

Chapter 2

PROPERTIES, IDENTIFICATION, AND HEAT TREATMENT OF METALS

GENERAL

PURPOSE

This chapter contains basic information pertaining to properties and identification of metal and heat-treating procedures used for metals. For more specific information on metal and heat-treating techniques, refer to TM 43-0106.

METAL CLASSIFICATION

All metals may be classified as ferrous or nonferrous. A ferrous metal has iron as its main element. A metal is still considered ferrous even if it contains less than 50 percent iron, as long as it contains more iron than any other one metal. A metal is nonferrous if it contains less iron than any other metal.

Ferrous

Ferrous metals include cast iron, steel, and the various steel alloys. The only difference between iron and steel is the carbon

content. Cast iron contains more than 2-percent carbon, while steel contains less than 2 percent. An alloy is a substance composed of two or more elements. Therefore, all steels are an alloy of iron and carbon, but the term "alloy steel" normally refers to a steel that also contains one or more other elements. For example, if the main alloying element is tungsten, the steel is a "tungsten steel" or "tungsten alloy." If there is no alloying material, it is a "carbon steel."

Nonferrous

Nonferrous metals include a great many metals that are used mainly for metal plating or as alloying elements, such as tin, zinc, silver, and gold. However, this chapter will focus only on the metals used in the manufacture of parts, such as aluminum, magnesium, titanium, nickel, copper, and tin alloys.

PROPERTIES OF METALS

GENERAL

The internal reactions of a metal to external forces are known as mechanical properties. The mechanical properties are directly related to each other. A change in one property usually causes a change in one or more additional properties. For example, if the hardness of a metal is increased, the brittleness usually increases and the toughness usually decreases. Following is a brief explanation of the mechanical properties and how they relate to each other.

TENSILE STRENGTH

Tensile strength is the ability of a metal to resist being pulled apart by opposing forces acting in a straight line (Figure 2-1). It is expressed as the number of pounds of force required to pull apart a bar of the material 1 inch wide and 1 inch thick.

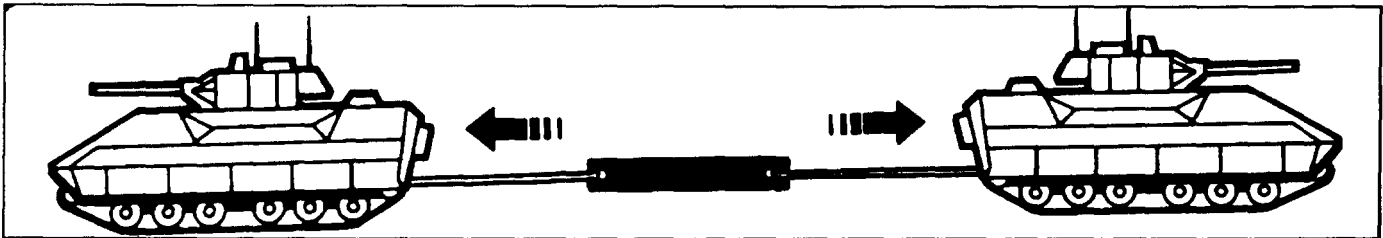


Figure 2-1. Tensile strength

SHEAR STRENGTH

Shear strength is the ability of a metal to resist being fractured by opposing forces not acting in a straight line (Figure 2-2). Shear strength can be controlled by varying the hardness of the metal.

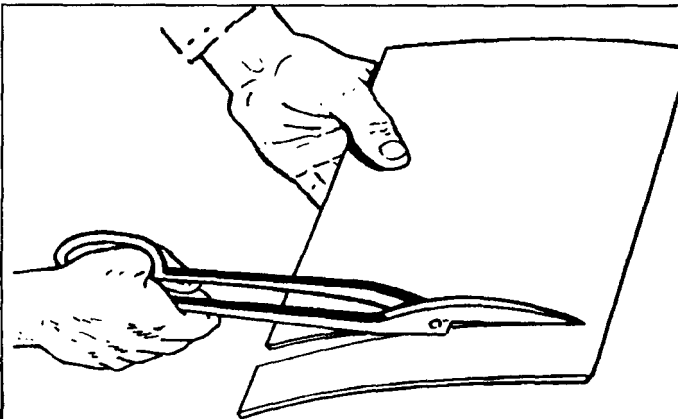


Figure 2-2. Shear strength.

COMPRESSIVE STRENGTH

Compressive strength is the ability of a metal to withstand pressures acting on a given plane (Figure 2-3).

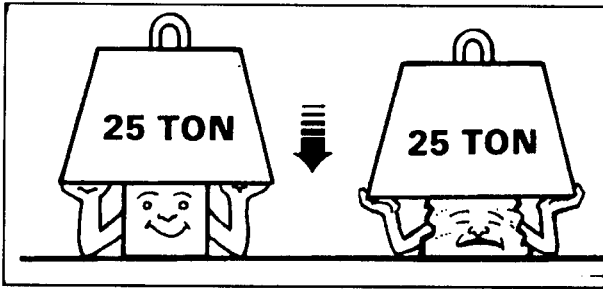


Figure 2-3. Compressive strength.

ELASTICITY

Elasticity is the ability of metal to return to its original size and shape after being stretched or pulled out of shape (Figure 2-4).

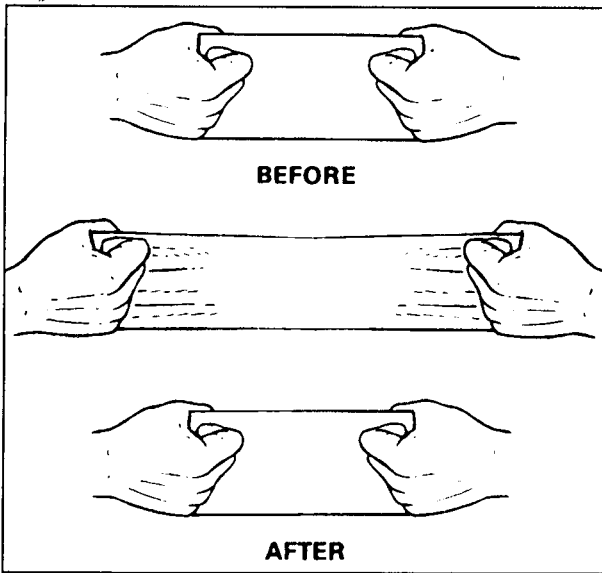


Figure 2-4. Elasticity.

DUCTILITY

Ductility is the ability of a metal to be drawn or stretched permanently without rupture or fracture (Figure 2-5). Metals that lack ductility will crack or break before bending.

MALLEABILITY

Malleability is the ability of a metal to be hammered, rolled, or pressed into various shapes without rupture or fracture (Figure 2-6).

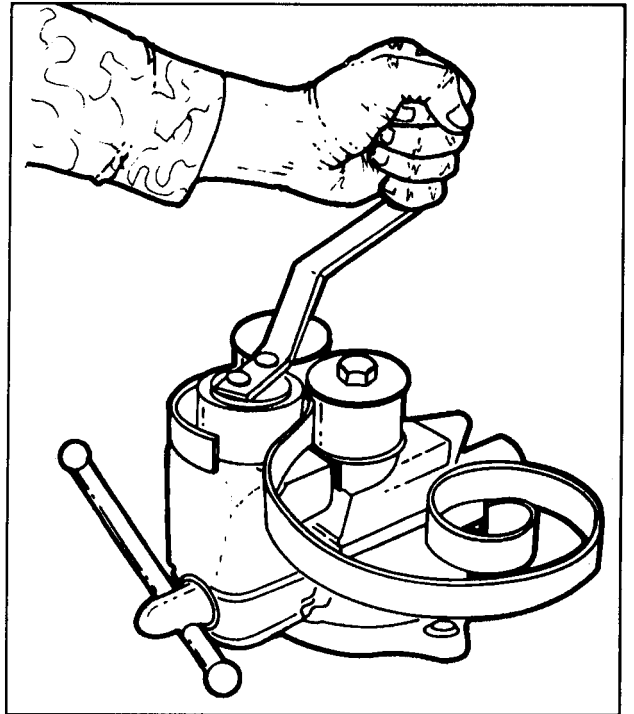


Figure 2-5. Ductility.



Figure 2-6. Malleability.

TOUGHNESS

Toughness is the ability of a metal to resist fracture plus the ability to resist failure after the damage has begun. A tough metal can withstand considerable stress, slowly or suddenly applied, and will deform before failure.

HARDNESS

Hardness is the ability of a metal to resist penetration and wear by another metal or material. It takes a combination of hardness and toughness to withstand heavy pounding. The hardness of a metal limits the ease with which it can be machined, since toughness decreases as hardness increases. The hardness of a metal can usually be controlled by heat treatment.

MACHINABILITY AND WELDABILITY

Machinability and weldability are the ease or difficulty with which a material can be machined or welded.

CORROSION RESISTANCE

Corrosion resistance is the resistance to eating or wearing away by air, moisture, or other agents.

HEAT AND ELECTRICAL CONDUCTIVITY

Heat and electrical conductivity is the ease with which a metal conducts or transfers heat or electricity.

BRITTLENESS

Brittleness is the tendency of a material to fracture or break with little or no deformation, bending, or twisting. Brittleness is usually not a desirable mechanical property. Normally, the harder the metal, the more brittle it is.

IDENTIFICATION OF METALS

GENERAL

Part of the metalworker's skill lies in the ability to identify various metal products brought to the shop. The metalworker must be able to identify the metal so the proper work methods can be applied. For Army equipment, drawings should be available. They must be examined in order to determine the metal to be used and its heat treatment (if required). If no drawing is available, knowledge of what the parts are going to do will serve as a guide to the type of metal to use.

TESTING OF METALS

Simple tests can be made in the shop to identify metals. Since the ability to judge metals can be developed only through personal experience, practice these tests with known metals until familiar with the reactions of each metal to each type of test.

Appearance Test

This test includes such things as the color and appearance of machined as well as unmachined surfaces.

Fracture Test

Some metals can be quickly identified by looking at the surface of the broken part or by studying the chips produced with a hammer and chisel.

Spark Test

This is a simple identification test used to observe the color, spacing, and quantity of sparks produced by grinding. It is a fast and convenient method of sorting mixed steels with known spark characteristics. This test is best conducted by holding the steel stationary and touching a high-speed portable grinder to the steel with sufficient pressure to throw a spark stream about 12 inches long. The characteristics of sparks generated by a spark grinding test are shown in Figure 2-7. These spark patterns provide general information about the type of steel, cast iron, or alloy steel. In all cases, it is best to use standard samples of metal when comparing their sparks with that of the test sample.

	WROUGHT IRON	GRAY CAST IRON	WHITE CAST IRON	ANNEALED MALLEABLE IRON	MACHINE STEEL (AISI 1020)	CARBON TOOL STEEL	HIGH SPEED STEEL (H.S. 1)	AUSTENITIC MANGANESE STEEL	STAINLESS STEEL (TYPE 304)	TUNGSTEN CHROMIUM DIE STEEL	STELLITE	CEMENTED TUNGSTEN CARBIDE	NICKEL
STREAM													
VOLUME	LARGE	SMALL	VERY SMALL	MODERATE	LARGE	MODERATELY LARGE	SMALL	MODERATELY LARGE	MODERATE	SMALL	VERY SMALL	EXTREMELY SMALL	VERY SMALL
LENGTH	LONG	SHORT	SHORT	SHORT	LONG	LONG	LONG	LONG	LONG	AVERAGE	SHORT	VERY SHORT	SHORT
COLOR CLOSE TO WHEEL	STRAW	RED	RED	RED	WHITE	WHITE	RED	WHITE	STRAW	RED	ORANGE	LIGHT ORANGE	ORANGE
STREAMS NEAR END OF STREAM	WHITE	STRAW	STRAW	STRAW	WHITE	WHITE	STRAW	WHITE	WHITE	STRAW BLUE WHITE	ORANGE	LIGHT ORANGE	ORANGE
QUANTITY OF SPURTS	VERY FEW	MANY	FEW	MANY	FEW	VERY MANY	EXTREMELY FEW	MANY	MODERATE	MANY	NONE	NONE	NONE
NATURE OF SPURTS	FORKED	FINE REPEATING		FORKED		FINE REPEATING	FORKED	FINE REPEATING	FORKED	FINE REPEATING			

Figure 2-7, Spark test.

THE ROCKWELL HARDNESS NUMBER IS DETERMINED BY THE DEPTH OF THE IMPRESSION WHILE THE BRINELL HARDNESS NUMBER IS DETERMINED BY THE AREA OF THE IMPRESSION

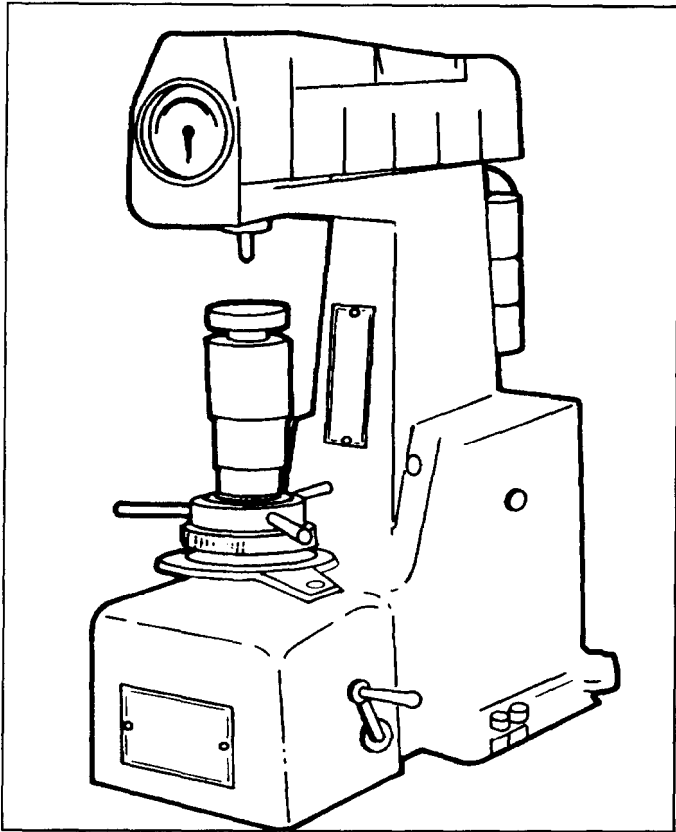


Figure 2-8. Rockwell hardness tester.

File Test

One simple way to check for hardness in a piece of metal is to file a small portion of it. If it is soft enough to be machined with regular tooling, the file will cut it. If it is too hard to machine, the file will not cut it. This method will indicate whether the material being tested is softer or harder than the file, but it will not tell exactly how soft or hard it is. The file can also be used to determine the harder of two pieces of metal; the file will cut the softer metal faster and easier. The file method should only be used in situations when the exact hardness is not required. This test has the added advantage of needing very little in the way of time, equipment, and experience.

Rockwell Hardness Test

This test determines the hardness of metals by measuring the depth of impression which can be made by a hard test point under a known load. The softer the metal, the deeper the impression. Soft metals will be indicated by low hardness numbers. Harder metals permit less of an impression to be made, resulting in higher hardness numbers. Rockwell hardness testing is accomplished by using the Rockwell hardness testing machine (Figure 2-8).

Brinell Hardness Test

Brinell hardness testing operates on almost the same principle as the Rockwell test. The difference between the two is that the Rockwell hardness number is determined by the depth of the impression while the Brinell hardness number is determined by the area of the impression. This test forces a hardened ball, 10 mm (0.3937 in) in diameter, into the surface of the metal being tested, under a load of 3,000 kilograms (approximately 6,600 lb). The area of this impression determines the Brinell hardness number of the metal being tested. Softer metals result in larger impressions but have lower hardness numbers.

NUMERICAL CODES

Perhaps the best known numerical code is the Society of Automotive Engineers (SAE) code. For the metals industry, this organization pioneered in developing a uniform code based on chemical analysis. SAE specification numbers are now used less widely than in the past; however, the SAE numerical code is the basic code for ferrous metals (Figure 2-9).

The SAE system is based on the use of four-or five digit numbers.

- The first number indicates the type of alloy used; for example, 1 indicates a carbon steel.
- Two indicates nickel steel.
- The second, and sometimes the third, number gives the amount of the main alloy in whole percentage numbers.
- The last two, and sometimes three, numbers give the carbon content in hundredths of 1 percent (0.01 percent).

The following examples will help you understand this system:

SAE 1045

1- Type of steel (carbon).

0- Percent of alloy (none).

45- Carbon content (0.45-percent carbon).

TYPES OF STEEL	SAE NUMBERS
CARBON STEELS	1XX
Plain Carbon	10XX
Free Cutting, Manganese	X13XX
Free Cutting, Screw Stock	11XX
HIGH MANGANESE	T13XX
NICKEL STEELS	2XX
.50% Nickel	20XX
1.50% Nickel	21XX
3.50% Nickel	23XX
5.00% Nickel	25XX
NICKEL-CHROMIUM STEELS	3XX
1.25% Nickel : .60% Chromium	31XX
1.75% Nickel : 1.00% Chromium	32XX
3.50% Nickel : 1.50% Chromium	33XX
3.00% Nickel : .80% Chromium	34XX
Corrosion and Heat Resisting	30XXX
MOLYBDENUM STEELS	4XX
Chromium-Molybdenum	41XX
Chromium-Nickel-Molybdenum	43XX
Nickel-Molybdenum	46XX & 48XX
CHROMIUM STEELS	5XX
.60% to 1.10% Chromium	51XX
1.2% to 1.5% Chromium	52XXX
Corrosion and Heat Resistant	51XXX
Chromium-Vanadium Steels	6XX
Tungsten Steels	7XXXX & 7XX
Silicon-Manganese Steels	9XX

Figure 2-9. SAE numerical code.

SAE 2330

- 2- Type of steel (nickel).
- 3- Percent of alloy (3-percent nickel).
- 30- Carbon content (0.30-percent carbon).

SAE 71650

- 7- Type of steel (tungsten).
- 16- Percent of alloy (16-percent tungsten).
- 50- Carbon content (0,50-percent carbon).

SAE 50100

- 5- Type of steel (chromium).
- 0- Percent of alloy (less than 1-percent chromium).
- 100- Carbon content (1-percent carbon).

AA Code

A system similar to the SAE classifications for steel and alloys has been developed by the Aluminum Association (AA) for wrought aluminum and aluminum alloys.

This identification system of aluminum, as shown in Figure 2-10, consists of a four-digit number which indicates the type of alloy, control over impurities, and the specific alloy. The first number indicates the type of alloy. For example, 2 is copper, 3 is manganese, 4 is silicone, and so forth. The second number indicates the control that has been used. The last two numbers usually indicate an assigned composition. Thus, AA-2024 means:

- 2 - Type of alloy (copper).
- 0 - Control of impurities.
- 24 - Exact composition (AA number 24).

Aluminum alloys vary greatly in their hardness and physical condition. These differences are called "temper." Letter symbols represent the different tempers. In addition to a letter, one or more numbers are sometimes used to indicate further differences. The temper designation is separated from the basic four-digit identification number by a dash; for example, 2024-T6. In this case there is an aluminum alloy, 2024, with a T6 temper (solution heat treated and then artificially aged). Figure 2-11 shows the numerals 2 through 10 that have been assigned in the AA system to indicate specific sequences of annealing, heat treating, cold working, or aging.

MAJOR ALLOYING ELEMENTS	
ALUMINUM AT LEAST 99% PURE -----	1XXX
COPPER -----	2XXX
MANGANESE -----	3XXX
SILICON -----	4XXX
MAGNESIUM -----	5XXX
MAGNESIUM AND SILICON -----	6XXX
ZINC -----	7XXX
OTHER ELEMENTS -----	8XXX
UNUSED SERIES -----	9XXX

Figure 2-10. Aluminum alloy groups.

METHODS OF MARKING

Stenciling

A stencil and white or black paint, whichever shows up better on the metal being marked, should be used when the size of the metal piece permits. The federal or military specification numbers should be stenciled on the metal in vertically or horizontally aligned rows. The distance between the vertical rows should not exceed 36 inches, and the distance between the horizontal rows should not exceed 10 inches.

GENERAL

Stamping

Stamping the specification number into the metal should be used when it is impossible to use the stencil method. It is usually necessary to cut or eliminate the marked portion of the metal prior to using the material for work stock. Therefore, the marking should be located where waste will be held to a minimum. Gothic style numerals and letters should be used; the height may be 1/16 inch, 1/8 inch, or 1/4 inch, depending upon the size of the material being marked.

TEMPER DESIGNATION	
Symbol	Designation
—F	As fabricated.
—O	Annealed, recrystallized (wrought products only).
—H	Strain hardened.
—H1	Plus one or more digits. Strain hardened only.
—H2	Plus one or more digits. Strain hardened and then partially annealed.
—H3	Plus one or more digits. Strain hardened and stabilized.
—W	Solution heat treated—unstable temper. This designation is specified only when the period of natural aging is indicated.
—T	Treated to produce stable tempers other than —F, —O, or —H.
—T2	Annealed (cast products only).
—T3	Solution heat-treated and then cold worked.
—T4	Solution heat-treated.
—T5	Artificially aged only.
—T6	Solution heat-treated and then artificially aged.
—T7	Solution heat-treated and then stabilized.
—T8	Solution heat-treated cold-worked and then artificially aged.
—T9	Solution heat-treated, artificially aged and then cold-worked.
—T10	Artificially-aged and then cold worked.

Figure 2-11. Temper designation of aluminum.

FERROUS METALS

CAST IRON

Ferrous metals are those that contain iron as the base metal. The properties of ferrous metals may be changed by adding various alloying elements. The chemical and mechanical properties need to be combined to produce a metal to serve a specific purpose. The basic ferrous metal form is pig iron. Pig iron is produced in a blast furnace that is charged with an iron ore, coke, and limestone. The four principal iron ores are hematite, limonite, magnetite and faconite.

Cast iron is a metal that is widely used. It is a hard, brittle metal that has good wear resistance. Cast iron contains 2 to 4 percent carbon. White cast iron is very hard and is used mostly where abrasion and wear resistance is required. White cast iron may be made into malleable iron by heating it; then cooling it very slowly over a long period of time. Malleable iron is stronger and tougher than white cast iron; however, it is much more expensive to produce. Gray iron is another form of cast iron. It is used mostly for castings because of its ability to flow easily into complex shapes.

WROUGHT IRON

Wrought iron is an iron that has had most of its carbon removed. It is tough; however, it can be bent or twisted very easily. Wrought iron is used mostly in ornamental ironwork, such as fences and handrails, because it is welded or painted easily and it rusts very slowly.

STEEL

Steel is an alloy of iron and carbon or other alloying elements. When the alloying element is carbon, the steel is referred to as carbon steel. Carbon steels are classified by the percentage of carbon in "points" or hundredths of 1 percent they contain.

Low Carbon Steel

(Carbon content up to 0.30 percent or 30 points).

This steel is soft and ductile and can be rolled, punched, sheared, and worked when either hot or cold. It is easily machined and can be readily welded by all methods. It does not harden to any great amount; however, it can be easily case- or surface-hardened.

Medium Carbon Steel

(Carbon content from 0.30 to 0.50 percent or 30 to 50 points).

This steel may be heat-treated after fabrication. It is used for general machining and forging of parts that require surface hardness and strength. It is made in bar form in the cold-rolled or the normalized and annealed condition. During welding, the weld zone will become hardened if cooled rapidly and must be stress-relieved after welding.

High Carbon Steel

(Carbon content from 0.50 to 1.05% or 50 to 105 points)

This steel is used in the manufacture of drills, taps, dies, springs, and other machine tools and hand tools that are heat-treated after fabrication to develop the hard structure

necessary to withstand high shear stress and wear. It is manufactured in bar, sheet, and wire forms, and in the annealed or normalized condition in order to be suitable for machining before heat treatment. This steel is difficult to weld because of the hardening effect of heat at the welding joint.

Tool Steel

(carbon content from 0.90 to 1.70 percent or 90 to 170 points)

This steel is used in the manufacture of chisels, shear blades, cutters, large taps, woodturning tools, blacksmith's tools, razors, and other similar parts where high hardness is required to maintain a sharp cutting edge. It is difficult to weld due to the high carbon content.

High-Speed Steel

High-speed steel is a self-hardening steel alloy that can withstand high temperatures without becoming soft. High-speed steel is ideal for cutting tools because of its ability to take deeper cuts at higher speeds than tools made from carbon steel.

Tungsten Carbide

Tungsten carbide is the hardest man-made metal. It is almost as hard as a diamond. The metal is molded from tungsten and carbon powders under heat and pressure. Tools made from this metal can cut other metals many times faster than high-speed steel tools.

Alloy Steels

Steel is manufactured to meet a wide variety of specifications for hardness, toughness, machinability, and so forth. Manufacturers use various alloying elements to obtain these characteristics. When elements other than carbon, such as chromium, manganese, molybdenum, nickel, tungsten, and vanadium are used. The resulting metals are called alloy steels. Figure 2-12 shows some of the general characteristics obtained by the use of various alloying elements.

NONFERROUS METALS

There are many metals that do not have iron as their base metal. These metals, known as nonferrous metals, offer specific properties or combinations of properties that make them ideal for tasks where ferrous metals are not suitable. Nonferrous metals are often used with iron base metals in the finished product.

ALUMINUM

Aluminum and its alloys are produced and used in many shapes and forms. The common forms are castings, sheet, plate, bar, rod, channels, and forgings. Aluminum alloys have many desirable qualities. They are lighter than most other metals and do not rust or corrode under most conditions. Aluminum can be cast-forged, machined, and welded easily.

MAGNESIUM

Magnesium alloys are produced and used in many shapes and forms, for example, castings, bars, rods, tubing, sheets and plates, and forgings. Their inherent strength, light weight, and shock and vibration resistance are factors which make their use advantageous. The weight for an equal volume of magnesium is approximately two-thirds of that for aluminum and one-fifth of that for steel. Magnesium has excellent machining qualities; however, care must be taken when machining because the chips are highly flammable. Magnesium fires burn so hot that they cannot be extinguished by conventional fire extinguishers.

COPPER

Copper is a reddish metal, very ductile and malleable, and has high electrical and heat conductivity. Copper can be forged, cast, and cold worked. It also can be welded, but its machinability is only fair. The principal use of commercially pure copper is in the electrical industry where it is made into

wire or other such conductors. It is also used in the manufacture of nonferrous alloys such as brass, bronze, and monel metal. Typical copper products are sheet roofing, cartridge cases, bushings, wire, bearings, and statues.

BRASS AND BRONZE

Brass, an alloy of copper and zinc (60 to 68 percent copper and 32 to 40 percent zinc), has a low melting point and high heat conductivity. There are several types of brass such as naval, red, admiralty, yellow, and commercial. All differ in copper and zinc content. All may be alloyed with other elements such as lead, tin, manganese, or iron, and all have good machinability and can be welded. Bronze is an alloy of copper and tin and may contain lead, zinc, nickel, manganese, or phosphorous. It has high strength, is rust or corrosion resistant, has good machinability, and can be welded.

TYPES OF STEEL	SAE NUMBERS (GENERAL SERIES)	CHARACTERISTICS RESULTING FROM THE ALLOYING ELEMENTS ADDED
CARBON STEELS	1000	Surface Hardness and Strength
NICKEL STEELS	2000	Toughness
CHROME-NICKEL STEELS	3000	Toughness and Depth Hardness
MOLYBDENUM STEELS	4000	Eliminates Brittleness and In- creases Depth Hardness
CHROME-MOLYBDENUM STEELS	4100	High Strength and Toughness
CHROMIUM STEELS	5000	Corrosion Resistance and Hardness
CHROME-VANADIUM	6000	Depth Hardness and toughness at Sub-zero Temperature
TUNGSTEN STEELS	7000	Hardness at High Temperatures
CHROME-NICKEL- MOLYBDENUM STEELS	8000	Toughness and Strength- (General Purpose Steel)
SILICONE-MANGANESE STEELS	9000	Depth Hardness and Toughness Under Impact

Figure 2-12. General characteristics of common alloys.

LEAD

Lead is used mainly in the manufacture of electrical equipment such as lead-coated power and telephone cables and storage batteries. Zinc alloys are used in the manufacture of lead weights, bearings, gaskets, seals, bullets, and shot. Many types of chemical compounds are produced from lead. Among these are lead carbonate (paint pigment) and tetraethyl lead (antiknock gasoline). Lead is also used for X-ray protection (radiation shields). Lead has more fields of application than any other metal. It can be cast, cold worked, welded, and machined. Lead has low strength with heavy weight.

TIN

The major use of tin is in coating steel. It is the best container for preserving perishable food. Tin, in the form of foil, is often used in wrapping food products. A second major use of tin is as an alloying element. Tin is alloyed with copper to produce bronze, with lead to produce solder, and with antimony and lead to form babbitt. Tin can be die cast, cold worked, machined, and soldered; however, it cannot be welded.

NICKEL

Nickel is used in making alloys of both ferrous and nonferrous metals. Chemical and food processing equipment, electrical resistance heating elements, ornamental trim, and

parts that must withstand elevated temperatures are all produced from nickel containing metal. Alloyed with chromium, it is used to make stainless steel. Nickel alloys are readily welded by either gas or arc methods and can be machined, forged, cast, and easily formed.

COBALT-CHROMIUM-TUNGSTEN MOLYBDENUM WEAR-RESISTANT ALLOYS

These alloys feature a wear resistance which makes them ideal for metal-cutting operations. Their ability to retain hardness even at red-heat temperatures also makes them especially useful for cutting tools. Common cutting tools will lose their edge at high heat, whereas this alloy group is actually tougher at red heat than it is when cold; as a result, higher speeds and feeds may be used when machining with tools made with these alloys.

PRECIOUS METALS

These include silver, gold, platinum, palladium, iridium, osmium, rhodium, and ruthenium, and their alloys. These alloys are produced under technical and legal requirements. Gold alloys used for jewelry are described in karats. The karat is the content of gold expressed in twenty-fourths. An 18-karat gold alloy would contain 18/24 gold (75 percent by weight). Other than jewelry, there are many industrial uses for precious metals.

HEAT TREATMENT OF METALS

Heat treatment is any one of a number of controlled heating and cooling operations used to bring about a desired change in the physical properties of a metal. Its purpose is to improve the structural and physical properties for some particular use or for future work of the metal. There are five basic heat treating processes: hardening, case hardening, annealing, normalizing, and tempering. Although each of these processes bring about different results in metal, all of them involve three basic steps: heating, soaking, and cooling.

HEATING

Heating is the first step in a heat-treating process. Many alloys change structure when they are heated to specific temperatures. The structure of an alloy at room temperature can be either a mechanical mixture, a solid solution, or a combination solid solution and mechanical mixture.

A mechanical mixture can be compared to concrete. Just as the sand and gravel are visible and held in place by the cement. The elements and compounds in a mechanical mixture are clearly visible and are held together by a matrix of base metal. A solid solution is when two or more metals are absorbed, one into the other, and form a solution. When an alloy is in the form of a solid solution, the elements and compounds forming the metal are absorbed into each other in much the same way that salt is dissolved in a glass of water. The separate elements forming the metal cannot be identified even under a microscope. A metal in the form of a mechanical mixture at room temperature often goes into a solid solution or a partial solution when it is heated. Changing the chemical composition in this way brings about certain predictable changes in grain size and structure. This leads to the second step in the heat treating process: soaking.

SOAKING

Once a metal part has been heated to the temperature at which desired changes in its structure will take place, it must remain at that temperature until the entire part has been evenly heated throughout. This is known as soaking. The more mass the part has, the longer it must be soaked.

COOLING

After the part has been properly soaked, the third step is to cool it. Here again, the structure may change from one chemical composition to another, it may stay the same, or it may revert to its original form. For example, a metal that is a solid solution after heating may stay the same during cooling, change to a mechanical mixture, or change to a combination of the two, depending on the type of metal and the rate of cooling. All of these changes are predictable. For that reason, many metals can be made to conform to specific structures in order to increase their hardness, toughness, ductility, tensile strength, and so forth.

HEAT TREATMENT OF FERROUS METALS

All heat-treating operations involve the heating and cooling of metals. The common forms of heat treatment for ferrous metals are hardening, tempering, annealing, normalizing, and case hardening.

HARDENING

A ferrous metal is normally hardened by heating the metal to the required temperature and then cooling it rapidly by plunging the hot metal into a quenching medium, such as oil, water, or brine. Most steels must be cooled rapidly to harden them. The hardening process increases the hardness and strength of metal, but also increases its brittleness.

TEMPERING

Steel is usually harder than necessary and too brittle for practical use after being hardened. Severe internal stresses are set up during the rapid cooling of the metal. Steel is tempered after being hardened to relieve the internal stresses and reduce its brittleness. Tempering consists of heating the metal to a specified temperature and then permitting the metal to cool. The rate of cooling usually has no effect on the metal structure during tempering. Therefore, the metal is usually permitted to cool in still air. Temperatures used for tempering are normally much lower than the hardening temperatures. The higher the tempering temperature used, the softer the metal becomes. High-speed steel is one of the few metals that becomes harder instead of softer after it is tempered.

ANNEALING

Metals are annealed to relieve internal stresses, soften them, make them more ductile, and refine their grain structures. Metal is annealed by heating it to a prescribed temperature, holding it at that temperature for the required time, and then cooling it back to room temperature. The rate at which metal is cooled from the annealing temperature varies greatly. Steel must be cooled very slowly to produce maximum softness. This can be done by burying the hot part in sand, ashes, or some other substance that does not conduct heat readily (packing), or by shutting off the furnace and allowing the furnace and part to cool together (furnace cooling).

NORMALIZING

Ferrous metals are normalized to relieve the internal stresses produced by machining, forging, or welding. Normalized steels are harder and stronger than annealed steels. Steel is much tougher in the normalized condition than in any other condition. Parts that will be subjected to impact and parts that require maximum toughness and resistance to external stresses are usually normalized. Normalizing prior to hardening is beneficial in obtaining the desired hardness, provided the hardening operation is performed correctly. Low carbon steels do not usually require normalizing, but no harmful effects result if these steels are normalized. Normalizing is achieved by heating the metal to a specified temperature (which is higher than either the hardening or annealing temperatures), soaking the metal until it is uniformly heated, and cooling it in still air.

CASE HARDENING

Case hardening is an ideal heat treatment for parts which require a wear-resistant surface and a tough core, such as gears, cams, cylinder sleeves, and so forth. The most common case-hardening processes are carburizing and nitriding. During the case-hardening process, a low-carbon steel (either straight carbon steel or low-carbon alloy steel) is heated to a specific temperature in the presence of a material (solid, liquid, or gas) which decomposes and deposits more carbon into the surface of a steel. Then, when the part is cooled rapidly, the outer surface or case becomes hard, leaving the inside of the piece soft but very tough.

HEAT TREATMENT OF NONFERROUS METALS

Two types of heat-treating operations can be performed on nonferrous metals. They are annealing and solution heat treating.

ANNEALING

Most nonferrous metals can be annealed. The annealing process consists of heating the metal to a specific temperature, soaking, and cooling to room temperature. The temperature and method of cooling depend on the type of metal. Annealing is often accomplished after various cold working operations because many nonferrous metals become hard and brittle after cold working. Also, annealing is used to remove the effects of solution heat treatment so that machining or working qualities can be improved.

SOLUTION HEAT TREATMENT

The tensile strength of many nonferrous alloys can be increased by causing the materials within the alloy to go into a solid solution and then controlling the rate and extent of return to an altered mechanical mixture. This operation is called solution heat treatment. After an alloy has been heated to a specified temperature, it is "quenched" or cooled rapidly, which traps the materials in the solid solution attained during the heating process. From this point, the process varies greatly depending on the metal. To be sure the materials in the alloy do not revert to their original configuration after a period of time, a process of aging or precipitation hardening must follow. In this process the materials in the alloy are allowed to change or to precipitate out of the solid solution.

This process occurs under controlled conditions so that the resultant grain structure will produce a greater tensile strength in the metal than in its original condition. Depending on the alloy, this precipitation process can also consist of simply aging the alloy at room temperature for a specified time and then air-cooling it; this is called artificial aging.

Aluminum alloys can be obtained in various conditions of heat treatment called temper designations. Figure 2-11, on page 2-9, shows the various temper designations and the process to which they apply. The term "strain-hardened" refers to aging or hardening that has been brought about by coldworking the alloy. "Stabilizing" refers to a particular aging process that freezes or stops the internal changes that normally would take place in the alloy at room temperature. Magnesium alloys can be subjected to all of the nonferrous heat treatments, but the different alloys within the series require different temperatures and times for the various processes. Copper alloys are generally hardened by annealing. The nickel alloys can also be annealed and certain types can be hardened by heat treatment. Likewise, titanium may be annealed (mostly relieve machining or cold-working stresses) but is not noticeably affected by heat treatment.