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BASICS OF METAL PROPERTIES & HEAT TREATMENT

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MAT-116 EXAM PREVIEW

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Exam Preview:

1. There is no simple definition of metal; however, any chemical element having "metallic properties" is classed as a metal. "Metallic properties" are defined as luster, good thermal and electrical conductivity, and the capability of being permanently shaped or deformed at elevated temperature.
   a. True
   b. False
2. An "alloy" is defined as a substance having metallic properties that is composed of two or more elements. The elements used as alloying substances are usually metals or metalloids. The properties of an alloy differ from the properties of the pure metals or metalloids that make up the alloy and this difference is what creates the usefulness of alloys. By combining metals and metal- loids, manufacturers can develop alloys that have the particular properties required for a given use.
   a. True
   b. False
3. Strength is the property that enables a metal to resist deformation under load. The ultimate strength is the maximum strain a material can withstand. Tensile strength is a measurement of the resistance to being pulled apart when placed in a tension load. _____ is the ability of material to resist various kinds of rapidly changing stresses and is ex- pressed by the magnitude of alternating stress for a specified number of cycles.
   a. Impact strength
   b. Fatigue strength
   c. Creep strength
   d. Yield strength

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4. ______ is the property that enables a material to withstand shock and to be deformed without rupturing. It may be considered as a combination of strength and plasticity. Table 1-2 shows the order of some of the more common materials for toughness as well as other properties.
    a. Elasticity
    b. Hardness
    c. Toughness
    d. Tensile strength
5. Corrosion resistance, although not a mechanical property, is important in the discussion of metals. Corrosion resistance is the property of a metal that gives it the ability to withstand attacks from atmospheric, chemical, or electrochemical conditions. Corrosion, sometimes called oxidation, is illustrated by the rusting of iron.
    a. True
    b. False
6. The 200-300 series of stainless steel is known as Ferritic. This type of steel is very tough and ductile in the as-welded condition; therefore, it is ideal for welding and requires no annealing under normal atmospheric conditions. The most well-known types of steel in this series are the 302 and 304. They are commonly called 18-8 because they are composed of 18% chromium and 8% nickel. The chromium nickel steels Low-Carbon Steel are the most widely used and are normally nonmagnetic.
    a. True
    b. False
7. Through heat treating, we can make a metal harder, stronger, and more resistant to impact. Also, heat treating can make a metal softer and more ductile. The one disadvantage is that no heat-treating procedure can produce all of these characteristics in one operation. Some properties are improved at the expense of others; for example, hardening a metal may make it brittle.
    a. True
    b. False
8. ____ steel is a case-hardening process by which carbon is added to the surface of low-carbon steel. This results in a ____ steel that has a high-carbon surface and a low-carbon interior. When the ____ steel is heat-treated, the case becomes hardened and the core remains soft and tough.
    a. Carburized
    b. Flame hardening
    c. Case hardening
    d. Nitriding

9. The purpose of tempering is to reduce the brittleness imparted by hardening and to produce definite physical properties within the steel. Tempering always follows, never precedes, the hardening operation. Besides reducing brittleness, tempering softens the steel. That is un- avoidable, and the amount of hardness that is lost depends on the temperature that the steel is heated to during the tempering process. That is true of all steels except high-speed steel. Tempering increases the hardness of high-speed steel.
   a. True
   b. False
10. The quenching rate of an object depends on many things. The size, composition, and initial temperature of the part and final properties are the deciding factors in selecting the quenching medium. A quenching medium must heat the metal at a rate rapid enough to produce the desired results.
   a. True
   b. False

CHAPTER 1

PROPERTIES AND USES OF METAL

In the seabees, Steelworkers are the resident experts on the properties and uses of metal. We lay airfields, erect towers and storage tanks, assemble pontoon causeways, and construct buildings. We use our expertise to repair metal items, resurface worn machinery parts, and fabricate all types of metal objects. To accomplish these tasks proficiently, one must possess a sound working knowledge of various metals and their properties. As we learn their different properties and characteristics, we can then select the right type of metal and use the proper method to complete the job. Steelworkers primarily work with iron and steel; however, we also must become familiar with the nonferrous metals coming into use more and more each day. As Steelworkers, we must be able to identify various metals and to associate their individual properties with their proper application or use.

The primary objective of this chapter is to present a detailed explanation of some of the properties of different metals and to provide instruction on using simple tests in establishing their identity.

METAL PROPERTIES

There is no simple definition of metal; however, any chemical element having "metallic properties" is classed as a metal. "Metallic properties" are defined as luster, good thermal and electrical conductivity, and the capability of being permanently shaped or deformed at room temperature. Chemical elements lacking these properties are classed as nonmetals. A few elements, known as metalloids, sometimes behave like a metal and at other times like a nonmetal. Some examples of metalloids are as follows: carbon, phosphorus, silicon, and sulfur.

Although Steelworkers seldom work with pure metals, we must be knowledgeable of their properties because the alloys we work with are combinations of pure metals. Some of the pure metals discussed in this chapter are the base metals in these alloys. This is true of iron, aluminum, and magnesium. Other metals discussed are the alloying elements present in small quantities but important in their effect. Among these are chromium, molybdenum, titanium, and manganese.

An "alloy" is defined as a substance having metallic properties that is composed of two or more elements. The elements used as alloying substances are usually metals or metalloids. The properties of an alloy differ from the properties of the pure metals or metalloids that make up the alloy and this difference is what creates the usefulness of alloys. By combining metals and metalloids, manufacturers can develop alloys that have the particular properties required for a given use.

Table 1-1 is a list of various elements and their symbols that compose metallic materials.

Table 1-1.—Symbols of Base Metals and Alloying Elements

Element	Symbol
Aluminum	Al
Antimony	Sb
Cadmium	Cd
Carbon	C
Chromium	Cr
Cobalt	Co
Copper	Cu
Iron	Fe
Lead	Pb
Magnesium	Mg
Manganese	Mn
Molybdenum	Mo
Nickel	Ni
Phosphorus	P
Silicon	Si
Sulfur	S
Tin	Sn
Tungsten	W
Vanadium	V
Zinc	Zn

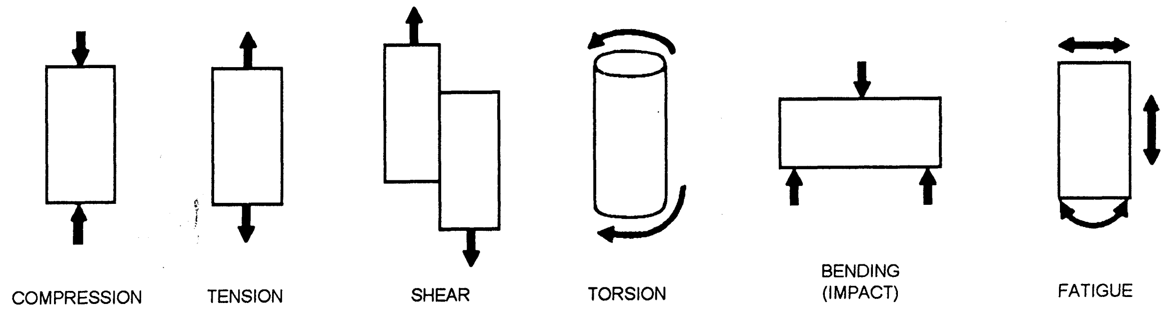

Figure 1-1.—Stress applied to a material.

Very rarely do Steelworkers work with elements in their pure state. We primarily work with alloys and have to understand their characteristics. The characteristics of elements and alloys are explained in terms of physical, chemical, electrical, and mechanical properties. Physical properties relate to color, density, weight, and heat conductivity. Chemical properties involve the behavior of the metal when placed in contact with the atmosphere, salt water, or other substances. Electrical properties encompass the electrical conductivity, resistance, and magnetic qualities of the metal. The mechanical properties relate to load-carrying ability, wear resistance, hardness, and elasticity.

When selecting stock for a job, your main concern is the mechanical properties of the metal. The various properties of metals and alloys were determined in the laboratories of manufacturers and by various societies interested in metallurgical development. Charts presenting the properties of a particular metal or alloy are available in many commercially published reference books. The charts provide information on the melting point, tensile strength, electrical conductivity, magnetic properties, and other properties of a particular metal or alloy. Simple tests can be conducted to determine some of the properties of a metal; however, we normally use a metal test only as an aid for identifying apiece of stock. Some of these methods of testing are discussed later in this chapter.

MECHANICAL PROPERTIES

Strength, hardness, toughness, elasticity, plasticity, brittleness, and ductility and malleability are mechanical properties used as measurements of how metals behave under a load. These properties are described in terms of the types of force or stress that the metal must withstand and how these are resisted. Common types of stress are compression, tension, shear, torsion, impact, 1-2 or a combination of these stresses, such as fatigue. (See fig. 1-1.)

Compression stresses develop within a material when forces compress or crush the material. A column that supports an overhead beam is in compression, and the internal stresses that develop within the column are compression.

Tension (or tensile) stresses develop when a material is subject to a pulling load; for example, when using a wire rope to lift a load or when using it as a guy to anchor an antenna. “Tensile strength” is defined as resistance to longitudinal stress or pull and can be measured in pounds per square inch of cross section. Shearing stresses occur within a material when external forces are applied along parallel lines in opposite directions. Shearing forces can separate material by sliding part of it in one direction and the rest in the opposite direction.

Some materials are equally strong in compression, tension, and shear. However, many materials show marked differences; for example, cured concrete has a maximum strength of 2,000 psi in compression, but only 400 psi in tension. Carbon steel has a maximum strength of 56,000 psi in tension and compression but a maximum shear strength of only 42,000 psi; therefore, when dealing with maximum strength, you should always state the type of loading.

A material that is stressed repeatedly usually fails at a point considerably below its maximum strength in tension, compression, or shear. For example, a thin steel rod can be broken by hand by bending it back and forth several times in the same place; however, if the same force is applied in a steady motion (not bent back and forth), the rod cannot be broken. The tendency of a material to fail after repeated bending at the same point is known as fatigue.

Table 1-2.—Mechanical Properties of Metals/Alloys

TOUGHNESS	BRITTLENESS	DUCTILITY	MALLEABILITY	CORROSION RESISTANCE
Copper	White Cast Iron	Gold	Gold	Gold
Nickel	Gray Cast Iron	Silver	Silver	Platinum
Iron	Hardened Steel	Platinum	Aluminum	Silver
Magnesium	Bismuth	Iron	Copper	Mercury
Zinc	Manganese	Nickel	Tin	Copper
Aluminum	Bronzes	Copper	Lead	Lead
Lead	Aluminum	Aluminum	Zinc	Tin
Tin	Brass	Tungsten	Iron	Nickel
Cobalt	Structural Steels	Zinc		Iron
Bismuth	Zinc	Tin		Zinc
	Monel	Lead		Magnesium
	Tin			Aluminum
	Copper			
	Iron			

* Metals/alloys are ranked in descending order of having the property named in the column heading

Strength

Strength is the property that enables a metal to resist deformation under load. The ultimate strength is the maximum strain a material can withstand. Tensile strength is a measurement of the resistance to being pulled apart when placed in a tension load.

Fatigue strength is the ability of material to resist various kinds of rapidly changing stresses and is expressed by the magnitude of alternating stress for a specified number of cycles.

Impact strength is the ability of a metal to resist suddenly applied loads and is measured in foot-pounds of force.

Hardness

Hardness is the property of a material to resist permanent indentation. Because there are several methods of measuring hardness, the hardness of a material is always specified in terms of the particular test that was used to measure this property. Rockwell, Vickers, or Brinell are some of the methods of testing. Of these tests, Rockwell is the one most frequently used. The basic principle used in the Rockwell testis that a hard material can penetrate a softer one. We then measure the amount of penetration and compare it to a scale. For ferrous metals, which are usually harder than nonferrous metals, a diamond tip is used and the hardness is indicated by a Rockwell “C” number. On nonferrous metals, that are softer, a metal ball is used and the hardness is indicated by a Rockwell “B” number. To get an idea of the property of hardness, compare lead and steel. Lead can be scratched with a pointed wooden stick but steel cannot because it is harder than lead.

A full explanation of the various methods used to determine the hardness of a material is available in commercial books or books located in your base library.

Toughness

Toughness is the property that enables a material to withstand shock and to be deformed without rupturing. Toughness may be considered as a combination of strength and plasticity. Table 1-2 shows the order of some of the more common materials for toughness as well as other properties.

Elasticity

When a material has a load applied to it, the load causes the material to deform. Elasticity is the ability of a material to return to its original shape after the load is removed. Theoretically, the elastic limit of a material is the limit to which a material can be loaded and still recover its original shape after the load is removed.

Plasticity

Plasticity is the ability of a material to deform permanently without breaking or rupturing. This property is the opposite of strength. By careful alloying of metals, the combination of plasticity and strength is used to manufacture large structural members. For example, should a member of a bridge structure become overloaded, plasticity allows the overloaded member to flow allowing the distribution of the load to other parts of the bridge structure.

Brittleness

Brittleness is the opposite of the property of plasticity. A brittle metal is one that breaks or shatters before it deforms. White cast iron and glass are good examples of brittle material. Generally, brittle metals are high in compressive strength but low in tensile strength. As an example, you would not choose cast iron for fabricating support beams in a bridge.

Ductility and Malleability

Ductility is the property that enables a material to stretch, bend, or twist without cracking or breaking. This property makes it possible for a material to be drawn out into a thin wire. In comparison, malleability is the property that enables a material to deform by compressive forces without developing defects. A malleable material is one that can be stamped, hammered, forged, pressed, or rolled into thin sheets.

CORROSION RESISTANCE

Corrosion resistance, although not a mechanical property, is important in the discussion of metals. Corrosion resistance is the property of a metal that gives it the ability to withstand attacks from atmospheric, chemical, or electrochemical conditions. Corrosion, sometimes called oxidation, is illustrated by the rusting of iron.

Table 1-2 lists four mechanical properties and the corrosion resistance of various metals or alloys. The first metal or alloy in each column exhibits the best characteristics of that property. The last metal or alloy in each column exhibits the least. In the column labeled "Toughness," note that iron is not as tough as copper or nickel; however, it is tougher than magnesium, zinc, and aluminum. In the column labeled "Ductility," iron exhibits a reasonable amount of ductility; however, in the columns labeled "Malleability" and "Brittleness," it is last.

METAL TYPES

The metals that Steelworkers work with are divided into two general classifications: ferrous and nonferrous. Ferrous metals are those composed primarily of iron and iron alloys. Nonferrous metals are those composed primarily of some element or elements other than iron. Nonferrous metals or alloys sometimes contain a small amount of iron as an alloying element or as an impurity.

FERROUS METALS

Ferrous metals include all forms of iron and steel alloys. A few examples include wrought iron, cast iron, carbon steels, alloy steels, and tool steels. Ferrous metals are iron-base alloys with small percentages of carbon and other elements added to achieve desirable properties. Normally, ferrous metals are magnetic and nonferrous metals are nonmagnetic.

Iron

Pure iron rarely exists outside of the laboratory. Iron is produced by reducing iron ore to pig iron through the use of a blast furnace. From pig iron many other types of iron and steel are produced by the addition or deletion of carbon and alloys. The following paragraphs discuss the different types of iron and steel that can be made from iron ore.

PIG IRON.— Pig iron is composed of about 93% iron, from 3% to 5% carbon, and various amounts of other elements. Pig iron is comparatively weak and brittle; therefore, it has a limited use and approximately ninety percent produced is refined to produce steel. Cast-iron pipe and some fittings and valves are manufactured from pig iron.

WROUGHT IRON.— Wrought iron is made from pig iron with some slag mixed in during manufacture. Almost pure iron, the presence of slag enables wrought iron to resist corrosion and oxidation. The chemical analyses of wrought iron and mild steel are just about the same. The difference comes from the properties controlled during the manufacturing process. Wrought iron can be gas and arc welded, machined, plated, and easily formed; however, it has a low hardness and a low-fatigue strength.

CAST IRON.— Cast iron is any iron containing greater than 2% carbon alloy. Cast iron has a high-compressive strength and good wear resistance; however, it lacks ductility, malleability, and impact strength. Alloying it with nickel, chromium, molybdenum, silicon, or vanadium improves toughness, tensile strength, and hardness. A malleable cast iron is produced through a prolonged annealing process.

INGOT IRON.— Ingot iron is a commercially pure iron (99.85% iron) that is easily formed and possesses good ductility and corrosion resistance. The chemical analysis and properties of this iron and the lowest carbon steel are practically the same. The lowest carbon steel, known as dead-soft, has about 0.06% more carbon than ingot iron. In iron the carbon content is considered an impurity and in steel it is considered an alloying element. The primary use for ingot iron is for galvanized and enameled sheet.

Steel

Of all the different metals and materials that we use in our trade, steel is by far the most important. When steel was developed, it revolutionized the American iron industry. With it came skyscrapers, stronger and longer bridges, and railroad tracks that did not collapse. Steel is manufactured from pig iron by decreasing the amount of carbon and other impurities and adding specific amounts of alloying elements.

Do not confuse steel with the two general classes of iron: cast iron (greater than 2% carbon) and pure iron (less than 0.15% carbon). In steel manufacturing, controlled amounts of alloying elements are added during the molten stage to produce the desired composition. The composition of a steel is determined by its application and the specifications that were developed by the following: American Society for Testing and Materials (ASTM), the American Society of Mechanical Engineers (ASME), the Society of Automotive Engineers (SAE), and the American Iron and Steel Institute (AISI).

Carbon steel is a term applied to a broad range of steel that falls between the commercially pure ingot iron and the cast irons. This range of carbon steel may be classified into four groups:

Low-Carbon Steel . . . . 0.05% to 0.30% carbon

Medium-Carbon Steel . . . . . . 0.30% to 0.45% carbon

High-Carbon Steel . . . . 0.45% to 0.75% carbon

Very High-Carbon Steel . . . . . 0.75% to 1.70% carbon

LOW-CARBON STEEL.— Steel in this classification is tough and ductile, easily machined, formed, and welded. It does not respond to any form of heat treating, except case hardening.

MEDIUM-CARBON STEEL.— These steels are strong and hard but cannot be welded or worked as easily as the low-carbon steels. They are used for crane hooks, axles, shafts, setscrews, and so on.

HIGH-CARBON STEEL/VERY HIGH-CARBON STEEL.— Steel in these classes respond well to heat treatment and can be welded. When welding, special electrodes must be used along with preheating and stress-relieving procedures to prevent cracks in the weld areas. These steels are used for dies, cutting tools, mill tools, railroad car wheels, chisels, knives, and so on.

LOW-ALLOY, HIGH-STRENGTH, TEMPERED STRUCTURAL STEEL.— A special low-carbon steel, containing specific small amounts of alloying elements, that is quenched and tempered to get a yield strength of greater than 50,000 psi and tensile strengths of 70,000 to 120,000 psi. Structural members made from these high-strength steels may have smaller cross-sectional areas than common structural steels and still have equal or greater strength. Additionally, these steels are normally more corrosion- and abrasion-resistant. High-strength steels are covered by ASTM specifications.

NOTE: This type of steel is much tougher than low-carbon steels. Shearing machines for this type of steel must have twice the capacity than that required for low-carbon steels.

STAINLESS STEEL.— This type of steel is classified by the American Iron and Steel Institute (AISI) into two general series named the 200-300 series and 400 series. Each series includes several types of steel with different characteristics.

The 200-300 series of stainless steel is known as AUSTENITIC. This type of steel is very tough and ductile in the as-welded condition; therefore, it is ideal for welding and requires no annealing under normal atmospheric conditions. The most well-known types of steel in this series are the 302 and 304. They are commonly called 18-8 because they are composed of 18% chromium and 8% nickel. The chromium nickel steels are the most widely used and are normally nonmagnetic.

The 400 series of steel is subdivided according to their crystalline structure into two general groups. One group is known as FERRITIC CHROMIUM and the other group as MARTENSITIC CHROMIUM.

Ferritic Chromium.—This type of steel contains 12% to 27% chromium and 0.08% to 0.20% carbon. These alloys are the straight chromium grades of stainless steel since they contain no nickel. They are nonhardenable by heat treatment and are normally used in the annealed or soft condition. Ferritic steels are magnetic and frequently used for decorative trim and equipment subjected to high pressures and temperatures.

Martensitic Chromium.— These steels are magnetic and are readily hardened by heat treatment. They contain 12% to 18% chromium, 0.15% to 1.2% carbon, and up to 2.5% nickel. This group is used where high strength, corrosion resistance, and ductility are required.

ALLOY STEELS.— Steels that derive their properties primarily from the presence of some alloying element other than carbon are called ALLOYS or ALLOY STEELS. Note, however, that alloy steels always contain traces of other elements. Among the more common alloying elements are nickel, chromium, vanadium, silicon, and tungsten. One or more of these elements may be added to the steel during the manufacturing process to produce the desired characteristics. Alloy steels may be produced in structural sections, sheets, plates, and bars for use in the "as-rolled" condition. Better physical properties are obtained with these steels than are possible with hot-rolled carbon steels. These alloys are used in structures where the strength of material is especially important. Bridge members, railroad cars, dump bodies, dozer blades, and crane booms are made from alloy steel. Some of the common alloy steels are briefly described in the paragraphs below.

Nickel Steels.— These steels contain from 3.5% nickel to 5% nickel. The nickel increases the strength and toughness of these steels. Nickel steel containing more than 5% nickel has an increased resistance to corrosion and scale. Nickel steel is used in the manufacture of aircraft parts, such as propellers and airframe support members.

Chromium Steels.—These steels have chromium added to improve hardening ability, wear resistance, and strength. These steels contain between 0.20% to 0.75% chromium and 0.45% carbon or more. Some of these steels are so highly resistant to wear that they are used for the races and balls in antifriction bearings. Chromium steels are highly resistant to corrosion and to scale.

Chrome Vanadium Steel.— This steel has the maximum amount of strength with the least amount of weight. Steels of this type contain from 0.15% to 0.25% vanadium, 0.6% to 1.5% chromium, and 0.1% to 0.6% carbon. Common uses are for crankshafts, gears, axles, and other items that require high strength. This steel is also used in the manufacture of high-quality hand tools, such as wrenches and sockets.

Tungsten Steel.— This is a special alloy that has the property of red hardness. This is the ability to continue to cut after it becomes red-hot. A good grade of this steel contains from 13% to 19% tungsten, 1% to 2% vanadium, 3% to 5% chromium, and 0.6% to 0.8% carbon. Because this alloy is expensive to produce, its use is largely restricted to the manufacture of drills, lathe tools, milling cutters, and similar cutting tools.

Molybdenum.— This is often used as an alloying agent for steel in combination with chromium and nickel. The molybdenum adds toughness to the steel. It can be used in place of tungsten to make the cheaper grades of high-speed steel and in carbon molybdenum high-pressure tubing.

Manganese Steels.— The amount of manganese used depends upon the properties desired in the finished product. Small amounts of manganese produce strong, free-machining steels. Larger amounts (between 2% and 10%) produce a somewhat brittle steel, while still larger amounts (11% to 14%) produce a steel that is tough and very resistant to wear after proper heat treatment.

NONFERROUS METALS

Nonferrous metals contain either no iron or only insignificant amounts used as an alloy. Some of the more common nonferrous metals Steelworkers work with are as follows: copper, brass, bronze, copper-nickel alloys, lead, zinc, tin, aluminum, and Duralumin.

NOTE: These metals are nonmagnetic.

Copper

This metal and its alloys have many desirable properties. Among the commercial metals, it is one of the most popular. Copper is ductile, malleable, hard, tough, strong, wear resistant, machinable, weldable, and corrosion resistant. It also has high-tensile strength, fatigue strength, and thermal and electrical conductivity. Copper is one of the easier metals to work with but be careful because it easily becomes work-hardened; however, this condition can be remedied by heating it to a cherry red and then letting it cool. This process, called annealing, restores it to a softened condition. Annealing and softening are the only heat-treating procedures that apply to copper. Seams in copper are joined by riveting, silver brazing, bronze brazing, soft soldering, gas welding, or electrical arc welding. Copper is frequently used to give a protective coating to sheets and rods and to make ball floats, containers, and soldering coppers.

True Brass

This is an alloy of copper and zinc. Additional elements, such as aluminum, lead, tin, iron, manganese, or phosphorus, are added to give the alloy specific properties. Naval rolled brass (Tobin bronze) contains about 60% copper, 39% zinc, and 0.75% tin. This brass is highly corrosion-resistant and is practically impurity free.

Brass sheets and strips are available in several grades: soft, 1/4 hard, 1/2 hard, full hard, and spring grades. Hardness is created by the process of cold rolling. All grades of brass can be softened by annealing at a temperature of 550°F to 600°F then allowing it to cool by itself without quenching. Overheating can destroy the zinc in the alloy.

Bronze

Bronze is a combination of 84% copper and 16% tin and was the best metal available before steel-making techniques were developed. Many complex bronze alloys, containing such elements as zinc, lead, iron, aluminum, silicon, and phosphorus, are now available. Today, the name bronze is applied to any copper-based alloy that looks like bronze. In many cases, there is no real distinction between the composition of bronze and that of brass.

Copper-Nickel Alloys

Nickel is used in these alloys to make them strong, tough, and resistant to wear and corrosion. Because of their high resistance to corrosion, copper nickel alloys, containing 70% copper and 30% nickel or 90% copper and 10% nickel, are used for saltwater piping systems. Small storage tanks and hot-water reservoirs are construtted of a copper-nickel alloy that is available in sheet form. Copper-nickel alloys should be joined by metal-arc welding or by brazing.

Lead

A heavy metal that weighs about 710 pounds per cubic foot. In spite of its weight, lead is soft and malleable and is available in pig and sheet form. In sheet form, it is rolled upon a rod so the user can unroll it and cut off the desired amount. The surface of lead is grayish in color; however, after scratching or scraping it, you can see that the actual color of the metal is white. Because it is soft, lead is used as backing material when punching holes with a hollow punch or when forming shapes by hammering copper sheets. Sheet lead is also used to line sinks or protect bench tops where a large amount of acid is used. Lead-lined pipes are used in systems that carry corrosive chemicals. Frequently, lead is used in alloyed form to increase its low-tensile strength. Alloyed with tin, lead produces a soft solder. When added to metal alloys, lead improves their machinability.

CAUTION

When working with lead, you must take proper precautions because the dust, fumes, or vapors from it are highly poisonous.

Zinc

You often see zinc used on iron or steel in the form of a protective coating called galvanizing. Zinc is also used in soldering fluxes, die castings, and as an alloy in making brass and bronze.

Tin

Tin has many important uses as an alloy. It can be alloyed with lead to produce softer solders and with copper to produce bronze. Tin-based alloys have a high resistance to corrosion, low-fatigue strength, and a compressive strength that accommodates light or medium loads. Tin, like lead, has a good resistance to corrosion and has the added advantage of not being poisonous; however, when subjected to extremely low temperatures, it has a tendency to decompose.

Aluminum

This metal is easy to work with and has a good appearance. Aluminum is light in weight and has a high strength per unit weight. A disadvantage is that the tensile strength is only one third of that of iron and one fifth of that of annealed mild steel.

Aluminum alloys usually contain at least 90% aluminum. The addition of silicon, magnesium, copper, nickel, or manganese can raise the strength of the alloy to that of mild steel. Aluminum, in its pure state, is soft and has a strong affinity for gases. The use of alloying elements is used to overcome these disadvantages; however, the alloys, unlike the pure aluminum, corrodes unless given a protective coating. Threaded parts made of aluminum alloy should be coated with an antiseize compound to prevent sticking caused by corrosion.

Table 1-3.—Surface Colors of Some Common Metals

Metals	Color of unfinished, unbroken surface	Color and structure of newly fractured surface	Color of freshly filed surface
White cast iron	dull gray	silvery white; crystalline	silvery white
Gray cast iron	dull gray	dark gray; crystalline	light silvery gray
Malleable iron	dull gray	dark gray; finely crystalline	light silvery gray
Wrought iron	light gray	bright gray	light silvery gray
Low-carbon and cast steel	dark gray	bright gray	bright silvery gray
High-carbon steel	dark gray	light gray	bright silvery gray
Stainless steel	dark gray	medium gray	bright silvery gray
Copper	reddish brown to green	bright red	bright copper color
Brass and bronze	reddish yellow, yellow-green, or brown	red to yellow	reddish yellow to yellowish white
Aluminum	light gray	white; finely crystalline	white
Monel metal	dark gray	light gray	light gray
Nickel	dark gray	off-white	bright silvery white
Lead	white to gray	light gray; crystalline	white

Duralumin

One of the first of the strong structural aluminum alloys developed is called Duralumin. With the development of a variety of different wrought-aluminum alloys, a numbering system was adopted. The digits indicate the major alloying element and the cold-worked or heat-treated condition of the metal. The alloy, originally called Duralumin, is now classified in the metal working industries as 2017-T. The letter *T* indicates that the metal is heat-treated.

Alclad

This is a protective covering that consists of a thin sheet of pure aluminum rolled onto the surface of an aluminum alloy during manufacture. Zinc chromate is a protective covering that can be applied to an aluminum surface as needed. Zinc chromate is also used as a primer on steel surfaces for a protective coating.

Monel

Monel is an alloy in which nickel is the major element. It contains from 64% to 68% nickel, about 30% copper, and small percentages of iron, manganese, and cobalt. Monel is harder and stronger than either nickel or copper and has high ductility. It resembles stainless steel in appearance and has many of its qualities. The strength, combined with a high resistance to corrosion, make Monel an acceptable substitute for steel in systems where corrosion resistance is the primary concern. Nuts, bolts, screws, and various fittings are made of Monel. This alloy can be worked cold and can be forged and welded. If worked in the temperature range between 1200°F and 1600°F, it becomes “hot short” or brittle.

K-Monel

This is a special type of alloy developed for greater strength and hardness than Monel. In strength, it is comparable to heat-treated steel. K-monel is used for instrument parts that must resist corrosion.

Inconel

This high-nickel alloy is often used in the exhaust systems of aircraft engines. Inconel is composed of 78.5% nickel, 14% chromium, 6.5% iron, and 1% of other elements. It offers good resistance to corrosion and retains its strength at high-operating temperatures.

METAL IDENTIFICATION

Many methods are used to identify a piece of metal. Identification is necessary when selecting a metal for use in fabrication or in determining its weldability. Some common methods used for field identification are surface appearance, spark test, chip test, and the use of a magnet.

SURFACE APPEARANCE

Sometimes it is possible to identify metals by their surface appearance. Table 1-3 indicates the surface colors of some of the more common metals. Referring to the table, you can see that the outside appearance of a metal helps to identify and classify metal. Newly fractured or freshly filed surfaces offer additional clues.

A surface examination does not always provide enough information for identification but should give us enough information to place the metal into a class. The color of the metal and the distinctive marks left from manufacturing help in determining the identity of the metal. Cast iron and malleable iron usually show evidence of the sand mold. Low-carbon steel often shows forging marks, and high-carbon steel shows either forging or rolling marks. Feeling the surface may provide another clue. Stainless steel is slightly rough in the unfinished state, and the surfaces of wrought iron, copper, brass, bronze, nickel, and Monel are smooth. Lead also is smooth but has a velvety appearance.

When the surface appearance of a metal does not give enough information to allow positive identification, other identification tests become necessary. Some of these tests are complicated and require equipment we do not usually have; however, other tests are fairly simple and reliable when done by a skilled person. Three of these tests areas follows: the spark test, the chip test, and the magnetic tests.

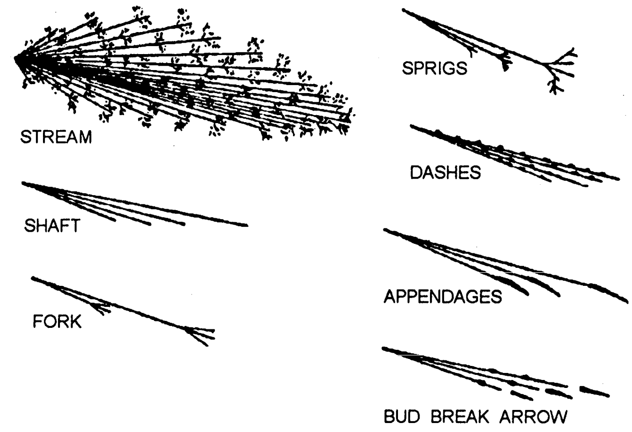

Figure 1-2.—Terms used in spark testing.

SPARK TEST

The spark test is made by holding a sample of the material against an abrasive wheel. By visually inspecting the spark stream, an experienced metalworker can identify the metals with considerable accuracy. This test is fast, economical, convenient, and easily accomplished, and there is no requirement for special equipment. We can use this test for identifying metal salvaged from scrap. Identification of scrap is particularly important when selecting material for cast iron or cast steel heat treatment.

When you hold a piece of iron or steel in contact with a high-speed abrasive wheel, small particles of the metal are torn loose so rapidly that they become red-hot. As these glowing bits of metal leave the wheel, they follow a path (trajectory) called the carrier line. This carrier line is easily followed with the eye, especial] y when observed against a dark background.

The sparks given off, or the lack of sparks, aid in the identification of the metal. The length of the spark stream, the color, and the form of the sparks are features you should look for. Figure 1-2 illustrates the terms used in referring to various basic spark forms produced in spark testing.

Steels having the same carbon content but differing alloying elements are difficult to identify because the alloying elements affect the carrier lines, the bursts, or the forms of characteristic bursts in the spark picture, The effect of the alloying element may slow or accelerate the carbon spark or make the carrier line lighter or darker in color. Molybdenum, for example, appears as a detached, orange-colored spearhead on the end of the carrier line. Nickel appears to suppress the effect of the carbon burst; however, the nickel spark can be identified by tiny blocks of brilliant white light. Silicon suppresses the carbon burst even more than nickel. When silicon is present, the carrier line usually ends abruptly in a white flash of light.

Spark testing may be done with either a portable or stationary grinder. In either case, the speed on the outer rim of the wheel should not be less than 4,500 feet per minute. The abrasive wheel should be rather coarse, very hard, and kept clean to produce a true spark

To conduct a spark test on an abrasive wheel, hold the piece of metal on the wheel in a position that allows the spark stream to cross your line of vision. By trial and error, you soon discover what pressure is needed to get a stream of the proper length without reducing the speed of the grinder. Excessive pressure increases the temperature of the spark stream. This, in turn, increases the temperature of the burst and gives the appearance of a higher carbon content than actually is present. When making the test, watch a point about one third of the distance from the tail end of the spark stream. Watch only those sparks that cross your line of vision and try to forma mental image of the individual spark. Fix this spark image in your mind and then examine the whole spark picture.

While on the subject of abrasive wheels, it is a good idea to discuss some of the safety precautions associated with this tool.

- Never use an abrasive wheel that is cracked or out of balance because the vibration causes the wheel to shatter. When an abrasive wheel shatters, it can be disastrous for personnel standing in line with the wheel.

- Always check the wheel for secure mounting and cracks before putting it to use. When you install a new wheel on a grinder, be sure that it is the correct size. Remember, as you increase the wheel radius, the peripheral speed at the rim also increases, even though the driving motor rpm remains the same. Thus, if you should use an oversized wheel, there is a distinct danger the peripheral speed (and consequent centrifugal force) can become so great that the wheel may fly apart. Use wheels that are designed for a specific rpm. Guards are placed on grinders as protection in case a wheel should shatter.

- Never use a grinder when the guards have been removed. When turning the grinder on, you should stand to one side. This places you out of line with the wheel in case the wheel should burst.

- Never overload a grinder or put sideways pressure against the wheel, unless it is expressly built to withstand such use.

- Always wear appropriate safety goggles or a face shield while using the grinder. Ensure that the tool rest (the device that helps the operator hold the work) is adjusted to the minimum clearance for the wheel. Move the work across the entire face of the wheel to eliminate grooving and to minimize wheel dressing. Doing this prolongs the life of the wheel.

- Keep your fingers clear of the abrasive surface, and do not allow rags or clothing to become entangled in the wheel.

- Do not wear gloves while using an abrasive wheel.

- Never hold metal with tongs while grinding.

- Never grind nonferrous metals on a wheel intended for ferrous metals because such misuse clogs the pores of the abrasive material. This buildup of metal may cause it to become unbalanced and fly apart.

- Grinding wheels require frequent reconditioning. *Dressing* is the term used to describe the process of cleaning the periphery. This cleaning breaks away dull abrasive grains and smooths the surface, removing all the grooves. The wheel dresser shown in figure 1-3 is used for dressing grinding wheels on bench and pedestal grinders. For more information on grinding wheels, you should consult chapter 5 of NAVEDTRA 10085-B2 *(Tools and Their Uses).*

Referring now to figure 1-4, notice that in low-carbon steel (view A), the spark stream is about 70 inches long and the volume is moderately large. In high-carbon steel (view B), the stream is shorter (about 55 inches) and the volume larger. The few sparklers that may occur at any place in low-carbon steel are forked,

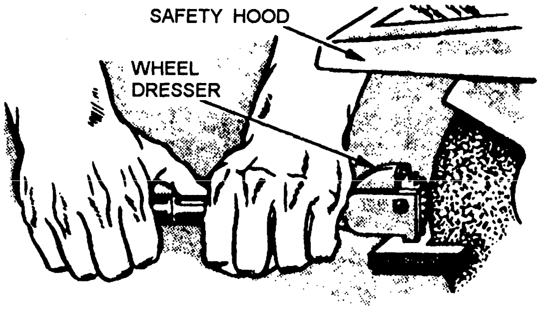

Figure 1-3.—Using a grinding wheel dresser.

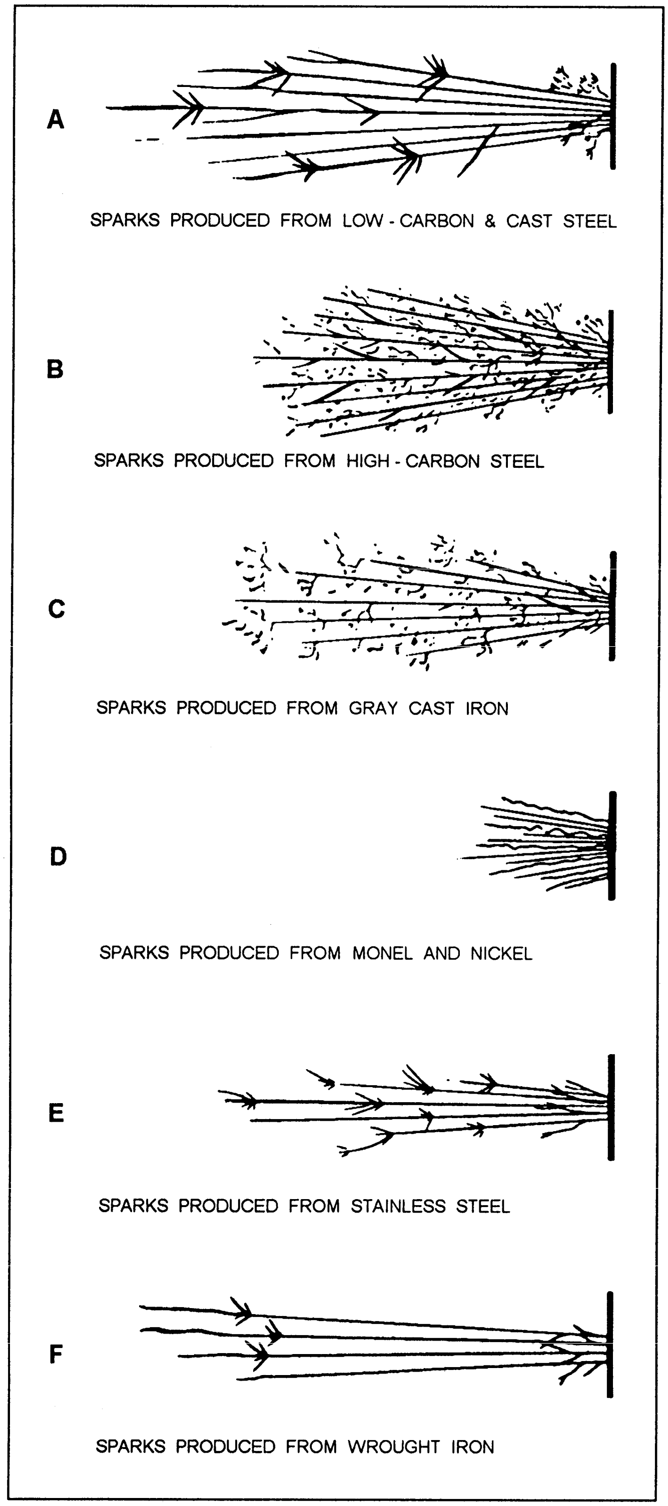

Figure 1-4.—Spark patterns formed by common metals.

Table 1-4.—Metal Identification by Chip Test

METALS	CHIP CHARACTERISTICS
WHITE CAST IRON	Chips are small, brittle fragments. Chipped surfaces not smooth.
GRAY CAST IRON	Chips are about 1/8 inch in length. Metal not easily chipped; therefore, chips break off and prevent smooth cut.
MALLEABLE IRON	Chips vary from 1/4 to 3/8 inch in length (larger than chips from cast iron). Metal is tough and hard to chip.
WROUGHT IRON	Chips have smooth edges. Metal is easily cut or chipped, and a chip can be made as a continuous strip.
LOW-CARBON AND CAST STEEL	Chips have smooth edges. Metal is easily cut or chipped, and a chip can be taken off as a continuous strip.
HIGH-CARBON STEEL	Chips show a fine-grain structure. Edges of chips are lighter in color than chips of low-carbon steel. Metal is hard, but can be chipped in a continuous strip.
COPPER	Chips are smooth, with sawtooth edges where cut. Metal is easily cut as a continuous strip.
BRASS AND BRONZE	Chips are smooth, with sawtooth edges. These metals are easily cut, but chips are more brittle than chips of copper. Continuous strip is not easily cut.
ALUMINUM AND ALUMINUM ALLOYS	Chips are smooth, with sawtooth edges. A chip can be cut as continuous strip.
MONEL	Chips have smooth edges. Continuous strip can be cut. Metal chips easily.
NICKEL	Chips have smooth edges. Continuous strip can be cut. Metal chips easily.
LEAD	Chips of any shape may be obtained because the metal is so soft that it can be cut with a knife.

and in high-carbon steel, they are small and repeating. Both metals produce a spark stream white in color.

Gray cast iron (view C) produces a stream of sparks about 25 inches in length. The sparklers are small and repeating, and their volume is rather small. Part of the stream near the wheel is red, and the outer portion is straw-colored.

Monel and nickel (view D) form almost identical spark streams. The sparks are small in volume and orange in color. The sparks form wavy streaks with no sparklers. Because of the similarity of the spark picture, these metals must be distinguished from each other by some other method.

Stainless steel (view E) produces a spark stream about 50 inches in length, moderate volume, and with few sparklers. The sparklers are forked. The stream next to the wheel is straw-colored, and at the end, it is white.

The wrought-iron spark test (view F) produces a spark stream about 65 inches in length. The stream has a large volume with few sparklers. The sparks appear near the end of the stream and are forked. The stream next to the wheel is straw-colored, and the outer end of the stream is a brighter red.

One way to become proficient in spark testing ferrous metals is to gather an assortment of samples of known metals and test them. Make all of the samples about the same size and shape so their identities are not revealed simply by the size or shape. Number each sample and prepare a list of names and corresponding numbers. Then, without looking at the number of the sample, spark test one sample at a time, calling out its name to someone assigned to check it against the names and numbers on the list. Repeating this process gives you some of the experience you need to become proficient in identifying individual samples.

CHIP TEST

Another simple test used to identify an unknown piece of metal is the chip test. The chip testis made by removing a small amount of material from the test piece with a sharp, cold chisel. The material removed varies from small, broken fragments to a continuous strip. The chip may have smooth, sharp edges; it maybe coarse-grained or fine-grained; or it may have sawlike edges. The size of the chip is important in identifying the metal. The ease with which the chipping can be accomplished should also be considered. The information given in table 1-4 can help you identify various metals by the chip test.

MAGNETIC TEST

The use of a magnet is another method used to aid in the general identification of metals. Remember that ferrous metals, being iron-based alloys, normally are magnetic, and nonferrous metals are nonmagnetic. This test is not 100-percent accurate because some stainless steels are nonmagnetic. In this instance, there is no substitute for experience.

CHAPTER 2

BASIC HEAT TREATMENT

As Steelworkers, we are interested in the heat treatment of metals, because we have to know what effects the heat produced by welding or cutting has on metal. We also need to know the methods used to restore metal to its original condition. The process of heat treating is the method by which metals are heated and cooled in a series of specific operations that never allow the metal to reach the molten state. The purpose of heat treating is to make a metal more useful by changing or restoring its mechanical properties. Through heat treating, we can make a metal harder, stronger, and more resistant to impact. Also, heat treating can make a metal softer and more ductile. The one disadvantage is that no heat-treating procedure can produce all of these characteristics in one operation. Some properties are improved at the expense of others; for example, hardening a metal may make it brittle.

HEAT-TREATING THEORY

The various types of heat-treating processes are similar because they all involve the heating and cooling of metals; they differ in the heating temperatures and the cooling rates used and the final results. The usual methods of heat-treating ferrous metals (metals with iron) are annealing, normalizing, hardening, and tempering. Most nonferrous metals can be annealed, but never tempered, normalized, or case-hardened.

Successful heat treatment requires close control over all factors affecting the heating and cooling of a metal. This control is possible only when the proper equipment is available. The furnace must be of the proper size and type and controlled, so the temperatures are kept within the prescribed limits for each operation. Even the furnace atmosphere affects the condition of the metal being heat-treated.

The furnace atmosphere consists of the gases that circulate throughout the heating chamber and surround the metal, as it is being heated. In an electric furnace, the atmosphere is either air or a controlled mixture of gases. In a fuel-fired furnace, the atmosphere is the mixture of gases that comes from the combination of the air and the gases released by the fuel during combustion. These gases contain various proportions of carbon monoxide, carbon dioxide, hydrogen, nitrogen, oxygen, water vapor, and other various hydrocarbons. Fuel-fired furnaces can provide three distinct atmospheres when you vary the proportions of air and fuel. They are called oxidizing, reducing, and neutral.

STAGES OF HEAT TREATMENT

Heat treating is accomplished in three major stages:

- Stage l—Heating the metal slowly to ensure a uniform temperature
- Stage 2—Soaking (holding) the metal at a given temperature for a given time and cooling the metal to room temperature
- Stage 3—Cooling the metal to room temperature

HEATING STAGE

The primary objective in the heating stage is to maintain uniform temperatures. If uneven heating occurs, one section of a part can expand faster than another and result in distortion or cracking. Uniform temperatures are attained by slow heating.

The heating rate of a part depends on several factors. One important factor is the heat conductivity of the metal. A metal with a high-heat conductivity heats at a faster rate than one with a low conductivity. Also, the condition of the metal determines the rate at which it may be heated. The heating rate for hardened tools and parts should be slower than unstressed or untreated metals. Finally, size and cross section figure into the heating rate. Parts with a large cross section require slower heating rates to allow the interior temperature to remain close to the surface temperature that prevents warping or cracking. Parts with uneven cross sections experience uneven heating; however, such parts are less apt to be cracked or excessively warped when the heating rate is kept slow.

SOAKING STAGE

After the metal is heated to the proper temperature, it is held at that temperature until the desired internal structural changes take place. This process is called SOAKING. The length of time held at the proper temperature is called the SOAKING PERIOD. The soaking period depends on the chemical analysis of the metal and the mass of the part. When steel parts are uneven in cross section, the soaking period is determined by the largest section.

During the soaking stage, the temperature of the metal is rarely brought from room temperature to the final temperature in one operation; instead, the steel is slowly heated to a temperature just below the point at which the change takes place and then it is held at that temperature until the heat is equalized throughout the metal. We call this process PREHEATING. Following preheat, the metal is quickly heated to the final required temperature.

When apart has an intricate design, it may have to be preheated at more than one temperature to prevent cracking and excessive warping. For example, assume an intricate part needs to be heated to 1500°F for hardening. This part could be slowly heated to 600°F, soaked at this temperature, then heated slowly to 1200°F, and then soaked at that temperature. Following the final preheat, the part should then be heated quickly to the hardening temperature of 1500°F.

NOTE: Nonferrous metals are seldom preheated, because they usually do not require it, and preheating can cause an increase in the grain size in these metals.

COOLING STAGE

After a metal has been soaked, it must be returned to room temperature to complete the heat-treating process. To cool the metal, you can place it in direct contact with a COOLING MEDIUM composed of a gas, liquid, solid, or combination of these. The rate at which the metal is cooled depends on the metal and the properties desired. The rate of cooling depends on the medium; therefore, the choice of a cooling medium has an important influence on the properties desired.

Quenching is the procedure used for cooling metal rapidly in oil, water, brine, or some other medium. Because most metals are cooled rapidly during the hardening process, quenching is usually associated with hardening; however, quenching does not always result in an increase in hardness; for example, to anneal copper, you usually quench it in water. Other metals, such as air-hardened steels, are cooled at a relatively slow rate for hardening.

Some metals crack easily or warp during quenching, and others suffer no ill effects; therefore, the quenching medium must be chosen to fit the metal. Brine or water is used for metals that require a rapid cooling rate, and oil mixtures are more suitable for metals that need a slower rate of cooling. Generally, carbon steels are water-hardened and alloy steels are oil-hardened. Nonferrous metals are normally quenched in water.

HEAT COLORS FOR STEEL

You are probably familiar with the term *red-hot* as applied to steel. Actually, steel takes on several colors and shades from the time it turns a dull red until it reaches a white heat. These colors and the corresponding temperatures are listed in table 2-1.

During hardening, normalizing, and annealing, steel is heated to various temperatures that produce color changes. By observing these changes, you can determine the temperature of the steel. As an example, assume that you must harden a steel part at 1500°F. Heat the part slowly and evenly while watching it closely for any change in color. Once the steel begins to turn red, carefully note each change in shade. Continue the even heating until the steel is bright red; then quench the part.

The success of a heat-treating operation depends largely on your judgment and the accuracy with which you identify each color with its corresponding temperature. From a study of table 2-1, you can see that close observation is necessary. You must be able to tell the difference between faint red and blood red and between dark cherry and medium cherry. To add to the difficulty, your conception of medium cherry may differ from that of the person who prepared the table. For an actual heat-treating operation, you should get a chart showing the actual colors of steel at various temperatures.

TYPES OF HEAT TREATMENT

Four basic types of heat treatment are used today. They are annealing, normalizing, hardening, and tempering. The techniques used in each process and how they relate to Steelworkers are given in the following paragraphs.

ANNEALING

In general, annealing is the opposite of hardening, You anneal metals to relieve internal stresses, soften them, make them more ductile, and refine their grain structures. Annealing consists of heating a metal to a specific temperature, holding it at that temperature for a set length of time, and then cooling the metal to room temperature. The cooling method depends on the

Table 2-1.—Heat Colors for Steel

Color	Temperature °F	Temperature °C
Faint red visible in dark	750	399
Faint red	900	482
Blood red	1050	565
Dark cherry	1075	579
Medium cherry	1250	677
Cherry or full red	1375	746
Bright red	1550	843
Salmon	1650	899
Orange	1725	940
Lemon	1825	996
Light yellow	1975	1079
White	2200	1204
Dazzling white	2350	1288

Table 2-2.—Approximate Soaking Periods for Hardening, Annealing, and Normalizing Steel

Thickness of Metal (inches)	Time of heating to Required Temperature (hr)	Soaking Time (hr)
Up to 1	3/4	1/2
1 to 2	1 1/4	1/2
2 to 3	1 3/4	3/4
3 to 4	2 1/4	1
4 to 5	2 3/4	1
5 to 8	3 1/2	1 1/2

metal and the properties desired. Some metals are furnace-cooled, and others are cooled by burying them in ashes, lime, or other insulating materials.

Welding produces areas that have molten metal next to other areas that are at room temperature. As the weld cools, internal stresses occur along with hard spots and brittleness. Welding can actually weaken the metal. Annealing is just one of the methods for correcting these problems.

Ferrous Metal

To produce the maximum softness in steel, you heat the metal to its proper temperature, soak it, and then let it cool very slowly. The cooling is done by burying the hot part in an insulating material or by shutting off the furnace and allowing the furnace and the part to cool together. The soaking period depends on both the mass of the part and the type of metal. The approximate soaking periods for annealing steel are given in tablc 2-2.

Steel with an extremely low-carbon content requires the highest annealing temperature. As the carbon content increases, the annealing temperatures decrease.

Nonferrous Metal

Copper becomes hard and brittle when mechanically worked; however, it can be made soft again by annealing. The annealing temperature for copper is between 700°F and 900°F. Copper maybe cooled rapidly or slowly since the cooling rate has no effect on the heat treatment. The one drawback experienced in annealing copper is the phenomenon called "hot shortness." At about 900°F, copper loses its tensile strength, and if not properly supported, it could fracture.

Aluminum reacts similar to copper when heat treating. It also has the characteristic of "hot shortness." A number of aluminum alloys exist and each requires special heat treatment to produce their best properties.

NORMALIZING

Normalizing is a type of heat treatment applicable to ferrous metals only. It differs from annealing in that the metal is heated to a higher temperature and then removed from the furnace for air cooling.

The purpose of normalizing is to remove the internal stresses induced by heat treating, welding, casting, forging, forming, or machining. Stress, if not controlled, leads to metal failure; therefore, before hardening steel, you should normalize it first to ensure the maximum desired results. Usually, low-carbon steels do not require normalizing; however, if these steels are normalized, no harmful effects result. Castings are usually annealed, rather than normalized; however, some castings require the normalizing treatment. Table 2-2 shows the approximate soaking periods for normalizing steel. Note that the soaking time varies with the thickness of the metal.

Normalized steels are harder and stronger than annealed steels. In the normalized condition, steel is much tougher than in any other structural condition. Parts subjected to impact and those that require maximum toughness with resistance to external stress are usually normalized. In normalizing, the mass of metal has an influence on the cooling rate and on the resulting structure. Thin pieces cool faster and are harder after normalizing than thick ones. In annealing (furnace cooling), the hardness of the two are about the same.

HARDENING

The hardening treatment for most steels consists of heating the steel to a set temperature and then cooling it rapidly by plunging it into oil, water, or brine. Most steels require rapid cooling (quenching) for hardening but a few can be air-cooled with the same results. Hardening increases the hardness and strength of the steel, but makes it less ductile. Generally, the harder the steel, the more brittle it becomes. To remove some of the brittleness, you should temper the steel after hardening.

Many nonferrous metals can be hardened and their strength increased by controlled heating and rapid cooling. In this case, the process is called heat treatment, rather than hardening.

To harden steel, you cool the metal rapidly after thoroughly soaking it at a temperature slightly above its upper critical point. The approximate soaking periods for hardening steel are listed in table 2-2. The addition of alloys to steel decreases the cooling rate required to produce hardness. A decrease in the cooling rate is an advantage, since it lessens the danger of cracking and warping.

Pure iron, wrought iron, and extremely low-carbon steels have very little hardening properties and are difficult to harden by heat treatment. Cast iron has limited capabilities for hardening. When you cool cast iron rapidly, it forms white iron, which is hard and brittle. And when you cool it slowly, it forms gray iron, which is soft but brittle under impact.

In plain carbon steel, the maximum hardness obtained by heat treatment depends almost entirely on the carbon content of the steel. As the carbon content increases, the hardening ability of the steel increases; however, this capability of hardening with an increase in carbon content continues only to a certain point. In practice, 0.80 percent carbon is required for maximum hardness. When you increase the carbon content beyond 0.80 percent, there is no increase in hardness, but there is an increase in wear resistance. This increase in wear resistance is due to the formation of a substance called hard cementite.

When you alloy steel to increase its hardness, the alloys make the carbon more effective in increasing hardness and strength. Because of this, the carbon content required to produce maximum hardness is lower than it is for plain carbon steels. Usually, alloy steels are superior to carbon steels.

Carbon steels are usually quenched in brine or water, and alloy steels are generally quenched in oil. When hardening carbon steel, remember that you must cool the steel to below 1000°F in less than 1 second. When you add alloys to steel, the time limit for the temperature to drop below 1000°F increases above the l-second limit, and a slower quenching medium can produce the desired hardness.

Quenching produces extremely high internal stresses in steel, and to relieve them, you can temper the steel just before it becomes cold. The part is removed from the quenching bath at a temperature of about 200°F and allowed to air-cool. The temperature range from 200°F down to room temperature is called the "cracking range" and you do not want the steel to pass through it.

In the following paragraphs, we discuss the different methods of hardening that are commercially used. In the Seabees, we use a rapid surface hardening compound called "Case" that can be ordered through the Navy supply system. Information on the use of "Case" is located in the *Welding Materials Handbook,* P-433.

Case Hardening

Case hardening produces a hard, wear-resistant surface or case over a strong, tough core. The principal forms of casehardening are carburizing, cyaniding, and nitriding. Only ferrous metals are case-hardened.

Case hardening is ideal for parts that require a wear-resistant surface and must be tough enough internally to withstand heavy loading. The steels best suited for case hardening are the low-carbon and low-alloy series. When high-carbon steels are case-hardened, the hardness penetrates the core and causes brittleness. In case hardening, you change the surface of the metal chemically by introducing a high carbide or nitride content. The core remains chemically unaffected. When heat-treated, the high-carbon surface responds to hardening, and the core toughens.

CARBURIZING.— Carburizing is a case-hardening process by which carbon is added to the surface of low-carbon steel. This results in a carburized steel that has a high-carbon surface and a low-carbon interior. When the carburized steel is heat-treated, the case becomes hardened and the core remains soft and tough.

Two methods are used for carburizing steel. One method consists of heating the steel in a furnace containing a carbon monoxide atmosphere. The other method has the steel placed in a container packed with charcoal or some other carbon-rich material and then heated in a furnace. To cool the parts, you can leave the container in the furnace to cool or remove it and let it air cool. In both cases, the parts become annealed during the slow cooling. The depth of the carbon penetration depends on the length of the soaking period. With today's methods, carburizing is almost exclusively done by gas atmospheres.

CYANIDING.— This process is a type of case hardening that is fast and efficient. Preheated steel is dipped into a heated cyanide bath and allowed to soak. Upon removal, it is quenched and then rinsed to remove any residual cyanide. This process produces a thin, hard shell that is harder than the one produced by carburizing and can be completed in 20 to 30 minutes vice several hours. The major drawback is that cyanide salts are a deadly poison.

NITRIDING.— This case-hardening method produces the hardest surface of any of the hardening processes. It differs from the other methods in that the individual parts have been heat-treated and tempered before nitriding. The parts are then heated in a furnace that has an ammonia gas atmosphere. No quenching is required so there is no worry about warping or other types of distortion. This process is used to case harden items, such as gears, cylinder sleeves, camshafts and other engine parts, that need to be wear resistant and operate in high-heat areas.

Flame Hardening

Flame hardening is another procedure that is used to harden the surface of metal parts. When you use an oxyacetylene flame, a thin layer at the surface of the part is rapidly heated to its critical temperature and then immediately quenched by a combination of a water spray and the cold base metal. This process produces a thin, hardened surface, and at the same time, the internal parts retain their original properties. Whether the process is manual or mechanical, a close watch must be maintained, since the torches heat the metal rapidly and the temperatures are usually determined visually.

Flame hardening may be either manual or automatic. Automatic equipment produces uniform results and is more desirable. Most automatic machines have variable travel speeds and can be adapted to parts of various sizes and shapes. The size and shape of the torch depends on the part. The torch consists of a mixing head, straight extension tube, 90-degree extension head, an adjustable yoke, and a water-cooled tip. Practically any shape or size flame-hardening tip is available (fig. 2-1).

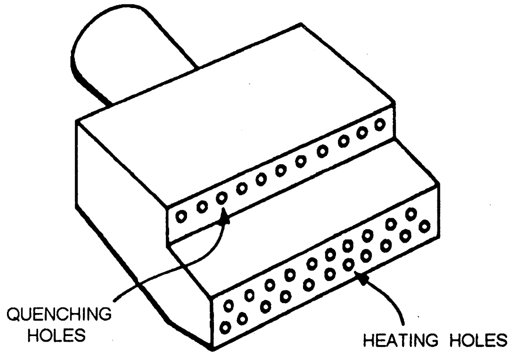

Figure 2-1.—Progressive hardening torch tip.

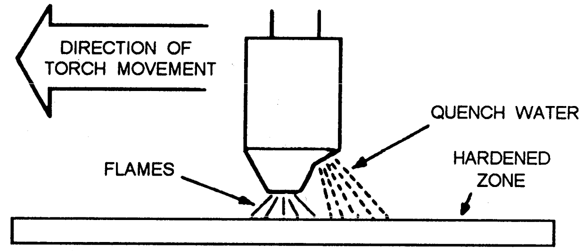

Figure 2-2.—Progressive hardening.

Tips are produced that can be used for hardening flats, rounds, gears, cams, cylinders, and other regular or irregular shapes.

In hardening localized areas, you should heat the metal with a standard hand-held welding torch. Adjust the torch flame to neutral (see chapter 4) for normal heating; however, in corners and grooves, use a slightly oxidizing flame to keep the torch from sputtering. You also should particularly guard against overheating in comers and grooves. If dark streaks appear on the metal surface, this is a sign of overheating, and you need to increase the distance between the flame and the metal.

For the best heating results, hold the torch with the tip of the inner cone about an eighth of an inch from the surface and direct the flame at right angles to the metal. Sometimes it is necessary to change this angle to obtain better results; however, you rarely find a deviation of more than 30 degrees. Regulate the speed of torch travel according to the type of metal, the mass and shape of the part, and the depth of hardness desired.

In addition, you must select the steel according to the properties desired. Select carbon steel when surface hardness is the primary factor and alloy steel when the physical properties of the core are also factors. Plain carbon steels should contain more than 0.35% carbon for good results inflame hardening. For water quenching, the effective carbon range is from 0.40% to 0.70%. Parts with a carbon content of more than 0.70% are likely to surface crack unless the heating and quenching rate are carefully controlled.

The surface hardness of a flame-hardened section is equal to a section that was hardened by furnace heating and quenching. The decrease in hardness between the case and the core is gradual. Since the core is not affected by flame hardening, there is little danger of spalling or flaking while the part is in use. Thus flame hardening produces a hard case that is highly resistant to wear and a core that retains its original properties.

Flame hardening can be divided into five general methods: stationary, circular band progressive, straight-line progressive, spiral band progressive, and circular band spinning.

STATIONARY METHOD.— In this method the torch and the metal part are both held stationary.

CIRCULAR BAND PROGRESSIVE METHOD.— This method is used for hardening outside surfaces of round sections. Usually, the object is rotated in front of a stationary torch at a surface speed of from 3 to 12 inches per minute. The heating and quenching are done progressively, as the part rotates; therefore, when the part has completed one rotation, a hardened band encircles the part. The width of the hardened band depends upon the width of the torch tip. To harden the full length of a long section, you can move the torch and repeat the process over and over until the part is completely hardened. Each pass or path of the torch should overlap the previous one to prevent soft spots.

STRAIGHT-LINE PROGRESSIVE METHOD.— With the straight-line progressive method, the torch travels along the surface, treating a strip that is about the same width as the torch tip. To harden wider areas, you move the torch and repeat the process. Figure 2-2 is an example of progressive hardening.

SPIRAL BAND PROGRESSIVE METHOD.— For this technique a cylindrical part is mounted between lathe centers, and a torch with an adjustable holder is mounted on the lathe carriage. As the part rotates, the torch moves parallel to the surface of the part. This travel is synchronized with the parts rotary motion to produce a continuous band of hardness. Heating and quenching occur at the same time. The number of torches required depends on the diameter of the part, but seldom are more than two torches used.

CIRCULAR BAND SPINNING METHOD.— The circular band spinning method provides the best results for hardening cylindrical parts of small or medium diameters. The part is mounted between lathe centers and turned at a high rate of speed pasta stationary torch. Enough torches are placed side by side to heat the entire part. The part can be quenched by water flowing from the torch tips or in a separate operation.

When you perform heating and quenching as separate operations, the tips are water-cooled internally, but no water sprays onto the surface of the part.

In flame hardening, you should follow the same safety precautions that apply to welding (see chapter 3). In particular, guard against holding the flame too close to the surface and overheating the metal. In judging the temperature of the metal, remember that the flame makes the metal appear colder than it actually is.

TEMPERING

After the hardening treatment is applied, steel is often harder than needed and is too brittle for most practical uses. Also, severe internal stresses are set up during the rapid cooling from the hardening temperature. To relieve the internal stresses and reduce brittleness, you should temper the steel after it is hardened. Tempering consists of heating the steel to a specific temperature (below its hardening temperature), holding it at that temperature for the required length of time, and then cooling it, usually instill air. The resultant strength, hardness, and ductility depend on the temperature to which the steel is heated during the tempering process.

The purpose of tempering is to reduce the brittleness imparted by hardening and to produce definite physical properties within the steel. Tempering always follows, never precedes, the hardening operation. Besides reducing brittleness, tempering softens the steel. That is unavoidable, and the amount of hardness that is lost depends on the temperature that the steel is heated to during the tempering process. That is true of all steels except high-speed steel. Tempering increases the hardness of high-speed steel.

Tempering is always conducted at temperatures below the low-critical point of the steel. In this respect, tempering differs from annealing, normalizing, and hardening in which the temperatures are above the upper critical point. When hardened steel is reheated, tempering begins at 212°F and continues as the temperature increases toward the low-critical point. By selecting a definite tempering temperature, you can predetermine the resulting hardness and strength. The minimum temperature time for tempering should be 1 hour. If the part is more than 1 inch thick, increase the time by 1 hour for each additional inch of thickness.

Normally, the rate of cooling from the tempering temperature has no effect on the steel. Steel parts are usually cooled in still air after being removed from the tempering furnace; however, there are a few types of steel that must be quenched from the tempering temperature to prevent brittleness. These blue brittle steels can become brittle if heated in certain temperature ranges and allowed to cool slowly. Some of the nickel chromium steels are subject to this temper brittleness.

Steel may be tempered after being normalized, providing there is any hardness to temper. Annealed steel is impossible to temper. Tempering relieves quenching stresses and reduces hardness and brittleness. Actually, the tensile strength of a hardened steel may increase as the steel is tempered up to a temperature of about 450°F. Above this temperature it starts to decrease. Tempering increases softness, ductility, malleability, and impact resistance. Again, high-speed steel is an exception to the rule. High-speed steel increases in hardness on tempering, provided it is tempered at a high temperature (about 1550°F). Remember, all steel should be removed from the quenching bath and tempered before it is complete] y cold. Failure to temper correctly results in a quick failure of the hardened part.

Permanent steel magnets are made of special alloys and are heat-treated by hardening and tempering. Hardness and stability are the most important properties in permanent magnets. Magnets are tempered at the minimum tempering temperature of 212°F by placing them in boiling water for 2 to 4 hours. Because of this low-tempering temperature, magnets are very hard.

Case-hardened parts should not be tempered at too high a temperature or they may loose some of their hardness. Usually, a temperature range from 212°F to 400°F is high enough to relieve quenching stresses. Some metals require no tempering. The design of the part helps determine the tempering temperature.

Color tempering is based on the oxide colors that appear on the surface of steel, as it is heated. When you slowly heat a piece of polished hardened steel, you can see the surface turn various colors as the temperature changes. These colors indicate structural changes are taking place within the metal. Once the proper color appears, the part is rapidly quenched to prevent further structural change. In color tempering, the surface of the steel must be smooth and free of oil. The part may be heated by a torch, in a furnace, over a hot plate, or by radiation.

Table 2-3.—Oxide Colors for Tempering Steel

Color	Temperature	
	°F	°C
Pale yellow	428	220
Straw	446	230
Golden yellow	469	243
Brown	491	255
Brown dappled with purple	509	265
Purple	531	277
Dark blue	550	288
Bright blue	567	297
Pale blue	610	321

Cold chisels and similar tools must have hard cutting edges and softer bodies and heads. The head must be tough enough to prevent shattering when struck with shammer.The cutting edge must be more than twice as hard as the head, and the zone separating the two must be carefully blended to prevent a lineof demarcation. A method of color tempering frequently used for chisels and similar tools is one in which the cutting end is heated by the residual heat of the opposite end of the same tool. To harden and tempera cold chisel by this method, you heat the tool to the proper hardening temperature and then quench the cutting end only. Bob the chisel up and down in the bath, always keeping the cutting edge below the surface. This method air-cools the head while rapidly quenching the cutting edge. The result is a tough head, fully hardened cutting edge, and a properly blended structure.

When the cutting end has cooled, remove the chisel from the bath and quickly polish the cutting end with a buff stick (emery). Watch the polished surface, as the heat from the opposite end feeds back into the quenched end. As the temperature of the hardened end increases, oxide colors appear. These oxide colors progress from pale yellow, to a straw color, and end in blue colors. As soon as the correct shade of blue appears, quench the entire chisel to prevent further softening of the cutting edge. The metal is tempered as soon as the proper oxide color appears and quenching merely prevents further tempering by freezing the process. This final quench has no effect on the body and the head of the chisel, because their temperature will have dropped below the critical point by the time the proper oxide color appears on the cutting edge. When you have completed the above described process, the chisel will be hardened and tempered and only needs grinding.

During the tempering, the oxide color at which you quench the steel varies with the properties desired in the part. Table 2-3 lists the different colors and their corresponding temperatures. To see the colors clearly, you must turn the part from side to side and have good lighting. While hand tempering produces the same result as furnace tempering, there is a greater possibility for error. The slower the operation is performed, the more accurate are the results obtained.

QUENCHING MEDIA

The cooling rate of an object depends on many things. The size, composition, and initial temperature of the part and final properties are the deciding factors in selecting the quenching medium. A quenching medium must cool the metal at a rate rapid enough to produce the desired results.

Mass affects quenching in that as the mass increases, the time required for complete cooling also increases. Even though parts are the same size, those containing holes or recesses cool more rapidly than solid objects. The composition of the metal determines the maximum cooling rate possible without the danger of cracking or warping. This critical cooling rate, in turn, influences the choice of the quenching medium.

The cooling rate of any quenching medium varies with its temperature; therefore, to get uniform results, you must keep the temperature within prescribed limits. The absorption of heat by the quenching medium also depends, to a large extent, on the circulation of the quenching medium or the movement of the part. Agitation of the liquid or the part breaks up the gas that forms an insulating blanket between the part and the liquid.

Normally, hardening takes place when you quench a metal. The composition of the metal usually determines the type of quench to use to produce the desired hardness. For example, shallow-hardened low-alloy and carbon steels require severer quenching than deep-hardened alloy steels that contain large quantities of nickel, manganese, or other elements. Therefore, shallow-hardening steels are usually quenched in water or brine, and the deep-hardening steels are quenched in oil. Sometimes it is necessary to use a combination quench, starting with brine or water and finishing with oil. In addition to producing the desired hardness, the quench must keep cracking, warping, and soft spots to a minimum.

The volume of quenching liquid should be large enough to absorb all the heat during a normal quenching operation without the use of additional cooling. As more metals are quenched, the liquid absorbs the heat and this temperature rise causes a decrease in the cooling rate. Since quenching liquids must be maintained within definite temperature ranges, mechanical means are used to keep the temperature at prescribed levels during continuous operations.

LIQUID QUENCHING

The two methods used for liquid quenching are called still-bath and flush quenching.

Instill-bath quenching, you cool the metal in a tank of liquid. The only movement of the liquid is that caused by the movement of the hot metal, as it is being quenched.

For flush quenching, the liquid is sprayed onto the surface and into every cavity of the part at the same time to ensure uniform cooling. Flush quenching is used for parts having recesses or cavities that would not be properly quenched by ordinary methods. That assures a thorough and uniform quench and reduces the possibilities of distortion.

Quenching liquids must be maintained at uniform temperatures for satisfactory results. That is particularly true for oil. To keep the liquids at their proper temperature, they are usually circulated through water-cooled coils. Self-contained coolers are integral parts of large quench tanks.

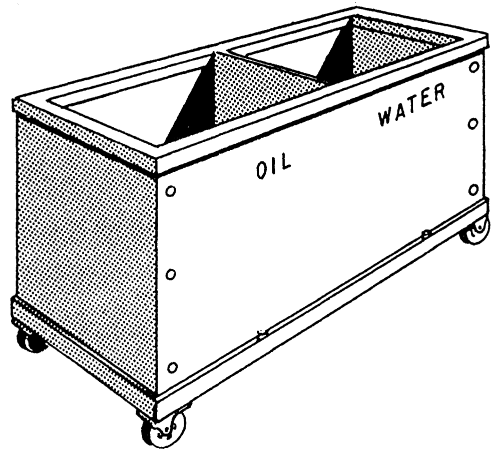

Figure 2-3.—Portable quench tank.

A typical portable quench tank is shown in figure 2-3. This type can be moved as needed to various parts of the heat-treating shop. Some tanks may have one or more compartments. If one compartment contains oil and the other water, the partition must be liquid-tight to prevent mixing. Each compartment has a drain plug, a screen in the bottom to catch scale and other foreign matter, and a mesh basket to hold the parts. A portable electric pump can be attached to the rim of the tank to circulate the liquid. This mechanical agitation aids in uniform cooling.

Water

Water can be used to quench some forms of steel, but does not produce good results with tool or other alloy steels. Water absorbs large quantities of atmospheric gases, and when a hot piece of metal is quenched, these gases have a tendency to form bubbles on the surface of the metal. These bubbles tend to collect in holes or recesses and can cause soft spots that later lead to cracking or warping.

The water in the quench tank should be changed daily or more often if required. The quench tank should be large enough to hold the part being treated and should have adequate circulation and temperature control. The temperature of the water should not exceed 65°F.

When aluminum alloys and other nonferrous metals require a liquid quench, you should quench them in clean water. The volume of water in the quench tank should be large enough to prevent a temperature rise of more than 20°F during a single quenching operation. For

Table 2-4.—Properties and Average Cooling Abilities of Quenching Media

Quenching Medium	Cooling Rate Compared To Water	Flash Point (°F)	Fire Point (°F)
Sodium Hydroxide (10%)	2.06		
Brine (10%) at 65°F	1.96		
Caustic Soda (10%)	1.38		
Water at 65°F	1.00		
Prepared Oil	0.44	365	405
Fuel Oil	0.36	205	219
Cottonseed Oil	0.36	610	680
Neatsfoot Oil	0.33	500	621
Sperm Oil	0.33	500	581
Fish Oil	0.31	401	446
Castor Oil	0.29	565	640
Machine Oil	0.22	405	464
Lard Oil	0.19	565	685
Circulated Air	0.032		
Still Air	0.0152		

heavy-sectioned parts, the temperature rise may exceed 20°F, but should be kept as low as possible. For wrought products, the temperature of the water should be about 65°F and should never exceed 100°F before the piece enters the liquid.

Brine

Brine is the result of dissolving common rock salt in water. This mixture reduces the absorption of atmospheric gases that, in turn, reduces the amount of bubbles. As a result, brine wets the metal surface and cools it more rapidly than water. In addition to rapid and uniform cooling, the brine removes a large percentage of any scale that may be present.

The brine solution should contain from 7% to 10% salt by weight or three-fourths pound of salt for each gallon of water. The correct temperature range for a brine solution is 65°F to 100°F.

Low-alloy and carbon steels can be quenched in brine solutions; however, the rapid cooling rate of brine can cause cracking or stress in high-carbon or low-alloy steels that are uneven in cross section.

Because of the corrosive action of salt on nonferrous metals, these metals are not quenched in brine.

Oil

Oil is used to quench high-speed and oil-hardened steels and is preferred for all other steels provided that the required hardness can be obtained. Practically any type of quenching oil is obtainable, including the various animal oils, fish oils, vegetable oils, and mineral oils. Oil is classed as an intermediate quench. It has a slower cooling rate than brine or water and a faster rate than air. The quenching oil temperature should be kept within a range of 80°F to 150°F. The properties and average cooling powers of various quenching oils are given in table 2-4.

Water usually collects in the bottom of oil tanks but is not harmful in small amounts. In large quantities it can interfere with the quenching operations; for example, the end of a long piece may extend into the water at the bottom of the tank and crack as a result of the more rapid cooling.

Nonferrous metals are not routinely quenched in oil unless specifications call for oil quenching.

Caustic Soda

A solution of water and caustic soda, containing 10 percent caustic soda by weight, has a higher cooling rate than water. Caustic soda is used only for those types of steel that require extremely rapid cooling and is NEVER used as a quench for nonferrous metals.

WARNING

CAUSTIC SODA REQUIRES SPECIAL HANDLING BECAUSE OF ITS HARMFUL EFFECTS ON SKIN AND CLOTHING.

DRY QUENCHING

This type of quenching uses materials other than liquids. Inmost cases, this method is used only to slow the rate of cooling to prevent warping or cracking.

Air

Air quenching is used for cooling some highly alloyed steels. When you use still air, each tool or part should be placed on a suitable rack so the air can reach all sections of the piece. Parts cooled with circulated air are placed in the same manner and arranged for uniform cooling. Compressed air is used to concentrate the cooling on specific areas of a part. The airlines must be free of moisture to prevent cracking of the metal.

Although nonferrous metals are usually quenched in water, pieces that are too large to fit into the quench tank can be cooled with forced-air drafts; however, an air quench should be used for nonferrous metal only when the part will not be subjected to severe corrosion conditions and the required strength and other physical properties can be developed by a mild quench.

Solids

The solids used for cooling steel parts include cast-iron chips, lime, sand, and ashes. Solids are generally used to slow the rate of cooling; for example, a cast-iron part can be placed in a lime box after welding to prevent cracking and warping. All solids must be free of moisture to prevent uneven cooling.