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

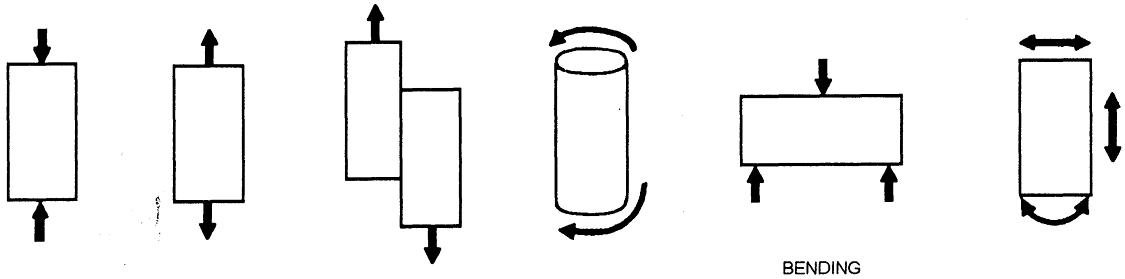

Figure 1-1.—Stress applied to a material.

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.

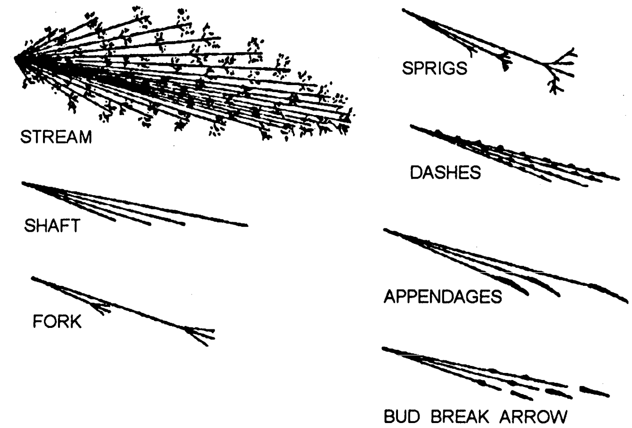

Figure 1-2.—Terms used in spark testing.

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,

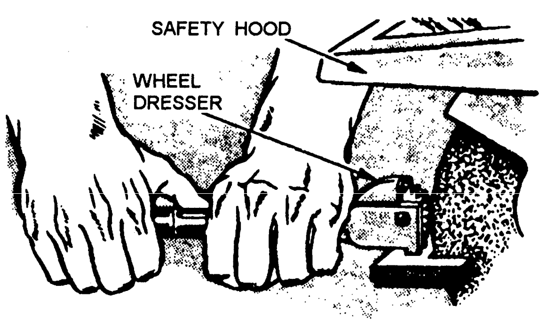

Figure 1-3.—Using a grinding wheel dresser.

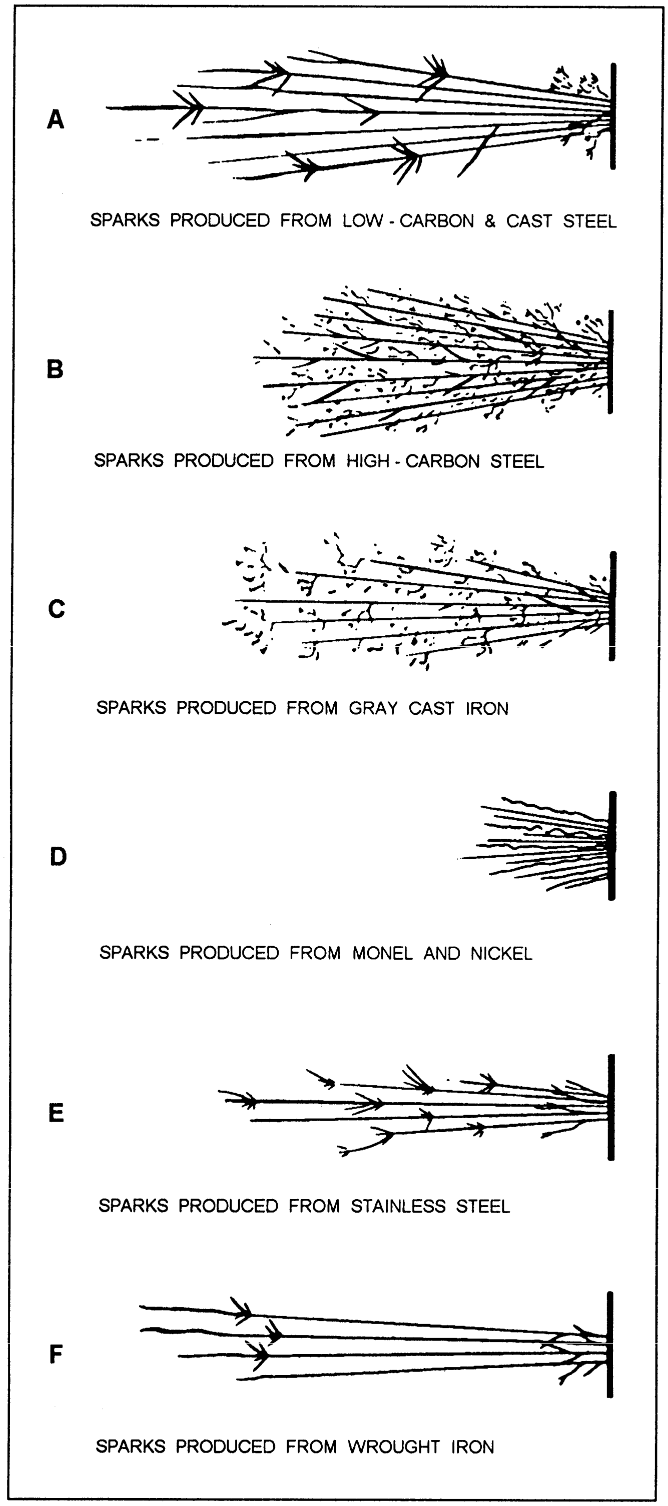

Figure 1-4.—Spark patterns formed by common metals.

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.