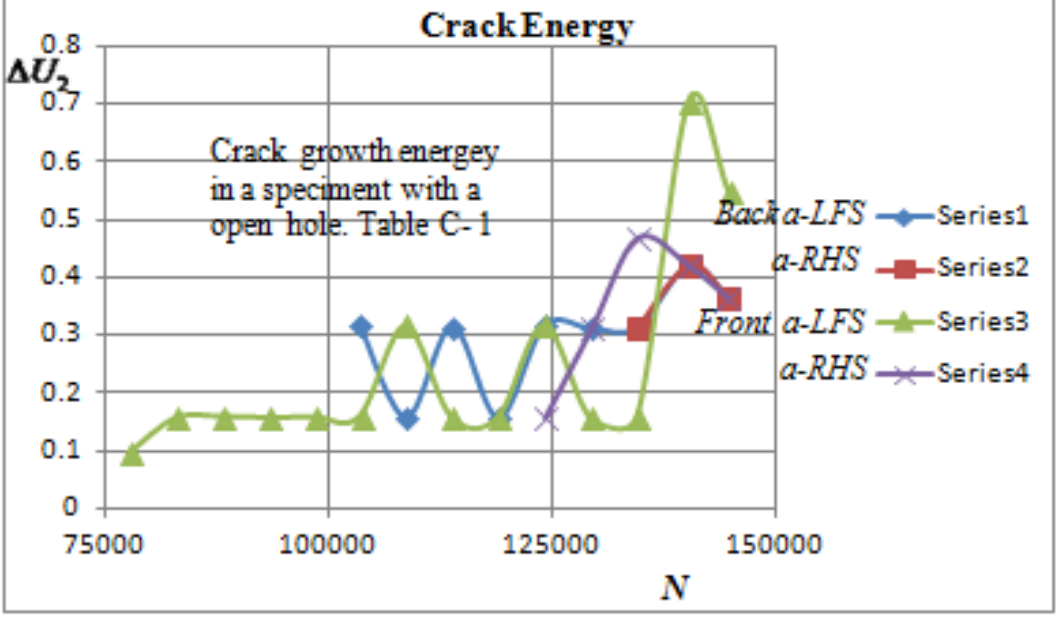


Figure 4.28



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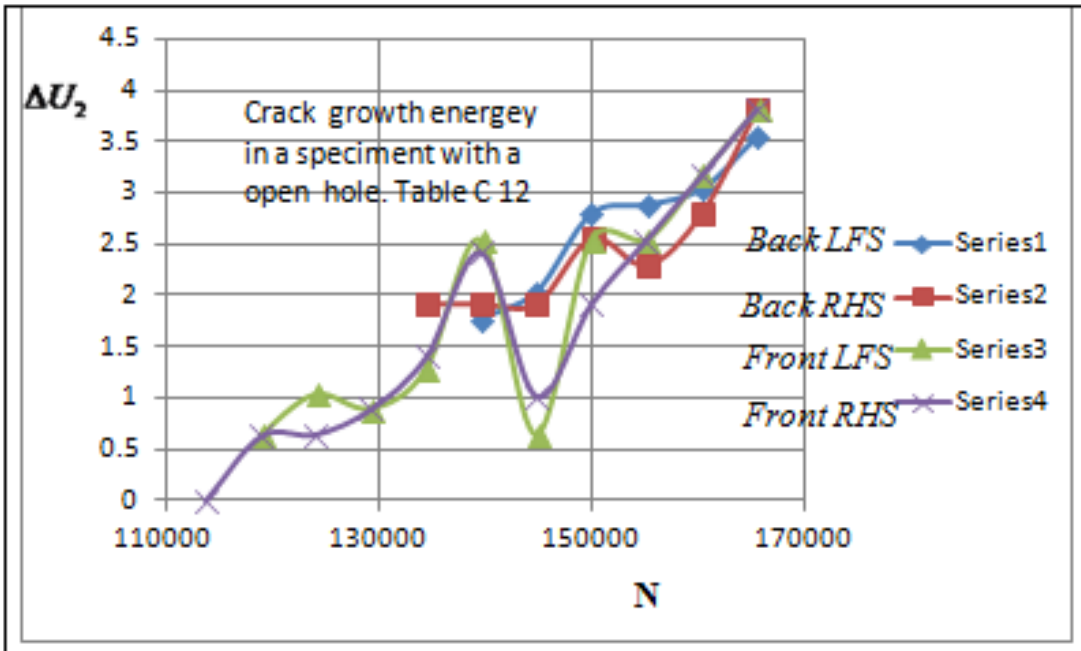

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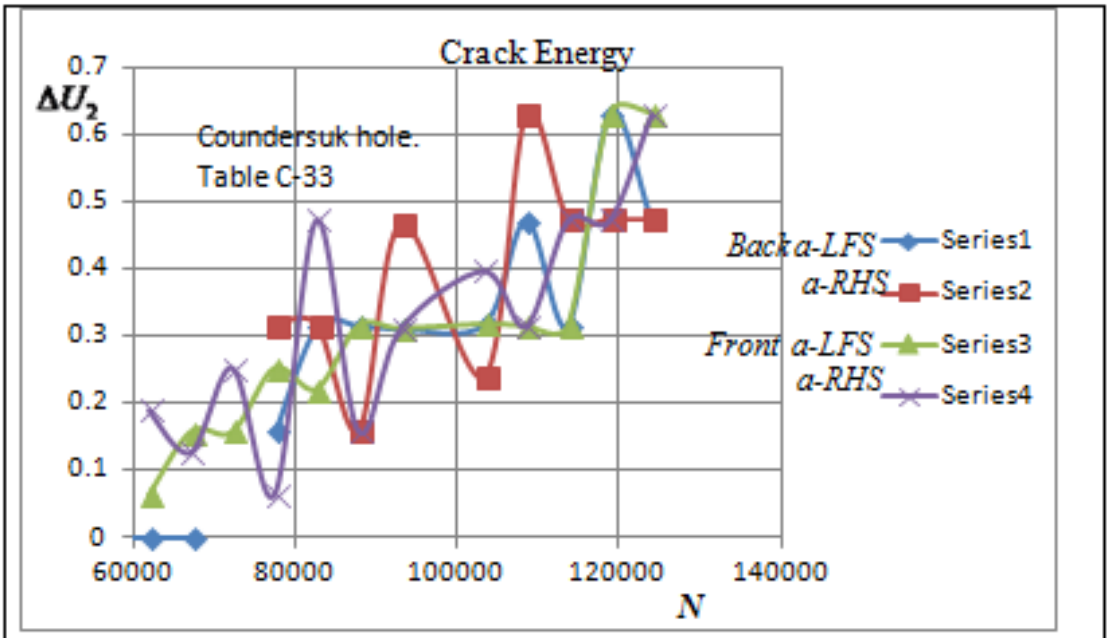

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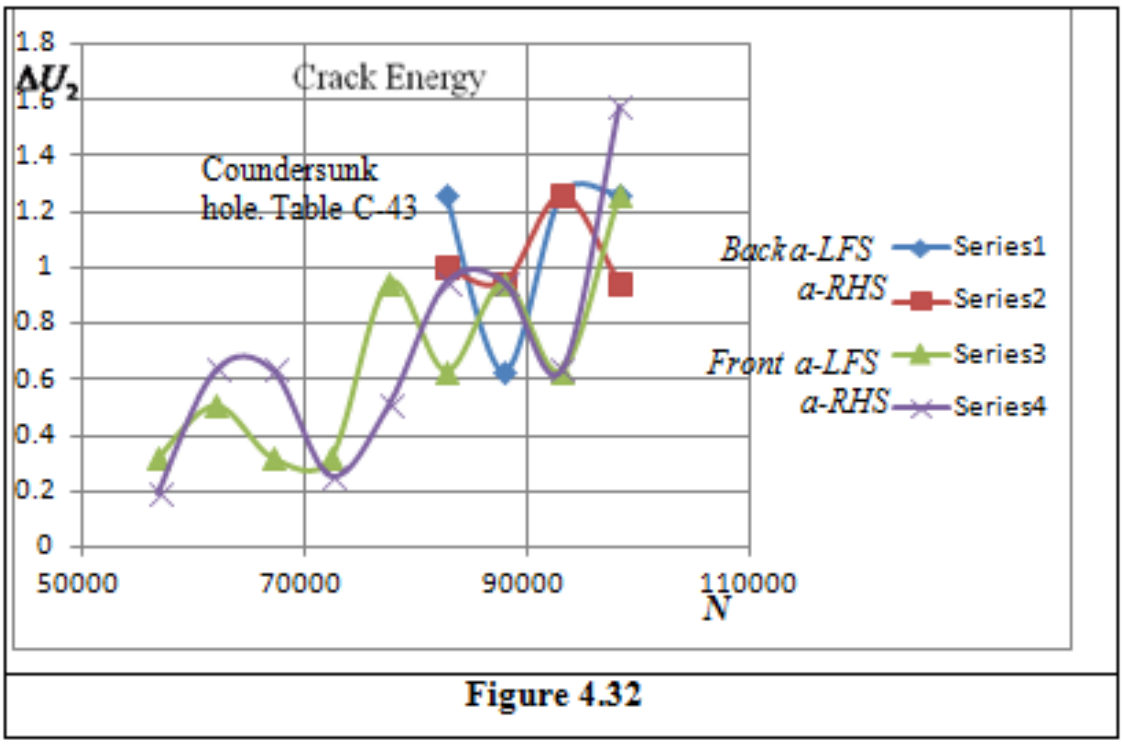

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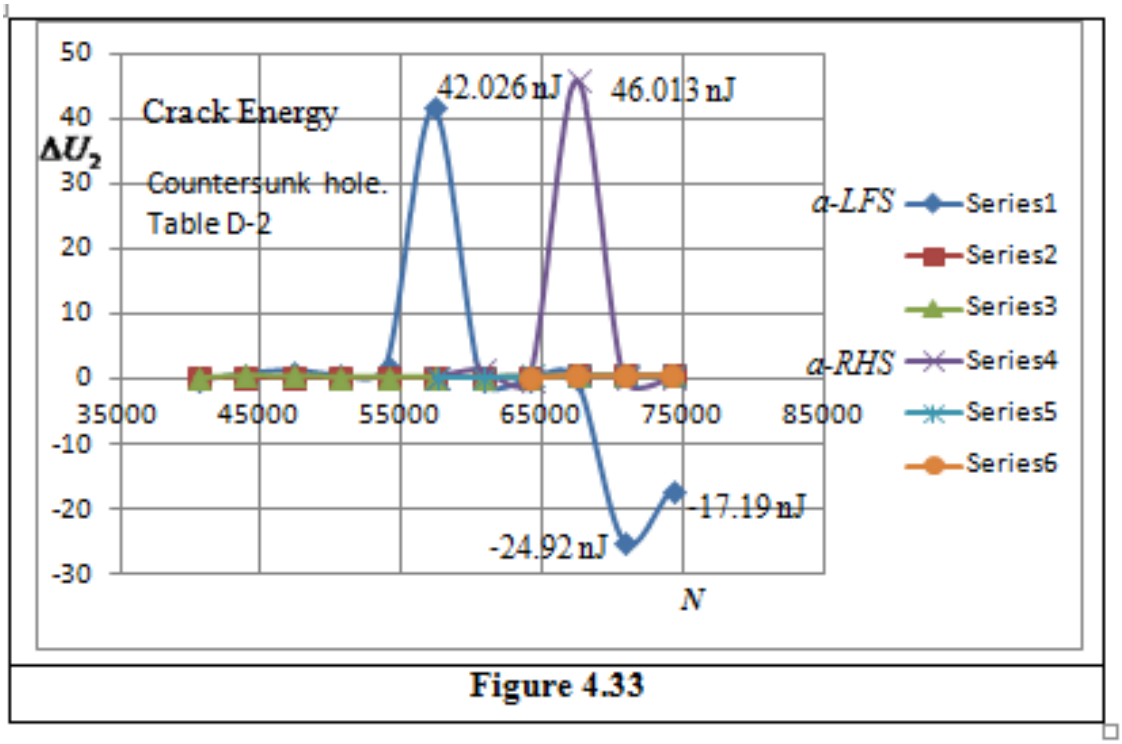

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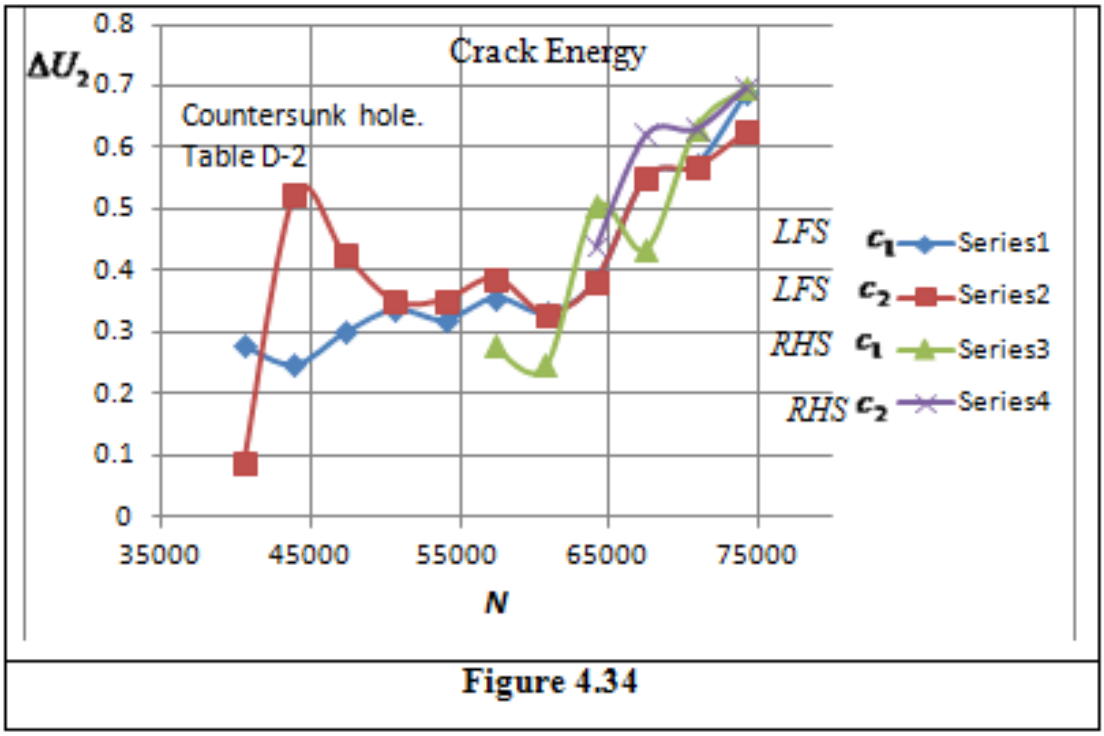

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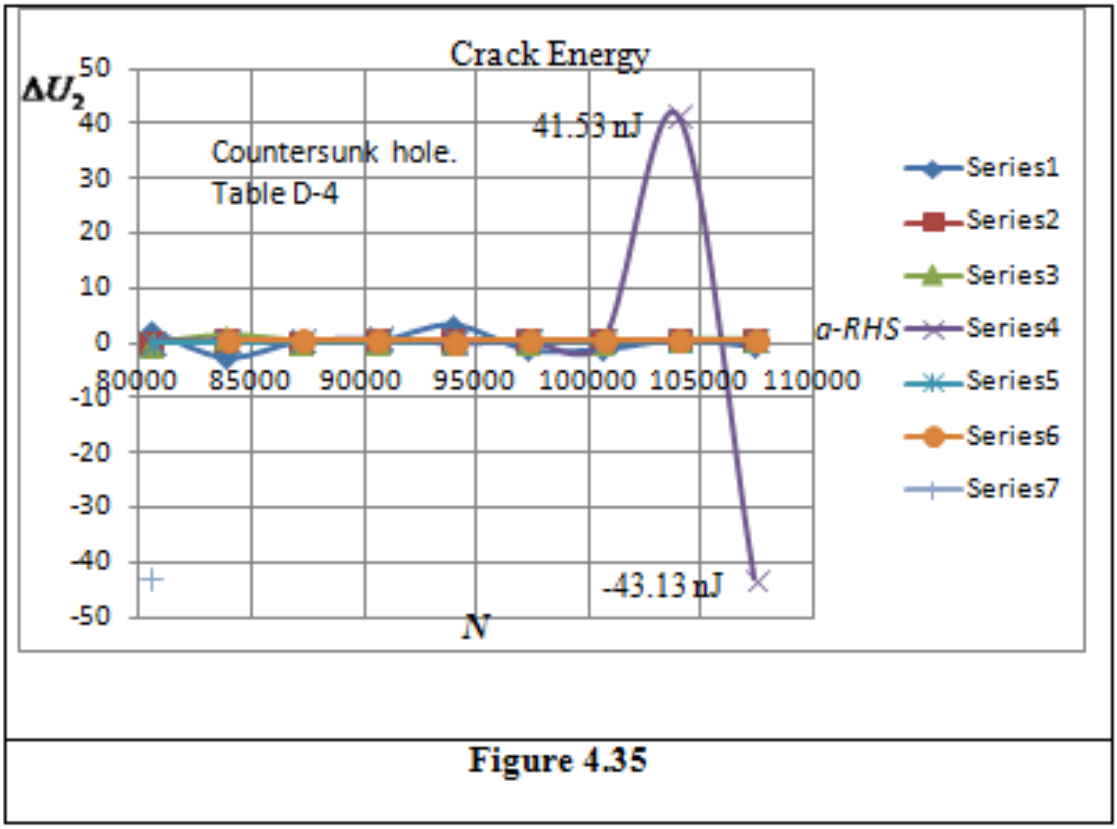

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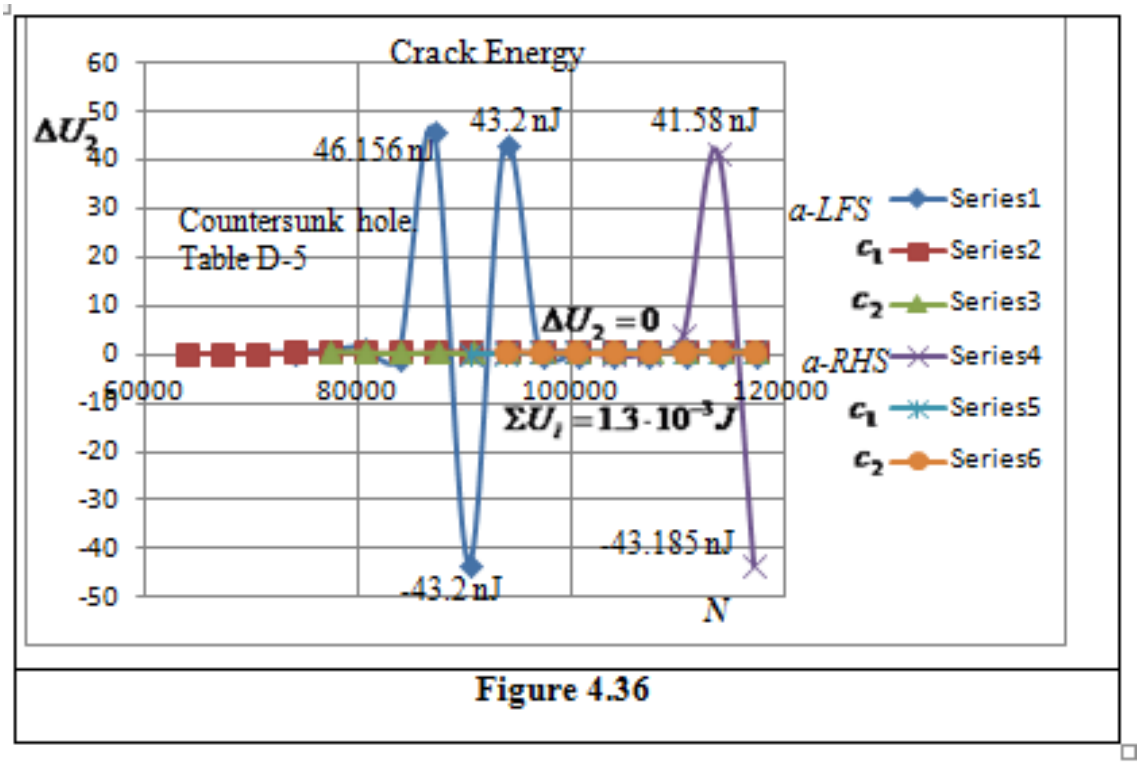

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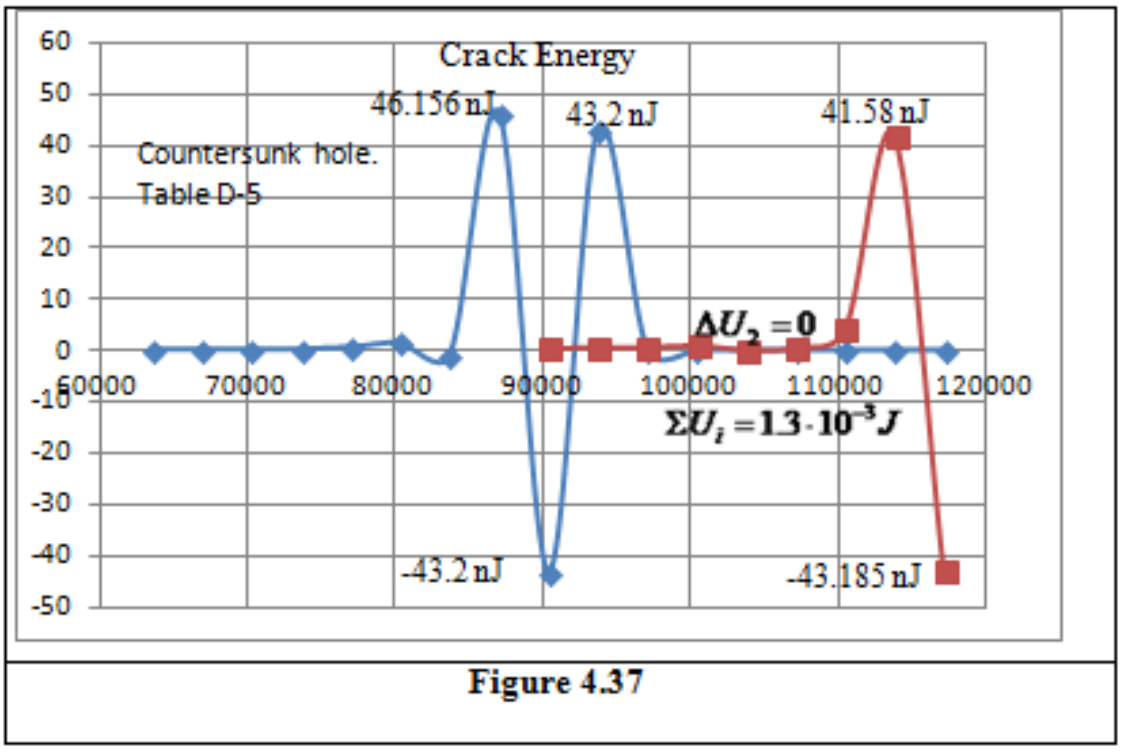

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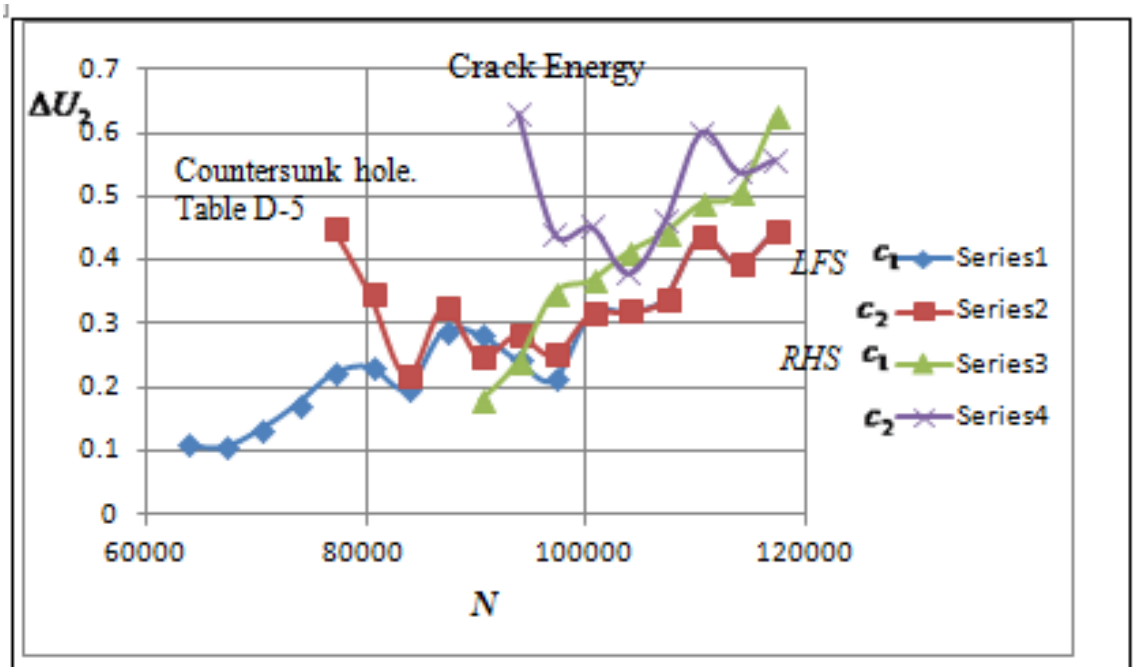

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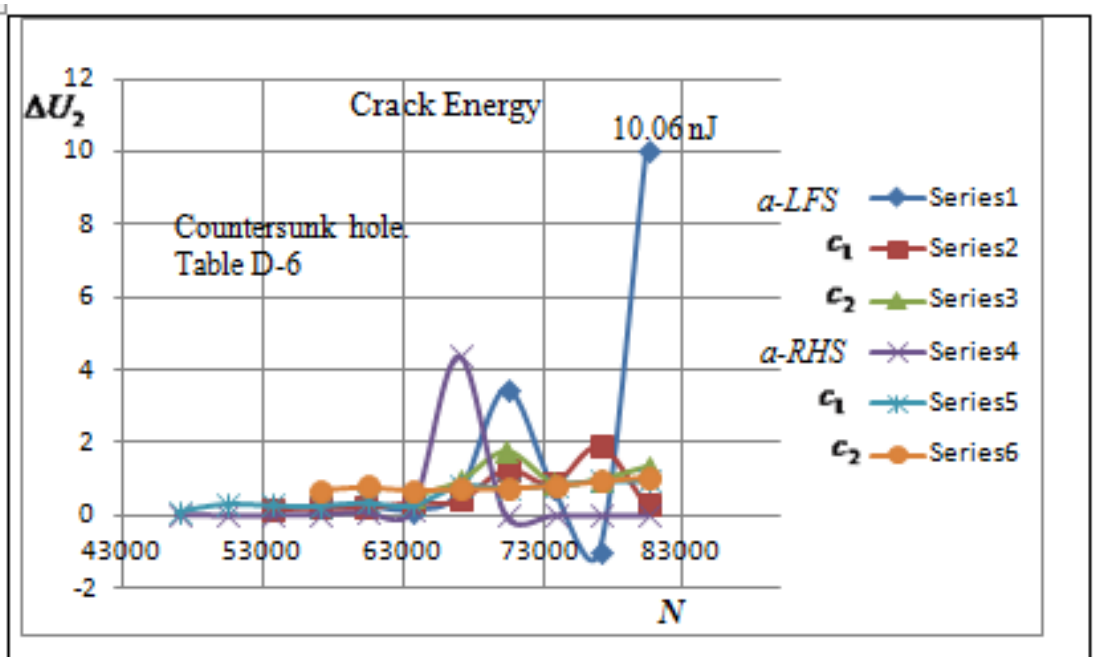

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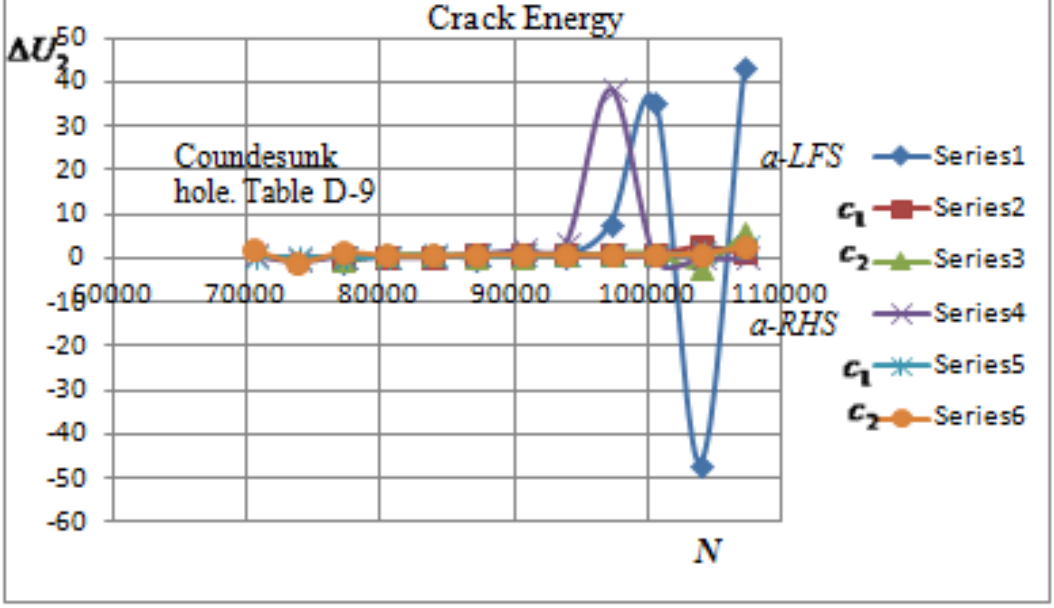

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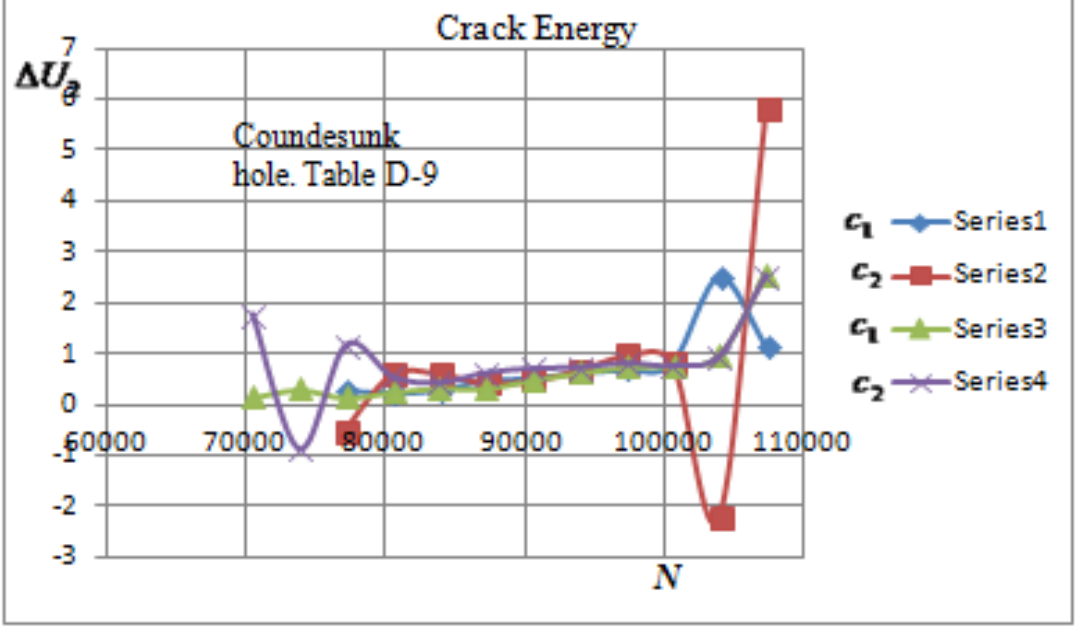

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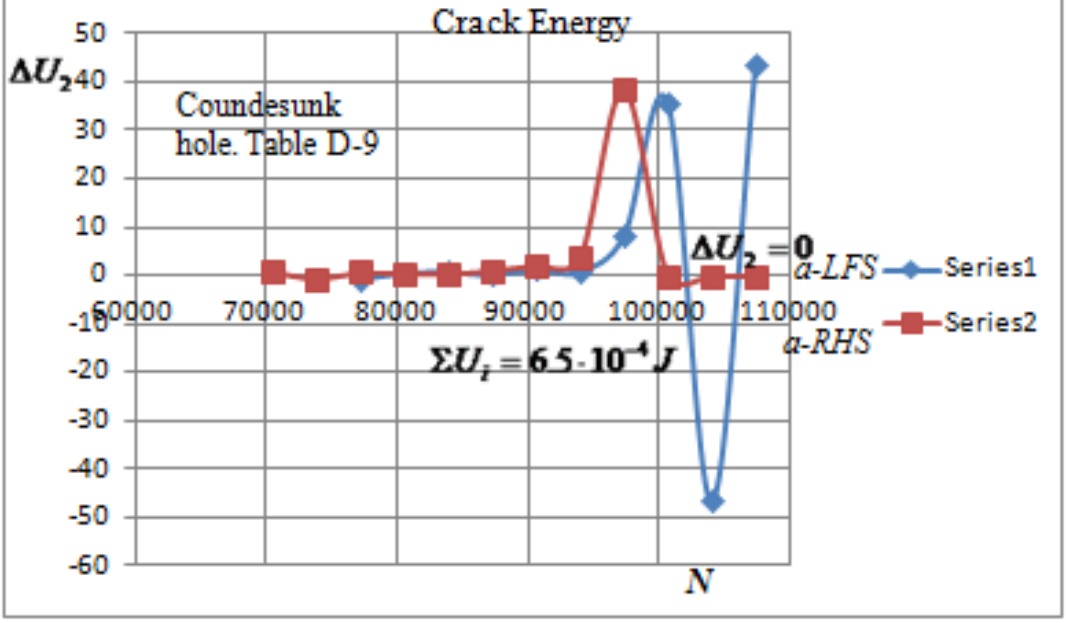

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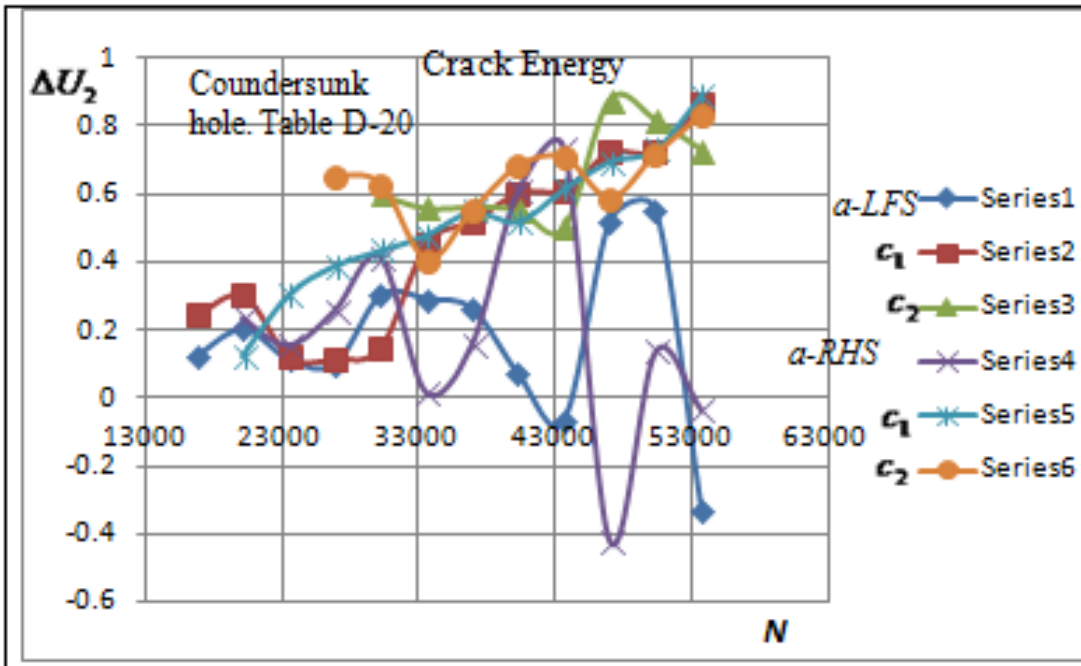

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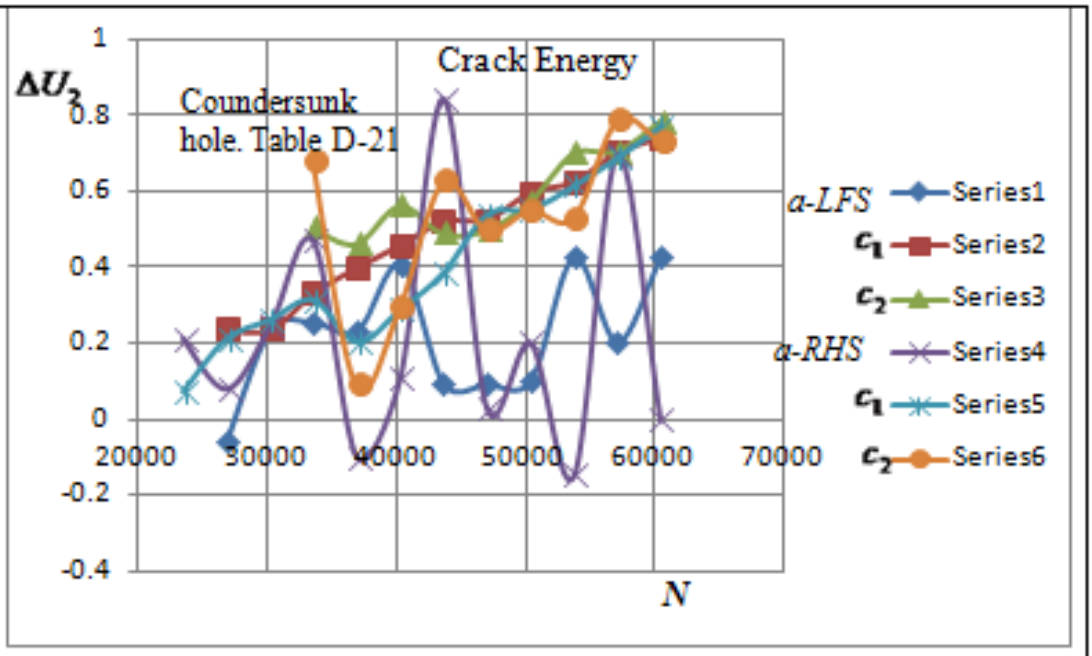

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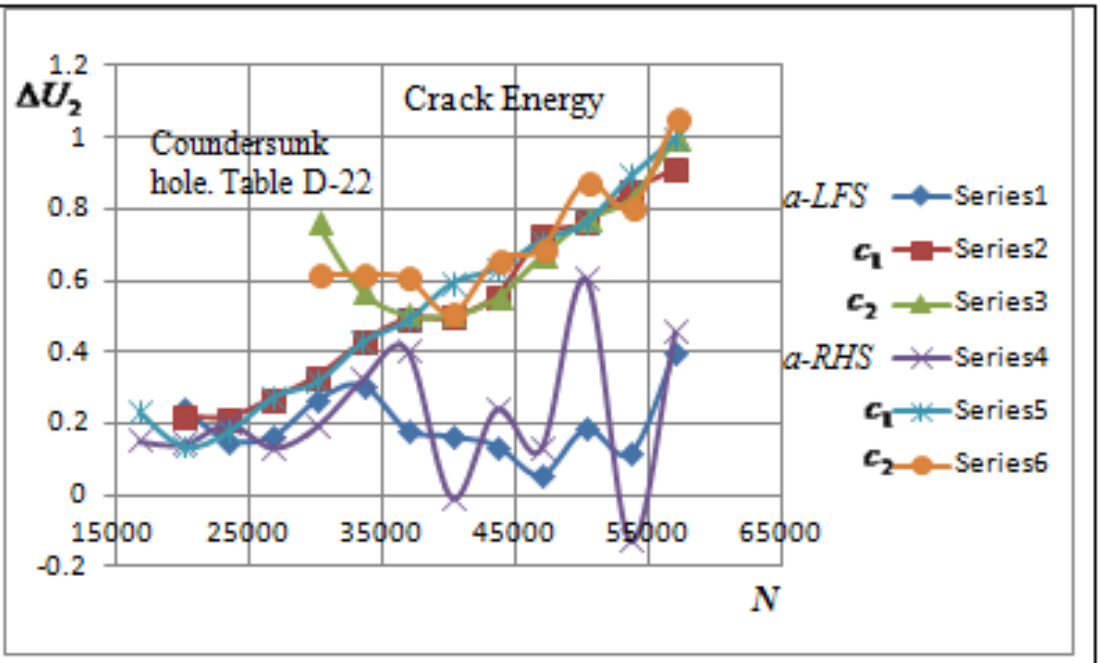

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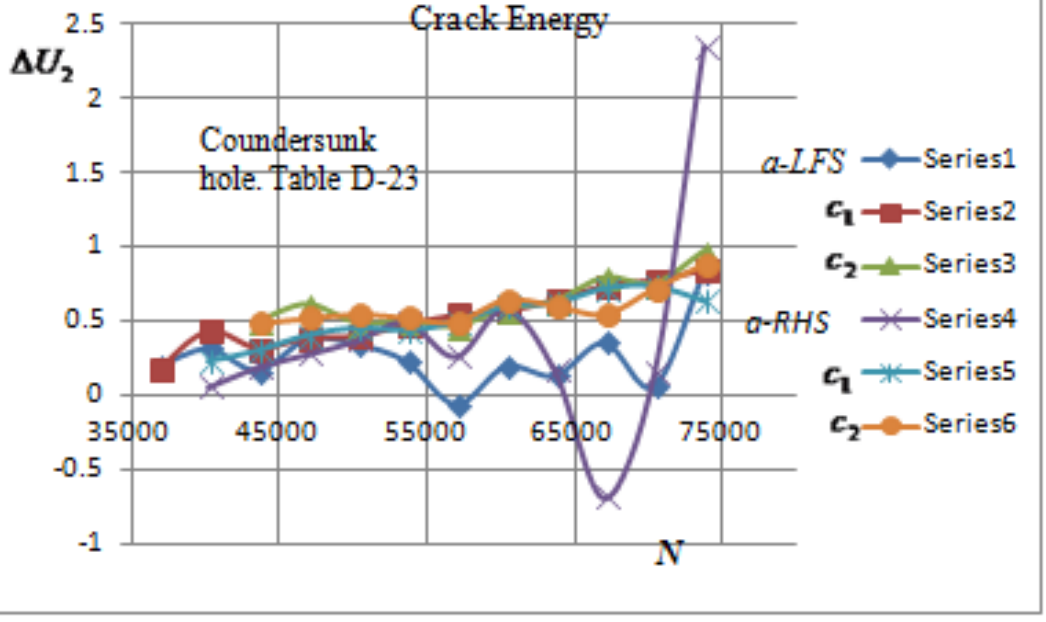

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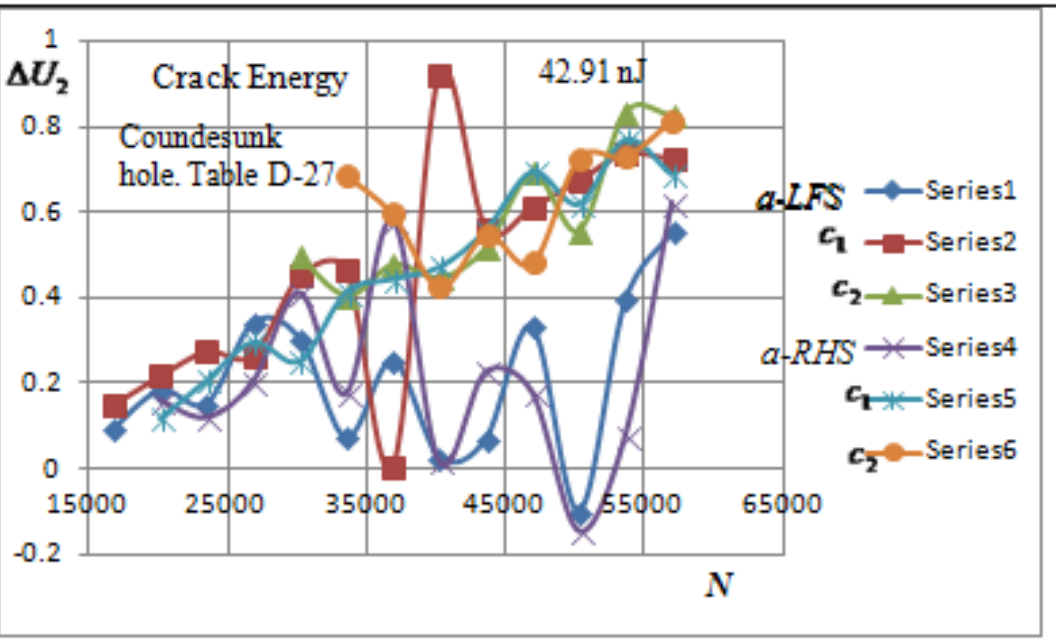

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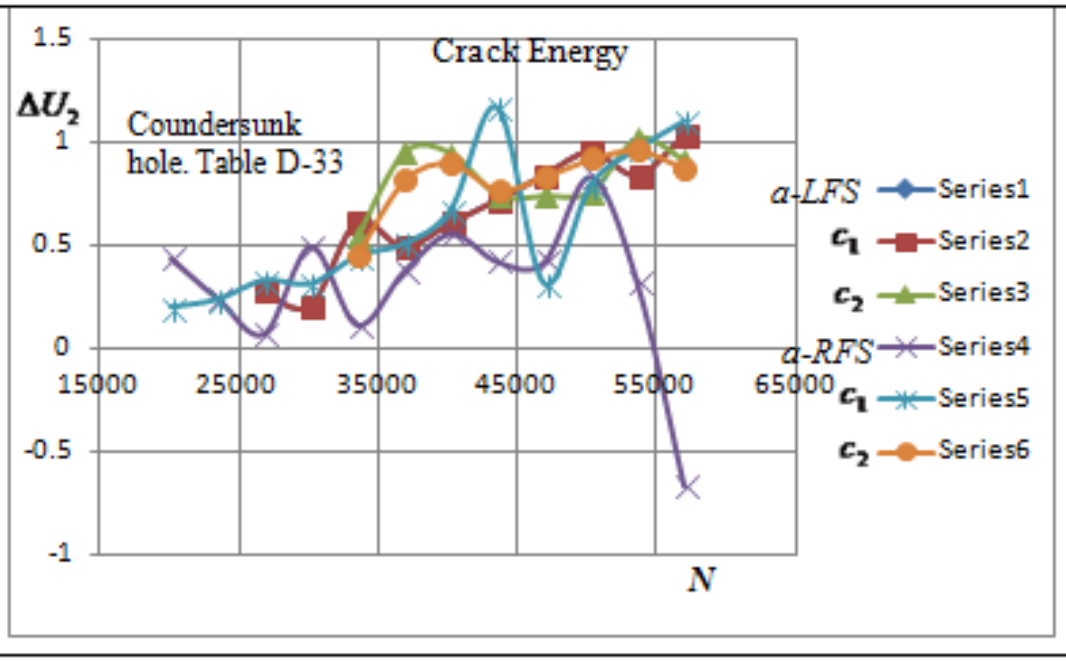

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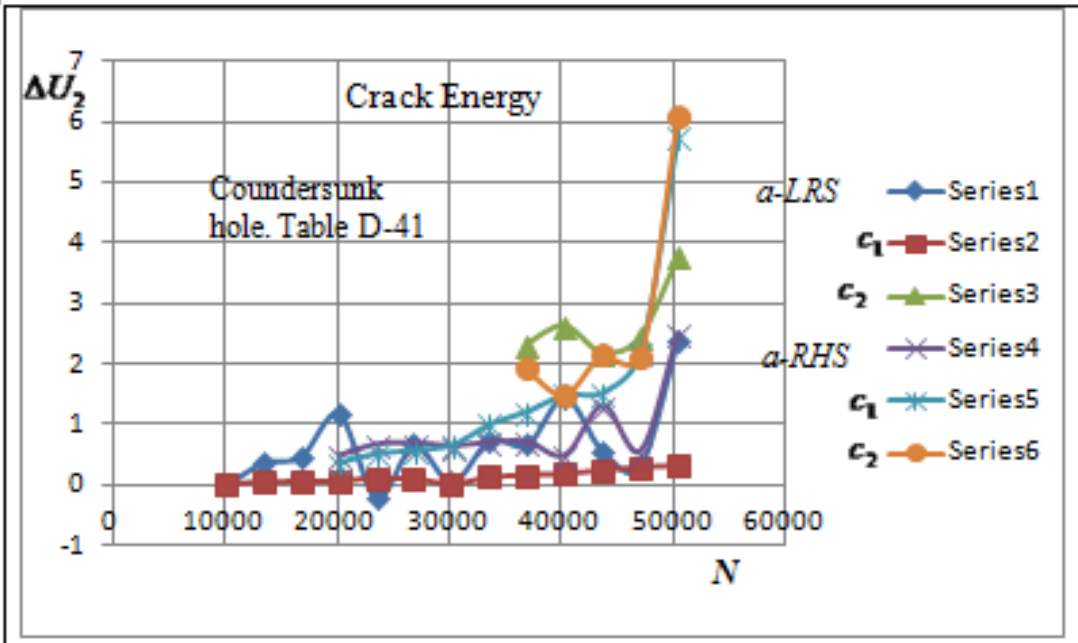

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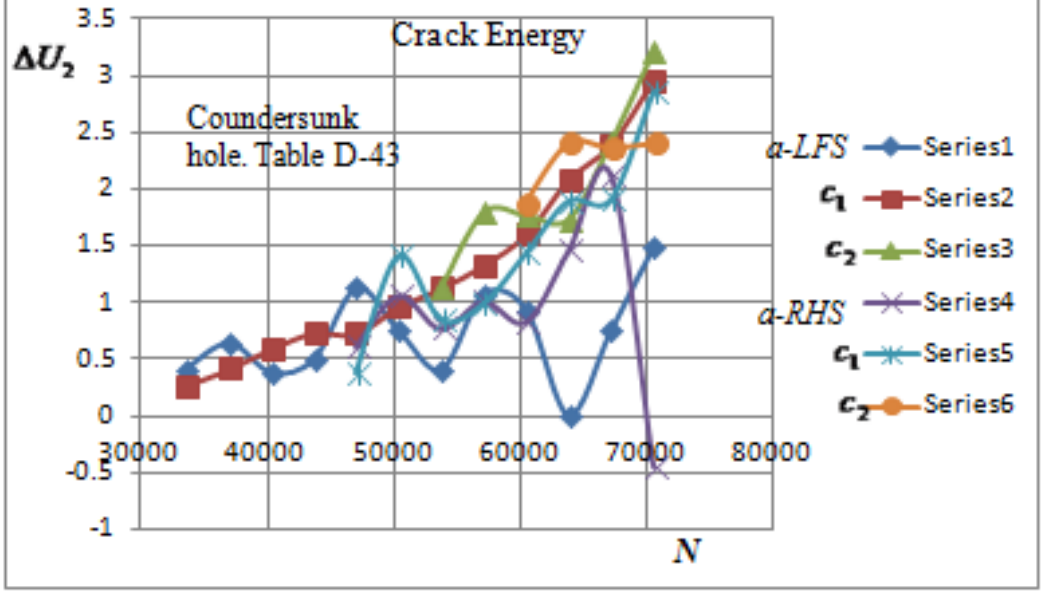

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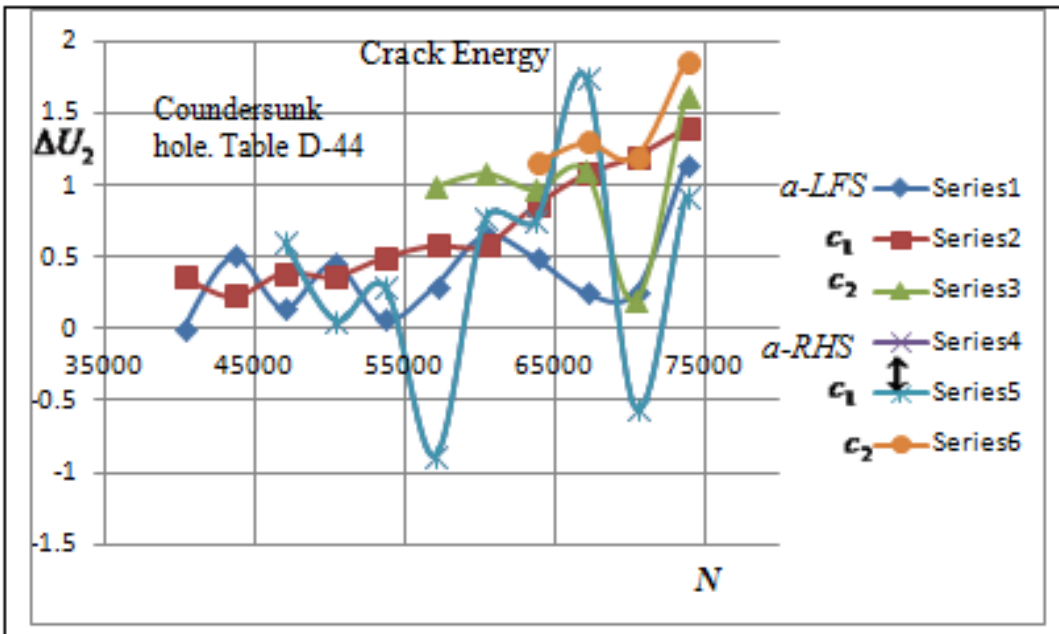

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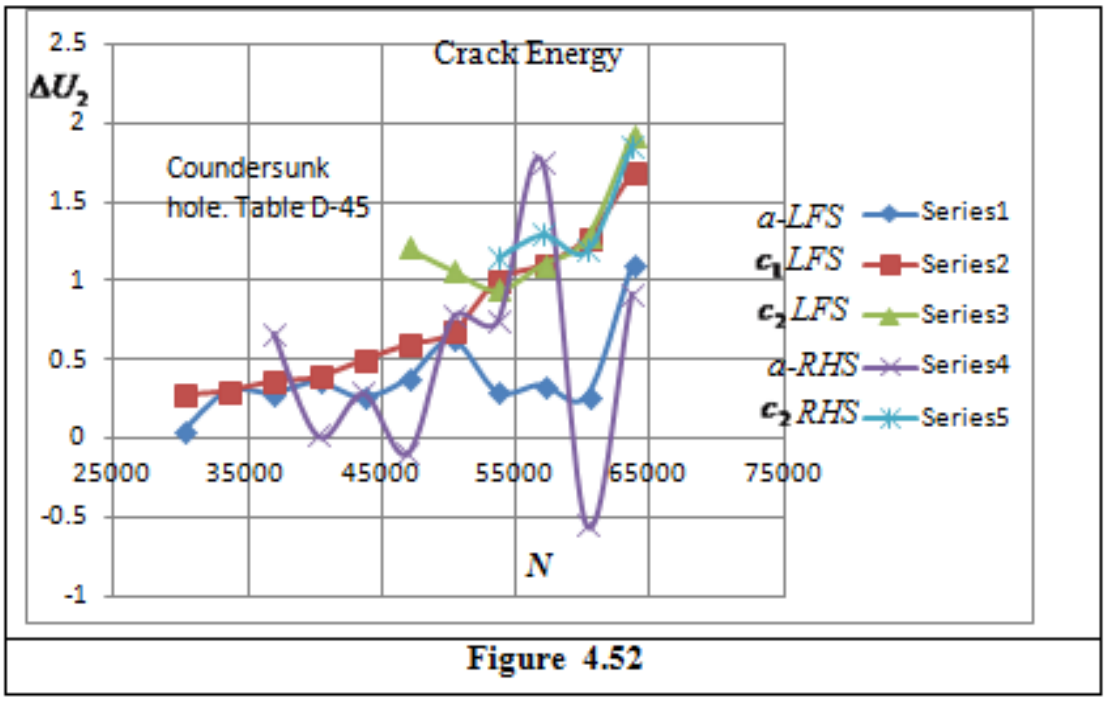

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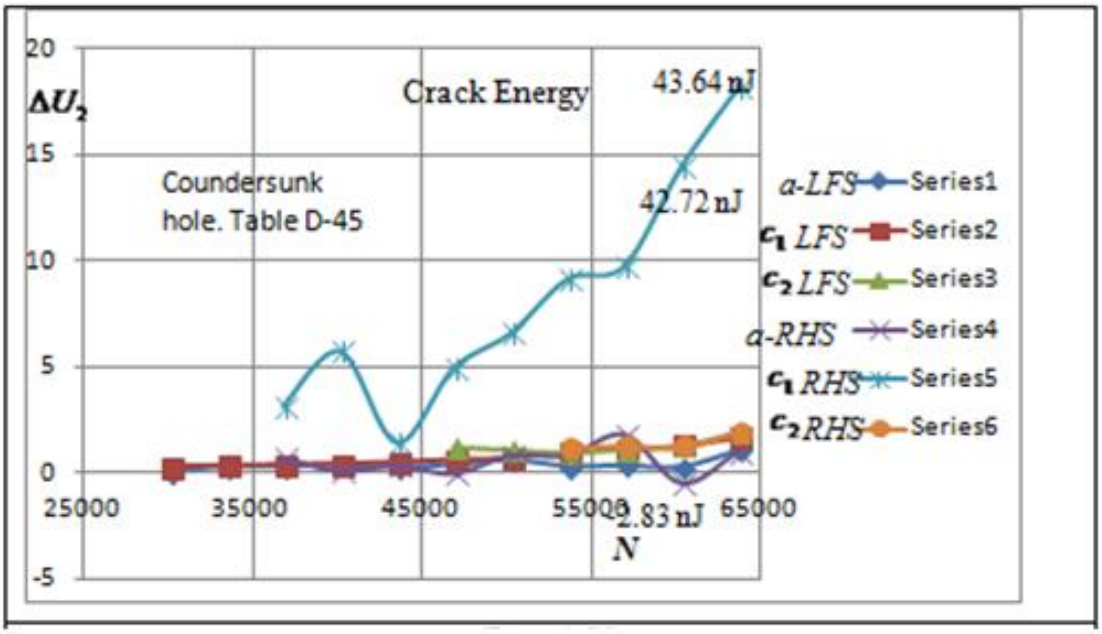


Figure 4.53

Thirty figures contain 167 charts. Detailed analysis of the characteristics of destruction of samples goes beyond of our study. We mention only the most important differences between tables and graphs obtained when the main parameter is the energy from those when the fracture parameters are the stress

intensity factors (SIF).

1. The law of energy conservation is a fundamental law of nature and all forms of energy are measured by one unit, while SIF is not a physical parameter and is unrelated to energy.

2. Physical parameters of the material are not included in the equations of which are used in the stress intensity factors. In [4.14] used seven types of SIF.

3. 3. Crack a, is not measured (see Fig. 4.22b), but is calculated by the formula $2a_i = c_{LHSi} + c_{RHSi} + d$ (1 *) where d is rivet fastener hole diameter. The mean of a is $a_{ave} = \frac{1}{2}(a_{i+1} - a_i)$ (2 *). The difference between the stress intensity factors is calculated by the

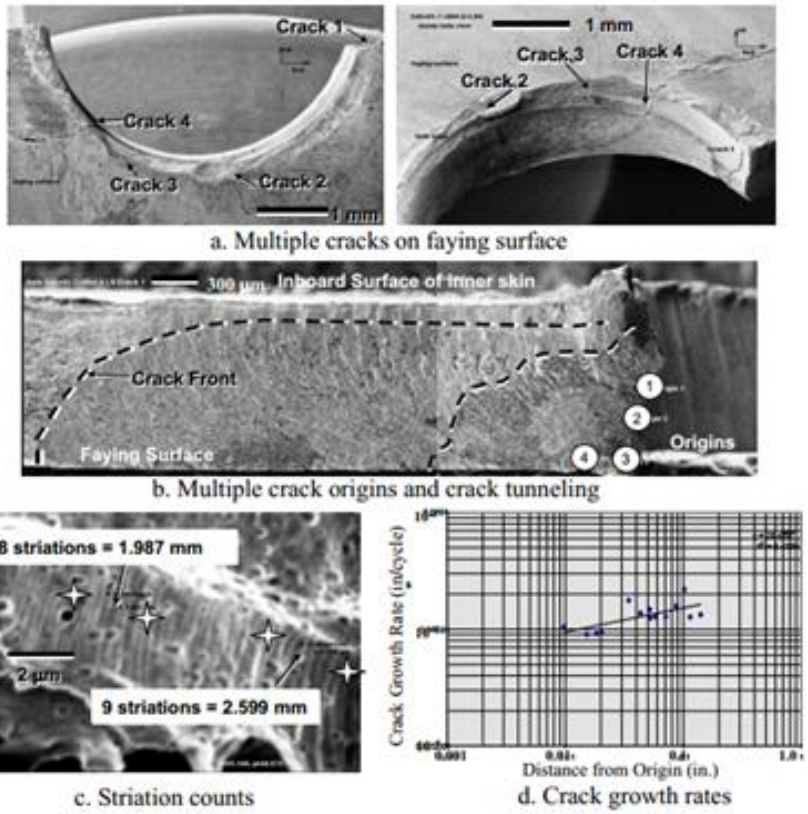


Figure 4.54 [4.15]

formula $\Delta K = \frac{P_{\max} - P_{\min}}{tW}\left(\pi a_{ave} \sec\frac{\pi a_{ave}}{W}\right)^{1/2}$ (3 *) and $\frac{da}{dN} = \frac{a_{i+1} - a_i}{N_{i+1} - N_i}$ (* 4). Here P_{max} and P_{min} the applied force maximum and minimum, t-sample thickness, W-width of the sample.

Note that, first, substituting (1) into (2) and (3), we get $a_{ave} = \frac{1}{4}(\Delta c_{CLS} + \Delta c_{CRS} + \Delta d)$ and $a = 2a_{ave}$. This means that the introduction of pseudo-crack a is meaningless. Secondly, the nature of growth of several of cracks, especially with additional bending is different, as evidenced by the graphs of C and

D groups. Third, there are no experimental evidences for the using of these formulas. However, importantly, averaging of cracks is unacceptable, because they are independent and any of them can lead to destruction!

Conclusions

1. Energy is the most accurate and versatile physical parameter of all processes regardless of their nature, mechanism and consistency. The quantitative ratio of this parameter remains unchanged in all processes.
2. Cracking and destruction has spasmodic character due to the accumulation of defects leading to weakening of the material, and energy storage, leading to rupture of bonds and loss of integrity of the material.
3. Radiation energy is stimulated by nature, in which the power of the radiation energy increases sharply.
4. Formation areas of maximum concentration of defects and of the maximum energy density have a local character. Such local areas can be spatially separated. In this regard, defect density and the energy density reaches a value at which the role of a trigger mechanism plays a low energy signal causes stimulated emission of energy and destruction.
5. Modern methods allow to detecting ultra-weak energy radiation in a wide spectral range from subsonic to gamma radiation. This allows controlling the process of energy storage and locating sources of energy.
6. 6. Modern physical methods allow investigating the structural changes in the local nanoscale regions, i.e, to control the initiation and development of defects and energy sources.
7. Crack or fracture is due of the energy that is accumulated up to the occurrence of radiation. Quantitative evaluation of the energy source, its critical value and its location can be given only by the energy method, one of which is proposed.
8. Thus, modern experimental techniques can provide complete information to assess the state of the elements of technical facilities and installations.
9. The quantitative assessment of the critical state, wear and residual life can prevent catastrophic failure of the controlled object.
10. Huge database of experimental data has accumulated in the study of S-N curves, aging of material, and indentation, including nanoindentation. This entire array of data can be recounted without expensive experimental studies.

2. The energy of the destruction source should be the main parameter for mathematical

programs such as the finite element method.

References to Chapter IV

4.1. Aircraft Accident Report – Aloha Airlines, Flight 243, Boeing 737 – 200, N73711, near Maui, Hawaii, April 1988", NTSB/AAR-89/03, National Transportation Safety Board, Washington, D.C. 20594, June 1989.

4.2. C.-S. Chen, P. Wawzynek and A.Ingraffea: *Crack Growth Sumulation and Risidual Strength Prediction in Airplane Fuselage*, NASA/CR-1999-209115.

4.3. *Evaluation and Verification of Advanced Methods to Assess Multiple-Site Damage of Aircraft Structure,* DOT/FAA/AR-04/42,I, October 2004, Final Report.

4.4. J. H. Starnes, Jr., J. C. Newman, Jr., C. E. Harris, R.S. Piascik, R. D. Young and C. A. Rose: *Advances in Structural Integrity Analysis Methods for Aging Metallic Airframe Structures with* Local Damage Defense Technical Information Center Compilation Part Notice ADP014079 (2001).

4.5. R.G. Forman, V. Shuvakumar, J.W.Cardinal, L.C. Williams, and P.C. McKoighan: *Fatigue Crack Growth Database for Domage Tolerance Analysis, Final Report* U.S. Departament of Transportarion, Federal Aviation Administration 2005 pp.126.

4.6. Silva L.M. Gonçalves, J.P. Oliveira, F M F de Castro: *Applicability of SPATE technique to detection of hidden cracks,* NDT & Internatinal 2000, **33**, 7-13.

4.7. Silva L.M. Gonçalves, J.P. Oliveira, F M F de Castro: *Multiple Site Damage in Riveted Lap-joint Spacimens,* Faculdade de Engenharia da Universidade do Porto, Portugal, http__paginas.fe.up.pt_Lucas_Albuq.

4.8. J.G. Bakuckas Jr., A Carter: *Destructive evaluation and testing of retired aircraft structure*. 6th Joint FAA/ NASA/DoD Aging Aircraft Conference September 16-19 2002 San Francisco, CA. http://www.galaxyscientific.com/agingaircraft2002/SESSIONS/7/7A1_BAKUCKAS_PPT.PDF

4.9. J. G. Bakuckas, Jr, C. A. Bigelow, and Paul W. Tan*: Characteruzation of Fatigue Behavior of Aircraft Fuselage Structures*, ICAF 2003 – Fatigue of Aeronautical Structures as an Engineering Chalenges P.18.

4.10. B. L. Anderson, C-L. Hsu, P. J. Carr, J. G. Lo, J-C. Yu, and C. N. Duong*: Evaluation and Verification of Advanced Methods to Assess Multiple-Site Damage of Aircraft Structure,* DOT/FAA/AR-04/42, I, October 2004 Final Report, pp. 309.

4.11. A. Ahmed, *Initiation and Growth of Multiple-Site Damage in the Riveted Lap Joint of a Curved Stiffened Fuselage Panel: An Experimental and Analytical Study ,*Thesis Submitted to the Faculty of Drexel University 2007, pp.328

4.12. B. R. Mosinyi, *Fatigue Damage Assessment of High-Usage In-Service Aircraft Fuselage Structure,* A Thesis Submitted to the Faculty of Drexel University 2007, pp.423.

4.13. S. A. Fawaz, B. Andersson, J. C. Newman Jr**,** *Experimental Verification of Stress Intensity Factor Solutions for Corner Cracks at a Hole Subject to General Loading*, ICAF 2003–Fatigue of Aeronautical Structures as an Engineering Challenge .pp.31.

4.14. J.J.M. Rijck, *Stress Analysis of Fatigue Cracks in Mechanically Fastened Joints,* Thesis Submitted to the Institute of Metals in the Netherland, 2005, ae_rijck_2005617.pdf, pp 316.

4.15. B. R. Mosinyi, *Fatigue Damage Assessment of High-Usage In-Service Aircraft Fuselage Structure,* A Thesis Submitted to the Faculty of Drexel University 2007, pp.423.

CHAPTER V. METHOD TO ASSESS THE WEAR AND RESIDUAL LIFE OF STRUCTURES AND DEVICES

It is impossible solve the problem at the same level at which it originated. It is necessary to rise above this problem, up to the next level.

A. Einstein

The basis of the method proposed for the prediction the technical condition of buildings and equipment, is Maxwell's foresight that the potential energy the radiation of which leads to destruction, caused by an unknown him new type of interaction.

Let me quote one more paragraph from his work [A Treatise on Electricity and Magnetism (1873), Vol. 2, 439, A Medium Necessary].

"But in all of these theories the question naturally occurs:-If something is transmitted from one particle to another at a distance, what is its condition after it has left the one particle and before it has reached the other? If this something is the potential energy of the two particles, as in Neumann's theory, how are we to conceive this energy as existing in a point of space, coinciding neither with the one particle nor with the other? In fact, whenever energy is transmitted from one body to another in time, there must be a medium or substance in which the energy exists after it leaves one body and before it reaches the other, for energy, as Torricelli remarked, 'it is a quintessence of so subtile a nature that it cannot be contained in any vessel except the in most substance of material things.' Hence all this theories lead to the conception of a medium in which the propagation take place, and if we admit this medium as a hypothesis, I think it ought to occupy a prominent place in our investigations, and that we ought to endeavour to construct a mental representation of all the details of its action, and this has been my constant aim in this treatise."

Maxwell showed that the energy carrier is electromagnetic waves. It was found that electromagnetic waves travel at the speed of light. Hence Maxwell concludes that the light is an electromagnetic wave.

Modern physics has revealed the laws of interaction of electromagnetic waves with atoms.

This is the next level about which Maxwell had dreamed.

Scientific discoveries made by Maxwell, due to deep understanding the physical phenomena whose description he used mathematical apparatus only when he could confirm the findings using correctly staged experiment.

Differential and integral calculus has been developed by Newton and Leibniz. Maxwell repeatedly and successfully used it in his works. Schrödinger and Dirac differential equations are the basis of

quantum mechanics.

The method proposed by me, based on the analysis of numerous experimental facts, but it remains a hypothesis that needs direct experimental confirmation.

I'll use the Maxwell's testament: "Of all the hypotheses ... choose one that does not stop thinking about further investigating of things," hoping that the quantum-mechanical theory of strength and fracture solid will be developed.

Following Maxwell, I have tried to demonstrate this method for solving specific engineering problems.

5.1. Domain of destruction and its energy

Quantum mechanics allows us to estimate the energy state of an atom or group of atoms in the local region of the metal in theory and modern experimental base allows checking out this assessment. Therefore, by analogy with fatigue, we introduce the notion of normal and morbid (pathological, painful) atoms *AM*.

Assume that all atoms (ions), under which the property of the material does not change a normal AN regardless of what they represent. Changing the properties of the material means that there was a change of parameters of a group of atoms.

We can describe all of the changes that occurred in the technical element of the structure or device using four nuclear reactions:

1. $AN + h\nu \rightarrow AN^* = AM$ Electron transfer to the metastable level.
2. $AN + h\nu_1 \rightarrow AM^+ + e^-$ Forced additional ionization.
3. $AN + e^- \rightarrow AM^- + h\nu_2$ Ion and electron recombination.
4. $AN^* - h\nu_3 \rightarrow AN$ Spontaneous or stimulated transition of an electron from the metastable level.

Here AM^+ is a morbid atom (ion) the charge of which is increased; AM^- is a morbid atom whose charge has fallen.

The existence of metastable (long-lived) morbid atoms confirmed experimentally. Maximum energy accumulates the metastable morbidity atom after additional ionization. The removal of electrons from the inner shells of an atom is accompanied by the emission of X-rays, but the lifetime of the atom does not exceed 10^{-8} s.

5.1.1. Formation domain of destruction

Destruction is the result of the rupture of bonds between atoms, due to which the integrity of the

object is compromised and its further operation is impossible.

For the most accurate and objective assessment of technical condition and remaining life of structures and equipment items the main problem must be solved: how and where there is an accumulation of energy, sufficient to destroy, and why it is emitted

To break the bond requires the energy absorbed the atoms exceeded the binding energy.

Maximum accuracy in determining the time after which the operation of the construction or device must cease, is important because premature stop leads to unnecessary losses, whereas unwarranted extension-to disaster.

Modern methods of estimation based on the quantity, quality, and location of structural defects. These defects are due to changes in the position of the atoms. The defect danger that is likely to disrupt the integrity (cracks, pores) is obvious. However, during the operation, there are areas in which the metal is strengthened. Are they dangerous?

The main source of energy is the energy of tension, which, as shown above is lower than the energy of a change in the energy state of a group of atoms, in which there was a structural change.

As noted above, the energy of the external influence is distributed unevenly in the metal due to the formation of standing waves deformation in the local areas. In the antinodes wave energy density is higher than in the node. In absorbed energy atoms is the transition of electrons to higher energy levels, some of which has a lifetime in excess of a period of cyclical influences. Maximum energy corresponds to the ionization potential. In this case, the electron is emitted. There is a certain probability that it will be absorbed by another atom. Maximum chance of absorbing an electron has an atom, located in the node. Thus, under certain conditions the energy of the external action expended on ionization emitted during the recombination of an electron with another ion. Since these processes are spontaneous, the photons emitted by recombination, are scattered in the environment, or heat the metal.

Eventually, after some time two areas are formed in the metal, in one of which atoms accumulate AM^+, while in the other- AM^-. Let's call the first area as the metastable area of the maximum energy density (MAMED), another area - the metastable area, the maximum defect concentration (MAMDC). Spontaneous transition of electrons from MAMDC in MAMED leads to the spontaneous photons emission, their dispersion and heat, i.e. energy dissipation.

The term of safe operation of the facility or device depends on the ratio of the rate of accumulation and the rate of energy dissipation in these two areas, which form the *domain of destruction*.

The higher is the rate of energy storage, the shorter the lifespan. The maximum rate of energy

accumulation is under the influence of electromagnetic impulse created by laser or electric shock. It is a bit smaller in mechanical impact. Rate of energy dissipation is caused by the thermal conductivity and borders transparency for the photons of the area where the radiation is.

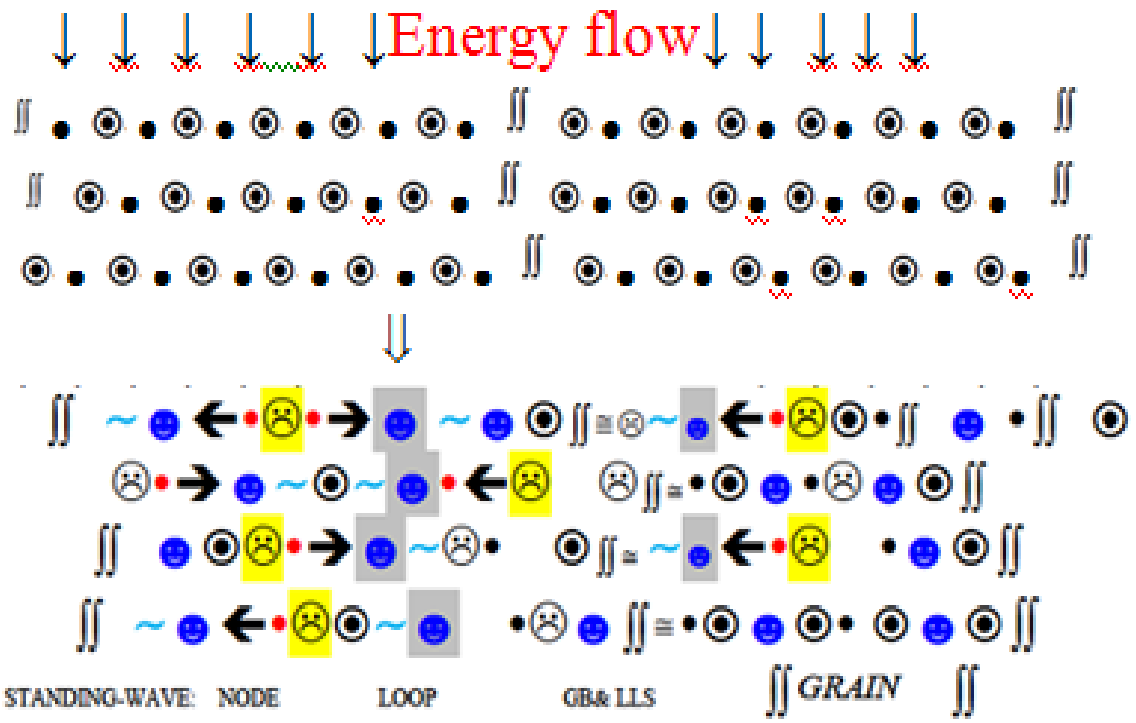
Explosive nature of the destruction is caused by the stimulated (induced) transition of electrons from MAMED to MAMDC and energy radiation. Such radiation which is caused by photons is coherent and highly directional short-term due to the high speed of the photons. The radiation power depends on the energy stored in the domain of destruction.

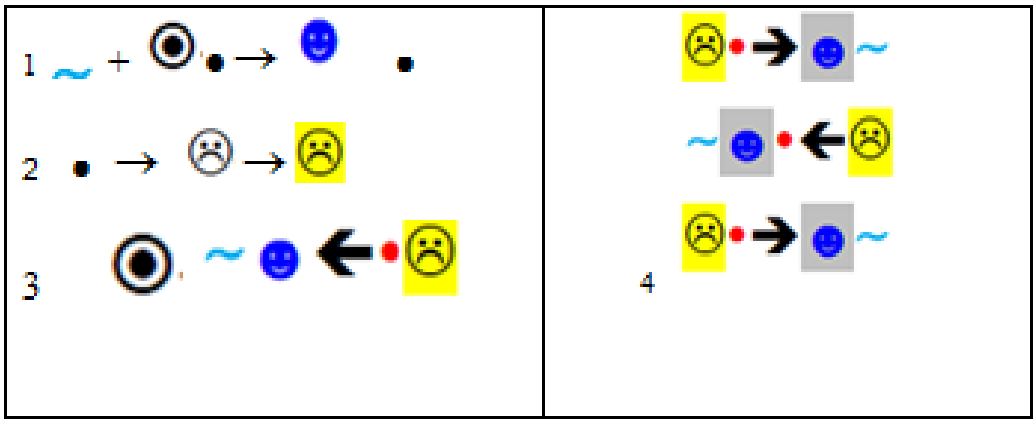
*The energy dissipation rate of the domain destruction increases with increasing of the temperature. However, the speed of energy storage can also increase***.**

Forced (stimulated) energy dissipation from the domain of destruction, not leading to the destruction or deterioration of the metal properties, extends its safe operation Following Feynman's recommendation let's proffer the diagram of domain destruction, using "a little bit of imagination and ideas."

5.1.2. Domain destruction scheme

Following Feynman's recommendation let's proffer the diagram of domain destruction, using "a little bit of imagination and ideas."





The mechanism of domain destruction of the metal covering two grains is shown above schematically. "The names of all participants" are shown at the picture. Let's assume that normal atoms (*AN*) are source ions such as Fe^{2+}. Energy flow causes the deformation under the influence of which in the antinodes of the standing wave formed positive ions Fe^{3+} (AM^{+}), and in the node - ions Fe^{1+}( ), which are conventionally called negative morbid ions AM^{-}.

We note that the proposed scheme corresponds to the real redox reaction (by which a living organism is provided with energy.

Zero-valent iron is not only known, but also has a practical application. Two groups of morbid atoms form domain of destruction.

Amorphous layer formed on the grain boundaries, facilitates the process of destruction.

Morbid atoms (AM^- ☹) emit electrons, which recombine with morbid atoms (AM^+ ☻), forming photons. Two groups of morbid atoms form domain destruction. Stimulated emission energy from domain is sufficient for the crack formation or destruction.

Atom can only absorb energy as a photon (reaction number 2). This process occurs at the antinodes of the standing waves, which are generated in local areas, such as grain. This means that mechanical energy is converted into an electromagnetic deformation process. Electromagnetic energy of atoms converted into mechanical energy of destruction in strict accordance with the law of conservation of energy (reaction number 3).

The basis of the method proposed for predicting the technical condition of structures and devices is Maxwell's prediction that the potential energy the radiation of which leads to the destruction due to the new type of interaction. Modern physics has revealed the laws of this interaction, called electromagnetic.

Scientific discoveries made by Maxwell, due to deep understanding the physical phenomena whose description he used mathematical apparatus only when he could confirm the findings using correctly staged experiment differential and integral calculus has been developed by Newton and Leibniz. Maxwell repeatedly and successfully used it in his works. Schrödinger and Dirac differential equations are the basis of quantum mechanics.

The method proposed by me, based on the analysis of numerous experimental facts, but it remains a hypothesis that needs direct experimental confirmation.

I'll use the Maxwell's testament: "Of all the hypotheses ... choose one that does not stop thinking about further investigating of things," hoping that the quantum-mechanical theory of strength and fracture solid will be developed.

Following Maxwell, I have tried to demonstrate this method for solving specific engineering problems.

Warning.

All problem solving should be considered only as a demonstration of the method.

Application of the method in practice needs to be further targeted research and a more accurate evaluation.

Problem # 1. *Find the quantitative criterion for safe operation the element of structure or device.*

Basic data:

Crack length Δl

Metal thickness h

Modulus of elasticity E

The lattice constant a

Binding energy between the atoms ε_b

The maximum mechanical stress σ_m

The number of cycles ΔN.

For crack formation is necessary that the external source energy absorbed by atoms exceeds the total binding energy of atoms in the cells forming the two crack surfaces, i.e.

$$\Sigma U_i > U_2 = \frac{h\Delta l \varepsilon_b}{a^2} \quad (5.1).$$

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$$\Sigma U_i > U_2 = \frac{h\Delta l \varepsilon_b}{a^2} \quad (5.1).$$

Strain energy accumulated in the element volume V, equal $U_{ei} = V\frac{\sigma^2_{\max}\Delta N}{E}$. Critical energy absorbed by the cells, between which will take place the crack $R_2 = C_f V_1 \frac{\sigma^2_{\max}\Delta N}{E} = \frac{h\Delta l \varepsilon_b}{a^2}$, where C_f is the dimensionless coefficient characterizing the work, which was executed on the crack formation, $V_1 = 2ah\Delta l$ the volume of cells. Thus,

$$2C_f = C_d = \frac{E}{\sigma^2_{\max}\Delta N} \cdot \frac{\varepsilon_b}{a^3} = \frac{1}{W_d} \cdot W_b,$$

where W_b-specific binding energy (energy density), W_d-specific destruction energy (energy density).

$$C_d = \frac{W_b}{W_d} \quad (5.2).$$

Отсюда $W_b = C_{rd} W_d$ или $W_b - C_{rd} W_d = 0$ (5.3)

Equation (5,3) *is the criterion of the structure or device element safe operation*.

Safe operation is provided by the inequality

$W_d < W_b$ (5.4),

which is an analogue of Maxwell inequality (4.3). At $W_d \to 0$, $C_d \to \infty$.

Note that the practical use of the criterion (5.4) for each item is possible only after the experimental verification.

Problem # 2. Find the safe operation time of the structure or device element t_c.

Input the element of the structure or device in operation is allowed only when the ratio of the number of morbid atoms $N_m(0)$ to the number of normal atoms $N_n(0)$ is negligibly small (ideally zero). During operation N_m increases and N_n decreases. At some point $t=t_c$ reaching a critical emergency situation in which any accidental exposure can lead to destruction. Thus, the problem reduces to the experimental definition

$$t_c = f\left(N_n / N_m\right).$$

We proceed from the fact that firstly; energy is stored in the atoms in which there was a transition of electrons to the metastable level. Energy dissipation is due to thermal vibrations (phonon emission), radiationless transitions from the metastable level, and spontaneous emission from it. Thus all kinds of defects generated, including AM called damage. Secondly, that the formation of pores, cracks and destruction occurs only under photons by stimulated emission.

The total energy of atoms of an element in the initial time $t=0$ is due to the energy state of normal atoms

$$U_1(0) = \sum_{i,j} \varepsilon_i N_{n,j}(0) \quad (5.5),$$

where ε_i is the energy of an i type of normal atom, $N_{i,j}$ the number of atoms in this tipe. With energy possessed by morbid atoms we ignore. At the time $t = t_c$ the total energy

$$U(t_c) = \sum_{i,j} \varepsilon_i N_{n,j}(t_c) + \sum_{k,l} \varepsilon_k N_{m,l}(t_c) \quad (5.6),$$

where

$$U_2(t_c) = \sum_{k,l} \varepsilon_k N_{m,l}(t_c) \quad (5.7),$$

ε_k is energy of morbid atoms k-type, $N_{m,j}$ is their number. Limited to one type of normal and one type of morbid atoms, we can write

$$U(t_c) = \varepsilon_i N_n(t_c) + \varepsilon_k N_m(t_c) \quad (5.8).$$

Experimental confirmation of the formula Zhurkova under studies of various crystalline and amorphous materials suggests that the number of morbid atoms increases exponentially:

$$N_m(t_c) = N_m(0)e^{\Gamma} = N_m(0)e^{\frac{A}{Dk_BT}} \quad (5.9),$$

where

$$\Gamma = A/Dk_BT \quad (4.10)$$

is *degree of wear*, which is the ratio of energy accumulation velocity A in the domain of destruction

$A = U_2 / t$ (5.11)

to energy dissipation velocity

$B = Dk_B T$. (5.12),

where D is reduced phonon frequency, k_B is Boltzmann constant, T is Kelvin temperature.

Parameter Γ *has no analogues in classical mechanics. Its introduction is due to the Heisenberg uncertainty principle* $\Delta E \cdot \Delta t \geq \frac{\hbar}{2}$, *where* $\hbar$ *is the Dirac constant, since the accumulation of energy due to the emission and absorption of photons, whereas the energy dissipation due by spontaneous and thermal radiation*.

We proceed from that even in an ideal material at some point there are morbid atoms occur, i.e. $N_m(0) > 0$. If $A = B$, then

$$N_m(t) = N_m(0)e \quad (5.13).$$

Then

$$N_m(t_c) = N_m(0)e^{\frac{A}{Dk_B T}} = N_m(0)e^{\frac{U_2}{t_c Dk_B T}} \quad (5.14).$$

From which we obtain:

$$\ln N_m(t_c) - \ln N_m(0) = A / Dk_B T = U_2 / t_c \, Dk_B T \quad (5.15)$$

or

$$t_c = \frac{U_2}{Dk_B T[\ln(N_m(t) - \ln N_m(0)]} \quad (5.16).$$

Neglecting the number of morbid atoms in the early operation, we find

$$t_c = \frac{U_2}{Dk_B T[\ln(N_m(t)]} \quad (5.17).$$

Balance between accumulated and dissipated energy takes place at a linear deformation, followed by a slow wear (aging).

The nonfailure operation time is determined by the design, choice of material, its construction, and evaluation of theoretical and actual degree of fatigue.

Residual resource is the time between the moment of the study and the time at which a critical condition occur. In this case, a zero reading is taken the testing.

Problem #3.

Find the criteria for rotating rigid body safe operation.

Solving this problem, we will show using the results of experimental studies [5.1].

Disc of turbine compressor having 12 bolt holes, collapsed into five fragments during a frequency ω = 9469 rpm, as shown in Fig. 5.1. Crack between holes A and B of length 0.39 mm, was found at a frequency ω = 8533 rpm and increased toward the hole B.

Theoretical analysis was performed in [5.1] by finite element method using the stress intensity factors. Recommendations on how to predict the possibility of destruction in the article are not given. We note that the destruction has occurred as a result of branching in the energy flow direction from hole to hole and perpendicular to it.

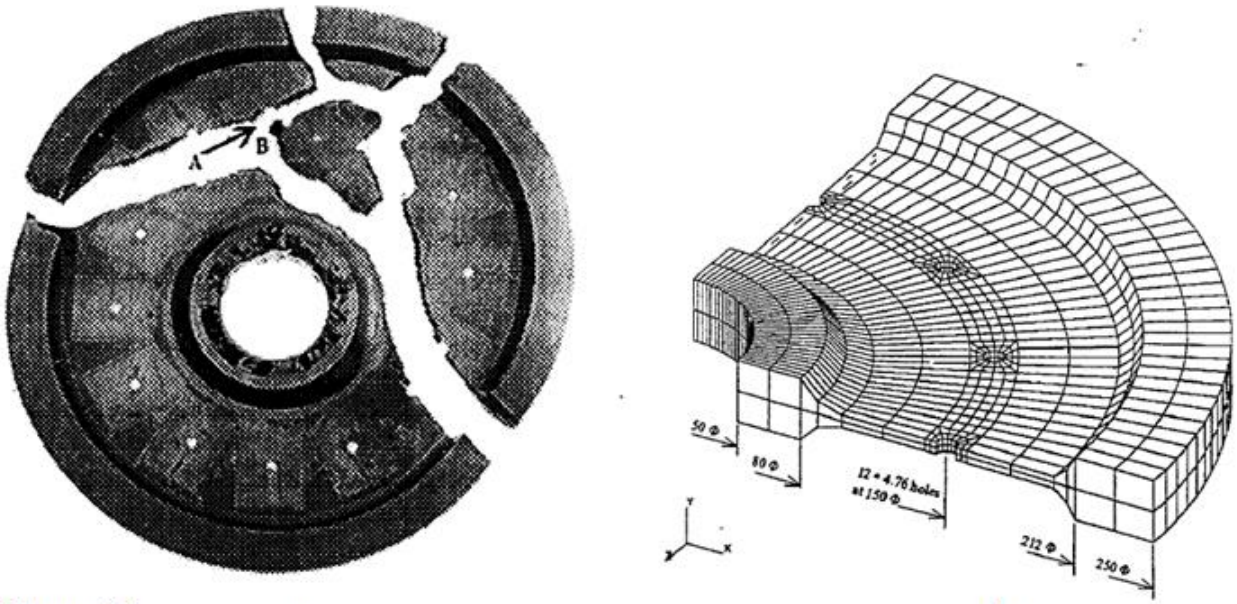

Figure 5.1 **a** **b**

Geometric parameters of the disk are shown in Fig. 5.1.b.

The energy required for the formation of a crack or of destruction of a rotating body, due to the kinetic energy $E_{kin} = \frac{I\varpi^2}{2}$, where I is the moment of inertia, ϖ is the average value of the cyclic frequency. In connection with this energy of crack extension is $\Delta U_s = C_r(\omega_{i+1}^2 - \omega_i^2)$, wherein C_r is the proportionality coefficient which is equal to $C_r = \frac{\Delta U_s}{\omega_{i+1}^2 - \omega_i^2}$. The energy required to extend the crack is equal to $\Delta U_s = \frac{h\varepsilon_b \Delta l}{a^2}$. We use the tabulated values given in [5.1], the binding energy $\varepsilon_b = 7.768 \cdot 10^{-19}\, J$, the lattice constant $a = 2.95 \cdot 10^{-10}\, m$ of titanium and disk thickness $h = 3 \cdot 10^{-3}\, m$.

$$C_r = \frac{3\cdot 10^{-3}\cdot 7.768\cdot 10^{-19}}{2.95^2\cdot (10^{-10})^2}\cdot\frac{\Delta h}{\omega_{i+1}^2-\omega_i^2} = 2.678\cdot 10^{-5}\,\frac{\Delta l}{\omega_{i+1}^2-\omega_i^2}$$ (5.1). The experimental studies of crack growth, received in [5.1] are shown in the first and third column of Table 5.1, in the second column it referred to the rate rps, the fourth column shows the values of C_r, which must be reduced to 10^{-6} times · calculated according to formula (5.1).

Relationship between Cr and ω is shown graphically in Figure 5.2.

As we can see, the C_r change is uneven. The frequency increasing is accompanied by an increase C_r. It should take into account the fact that before each measurement of crack length, the disc stops.

The sharp C_r increase at each subsequent test indicates that the rate of accumulation of energy grows faster than the rate of its dissipation, reaching the limit value in the frequency range 9459-9469 rpm.

Then

$$N_m(t_c) = N_m(0)e^{\frac{A}{Dk_BT}} = N_m(0)e^{\frac{U_2}{t_cDk_BT}}$$ (5.14).

From which we obtain:

$$\ln N_m(t_c) - \ln N_m(0) = A/Dk_B T = U_2/t_c\, Dk_B T \quad (5.15)$$

or

$$t_c = \frac{U_2}{Dk_BT[\ln(N_m(t) - \ln N_m(0)]}$$ (5.16).

Neglecting the number of morbid atoms in the early operation, we find

$$t_c = \frac{U_2}{Dk_BT[\ln(N_m(t)]}$$ (5.17).

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Theoretical analysis was performed in [5.1] by finite element method using the stress intensity factors.

Recommendations on how to predict the possibility of destruction in the article are not given. We note that the destruction has occurred as a result of branching in the energy flow direction from hole to hole and perpendicular to it.

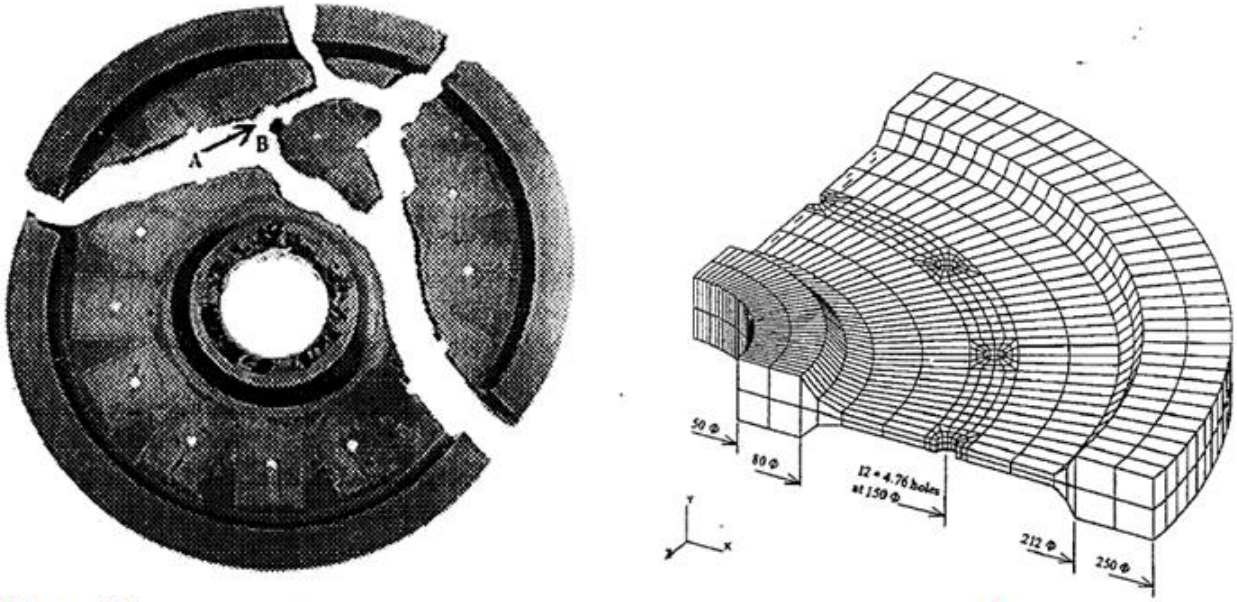


Figure 5.1 **a** **b**

Geometric parameters of the disc are shown in Fig. 5.1.b.

The energy required for the formation of a crack or of destruction of a rotating body, due to the kinetic energy $E_{kin} = \frac{I\varpi^2}{2}$, where I is the moment of inertia, ϖ is the average value of the cyclic frequency. In connection with this energy of crack extension is $\Delta U_s = C_r(\omega_{i+1}^2 - \omega_i^2)$, wherein C_r is the proportionality coefficient which is equal to $C_r = \frac{\Delta U_s}{\omega_{i+1}^2 - \omega_i^2}$. The energy required to extend the crack is equal to $\Delta U_s = \frac{h\varepsilon_b \Delta l}{a^2}$. We use the tabulated values given in [5.1], the binding energy $\varepsilon_b = 7.768 \cdot 10^{-19} J$, the lattice constant $a = 2.95 \cdot 10^{-10} m$ of titanium and disk thickness

Table 5.1

ω rpm	ω rps	l	C_r
8553	142.55	0.39	
8758	145.9667	0.54	4.075
8963	149.3833	0.88	2.506
9178	152.9667	1.36	11.86
9400	156.6667	3	38.334
9401	156.6833	3.1	512.76
9403	156.7167	3.3	512.68
9405	156.75	3.55	640.72
9407	156.7833	3.95	1024.9
9409	156.8167	4	128.09
9414	156.9	4.4	409.73
9419	156.9833	4.7	307.13
9424	157.0667	5.55	869.75
9434	157.2333	9.7	2121.5
9439	157.3167	10.4	715.13
9449	157.4833	18.9	4338.4
9459	157.65	32	6679.2
9469	157.8167		∞

$h = 3 \cdot 10^{-3} m$.

$C_r = \frac{3 \cdot 10^{-3} \cdot 7.768 \cdot 10^{-19}}{2.95^2 \cdot (10^{-10})^2} \cdot \frac{\Delta h}{\omega_{i+1}^2 - \omega_i^2} = 2.678 \cdot 10^{-5} \frac{\Delta l}{\omega_{i+1}^2 - \omega_i^2}$ (5.1). The experimental studies of crack growth, received in [5.1] are shown in the first and third column of Table 5.1, in the second column it referred to the rate rps, the fourth column shows the values of C_r, which must be reduced to 10^{-6} times · calculated according to formula (5.1).

Relationship between Cr and ω is shown graphically in Figure 5.2.

As we can see, the C_r change is uneven. The frequency increasing is accompanied by an increase C_r. It should take into account the fact that before each measurement of crack length, the disc stops.

The sharp C_r increase at each subsequent test indicates that the rate of accumulation of energy grows faster than the rate of its dissipation, reaching the limit value in the frequency range 9459-9469 rpm.

Analysis of changes in Cr shows: a) that each subsequent crack extension occurs at lower energy; b) that the accumulation of energy and its emission is spasmodic; c) that the factor called residual stress, due to this increased degree of fatigue at which energy plays a small role stimulator radiation energy domain. Only energy-stimulated signal acquires such power, which is enough to destroy; d) that the prediction of this condition is the last opportunity to prevent catastrophic destruction; e) that the crack between the holes was a harbinger of the destruction that occurred due to rupture of metal not only near the hole, but away from them, including the peripheral part of the disc, the thickness of which is five times greater than in the central part.

We draw attention to the fact that firstly under the disc fracture, crack formed near the opening A both in the direction of growth and opposite, second, destruction occurred at only one side of the disc.

Features of this destruction are due to the fact that when the disc rotate the free electrons move from the center to it periphery. This leads not only to the potential difference, but also to the recombination of electrons and ions on the periphery, followed by radiation energy, bonds weakening, scaling, erosion, corrosion more intense as it is observed on the turbine blades.

Speed increase is accompanied by increasing of the centrifugal force to such an extent that there is additional ions ionization. As a result, the number of morbid atoms AM^+ was increased in the central part of the disc, while the number of morbid atoms AM^- increased on the periphery.

Critical state occurs at a certain frequency of rotation when the electromagnetic signal is able to stimulate the radiation of energy stored in the domains of destruction.

Artificial density reduction of the electron cloud, using a reverse potential difference will reduce the risk of the rotating element collapse and extend the service life.

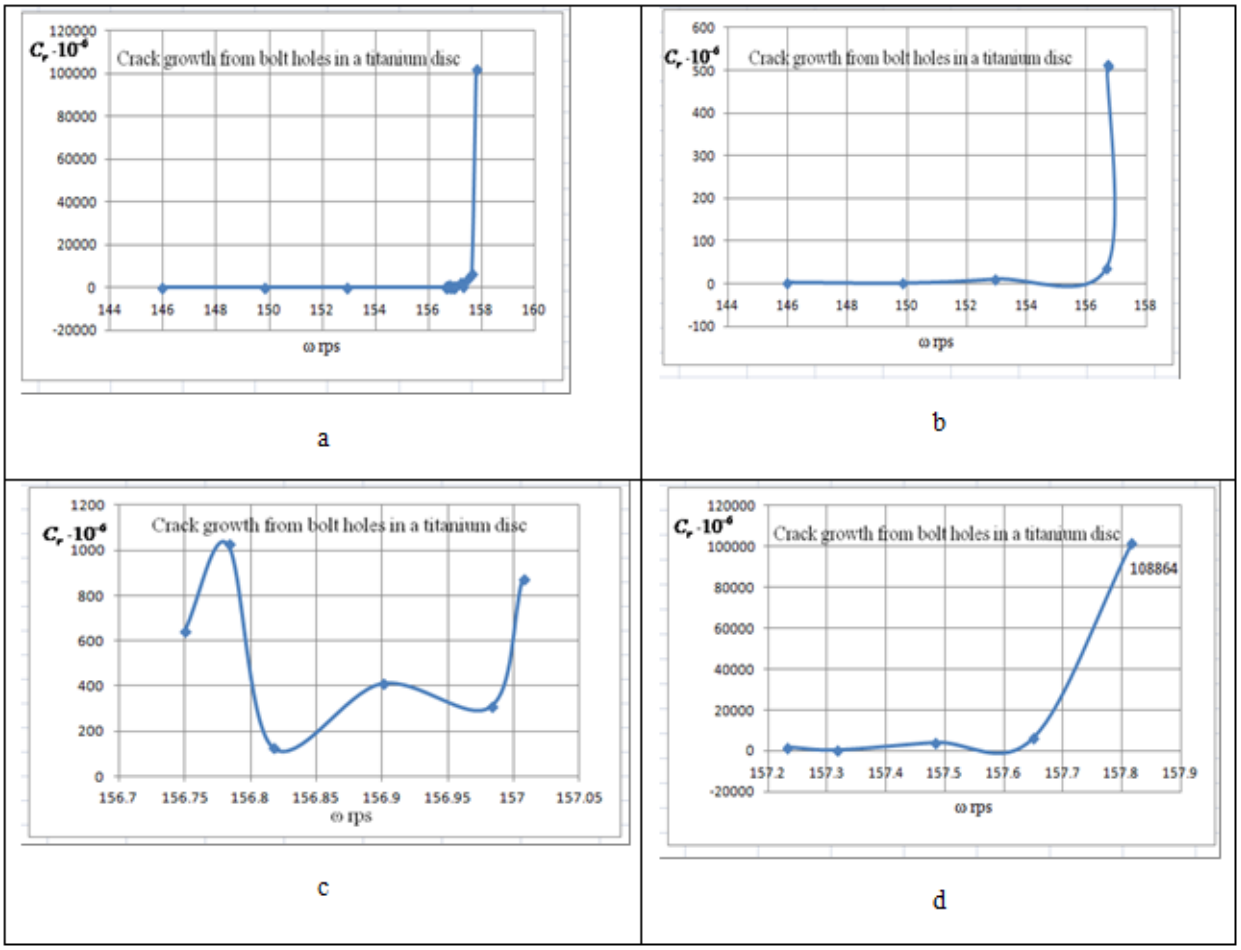


Figure 5.2

The graphs shown in Figure 5.2 help us to understand the nature of the energy processes accumulation and radiation. Changes C_r are shown for narrow frequency intervals.

However, a more precise definition of criteria for safe operation needs further experimental verification by rotated for different bodies, the construction of which should be complicated.

In addition, testing should be considered when the conditions and duration of operation, and the time during which the study is conducted at a predetermined rotation frequency.

Problem # 4. Estimate the domain of destruction size under copper rod spall fracture.

Photons emitted at a spall, allow us to estimate not only the location of the domain of destruction, but also to calculate its limiting sizes.

We estimate the size of the domain of destruction, using the experimental data.

Photon energy emitted under a spall of the copper rod Cu-ε_p=3.42 · 10^{-19} J, as it was shown in [5.2-5.5]. Atomic binding energy-ε_b 5.6 · 10^{-19} J, crystal structure, face-centered cubic, the number of atoms in the unit cell 4, the lattice constant-a = 3.61 · 10^{-10} m, the diameter of the rod-d_s = 1 · 10-2

m.

This allows us to estimate the domain energy and its size.

The diameter of the rod was d_s=1·10^{-2} m, crystal lattice constant Cu a=3.61·10^{-10} m, the binding energy of atoms ε_b =5.6·10^{-19} J, the photons energy is ε_b =5.6·10^{-19} J.

Performing simple calculations, we obtain cross-sectional area $S_s = \frac{\pi d_s^2}{4}$, the number of cells in it $n_s = \frac{\pi d_s^2}{4a^2}$, the energy required for this- $\varepsilon_s = \frac{\pi d_s^2}{4a^2}\varepsilon_b$.

Let as to denote the diameter of the fracture domain d_d. Then the volume of cells, which atoms radiated energy will be $V_d = \frac{4\pi d_d^3}{3}$, the number of atoms $N_d = \frac{4\pi d_d^3}{3a^3}$, radiated energy - $\varepsilon = \frac{4\pi d_d^3}{3a^3}\varepsilon_p = \varepsilon_s$. So $\frac{4\pi d_d^3 \varepsilon_p}{3a^3} = \frac{\pi d_s^2 \varepsilon_b}{4a^2}$, from which $d_d = \sqrt[3]{\frac{3d_s^2 a\varepsilon_b}{16\varepsilon_p}}$, or

$$d_d = \sqrt[3]{\frac{3\cdot 1\cdot 10^{-4}\cdot 3.61\cdot 10^{-10}\cdot 5.6\cdot 10^{-19}}{16\cdot 3.42\cdot 10^{-19}}} = 4.64\cdot 10^{-4}(m)$$

Consequently, the fracture domain is a nano-object, which accumulates enough energy to fracture. However, it is not detected by the methods suggested by the standards and patents.

Problem # 5. Estimate the project and the real degree of wear of the rod fastening cable-stayed of the Ice Palace Krylatskoye roofing and the parameters domain of destruction (Russia, 2007).

Steel rod holding the cable-stayed the roof of the Ice Palace Krylatskoye, split so that one-third fell, while the remainder held roof.

The original data.

Rod diameter d = 0.528 m,

Lattice constant a = 2.87 · 10^{-10} m,

Binding energy ε_b = 6.87 · 10^{-19} J,

Photon energy (conventionally): εp = 3.44 · 10^{-19} J,

Date of completion: September 2004,

Date of destruction: November 2007,

Warranty period: t_g = 50 years = $4.383 \cdot 10^5$ hours

Real time of operating: $t_r = 3.646 \cdot 10^4$ hours.

Solution

The energy required to split the rod is $U_2 = \frac{\pi d^2}{4a^2}\varepsilon_b$ or $U_2 = \frac{3.14 \cdot 0.528^2 \cdot 6.87 \cdot 10^{-19}}{2.87^2 \cdot 10^{-20}} = 1.825$ (*J*).

Guaranteed rate of accumulation of energy A_g must be less than $A_g < \frac{U_2}{t_g}$.

Therefore, the limit value A_g should be not higher than

$A_g = \frac{1.825}{4.383 \cdot 10^5} = 4.164 \cdot 10^{-6}$ (*J/hour*).

However, the actual rate of energy accumulation A_r was t_g/t_r=$4.383 \cdot 10^5/3.646 \cdot 10^4 \approx 12$ times higher.

The number of morbid atoms radiation energy of which led to fracture equal to $N_m(t) = \frac{U_2(t)}{\varepsilon_p}$, or $N_m(t) = 5.3 \cdot 10^{18}$.

The degree of wear is $\Gamma = \frac{A_g}{Dk_BT} = \ln[N_m(t)]$ or $\Gamma_{\max} = \ln(5.3 \cdot 10^{18}) = 43.11$

Average annual air temperature in Moscow is 280 *K*. Hence the reduced frequency of acoustic oscillations will be $D = \frac{A_g}{\Gamma_{\max} k_B T}$ or $D = \frac{4.164 \cdot 10^{-6}}{43.11 \cdot 1.38 \cdot 10^{-23} 280} = 2.5 \cdot 10^{13}$ (*Hz*).

We note that this frequency is characteristic for hypersonic waves, just as it takes place in Zhurkov's formula.

However, $A_r = \frac{1.825}{3.648 \cdot 10^4} = 5.00 \cdot 10^{-5}$ (*J/hour=J/h*).

Increasing the speed of energy accumulation leads to the reduction of safe operation. Especially dangerous is the case when at the same time reduced the rate of energy dissipation due to a number of factors, including the specific design of the element. Accumulation of energy occurs in the local area, however, this factor in the design and operation is not taken into account. But it was exactly the cause of the break of one of 19 cable-stayed roof fasteners. However, the collapse of the whole roof has not occurred as a result of redistribution of energy.

Destruction of the rod occurred after the number of atoms morbid reached or exceeded, i,e, $\Gamma = 43.11$. Security conditions require that the operation of element of the device or facility has been discontinued before the critical state. Thus, $t_g = t_c - \Delta t$. The time interval Δt is set on the basis of numerous experimental tests and corrected during the operation on the basis of a real kind of experimental monitoring the accumulation rate and the energy dissipation. Assume that an interval set number of morbid atoms 3-4 orders of magnitude below the critical value. In this case, the degree of guaranteed wear should not exceed $34.54 \div 36.84$.

Note.

The fact that 2/3 of the rod held the roof means that the material strength was sufficient, but the distribution of strain energy led to high accumulation rate in the local area that does not correspond to calculations based on the stress distribution.

This case is evidence that reliability and durability of the element of the structure or device caused not only strength but also more uniform energy distribution.

Problem # 6. Assess the degree of wear and the domains of destruction size of the Gusset U10 of I-35 *W Bridge, which catastrophic failure occurred after forty years of operation (USA, 2007).*

The fracture behavior of this element of the bridge, in which the disaster occurred, was demonstrated in Chapter I.

The original data.

Crack length between rivets $l = 1.3 \cdot 10^{-2}$ m

The plate thickness $h = 1.27 \cdot 10^{-2}$ m

Operating time $t = 3.51 \cdot 10^5$ hours.

Lattice constant $a = 2.87 \cdot 10^{-10}$ m,

Binding energy $\varepsilon_b = 6.87 \cdot 10^{-19}$ *J*,

Photon energy: $\varepsilon_p = 3.44 \cdot 10^{-19}$ *J*

Features of the Gusset U10 destruction is that: a) the break of the metal near holes 1, 3, 5, 7 characteristics for the brittle material, while break of the metal near the holes 2, 4, 6, 8 characteristics for plastic; b) The corrosion resistance of the material near the even and odd holes are different.

It is generally accepted that the formation of cracks has the elastic-plastic nature. Therefore, in this case two types of domain were formed with different ratios of the destruction of the hardened and weakened areas. Structural studies of these areas would allow the more accurate description of the mechanism of destruction of the rivet connection and more accurately predict its condition. But they

were not carried out.

Calculations performed using the method as set out above showed that the cause of the disaster is the radiation of energy from two types of domains of destruction, an average diameter of which is d_d = $5.66 \cdot 10^{-5}$ m.

In addition, following data were obtained: speed of energy accumulation

A=$3.92 \cdot 10^{-9}$ J/hour, the energy dissipation rate Dk_BT=$1.10 \cdot 10^{-10}$ *J*/hour, maximum allowable degree of wear $\Gamma_g = 29.93$, real degree of wear $\Gamma_r = 35.92$ and excess is $\Delta\Gamma = \Gamma_r - \Gamma_p \approx 6$. Hence, the risk of the destruction increased by $e^6 \approx 400$ times and the destruction happened.

Problem #7. *Assess the maximum allowable and the real degree of wear of the API 5L X46 pipeline* (Argentina, 1988).

The fracture behavior was examined in Chapter I.

The original data.

Crack length l = 4.8 m,

Wall thickness h = $6.3 \cdot 10^{-3}$ m,

Lattice constant a=$2.87 \cdot 10^{-10}$ m,

Binding energy ε_b=$6.87 \cdot 10^{-19}$ J,

Photon energy: ε_p=$3.44 \cdot 10^{-19}$ J,

Operating time t_r = $1.753 \cdot 10^5$ hours,

Guaranteed term of operation life t_g=$4.38 \cdot 10^5$ hours.

These results:

Maximum allowable degree of wear $\Gamma_p = 32.24$, real degree of wear $\Gamma_r = 38.83$ and excess is $\Delta\Gamma = \Gamma_r - \Gamma_p = 6.59$. Hence, the risk of the destruction increased by $e^{6.59} \approx 728$ times and the destruction happened.

Problem # 8. *Assess the maximum allowable and the real degree of wear of the rail (Hatfield, UK, 2000) and domain of destruction size*.

The fracture behavior was examined in Chapter I

The original data.

Crack area S=$8.26 \cdot 10^{-3}$ m^2

Lattice constant a=$2.87 \cdot 10^{-10}$ m,

Binding energy ε_b=$6.87 \cdot 10^{-19}$ J,

Photon energy: $\varepsilon_p=3.44\cdot10^{-19}$ J,

Operating time $t_r = 1.753\cdot10^5$ hours,

Guaranteed term of operation life $t_g=4.38\cdot10^5$ hours.

Solution.

Energy of the domain of destruction is $U_s=6.89\cdot10^{-2}$ *J;* diameter of the domain of destruction is $d_d=2.11\cdot10^{-4}$ m; maximum allowable degree of wear $\Gamma_p = 32.24$, real degree of wear $\Gamma_r = 39.14$ and excess is $\Delta\Gamma = \Gamma_r - \Gamma_p = 6.59$. Hence, the risk of the destruction increased by $e^{6..9.} \approx 990$ times and the destruction happened.

Problem # 9. Carry out a comparative analysis of the results of experimental studies of riveted joints wear of Boeing 727-232 fuselage fragment with wear during its operation.

In riveted joints of the Boeing 727-232 (B727) fuselage fragment there was a crack length of 0.5 mm. A result of testing [5.2] the crack increased to 1.27 mm.

Estimate the parameters of domain destruction, conditionally accepting that the photon energy is equal to $\varepsilon_p = 0.5\ \varepsilon_b$.

The original data.

Skin thickness $h=2.52\cdot10^{-3}$ m,

The initial crack length $l=5\cdot10^{-4}$ m,

Operating time $t_1 = 66412$ hours

Crack elongation $\Delta l = 7.7 \cdot 10^{-4}$ m,

Number of test cycles $\Delta N = 7.636 \cdot 10^4$

Impact frequency 10 Hz,

Lattice constant $a = 4.05 \cdot 10^{-10}$ m,

Binding energy $\varepsilon_b = 5.34 \cdot 10^{-19}$ J,

Photon energy $\varepsilon_p = 2.67 \cdot 10^{-19}$ J,

All the parameters related to the formation of the first crack, denote with the index 1, the parameters related to experimental research-with the index 2.

1. Using equation $U_{21} = \frac{l_1 h}{a^2}\varepsilon_b$, we obtain $U_{21} = 4.10\cdot10^{-6} J$ and similarly $U_{22} = 6.32\cdot10^{-6} J$

2. Experiment time determined by the formula $t_2 = \frac{N}{3600\nu}$ or t_2=2.12 hour.

3. Using equation $A = \frac{U}{t}$, we obtain the number of morbid atoms $N_m(t_1) = 1.54 \cdot 10^{13}$ and $N_m(t_2) = 2.37 \cdot 10^{13}$.

4. Using equation $\Gamma_1 = \frac{A_1}{D_1 k_B T} = \ln[N_m(t_1)]$ we obtain the wear rate $\Gamma_1 = 30.37$ and $\Gamma_2 = \frac{A_2}{D_2 k_B T} = \ln[N_m(t_2)] + \ln[N_m^*(t_1)]$.

The term $\ln[N_m^*(t_1)]$ is taken with a plus sign, as it characterizes the number of those morbid atoms, the energy of which was not rejected by the first crack formation. In this case, we neglect it.

Thus, $\Gamma_2 = 30.8$. Consequently $\Gamma_2 - \Gamma_1 = 0.44$. It follows that the wear rate in the experimental study is accelerated in $e^{0.44} = 1.55$ times.

Problem # 10. Assess the value of the residual energy in the riveted joints of the Boeing 727-232 *fuselage, radiation of which leads to destruction.*

The maxima and minima of a function $U_2 = F(N)$ suggest that during the deformation there is energy accumulating and emitting, which leads to the disaster. However, part morbid atoms remain in a metastable state. This condition is called in fracture mechanics stressed state. But it cannot be quantitatively measured, whereas experimentally determine the energy state of a local group of atoms is possible.

Thus, the solution of this problem is reduced to finding the term preceding the catastrophic failure. For this we use the experimental data that were obtained in [5.3], without pretending to accuracy assessment since this requires additional purposeful research.

Minimum crack Δl_1 = 0.0169 "(0.429 mm), according to the given results, was fixed near the rivet holes A22-R after N_1 = 40090 cycles.

The original data.

Skin thickness h=1.6·10^{-3}m,

Lattice constant a= 4.05·10^{-20} m,

Binding energy ε_b=5.34·10^{-19} J,

Impact frequency ν=0.04 Hz,

Maximal stress iσ_{max}=1.103·10^5 Pa

The crack length Δl_1=4.293·10^{-4} m

Number of test cycles N_1=40090

Photon energy ε_p=2.67·10^{-19} J

Consequently, the time of the experiment continued Δt_1=40090·25:3600≈278.4 hours.

The energy required for the crack formation was $U_{21} = 2.236 \cdot 10^{-5} J$.

The rate of energy accumulation was $A_1 = 8.03 \cdot 10^{-8} J/h$, number of morbid atoms $N_m(t_1) = 8.37 \cdot 10^{13}$, degree of wear $\Gamma_1 = 32.06$.

1. Crack Δl_2=0.4758"=12.085·10^{-3} m formed near the A22-L hole as a result of exposure to cyclic N_2=106160 Δt_2=737.22 *h*.

Simultaneously with it near the holes A22-R and A23-L cracks were formed whose length was Δl_3=11.68·10^{-3} and Δl_4=16.61·10^{-3} m, respectively. The total length of the cracks was Δl=40.375 10^{-3} m. The total value of the energy $U_{22} = 2.03 \cdot 10^{-4} J$, rate of energy accumulation $A_2 = 2.85 \cdot 10^{-6} J/h$ the number of morbid atoms $N_m(t_2) = 7.88 \cdot 10^{14}$, and degree of wear $\Gamma_2 = 34.30$. We have neglected with morbid atoms that are not rejected energy, although an increase in the number of cycles to 2.65 times the parameters characterizing the destruction increased almost eight times.

2. The crack $\Delta l_5 = 72.898 \cdot 10^{-3}$m was formed at N = 106,217, i.e. a difference of 57 cycles. In this case, G. This means that the external influence increased only of 0.005%, while the character of fracture increased by 81%. To neglect the energy that was accumulated previously is extremely dangerous!

3. Crack Δl_6=4.074·10^{-1} m, was formed under *N* = 107,458 cycles.

This crack will inevitably lead to a catastrophic depressurization!!

But the number of cycles increased by only one percent!

This means that the number of morbid atoms exceeds a critical value!!!

Extremely important for understanding catastrophic destruction has the final experiment in which crack was formed Δl_7 = 1.925 m. It happened under stress $\sigma_{max} = 17.83$ psi (522,622.6 Pa) and $N = 174$,458 cycles.

A characteristic feature of this experiment is the fact that the destruction was of abrupt nature, in which the energy was emitted, is $U_{24} = 1.00 \cdot 10^{-2}$ J. Since the failure occurred, we must consider the degree of wear of the critical, although the number of morbid atomic energy radiation of which was

enough for it was $N_m(t_c) = \frac{1.00 \cdot 10^{-2}}{2.67 \cdot 10^{-19}} = 3.75 \cdot 10^{16}$ and degree wear is $\Gamma_c = 38.16$. Thus, the difference between the degree of wear of the first fracture and catastrophic main crack was. Consequently, the degree of wear during the experiment change is $\Delta\Gamma = 38.16 - 34.30 = 3.86$. Consequently, the degree of wear during the entire experiment changed in $e^{3.86} = 47.47$ times. This conclusion causes bewilderment, since we got the value of the degree of wear on the order of magnitude lower than previously, although the crack is 10,000 times longer.

Here we once again came to the paradoxical situation because only limited by mathematical extrapolation. First, we did not consider that stress increased, and secondly, we were limited to with morbid atoms, in which the accumulation of energy occur, but completely ignored those atoms, the binding strength between them decreased in the third, we do not take into account the time of which occur radiation of energy.

The experiment was performed at a frequency of 0.04 Hz. Consequently, it continued 174458:0.04 = 4,361,450 seconds. It is known that the rate of crack formation is comparable to the shear wave velocity. In aluminum, it is equal to $6.42 \cdot 10^3$ m/s. Consequently, the emission time should be less than $1 \cdot 10^{-4}$ seconds. If we assume that the energy was radiated only one percent of morbid atoms, the radiation power exceeds the capacity of the energy storage in the tens of millions of times. But in reality, the radiation time is about 8.10 seconds. Furthermore, emission of electromagnetic energy is directed strictly along the rivet connection.

And this is due to its destructive effect.

Problem # 11. Are reliable modern techniques of forecasting residual life of structures and devices?

Figure 5.3

We considered the solution of ten problems that are associated with the destruction, including catastrophic. In two of them (№ № 6 and 8) people were killed, the other two (№ № 5 and 7), fortunately, nobody was hurt.

The proposed method allows to analyze the destruction of a material as in experimental studies, as well as emergencies, two of which we will consider.

During the flight, Boeing 737-300, April 1, 2011 at an altitude of 34,000 feet (10,200 m) in the fuselage of crack was formed size of 59 × 9 "(1498.6 × 228.6 mm^2), which is shown in Fig. 5.3. At the time of the accident, the aircraft had completed 48,748 hours and 39,786 cycles.

Fracture parameters $U_2 = 6.19 \cdot 10^{-3} J$, $A = 1.02 \cdot 10^{-7}$ J/h, $N_m(t_c) = 2.23 \cdot 10^{16}$, $\Gamma = 37.46$, are similar to those observed in laboratory studies.

However, the essential difference is that cracked preceding catastrophic failure, in this case, was not.

After the incident was investigated hundreds of aircraft series 737-300, 737 - 400 and 737-500. Only in six of them were found cracks. All other aircraft were eligible to operating practices.

This conclusion is erroneous.

The formation of catastrophic crack becomes possible when the rate of accumulation of energy exceeds the rate of dissipation so that in some element the energy of domain of destruction, or a group of domains, reaches a critical value.

Domain of destruction consists from atoms of the same elements that created the material. It can only be detected when the interaction of the atoms change so that it will lead to such a change of the material structure which can be recorded by the existing physical methods.

The main differences between domains of destruction from other defects are the spectrum of emission and absorption of electromagnetic waves. It extends from the infrared to X-ray, as it follows from the analysis of experiments, which have been discussed in earlier chapters.

This allows designing new experimental methods for the detection and destruction of research domains. Parameters of domain of destruction in each element of the structure or device allow

developing a new computer program to monitor wear and residual life, prevents catastrophic failure.

Thus, the safety of aircraft series 737-300, 734-400, *and* 737-500*, which have been recognized as a result of fit test, carried out in connection with the incident, is not guaranteed Catastrophic destruction of each of them possibly because the main source of destruction was not identified.*

Examples that show how to do this are given in the next chapter.

Problem # 12. Volgograd Bridge (Russia), as shown in Figure 5.5, 20 May 2010 for a long time fluctuated, amplitude of which reached one meter. In construction, made from metal and concrete, after such intense vibrations defects not detected and it was declared fit for service.

This phenomenon in the framework of modern mechanics cannot be explained. Explain this phenomenon from the position of physics of destruction.

This is an extremely rare phenomenon cannot be explained only by mechanical phenomena caused by the wind, as happened with the (Tacoma Narrows Bridge), called the "Galloping Gertia." But first, the Tacoma bridge was hanging secondly, and most importantly, it collapsed on 131 days after the start of operation, and thirdly, it was considerably shorter. We will not discuss the mechanism of Tacoma bridge destruction. We only note the fact that the collapse of the bridge was the starting point for numerous serious researches.

Fluctuations in the Volgograd Bridge should be considered as a new scientific problem to be solved, which, following Einstein's opinion can only be found at a new higher level, i.e. the quantum mechanics level.

We have considered above various kinds of destruction from electromagnetic shock that occurs through the millionth of a second after impact, before the destruction of the bridge, which took place forty years after the start of operation. Each crack formation and destruction processes preceded the accumulation of energy and its dissipation.

Nature has once again demonstrated the phenomenon, the practical use of which surpasses all imagination.

It is necessary to explain why the concrete became ductile like rubber.

We will try to explain this phenomenon from the point of physics of failure, based on the fact that the domain of destruction consists of two areas, in one of which is a weakening of binding force and reduction of energy in the other binding force increases and the energy is stored. These processes are accompanied by energy dissipation the mechanism of which differs from coupled pair the In this case, the mechanical oscillations play the role of a trigger of photon emission frequency energy which was

not enough to break the bond, but enough for such displacements of atoms at which the any huge waves. mechanism of accumulation. Morbid atoms in the domain of destruction emit photons of different frequencies, part of which goes to heating only.

In this regard, in some moments, the speed of dissipation can exceed the speed of energy accumulation or remain below it.

Fluctuations in the Volgograd Bridge indicate that the force between the atoms of cement weakened so that made possible the displacement of one atom relative to another, corresponding plastic deformation. At the same time, the vibrations of the bridge caused by external force, stimulated emission of energy of domains of destruction before their state has reached critical value. In this case, the mechanical oscillations play the role of a trigger.

There appeared the system similar to LC circuit in which the source of energy similar to capacitor served domains of destruction. Similar processes occurred in the metal, because the thermal conductivity of the metal is many times higher t t is possible that the mechanism proposed by me, needs to be clarified, but we have no right to bury this unique and very rare. It is possible that the mechanism proposed by me, needs to be clarified, but we have no right to bury this unique and very rare. Here it is necessary to recall the work of Maxwell and his foresight of processes of features that occur in the precritical mode.

Changing the bridge structure to suppress such fluctuations cannot be made without understanding the mechanism of this mysterious phenomenon. They can lead to a decrease in the rate of dissipation of energy. Degree of wear will increase to such a limit *that the disaster would be inevitable.*

Disaster can happen in a few months, as happened with the bridge in Tacoma (USA), the Transvaal aqua park (Russia), the rod fastening cable-stayed of the roof of the Ice Palace Krylatskoye (Russia), or decades later, as happened with the I-35 W Bridge (U.S.).

Conclusions

1. *Experimental evaluation of the total energy of morbid atoms in local areas of the element of structure or device during its operation allows controlling the technical condition of the item and preventing its catastrophic failure.*

2. *Cracks, as well as other damages are the result of changes in the energy state of the local groups of atoms, but their absence does not guarantee the reliability of the element of the structure or device.*

3. *Disclosure laws of accumulation and dissipation of energy in the domains of destruction allows not only to prevent catastrophic disaster, but also to control domains in order to prolong the time for safe operation.*

4. *Method proposed above, its use is universal and not limited to the examples given above.*

5. *This instills confidence that the man-made disasters can be prevented only when will be established continuous monitoring of the degree of wear. But such control is not yet available.*

Examples of the experimental methods by which such control can be adjusted, are given in the next chapter.

References to Chapter V

5.1. W. Z. Zhuang, G. J. Stocks, and C. H. Wang, *Prediction of Fatigue Crack Growth from Bolt Holes in a Titanium Disc,* Council of the Aeronautical Sciences (ICAS) and the American Institute of Aeronautics and Astronautics, Inc.1998, ICAS-5,2,3; A98-31629, pp.7.

5.2. Atre, W. S. Johnson, and J. C. Newman, Jr. *Assessment of Residual Stresses and Hole Quality on the Fatigue Behavior of Aircraft Structural Joints*, Volume 3: Finite Element Simulation of Riveting Process and Fatigue Lives, DOT/FAA/AR-07/56,V3, 2009, pp.166.

5.3. A. Ahmed, *Initiation and Growth of Multiple-Site Damage in the Riveted Lap Joint of a Curved Stiffened Fuselage Panel: An Experimental and Analytical Study ,*Thesis Submitted to the Faculty of Drexel University 2007, pp.328.

5.4. В.П. Ромбах, *Почему не рухнул Волгоградский мост и как избежать катастрофы*, Вестник ВолГУ. 2011, Серия 10: Инновационная деятельность, 72-80.

CHAPTER VI. DOMAIN OF DESTRUCTION: ITS MANIFESTATIONS AND DETECTION

In the world there are things more important than the most beautiful discoveries- this is knowledge of the method by which they are made.

G. W. Leibniz

6.1. Theoretical and experimental confirmation of the atomic model of the destruction

Attentive reader should pay attention to the fact that the energy required for the cracks, formation measured in nanojoules. Even for the formation of a crack whose length is 0.4074 m, took only $2.12 \cdot 10^{-3}$ J. Naturally, there is a suspicion that I made an error in the calculations. It is easy to calculate that the ball of mass 10 grams, which fell on the fuselage from a height of 1 meter, pass it the energy $9.81 \cdot 10^{-2}$ joules, which is 46 times more. Therefore, a crack of length 16 meter has to arise, which, of course, no. But we get a different result if we use the physics of destruction, but not the mathematical extrapolation.

Assume that the impact lasted $1 \cdot 10^{-3}$ seconds. In this case, the acoustic wave velocity of which in aluminum is 6400 m/s will transfer the impact energy to atoms at a distance of 6.4 m. The number of atoms in this volume is equal 10^{26}. Thus, the problem is reduced to that to determine the change in the energy of thermal motion of the atoms ~ 10^{26} after the impact. These changes will not lead to dangerous consequences.

Now suppose that the velocity of the ball has increased by 150 times, i.e. is 600 m/s. Bullet, flying at such velocity punches the fuselage skin, as its energy is distributed among a smaller number of atoms.

This example is included to show that the problem of cracking and with it of the problem destruction can be solved only by taking into account the processes that occur at the nanoscale. In this regard, it is necessary to once again return to the ideas of Feynman.

“When we get to the very, very small world-say circuits of seven atoms-we have a lot of new things that would happen that represent completely new opportunities for design.

Atoms on a small scale behave like nothing on a large scale, for they satisfy the laws of quantum mechanics. So, as we go down and fiddle around with the atoms down there, we are working with different laws, and we can expect to do different things.”

In his Nobel lecture, Feynman talks about how the work of Dirac influenced him. Why Dirac, but not the other founders of quantum mechanics?

For physicists, it's clear.

Dirac’s quantum mechanics is a synthesis of the Schrödinger wave mechanics and Einstein's relativistic mechanics. Writing relativistic Schrödinger equation for the electron Dirac got two

solutions, one of which made this decision meaningless, since the electron mass was negative. But Dirac it has not confused, he suggested that there should be electron with a positive charge, and opened for mankind antiworld.

Everyone understands that the work of Feynman opened to us the new world, new technology. This book, as noted earlier, is primarily designed for those who need and can prevent man-made disaster, but *without the new physical ideas it is impossible*.

New ideas aimed at preserving life and health, should be used or disproved. No middle ground.

Advances in the study of the properties of nano-objects allow us to draw the following conclusions:

Strength of nano-, meso-and macro object caused the distribution of energy between the atoms: maximum strength possessed by those objects in which the energy of the external impact is distributed evenly between the atoms;

In those cases when energy of the external impact is unevenly distributed due to the formation of standing waves, in the local volume on the metastable energy levels of atoms accumulated energy that may be enough to break the bonds, of crack formation, or even destruction.

In fairness it should be noted that attempts to account for the effect of deformation on the electron transition from the normal to the excited level have been made earlier. Thus, in [6.1] has been shown experimentally that the deformation of alkali halide crystals are excited atoms and luminescence. However, the mechanism of excitation of atoms is not disclosed.

Thus, we need to show how energy is accumulated in the atoms, which is enough to break the bonds between them.

Feynman was not only widely used modern mathematical methods in his research papers, but he suggested a method, called Feynman diagrams. He was one of the founders of quantum electrodynamics. But in his lecture, which was the starting point of nanoscience and nanotehnoliogy, used only simple arithmetic unit. We will follow his example.

Admits that the metal contained an linear chain of seven atoms, similar to the one on which Feynman wrote. These atoms may be of linear cluster, or even an atoms nodal line. At external stress, such as a laser beam, the electrons in them jumped to the excited level, the lifetime of which is 10^{-8} seconds. Hence electrons spontaneously jump to a normal level, emitting photons, which are transformed into heat. This type of emission is called resonance fluorescence. However, the energy emitted by each atom may not be enough to break the atomic bond. Consequently, the break is due to the fact that the energy is summed up in a certain place. In spontaneous emission photons are emitted not simultaneously and in different directions. Besides spontaneous emission there is possible stimulated

(induced) emission. In our example, this happens if the photon emitted by the first atom will pass along the chain, stimulating the emission of the other six. It is these processes occur in the laser. In this case, the total momentum transferred to any atom, may be sufficient to break the bond between this atom and its neighbors.

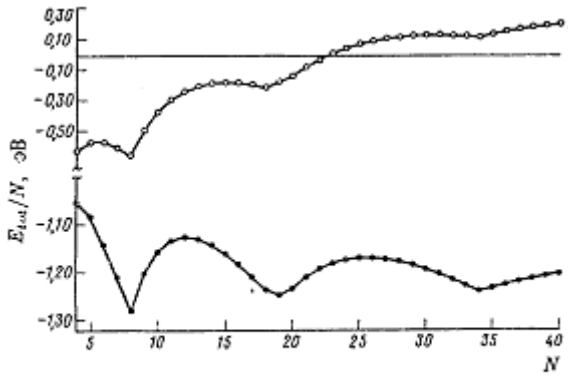


Figure 6.1 [6.2]

It is established that there are groups of atoms forming the cluster containing from three to hundreds of thousands of atoms. This problem has been discussed in more detail in [1.6]. Here we restrict ourselves to a brief comment related to the destruction of nanoobject.

Figure 6.1 shows the change in the total energy per atom, adiabatic oscillations of atoms in the cluster [6.2]. The energies were calculated in the Hartree-Fock approximation for the most stable clusters with filled casing 8, 18, 34, 40 both in terms of the exchange (bottom graph), and excluding exchange. Let's note that in the absence of exchange (top graph) cluster containing 22 atoms, has zero energy.

This means that with a further increase in the number of atoms, isolated cluster collapses.

This conclusion is consistent with Feynman's idea of a special behavior of atoms in nanoobjects, which cited above.

6.1.1. Luminescence of surface of spalling

Luminescence of surface of spalling of metals Ag, Al, Cu, Fe, Mo, Ti, Zr and some titanium alloys were observed in experiments by K. Abramova and coworkers [6.3-6.6].

We present the main results of this works, accompanying them with a brief commentary (in italics).

1. Radiation occurs in flashes and is set in the near-ultraviolet, visible or infrared areas.

For the emission of a photon with energy $h\nu_1$ the atom must absorb energy $h\nu_2$ though $h\nu_1 \leq h\nu_2$. A wide spectrum of the radiated waves, indicate the formation of the different modes of radiation. Flash (simultaneous emission of the energy by a group of atoms) indicates stimulated, but not spontaneous emission.

2. The fluorescence is not thermal and spectral composition does not coincide with the emission lines of metals or the emission bands of the oxide pellicles.

This conclusion clearly follows the preceding facts.

3. The nature of the radiation depends on the strain rate. a) For example, with the change of the impact

velocity from 3.8 to 5.5 m/s flash energy increased twice. b) At an impact velocity of 100 m/s it is observed 2-3 flashes.

This means that: a) the response of the atom to the external action is non-linear; b) there are 2-3 *different metastable levels with different lifetimes, perhaps in different locales.*

4. The fluorescence begins at regular intervals Δt_1 about 10^{-4} s after the impact and continues some time Δt_2 (to $3 \cdot 10^{-3}$ *s*) after termination.

Such a long time (Δt_1) for atomic processes, i.e. energy allocation delay after the destruction, due, most likely, by the fact that the excitation of the atoms due to the influence of multiply reflected waves in the sample. Long persistence (phosphorescence) describes the spontaneous emission of the atoms in the transition from the metastable level. Let's note that the lifetime of the excited atoms in the metastable level of chromium in the ruby laser is the same order of magnitude of

10^{-3} s, but the coincidence may be accidental. Therefore, in some areas there is an accumulation of energy and stimulated emission, in which the power increases dramatically, and in others the spontaneous emission, in which photons are emitted randomly in a different direction, are absorbed by the atoms and their energy is converted into heat.

5. Different areas of the fluorescence do not arise and ignite simultaneously; the temperature of the locally heated areas differs by hundreds of degrees. With the ultra-fast filming revealed that the deformable surface radiates nonuniformly, it has more and less bright spots.

The experiment confirms the uneven distribution of energy from the external impact and the different nature of its accumulation in different local areas.

6. Cu radiation has two maxima, 7200 -7300 Å and 5800 Å; emission maximum of Ag is 3040Å.

The energy of the photons emitted by atoms Cu is 1.71 *and* 2.14 *eV, Ag*-4.08 *eV. For comparison, there are the energy characteristics of some of these elements. Sublimation energy: Cu*-3.48*, Ag*-1.69 *eV, the activation energy of self-diffusion: Cu*-1.06*, Ag*-1.99 *eV, the energy of single covalent bonds: Cu*-2.02*, Ag*-1.69 *eV, the energy (heat) of fusion: Cu*-0.13*, Ag -0.*12 *eV energy (potential) of free atom ionization: Cu*-7.73*, Ag*-7.58 *eV, the work function of the electron: Cu*-4.4*, Ag-4.3 eV.*

Thus, it can be noted that the energy stored in a single metal atom under the influence of a single mechanical impact at a certain speed, comparable to the energy required to break a single bond, is considerably higher than the heat of fusion. <u>Consequently, the simultaneous (stimulated) radiation of energy of nanoobject atoms may be sufficient for the crack formation</u>.

7. Increasing the thickness of the copper sample reduces the intensity of the radiation, and

7 mm thickness of radiation is not registered.

In order to break more links it is needed more energy on impact. If the mass and velocity of the projectile does not change, the answer is obvious: all the energy stored by atoms is spent and there are no more active atoms on the surface.

8. If the metal has previously been strongly deformed, then the destruction of the emission intensity increases 2-3 times, this also applies to cases of repeated spalling.

The time of pulse rise and remission with repeated spalling decreased hundred times compared with the first one.

Consequently, in the pre-deformed metal has occurred formation of morbid atoms. With the first energy impact of morbid atoms it was enough just to break into two fragments and the atoms remained morbid in the metal. With the repeated impact their number has increased nonlinear due to the weakening of connection and energy redistribution.

9. After the first spalling, a piece of metal was removed to a depth of 0.5 mm from the spalling surface, and then with the repeated spalling the sample was destroyed, the nature of the fluorescence was the same as in the first spalling.

The results of this experiment are concordant with previous. After the first spalling the part of morbid atoms remains at a depth less than 0.5 *mm.*

Conclusion

Investigation of luminescence under spall fracture allows determining photon energy radiation of which entails destruction, to determine the location of domain of destruction, the accumulated, radiated, and residual energy.

Electromagnetic radiation in the visible and X-ray range, which was observed in the bundle of tape due to the same processes as triboluminescence or electrification by friction. When one of the dielectric frictions on the other electrons in the atoms cut off of the body, move to the atoms of another body. This process is made possible by the fact that the atoms of these bodies have different ionization potential and / or different electron affinities.

Bodies electrified in such a way contain morbid atoms AM^+ or AM^-. Such atoms may be in a metastable state for a long time, during which they can be examined.

Reverse exchange of electrons depends on the difference between of energy of the atoms and the electric resistance of the material in which they are located. Density of morbid atoms of one kind can reach enormous value.

The potential difference between thunderclouds is up to several million volts. The Van de Graaff generator allows creating a potential difference between the balls to one million volts. The maximum

energy of the radiation observed in the bundle adhesive tape was 15 keV!

Conclusion.

Investigation the triboluminescence of charged bodies, their electrical breakdown processes allows us to investigate the formation of the domain of destruction.

6.1.2. Quantization of electric conductivity.

Jumps of strain under tension of nanowire from gold accompanied by an abrupt decrease in conductivity, as shown in Fig. 6.2 [6.7]

When the thickness of the wire was reduced to one-atom, the rupture has not happened. Additional stretching of 20 Å, (which is approximately equal to the lattice constant 5) also did not lead to rupture and change in electrical conductivity, which remains equal to one unit of quantum conductivity. In compression occurred hysteresis.

A detailed analysis of this phenomenon is the subject of a separate study. Particularly important for us is the fact that before the break occurred, the conductor was a chain from four to seven atoms. *Consequently, it was the object mentioned by Feynman*.

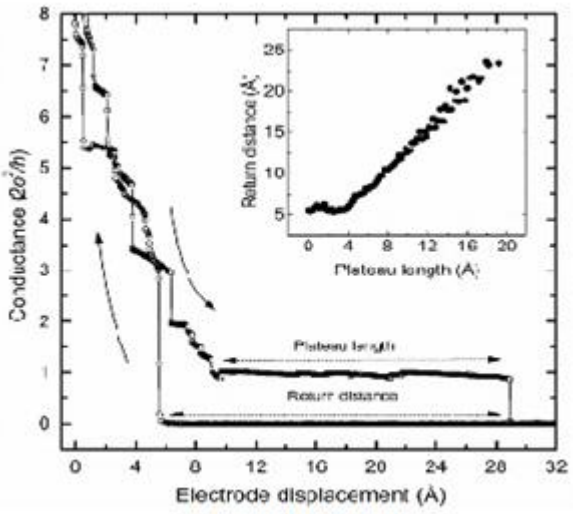


Figure 6.2 [6.7]

The study was conducted at a temperature of 4.2 *K*. The conclusion is based on ~ 100,000 experimental results. Found that the jump distance does not correspond to the quantum unit of electrical $G_0 = 2e^2/h$, and ranges from 0.8 to 1.2 G_0. In this case, the current density was $8 \cdot 10^{14}$ A/m^2 (current - 80 μA, voltage - 1 V), the length of the plateau before the break had various values.

The mechanism of this phenomenon is not explained by the authors. Only the hypothesis of one-dimensional excitation of phonons and plasmons, the possible formation of a Peierls transition or Tomonaga-Luttinger liquid was expressed. In a number of papers on the subject, to explain the phenomenon the ballistic hypothesis is used.

Let us to pay attention to a very important detail: thin wires explode at a current density ~10^9 A/m^2. In this case, the current density was five orders higher. Consequently, the energy is dissipated thanks to the fact that atoms do not scatter. It is possible that the atoms form a plasma

column, which is retained by the magnetic field. Perhaps it sounds fantastic, but no more than a hypothesis above.

Comparing the results of studies of sodium and gold noncontact authors write:

"Although it is not clear to us at this moment what determines the difference in behavior between gold end sodium, this result is consistent with the fact that we do not observe chain formation of sodium in the low-temperature experiments"

This fact can be explained. In the gap between the electrodes the electrostatic field is very high, the density of the electron gas on the surface of the electrodes is also high. The time of photons between the atoms is about 10^{-17} s. The electronic configuration of excited atoms are Na,-$2p^6 3s^1$, Au-$5d^{10}6s^1$. It is known [6.8] that it is possible the electronic configuration in gold atoms: Au^-, Au^{1+}, Au^{2+}, Au^{3+} and dimer Au_2, associated with the ionization of electrons with *d*- electron shell, while the transfer of electrons from p^6 electron shell of sodium in these conditions does not occur.

Thus, we conclude that, in this very small "Feynman's area" quantum laws manifest themselves differently. *Figuratively speaking: virtual photons become real*.

Conclusion

The reliability of nonmaterial, as it was mentioned above, due to a more uniform distribution of the energy of an external impact. Experiments with nanowires show that in nanoobjects occur more intense energy dissipation than in the meso-and macro objects. The idea that an important role in these processes play plasmons is of great interest.

Therefore, the study of plasmons can be one of the most promising methods for detecting domains of destruction.

6.1.3. Tin plague

Phase transition β-Sn→α-Sn at 13.2 º C is accompanied by 25.6% increase in the specific volume of (density of α-Sn is 5.75 g/cm^3 density □-Sn 7.228 g/cm^3), which turns gray tin in a powder. The reason of this transformation was discovered by L. Pauling. Pauling concluded that decreasing temperature causes the transition of atoms $Sn^{4+}+2e \rightarrow Sn^{2+}+2h\nu$. The ionic radius is Sn^{4+}-0.69, Sn^{2+}-1.05 Å. Increase in volume and release of energy leads to the destruction of white tin. The most extensive experimental studies to reveal the mechanism of this phenomenon were performed by A. Styrkas. These experiments were described in a number of his works, including [6.9].

As has been established [6.9], SnO molecules in β-Sn phase, have the role of the fetus, accelerating

the reaction of transition β-Sn→α-Sn. These molecules are the" memory keepers" of the transformation of white tin to gray that has already happened once.

Here is the quote: "For experimental verification of this hypothesis includes measures to prevent the possibility of oxidation of gray tin. For this purpose, a sample of tin with a seed placed in a vacuum and cooled to complete the transition of white to gray tin. Then, during the week the sample was kept at room temperature in order to guarantee the transition of tin in β-phase, and only after that the vial was opened. Tin powder particles, taken from different parts of the sample, as far as possible away from the place of seed, were again placed in the cold. None of the sample was transferred to the α-phase *within two months of testing, while the conventional powder particles of the kind had been in α-position in the air for 10-30 minutes "remember" about it."* (Italic supplied).

It is shown that the tin powder sample that has undergone 50 cycles of β-α-β-turn, contains, according to the gas analysis, 0.17-0.23 weight % of oxygen. "Memory" can be "erased" by remelting the metal. Thus, initially we can assume Sn^{4+} ions as normal, and the newly formed ions Sn^{2+} as morbid AM^{2-}.

Let's suppose that in the sample which is in the β-Sn phase, there are both ions Sn^{2+} and Sn^{4+}, the ratio of which is $S_{ft}^{1} = \frac{n_{11}(Sn^{2+})}{n_{21}(Sn^{4+})}$ where n_{11} and n_{21} the number of ions in a local volume. The ratio of white tin is functioning properly, so all atoms can be considered normal.

After cooling during Δt_1 ratio has changed and became $S_{ft}^{2} = \frac{n_{12}(Sn^{2+})}{n_{22}(Sn^{4+})}$, but after increasing the temperature pattern can be used, i.e. there is a tolerance to damage. The rate of accumulation of defects is calculated by the formula $v(t) = \frac{S_{ft}^{2} - S_{ft}^{1}}{\Delta t_1}$. Completing a number of measurements we can find the law of change of the velocity and determine the limit, after which the sample should not be used.

Conclusion

The appearance of Sn^{2+}ions leads to a weakening of the bonds between atoms and the loosening of the metal. However, is possible the reverse reaction $Sn^{2+} + e^{-} \rightarrow Sn^{3+} + h\nu_1$ and further $Sn^{3+} + e^{-} \rightarrow Sn^{4+} + h\nu_2$, in which energy is released. Thus, the reactions are accompanied by energy absorption and emission of photons.

These reactions can be studied using the calorimetric and spectroscopic studies. Isotope of tin ^{119}Sn *allows executing research of the domain of destruction, using the Mössbauer effect.*

6.1.4.. Catalyst of morbid atoms

The example with the SnO shows that the oxygen in the α-Sn acts as a catalyst of a phase transition in which the failure occurs.

Saturation of metals with hydrogen leads to embrittlement. This is particularly intense with palladium, which, like the β-Sn phase, turns into powder.

Segregation of impurities on the surface of the grains leads to a change in the properties of the grains. A thin layer of tin on the surface of zinc leads to changes in the properties of zinc, its embrittlement.

In hardening steel strength increases, but burnt alloy may explode.

The instilling of impurities into pure metal changes its properties.

All these examples show that the change in the properties of the metal is caused not only by changing the position of the atoms, but change their energy state also.

6.1.5. Bauschinger effect

Metal pre-compressed, destroyed at a lower load than not subject to external influence. This phenomenon is called the Bauschinger effect, who first described it. The temperature change is always accompanied by compression or extension, the electrical conductivity changes, melting point, etc. These changes may be accompanied by either increase or decrease of any option, even in the nanomaterial.

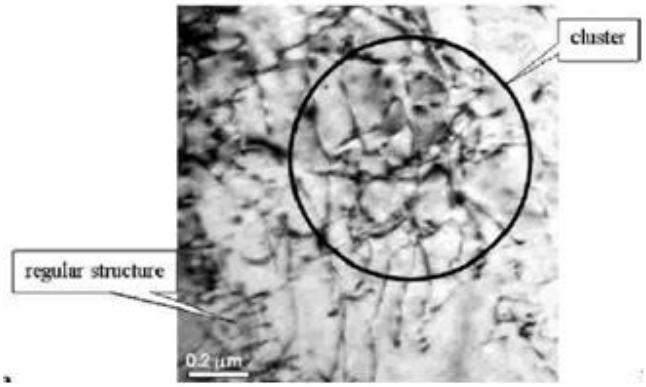


Figure 6.3 [6.12]

It is known that a decrease in the size of nanoparticles the melting temperature is reduced. This is explained by the increasing role of surface where atoms do not form an ordered structure. However, it turned out [6.10] that the germanium nanocrystals with a diameter of 2.5 nm in a matrix of SiO_2 melt at a temperature of 1448 K and crystallized at 919 K, while the melting temperature of the bulk samples is 1211 C. Hypothermia is a well-known fact, but 19.6% overheating, for the nanocrystals, demands an explanation. It is not associated with changes in pressure, since the coefficient of thermal expansion of silicon dioxide is higher than that of germanium. Consequently, this germanium melting feature related to the fact that some of the energy is not to increase the amplitude of vibration of the atoms, but the excitation of electronic transitions. The stored energy is emitted in the form of photons that pass through the SiO_2

A huge number of studies are devoted to Bauschinger effect mechanism, based mainly on the dislocation model. As noted in a number of papers on the mechanical properties of nanomaterials (eg, [6.11]), there are no sources of dislocations in them. However, the study of A. Kostrishev [6.12] performed using a tunneling electronic microscope there are not only dislocation photos but also photos of dislocation clusters, as it's shown in Figure 6.3.

Obviously, it is necessary to understand this contradiction.

We proceed from the fact that when the compressive strain, as during the white tin temperature lowering atoms become closer and their interaction is changing. It leads to changes in the energy states of the atoms. With non-linear deformation of the atoms after stress relief are in a new meta-stable state, ie, become morbid. In the metastable state, they have excess energy that can be emitted in the form of photons.

Showing this picture, the author does not comment on what the dislocation cluster is, how after removal of the external voltage the concentration of energy occurs needed to break. Supporters of the dislocation model of Bauschinger effect presume that the dislocations caused by the compression is due to the residual stress, which adds up to the voltage with a change of sign, enhances its effect.

We show that this conclusion is wrong.

Imagine that after a spring compression in a part of nonlinear deformation occurred. Will this spring return the energy in tension? No.

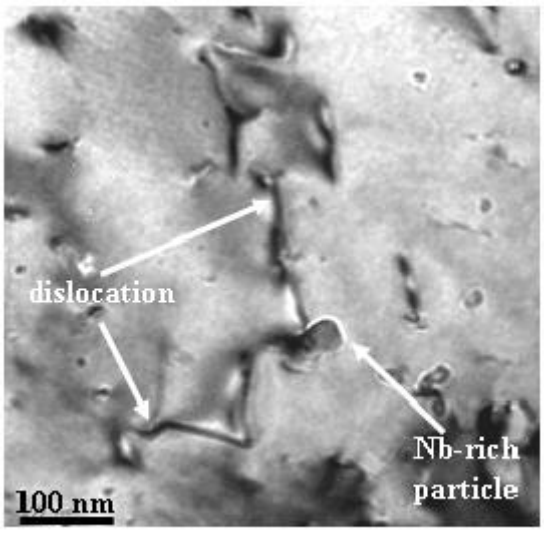


Figure 6.4 [6.12]

On the example of tin plague we have a metastable object, which is an ion Sn^{2+}. Upon heating it will emit the energy of recombination $Sn^{2+}+2e^{-}\rightarrow Sn^{4+}+2h\nu$ in the form of two photons.. Similarly, the ions forming a dislocation as a result of recombination emit energy that is added to the energy, reported by atoms in tension. This sum does not depend on how the ions were located.

Thus, the formation of morbid atoms in Bauschinger effect is a result of the same physical processes, as in spall fracture or tin plague.

6.2. Nanoparticles in solids

6.2.1. X-ray spectra of atoms morbid

The key to understanding the processes occurring in the alloy during its deformation Kostrishev considers the interaction of nanoparticles with the dislocation. He is considering two options for interaction, in one of which dislocation cuts the nanoparticle, in the other rounds it.

It seems that a dislocation and nanoparticles are converging solids, at the time, as it is a dynamic system in which there is a continuous exchange of electrons and energy between atoms. The ion which is located in the dislocation line, having captured the electron, breaks it. At the same time the atom located in the center of the nanoparticles, which has lost an electron, can be considered as an element of the dislocation. Nanoparticle as dislocation is a quantum mechanical object. To describe the mechanism of their formation and interaction it is required the inclusion of electron-wave processes, especially the photographs obtained by tunneling electron microscope due to electron diffraction subbarrier (tunnel) transitions.

It is the research in alloys Ti, V, Nb, and Cu, intended for oil and gas pipelines operating in the Arctic. Therefore, this work is of special interest.

Figure 6.4 shows the dislocation and the nanoparticle rich with niobium.

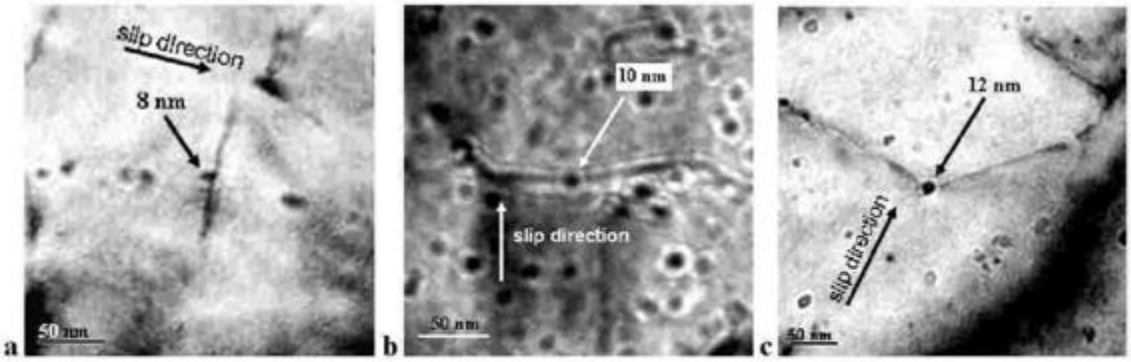


Figure 6.5 [6.12]

Further was investigated the effect of the size of nanoparticles in annealed alloy CV-Nb on the development of the dislocation, which is shown in Figure 6.5. It is noted that the nanoparticles with a diameter less than 12 nm do not hamper the development of the dislocation (Fig. 6.5 a, b), while particles with a diameter of 12 nm and above inhibit the dislocation development (Fig.6.5 c). Effect of nanoparticles is analyzed only from the point of geometry, size, ellipticity, position. Of course, in this approach, the mechanism of the phenomenon cannot be disclosed. At the same time, the results of the studies provide material for analyzing the mechanism of the Bauschinger effect.

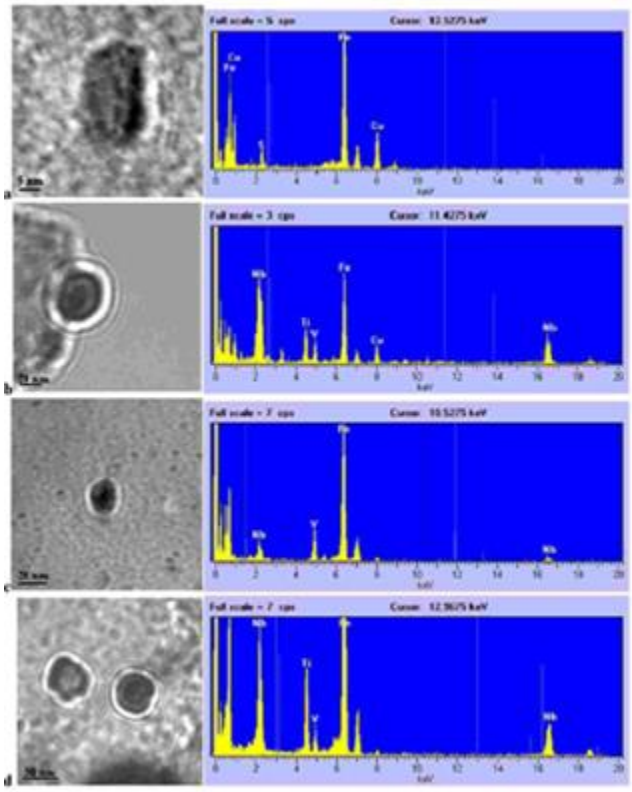


Figure 6.6 [6.12]

Detailed analysis of the spectra is of great interest, but requires special investigation.

In this study, we limit ourselves to a few fragments.

1. If we use the scale shown in Fig. 6.4, the diameter of the nano-particle is 35-40 nm, the width of the dislocation line, 10-13 nm. Assuming that the dark line is indeed a dislocation, it contains an AM^+, being the electron donor; in this case the nanoparticle is its acceptor, which is dominated by AM^-. Atoms' ionization (formation of dislocation) occurs in the area of maximum absorption of the energy of deformation. Thus, the energy stored in the dislocation, and the electrons in the nanoparticle. In the transition of electrons from the nanoparticles in the dislocation, which is in a phase of expansion, the

additional energy is released. Dislocation dragging by larger nanoparticles can be explained by the depletion of the strain energy that goes into the formation of dislocations. The proposed mechanism, similar to the formation of pitting defect should be considered as a working hypothesis for the unknown potentials of nanoparticles and dislocations, both the linear and the cluster shown in Fig.6.3. It may be that the line, called the dislocation, is just a collection of other defects. For a more accurate description of processes more information is needed.

2. The fact that the Bauschinger effect is due to electronic processes in the nanoparticles and their surroundings, is shown on the nanoparticles pictures taken using a tunneling microscope, and energy spectra, obtained by X-ray scattering, as shown on Fig. 6.6. On the three of the four pictures (b, c, d) presented here you can seen "halo" around the nanoparticles representing an interference picture in the form of concentric circles. Nanoparticle 6.5a is small. In fact, its size is equal to the size of the nanoparticles' core shown in other photos. But the given range of the energy distribution of the X-rays scattering is especially important so that the particle contains three elements: copper, iron and sulfur. Below we will examine this particle and its spectrum separately.

3. Maximum valence of vanadium and niobium which alloys are investigated [6.12] is five. However,

with oxygen they form compounds VO, V_2O_3, VO_2, V_2O_5; NbO, NbO_2, $NbO_{2.4}$, $NbO_{2.5}$, Nb_2O_5. With oxygen, niobium forms complex compounds with iron and titanium. These properties are used in the creation of complex alloys of these metals. But the variable valence of the metal determines the possible presence of two metal atoms with different configurations of the electron shell in a single nanoparticle. This refers to niobium. Let's pay attention to the spectra of the nanoparticles (Fig.6.6 b, c, d.) Niobium exhibits two maxima in each of them. We can compare the maximum with the "halo" around nanoparticle in the sequence b, c, and d. Each nanoparticle corresponds to its maximum. The bigger is the nanoparticle and brighter "halo", the higher is the maximum.

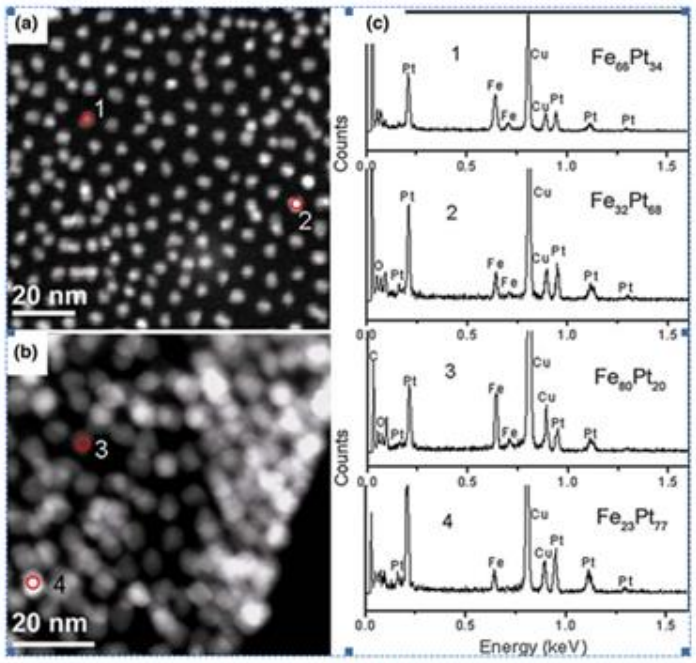


Figure 6.7 [6.13]

Conclusion

Every maximum of energy X-ray scattering corresponds to the valence of the ions forming the nanoparticles. The presence of two peaks in niobium spectra shows the simultaneous existence of two types of ions in different energy states. Diffraction pattern, which is formed around the nanoparticles, characterize the peculiarities of interaction of electromagnetic waves and nanoparticles.

The distinctive feature of the spectrum of nanoparticles (Fig. 6.6) is the presence of two peaks of copper, one of which coincides with the peak of iron, and the two peaks in iron.

The study this alloy distinctive feature is of particular importance due to the fact that it is mainly consists of copper atoms and ferromagnetic iron.

Here it is necessary to return to the experiments from which began the era of nanotechnology. As is known, the discovery of the *quantum mirage* played a particularly important role in the development of nanoscience, and with it in nanotechnology.

Quantum mirage was observed in the interaction of copper atoms with ferromagnetic cobalt atom. This effect was confirmed Feynman's foresight that the physical properties of a nanocrystal consisting of 36 cobalt atoms located above the copper atoms differ significantly from the properties of macroscopic objects.

The interaction between the atoms of iron and copper in nanoobjects is thought of particular interest to theoretical physics. It is connected with the problem of electrons scattering by magnetic impurities, known as "Kondo problem" (Kondo resonance) or other similar problems related to the behavior of electrons in the *perturbed and unperturbed system*.

There is an opinion that the solution of such problems has no practical value. But let us recall once again the prediction Feynman: "We *can use, not just circuits, but some system involving the* ***quantized energy levels, or the interactions of quantized spins****, etc."*

Any atom, with the seat in a metastable state, is perturbed. Region of the alloy, which contains morbid atoms, is perturbed. This disturbance is most clearly shows the diffraction patterns of the photograph in Fig. 6.6 b, c, and d.

Figure 6.7 shows photographs and X-ray scattering spectra of particles containing atoms of iron and platinum. In contrast to [6.12], in this study we investigated the structure of nanoparticles and determined the ratio of atoms of elements in them. Fig. 6.7 (a) shows the particles with a diameter of 4.5 nm, Fig. 6.7 b of 6 mm. Particles with a predominance of iron atoms marked 1 and 2; particles with a predominance of platinum atoms are numbered 3 and 4.

We note some features of the spectrum X-ray scattering.

• The number of maxima Fe is 2, Cu is 2, and Pt is 4 indicates a heterovalent of ions.

• Magnetic properties of different elements: Fe-ferromagnetic, Cu-diamagnetic, Pt-paramagnetic.

- The elements Fe and Pt are arranged in the subgroup VIII A of the Periodic System, Cu is arranged the subgroup IB.
- Nanoparticles have a face-centered cubic structure.
- The nanoparticle $Fe_{50}Pt_{50}$ is a ferromagnetic, the coercive force is equal to 9.8 kOe=7.8 x 10^6 A/m.

Table 6.1. Ionization potentials I_n of isolated atoms and affinity (eV)

Atom	I_1	I_2	I_3	I_4	Affinity
Fe	7.87	16.2	30.6	55	0.151
Cu	7.37	20.29	36.8		1.236
Pt	9.00	18.6	41	54.8	2.125

• Table 6.1 shows the values of the ionization potentials and electron affinities for the free atoms. Note that in the nanoparticles, these parameters depend on the total number of atoms and their relationship. This is probably due to differences in the X-ray scattering spectra and other parameters. For example, ionization potentials I_4 by iron and platinum are practically equal, but the affinity for platinum atoms to electron is 14 times higher than that of iron. This has led to what is observed in platinum four maxima, while iron only two.

Of particular importance is the fact that there are three isotope ^{57}Fe, ^{195}Pt and ^{196}Pt, in which the

Mössbauer effect is observed.

Conclusion

Paramagnetic, ferromagnetic, gamma-resonance; spectra of emission, absorption, and scattering of X-rays allow for extensive research to detect domains of destruction and estimation and estimation of their parameters.

The paradox, as it has already been noted above, is that the problem of the destruction and other problems of metallophysics considered in most publications without the discoveries made in nanoregions. This hinders the development of technology, harms the learning process.

6.2.2. Excitons and domains of destruction

Y. I. Frenkel's idea about the possible existence in dielectrics and semiconductors quasiparticles called exciton, formulated in 1931. It is viable and remains relevant today. Frankel suggested that this excited state will be able to travel through the crystal, transferring energy without changing the charge.

Excitons may be treated in two limiting cases, depending on the properties of the material: Frenkel exciton and Wannier-Mott exciton. The existence of excitons confirmed experimentally in dielectrics, semiconductors. The existence of excitons in insulators, semiconductors and molecular crystals is confirmed experimentally. It was established that the photosynthesis of plants is due to energy transfer with excitons. The existence of an exciton in the metal does not contradict the idea of Frenkel, but experimental confirmation came only 83 years later, [6.14], when it became possible to overcome a major obstacle due to the exciton by free electrons shielding. Exciton, or a long-lived excited atom has the same charge as the normal atom *AN* before it has absorbed a photon. This atomic reaction

1. $AN + h\nu \rightarrow AN^* = AM$ was considered by us in Chapter IV.

Consequently, the exciton can be considered as a morbid atom, the degree of ionization of which is not changed. The time during which the free electrons can "react" to change of the electromagnetic field is 10^{-15}-10^{-17} seconds due to the high velocity of electromagnetic waves, and small distances between atoms.

The authors of [6.14] got around this obstacle by using femtosecond (10^{-15} s) laser pulses.

Conclusion

Excitons (morbid atoms AM), whose lifetime is longer than the period of exposure (accumulation rate exceeds the rate of energy dissipation) are sources of the energy in the domain of destruction.

This means that the experimental methods by which excitons examines can be used for detecting the domain of destruction.

6.2.3. Heteropauling and morbid atoms

The existence of excitons in metal proved experimentally [6.14], allows us to revisit the idea of heteropauling atoms proposed in [1.6].

As noted in the introduction of the metal atomic model proposed in the book "Atom Parameters and Metal Properties" is based on two postulates, the first postulate of which ran that a metal may consist of atoms of one element having different electron shell configurations, i.e., atoms with varying energy states may be present in the metal simultaneously.

A new parameter of the atom $R_p = \frac{i}{r}$ has been suggested. Here *i*-total ionization potential, *r*-ion radius. For i = 1 eV, r = 1Å, R_p = 1.602 nanonewtons. This parameter named pauling in honor of Linus Pauling whose idea of chemical bond ostsillating became the basis for the proposed model. Oscillations of the chemical bond, predicted by Pauling, were confirmed experimentally [6.15]. This discovery was the birth of a new branch of science called coherent (femtosecond) chemistry.

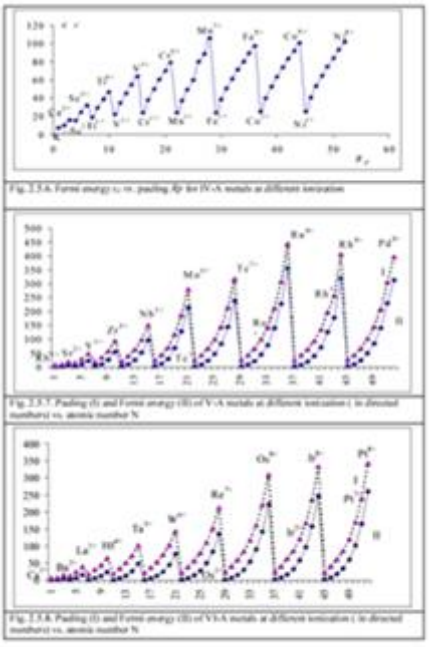


Figure 6.8 [1.6]

It has been shown that the change of pauling from atom to atom is subject to the periodic law.

Atoms (ions), which have different pauling, named heteropauling.

It is shown that pauling is well correlated with other parameters of the atom and metal. The Fermi energy is one of the most important parameters of the quantum theory of metals. Communication between the Fermi energy of the atoms of metal and pauling is shown in Figure 6.8 for three periods of the periodic system of elements. Changes of pauling from element to element are synchronous with the changes of the Fermi energy.

Thus, the exciton has certain pauling and can be considered as heteropauling atom.

The main characteristic of the morbid atom is it energy. Functional relationship between pauling and the Fermi energy means that theoretically can be found the connection between the Fermi energy and the energy of the domain of destruction. There are a large number of experimental methods for estimating the domain of destruction energy.

It is possible that among them there is one correct method, about which Maxwell dreamed, believing that it will help to develop a mathematical theory of the strength of solids.

Modern theoretical physics is able to create a quantum theory of strength and fracture, based on modern experimental techniques.

6.2.4. Hydrogen embrittlement and segregation of impurities

Damage brought by these events is enormous. However, the mechanism of this phenomenon remains unclear and there are no quantitative criteria. Effective method for studying the effect of hydrogen is the use of tritium. Results of some studies of these phenomena have been considered in [1.6].

The main drawback of these studies was that in them were not measured the changes of energy states of the atoms of the base material, which occur as a result of exposure to hydrogen or impurities which segregate. Of particular interest are the study of the effect of hydrogen on the strength of palladium and bismuth alloy segregation in CuBi. Palladium is converted into a powder with a definite concentration of hydrogen; monatomic layer of bismuth sufficient to embrittlement. Probable that the domains of destruction in these two cases consist of a small number of atoms. Note that the atomic weight of hydrogen is 106 times smaller than the atomic weight of palladium. In connection with this high rate of diffusion of hydrogen atoms is a natural one. Diffusion of bismuth atoms between copper atoms requires an explanation. The atomic mass of bismuth is 3.27 times higher than that of copper. Moreover maximum valency of bismuth is 5+.

Almost all isotopes of bismuth are radioactive. This simplifies the study, similar studies of tritium in the metal. Bismuth is an element with the most explicitly diamagnetic susceptibility.

6.2.5. Photons and phonons

Ultrasonic methods of solid-state research so widely used, that it is not necessary to describe them additional. We confine ourselves to the two amendments related to the problem of detecting the domains destruction**.**

The formula $2C_f = C_d = \frac{E}{\sigma_{\max}^2 \Delta N} \cdot \frac{\varepsilon_b}{a^3} = \frac{1}{W_d} \cdot W_b$ was obtained by solving the problem number 1 (Chapter V).

Three parameters: modulus of elasticity E, the lattice constant a, and the binding energy ε_b adequately characterize the properties of the material during operation. Irreversible change in any of these parameters leads to nonlinear deformation.

Modulus of elasticity is a macroscopic parameter change of which lead to change of the speed of sound $v = \sqrt{\frac{E}{\rho}}$, where ρ is the density. So, $E = \rho v^2$. But this pattern is not stored during the formation of cracks and fracture. Consequently, only the simultaneous measurement of changes in all the parameters can give more detailed information about the technical state of components of the device or structure.

Parameter τ_0 in Zhurkov's formula $\tau = \tau_0 e^{\frac{U-\gamma\sigma}{k_B T}}$ corresponds to the period of thermal oscillations $\tau_0 = 10^{-13}$ seconds, reduced frequency D, which characterizes the rate of energy dissipation morbid atoms in the formula $N_m(t) = N_m(0) e^{\frac{A}{Dk_B T}}$ varies from 10^{12}-10^{14} Hz.

Radiation of hypersound often observed at destruction. It is known that these oscillations correspond to the thermal vibrations of atoms.

This coincidence cannot be considered accidental, because the acoustic waves of that range intensively interact with related as well as free electrons. It follows that the influence of acoustic waves of hypersonic range on the formation and accumulation areas of energy by atoms is particularly high. We only limit ourselves to some brief remarks.

Experimentally proved [6.16], that the rate of the crack is higher than the velocity of shear waves. In aluminum and iron sound velocity is ~ 6000 m/s. Therefore, the frequency of the standing waves in nanograins is ~ 10^{11}-10^{12} Hz corresponding to hypersonic vibrations. Crystal lattice constant of the metal is less than 4 Å. Photon to overcome this distance needs approximately 10^{-18} s, but the crack 10^{-13}, i. e., in hundred thousand times more. If the photon energy absorbed by an atom exceeds sublimation energy, the atom evaporates. Atoms can get the energy which is enough for breaking the bonds with the mechanical impact at a certain speed of collision. This will cause the destruction or spall formation of visible or internal cracks. With the change of the impact velocity changes the velocity of acoustic waves, the speed of crack propagation. It is known that phonons emitted by thermal vibrations of atoms are incoherent. Consequently, the interference pattern is formed under the influence of any other coherent processes. But it is known that the stimulated emission of photons is coherent. Phonons generated by the deformation of the metal interact with thermal phonons. The nature of the interaction of generated and heat phonons strongly depend on the frequency of the

generated phonon. Ultrasonic range phonons only violate the equilibrium distribution of thermal phonons, which is then restored. Influence of coherent phonons of hypersonic range is non-linear. This leads to the fact that part of the energy is transferred to atoms.

As a result, an ordered far from equilibrium a dissipative structure is formed.

But the energy state of the system does not correspond the absolute minimum of the potential energy, i.e., the system is in a metastable state.

Another important factor of energy accumulation in such a system is that the time of propagation of cracks in the nanometer areas coincides with the period of thermal vibrations of atoms. Therefore, under certain conditions, the accumulation of energy by some atoms has a resonant character. It is a response not of entire structure, but only a group of atoms in a local nanometer region.

The interaction of light (photons) with hypersonic (phonons) leads to the scattering of light, received the name of the Mandelstam – Brillouin scattering. Using a powerful laser radiation leads to a strengthening of the effect, which is called the stimulated Mandelstam – Brillouin scattering. Similarly, under the influence of a powerful laser beam is amplified stimulated Raman scattering. Two of these effects are widely used to study changes in the energy state of the atoms.

Conclusion

Studies of the interaction of photons and phonons, especially hypersonic frequencies, are of particular importance for the elucidation of their role in the domain of destruction formation.

6.3. Quasicrystals and domain of destruction.

The discovery of quasicrystals was a surprise to solid state physics, especially crystallography. During 70 years since the application of X-ray analysis (1913) believed that crystals can have only the second, third, fourth and sixth fold axis of symmetry. The presence of five-fold symmetry axis was established experimentally in a study the radiographs of cooled aluminum-manganese alloy of in 1984. Further studies showed that in the new material a new type of order, the non-crystalline, but not amorphous is realized. Therefore, this substance has been called a quasicrystal. Today there are hundreds of similar alloys with a symmetry axis of n-fold axis higher than the sixth.

Let's briefly describe the properties of quasicrystals, which are due to feature in their atomic structure, limited to a small number of publications [6.17-6.20].

Quasicrystals have strictly aperiodic long-range order. It is found that the frequency is not necessary for the existence of long-range atomic order.

Features of quasicrystals properties are defined as aperiodic long-range order and local atomic

structure. As alloys of metallic elements, quasicrystals are not ordinary metals, insulators or semiconductors [6.17].

Specificity is defined as properties of quasicrystals aperiodic long-range order and local atomic structure. As alloys of metallic elements, quasicrystals are not ordinary metals, insulators or semiconductors

Specificity is defined as the properties of quasicrystals, aperiodic long-range order and local atomic structure. Quasicrystals are not conventional metals, semiconductors or insulators, in spite of the fact that they are alloys of metals [6.13-6.16].

While in normal metals all crystal face are identical and the electrons can pass from one crystal face to the other in the quasi-crystals cannot. While in normal metals all faces are identical and the electrons can pass from one face to another, this does not occur in quasicrystals.

Assume that the low electrical and thermal conductivity associated with this factor [6.20].

All properties of quasicrystals, their spectra of single-particle and collective excitations are different from those which are close on the structure of the crystalline and amorphous phases.

It is found that cluster structure is characterized for quasicrystals.

Analysis of the diffraction pattern of the quasicrystalline phase showed the presence of specific structural defects, called phasons. Phasons are quasicrystal lattice excitation caused by the redistribution of atomic nodes [6.17, 6.18].

There is no three-dimensional periodicity in quasicrystals. Often it is described by a sequence of Fibonacci numbers or geometric analog-Fibonacci chain. Changing the properties of quasi-crystals is described by the Fibonacci sequence so often that in some papers it is seen as a sign of a quasicrystal [6.19].

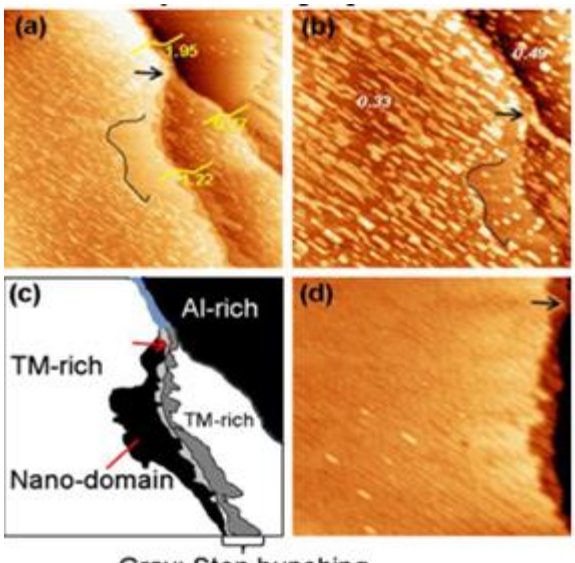


Figure 6.9 [6.19]

Extremely interesting experimental fact was established in [6.19] to investigate the surface of quasicrystals $Al_{63.2}Co_{19.5}Cu_{17.3}$. In nanocrystals was found two areas, one of which is rich atoms Al (Al-rich) other rich transition metal atoms Cu and Co (TM-rich), with the interface. It was found that the aluminum atoms form a kind of domain (phason) in TM-rich, while the atom of copper and cobalt in the Al-rich region does not pass.

Figure 6.9 a and (b) shows the areas (500x500 nm) TM-rich (left) and the Al-rich, separated by boundary. Nanodomain containing atoms of Al, is located in the area indicated by arrows. (d) - the region TM-rich, situated away from the domain. Scheme of the nanodomain is shown at Figure 6.9 (c). The authors suggest that the formation of nanodomain is due to the fact that the surface energy of the TM-rich region is greater and the bond is weaker.

In this experiment, we are interested in the fact that the interface between the two regions has a one-way transparent to the ions, and hence to the electrons. Questions arise. What is common between a quasicrystal and domain destruction? What role could the example play to predict the state of elements of structures and devices?

At least hundreds of experimental evidence on the validity of postulates of the metal model proposed by the author, and the role played by the standing waves in the change of the deformation properties of the metal are presented above. It is proved experimentally that the normal crystal and the quasicrystal differ not only in different positions of atoms, but within these energy state atoms.

This means that the aluminum atom in a normal metal can be considered normal, while in the quasicrystal as a morbid atom or vice versa.

Quasicrystalline state is metastable. The fact that the energy stored during the deformation process indicates the presence of the metal cluster, which is metastable.

The term "aperiodic crystal", which is so important for understanding the processes in a quasicrystal, Schrödinger introduced [6.21] in connection with the discussion of the problems of heredity from the standpoint of physics. This work is considered to be the starting point in the birth of Theoretical Biology. Experimental confirmation of the idea of Schrödinger used for quasicrystals was obtained 40 years later. But in the same paper, Schrödinger solved another major problem. Schrödinger showed

that the cell in which the program is laid growth of a living organism, the entropy does not increase, but decreases due to the influx of energy sourced from the *Sun*.

This conclusion is equitable for both quasicrystals and domain of destruction.

Conclusion

All of the experimental methods by which quasicrystals have been discovered and investigated can be successfully used to detect the source of energy of destruction, its rate of accumulation, the definition of the limit of its importance, and the development of methods for its dissipation.

6.4. Domain of destruction and metal corrosion

The danger of occurrence of morbid atoms (ions) in the metal is increased in the presence of nonmetal repeatedly due to the possibility of a chemical reaction, called corrosion. A particular danger is stress corrosion cracking (SCC). This phenomenon is well known and repeatedly described. Attempts to associate the effect of corrosion and deformation have been made repeatedly. For example, the talking about corrosion is in only one [4.12] of the seven papers cited [4.8-4-14]. B. R. Mosinyi draws attention to the corrosion of the rivet holes near the (A22-A25, A38, A40), which we discussed above. First, however, he only writes about fretting corrosion, secondly, he does not associate it with the strain, and thirdly, he does not consider the mechanism of this phenomenon. The mechanism of this phenomenon can be understood and expressed by means of equations only in the framework of quantum mechanics. Corrosion is the result of the interaction of atoms in which there is an exchange by electrons, the change of the atoms and the formation of compounds. A method of modern chemistry allows us to trace and assess quantitative and qualitative changes due to chemical reaction, as in nano-as well as macroscopic level. Mechanical action on the solid and the response on it can be expressed through the change of atoms. But to evaluate or describe a chemical reaction by methods of classical mechanics is impossible.

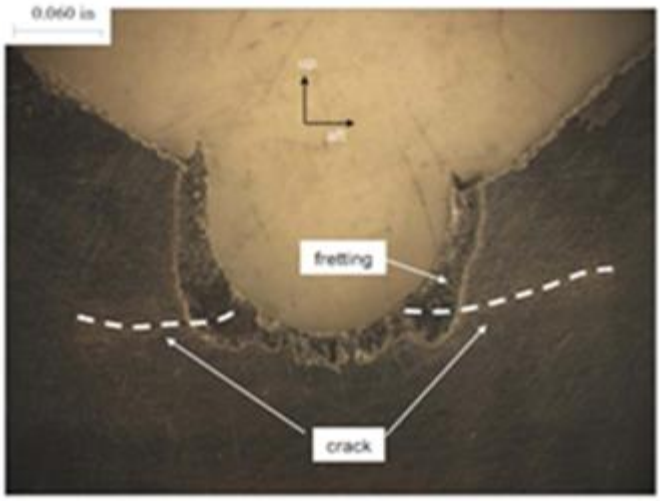


Figure 6.10 [4.12]

This means that attempts to obtain an equation on the basis of which it is possible to describe or

evaluate the simultaneous chemical and mechanical exposure in fracture mechanics, hopeless.

As noted earlier, Maxwell proceeded from the fact that the energy radiation that leads to destruction, by its very nature is not mechanical. All mechanical processes can be described using the electromagnetic interaction.

Therefore, a rigorous mathematical theory of SCC can be created.

Creation of such a theory is beyond the scope of this study, the main aim of which is to prevent catastrophic failure of elements structures and devices.

It was established experimentally that the most dangerous types of corrosion to the fuselage are fretting, pitting and bloating caused by the formation of metal-nonmetal compounds between the layers of the skin.

It was established that the corrosion due to the formation of aluminum compounds Al_2O_3, $Al_2O_3 \cdot 3H_2O$ и $Al(H_2O)_3$. These compounds are formed from two (Al, O) or three (Al, H, O) of the chemical elements. Aluminum ion Al^{3+} may occur in the domain destruction to the deformation. This ion can react

$$2Al^{3+} + 3O^{2-} \rightarrow Al_2O_3 + Q,$$

where Q = 17.36 eV is heat of the reaction.

The thermal effect in the formation of $Al_2O_3 \cdot 3H_2O$ и $Al(H_2O)_3$ is significantly higher than Al_2O_3

The binding energy of aluminum is 3.34 eV/atom. Therefore, this energy is sufficient to break five bonds between the atoms. However, the behavior of atoms obeys the laws of quantum mechanics, following which, the atom absorbs only a certain amount of energy. Another matter is the thermal vibrations of atoms. Melting heat of aluminum is 0.11 eV/atom.

Figure 6.11 [6.22]

Consequently, the energy of the radiation is sufficient to melt ~ 170 of aluminum cells. Of course, that much of the radiated energy is dissipated as heat. Forming a melt, along with cracks observed repeatedly.

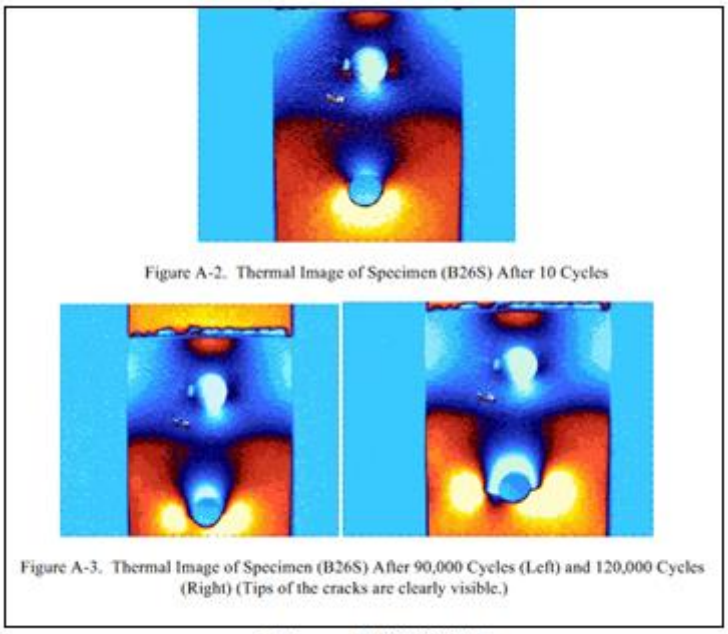


Figure A-2. Thermal Image of Specimen (B26S) After 10 Cycles

Figure A-3. Thermal Image of Specimen (B26S) After 90,000 Cycles (Left) and 120,000 Cycles (Right) (Tips of the cracks are clearly visible.)

Figure 6.12 [6.22]

These processes are shown in the photograph of the rivet holes 6.10 for A24, taken from [4.12], and 6.11 of the later work A. Atre *et al*. [6.22]. Objects of study in [4.11, 4.12 and 6.22] were fragments of the fuselage of the same aircraft. Work [6.22] is devoted mainly using the finite element method. However, the authors examine fretting corrosion in this case too. Over sixty photographs showing the simultaneous influence of corrosion and deformation processes of destruction riveted joint is given by the authors.

It is noted that in some cases, on the surface of the metal ring grooves appear, while in others they are absent.

The authors believe that: "Fretting wear has been expressed in terms of volume of material abraded, V (2NWfδ), or the average depth of the fretting damage also known as wear scar, y (2NWfpδ). Here, N is the number of fretting cycles, f if the normal contact force, p is the contact pressure, W is the specific wear rate, and δ is the local slip amplitude. Fretting wear is favored by large values of W, p and δ." All these parameters indeed affect on the wear of the material, but the authors have noted that: "*The amount of fretting wear is not proportional to the risk of critical crack formation. At large slip amplitudes, cracks may be abraded resulting in a metal loss."* (Italic supplied).

But in the cited paper is not specified how the fretting and fretting corrosion is taken into account in the finite element method.

Three photographs shown in Figure 6.12, demonstrate the use of thermographic method for stress analysis. The first of them was made after ten cycles, the second after 90,000, and the third-after 120,000.

As the authors note, the crack is observed only after 70,000-80,000 cycles.

This fact is extremely important.

First, it suggests that the thermal vibrations of infrared photons cannot form a crack. Consequently, the hypothesis of thermofluctuation microcrack nucleation is untenable. Secondly, it is necessary to investigate not only the radiation energy in the infrared range, but at higher frequencies, including x-ray. Third, the domain of destruction formation is accompanied by changes in the structure. Consequently, simultaneously with thermography is necessary to carry out X-ray studies of the

structure.

6.4.1. Deformation and corrosion

First of all, let us recall the scientific discovery, marked by the Nobel Prize. Gerhard Ertl showed that nitrogen is adsorbed on the metal surface in the form of atoms, and only then connected in series with three hydrogen atoms, forming a molecule $N^{3+}H_3^{1-}$. Metal acts as a catalyst, speeding up the process. This discovery has become a key to understanding the processes of metal corrosion.

Domain of destruction and corrosion occur as a result of the exchange of atoms (ions), by electrons and photons. Increase in the accumulation rate of the deformation energy accompanied by the increasing the number of free electrons, which are more readily absorbed by the non-metal atoms.

The oxidation reaction of the metal, as well as the formation of other chalcogenides, is exothermic. Energy is emitted in the form of photons, which accelerate the formation the domain of destruction. Thus, deformation and corrosion are synergistic. The danger of simultaneous chemical and mechanical exposure is conditioned by this factor.

Let us consider one more important feature of fretting corrosion.

As known [6.23], the Al_2O_3 film prevents the metal from further oxidation. This film is formed in dry air a thickness of 30-40 Å for 5 years. It has been established that the thickness of the Al_2O_3 film reached 50,000 Å in the presence of moisture over 12 days.

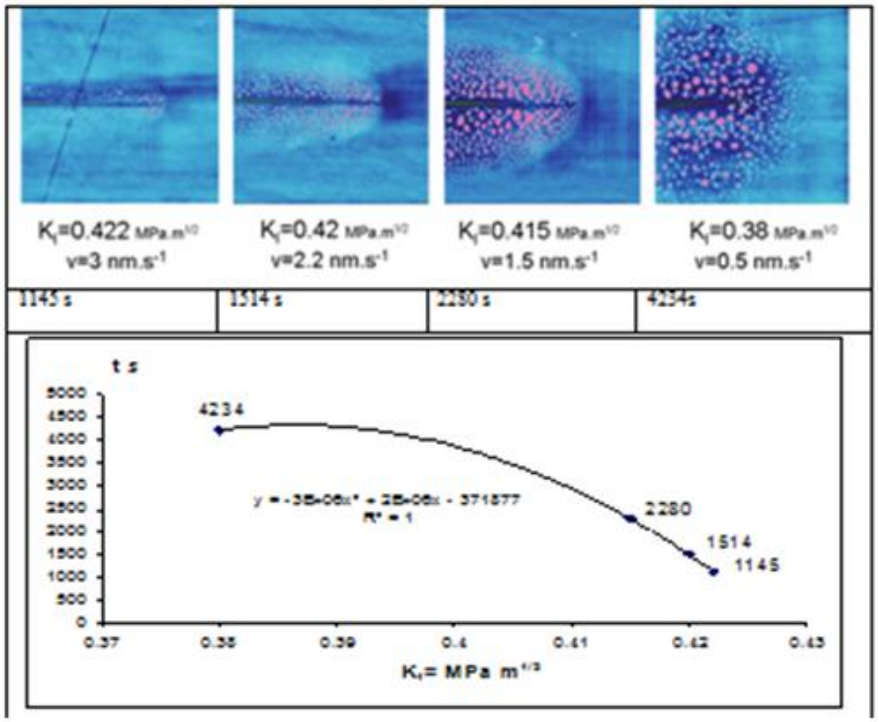


Figure 6.13 [6.23]

The thickness of the porous film Al_2O_3 come up to 3-35μm. Film Al_2O_3, formed in the gap between the rivet and bore wall quickly removed when bending and stretching deformation. Moreover, Al_2O_3 (corundum) plays an abrasive. At displacement the clearance increases and the abrasive layer increases.

These two processes are accompanied by an increase of the radiation energy, which leads to an increase in temperature, local

melting, breaking bonds, and the formation of the circumferential grooves.

Damage caused by fritting corrosion and deformation, shown in Figure 6.10 [6.21] and other works cited. Similar pictures can be found in the literature on how the deformation of the fuselage, and its corrosion, but the nature of the phenomenon and mechanism of SCC is not disclosed. In this regard, we consider another example of material response to simultaneous mechanical and chemical influence.

Figure 6.13 [6.23] shows four pictures of crack in the glass, in which the sodium ions are implanted [4.34]. Crack formation in a humid atmosphere accompanied by the oxidation reaction of sodium (corrosion). The photos are taken using an atomic force microscope.

The values of stress intensity factor and crack formation rate are given under each photo.

I have evaluated the time during which the experiment was conducted on the basis of the data available in the article.

The stress at which crack was formed, shown in the second photo, decreased by 0.5%, while the rate decreased by 36%. Accordingly, further reduction of one percent resulted in a reduction rate of 47%. But the most interesting is the fourth picture: the load, which is 0.38 MPa, the rate decreased to 0.5 nm/sec. This means that almost one bond breaks per second. However, corrosion is not only continuing, but is accelerating.

Foregoing experiment allows us to answer the question why the most dangerous type of fracture is stress corrosion cracking, (SCC)?

At simultaneous mechanical and chemical influences (nonlinear deformation and corrosion), the electron-photon processes occur so that the weakening of the bond caused by corrosion, reduces the energy dissipation rate, temperature rise in the local areas in which the failure occurs at a lower energy density of domain of destruction.

6.4.2. Pillowing of the fuselage

Bloating of the Stratotanker C/KC-135 fuselage induced by corrosion is considered in works [6.24-6.27]. The authors of these works describe this phenomenon as follows:

“A chemical analysis on corrosion samples taken from service-exposed lap joints indicated that the insoluble product contained a mix of oxides, primarily aluminum oxide trihydrate, which has a molecular volume ratio 6.454 times that the aluminum. It is this high molecular volume ratio that is responsible for the deformation of the riveted skins in a joint resulting in the appearance commonly referred to as “pillowing”. The presence of these non-surface breaking cracks referred to as pillowing cracks, has raised concerns into the effect they could have on the structural integrity of corroded

fuselage lap joints. Visual examination of lap joint faying surfaces that were cleaned of corrosion product revealed that pillowing cracks could extent to approximately one-quarter to one-half the rivet pitch." [6.24]

P. W. Whaley [6.27] clarifies, referring to [6.24-6.26]. He writes: "This corrosion by-product material increases volume by approximately 6.5 times the original uncorroded aluminum. When these corrosion by-products build up between two layers of skin, the volume increase deforms the skin structure between the rivet rows leading to a phenomenon known as skin pillowing. Skin pillowing increases the damage corrosion does to the airframe by substantially increasing the stress in the lap joint."

The mechanism of this phenomenon becomes clear if we consider those physical processes by which it is due.

The bulk density of the compound formed between two layers of metallic coating is 2.7:6.5 ≈ 0.42 g/cm^3, while the density of Al_2O_3 is 4 g/cm^3. However, this porous material whose melting point is 2050 º C, formed not instantaneously, but the molecule by molecule.

Formation of porous Al_2O_3, sufficient to bloating occurred for several years. Consequently, the growth rate is such that the pore formation starts at the nanoscale as a nanofilm in dry or humid air, which is formed by exfoliation from the metal particles. At this stage, the special role played the interaction of photons with the metal, resulting in a phenomenon called collective photoheating. A distinctive feature of these transitions is the participation in it photons whose energy is 3 orders of magnitude greater than the elastic energy. But no less important is the fact that nano-objects, which are smaller than the wavelength of light, are the phenomenon called *surface plasmon resonance*.

Plasmon resonance due to the fact that at a certain frequency of light metal not only reflects the electromagnetic wave, but also absorbs some of it. This absorption is especially strong when the wave frequency coincides with the frequency of the collective oscillations of the electron gas. This collective motion in quantum mechanics is considered as a quasiparticle called plasmon. Of course, that such a problem can be solved only in quantum mechanics, but analogues in classical mechanics, it does not.

Experimentally it has been shown [6.25], that the collective action of the photons leads to an increase in the temperature not only in the nanoscale but in nanometer region also. Moreover, this increase in the millimicrons region is ~ 7 º. This is due to the high ratio of surface to volume.

The thermal effect in the formation of $Al_2O_3 \cdot 3H_2O$ and Al $(H_2O)_3$ is significantly higher than Al_2O_3. Therefore, bloating is not due to the expansion of crystalline hydrate, but under expansion of the heated metal exposed to high vapor pressure.

In order to understand what caused the difference in the formation of cracks in different types of corrosion, consider the result of other experimental studies.

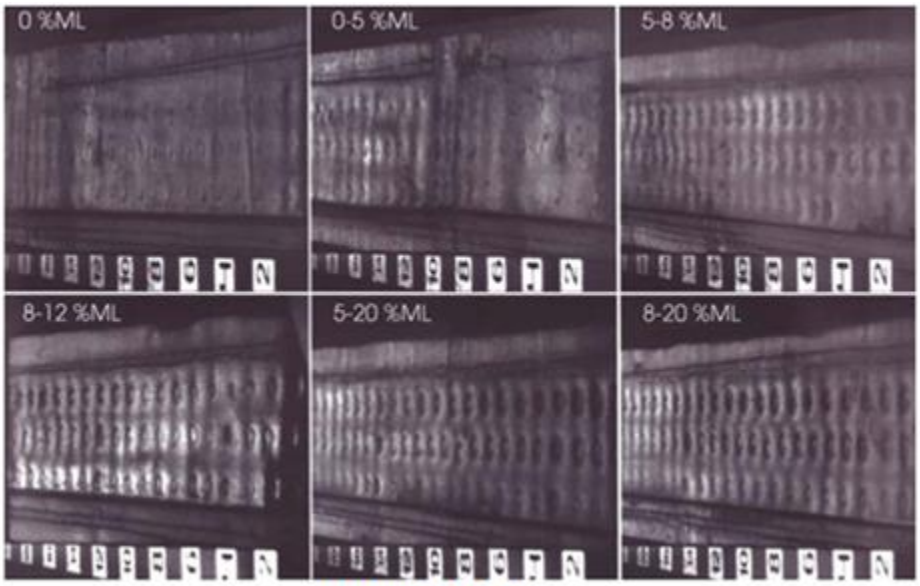


Figure 6.14 [6.24]

Figure 6.14 shows the six fragments of the fuselage of the Airbus A300 on which bloating happened. Visible cracks in the photo are not observed, but this does not mean that they do not exist at all.

They were detected by using both optical and scanning electron microscopy.

To determine the failure mode of these pillowing cracks, a number of cracks were examined using both optical and scanning electron microscopy.

Cracks occurred near the rivet holes are shown in Figure 6.15 [6.26]. Cause of cracking near the rivet holes Bellinger describes as follows: "Pillowing cracks tended to occur in groups (i.e., "star-shape" pattern cracks at more than one rivet hole), which did not normally penetrate through the thickness. The cracks always occurred on the side of the hole that was affected by the increased stress due to the pillowing and tended to propagate into the pillowed region." One of these

Figure 6.15 [6.24]

cracks is shown in Figure 6.16.

We draw attention to the fact that the cracks were formed in the *cylindrical region* bordering with rivet hole. Cracks do not extend beyond these areas, the structure of which has changed. The cracking indicates that in this area there is radiation energy and atomic bond rupture. The maximum energy was absorbed at the boundary rivet-base metal. Consequently, the power source was located in this intermediate region. The cracking indicates that in this area there radiation energy and decoupling of atoms happened.

What is it? Let us describe the mechanism of its formation.

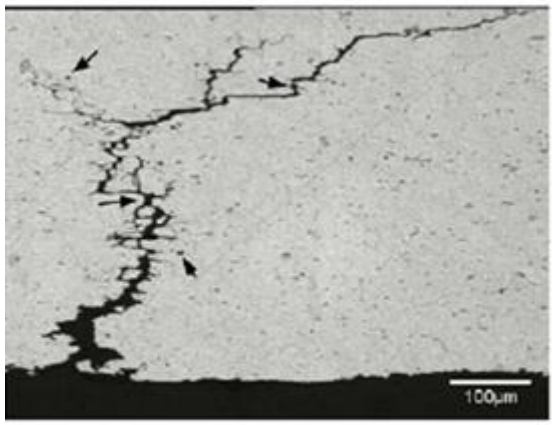


Figure 6.16 [6.24]

It is known that corrosion becomes possible at the presence of a nonmetal, such as oxygen, only when the metal acts as a cathode. This allows us to understand the mechanism of simultaneous chemical and mechanical exposure near the contact rivet base metal.

Oxygen and moisture penetrate into the clearance between the rivet and the solid metal during bending and elevation of temperature. A potential difference occurs between the metal and nonmetal. Bending and increase in temperature leads to the fact that the clearance increases, the access of oxygen increases also, and in the clearance formed molecules of metal-nonmetal compounds, just as it occur when bloating. Photons emitted by the chemical reaction, heat the metal, change its structure, but cannot form cracks. But some of the photons absorbed by the atoms, in which accumulated energy. Those atoms form the domain of destruction, as previously described.

Rivet also subjected to damage, but the nature of these lesions is different from the damage of the fuselage skin. This damage is caused not only by the composition and structure of the material, but also by geometry. For small displacements and vibrations thin layer of Al_2O_3 exfoliate. Turning into an abrasive, it polishes the metal, accelerating the emergence of new oxide layers.

These changes occur abruptly, which resulted in the formation of the strata, as seen in Figure 6.17, made with a scanning electron microscope. Radiation power under the compound Al_2O_3 formation is insufficient for the formation of cracks due to the large reaction time, but the energy released at the same time is so great that the structure of the metal around the hole is changing.

Corrosion, which occurs between two skin layers, leading to the compounds Al_2O_3, $Al_2O_3 \cdot 3H_2O$ and $Al(OH)_3$ appearance, which results in local heating of the metal, its melting, air and water vapor, temperature increase, and the acceleration of chemical reactions. This leads to an increase in pressure and to pillowing. Thus, a porous substance, whose bulk density is 2.7: 6.5≈ 0.42 g/cm^3, is formed in a free space. An important role of the compounds forming plays physical and chemical processes due to the fact that they originate in the nanoobjects. The distinctive feature of such processes is the participation of a photon whose energy is 3 orders of magnitude greater than the elastic energy. But no less important is fact that in the nano-objects whose size is comparable to the wavelength of light, there is an effect called plasmon resonance.

Changes in the structure caused by the simultaneous chemical and mechanical exposure, resulting in serious injury, which are shown in Figures 6.10, 6.11.

The formation of cracks near the rivet holes were considered in Chapter IV. The source of the fracture energy was the energy of mechanical action. Corrosion weakens the metal, slowly destroying it; however, without mechanical stress cracks are not formed.

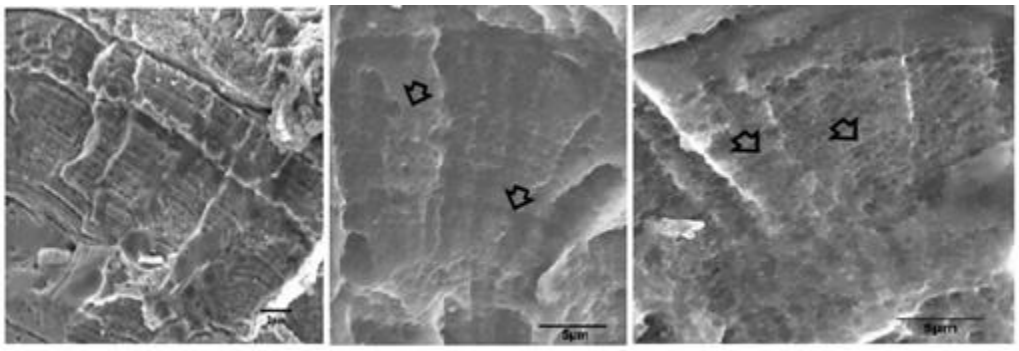


Figure 6.17 [6.24]

Attempts to quantify the contribution of corrosion have been made repeatedly. We only mention a few of them [6.26-6.29], which is mainly considered fretting corrosion.

The authors of [6.25] note *that one of the main* factors affecting the integrity of the riveted joint is the volume of product formed as a result of corrosion, but not the loss of its thickness, expressed as a percentage. The authors, however, did not explain the basis on which this conclusion is reached. Indeed, firstly, the volume of the product is not important, but its weight, secondly, only in the case when there is corrosion at a shallow depth, and it's mass due to the large area at which it occurs.

Dynamics of fretting corrosion formation is shown in Figure 6.18.

Quantitative criterion was the size of the defect. Estimation of the area was carried out for all four sides by a five-point system, and determined the average value, which is specified. Since the work is given only a description of the observed phenomenon, but any conclusions about the mechanism is

not done, we will confine ourselves to one comment.

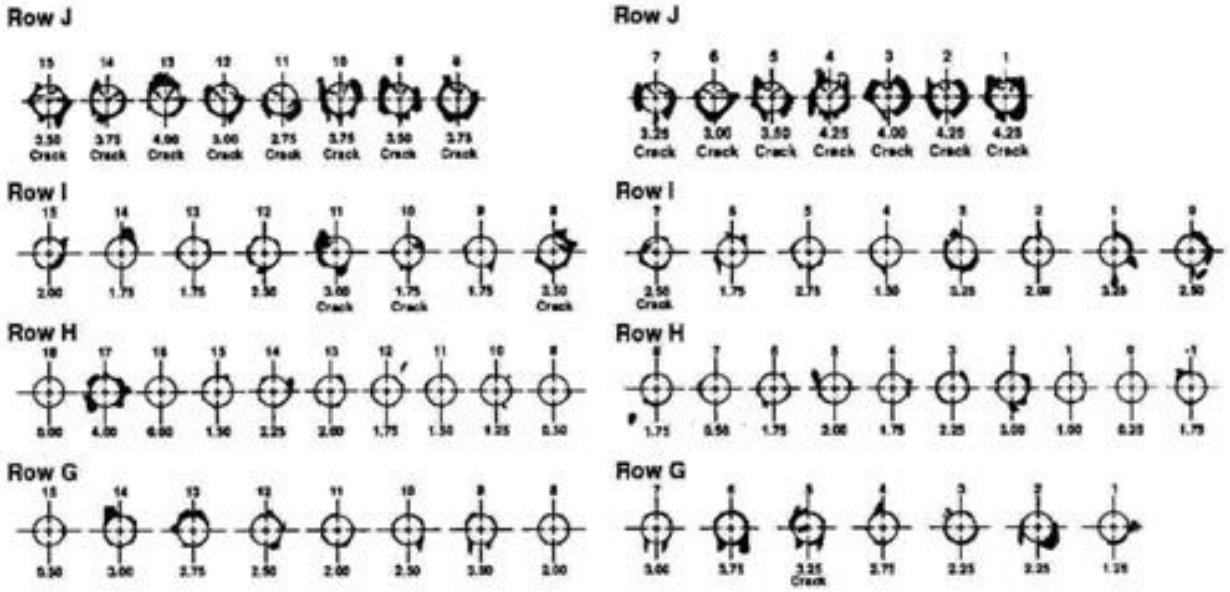


Figure 6.18 [6.29]

The surface area of the metal, which is struck by corrosion, shall be taken into account when assessing the wear and remaining life, but can only be considered as a accessory parameter, because the main parameter is the ratio of the speed of accumulation of energy to its dissipation rate.

Thus, the fuselage simultaneously subjected to mechanical stress and various types of corrosion. The ratio of these factors may be different. Fretting corrosion plays an important role in the destruction of the aircraft fuselage. However, this does not mean that when weak fretting corrosion crack is formed and there is no danger. It is necessary to consider the influence of another type of corrosion-pitting corrosion Pitting corrosion can lead to the formation of small holes, which will lead to depressurization. At the point where the thinning occurred, the probability of crack initiation is maximized.

6.4.3. Pitting corrosion of the fuselage

Material wear due to corrosion, as well as other types of defects, needs to quantify.

We have already noted the work in which area of the material, corroded, was chosen as a quantitative criterion. Loss of thickness or volume of pitting defects is also considered as a quantitative criterion in several papers.

Geometric parameters of the defect, including pitting, cannot be used to assess the wear and prediction the residual resource, since such defects can turn from passive to active and vice versa.

Wear assessment and prediction the residual resource is possible only on the basis of physical parameters. In this regard, we will hold a more detailed physical-chemical analysis of the pitting corrosion formation.

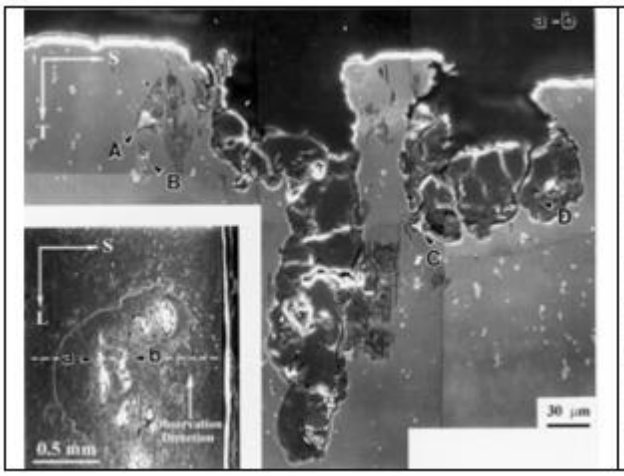


Figure 6.19 [6.30]

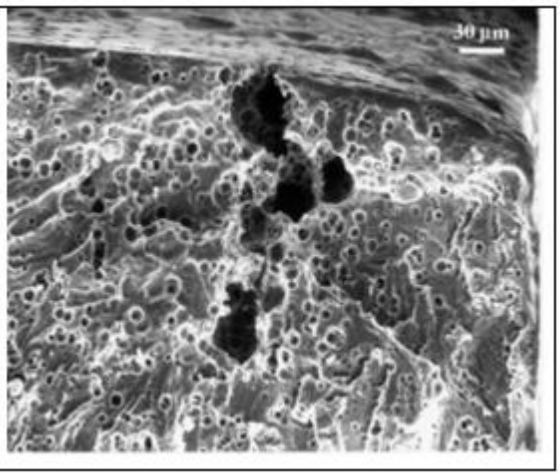


Figure 6.20 [6.30]

Figures 6.19, 6.20 shows the photographs of pits in aluminum alloy 2024-T3, taken with a scanning electron microscope [6.30].

The aim of the study was to find the functional dependence of the size of the pits of the external influence time. The authors write: “A probability model for the growth of corrosion pits in aluminum alloys in aqueous environments, in which the focus is the role of clustered particles, is suggested as a basis for estimating the distributions in size and location of fatigue cracks, as a function of time, for use in multiple-site damage (MSD) analyses. MSD is a condition in which multiple fatigue cracks occur within the same structural element, which is precipitated by pitting corrosion.”

As we can see, the authors proceeded from the fact that pitting defect is the source of fatigue cracks.

This conclusion was based on a pilot study of 12 samples of the size 800x800 μm. In this case either cationic or anionic clusters were detected that form a complex, called pitting particle. It was determined that such particles contain from 9 to 22 clusters. Their photos, taken with a scanning electron microscope, are shown at Figure 6.21 [6.31].

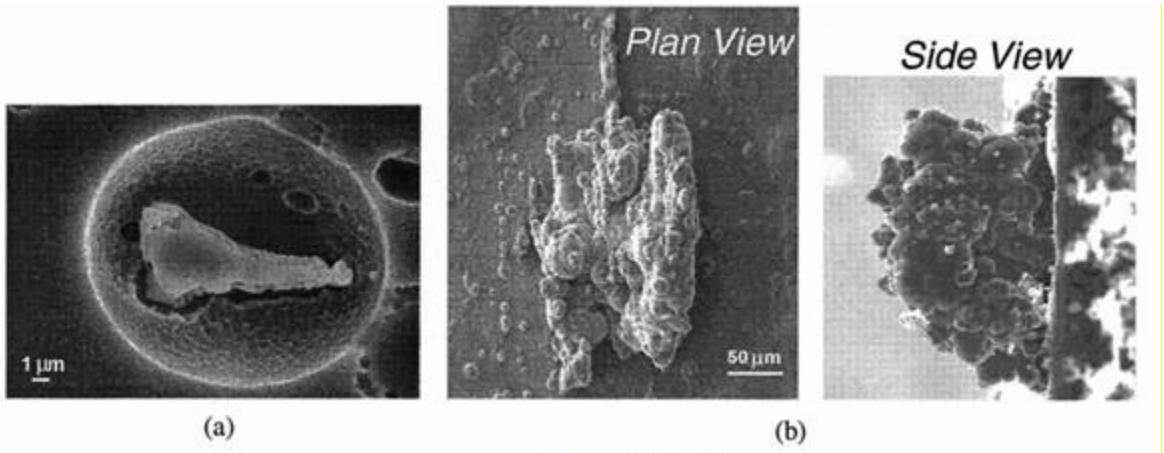


Figure 6.21 [6.31]

Any theoretical model aimed to forecast the technical condition of the fuselage, is of great interest, no matter how plausible or fantastic it may seem. But, since we are talking about safety, it must be subjected to careful scientific analysis and experimental verification. It should be recalled of the pitting defect danger.

With its small surface the defect depth can be such that it would lead to seal failure with severe consequences. For example, two small holes in the collector (Guadalajara, Mexico, 1992) led to a gas leak in the underground communications. There were 9 blasts, which killed 215 people, injured about 1,500 people and damaged about 1,600 buildings.

As noted above, the effect of the pitting defect is not due to its size and weight but the depth of damage caused by it. Since the formation of compounds $Al_2O_3 \cdot 3H_2O$ and Al $(H_2O)_3$, Al_2O_3 energy is released, then the important role is played by the rate of a chemical reaction, which is impossible to be assessed with the methods of mechanics. It is impossible to determine the direction in which it is emitted. The authors of most publications on the pitting corrosion believe that it is dangerous even with sizes less than 20 microns.

This means that its birth and development requires a careful monitoring, which is possible only by the physical non-destructive methods. The authors of the work [6.26] drew attention to the fact that a crack is formed with a certain amount of pitting particle. This means that the critical mass at which the trigger mechanism is activated, leading to a chain reaction with a multiplication factor, is more than one photon.

6.4.4. Photoelectric effect and corrosion

As noted above, the fuselage of the aircraft while in the transcendental atmosphere, is subjected the light output intensity, under the influence of which a phenomenon called the photoelectric effect arises in substance. The internal and external photoelectric effect can be distinguished. By the action of light

the photoionization of atoms occurs, leading to an increase in the number of free electrons and, consequently, to an increase in electrical conductivity. The photon energy is spent on electron detachment, transport it to the surface, and remove from the surface. In the metal, induced by photons, in the first place, electrons are accelerated from the surface, forming above the negatively charged cloud. The metal surface is positively charged. In the vacuum photocell in the circuit, the current is created even in the absence of external source. The current above the fuselage is conditioned by the fact that some of the electrons are captured by ions. However, we are interested in photocurrents arising along the fuselage due to the inhomogeneity of the alloy. As it is well known, the pitting defect formation is due to formation of the anode (in the center) and cathode areas.

Let me draw attention to the geometric features of the location of the cathode clusters. When irradiated with light surface, the electrons, torn by photons, can significantly accelerate the oxidation reaction.

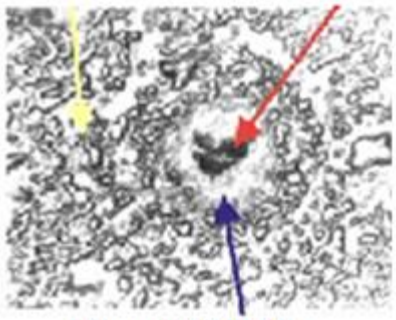


Figure 6.22 [6.32]

Photoelectron energy $\frac{mv^2}{2}$, according to Einstein's formula $h\nu = A + \frac{mv^2}{2}$, is due to the photon energy and the work function A. The strength of the photocurrent is proportional to the number of photons. As noted above, the work function of the electrons is under the influence of the deformation decreases.

In order to study the electrochemical processes in thin layers of metal under the influence of light, Williams [6.33] used an electrochemical microscopy.

Scanning electron tunneling microscopy has been adapted for the study of the photocurrent. Let me briefly describe the outcome of the experiment.

It was found that the nature of the formation of pitting defect and its speed depends on the state of the boundary, including thickness. Passive defect can become active and vice versa. Boundary plays the role of a trigger, accelerating or slowing down the reaction.

The film of iron with a small amount of impurities (99,999) in the aggressive solution after the 20 minute exposures was irradiated with laser light; a small spot is moved over the surface. Impurities had been formed around the oxide**.**

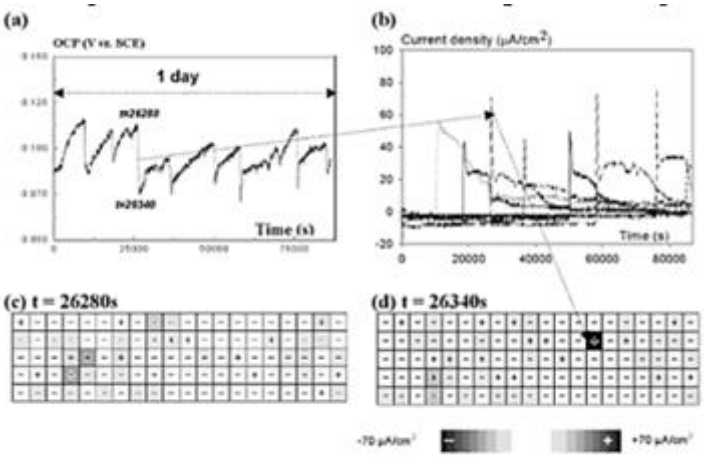


Figure 6.23 [6.34]

Oscillations of the potential (OCP) and the current density can be most clearly illustrated by the corrosion of copper in drinking water containing chlorine (5 ppm Cl_2) and aluminum (2ppm Al-$Al(OH)_3$ Oscillations take place even at room temperature [6.33].

The character of potential and current changes is different. Potential oscillations 6.23 (a) have a characteristic smooth rise and sharp decline, whereas for the current oscillations 6.23 (b) is characterized by the abrupt increase and slow decline, indicating a change in the concentration of free electrons. This means that there are periodic ionization and recombination processes, which are accompanied by a constant current. Pattern stationary currents at t = 26280 s (c) and t = 264 s (d) are shown below. The moment at which at one of the electrodes is formed pitting defect is shown below.

A wide range of problems related to corrosion of the metal, is considered in the monograph [6.35].

There are a large number of chemical reactions, indicating the heat of formation, characteristic of corrosion, including deals with the processes that lead to the SCC.

We confine ourselves to two aspects: the participation of different-valence ions in the formation of pitting defect and the mechanism of SCC.

. The experimental facts presented in it are of great scientific interest for understanding the nature and mechanism of destruction.

However, the author interprets them from the standpoint of fracture mechanics and general chemistry.

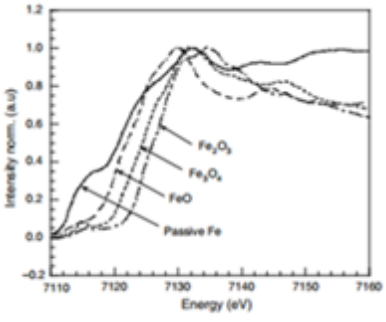


Figure 6.24 [6.35]

The discovery, made by Ertl and coherent chemistry allow us to interpret SCC from a position of not only the interaction of electrons and ions, as is done McCafferty, but with photons too.

Figure 6.24 shows the absorption spectra of X-rays in iron oxides. E. McCafferty marked out two areas: the absorption edge, which extends from 7110 to 7130 eV, he connects with the *K* shell electron ionization (1*s*-electrons) and *L* shell (2*s*, 2*p* electrons), while the oscillation energy in the range 7130-7160 eV, in his opinion, is due to photoelectrons of the

neighboring atoms.

In this experiment, we are interested in the presence of oxides *FeO, Fe_3O_4, Fe_2O_3*, the absorption edge of which is shifted to higher energies from *FeO*-7115 to *Fe_3O_4*-7117, *Fe_2O_3*-7120 eV. In fact, the compound Fe_3O_4 is not binary, but triple $Fe_2^{3+}Fe^{2+}O_4^{2-}$.

The transition from Fe_2O_3 will be possible with additional ionization $Fe^{2+}+hv \rightarrow Fe^{3+}+e^-$ -and the presence of oxygen. Maximum risk in the operation of technical installations is corrosion with simultaneous mechanical influence (SCC). Attempts to reveal the mechanism of this phenomenon made repeatedly, including monographs McCafferti.

6.4.5. Pits formation around chemical compounds

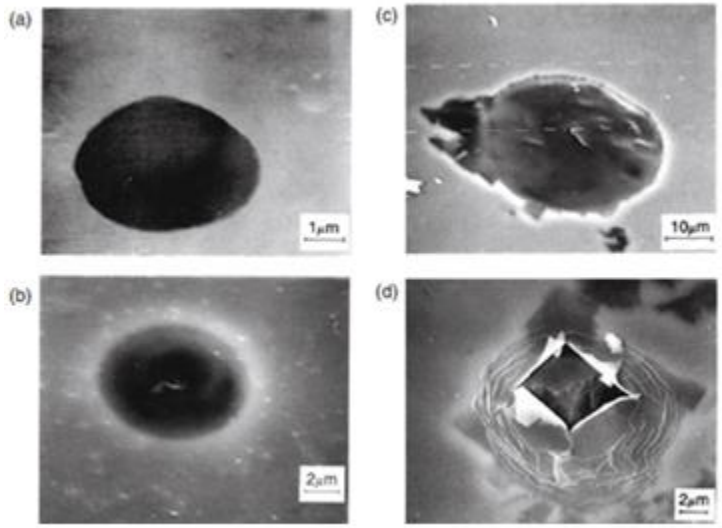


Figure 6.25 [6.35]

Four stages of pitting defect that grows into the metal, forming a blister is shown in Figure 6.25. Such a defect is especially dangerous in that the thickness of the metal is reduced and at some point it might happen depressurization of the fuselage. The initial stage of the oxide film formation under the recess due to the electrochemical reaction at the oxide/metal is shown in Figure 6.25 (a). The formation of a crack is shown in Figure 6.25 (b).

Corrosion on the perimeter of cavities and cracks, as shown in Figure 6.25 (c), due to, according to McCafferti, hydrolytic reaction with evolution of hydrogen. It is noted that hydrogen evolution was observed experimentally. The corrosion rate increases sharply as a result of the simultaneous action of hydrogen ions, oxygen and chlorine. A huge number of studies have been devoted to this problem. Schematically, this effect is shown in Figure 6.26.

As we can see, McCafferty actually limited only to a statement of fact. Moreover, the defect, as shown in Figure 6.25 (d), is significantly different from its predecessors. Clear faceting indicates that this crystal. Metal structure around the defect is also changed. As we can see, McCafferty actually limited only to a statement of fact. Moreover, the defect, as shown in Figure 6.25 (d), is significantly different from its predecessors. Clear faceting indicates that this crystal. Metal structure around the defect is also changed.

Six photos of metal-nonmetal compounds are shown in Figure 6.27. The characteristic feature of these defects is that cracks are formed just outside the metal-nonmetal compounds, as illustrated by the ten photographs presented in Figure 6.28.

As we can see, Murakami has chosen as the parameter the area of the defect. Using this option allows to establish the definite correlation between the area$^{1/2}$ of the defect, number of cycles N_f of external influence and the stress amplitude σ.

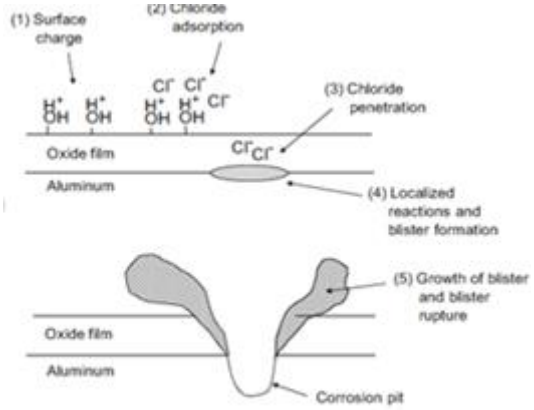


Figure 6.26 [6.35]

However, the area of the defect does not characterize the dynamics of the process and does not allow to predict that an external impact, which happen disruption especially in those cases when the material is subjected to mechanical and chemical or radiation exposure simultaneously or successively.

Twenty photographs shown in Figures 6.25, 6.27 6.28 indicate that there is a regular connection between the processes of destruction caused by mechanical and chemical effects that cannot be explained by the stress state.

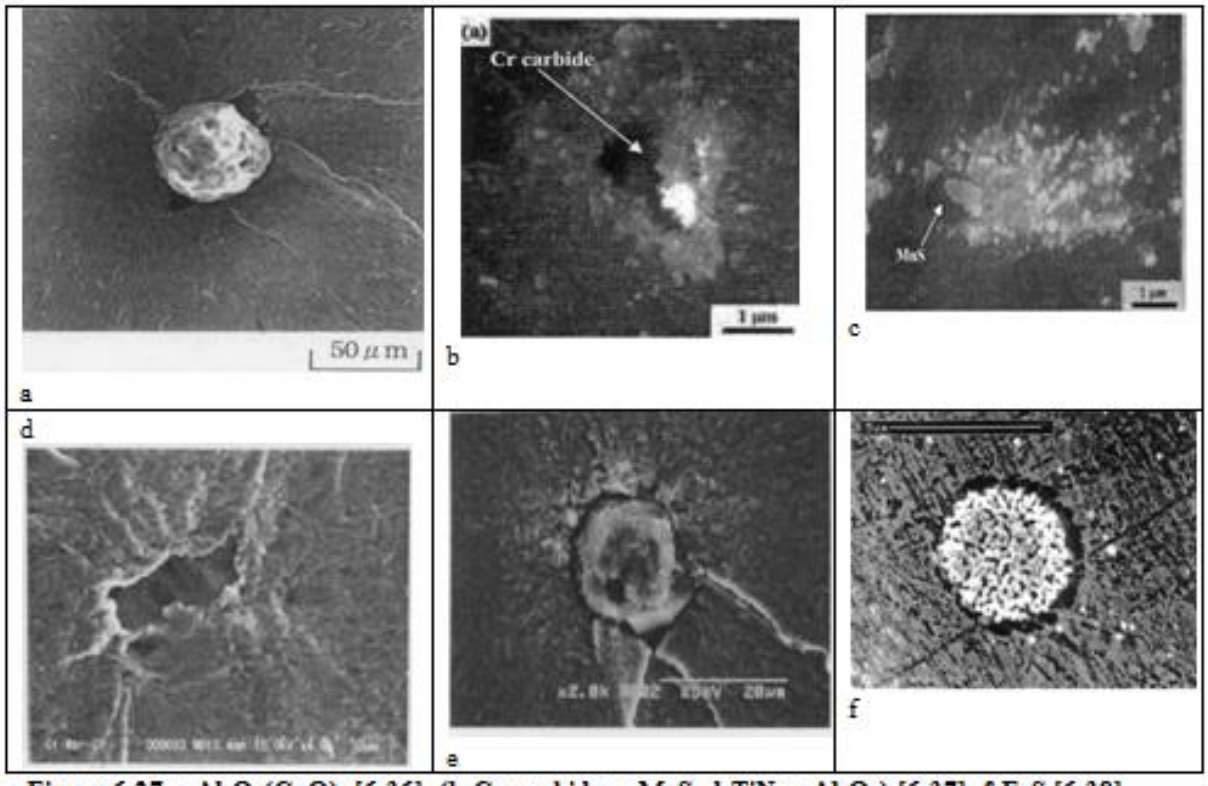


Figure 6.27 a-$Al_2O_3(CaO)_x$ [6.36], (b-Cr-carbide, c-MnS, d-TiN, e-Al_2O_3) [6.37], f-FeS [6.38]

Changes in the structure around defects called optically dark area (Fig. 6.28), similar to those observed

around the rivet holes, but in this case they are not as clearly defined. The structure of the optically dark areas formed by different elements, are different, as can be seen in Figure 6.27. Cathodic and anodic reactions leading to corrosion are shown using the model shown in Figure 6.29. However, the The scheme does not reflect the actual patterns that were discovered by Ertl.

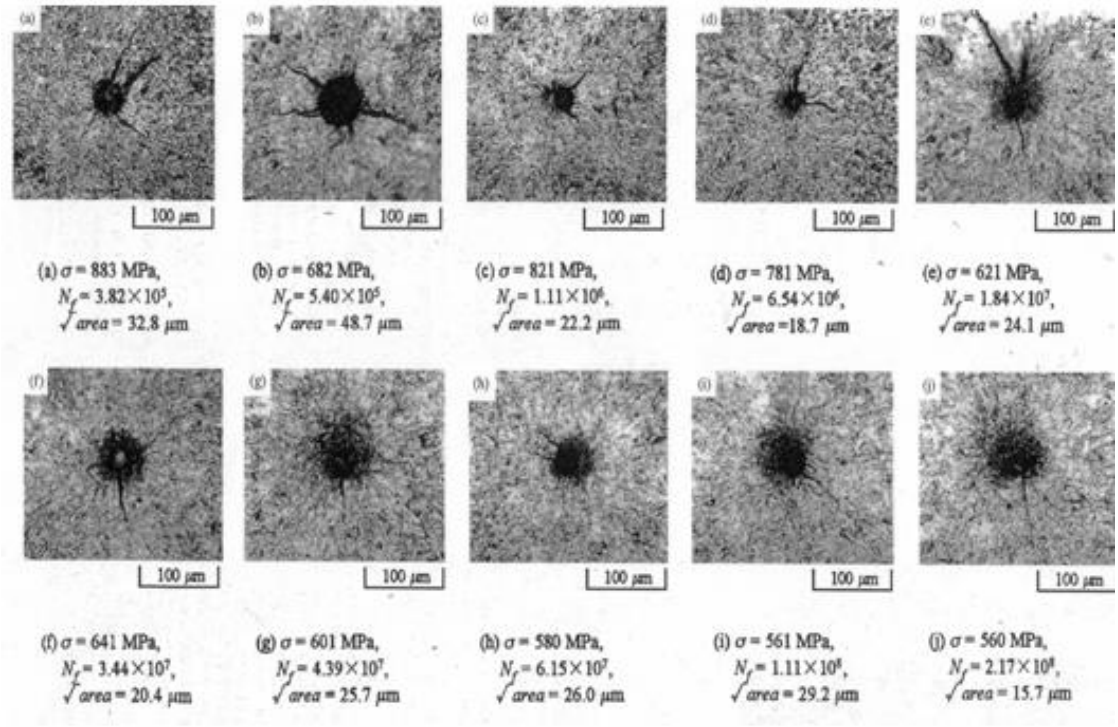


Figure 6.28 [6.39]

Corrosion is a result of a chemical reaction that can be accelerated or slowed by catalysts, pressure and temperature. Chemical reactions may be chain or oscillatory. They start with the any of the first phase, which can be called a trigger. Photons emitted at each stage, launching the next stage, but they do not accumulate. It was established experimentally that the passive slow-moving corrosion can be replaced by an intense attack.

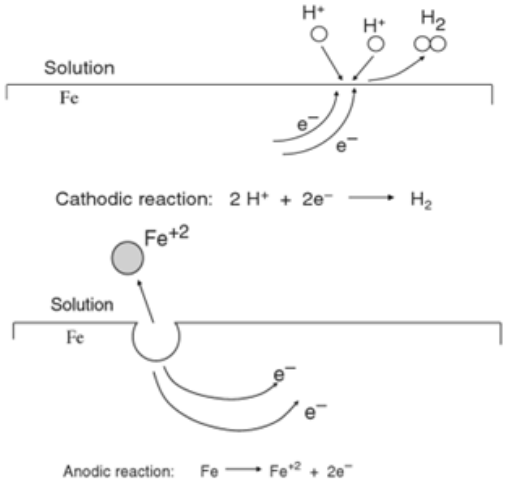


Figure 6.29 [6.35]

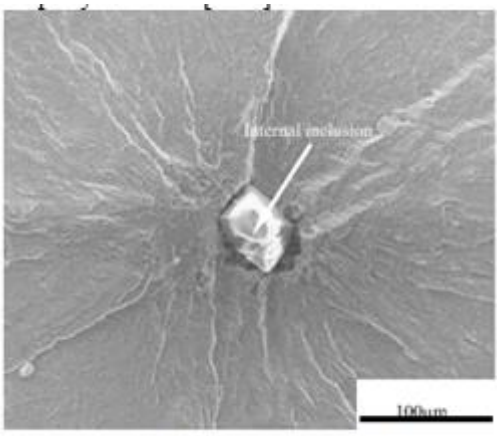


Figure 6.30 [6.45]

Accelerated process associated with the influence of chlorine. However, apart from this is significantly influenced by other impurities. Of particular interest generated works [6.40-6.45], in

which it was discussed the problem of corrosion of stainless steel.

The authors of [6.44] noted that the steel is not actually stainless due to the formation of pitting defects in it on the basis of MnS. One of these samples is shown in Figure 6.30 [6.45]. Has been suggested [6.40] that the area which accelerates corrosion formed around MnS impurities. Ryan et al. [6.41] concluded that in the steel matrix around the MnS particles chromium depletion occurs, which leads to a reduction of Cr: Fe ratio and dissolution. This area becomes the trigger of pitting formation. This hypothesis was confirmed on the basis of experimental studies that have been performed, using secondary ion mass spectroscopic analysis. However, Meng et al. [6.42] could not find the chromium-dispersive zones in the same steel using Energy-dispersive X-ray spectroscopy.

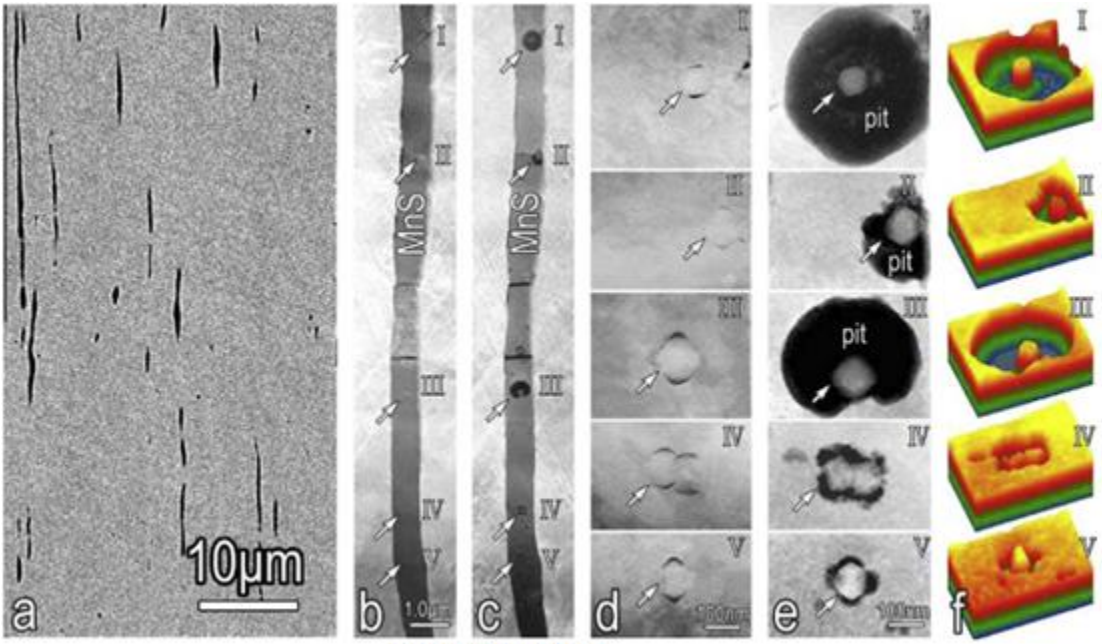


Figure 6.31 [6.44]

Further studies [6.43] showed "… that on exposure to water a very thin and porous metal-deficient polysulphide skin forms between the bulk of the inclusion and the steel, within which a pit can be triggered. The results resolve a controversy concerning the composition of the boundary region around inclusions in stainless steel and re-emphasise irs potential significance."

S. J. Zheng et al. [6.44] made a more detailed study of formation a pits in stainless steel. The experimental results obtained in this work are of particular importance, but unfortunately we confine ourselves only a few fragments in the hope that the reader will examine it fully.

The casting saw materials of stainless steels usually suffer a hot-rolling or cold-rolling before component-making, during which MnS inclusions were deformed to the needle-shaped. It was seen that the needle-shaped MnS inclusions were parallel to the rolling direction (Figure 6.31 a). The dimensions of MnS inclusions are typically 20-50 μm in length and 0.3-1.0 μm in width, respectively, which are obtained statistically on several hundred inclusions in the present study.

The observed phenomenon (Figure 6.31) the authors comment as follows: "(b) A High-Angle Annular Dark-Field Microscopy image showing a MnS inclusion section, in which several nano-particles embedded in MnS are arrowed and labeled. (c) The same section as that in (b) but suffering of corrosion in 1M NaCl solution for 45 min. The localized dissolution of MnS happened around the particles. (d) Zoom-in images of the nano-particles in (b) labeled with I, II, III, IV, and V. (e) Zoom-in images of the local dissolution around the nano-particles in (c). (f) Dissolution mode visualized by digitizing the contrast in the experimental images in (e)."

Four more photos (Fig. 6.32 6 33 and 6.34) are shown below.

The findings, which were made by the authors [6.44] on the basis of the study, stated in the article as follows.

1. "High-resolution TEM imaging shows that the remains of the MnS dissolution are structurally disordered.
2. The interface of $MnCr_2O_4$/pit is sharp while that of is irregular, confirming that the $MnCr_2O_4$ nano-particle had changed little while MnS dissolved.
3. Removing coarse-size oxide inclusions (usually at micrometer scale) has been one of the major concerns in steel-making processing, since it is known that they are not deformable and are consequently harmful to mechanical properties of steel.
4. The size distribution of the nano-particles before and after follows a similar spectrum according to statistical measurements on hundreds (300-500] of particles, implying that the particles remain unchanged during catalysing MnS dissolution."

At the "Concussions" of the article the authors write:

"We have applied in situ ex-environment transmission electron microscopy to indentify the initial state, at an atomic scale, of MnS dissolution, which is critically important but unclear so far for understanding the origin of pitting corrosion in stainless steel. We find that a "single-grained" MnS inclusion in the steel is compositionally and structurally inhomogeneous. Fine octahedral precipitates of spinel $MnCr_2O_4$, with dimensions of several tens of nanometers, are dispersedly distributed in the

MnS inclusions, generating local $MnCr_2O_4$/MnS nano-galvanic cells. … This work uncovers the origin of MnS dissolution in stainless steels and provides a new basis for understanding pitting corrosion of stainless steels."

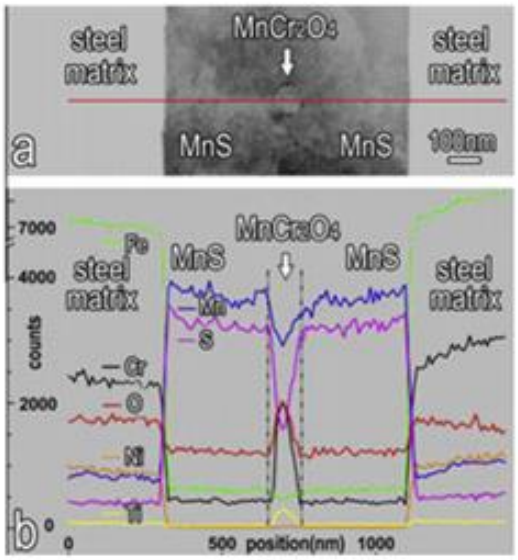


Figure 6.32 [6.44]

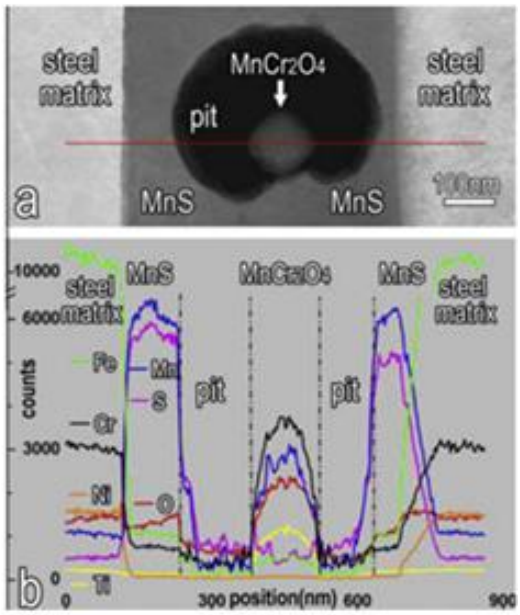


Figure 6.33 [6.44]

Ten-fold zooming (Fig. 6.31 d and 6.31e) allows for a better imagine the processes of formation not only the compound $MnCr_2O_4$, located in the center of the pit, but its crystallization.

MnS formation is accompanied by radiation of energy which is 773 kJ/mol, while the heat of fusion of steel is 84 kJ/mol, which is nine times less. This means that the energy radiated during the formation of one molecule of MnS, is sufficient to change the structure of nine cells, for example, melt them. Since the energy transfer occurs due to the emission and absorption of photons, but not phonons, the thermal conductivity of the material does not play a significant role.

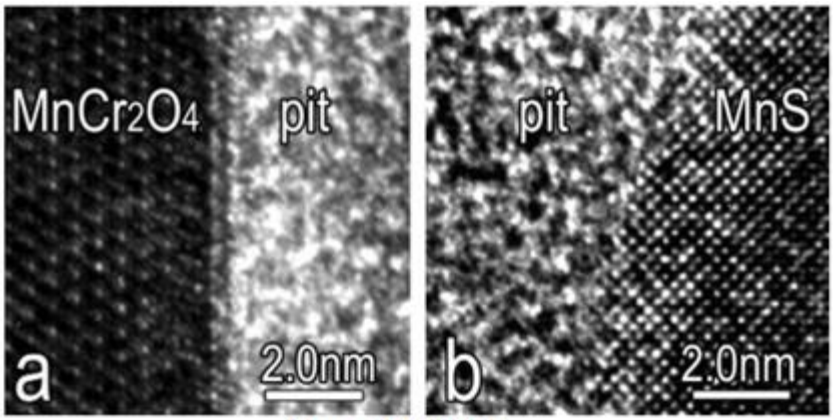


Figure 6.34 [6.44]

Localization of nanoparticles $MnCr_2O_4$, in MnS is shown in Figures 6.32 and 6.33. The nano-particle $MnCr_2O_4$ represents a diamond-type crystal, lattice constant of which is a = 8.4 Å. Thus, the formation of $MnCr_2O_4$ occurs in MnS a nonequilibrium

disordered medium, caused by higher temperature of the alloy, whereby the diffusion rate of the elements increases. The crystallization of $MnCr_2O_4$ is accompanied by the emission of energy. This leads to additional heating of the region, which borders on it. As a result creates a region around $MnCr_2O_4$, the bond between atoms in which impaired. This means that change the electronic configuration of the atoms forming the embryo of pits, i.e. some of the atoms (ions) has turned into morbid. This region is shown in Figure 6.32a. Morbid atoms this field interact with the atoms of the aqueous solution (ions H^+, O^{2-}, Na^+, Cl^-) differently than the same normal atoms (ions) of the alloy.

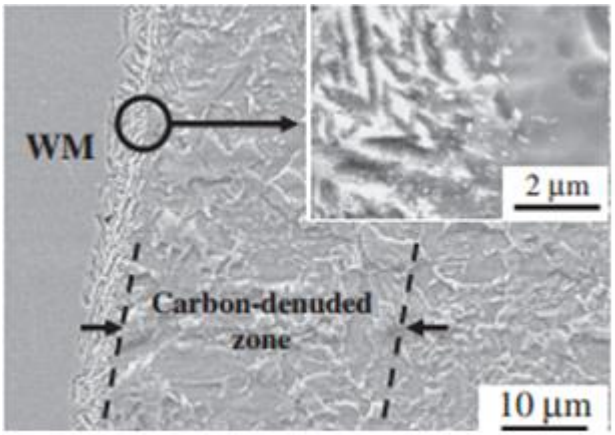


Figure 6.35 [6.47]

It is known that hydrogen plays an important role in reducing or enhancing the material strength, even at low concentrations. Analysis of the composition of elements in the region marked by a red line, indicating a low concentration or absence of hydrogen as before exposure the solution NaCl, so thereafter. This fact raises the concern that the concentration of hydrogen is not defined precisely.

Influence of carbon that it reaches on the mechanical properties of steels is extremely great. With oxygen, the carbon forms compound CO and CO_2. In the rolling process, in particular the hot rolling, the formation of these compounds occurs exothermically, loosening material and the formation of pores which takes place in the pit. Similar processes occur in the welding of metal, when as a result of migration of carbon atoms formed by heat-affected zone, as shown in Figure 6.35 [6.47].

Conclusions

Formation of MnS, $MnCr_2O_4$ and $MnCr_2O_4$/pit happened consistently, but no crack was formed. We use the results of this experiment in order to understand the mechanism of corrosion under stress, or more precisely, the SCC. Photos 6.31a and 6.31b indicate that the compound MnS was formed from the elements that have been included in the composition of the alloy. Formation of $MnCr_2O_4$ occurred with oxygen, which was absorbed from the air during manufacturing operations. Electronic configuration of atoms (ions) Mn, S, Cr, forming alloy, and oxygen atoms forming the molecule O_2, is different from the same atoms that form the molecule MnS and $MnCr_2O_4$. Thus, the atoms forming the molecule we shall assume morbid. But these morbid atoms do not "participate" in the formation of cracks or destruction.

Formation of MnS and $MnCr_2O_4$ molecules led to the fact that a crack forms in the material, the

geometrical and physical structure of which changed.

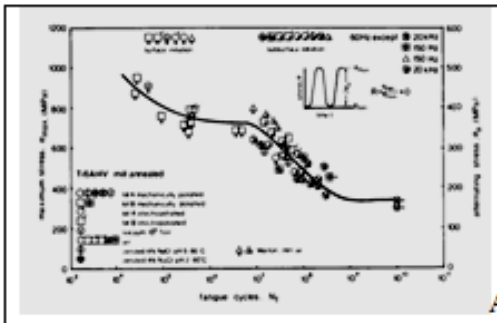
Therefore, the mechanism of corrosion and domain of destruction formation is the same.

But the atoms of the local area, which produces a domain of destruction, can repeatedly turn from normal to morbid, absorbing energy, and vice versa, radiate it. Atoms form a stable chemical compound, change the environment in which the strain energy is accumulated and dissipated until is stimulated radiation of such power, which would be sufficient for the formation of a crack or a complete destruction.

The difference of morbid atoms from normal one allows to predict the wear and residual life of the structure or device, using the results of experimental studies.

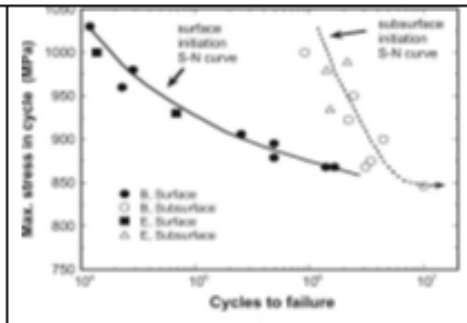
6.5. S-N curves and their interpretation

The transition to the physics of destruction does not mean that we should completely abandon the fracture mechanics and experimental methods used in it. These two approaches should complement each other. It is especially important to use all the results of experimental studies that have accumulated over many years. I'll demonstrate it using concrete examples.



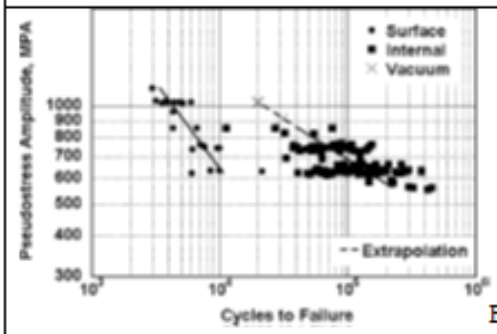
A

A. Atrens *et al. Scripta Metallurgica*, **17**, 601 (1983).



C

K. S. R. Chandran *et al. International Journal of Fatigue* **32**, 482 (2010).



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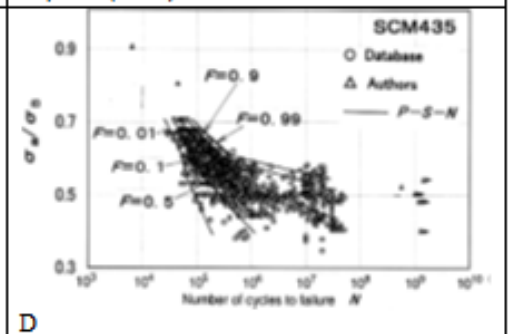
K.S. R. Chandran *et al. International Journal of Fatigue* **32**, 482 (2010).



D

T. Sakai *et al. International Journal of Fatigue*, **28**, 1486 (2006).

Figure 6.36

Study of the strength properties of alloys by S-N curves performed over a hundred years. It was created a huge process database of almost about all alloys. However, the self-descriptiveness of this method is extremely low, since each point of the curve is actually a separate experiment, to conduct which sometimes requires several months or even several years. For example, for a sample of an alloy which can withstand 10^{10} cycles at a load test frequency of 20 kHz requires ~ 580 days of continuous operation. To construct a single S-N curve must be received 9-10 points. If we consider that we need more information about the behavior of the metal under different atmospheric conditions, it becomes clear how this work is time consuming. But that's not all. The function $F=\varphi(S, N)$ displayed a space curve, but as usual we investigate the projection of this curve on the plane. Often on the S-N curve plateau appears sometimes two, which lead to uncertainty in determining the maximum allowable number of cycles at a given load. The difference may be two or three orders of magnitude.

Figures 6.36 A, B, C, D shows the SN curves, which are based on experimental studies. Of particular importance for the analysis has the plateau, after which the fracture occurs at a lower mechanical stress. In Figure 6.36 A there are two plateaus, one of which is associated with surface defects, another - with internal. The experiments were performed at a frequency of 150 Hz and 20 kHz in different conditions and after various treatments of the alloy Ti6Al4V. Pay attention to the reliability of the results and the information that can be obtained on the basis of nearly forty experiments. Even less informative are the S-N curves shown in Fig. 6.36 C.

As can be seen from Fig. 6.36 B authors averaged the results of studies on the basis of which revealed four plateau for cyclic loading in the range of $2\cdot10^3$-$1\cdot10^4$ cycles and three plateaus for the load in the range of $1\cdot10^4$-$5\cdot10^5$ cycles. Since the experiments were carried out on different samples, it is impossible to determine the cause of such differences: whether they are caused by the accumulation of defects or technological methods.

The use of the energy method, which was demonstrated in the fourth and fifth chapter, allows not only simplifying the calculations, but makes them more accurate and objective.

Especially important is the fact that the measurement data analyzed by the computer during operation. This allows controlling the technical condition as separate elements, and the whole structure or device.

The given examples show that extremely useful information can be obtained from those laboratories, which have survived experimental protocol of S-N curves. This does not need to re-conduct experimental research.

No fundamental difficulties complement experimental studies S-N curves using non-destructive testing methods, such as thermography, ultrasound, x-ray, etc. We will demonstrate this by an example.

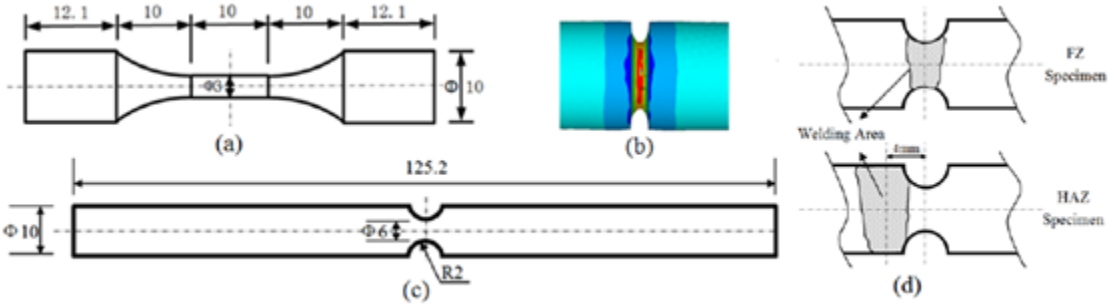


Figure 6.38 [6.48]

Samples of steel Q345 (Fig. 6. 38a), with a welded joint (Fig. 6.38 b, c, d), subjected to cyclic tensile tests [6.48].

We note the most important conclusions that have been made by the authors of this study (in italics) and comment them.

1. *The fatigue behavior in fusion zone and heat affected zone of alloy steel* Q345 *in very high cycle fatigue regime was experimentally with ultrasonic fatigue testing system. It was found that the fatigue failure of heat affected zone specimen still occurred beyond* 10^7 *cycles*.

A similar situation was seen above in the study of aluminum riveted joint (Fig. 6.12). Heat-affected zone appeared in aluminum, when the number of cycles was by three orders smaller. This difference is due to the conditions of accumulation and dissipation of energy, which, in turn, is related to the geometric characteristics of the samples, the physical parameters of the materials, and the nature of external influences.

2. *A horizontal platform was obtained for fusion zone specimen in very high cycle regime related to internal welding defects in fusing zone.*

The appearance of a plateau on the S-N curve is due to an increase in the degree of wear, in which there is accumulation of energy.

3. *When the amplitude of temperature variation was larger than 5° per 700 cycles, fatigue crack was started for base metal.*

Changes of body temperature are accompanied by a change in the radiation power per unit area. According to the Stefan-Boltzmann law $W_B = \sigma_B (T_1 - T_2)^4$. This means that an increase in temperature of the specimen by 5 degrees energy loss increased by 7%. Therefore, when the metal began to melt (1839 K), the energy loss raised to 625 times. Such energy losses in the specimen can be compensated only by the fact that the number of excited (morbid) atoms increased not less than 625 times.

4. *The temperature of base metal specimen would rise rapidly with the beginning of crack propagation.*

The sharp increase in temperature is due to stimulated emission energy of morbid atoms and increased photon-phonon interaction, which results in the bond breaking and cracks formation.

5. *Fatigue strength of the melting zone is many times lower than that of the base metal*.

Melting of alloy begins primarily in that region in which the bond between atoms weakened, and/or where the atoms absorb more energy. Domain of destruction consists of two metastable regions, in one of which is accumulated energy due to the higher ionization of atoms in the other-is a weakening of the bonds between atoms, in which degree of iconicity is lowered.

6. *Fractire crack propagation lives of heat affected zone and fusion zone were estimated by monitoring the natural frequency of specimen, which was varying with the crack size during the fatigue testing.*

Crack formed where the atoms absorb energy. This area are the area of the heat affected zone and the fusion zone. The appearance of a crack leads to a change in the shape and size of the resonator in which standing waves are formed, the natural frequency of which varies.

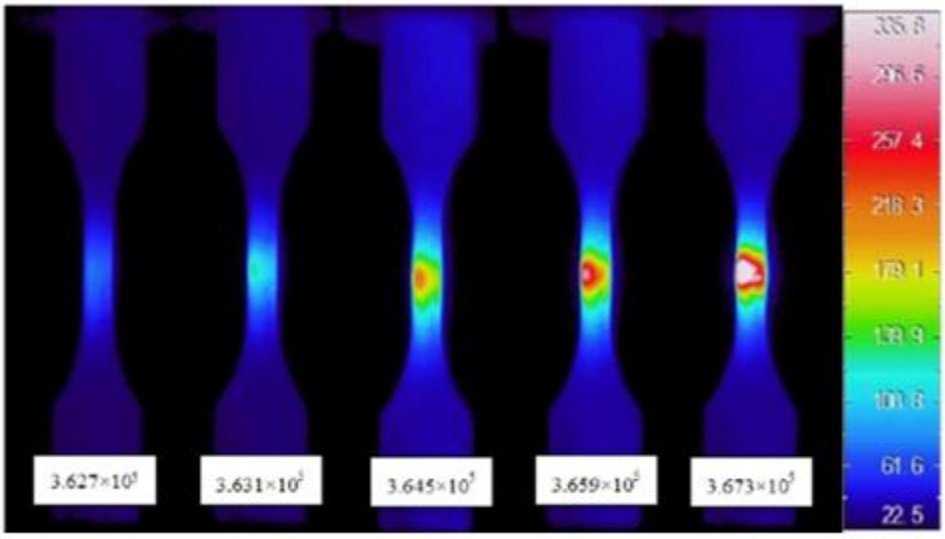


Figure 6.39 [6.48]

7. *The authors write: "...for base metal of the specimens it was found that the cyclic loading at an ultrasonic frecquence generated a substantial amount of heat, and the temperature of base metal specimen incrased significantly at a center of the gage length of spesimen as shown in Fig. 6.39. The temperature distributions in the gage-length section of the specimen during ultrasonic testing were heterogeneous along the axis of the specimen, with the highest temperature occurring at the high strain location."*

Domain of destruction has a certain size and frequency of natural oscillations. Intense energy absorption takes place when the frequency of external force coincides with the natural frequency of oscillation, i.e. resonance occurs. This becomes possible at certain dimensions of the region, having boundary inhomogeneities, such as grain or defects [6.49].

8. The authors write*: The crack initiation process occupied over 99% of the total fatige life for heat affected zone in very high cycle fatigue range. Therefore study on the mechanism of crack initiation was extremely important to clarify the fatigue properties in very high cycle fatigue. In addition, the life ratio of fusion zone specimens were much lager than that of base metal and heat affected zone, due to the fact that fatigue crack in fusion zone propagated directly from the welding defect with no apparent initiation process."*

This point is fundamental to understanding not only the mechanism of destruction, but also the nature of fatigue. It noted that there is a reason that the crack initiated at some moment. In atomic physics, this radiation energy is called stimulated or stimulated. induced radiation. Signal of this radiation is a photon, as stated repeatedly.

Conclusion

The work [6.48] *shows that the information content of the method of S-N curves increases many times when the deformation process is further controlled by highly sensitive energetic and structural methods.*

The emission spectrum of atoms forming the domain of destruction extends into the ultraviolet and even X-ray region. These rays whose frequency exceeds the frequency of the plasmons pass through the metal. Studies of this range will allow detecting the domain of destruction, located not only on the metal surface, but underneath it.

6.6. Mechanical nanoindentation

Indentation method was proposed in the early 20th century to determine the hardness of materials. Widespread it received, when it became possible to use high-resolution equipment, such as atomic force microscopes and computer programs. Indentation method was also applied to nanomaterials.

The information capabilities of nanoindentation are more fully described in Y.I. Golovin's review [6.50]. It was noted that nanoindentation allows determining Young's modulus E, hardness H, fracture toughness $K_{1,c}$; local nano features: contact stiffness C, critical power P_c, and contact stress $\langle \sigma'_c \rangle$ *of* elastoplastic transition, macroscopic yield stress σ_y, the energy absorbed in the cycle of loading -

unloading, duration of umps and the interval between them, moments of cracking at all stages of the test, the porosity, he porosity, the temperature of cold-storage capacity etc. The number of physical parameters characterizing the strength of the material, its durability, which can be determined by indentation is so large, it would seem that they are sufficient to predict the wear and remaining life, but it

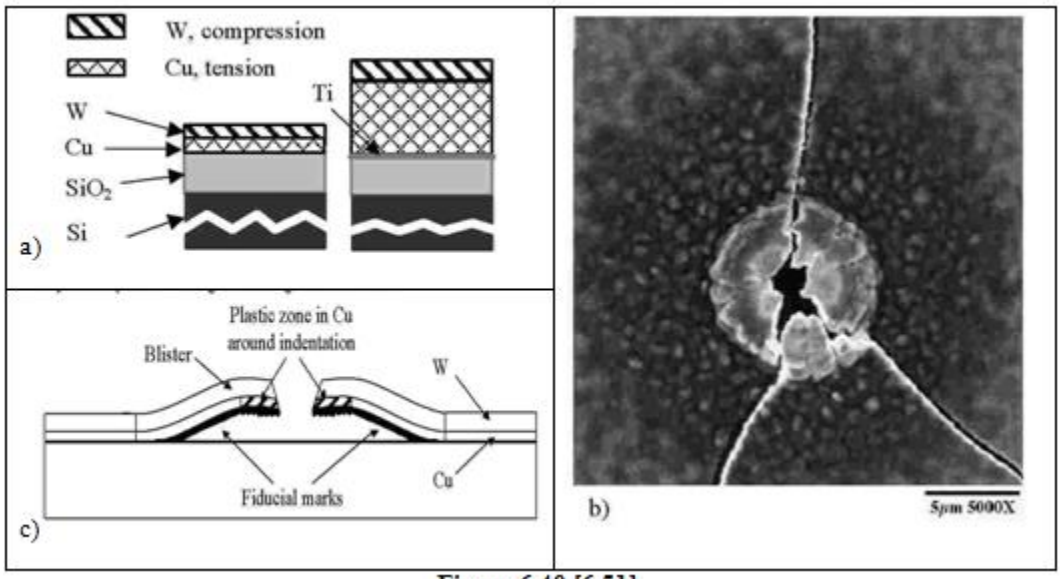


Figure 6.40 [6.51]

is not so.

The main reason lies in the fact that, theoretically, these parameters are used in the models based on classical mechanics, using which it is impossible to describe the processes due to the laws of quantum behavior of atoms.

We use the results of a series of experiments to show it.

Four-and five-layer samples are shown in Fig. 6.40, taken from the work of A.A. Volinsky et al. [6.51]. The thickness of the layers, placed on a substrate SiO_2, was: W-1 μm, Cu ~ 100 μm, Ti-10 nm, diameter of the diamond indenter is 1 μm. Delamination, which occurred during indentation, is shown in

Fig. 6.40 b, c. Part of the surface of Ti and SiO_2, delaminated during indentation, were studied by methods Auger spectroscopy, atomic force microscopy and scanning. Photos made in this study are shown in Fig. 6.41.

The authors describe the observed phenomenon as follows:

"It is known that diamond indenters wear during indentation of "hard"[6] films. Ti as well as W are

[6] The authors took the word in quotes because diamond is the hardest material and is used as the indenter. On the Moss's

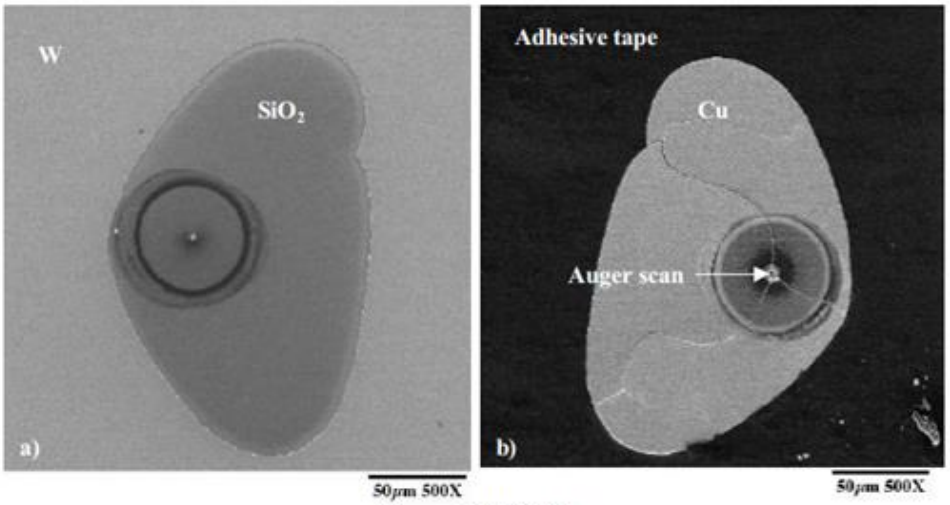


Figure. 6.41 [6.51]

known to "suck out" carbon from a diamond indenter. A similar process may occur in our case. Given a 20 nm thick fiducial mark (from AFM measurements) with a 50 mm blister radius, and assuming fully dense carbon (r=12 g/cm^3), one would find 1.9×10^{-9} grams loss per indent. This will result in a significant loss of almost two micrograms for a 1000 indents (a typical number of indents for adhesion testing), assuming that all carbon comes from a diamond." The carbon atoms that have been "lost" by diamond, adsorbed on the surface of copper, as shown in Fig. 6.40 c.

An interesting phenomenon, called spiral and sinusoidal cracks considered in A.A. Volinsky et al [6.52]. Photographs of these cracks in multilayer Mo / Si, obtained with an optical microscope are shown in Fig. 6.42.

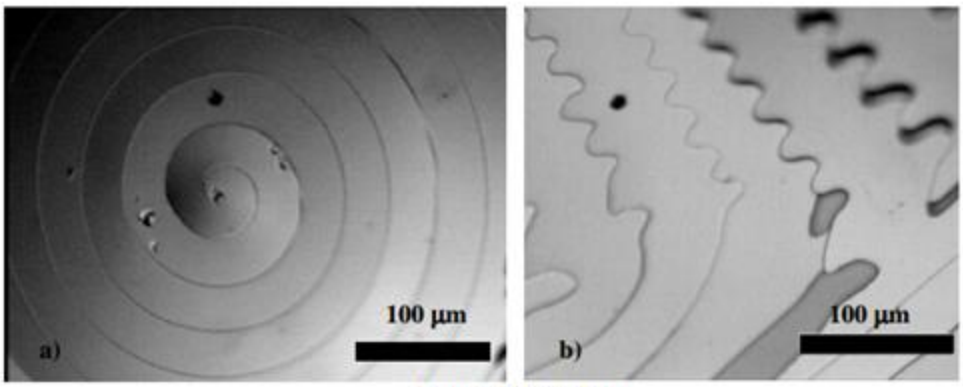


Figure 6.42 [6.52]

Cracking and delamination of thin metal films studied in the paper by A. Kravchenko [6.53]. The objects of the study were mirror designed for X-ray optics. For X-ray reflections used multilayer coating consisting of different materials. In this case it was Mo/Si, W/B_4C, W/Si, and NiC. Pictures shown by Kravchenko, similar to those shown in 6.42A, but instead of a right spiral, spiral on his photograph was left. He believes that the cracks are formed as a result of deformation and chemical reactions that are caused by X-rays.

Strata near the cracks, spiral and sinusoidal cracks indicate the existence of a mechanism that controls these processes.

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scale: diamond is10.00, tungsten is 9.00, titanium is 6.00.

A review of the destruction of the adhesive layer problem was published in the work [6.54].

Volynsky writes: “There are more than 200 different methods for measuring adhesion, suggesting it to be material, geometry and even industry specific. This availability has exploded at least partly due to the arrival of dissimilar material interfaces and thin films and the ease with which microfabrication technique apply to silicon technology. Having an eye toward those tests utilized for thin films, this paper reviews only a few of these techniques. The emphasis is on measuring thin film adhesion from the standpoint of fracture mechanics, when the film is mechanically or other means removed from the substrate, and the amount of the energy necessary for this process is calculated per unit area of the removed film. This tends to give values approaching the true work of adhesion at a small thickness and greater values of the practical work of adhesion at larger thickness, all being 30-30,000 nm range. The resulting large range of toughness is shown to be dependent on the scale of plasticity achieved as controlled by film thickness, chemistry and test temperature.”

We note that none Volynsky nor Kravchenko not cite the work of B.V. Derjagin et al. [6.55], in which it was shown that the destruction of the adhesive layer X-rays are emitted.

Since the theoretical analysis of these studies was carried out only on the basis of fracture mechanics and no conclusions about the mechanism is not done, then we will try to understand the nature of complex cracks kind (I) and the loss of carbon atoms from the diamond indenter (II).

Belousov-Zhabotinsky reaction was discussed in Chapter II and in [1.6]. Such reactions, which are called vibrational, accompanied by the so-called chemical waves. Some of these waves are shown in Figure 6.43.

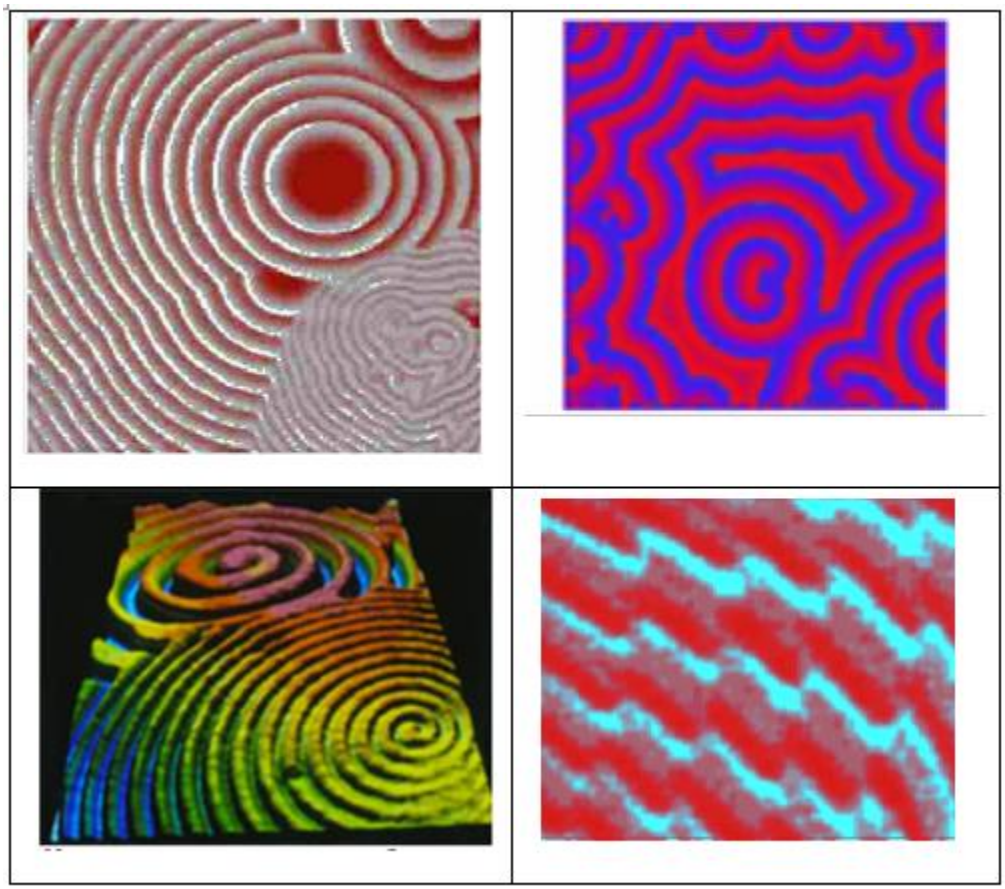

Figure 6.43

Ordered structure was observed in the chaotic environment in the late 19th century. It is known as Benard cells, or cells of Rayleigh-Benard problem. A huge number of publications devoted to the Belousov-Zhabotinsky today.

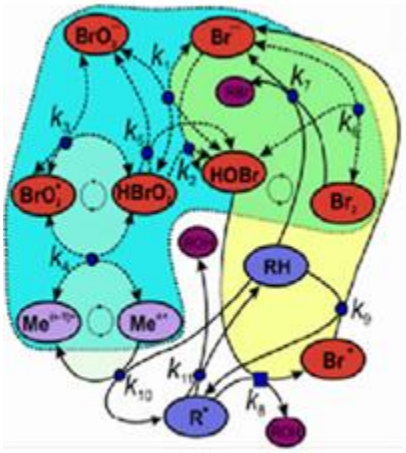

Figure 6.44

Spiral structure, which shows the photo in the lower left corner, formed by molecules of carbon monoxide on the surface of a platinum catalyst. Ways in which the proceeds Belousov-Zhabotinsky reaction are numerous. Their number reached 80. One of the variants of electrons transitions in the Belousov-Zhabotinsky reaction is shown in Fig. 6.44. (http://www.gazeta.ru/science/2008/02/19_a_2641806.shtml)

.All electronic transitions associated with the emission or absorption of photons. Points k_1-k_{11} are called the bifurcation point, in which the system is non-equilibrium and can go on this or that way.

This leads to a variety of shapes that occur in an ordered arrangement of the reagents during the chemical reaction and cracks.

The formations of cracks are due to the same electronic transitions, as well as chemical reaction.

This means that the founders of quantum theory of destruction can use all the experience that has been accumulated in quantum chemistry.

II. Carbon plays an extremely important role in human life, as in living organisms and plants contained ~ 18% of carbon. Steel properties depend strongly on the carbon content and the position of the atoms forming the crystal. In this connection, the loss of carbon from the diamond under the interaction with other metals is particular importance. Unambiguous answer to the question about what happens to the carbon and the metal on the basis of one of this experiment is difficult to quantify, because there are a number of other issues that need to be answered.

1 To what extent this phenomenon is inherent to other elements, which are used as indenter?

2. Will be sucked carbon from indenter made of a carbon nanotube?

3. Is the loss of carbon atoms from various facets of the diamond the same?

4. Adhesive tape contains a large number of carbon atoms and at its exfoliation emitted electromagnetic wave of a wide range including X rays. X-ray radiation is also occurring at break of the adhesive layer. Any deformation accompanied with electromagnetic radiation thus indentation cannot be an exception. Consequently, the indentation using a diamond should be accompanied by X-rays. To what extent the loss of carbon atoms from the diamond indenter is associated with X-rays?

5. It is known that steel decarbonization occurs as a result of deformation. Carbon formed defects, as shown in Figure 6.45. They are called optically dark area or graphite nodules. What is their role in the destruction?

In the photographs 6.45A, taken from [6.56] it is shown: austempered ductile iron microstructure, (a) low and (b) high magnification, GN-Graphite Nodeles; RA-Retained Austenite; B-Boinite

The determination of the retained austenite crystallographic orientation for an arrested crack nucleus using electron backscatter diffraction (EBSD) is show in Figure 6.45B. The angle of the crack plane was measured by serial sectioning. The crack was nucleated at a graphite nodule: (a) EBSD map, (b) SEM image, C-Fatigue failure nucleated at a graphite nodule.

These observations indicate that for cracks nucleated at graphite nodules, the maximum crack nucleus size depends on the nodule diameter and the ausferrite matrix microstructure.

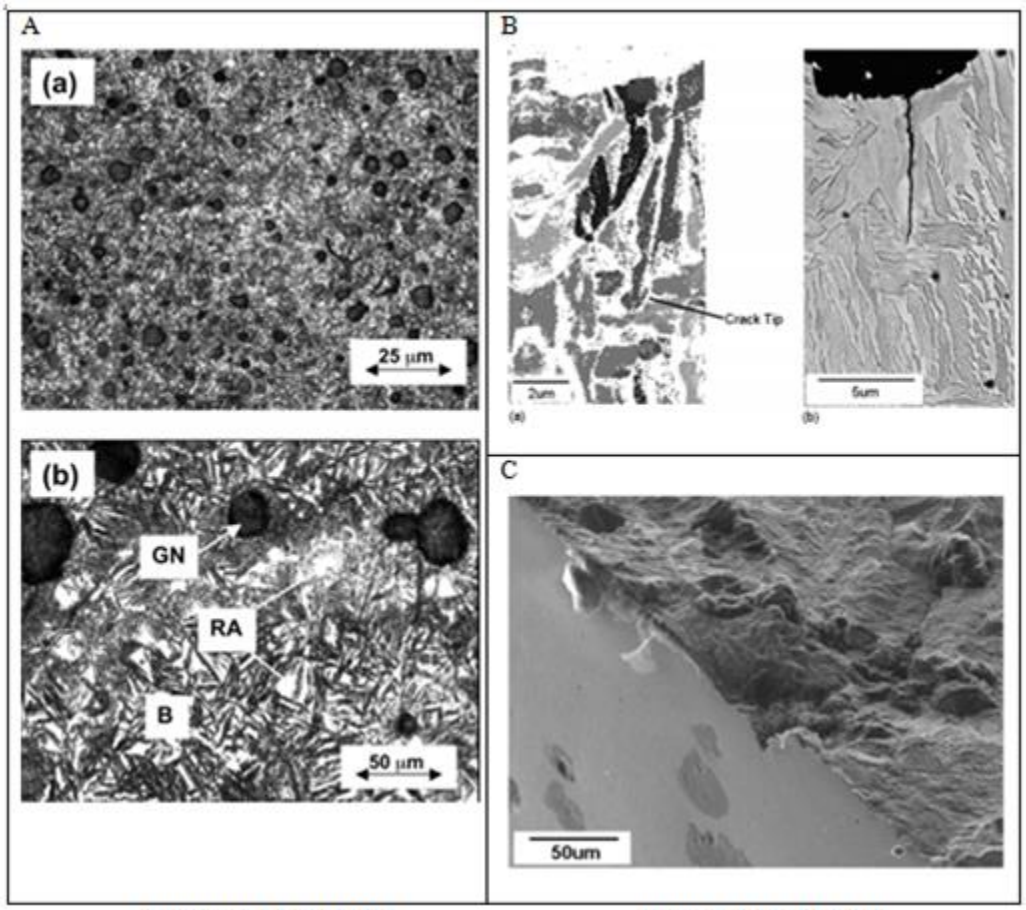

Figure 6.45 A [6.56] Figure 6.45 B [6.57]

6.7. Carbon in alloys

Fatal train crash, in which 35 meter was broken on 300 fragments, occurred October 17, 2000 (Hatfield, UK). It was examined in Chapter I. One of the fracture faces was bright, the other black.

This alternation could not be random. This fact was noted in the book [1.6]. The structure of the bright surface was investigated even earlier [6.58, 6.59]. It has been found that it was martensite hardness of which increased by 2.5-4 fold. Thin layer forming a dark surface, nobody has studied, and six years later the surface is subjected to intensive corrosion.

Modern technology has enabled more accurate investigate the effect of carbon on the fracture processes. We consider the results of an experimental study [6.60]. The aim of research and the main results were briefly stated in the abstract, which is quoted in full.

"The relationship between the crack nucleation and stress-induced martensitic transformation in the retained massive austenites (RM –γ's) of austempered ductile iron (ADIs) was examined in detail by carrying out tensile tests and scanning electron microscope (SEM) observations for an ADI material. The SEM observations revealed that cracks were not nucleated in the peripheral regions of graphite nodules, but were nucleated in the RM –γ's. Surface relief due to stress-induced martensitic

transformation was observed near the cracks in the RM –γ's, and it was also observed in the RM –γ's in which cracks were not visible. For this reason the cracks were concluded to be nucleated in the RN subjected to stress-induced martencitic transformation."

We restrict ourselves to a brief statement, without going into the details of the experiment.

Six photographs obtained using the SEM, are shown in Fig. 6.46.

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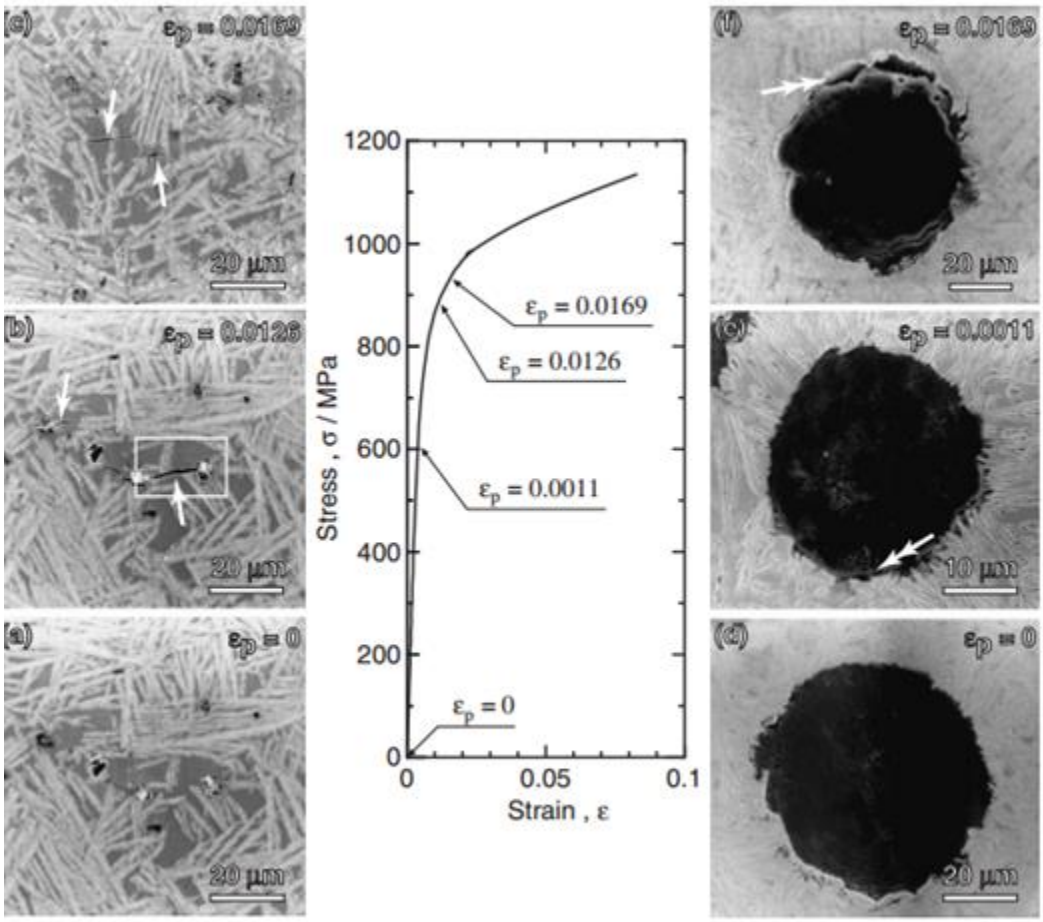

Figure 6.46 [6.60]

Locations of cracks in RM-γ indicated in the photographs (a), (b), (c) by arrows. These areas similar GN (Fig. 6.45) are shown in the photographs (e), (f), (d). Three stress-strain curves of material 623-ADI deformation are shown in the center. Value of ε_p, show the crack initiation point, double arrows indicate their location. The tension is directed vertically.

Fragment indicated by white rectangle in Fig. 6.46 (b), is of great importance for the understanding of the interaction of carbon atoms with other atoms in the alloy.

The authors write: "Fig. 6.47 shows an enlarged SEM microstructure of the white fragment framed area in 6.46 (b) from which the nucleation of a crack in RM –γ was examined in detail. A particular

surface relief is observed in the neighboring region of the crack, as previously reported. The surface relief is clearly formed by a shear strain, indicating that the corresponding regions are subjected to the stress-induced martensitic transformation. The formation of martensites is accompanied by hardening and volume expansion against a neighboring crystal, and a complex strain is generated in the RM –γ near the martensites. Therefore, the crack nucleation in RM –γ's is considered to be related to not only the existence of inclusion but also the stress-inducement of materials."

The area selected by rectangle represents the martensite. The main finding, as made in the conclusion is as follows: "Thus, the cracks were concluded to occur in the RM –γ's subjected to the stress-induced martensitic transformation."

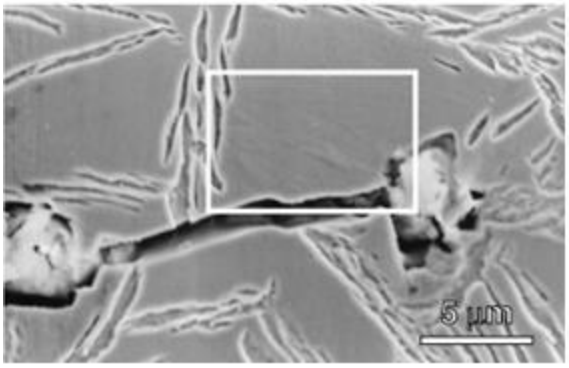

Figure 6.47 [6.60]

Thus, the authors do not deny the effect of carbon on the generation of the cracks, but did not appreciate its role, although it is very important. Firstly, the martensitic transformation is the result of change in the position of carbon in the crystal lattice in which result increased hardness of the material, changing its volume. This means that the bond between carbon and iron changed. Secondly, the existence of spherical inclusions of carbon indicates that the strength of this local area connection between the carbon atoms exceed the binding forces between carbon and metal atoms. The stress at which carried out the study, ranged from 890 to 1130 MPa, which is many times greater than that stress at which the adhesive tape exfoliate. The probability of optical and X-ray by carbon atoms radiation in this case is higher than in the tape deformation. Consequently, the region bordering on the carbon nodule is subjected to intense electromagnetic interference (heating). Third, the change in temperature leads to phase transformations, indicating a change in the interaction between the atoms of iron and carbon. The speed of the martensitic transformation is higher there, where the temperature is highest. It is known that the crystal structure of these

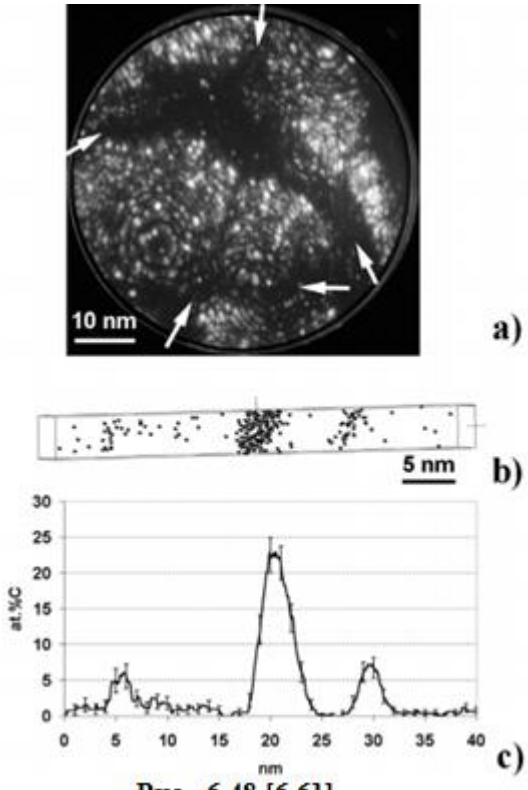

Рис. 6.48 [6.61]

phases varies. Consequently, is different ratio of the number of iron atoms and the number of carbon atoms. This change is due to a change in the energy state of the atoms of iron and carbon. It allows considering the atoms forming the austenite, as normal, and the atoms forming the martensite as morbid.

Let us denote the number of iron atoms in the unit cell of austenite n_{AN}^{Fe}, the carbon number of the same cell n_{AN}^{C}; the number of iron atoms in the unit cell of martensite n_{AM}^{Fe} and the number of carbons in the cell martensite n_{AM}^{C}. Thus, we are able to estimate the proportion of the iron atoms and the atoms of carbon in austenite $n_{AN}^{Fe} : n_{AN}^{C}$ and martensite $n_{AM}^{Fe} : n_{AM}^{C}$.

An important role in the cracks formation plays not only the ratio of the number of atoms, but also their position It is known that during the matrensit formation, the cell structure changes from face-centered to body-centered.

The speed of martensitic transformation reaches 1000 m/s. In a number of papers argues that carbon practically no diffuses from the region in which the martensitic transformation occurs. However, this does not exclude the fact that carbon segregation occurs atoms of which form on the surface a thin layer, like bismuth in the alloy Cu-Bi. It was established that the embrittlement of the alloy occurs even when of the grains surface a monoatomic layer of bismuth is formed.

Assume that on the surface of the martensite was formed a monatomic layer of carbon. This layer is called graphene. Its tensile strength does not concede the diamond. Two of these layers form graphite. Coupling strength between the layers is so small that the graphite is often used as a lubricant. Consequently, the shear strength is weakened repeatedly.

We use the results of research carried out in [6.61], to show that this is possible.

Photo (Fig. 6.48a formed by ion microscope) shows the concentration of carbon atoms at the interface of pearlitic steel nano-grains (indicated by arrows). Segregation of carbon is due to the fivefold torsional deformation of the specimen. The grain size was from 10 to 30 nm. Distribution of carbon atoms between the grains shown in Fig. 6.48 (b, c).

he QI particle size varied between from tens of nanometres to approximately 600 nm7

Let us consider another study [6.62], where it was shown that the plates like carbides are formed directly under the rolling track of the sample subjected to rolling deformation.

The authors believe that: "… platelike carbides form immediately underneath the rolling track of a specimen subjected to rolling contact fatigue test on the ball-washer trust of tester. The carbides are less likely to form when the carbon concentration of the martensite matrix is low and more likely to present themselves when the carbon content is high." They consider that the carbon diffuses into the matrix due to repeated stresses in the sample under rolling contact. The carbon atoms are trapped by dislocations located between oxygen inclusions in areas that are directly under the track rolling, where the density of dislocations is maximal. Their findings they do on the basis of photographs, two of which are shown in Fig. 6.49. Where: "Plate like carbides directly under flaking on the rolling track: (top) in the specimen of 62.5 HRC; (bottom) in the specimen of 56.0 HRC. The white constituents indicated by the arrow are plate like carbides."

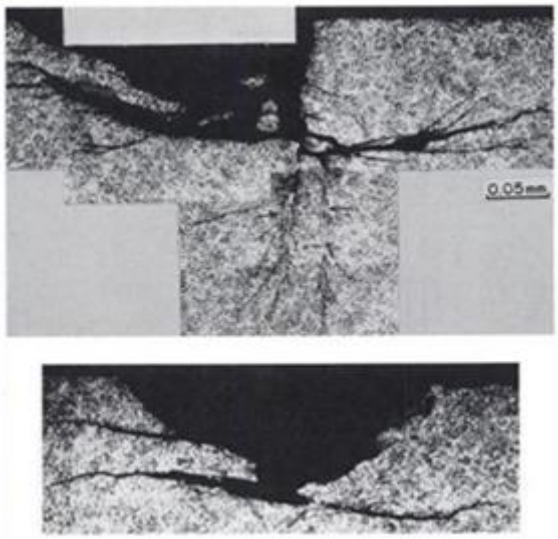

Figure 6.49 [6.62]

Carbide formation is accompanied by the emission of energy as a result of which the temperature in the local area increases. This weakens the bonds between atoms, of their rupture and flaking when the crack extends in the direction of rolling.

Shock wheels of the locomotive and wagons leads to cracks directed perpendicular the direction of travel, often at a certain angle. Carbon remaining at the hot surface discontinuity reacts with oxygen in air, forming a thin layer of soot was observed under faults. Such carbon fibers were observed on the surface of the rail fragments detected after a disaster (Hatfield, UK, 2000).

M. I. Zakirnichnaya and I. R. Kuzeev [6.63] observed three zones that are emerging on the inner wall of the coils for the pyrolysis furnace. These areas are: the base metal (Photo 6.51a), the transition zone (6.51b) and carburized zone with cracks (6.51c) extending from the inner surface, formed during the 10,000 hours. The base metal has an austenitic structure with a small amount of carbide phase. The grain size of austenite decreases but the amount of carbides increases as approaching the transition zone to the inner surface of the coil. Carburized zone contains about 50% of the carbide phase.

Thus, the formation of carbide phase occurs for 10,000 hours, whereas the cracking continued micro seconds. This means that, simultaneously with the formation of this phase *domains of destruction* were formed, energy radiation occurred, resulting in cracking.

Conclusion

Thus, the formation of martensite due to the deformation, accompanied by the loss of carbon, which forms on the boundary of martensite and residual austenite nanosize (perhaps monatomic) layer of graphite which reduces shear strength many times.

Figure 6.50 [6.63]

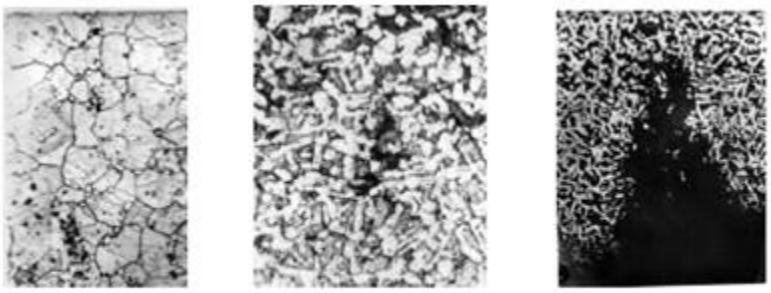

Figure 6.51 [6.63]

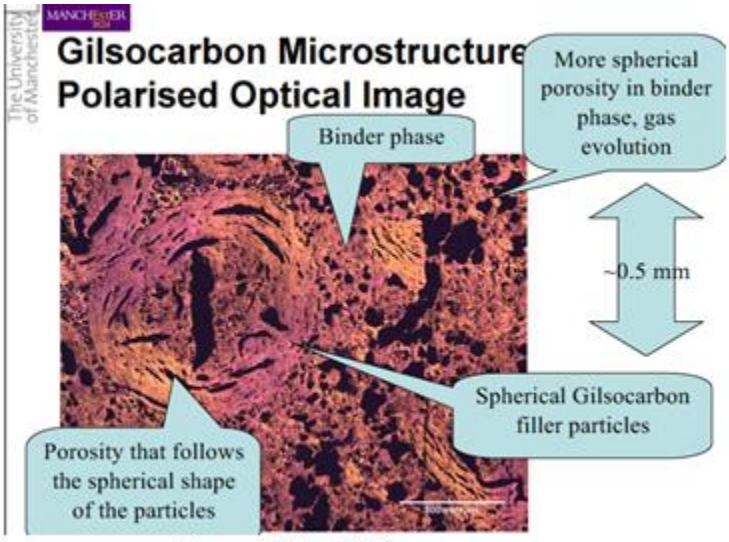

Figure 6.53 [6.65]

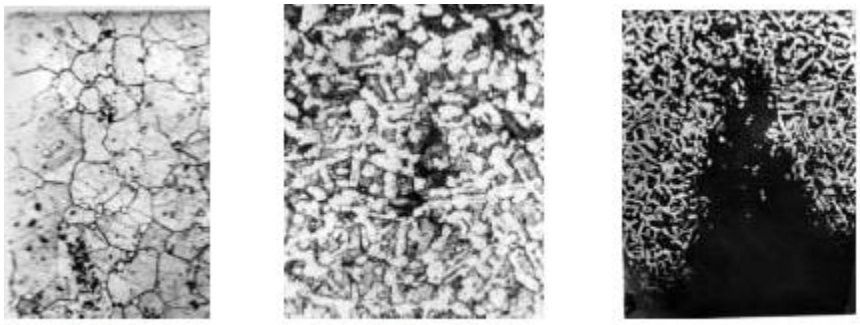

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Рис. 6.51 [6.63]

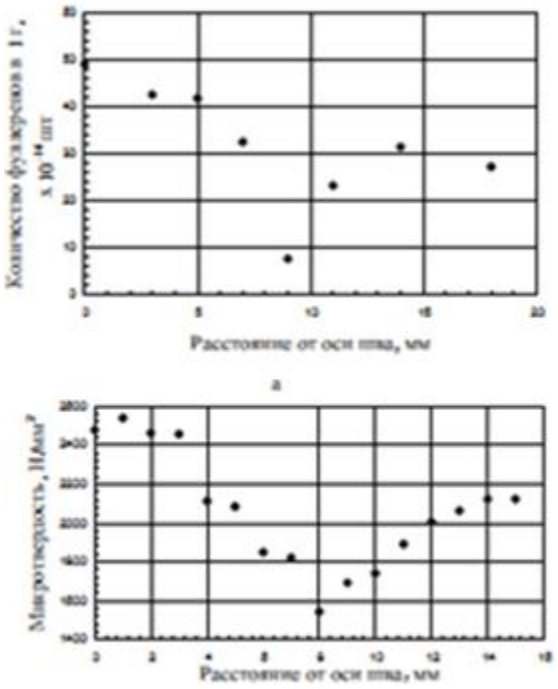
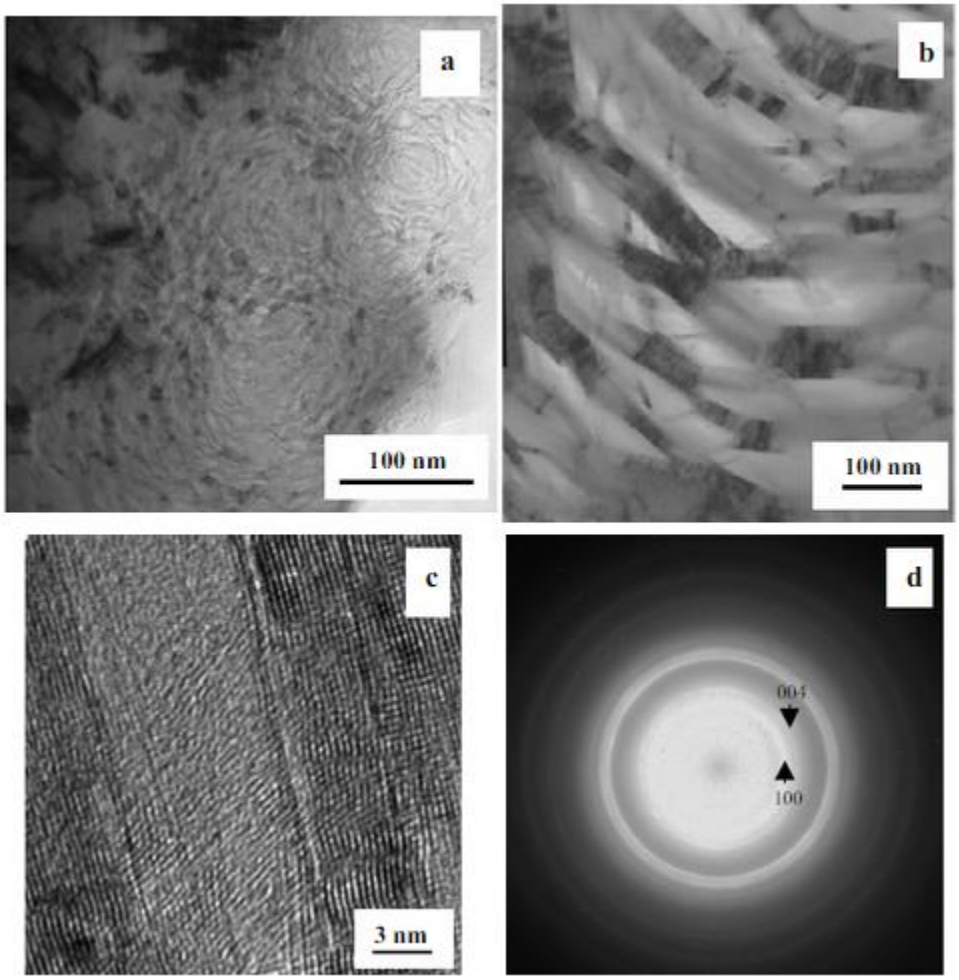


Figure 6.52 [6.63]



FTransmission electron microscopy image from Gilsocarbon A graphite showing agglomeration of four quinoline-insoluble (QI) particles; (b) higher magnification image showing the structure of QI particles; (c) high resolution transmission electron microscopy image from around centre of a QI particle; (d) selected area diffraction pattern from a QI particle.

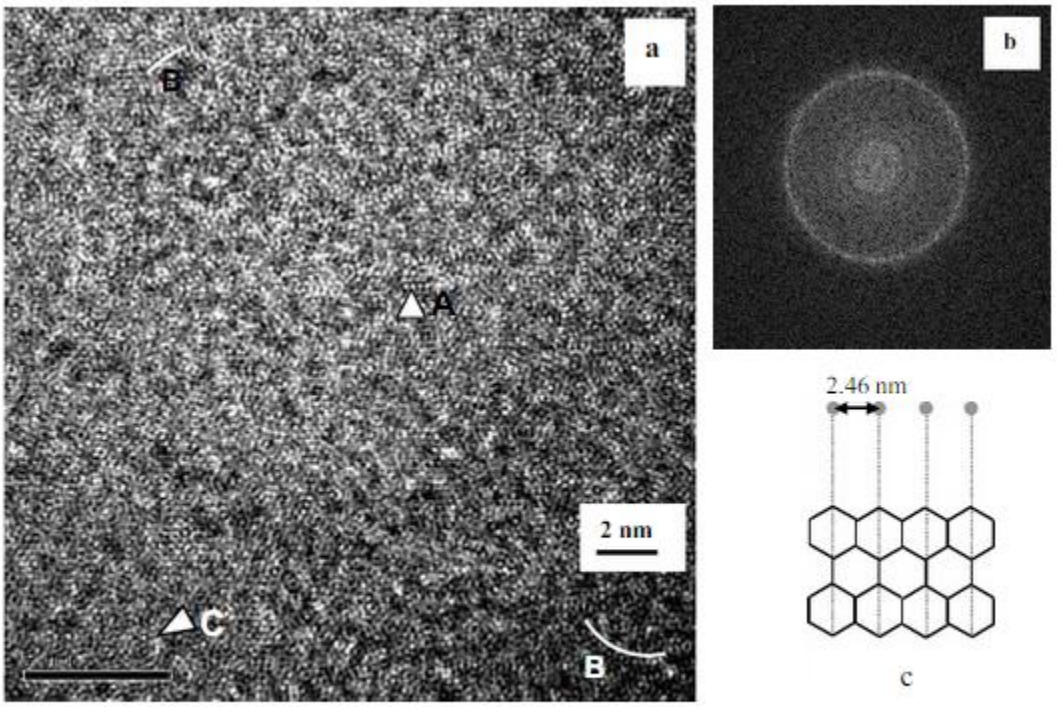


Fig.6 (a) HRTEM image of Gilsocarbon B graphite, some features are indicated; (b) fast Fourier transformation (FFT) of the image in (a); (c) a structure model of the feature A in (a).

Figure 6.55 (a) high resolution transmission electron microscopy image of Gilsocarbon B graphite, some features are indicated; (b) fast Fourier transformation (FFT) of the image in (a); (c) a structure model of the feature A in (a).

Figure 6a is a high resolution transmission electron microscopy image from Gilsocarbon B. This sample was prepared by microtome sectioning. It is difficult to find any two dimensional lattices with size larger than 1 nm. The fast Fourier transform of Figure 6a shows a clear (10) ring (Figure 6b), indicating short range order. A number of one dimensional and two dimensional features can be seen in Figure 6a (e.g. A, B and C). The feature, A, identifies an example feature formed of a short straight line of 4 white dots; B identifies an example of a curved line of white dots and C identifies a feature apparently formed of three concentric rings. The inner ring is approximately 0.7 nm in diameter and formed of dots. Part of the middle ring appears as a fringe and is mostly formed of dots. Only part of an outer ring can be observed as dots and a fringe.

References

6.1. В.А. Закревский, В.А. Пахотин, *Эмиссия отрицательных и положительных ионов при разрыве полимеров,* Физика твердого тела, 2010, **52**, 1083-1089.

6.2. В.К. Иванов, А.Н. Ипатов, В.А. Харченко, М.Л. Жижин: *Электронная структура адиабатических колебаний металлическиз кластеров*, Письма в ЖЭТФ, 1993 ,**58**, 649-655.

6.3. К.Б. Абрамова, А.Б.Пахомов, Б.П. Перегуд, Д.Н. Перунов , В.А. Рейнгольд ,И.П. Щербаков: *Спектр излучения, сопровождающего разрушение медных, алюминиевых и серебряных проводников током большой плотности*. - Оптика и спектроскопия, 1985, т.58, .809-814.

6.4. К.Б. Абрамова, А.Б.Пахомов, Б.П. Перегуд, И.П. Щербаков: *Механолюминесценция стали,* ЖТФ, 1986, **56**, 978-981

6.5. К.Б. Абрамова, А.Б. Пахомов, Б.П.Перегуд, И.П.Щербаков, Письма в ЖТФ, **9**, 769 (1983); ЖТФ, **56**, 978 (1986); ЖТФ, **58**, 817 (1988);).

6.6. К.Б. Абрамова, А.Б. Пахомов, Б.П.Перегуд, И.П.Щербаков. *Излучение света при динамическом разрушении титана.* - ЖТФ, 1990 **60**, 80-85.

6.7. A.I. Yanson, R.G.R. Bollinger, H.E. van den Brom, N. Agraït, and J.M. Ruitenbeek: *Formation and Manipulation of a Metallic Wire of Single Gold Atoms*, arXiv: cond-mar/9811093 1998.v1 1-5.

6.8. M.C. Gimeto: *The Chemistry of Gold*, 2008 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim ISBN: 978-3-527-32029-5, P. 64.

6.9. А. Д. Стыркас: *Разгадка «оловянной чумы*», http://wsyachina.narod.ru/physics/tin.html, Природа, 1996, № 11.

6.10. *Germanium Nanocrystals Embedded in Glass: They're Hotter Before They Melt and Colder Before The Freeze*, Berkley Research News, Berkley LAB, October 9 2006

6.11. В.В. Столяров: *Особенности механических свойств наноструктурных сплавов*, Вестник научно-технического развития, 2010, № 3 (31), 53-60.

6.12. A. G. Kostryzhev: *Bauschinger Effect in Nb and V Microlyed Line Pipe Steels*, 2009, School of Metallurgy and Materials College of Engineering and Physical Sciences The University of

Birmingham P.198.

6.13. H. B. Wang • H. Wang • J. Zhang • F. J. Yang, Y. M. Xu • Q. Li: *Study on Composition Distribution and Ferromagnetism of Monodisperse FePt Nanoparticles*, Nanoscale Res. Lett (2010) **5**, 489–493.

6.14. X. Cui, C. Wang, A. Argondizzo, S. Garrett-Roe, B. Gumhalter, and H. Petek, *Transient excitons at metal surfaces,* Nature Physics, DOI: 10.1038/NPHYS2981 Letters, 2014, pp 6

6.15. ***A.H. Zewail***, **Femtochemistry**: **recent progress** in **studies** of **dynamics** and control of reactions and **their transition states**, ***J***. ***Phys***. ***Chem***., ***1996,*** *100*, .***12701-12724.***

6.16. R. P. Singh, J. Lambros, A. Shukla, and A J. Rosakis, *Investigation of the mechanics of intersonic crack propagation along a biomaterial interface using coherent gradient sensing and photoelasticity,* Proc. R. Soc. Lond. A 1997, **453**, 2649–2667

6.17. .Ю. Х. Векилов, М. А. Черников: *Квазикристаллы*, УФН, 2010, **180**, 561-596.

6.18. *The Properties and Applications of Quasicrystals*, Seminar II, Author: Simon Jazbec, Mentor: prof. dr. Janez Dolinšek, Ljubljana, December 2009.pp. 18. http://mafija.fmf.uni-lj.si/seminar/files/2009_2010/Quasicrystals.pdf.

6.19 T. Duguet, B. Ünal, J. Ledieu, J.-M. Dubois, V. Fourne´e, and P. A. Thiel: *Nanodomains due to Phason Defects at a Quasicrystal Surface*, Phys. Rev. Lett. 2011, **106**, 076101-076104.

6.20. A. L. Pope, T. M. Tritt, M. Chernikov, M. Feuerbacher, S. Legault, R. Gagnon, J. Strom-Olsen: *Thermoelectric Properties of the AlPdMn*, Quasicrystalline System 1998 Fall Materials Research Society Symposium Z: Thermoelectric Materials, Department of Physics and Astronomy, Clemson University, Clemson, SC 29634 USA.

6.21. E. Schrödinger: What is Life? The Physical Aspect of the Living Cell, Cambridge University Press, 1944, pp 194

6.22 Z A. Atre, W. S. Johnson, and J. C. Newman, Jr.: *Assessment of Residual Stresses and Hole Quality on the Fatigue Behavior of Aircraft Structural* 2009, V. 3: Finite Element Simulation of Riveting Process and Fracture Lives, DOT/FAA/AR-07/56. pp. 166.

6.23 M. Ciccoty: *Stress-corrosion mechanisms in silicate glasses J. Phys. D: Appl. Phys*. 2009, **42,** 214006

6.24. N. C. Bellinger: Chapter 7 – *Corrosion Morphology: Corrosion Pillowing and Cracking*, 2002, RTO-AG-AVT-140, Institute for Aerospace Research, National Research Council, Ottawa, Ontario Canada, pp. 10.

6.25. N.C. Bellinger, S.Krishnakumar, and J. P Komorowski, *Modeling of Pillowing Due to Corrosion*

in Fuselage Lap Joints, Canadian Aeronautics and Space Journal, 1994, **40**, No. 3, 125-130.

6.26. N.C. Bellinger, S.Krishnakumar, and J. P Komorowski: *Implications of Corrosion Pillowing on the Structural Intensity of Fuselage Lap Joints*, FAA-NASA, Symposium on the Continued Airworthiness of Aircraft Structures, DOT/FAA/AR-97/2, 1997, 391-402.

6.27 P. W. Whaley "*Corrosion Damage Tolerance Methodology for C/KC-135 Fuselage Structure*." ARINC Incorporated (2006) pp. 23.

6.28. H. H. Richardson, M. T. Carlson, P. J. Tandler, P. Hernandez, and A. O. Govorov, *Experimental and Theoretical Studies of Light-to-Heat Conversion and Collective Heating Effects in Metal Nanoparticle Solutions, Nano Lett.*, 2009, *9* (3), pp 1139–1146, DOI: 10.1021/nl8036905.

6.29. R.S.Piascik, S.A.Willard, M. Miller, *Characterization of Widespread Fatigue Damage in Fuselage Structures,* NASA Technical Memorandum 109142 (1994) pp. 15.

6.30. N. R. Cawley, D. G. Harlow, and R. P. Wei: *Probability and Statistics Modeling of Constituent Particles and Corrosion Pits as a Basis for Maltiple-Site Damage Analysis*, FAA-NASA, Symposium on the Continued Airworthiness of Aircaft Structures, DOT/FAA/AR-97/2, 1997, 11, 531-542.

6.31. C. E. Harris, *NASA Airframe Structural Integrity Program*, 1990, NASA TM-102637

6.32. *Pitting corrosion*. http://www.corrosion-doctors.org/Localized/Pitting.htm/

6.33. D.E. Williams: *Electrochemical Microscopies Study of Passive Films*, Electrochemical Society Procedure 2000-4, 111-117

6.34. H. Cong,N.D. Budiansky,H.T. Miachels, and J.R. Scully, Use of Coupled Electrode Arrays to Eluciadate Copper Pitting as a Function of Potable Water Chemistry, ESC Transaction, 2007, 3(31), 531-544.

6.35. E. McCafferty: *Introduction to Corrosion Science, Springer* New York Dordrecht Heidelberg London, 2009 pp 583

6.36. Y. Furuya, S Matsuoka, and T. Abe, *A. Novel Inclusion Inspection Method Emploing 20 kHz Fatigue Testing,* Metallurgical and Mater. Transac. 2003, 34A, 2517-2526

6.37. Otsuka, H. Hitoshi, H. Nikshima, K. Sakamoto, M. Hayakawa, K. Hashizume, M. Sugusaki, Fusion Scence and Technology, *Observation of Hydrogen Distribution around Non-Metallic Inclusions in Steel with Tritium Microautoradiography* 2005, **48**, 708-711.

6.38. Y. Murakami, N.N. Youkoyama, and J. Nagata, *Mechanism of fatigue failure in ultralong life regime***,** *Fatigue Fract. Engng. Mater. Struct*. 2002, **25**, 735-746.

6.39. Y. Murakami, *Comprehensive Structural Integrity- Fracture of Materials from Nano to Macro, Cyclic Loading and Fatigue*, Elsiver, 2003, **4**, 41-76.

6.40. D.E. Williams: *Electrochemical Microscopies Study of Passive Films*, Electrochemical Society Procedure 2000-4, 111-117

6.41. M. R. Ryan, D. E. Williams et al. Why Stainless Steel Corroded, Nature, 2002, 415 (6873) 770-774.

6.42. Q. Meng, G.R. S. Frankel, H.O. Colijn, and S.H. Goss: *High-Resolution Characterization of the Region Around Manganese Sulfide,* CORROSION, 2004. **60**, No. 4, 346-355.

6.43. D. E. Williams, M. R. Kilburn, J. Cliff, G. I. N. Waterhouse, Composition changes around sulphide inclusions in stainless steels, and implications for the initiation of pitting corrosion, Corrosion Science. 01/2010; 52(11):3702-3716.

6.44. S. J. Zheng, Y. J Wang, B. Zhang, Y.L. Lhu, C.Liu, P. Hu, X.L. Ma, *Identification of* $MnCr_2O_4$ *nano–octahedron in catalyzing pitting corrosion of austenitic stainless steel,* Acta Materialia 2010, **58** 5070–5085.

6.45. J. W. Zhang, L. T. Lu, P.B. Wu, J.J. Ma, G.G. Wang, W. H. Zhang, *Inclusion size evaluation and fatigue strength analysis of 35CrMo alloy railway axle steel,* Materials Science and Engineering: 2013, A 562, 211–217.

6.46. Y. T. Zhou, Y. B. Xue, D. Chen, Y. J. Wang, B. Zhang, and X. L. Ma, Atomic-scale configurations of synchroshear-induced deformation twins in the ionic MnS crystal, Sci Rep. 2014; 4: 5118

6.47. W.-C. Chung, J.-Y. Huang, L.-W. Tsay and C. Chen, *Microstructure and Stress Corrosion Cracking Behavior of the Weld Metal in Alloy 52-A508 Dissimilar Welds,* Materials Transactions, 2011, **52**, No. 1, 12-19.

6.48. He Chao, Liu yongjie, Tian Ranhui, Wang qingyuan, *Gigacycle Fatigue Behaviors in Fusion Zone and Heat Affected Zone of* Q345 LA *Steel Welded Joints*, 13th Conference of Fracture June16-21, 2013, Beljing, China, pp 10.

6.49. Б. С. Семухин, Л. Б. Зуев, К. И. Бушмелева, *Скорость ультразвука в низкоуглеродистой стали, дефрмируемой на нижнем пределе текучести*, Прикладная мехника и техническая физика, 2000, **41**, 197-201.

6.50. Ю.И. Головин: *Наноиндентирование и механическе свойства твердых тел в субмикрообъектах, тонких приповерхностных слоях и пленках*, Физика твердого тела, 2008 **50**, 2113-2142.

6.51. A.A. Volinsky, W.M. Clift, N.R. Moody, and W.W. Gerberich: *Indentation-induced Debonding of Ductile Films,* Mater. Research Symp. Proc. Vol. 586: Symp. M: Interfacial Engineering for Optimized Properties II (1999) pp. 6

6.52. A. A. Volinsky, N. R. Moody, D. C. Meyer, *Stress-induced Periodic Fracture Patterns in Thin Films,* http://www.gruppofrattura.it/ocs/index.php/ICF/ICF11/paper/viewFile/9804/9220/

6.53. G. A. Kravchenko: *Crack Patterns in Thin Films and X-Ray Optics Thermal Deformation*, Thesises and Dissertations, University of South Florida 2008, P.344.

6.54. A.A. Volinsky, N.R. Moody, W.W. Gerberich, *Interfacial toughness measurements for thin films on substrates,* Acta Materialia 2002, **50,** 441–466.

6.55. V.V. Karasev, N.A. Krotova and B.W. Deryagin, "*Study of electronic emission during the stripping of a layer of high polymer from glass in a vacuum*," Dokl. Akad. Nauk. SSR, 1953, **88**, 777-780.

6.56. B. Stokes, N. Gao, P. A. S. Reed, *Effects of graphite nodules on crack growth behaviour of austempered ductile iron,* Materials Research Group, School of Engineering Sciences, University of Southampton, Southampton, SO17 1BJ, UK, http://eprints.soton.ac.uk/65052/1/MSE_finalweb.pdf/

6.57. T.J. Marrow, H. Çetinel, M. Al-Zalmah, *Fatigue Crack Nuclei in Austempered Ductile Cast Iron,* Manchester Materials Science Centre, UMIST, P.O. Box 88, Manchester, M60 1QD, UK,

http://www.gruppofrattura.it/ocs/index.php/esis/ECF14/paper/viewFile/6880/5180

6.58. Е.А. Шур, *Повреждение рельсов*, М: Транспорт 1971 С 111.

6.59. S-i. Nishida, K. Sugino, C.Ukashima and H. Masumoto. *Bulletin of JSME*, **28**, No 243, 1819 (1985).

6.60. Z. Yajima, Y. Kishi, K. Shimizu, H. Mochizuki and T. Yoshida, *Crack Nucleation Mechanism of Austempered Ductile Iron during Tensile Deformation,* Materials Transactions, 2006,. **47**, 82 – 89.

6.61. K. Tsubota and A. Koyanagi, *Effect of Platelie Carbides Below the Rolling Surface in a Ball-Washer Thrust Rolling Contact Fatigue Tester*, Rolling Fatigue Testing of Bearing Steels, ASTM STP 771, J.J.C. Hoo, Ed., American Society for Testing and Materials, 1982, 380-391.