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Microstructure investigation for advanced high strength steel through spot welding

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Abstract-

This paper discussed different issues related to the microstructure analyses of advanced high strength steel using a specific technique of spot welding. The required data for this investigation were totally collected from previous researches and experiments. The discussed data through this paper involve; the principle of operation of electric resistance spot welding; classification of electric resistant processes, the results of the carried out experimental researches and mechanical testing in addition to the behaviour of advanced high strength steel during the welding. The experimental investigation in this research was obtained using microscopic analysis for different spot welding samples . the heat fusion, heat affected , and the base materials zones were presented clearly during the microstructure results . hardness test using VICKERS hardness was used to find the hardness along these regions, where the highest hardness were recorded for the FZ and HAZ region and the lowest hardness was found for the base material . this results can be used as indication for the effect of spot welding on the mechanical properties of AHSS material

Keywords: welding, resistance, spot, advanced high strength steel, microstructure.

I. INTRODUCTION

Welding is the process of creating an inseparable compound by establishing interatomic bonds between welded parts, whereby heat and mechanical energy, and, if necessary, additional material, are used individually or in combination. The welding processes, which are most commonly used in practice [1], are based on the local heating of the material above the melting temperature when the welded joint is formed by curing (arc welding) or on the local warming of the material to the melting temperature when the welded joint is created with the addition of pressure (electric resistance welding) [2,3,4]. By welding it is possible to merge metals with metals, non-metals and non-metals, but in practical terms it is understood that metal and metal are combined. Today, 98 welding processes are considered to have been adopted and applied in practice, including soldering, as defined in ISO 4063:2009, corrected version 2010-03-01 (EN 24063): Welding and allied processes – Nomenclature of processes and reference numbers. **1. Arc Welding;** Carbon arc; Metal arc; Metal inert gas; Tungsten inert gas; Plasma arc; Submerged arc and Electro-slag. **2. Gas Welding;** Oxy-acetylene; Air-acetylene; Oxy-hydrogen. 3. **Resistance Welding;** Butt; Spot; Seam; Projection; Percussion; **4. Termite Welding. 5. Solid State Welding;** Friction; Ultrasonic; Diffusion; Explosive. **6. Related Process** Oxy-acetylene cutting; Arc cutting; hard facing; brazing; soldering [3]. In this project, the microstructure of advanced high strength steel will be analysed through the process of spot welding based on collecting relevant theoretical data and analysing them.

II. LITERATURE REVIEW

A. Electric resistance welding

Electric resistance welding (ERW) includes a group of processes for the connection of materials in which the material (usually metal) is heated by heat generated by electrical resistance, and the welded joint is formed by an additional force of the pressure between the electrodes. Electric resistance generates heat which is used to heat a certain amount of material to the welding temperature, as well as to heat the material in the surrounding zone for easier plastic deformation. Accordingly, the activation energy in an electric

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resistance welding process is of a combined type [1, 2, 5]. Through the electrodes, a high-current electric current is passed through (order of magnitude: 100 A to 100 000 A). However, this current is of low voltage (no more than 60 V to 80 V). When the electrical current passes through the electrodes and the basic material, due to the material's resistance, the electric current is transformed into a heat that locally softens the basic material (at certain contact points even the soluble basic material). Due to the effect of the pressure force, softened and partially melted basic material is combined into a monolithic structure - a weld joint [4,6,7].

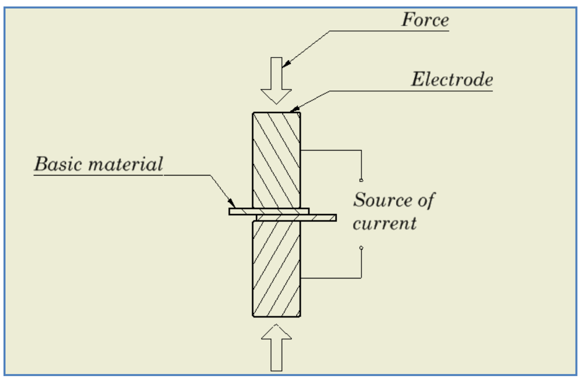

***Figure 1** Cheme of Electric resistance welding process[4].*

When the electric current passes through a conductor of a certain resistance, as a result, heat is obtained. The basic formula for heat energy is: $H = I^2 \times R$. Here is the "I" current of welding and "R" is a resistance. The thermal energy generated during the process is directly proportional to the resistance at each point of the circuit [1, 2].

Pressure Time: It is the time between attaching pressure (contact) between the pieces to the release of the current [8].

Welding or heating time: It is the time of pure welding in cycles [9].

Retention time: It is the time of holding the pressure (contact) after the finished welding - without power [10, 11].

Free time: It is the time when the electrodes release pressure until the next pressure build-up.

Devices for this type of welding are designed to have minimal losses in transformers, cables, and electrodes - to provide the most optimal welding parameters [12].

There are 6 main points of resistance in the field of work:

- Contact surface between the upper electrode and the upper working part;
- Upper work piece;
- Touch surface between work pieces;
- Lower work piece;
- Contact surface between the lower electrode and the lower working piece;
- Resistance of the electrodes themselves.

These resistances are serial and at each point there is a decrease in current [12].

B. Spot welding

Electric resistance spot welding is one of the oldest welding processes that are still used in industry today. The welded joint is formed thanks to three components: heat, pressure and time [1].

Electric resistance spot welding is a method of combining metals with a combined heat action, obtained by electric resistance in a closed circuit between two sheets (3) pressed to the rod-shaped electrodes (2), and the pressure forces F (Figure 2). In this case a joint (welded point) is obtained as in Figure 3, where the thickness of the sheet is s, d_s is the diameter of the welded point (lens), H is the height of the point, d_e is the electrode diameter, and h presents the hull [12].

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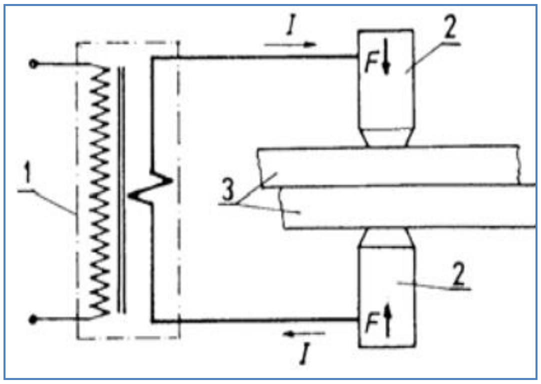

Figure 2 *Detailed cheme of Spot welding process [12]*

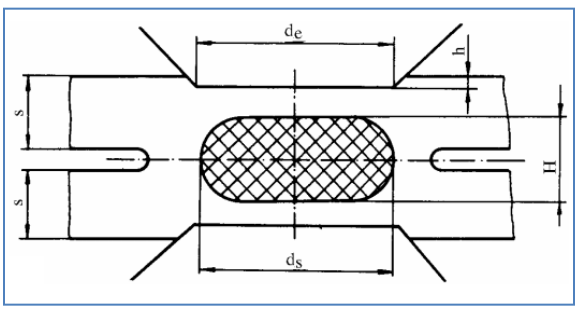

Figure 3 *spot welded points [12]*

Identifying devices that exist on the market and their capabilities is just the initial information for choosing the device. It is also necessary to consider other influential factors:

- The type of materials which have to be welded and their thickness;
- Types of coating on the material - if it exists;
- Configuration and construction of the work piece;
- Standards;
- Requirements for the visual appearance of a welded joint;
- Productivity (how many points we want at a certain time interval);
- The output power and the current for connection of the device;
- Available flow and pressure of compressed air and cooling fluid [10], [12].

The most common mistake in selecting an electro resistance welding device is when the choice is made only according to the KVA power. The factors that actually need to be checked (to obtain quality welded joint) are: welding force (pressure), amperage of welding and welding time expressed in cycles [10], [12].

An electro resistance welding device may consist of the following parts:

- time switch for turning the power on and off;
- electrodes and power supply elements;
- slippers and a mechanism for providing pressure;
- high power transformer that reduces voltage from 380 V or 220 V to 0.5 V to 10 V [10], [12].

The force of the pressure can be applied mechanically, or by hand, or automatically (hydraulic, electric or pneumatic). In the first case the pressure is constant, while in other cases the pressure value in the welding cycle can be changed [10], [12].

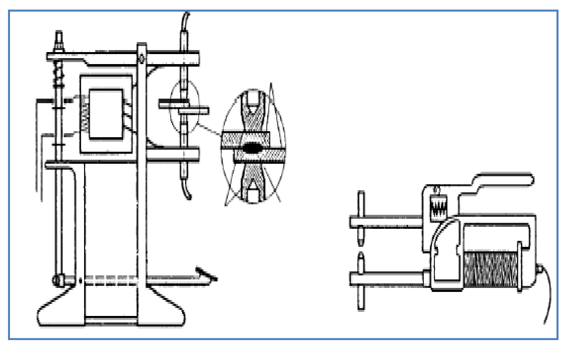

Figure 4 *Devices and equipment for Electric resistance spot welding [12]*

C. Materials for spot welding

Electro resistance spot welding process successfully use with:

- Galvanized sheet metal;
- CrNi sheets;
- Aluminium;
- Low carbon steel;
- Alloy steels, etc.

The welding process is extremely fast and can be easily automated. It is important to take into account the thicknesses being welded in this way. Welding of

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large thicknesses of materials would require an increase in investment in welding devices. The thickness limit for the use of spot welding is 6 mm for non-coated materials, or 4 mm for coated materials (it is thought of one-piece thickness). The recommended time of the welding cycle arises from the type and thickness of the basic welding materials, the welding current values, and the contact surface of the electrode tips with the base material [2], [8].

D. Advanced High-Strength Steel (AHSS)

Advanced High-Strength Steels (AHSS) represent the type of very complex as well as sophisticated materials, with thoroughly chosen chemical components and multiphase microstructures. All of this properties are results of precisely controlled heating and cooling processes. The main characteristic of this type of steels represents mix of the strength, ductility, toughness, and fatigue properties, what is very suitable for manufacturing process at all. These steels are uniquely light weight and prepared to resist all challenges and requirements of today's mechanical systems including vehicles, high reliability constructions as well as gears, shafts and etc. for stringent safety regulations, emissions reduction, solid performance, at low costs [11].

Advanced High-Strength Steels has a wide range of usability, especially in automotive industry. There is a continual need for product and production optimization in that area. The one that is main technology in this industry is electric resistance spot welding, when it is about automotive assembly production. It is possible to weld different materials and their combinations that aren't easy joinable, or actually impossible to combine by other welding techniques. Advanced high-strength steels (AHSS) are used in different parts of vehicles and interior parts designed to absorb a collision impact. Parts are typical connected to a much thinner and softer low-carbon sheets that serve as outer panels of cars [5].

The advanced High-Strength Steels includes Dual Phase (DP), Complex-Phase (CP), Ferritic-Bainitic (FB), Martensitic (MS or MART), Transformation-Induced Plasticity (TRIP), Hot-Formed (HF), and Twinning-Induced Plasticity (TWIP). In this article, the main emphasis is on Dual Phase (DP) and Transformation Induced Plasticity (TRIP steels) [6].

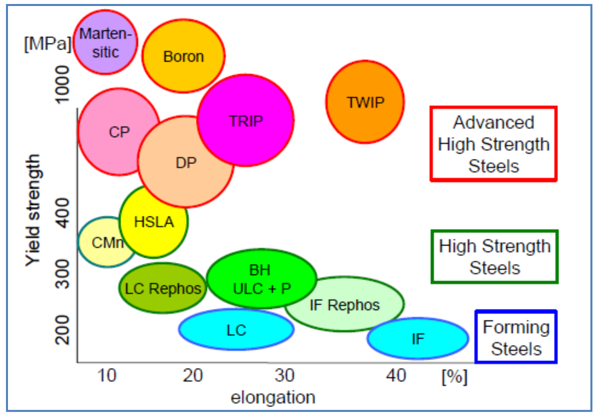

Figure 5 *Interdependence of Yield strength and elongation on example of Advanced High Strength Steels, High Strength Steels and Forming steels [6]*

Dual Phase steels is a high-strength steel that has a ferrite–martensitic microstructure. The advantages of Dual Phase steels are very good fatigue resistance, low yield strength as well as low yield to tensile strength ratio (yield strength / tensile strength = 0.5). Further, there are high initial strain hardening rates and good uniform elongation. The martensitic component of the steel which is typically around 20% is the reason of increases the strength of the material, while the reason of good formability is ferrite structure [6].

Dual Phase steels have an ability to absorb a lot of energy. The main reason for that is isotropic forming characteristics. That's reason why that's important to include dual phase materials in automotive parts which are often exposed to crashes [6].

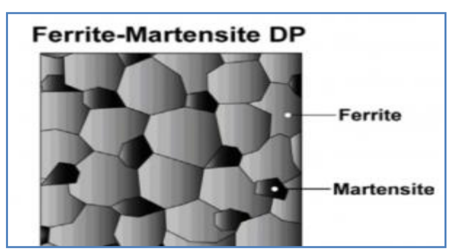

Figure 6 *Ferrite-Martensitic dual-phase steel [12]*

Transformation Induced Plasticity Steels at usual (room) temperature retains austenite structure. The reason for enhancing the ductility is ferrite-bainite matrix contains the austenite which is embedded in.

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After mechanical loading, the austenite transforms into martensite which has the effect on increasing the strength of the materials [6].

As it is described in paragraphs below, as Dual Phase steels, Transformation Induced Plasticity steels have very good isotropic forming characteristics which reflects on ability to absorb a lot of energy [6].

Depending on the composition, austenitic steels receive a pure austenitic structure (steel with 25% Cr and 20% Ni) or a mixed structure, with ferrite separation (steel with 18% Cr and 9% Ni) in primary crystallization. In the first case, steel is subjected to the formation of warm cracks, and in the second presence of 1-1.5% ferrite strongly reduces the advantage over warm cracks. The behaviour of some austenitic steels during welding affects their tendency to crystalline corrosion due to heating to 500-800 °C. The risk of intercrystallite corrosion is reduced by rapidly passing through this temperature interval and introducing elements such as Ti and Nb [2].

The behaviour of austenitic steels for electro-resistant welding is determined by:

a) High-temperature flow, which is considerably higher than in low-welded and low-alloy steels, requiring greater pressure between electrodes.

b) Increased electrical resistance and lower thermal conductivity than in low-alloy and low-alloy steels, which requires less current for their heating than for low-alloy steels of the same thickness.

c) High coefficient of thermal expansion α (for example, steel with 18% Cr and 9% Ni is $\alpha = 20 \times 10^{-6}$, and low-glazing glasses $\alpha = 12 \times 10^{-6}$), which can cause greater deformation during welding, this is, as a rule, compensated for with low thermal conductivity, so the heating and deformation zones are small [12].

It can be concluded that welding of austenitic steels should be carried out with high pressures and sharp regimes [2].

III. : THEORETICAL INVESTIGATION

A. Microstructure investigation

The quality of electric resistance welded joints depends on several factors, the most important of which are:

- Sufficiently large contact resistance at the point of contact of the work pieces;
- The welding process must be fast and dynamic.

The quality of spot welded joints is pre-controlled (preliminary control), during and after welding, and includes destructive and non-destructive testing [9].

Destruction tests are performed only on test tubes and are divided into:

- Testing the welded point by tightening;
- Examination of welded point by torsion;
- Examination of the welded point as a bundle;
- Testing of hardness and structure.

Non-destruction tests do not affect the properties of the welded joint by its action. Since they only serve for the detection and determination of sub-surface defects in the welded joint of the processed EURONORM EN 26520, they have the name and defectoscopy. The disadvantage of this method is to detect it and determine the defects that arose before defectoskopy implementation. It cannot be used in the direct prevention of defects [14].Energy Dispersive X-Ray Spectroscopy (EDS or EDX) represents a chemical microanalysis technique. EDX usually goes together with scanning electron microscopy (SEM). The EDS technique detects x-rays emitted from the sample during bombardment by an electron beam to characterize the elemental composition of the analyzed volume. Advantage of these methods is possibility of analyzation features or phases as small as 1 µm or less [13]. It is well-known that microstructure of welded elements depends on its chemical composition. The fact that different CE definitions are used for dissimilar concentrations of carbon so there are different regimes of working. The influence of different chemical elements is valuable for high carbon steels, regardless some elements like Cu and Cr are usually present only at the monitoring level. The relative influence of various elements

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reduces with reduction of the concentration of carbon in steel. Meanwhile, as carbon concentration is reducing, it is possible to relatively number of available other elements become higher [6].

When the proportion of influence between C and Cr is C/Cr = 2/1 then a steel includes 0.20 wt% C and 0.5 % Cr. If now we reduce concentration of carbon to 0.15 wt%, then level of influence will be C/Cr = 6/1. It is necessary to transform CE definition as the concentration of carbon becomes less than 18 %. This leads to fact that influence od Cr on the resultant hardness is getting bigger [6].

B. Effect of spot welding on mechanical properties of material and microstructure

The welded point has two axes of symmetry, a large axis that coincides with the line of contact of two cans and a small axis that coincides with the axis of electrodes. In the central zone of the welded point is the largest heating and the fastest cooling, and the temperature change is different in different directions, which explains the ellipticity of the welded point. Due to the different cooling rates in the welded microstructure, different zones can be seen (Figure 8). Zone 1 is an equilibrium structure, 2 is a zone with oriented dendrites, and 3 is a normalization zone, which is above A3 temperature, and has a fine-grained structure, which favourably affects all mechanical properties [12].

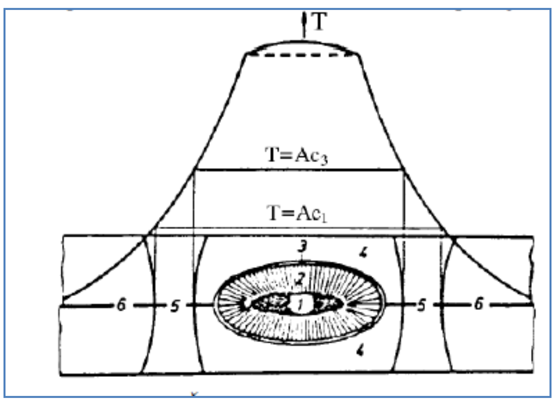

Figure 8 *A schematic representation of the temperature field for a spot welded joint [12]*

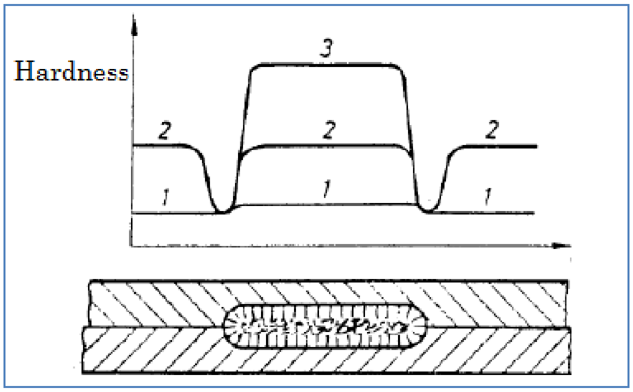

Figure 9 *Change in hardness in the welded area [12]*

Zone 4 is the area corresponding to temperatures A1 and A3. Zone 5 is the recrystallization area, and 6 is the zone of the basic material that is not subjected to the operation of the thermal cycle of welding. The change in the hardness in the welded joint area for three different steels (curve 1-1-1 austenitic steels, curves 2-2-2 cold-rolled low-grade steels, and curves 1-3-1 and 1-2-1 alloy steels) are given in the figure 8 [12].

The most common defects in spot welding resistance (porosity, bonding, cavities, spraying, burning) are shown in Figure 10, along with a well welded spot, in which the 1-dark ring, 2-gray medium zone, 3-outer a bright ring, a 4-inch light ring. The main cause of these defects is the wrong choice of welding parameters [12].

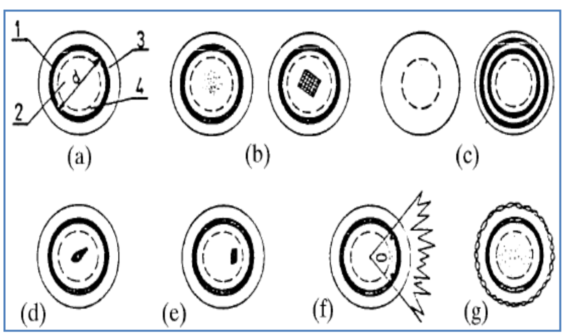

Figure 10 *Defects in spot welded joints on the radiogram: a) normal point b) porosity (middle zone dark or cube), c) gluing (no one or two dark rings), d) and e) cavity (black spot in the center zone), f) spraying, g) a burnt point [12]*

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Using different mechanical testing are provided mechanical properties and microstructure. There are two methods which are useable, tensile shear and coach peel method, and fracture was done using one and another method. While it is tested with coach peel method welded sheets separated, resulting in normal force on the weld point and causing fracture around the weld. Metering of diameter of weld point is much easier with using of coach peel method [7].

Mechanical properties of weld joint were verified by metering high value of load to failure. It was done with tensile shear test. It was method in which the force was placed parallel to the weld point. The main focus was to provide flatness in the testing process. Using a microscope fracture surfaces were investigated in both cases of testing [7].

When the discussion it's about hardness, the examinations were conducted with a Clemex MT-2001 Vickers micro hardness testing machine. The testing of micro hardness was done with 200 g load and hold time of 15 seconds. With process of micro hardness mapping using 0.2 mm grid spacing showed the hardness disposition and the values of hardness in pleaces of welded joints [7].Spot welding begins by pressing the pieces to ensure good contact. It is important to provide sufficient force to the pressure, Eastern is observed at the beginning of the process in too fast advocacy and insufficient pressure or at the end of the process due to overheating. Welding during electric resistance welding is short-lived (from microseconds up to a few seconds) and unevenly, with the highest part of the core point (core) warming up where the current is highest. In the initial phase of heating in the nucleus, the formation of large grains begins under the effect of the force of pressure, i.e. welding without melting. Further heating of the core melts, and by its hardening, a welded point is obtained, Figure 12 [12].

If the current is turned off before reaching the melting temperature, there are no cavities or pores in the structure of the welded point, but there are large grains and non-metal inclusions that reduce the toughness of the joint. On the contrary, cracks and pores are formed during melting and curing of the core, which can be prevented by the force of pressure. Therefore, the reduction in pressure on the electrodes should be delayed in relation to the power cut during t_k, sufficient otherwise the extrusion will occur as it is showed on Figure 11. [12]

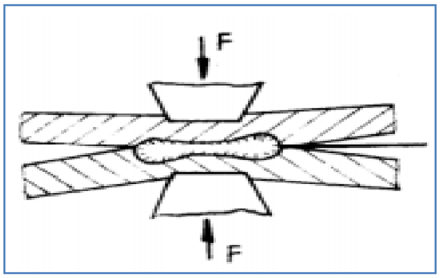

Figure 11 *Shrinking the core [12]*

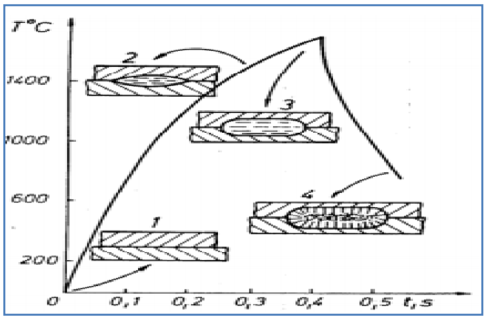

Figure 12: Changing the temperature in the core [12]

to complete the crystallization. By increasing the thickness of the pieces, cooling and crystallization slow down, and the time t_k is prolonged. For thicker sheets (steel thicker than 5-6 mm), the pressure force of the electrodes should not only be longer, but should also be increased to prevent the appearance of cavities and pore [12].

A special problem with electric resistance spot welding is the current diversion due to the presence of surrounding welded points, Figure 13. This phenomenon is more pronounced in one-sided welding, Figure 13 a), but with two-sided welding, Figure 13 b) [12].

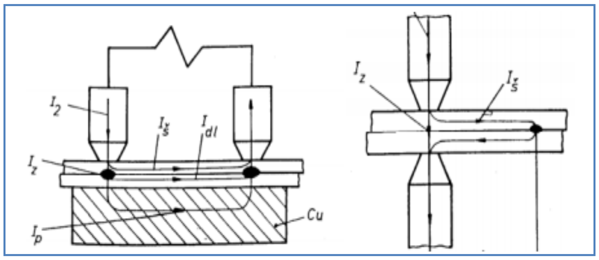

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Figure 13 *Turning current in spot welding: a) one-sided, b) two-sided [12]*

The yield strength, ultimate tensile strength, n-value, uniform and total elongation usually are provided by standard tensile test. As usual, a strain analysis has been done, making a forming limit diagram to check and evaluate a formability of material. Even these methods are presents of global forming behaviors, but it is not absolutely describing an advanced material's properties in discrete formability. Researchers can make a question do nowadays standard tests provide us a truly information's about microstructure and mechanical properties of materials. And if the answer is negative, the logical next step will be about making a new test for providing a precisely results [15].

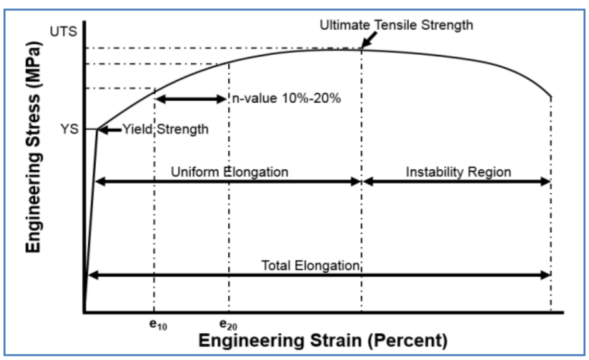

Figure 14 *Stress-Strain curve for AHSS* [15]

N-value (instantaneous) represents a new parameter of investigation. This parameter is described like strain gradient. Accurately this is behavior of material known as work-hardening in the moment of making contact with die geometry [15].

It can happen that the increase of work-hardening missed during deformation, if standard n-value (which is known as exponent of work hardening) is in between ten and twenty presents strain. There are two tests: the hole expansion and three-point bend which very often applies. The first test shows ability of the materials to stretch at the sheared edge. The second test shows the strechability of the material including minimum bend radius [15]. When we discus about Advanced High Strength Steel, we can conclude that AHSS is represented by few phase structures. The reason for that is to improve formability. These new-designed, advanced steels are being developed to make as better quality steel with higher value of strength and to least thickness [15].

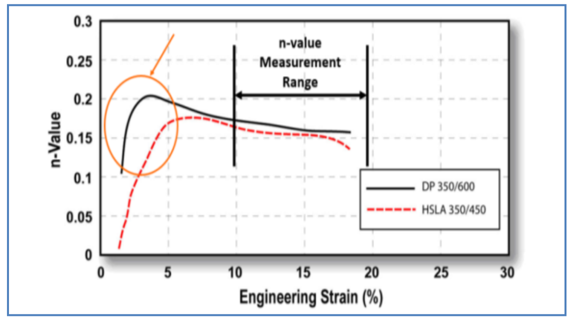

Figure15 *n-Value dependence on Engineering Strain (%)* [15]

This new knowledge about Advanced High Strength Steels provides a wide range of opportunities to make more optimization in process of Electric Resistance Spot Welding. With often measuring of parameters n-Values as well as standard mechanical properties values like yield strength, tensile strength and hardness, and making a good choice with parameters of welding, researchers can provide often improvement in this areas of science.

I. RESULTS OF ANALYSIS

In this research an investigation for the effect of spot welding on the mechanical properties of the advanced high strength steel, where the microstructure and hardness of four samples was investigated as shown in the following . the different microstructures of these samples were captured using microscopic techniques in Swansea university lab (SEM) , where the etching was applied to samples to clearly show the microstructure of the samples,

Figure 15 shows the microstructure of the first sample at the spot joint, where the different zones of the spot welding are clearly shown which are FZ, BM and HAZ , the FZ (Heat Fusion Zone) was melted and recrystalised based on the repeated thermal cycles of welding .where the elliptical shape of this region is clearly shown. the grains recrystalised in this region as equiaxed grains, in other words the grains due to the antiparallel heat flow.

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The equiaxed growth can be explained according the growth direction of the grains which is antiparallel to the direction of the heat flow toward the nugget centre. this result can be validated by the literature review , where the shrinkage elliptic shape for the Fz region presents extra pressure was applied to samples during welding process , but in the presented samples no shrinkage in the nugget .

The grains at the edges of the nugget affected by the thermal cycles of the welding where there size becomes smaller by the high cooling rate of fusion area , this region is called Heat affected Zone (HAZ) .

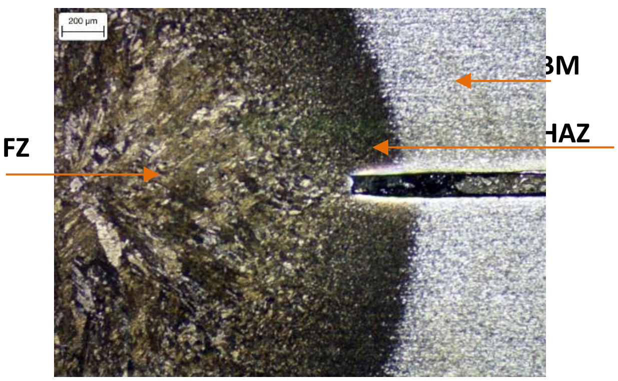

Figure 14 *Microstructure investigation for the first sample at the spot welding.*

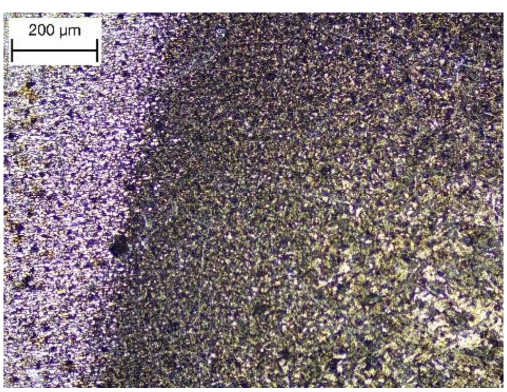

Figure 15 *Microstructure investigation for the second sample.*

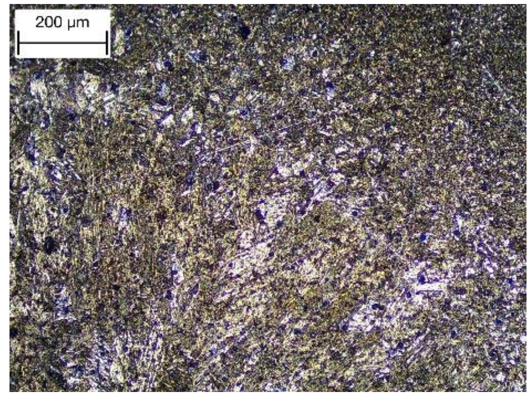

Figure 16 *Microstructure investigation for the second sample sowing contact between FZ and HAZ*

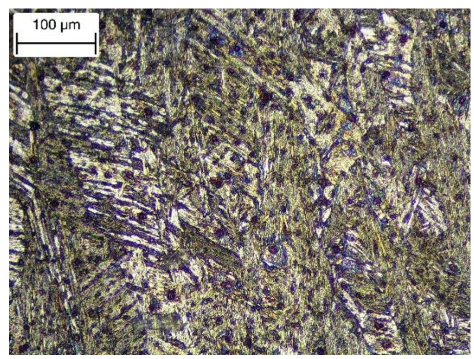

Figure 17 *Microstructure investigation for the third sample*

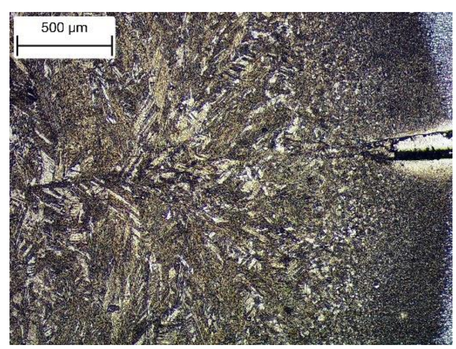

Figure 18 *Microstructure investigation for the fourth sample at the spot welding*

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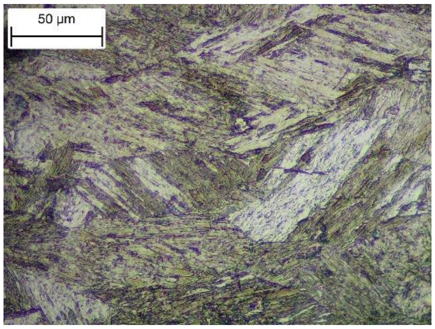
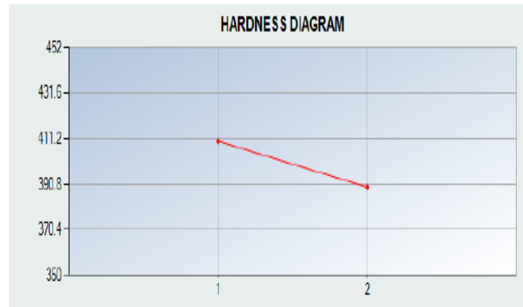
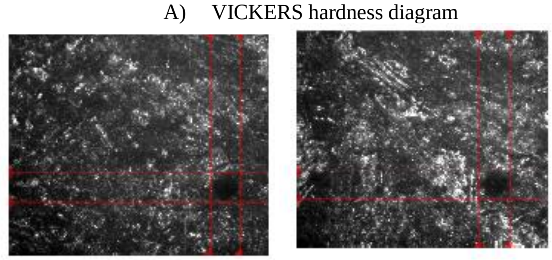


Figure 19 *Microstructure investigation for the fourth sample at the spot welding showing clearly FZ.*

The material base of the two samples are joined by the wielding where this region is less affected by the thermal cycles of the welding , where two layers of the base materials can be seen in figure 15 upper base material and lower base material layer. Figure 16 shows a zooming on the contact region between the HAZ and based material, for the second sample , it was noted the small grain size for the HAZ region comparing with base material, these small grains were produced by the high cooling rate for the FZ during the thermal cycles of wielding , also it can be seen the random growth in the grains toward nugget centre Figure 17 shows the microstructure of the third sample at FZ region , however the martensite phase transformation is generated at this region according to high temperature variation which can be validated according to literature review. Figure 18 shows the microstructure of the fourth sample , where the soften martensite structure for HAZ region can be shown clearly comparing with the bases material. Figure 19 shows a close zooming for the FZ microstructure to understand the difference between these region and their effect on the mechanical properties of AHSS. Mechanical Hardness was measured using VICKERS hardness test .where the results of VICKERS hardness were taken as average for the different locations along the samples. In addition two samples were tested for hardness test which are sample 3 and 4. figure 20 shows the results of hardness test for two records at the boundary of FZ region which is located at the centre of spot welding of sample 3.



A) VICKERS hardness diagram



B) Record 1 C) Record 2

Figure 20 *hardness investigation for the third sample at FZ. Zone .*

The hardness for different locations along sample 3 is shown in figure 21, where the maximum hardness was recorded at FZ region which has martensite structure. Where the hardness of the base material is less than the hardness of the HAZ and FZ regions, the low hardness region can be used to predict the failure location inside the material, in addition, the low hardness is produced by loss energy absorption. Figure 22 presents a sample for hardness record for the fourth sample at the welding . where the hardness at the boundary of the FZ region in range of 319.7- 330.2 HV. In the other hand, low hardness at the centre of FZ with value about 190.9 HV. comparing with results of the third sample the hardness was at this region in range of 351.4 to 410.1 HV which is the highest value also for the third sample. Figure 23 shows the hardness at different locations along the fourth sample, the low hardness was presented in the base material, where the highest

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values were recorded for the FZ and HAZ zone.

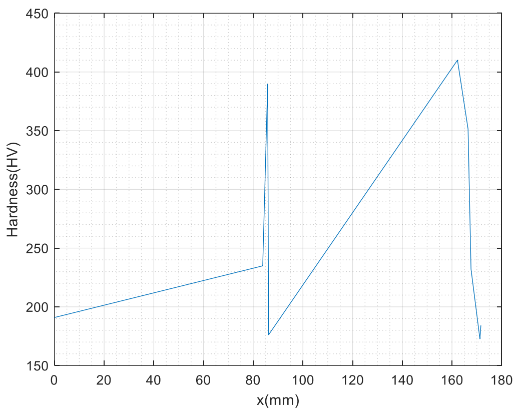
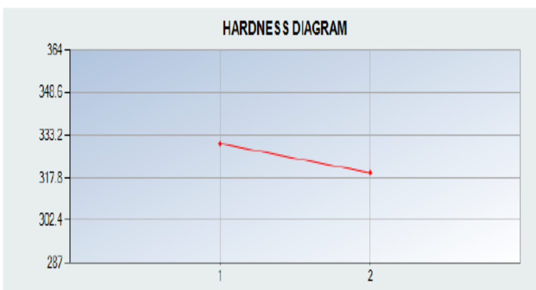
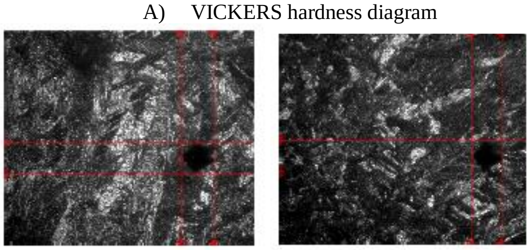


Figure 21*hardness records for the third sample.*



A) VICKERS hardness diagram



B) Record 1 C) Record 2

Figure 22 *hardness investigation for the fourth sample at FZ. Zone .*

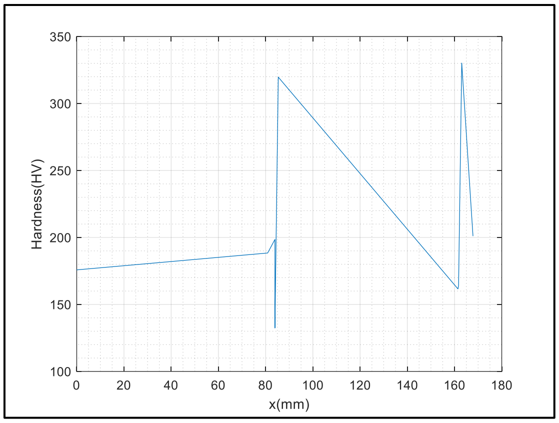


Figure 23 *hardness records for the fourth sample.*

II. CONCLUSION

Based on the collected data, it was discovered that destructive and non-destructive testing methods are used for microstructure analyses of steel where the welded joint obtained by the electric resistance spot welding is a non-destructive test method. By analysing the microstructure of Advanced High Strength Steels, all of its mechanical and chemical properties can be clearly defined. This research involves an investigation for the microstructure of four spot welded samples (AHSS samples), where the microscopic analysis with etching were used to find these captures of microstructure . it was noted there are three main regions are generated by the effect of the spot welding which are : Fusion zone , Heat affected zone , and the base material itself. regarding the FZ and HAZ REGION there is a random growth in grains toward nugget centre where the high cooling rate and the thermal cycles which are generated by the welding produce this behaviour, however these two regions can be seen with elliptical shape based on the heat recrystallisation behaviour. Regarding HAZ zone it has soften grains structure comparing with the base material which has low effect by the welding process. Hardness was measured using VICKERS hardness test .where the results of VICKERS hardness were taken as average for the different locations along the samples. the low hardness was presented in the base material, where the highest values were recorded for the FZ and HAZ zone.

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