CHAPTER 3

METALS AND PLASTICS

CHAPTER LEARNING OBJECTIVES

Upon completing this chapter, you should be able to do the following:

- *Explain the methods used to select metals for various applications.*
- *Explain the methods used to select plastics for various applications.*

An MR repairs broken parts and manufactures replacements according to samples and blueprints. To choose the metals and plastics best suited for that purpose, you must know the physical and mechanical properties of materials. You also must know how to identify materials that are not clearly marked. For instance, stainless steel and nickel-copper are quite similar in appearance, but they are completely different in their mechanical properties and cannot be used interchangeably. Some of the properties of materials that an MR must know are presented in this chapter.

As with any shop equipment you must observe all posted safety precautions. Review your equipment operators manual for safety precautions and any chapters of *Navy Occupational Safety and Health (NAVOSH) Program Manual for Forces Afloat,* OPNAV Instruction 5100.19B, that pertain to the equipment you will be operating.

Many alloy metals are toxic, and can be potentially carcinogenic. The dust or fumes given off by these alloys could be inhaled and cause serious health problems. Respiratory protection may be required when machining, sanding or melting alloy metals.

METALS

There are hundreds of metals and alloys that you may machine in a machine shop. You need not understand all metals and alloys, but you must have a working knowledge of them and know the common terms associated with them.

PROPERTIES OF METAL

The physical properties of a metal determine its behavior under stress, heat, and exposure to chemically active substances. In practical application, the behavior of a metal under these conditions determines its mechanical properties; indentation and rusting. The mechanical properties of a metal are important considerations in selecting material for a specific job.

Stress

Stress in a metal is its internal resistance to a change in shape when an external load or force is applied to it. There are three different forms of stress. Tensile stress pulls a metal apart. Compression stress squeezes the metal. Shear stress is forces from opposite directions that work to separate the metal. When a piece of metal is bent, both tensile and compression stresses are applied. The side of the metal where the force is applied undergoes tensile stress as the metal is stretched, while the opposite side is squeezed under compression stress. When a metal is subjected to torque, such as a pump shaft driven by an electric motor, all three forms of stress are applied to some degree.

Strain

Strain is the deformation or change in shape of a metal when a stress or load is applied. When the load is removed, the metal is no longer under a strain. The type of deformation will be similar to the form of stress applied.

Strength

Strength is the property of a metal that enables it to resist strain (deformation) when a stress (load) is applied. Strength may be expressed by several different terms. The most common term is *tensile strength,* or the maximum force required to pull metal apart. To find tensile strength, divide the force required to pull the metal apart by the area in square inches of a prepared specimen.

Another term used to describe the strength of a metal is *yield strength,* which you will determine during the test for tensile strength. Yield strength is established when the metal specimen begins to stretch while pressure is gradually applied. There is often a relationship between the tensile strength and the hardness of metals. As the hardness of a metal is increased, the tensile strength is also increased, and vice versa. Charts provide these values for the more commonly used metals.

Plasticity

Plasticity is the ability of a metal to withstand extensive permanent deformation without breaking or rupturing. Modeling clay is an example of a highly plastic material, since it can be deformed extensively and permanently without rupturing. Metals with high plasticity will produce long, continuous chips when machined on a lathe.

Elasticity

Elasticity is the ability of a metal to return to its original size and shape after an applied force has been removed. The action of spring steel is an example of applying this property.

Ductility

Ductility is the ability of a metal to be permanently deformed when it is bent or stretched into wire form without breaking. To find the ductility of a metal, apply the tensil strength test and measure the percentage of increased length. Copper is an example of a very ductile metal.

Malleability

Malleability is the ability of a metal to be permanently deformed by a compression stress produced by hammering, stamping, or rolling the metal into thin sheets. Lead is a highly malleable metal.

Brittleness

Brittleness is the tendency of a metal to break or crack when it has not been deformed. Generally, the harder a metal, the more brittle it is, and vice versa. Pot metal and cast iron are examples of brittle metals.

Toughness

Toughness is the ability of a metal to withstand shock, to endure stress, and to deform without breaking. A tough metal is not easily separated or cut and can be bent first in one direction and then in the opposite without fracturing.

Hardness

Hardness of a metal is generally defined as its ability to resist indentation, abrasion or wear, and cutting. The degree of hardness of many metals may be either increased or decreased by one or more heat-treatment processes. In most cases, as the hardness of a steel is decreased, its toughness is increased.

Hardenability

Hardenability is a measure of the depth (from the metal's surface toward its center) to which a metal can be hardened by heat treatment. A metal that achieves a shallow depth of hardness and retains a relatively soft and tough core has low hardenability. The hardenability of some metals changes by adding certain alloys during manufacturing.

Fatigue

Fatigue is the action that takes place in a metal after repeated stress. When you break a sample in a tensile machine, you need to apply a definite load to cause that fracture. However, the same material will fail under a much smaller load if you apply and remove the load many times. Fatigue may cause a shaft to break after months of use even though the load has not been changed.

Corrosion Resistance

Corrosion resistance is the ability of a metal to withstand surface attack by the atmosphere, fluids, moisture, and acids. Some metals can be made less

susceptible to corrosive agents by either coating or alloying them with other metals that are corrosion resistant.

Heat Resistance

Heat resistance is the property of a steel or alloy that permits it to retain its properties at high temperatures. Examples are tungsten steel, which can cut other metals even when red hot, and chromium molybdenum steel, which is used for piping and valves in high temperature, high-pressure steam systems.

Weldability

Weldability refers to the relative ease with which a metal can be welded. Weldability depends on many different factors. The basic factor is the chemical composition or the elements that were added during the metal's manufacture. A steel with a low carbon content will be much easier to weld than one with a high carbon content. You can weld a low alloy steel that has low hardenability easier than one with a high hardenability. You also must consider the welding procedure, such as gas or arc welding. Charts provide guidelines concerning the weldabilty of a metal and the recommended welding procedure. Always make weldability an integral part of planning a job that requires welding.

Machinability

Machinability is the relative ease with which a metal can be machined. Several factors affect the machinability of metal. They are different alloying elements, the method used by the manufacturer to form the metal bar (physical condition), any heat treatment that has changed the hardness, whether you use a high-speed steel or carbide cutting tool, and whether you use a cutting fluid. We'll discuss some of these factors later in this chapter.

TYPES OF METALS

Metals are divided into two general types—ferrous and nonferrous. Ferrous metals are those whose major element is iron. Iron is the basis for all steels. Nonferrous metals are those whose major element is not iron, but they may contain a small amount of iron as an impurity.

Ferrous Metals

Iron ore, the basis of all ferrous metals, is converted to metal (pig iron) in a blast furnace. Alloying elements can be added later to the pig iron to obtain a wide variety of metals with different characteristics. The characteristics of metal can be further changed and improved by heat treatment and by hot or cold working.

PIG IRON.—The product of the blast furnace is called pig iron. Pig iron is composed of approximately 93 percent iron, 3 to 5 percent carbon, and varying amounts of impurities. It is seldom used directly as an industrial manufacturing material, but it is the basic ingredient in cast iron, wrought iron, and steel.

CAST IRON.—Cast iron is produced by resmelting a charge of pig iron and scrap iron in a furnace and removing some of the impurities from the molten metal by using various fluxing agents. There are many grades of cast iron, based on strength and hardness. The quality depends upon the extent of refining, the amount of scrap iron used, and the method of casting and cooling the molten metal when it is drawn from the furnace. The higher the proportion of scrap iron, the lower the grade of cast iron. Cast iron has some degree of corrosion resistance and great compressive strength, but it is brittle and has a comparatively low tensile strength. It has limited use in marine service.

WROUGHT IRON.—Wrought iron is a highly refined pure iron that contains uniformly distributed particles of slag. It is considerably softer than cast iron and has a fibrous internal structure. Like cast iron, it is fairly resistant to corrosion and fatigue. Wrought iron, is used extensively for low-pressure pipes, rivets, and nails.

PLAIN-CARBON STEEL.—Pig iron is converted into steel by a process that separates and removes impurities from the molten iron by use of various catalytic agents and extremely high temperatures. During the refining process, practically all the carbon originally present in the pig iron is burned out. In the final stages when higher carbon alloys are needed, measured amounts of carbon are added to the relatively pure liquid iron to produce carbon steel of a desired grade. The amount of carbon added controls the mechanical properties of the finished steel. After the steel has been drawn from the furnace and allowed to solidify, it may be sent either to the stockpile or to shaping mills for rolling

and forming into plates, billets, bars, or structural shapes.

Plain steels that have small additions of sulfur (and sometimes phosphorous) are called free-cutting steels. These steels have good machining characteristics and are used in applications similar to carbon steels. The addition of sulfur and phosphorous limits their ability to be formed hot. We will now discuss a few of the plain carbon steels.

Low-carbon steel.—Low-carbon steel (0.05 to 0.30 percent carbon), usually called mild steel, can be easily cut and bent and does not have great tensile strength. Steels with less than 0.15 percent carbon are usually more difficult to machine than those with a higher carbon content.

Medium-carbon steel.—Medium-carbon steel (0.30 to 0.60 percent carbon) is considerably stronger than low-carbon steel. Heat-treated machinery parts arc made of this steel.

High-carbon steel.—High-carbon steel (0.60 to 1.50 percent carbon) is used for many machine parts, handtools, and cutting tools and is usually called carbon tool steel. Do not use cutting tools of high-carbon steel when the cutting temperature will exceed 400°F.

ALLOY STEELS.—The steels discussed so far are true alloys of iron and carbon. When other elements are added to iron during the refining process, the resulting metal is called alloy steel. There are many types, classes, and grades of alloy steel.

Alloy steels usually contain several different alloying elements, and each contributes a different characteristic to the metal. Alloying elements can change the machinability, hardenability, weldability, corrosion resistance, and surface appearance of the metal. If you know how each of the alloying elements affects a metal, you'll more readily select the best metal for a given application. In the following paragraphs, we'll discuss a few of the more common alloy steels and the effects of certain alloying elements upon the mechanical properties of steel.

Chromium.—Chromium is added to steel to increase hardenability, corrosion resistance, toughness, and wear resistance. The most common uses of chromium are in corrosion-resistant steel (commonly called stainless steel) and high-speed cutting tools. Stainless steel is often used to manufacture parts that are used in acids and salt water. It is also used in parts such as ball bearings, shafts, and valve stems that are subject to high pressure and high temperature.

Vanadium.—Vanadium is added in small quantities to steel to increase tensile strength, toughness, and wear resistance. It is most often combined with chromium. It is used for crankshafts, axles, piston rods, springs, and other parts where high strength and fatigue resistance are required. Greater amounts of vanadium are added to high-speed steel cutting tools to prevent tempering of their cutting edges during high temperatures.

Nickel.—Nickel is added to steel to increase corrosion resistance, strength, toughness, and wear resistance. Nickel is used in small amounts in the steel used to armor plate a ship because it resists cracking when penetrated. Greater amounts of nickel are added to chromium to produce a metal that withstands severe working conditions. Crankshafts, rear axles, and other parts subject to repeated shock are made from nickel chrome steel.

Molybdenum.—Molybdenum is added to steel to increase toughness, hardenability, shock resistance, and resistance to softening at high temperatures. Molybdenum steel is used for transmission gears, heavy-duty shafts, and springs. Carbon molybdenum (CMo) and chrome molybdenum (CrMo) are two alloy steels with molybdenum added that are widely used in high-temperature piping systems in Navy ships. Relatively large amounts of molybdenum are used in some of the cutting tools used in the machine shop.

Tungsten.—Tungsten is used primarily in high-speed steel or cemented-carbide cutting tools. It gives the cutting tools their hard, wear-resistant and heat-resistant characteristics. Tungsten can be air-hardened. It allows tools to be hardened without using oil or water to cool the tool after heating.

Nonferrous Metals

Copper, nickel, lead, zinc, tin, and aluminum are included among the nonferrous metals. These metals and their alloys are used in large amounts in the construction and maintenance of Navy ships.

COPPER ALLOYS.—Copper has a variety of uses. You will see it aboard ship in the form of wire, rod, bar, sheet, plate, and pipe. As a conductor of both heat and electricity, copper ranks next to silver and has a high resistance to saltwater corrosion.

Copper becomes hard when worked but can be softened easily if you heat it cherry red and then cool it. Its strength, however, decreases rapidly at temperatures above 400°F.

Pure copper is normally used in molded or shaped forms when machining is not required. Copper for normal shipboard use generally is alloyed with an element that provides good machinability.

Brass.—Brass is an alloy of copper and zinc. Complex brasses contain additional alloying agents, such as aluminum, lead, iron, manganese, or phosphorus. Naval brass is a true brass containing about 60 percent copper, 39 percent zinc, and 1 percent tin added for corrosion resistance. It is used for propeller shafts, valve stems, and marine hardware.

Brass used by the Navy is classified as either leaded or unleaded, meaning that small amounts of lead may or may not be used in the copper-zinc mixture. Lead improves the machinability of brass.

Bronze.—Bronze is primarily an alloy of copper and tin, although several other alloying elements are added to produce special bronze alloys. Aluminum, nickel, phosphorous, silicon, and manganese are the most widely used alloying metals.

Gunmetal.—Gunmetal, a copper-tin alloy, contains approximately 86-89 percent copper, 7 1/2-9 percent tin, 3-5 percent zinc, 0.3 percent lead, 0.15 percent iron, 0.05 percent phosphorous, and 1 percent nickel. As you can see by the rather complex analysis of this bronze alloy, the term *copper-tin* is used only to designate the major alloying elements. Gunmetal bronze is used for bearings, bushings, pump bodies, valves, impellers, and gears.

Aluminum Bronze.—Aluminum bronze is actually a copper-aluminum alloy that does not contain any tin. It is made of 86 percent copper, 8 1/2-9 percent aluminum, 2 1/2-4 percent iron, and 1 percent of miscellaneous alloys. It is used for valve seats and stems, bearings, gears, propellers, and marine hardware.

Copper-Nickel.—Copper-nickel alloy is used extensively aboard ship because of its high resistance to saltwater corrosion. It is used in piping and tubing. In sheet form it is used to construct small storage tanks and hot water reservoirs. Copper-nickel alloy may contain either 70 percent copper and 30 percent nickel or 90 percent copper and 10 percent nickel. It has the general working characteristics of copper but must be worked cold.

These and the many other copper alloys commonly used by the Navy have certain physical and mechanical properties (imparted by the various alloying elements) that cause one alloy to be more effective than another for a given application. Remember this if you go to the metal storage rack and select a bronze-looking metal without regard to the specific type. The part you make may fail prematurely in spite of the skill and attention to detail that you use to machine it.

NICKEL ALLOYS.—Nickel is a hard, malleable, and ductile metal. It is resistant to corrosion and therefore often is used as a coating on other metals. Combined with other metals, it makes a tough strong alloy.

Nickel-Copper.—Nickel-copper alloys are stronger and harder than either nickel or copper. They have high resistance to corrosion and are strong enough to be substituted for steel when corrosion resistance is of primary importance. Probably the best known nickel-copper alloy is Monel. It contains approximately 65 percent nickel, 30 percent copper, and small percentages of iron, manganese, silicon, and cobalt. Monel is used for pump shafts and internal parts, valve seats and stems, and many other applications requiring both strength and corrosion resistance.

K-Monel.—K-Monel is essentially the same as Monel except it contains about 3 percent aluminum and is harder and stronger than other grades of Monel. K-Monel stock is very difficult to machine. You can improve the metal's machinability considerably by annealing it immediately before machining. K-Monel is used for the shaft sleeves on many pumps because of its resistance to the heating and rubbing action of the packing.

There are several other nickel alloys that you may find in Navy equipment. Inconel; Inconel-X; and H, S, R, and KR Monel are a few of the more common alloys.

ALUMINUM ALLOYS.—Aluminum is being used more and more in ship construction because of light weight, easy workability, and good appearance. Pure aluminum is soft and not very strong. When alloying elements such as magnesium, copper, nickel, and silicon are added, however, a much stronger metal is produced.

Each of the aluminum alloys has properties developed specifically for a certain type of application. The hard aluminum alloys are easier to machine than the soft alloys and often are equal to low-carbon steel in strength.

ZINC ALLOYS.—Zinc is a comparatively soft, yet somewhat brittle, metal. Its tensile strength is only slightly greater than that of aluminum. Because of its resistance to corrosion, zinc is used as a protective coating for less corrosion-resistant metals, principally iron and steel.

Pure zinc has a strong anodic potential. It is used to protect the hulls of steel ships against electrolysis between dissimilar metals caused by electric currents set up by salt water. Zinc plates bolted on the hull, especially near the propellers, decompose quite rapidly, but greatly reduce localized pitting of the hull steel.

TIN ALLOYS.—Pure tin is seldom used except as a coating for food containers and sheet steel and in some electroplating applications. Several different grades of tin solder are made by adding either lead or antimony. One of the Navy's main uses of tin is to make bearing babbitt. About 5 percent copper and 10 percent antimony are added to 85 percent tin to make this alloy. Various grades of babbitt are used in bearings. Each grade may have additional alloying elements to give the babbitt the properties required.

LEAD ALLOYS.—Lead is probably the heaviest metal with which you will work. A cubic foot of it weighs approximately 700 pounds. It has a grayish color and is amazingly pliable. It is obtainable in sheets and pigs. The sheets normally are wound around a rod, and pieces can be cut off quite easily. One of the most common uses of lead is as an alloying element in soft solder.

DESIGNATIONS AND MARKINGS OF METALS

You must understand the standard designations of metals and the systems of marking metals used by the Navy and industry so you can select the proper material for a specific job. There are several different numbering systems currently in use by different trade associations, societies, and producers of metals and alloys. You may find several different designations that refer to a metal with the same chemical composition, or several identical designations that refer to metals with different chemical compositions. The Society of Automotive Engineers, Inc. (SAE), publishes *Unified Numbering System for Metals and Alloys.* It provides a clear and easily understood cross reference from the designation of one numbering system to other systems where a similar metal is involved. Some of the numbering systems that you may need to identify are as following:

Aluminum Association (AA)

American Iron and Steel Institute (AISI)

Society of Automotive Engineers (SAE)

Aerospace Materials Specifications (AMS)

American National Standards Institute (ANSI)

American Society of Mechanical Engineers (ASME)

American Society for Testing and Materials (ASTM)

Copper Development Association (CDA)

Military Specification (MIL-S-XXXX, MIL-N-XXXX)

Federal Specification (QQ-N-XX, QQ-S-XXX)

The Unified Numbering System lists all the different designations for a metal and assigns one number that identities the metal. This system covers only the composition of the metal and not its condition, quality, or form. Use of the Unified Numbering System by the various metal producers is voluntary, and it could be some time before its use is widespread. Another useful publication is NAVSEA 0900-LP-038-8010, *Ship Metallic Material Comparison and Use Guide.*

The two major systems used for iron and steel are the Society of Automotive Engineers (SAE) and the American Iron and Steel Institute (AISI). The Aluminum Association method is used for aluminum and is discussed later in this chapter. Other nonferrous metals are designated by the percentage and types of elements in their composition. The Navy uses these methods to mark metals so they can be identified readily.

Ferrous Metal Designations

You should be familiar with the SAE and AISI systems of steel classifications. These systems, which are in common use, have a four- or five-digit number to indicate the composition of the steel. The major difference between them is that the AISI system normally uses a letter before the numbers to show the

process used to make the steel, and the SAE system does not. The letters are *B*—acid Bessemer carbon steel; *C*—basic open-hearth or basic electric-furnace carbon steel; and *E*—electric-furnace alloy steel.

The first digit normally indicates the basic type of steel. Table 3-1 shows the SAE numbers with their corresponding alloying elements.

The second digit normally indicates a series within the group. The term *series* usually refers to the percentage of the major alloying element. Sometimes the second digit gives the actual percentage of the chief alloying element; in other cases, the second digit may indicate the relative position of the series in a group without reference to the actual percentage.

The third, fourth, and fifth digits indicate the average carbon content of the steel. If the carbon content is less than 1.00 you will have only four digits. The carbon content is expressed in points; for example: 2 points = 0.02 percent, 20 points = 0.20 percent, and 100 points = 1.00 percent. To make the various steels fit into this classification, it is sometimes necessary to vary the system slightly. However, you can easily understand such variations if you understand the system. Let's look at a few examples. Check them against the number in table 3-1.

Table 3-1.—SAE Numbers with Their Corresponding Alloying Elements

Type of Steel	SAE Number
Carbon Steels	1xxx
Plain carbon	10xx
Free cutting (screw lock)	11xx
High manganese	13xx
Nickel Steels	2xxx
3.50% nickel	23xx
5.00% nickel	25xx
Nickel-Chromium Steel	3xxx
1.25% nickel, 0.60% chromium	31xx
3.50% nickel, 1.50% chromium	33xx
Molybdenum Steels (0.25% molybdenum)	4xxx
1.0% chromium	41xx
0.5% chromium, 1.8% nickel	43xx
2% nickel	46xx
3.5% nickel	48xx
Chromium Steels	5xxx
Low chrome	51xx
Medium chrome	52xx
Chromium-Vanadium Steels	6xxx
Nickel-Chromium-Molybdenum (low amounts)	8xxx
Silicon-Manganese	92xx

(1) SAE 1035: The first digit is 1, so this is a carbon steel. The second digit, 0, shows there is no other important alloying element, so this is a PLAIN carbon steel. The next two digits, 35, show that the AVERAGE carbon content is 0.35 percent. There are also small amounts of other elements such as manganese, phosphorus, and sulfur.

(2) SAE 1146: This is a resulfurized carbon steel (often called free cutting steel). The first digit indicates a carbon steel. The second digit shows an average manganese content of 1.00 percent. The last two digits show an average carbon content of 0.46 percent. The amount of sulfur added to this steel ranges from 0.08 to 0.13 percent. Manganese and sulfur in this quantity make this series of steel one of the most easily machined steels available.

(3) SAE 4017: The first digit, 4, indicates that this is a molybdenum steel. The second digit, 0, indicates there is no other equally important alloying element, so this is a plain molybdenum steel. The last two digits, 17, show that the average carbon content is 0.17 percent.

Other series within the molybdenum steel group are identified by the second digit. If the second digit is 1, the steel is chromium-molybdenum steel; if the second digit is 3, the steel is a nickel-chromium-molybdenum steel; if the second digit is 6, the steel is a nickel-molybdenum steel. In such cases, the second digit does not indicate the actual percentage of the alloying elements, other than molybdenum.

(4) SAE 51100: This number identifies a chromium steel (first digit) with approximately 1.00 percent chromium (second digit) and an average carbon content of 1.00 percent (last three digits). The actual chromium content of SAE 51100 steels may vary from 0.95 to 1.10 percent.

(5) SAE 52100: This number identifies a chromium steel (first digit) of a higher alloy series (second digit) than the SAE 51100 steel just described. Note, however, that in this case the second digit, 2, merely identifies the series but does NOT show the percentage of chromium. A 52100 steel will actually have from 1.30 to 1.60 percent chromium

with an average carbon content of 1.00 percent (last three digits).

Navy blueprints and the drawings of equipment furnished in the manufacturers' technical manuals usually specify materials by federal or military specification numbers. For example, the coupling on a particular oil burner is identified as cast steel, class B, MIL-S-15083. This particular cast steel does not have a designation under any other metal identification systems because there are no chemically similar castings. On the other hand, a valve stem designated MIL-S-862, class 410 (a chromium stainless steel) may be cross referenced to several other systems. Some of the chemically similar designations for MIL-S-862, class 410 are as follows:

SAE = J405 (51410)

Federal Spec. = QQ-S-763(410)

AISI = 410

ASTM = A176(410)

ASM = 5504

ASME = SA194

Unified Numbering System for Metals and Alloys is a very useful book to use when cross referencing numbers.

Table 3-2.—Aluminum and Aluminum Alloy Classifications

Alloy	Percent of Aluminum	Numbers
Aluminum	99.00 percent pure	1xxx
Copper		2xxx
Manganese		3xxx
Silicon		4xxx
Magnesium		5xxx
Magnesium and Silicon		6xxx
Zinc		7xxx
Other		8xxx
Unused		9xxx

Nonferrous Metal Designations

Nonferrous metals are generally grouped according to their alloying elements. Examples of these groups are brass, bronze, copper-nickel, and nickel-copper. Specific designations of an alloy are described by the amounts and chemical symbols of the alloying elements. For example, a copper-nickel alloy might be described as copper-nickel, 70 Cu-30 Ni. The 70 Cu represents the percentage of copper, and the 30 Ni represents the percentage of nickel.

The following list contains common alloying elements and their symbols:

Aluminum . . . . Al

Carbon C

Chromium . . . . Cr

Cobalt . . . . Co

Copper . . . . Cu

Iron. . . . . Fe

Lead . . . . Pb

Manganese . . . . Mn

Molybdenum . . . . Mo

Nickel . . . . Ni

Phosphorus . . . . P

Silicon . . . . Si

Sulphur . . . . S

Tin . . . . Sn

Titanium . . . . Ti

Tungsten . . . . W

Vanadium V

Zinc . . . . Zn

In addition to the designations previously described, a trade name (such as Monel or Inconel) is sometimes used to designate certain alloys.

The Aluminum Association uses a four-digit designation system similar to the SAE/AISI system described for steels. The numerals assigned, with their meaning for the first digits of this system, are listed in table 3-2.

The first digit identifies the major alloying element, and the second digit indicates alloy

modifications or impurity limits. The last two digits identify the particular alloy or indicate the aluminum purity.

In the 1xxx group for 99.00 percent minimum aluminum, the last two digits show the minimum aluminum percentage to the right of the decimal point. The second digit shows modifications in impurity limits. If the second digit in the designation is zero, there is no special control on individual impurities. If the second digit is 1 through 9, it shows some special control of one or more individual impurities. As an example, 1030 indicates a 99.30 percent minimum aluminum without special control on individual impurities. Designations 1130, 1230, 1330, and so on, indicate the same purity with special control of one or more individual impurities.

Designations 2 through 8 are aluminum alloys. In the 2xxx through 8xxx alloy groups, the second digit indicates any alloy modification. The last two of the four digits identify the different alloys in the group.

In addition to the four-digit alloy designation, a letter or letter/number is included as a temper designation. This designation follows the four-digit alloy number and is separated from it by a dash. As an example, 2024-T6 is an aluminum-copper alloy solution. The T6 designation shows the metal is heat treated, then artificially aged; T6 is the temper designation. The following list contains the aluminum alloy temper designations and their meanings:

F Fabricated

O Annealed recrystallized (wrought only)

H Strain hardened (wrought only)

H1, plus one or more digits, strain hardened only

H2, plus one or more digits, strain hardened, then partially annealed

H3, plus one or more digits, strain hardened, then stabilized

W Solution heat treated, unstable temper

T Treated to produce stable tempers other than F, O, or H

T2 Annealed (cast only)

T3 Solution heat treated, then cold worked

T4 Solution heat treated and naturally aged to a substantially stable condition

T5 Artificially aged only

T6 Solution heat treated, then artificially aged

T7 Solution heat treated, then stabilized

T8 Solution heat treated, cold worked, then artificially aged

T9 Solution heat treated, artificially aged, then cold worked

T10 Artificially aged, then cold worked

Note that some temper designations apply only to wrought products and others to cast products; but most apply to both. A second digit may appear to the right of the mechanical treatment. This second digit indicates the degree of hardening; 2 is 1/4 hard, 4 is 1/2 hard, 6 is 3/4 hard, and 8 is full hard. For example, the alloy 5456-H32 is an aluminum/ magnesium alloy, strain hardened, then stabilized, and 1/4 hard.

Standard Marking of Metals

Metals used by the Navy are usually marked by the producer with the continuous identification marking system. We'll explain the system in the following paragraphs. Do not depend only on the markings to be sure you are using the correct metal. Often, the markings will be worn off or cut off and you are left with a piece of metal you are not sure about. Additional systems, such as separate storage areas or racks for different types of metal or etching on the metal with an electric etcher could save you time later.

The continuous identification marking system, which is described in Federal Standards, is a means for positive identification of metal products even after some portions have been used. In this system, the markings are actually "printed" on the metal with a heavy ink that is almost like a paint, and they appear at intervals of not more than 3 feet. So, if you cut off a piece of bar stock, the remaining portions will still carry the proper identification. Some metals, such as small tubing, coils of wire, and small bar stock cannot be marked readily by this method. On these items, tags with the marking information are fastened to the metal.

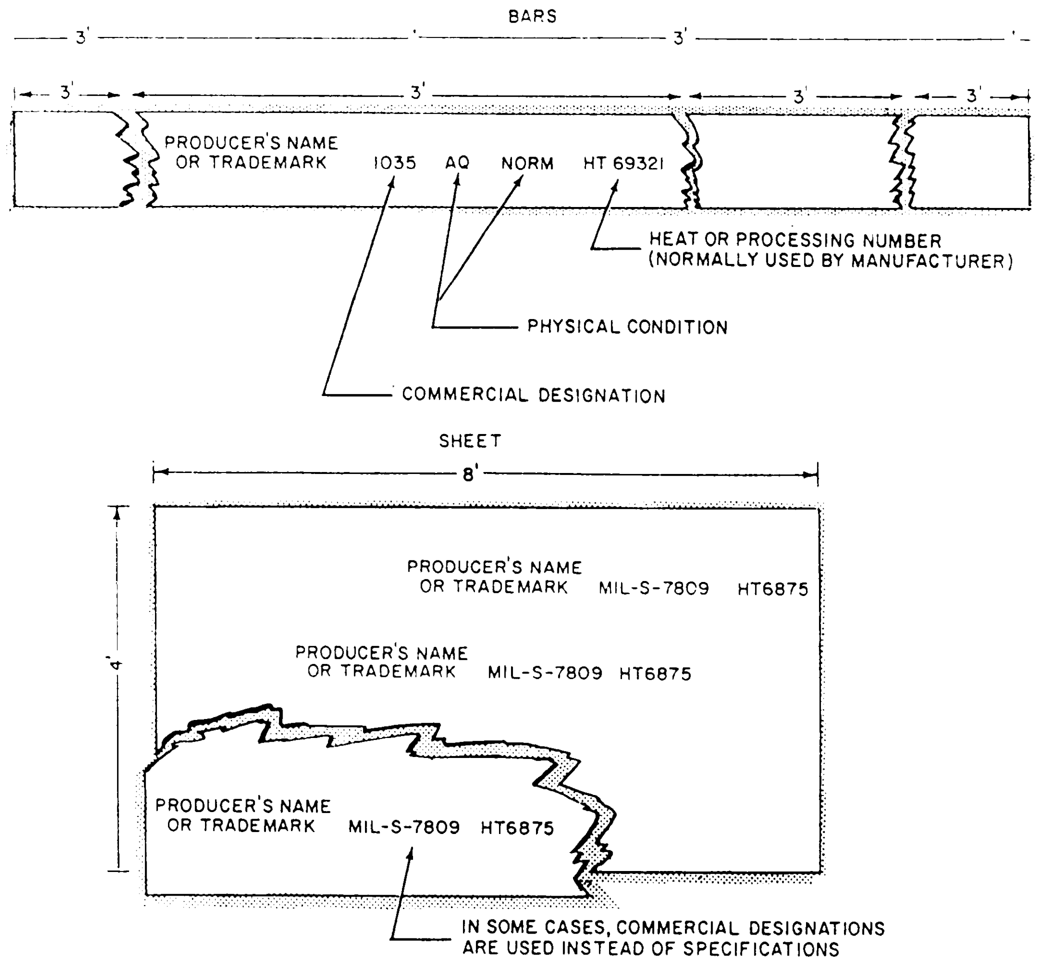

Figure 3-1.—Examples of continuous identification marking.

The manufacturer is required to make these markings on materials before delivery. The marking intervals for various shapes and forms are specified in the Federal Standard previously mentioned. Figure 3-1 shows the normal spacing and layout.

For metal products, the continuous identification marking must include (1) the producer's name or registered trademark and (2) the commercial designation of the material. In nonferrous metals the government specification for the material is often used. The producer's name or trademark shown is that of the producer who does the final processing or finishing before the material is marketed. The commercial designation includes the following information:

1. A material designation, such as an SAE number, an AISI number, or an ASTM (American Society of Testing Materials) specification

2. A "physical condition" and quality designation-that is, the designation of temper or other physical condition approved by a nationally recognized technical society or industrial association, such as the American Iron and Steel Institute

Some of the physical conditions and quality designations for various metal products are as follows:

CR . . . . cold rolled

CD . . . . cold drawn

HR . . . . hot rolled

AQ . . . . aircraft quality

CQ . . . . commercial quality

1/4H . . . . quarter hard

1/2H . . . . half hard

H . . . . hard

HTQ . . . . high tensile quality

AR . . . . as rolled

HT . . . . heat treated

G . . . . ground

IDENTIFICATION OF METALS

The various base metals, such as iron, copper, lead, zinc, and aluminum have certain identifying characteristics, such as surface appearance and weight. This helps persons who work with or handle these materials to distinguish one from another. There are, however, a number of related alloys that resemble each other and their base metal so closely that they defy accurate identification by simple means. You may have to send these metals to a shipyard for analysis.

There are other means of rapid identification of metals. These methods, however, do not provide positive identification and should not be used in critical situations where a specific metal is required. Some of the methods that we'll discuss here are magnet tests, chip tests, file tests, acid reaction tests, and spark tests. The latter two are most commonly used by the Navy and we'll discuss them in more detail. Table 3-3 contains information related to surface appearance, magnetic reaction, lathe chip test, and file test. When you perform these tests, you should compare the unknown metal with a known sample of some metal. You also will need good lighting, a strong permanent magnet, and access to a lathe. A word of caution: when you perform these tests, DO NOT be satisfied with the results of only one test. Use as many tests as possible so you can increase the chances of an accurate identification.

Spark Test

Spark testing is the identification of a metal by observing the color, size, and shape of the spark stream given off when you hold the metal against a grinding wheel. This method of identification is adequate for most machine shop purposes. When you must know the exact composition of a metal, make a chemical analysis. You need a lot of experience before you can identifiy metals by a spark test. To gain this experience, you'll need to practice by comparing the spark stream of unknown specimens

Table 3-3.—Rapid Identification of Metals

Metal	Surface Appearance or markings	Reaction to a Magnet	Lathe Chip test	Color of freshly filed surface
White cast iron	Dull gray	Strong	Short, crumbly chips	Silvery white
Gray cast iron	Dull gray	Strong	Short, crumbly chips	Light silvery gray
Aluminum	Light gray to white dull or brilliant	None	Easily cut, smooth long chips	White
Brass	Yellow to green or brown	None	Smooth long chips slightly brittle	Reddish yellow to yellowish white
Bronze	Red to brown	None	Short crumbly chips	Reddish yellow to yellowish white
Copper	Smooth; red brown to green (oxides)	None	Smooth long pliable chips	Bright copper color
Copper-nickel	Smooth; gray to yellow or yellowish green	None	Smooth, continuous chips	Bright silvery white
Lead	White to gray; smooth, velvety	None	Cut by knife, any shape chip	White
Nickel	Dark gray; smooth; sometimes green (oxides)	Medium	Cuts easily, smooth continuous chip	Bright silvery white
Nickel-copper	Dark gray, smooth	Very slight	Continuous chip; tough to cut	Light gray
Plain carbon steel	Dark gray; may be rusty	Strong	Varies depending upon carbon content	Bright silvery gray
Stainless steel (18-8) (25-20) "Note 1 below"	Dark gray; dull to brilliant; usually clean	None (faint if severely cold worked)	Varies depending upon heat treatment	Bright silvery gray
Zinc	Whitish blue, may be mottled	None	Easily cut; long stringy chips	White

1. Stainless steels that have less than 26 percent alloying elements react to magnet.

with that of known specimens. Many shops maintain specimens of known composition for this purpose.

Proper lighting conditions are essential for good spark testing. You should perform the test in an area where there is enough light, but no harsh or glaring light. You may find that many ships have a spark test cabinet. Generally, these cabinets consist of a box with a dark, painted interior, mounted on top of a workbench. A bench grinder is mounted inside the cabinet. Test specimens of known composition are stored in shelves at the end of the cabinet. Where possible, the testing area should be away from heavy drafts of air. Drafts can change the tail of the spark stream and may result in improper identification. Generally speaking, a suitable grinding wheel for spark testing is an 8-inch wheel of 30 to 60 grains turning at 3,600 rpm. This provides a surface speed of 7,537 feet per minute.

The speed of the grinding wheel and the pressure you exert on the samples greatly affect the spark test. The faster the speed of the wheel, the larger and longer the spark stream. The pressure of the piece against the wheel has a similar effect: the more pressure you apply to the test piece, the larger and longer the spark stream. Hold the test piece lightly but firmly against the wheel with just enough pressure to prevent the piece from bouncing. Remember, you must apply the same amount of pressure to the test specimen as to the sample you are testing.

Be sure to keep the wheel clean at all times. A wheel loaded with particles of metal will give off a spark stream of the type of metal in the wheel mixed with the spark stream of the metal being tested. This can confuse you and prevent you from properly identifying the metal. Dress the wheel before you begin spark testing and before each new test of a different metal.

To do a spark test, hold a sample of the material against a grinding wheel. The sparks given off, or the lack of sparks, help you identify the metal. Look for the length of the spark stream, its color, and the type of sparks.

Figure 3-2 shows the four fundamental spark forms. View A shows shafts, buds, breaks, and arrows. The arrow or spearhead is characteristic of molybdenum, a metallic element of the chromium group that resembles iron and is used to form steel-like alloys with carbon. The swelling, or buds, in the spark line indicate nickel with molybdenum. View B shows shafts and sprigs, or sparklers, that indicate a high carbon content. View C shows shafts, forks, and sprigs that indicate a medium carbon content. View D shows shafts and forks that indicate a low carbon content.

The greater the amount of carbon in a steel, the greater the intensity of bursting in the spark stream. To understand the cause of the bursts, remember that while the spark is glowing, the carbon in the particle contacts oxygen in the air and is burned to carbon dioxide (CO_2). The CO_2 in the gaseous state increases in volume and builds up pressure that is relieved by explosions of the particles. If you examine the small steel particles under a microscope when they are cold, you'll see they are hollow spheres with one end completely blown away.

Steels with the same carbon content but different alloying elements are not always easily identified because 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 retard 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 seems to suppress the effect of the carbon burst. But, the

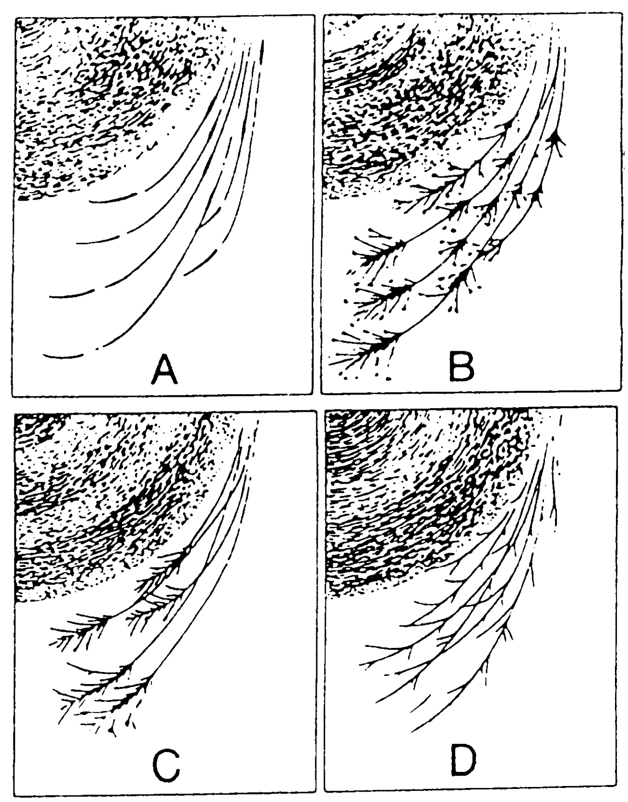

Figure 3-2.—Fundamental spark forms.

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 flash of white light.

To make the spark test, hold the piece of metal on the wheel so you throw the spark stream about 12 inches at a right angle to your line of vision. You'll need to spend a little time to learn at just what pressure you must hold the sample to get a stream of this length without reducing the speed of the grinder. Don't press too hard because the pressure will increase the temperature of the spark stream and the burst. It also will give the appearance of a higher carbon content than that of the metal being tested.

After practicing, select a couple of samples of metal with widely varying characteristics; for example, low-carbon steel and high-carbon steel. Hold first one and then the other against the wheel. Always touch the same portion of the wheel with each piece. With your eyes focused at a point about one-third the distance from the tail end of the stream of sparks, watch only those sparks that cross your line of vision. You'll find that after a little while you will form a mental image of an individual spark. After you can fix the spark image in mind, you are ready to examine the whole spark picture.

In the sample of low-carbon steel, notice that the spark stream is long (about 70 inches) and the volume is moderately large. The few sparklers that may occur are forked. In the sample of high-carbon steel, the stream is shorter (about 55 inches) and large in volume. The sparklers are small and repeating, and some of the shafts may be forked.

White cast iron produces a spark stream about 20 inches long (see fig. 3-3). The volume of sparks is small with many small, repeating sparklers. The color of the spark stream close to the wheel is red, while the outer end of the stream is straw-colored.

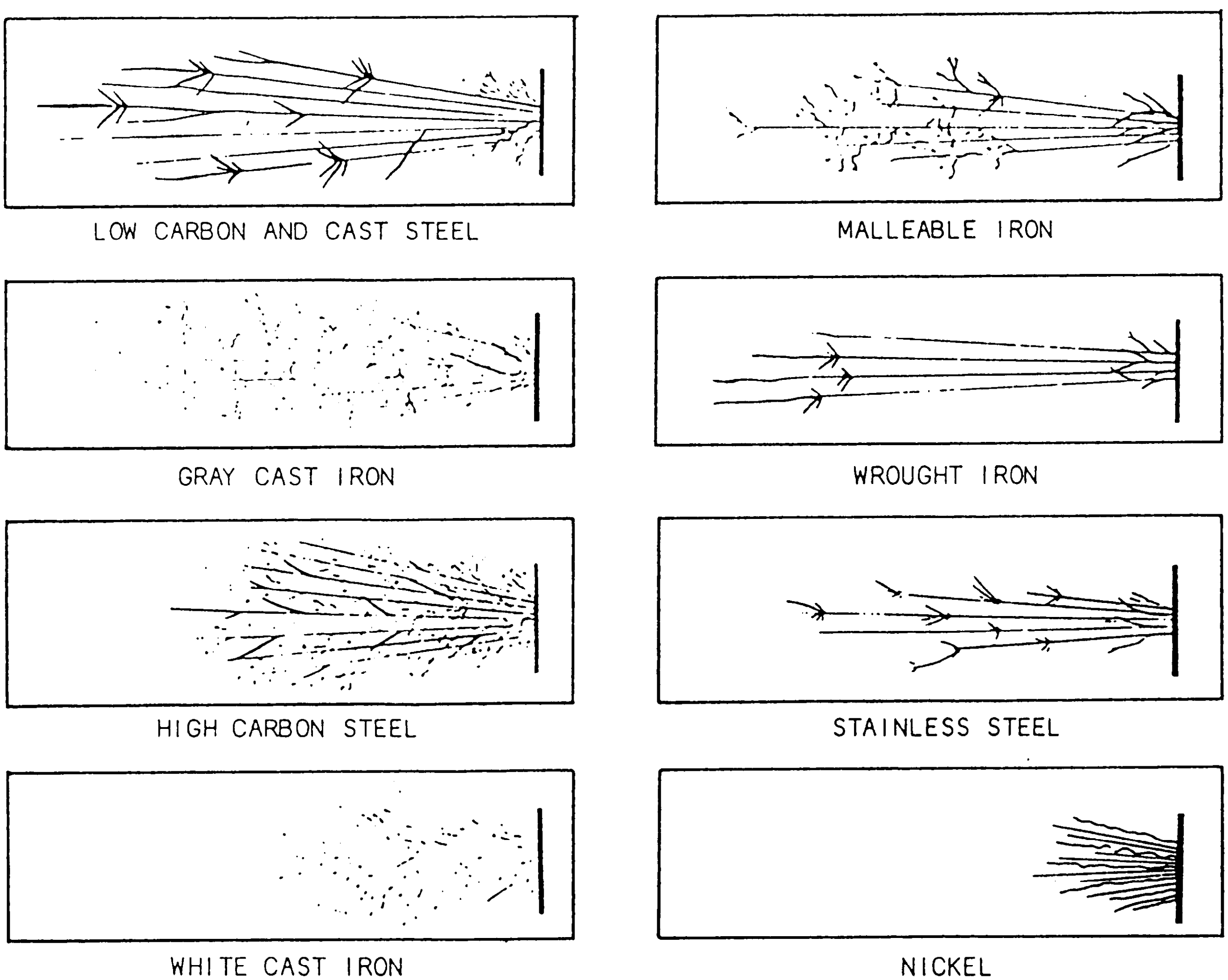

Figure 3-3.—Spark pictures formed by common metals.

Gray cast iron produces a spark stream about 25 inches long. It is small in volume with fewer sparklers than white cast iron. The sparklers are small and repeating. Part of the stream near the grinding wheel is red, and the outer end of the stream is straw-colored.

The malleable iron spark test will produce a spark stream about 30 inches long. It is of moderate volume with many small, repeating sparklers toward the end of the stream. The entire stream is straw-colored.

The wrought iron spark test produces a spark stream about 65 inches long. It has a large volume with few sparklers. The sparklers show up toward the end of the stream and are forked. The stream next to the grinding wheel is straw-colored, while the outer end of the stream is a bright red.

Stainless steel produces a spark stream about 50 inches long, of moderate volume, and with few sparklers. The sparklers are forked. The stream next to the wheel is straw-colored, and white at the end.

Nickel produces a spark stream only about 10 inches long. It is small in volume and orange in color. The sparks form wavy streaks with no sparklers.

Monel forms a spark stream almost identical to that of nickel and must be identified by other means. Copper, brass, bronze, and lead form no sparks on the grinding wheel, but you can identify them by other means, such as color, appearance, and chip tests.

You'll find the spark tests easy and convenient. They require no special equipment and are adaptable to most any situation. Here again, experience is the best teacher.

Acid Test

When you need to identify metal quickly, the nitric acid test is the most common and easiest test used in the Navy today, but you can use it only in noncritical situations. It requires no special training in chemistry. It is most helpful in distinguishing between stainless steel, Monel, copper-nickel, and carbon steels. Whenever you perform an acid test, be sure to observe all safety precautions.

To perform the nitric acid test, place one or two drops of concentrated (full strength) nitric acid on a metal surface that has been cleaned by grinding or filing. Observe the resulting reaction (if any) for about 2 minutes. Then, add three or four drops of water, one drop at a time, and continue observing the reaction. If there is no reaction at all, the test material may be one of the stainless steels. A reaction that produces a brown-colored liquid indicates' a plain carbon steel. A reaction that produces a brown to black color indicates a gray cast iron or one of the alloy steels with its principal element either chromium, molybdenum, or vanadium. Nickel steel reacts to the acid test by forming a brown to greenish-black liquid. A steel containing tungsten reacts slowly to form a brown-colored liquid with a yellow sediment.

You get a different result when you do an acid test on nonferrous metals and alloys. As the material desolves you'll see shades of green and blue instead of the brown-black colors that usually appear on ferrous metals. Except on nickel and Monel, the reaction is vigorous. Nickel's reaction to nitric acid proceeds slowly and develops a pale green color. On Monel the reaction takes place at about the same rate as on ferrous metals, but the characteristic color of the liquid is greenish-blue. Brass reacts vigorously, and the test material changes to a green color. Tin bronze, aluminum bronze, and copper all react vigorously and the liquid changes to a blue-green color. Aluminum and magnesium alloys, lead, lead-silver, and lead-tin alloys are soluble in nitric acid, but the blue or green color is lacking.

It's easy to see that you'll need good visual skill to identify the many different reactions of metals to nitric acid. Acid test kits are available containing several different solutions to identify the different metals. Some of the kits can identify between the different series of stainless steel (300, 400 series). They also can quickly identify low-alloy steels, nickel steels, and various bronze alloys. All large repair ships and shore repair facilities have a NON DESTRUCTIVE TEST (NDT) laboratory. The personnel assigned to them will help you to identify various metals in more critical situations, or when you need a greater accuracy on a repair job.

PLASTICS

Plastic materials are increasingly being used aboard ship. In some respects, they tend to surpass structural metals. Plastic is shock resistant, not susceptible to saltwater corrosion, and in casting, lends itself to mass production and uniformity of end product.

CHARACTERISTICS

Plastics are formed from organic materials, generally with some form of carbon as their basic element. Plastics are synthetic materials, but they are not necessarily inferior to natural material. On the contrary, they have been designed to perform particular functions that no natural material can perform. Plastics come in a variety of colors, shapes, and forms. Some are as tough, but not as hard, as steel; some are as pliable as rubber; some are more transparent than glass; and some are lighter than aluminum.

Plastic materials fall into two major divisions—THERMOSETTINGS and THERMOPLASTICS. It's necessary to know which one you are using if you are going to perform any kind of shopwork on plastics.

Thermosettings are tough, brittle, and heat hardened. When placed in a flame, they will not burn readily, if at all. Thermosettings are so hard that they resist the penetration of a knife blade; any such attempt will dull the blade. If the plastic is immersed in hot water and allowed to remain, it will neither absorb moisture nor soften.

Thermoplastics, on the other hand, become soft and pliable, or even melt when they are exposed to heat. When cooled, they retain the shape they took under the application of heat. Some thermoplastics will even absorb a small amount of moisture, if they are placed in hot water. A knife blade will cut easily into thermoplastics.

When you test a plastic by inserting it into a fire, be careful, because thermoplastics will burst into sudden intense flame and give off obnoxious gases. If you use the fire test, be sure to hold the plastic piece well away from you.

MAJOR GROUPS

You don't need to know the exact chemical composition of the many plastics in existence. But, it will help if you have a general idea of the composition of the plastics you are most likely to use. Table 3-4 provides information on some groups of plastics that a machinery repairman may use.

Laminated plastics are made by dipping, spraying, or brushing flat sheets or continuous rolls of paper, fabric, or wood veneer with resins, and then pressing several layers together to get hard, rigid, structural material. The number of layers that will be pressed into one sheet depends upon the thickness wanted. The end care of the product dictates the choice of paper, canvas, wood veneer, or glass fabric. Paper-based material is thin and quite brittle and it breaks if it's bent sharply, but canvas-based material is difficult to break. As layers are added to paper-based material, it gains in strength, but it's never as tough and strong in a laminated part as layers of glass fabric or canvas.

Laminated materials are widely used aboard ship. For example, laminated gears are used on internal-combustion engines, usually as timing or idler gears; on laundry equipment; and on certain pumps. In comparison with metal gears, plastic gears are quieter in operation, pick up less heat when friction is generated, and wear longer.

Plastics are identified by several commercial designations, by trade names, and by military and federal specifications. There is such a large number of types, grades, and classes of plastics within each major group that you cannot rely only on the recognition of a trade. Use the appropriate federal supply catalog to cross reference the military (MIL-P-XXXX) or federal (FED-L-P-XXXX) designations to the correct procuring data for the Federal Supply System.

MACHINING OPERATIONS

Since machining operations on plastics call for you to cut parts from sheet or rod stock, use various metal-cutting saws; remove stock from parts by rotating tools as in a drill press or a milling machine; cut moving parts with stationary tools, as on a lathe; and do finishing operations.

Sawing

You can use several types of saws—bandsaw, jigsaw, circular saw—to cut blanks from plastic stock. Watch the saw speed carefully. Since the plastic will not carry away most of the heat generated, there is always danger that the tool will overheat to the point that it will burn the work.

Drilling

In drilling plastics, back the drill out frequently to remove the chips and cool the tool. A liberal application of coolant will help keep the drill cool. To get a smooth, clean hole, use paraffin wax on the drill.

Table 3-4.—Major Groups of Plastic

Plastic Trade Names in ( )	Advantages and Examples of Uses	Disadvantages
	THERMOPLASTICS	
Acrylic (Lucite, Plexiglass)	Formability; good impact strength; good aging and weathering resistance; high transparency, shatter-resistance, rigidity. Used for lenses, dials, etc.	Softening point of 170° to 220°F; low scratch resistance.
Cellulose nitrate (Celluloid)	Ease of fabrication; relatively high impact strength and toughness; good dimensional stability and resilience; low moisture absorption. Used for tool handles, mallet heads, clock dials, etc.	Extreme flammability; poor electrical insulating properties; harder with age; low heat distortion point.
Polyamide (Nylon)	High resistance to distortion under load at temperatures up to 300°F; high tensile strength, excellent impact strength at normal temperatures; does not become brittle at temperatures as low as minus 70°F; excellent resistance to gasoline and oil; low coefficient of friction on metals. Used for synthetic textiles, special types of bearings, etc.	Absorption of water; large coefficient of expansion; relatively high cost; weathering resistance poor.
Polyethylene (Polythene)	Inert to many solvents and corrosive chemicals; flexible and tough over wide temperature range, remains so at temperatures as low as minus 100°F; unusually low moisture absorption and permeability; high electrical resistance; dimensionally stable at normal temperatures; ease of molding; low cost. Used for wire and cable insulation, and acid resistant clothing.	Low tensile, compressive, flexural strength; very high elongation at normal temperatures; subject to spontaneous cracking when stored in contact with alcohols, toluene, and silicone grease, etc.; softens at temperatures above 200°F; poor abrasion and cut resistance; cannot be bonded unless given special surface treatment.

Table 3-4.—Major Groups of Plastic—Continued

Plastic Trade Names in ( )	Advantages and Examples of Uses	Disadvantages
	THERMOPLASTICS	
Polytetrafluoroethylene (Teflon)	Extreme chemical inertness; high heat resistance; nonadhesive; tough; low coefficient of friction. Used for preformed packing and gaskets.	Not easily cemented; cannot be molded by usual methods; generates toxic fumes at high temperatures; high cost.
	THERMOSETTING PLASTICS	
Phenolformaldehyde (Bakelite, Durez, Resinox)	Better permanence characteristics than most plastics; may be used at temperatures from 250° to 475°F; good aging resistance; good electrical insulating properties; not readily flammable, does not support combustion; inserts can be firmly embedded; strong, light; low water absorption; low thermal conductivity; good chemical resistance; economical in production of complex shapes; free from cold flow; relatively insensitive to temperature; low coefficient of thermal expansion; no change in dimensions under a load for a long time; does not soften at high temperatures or become brittle down to minus 60°F; inexpensive. Used for handles, telephone equipment, electrical insulators, etc.	Difficult to mold when filled for greatest impact strength, or when in sections less than 3/32-inch thick; can be expanded or contracted by unusually wet or dry atmosphere.
Urea-formaldehyde (Beetle, Bakelite Urea, Plaskon)	High degree of translucency and light finish; hard surface finish; outstanding electrical properties when used within temperature range of minus 70° to plus 170°F; complete resistance to organic solvents; dimensionally stable under moderate loadings and exposure conditions. Used for instrument dials, electric parts, etc.	Low impact strength; slight warping with age; poor water resistance.

Lathe Operations

Lathe operations are about the same for plastics as for metals. The difference is in the type of tool and the manner in which it contacts the work. For plastics, set the tool slightly below center. Use cutting tools with zero or slightly negative back rake.

For both thermosettings and thermoplastics, recommended cutting speeds are 200 to 500 fpm with high-speed steel tools and 500 to 1,500 fpm with carbide-tipped tools.

Finishing Operations

Plastics must be finished to remove tool marks and produce a clean, smooth surface. Usually, sanding and buffing are sufficient for this purpose.

You can remove surface scratches and pits by hand sandpapering with dry sandpaper of fine grit. You also can wet-sand by hand, with water and abrasive paper of fine grade. If you need to remove a large amount of material, use sanding wheels or disks.

After you have removed the pits and scratches, buff the plastic. You can do this on a wheel made of loose muslin buffs. Use rouge buffing compounds, and deposit a layer of the compound on the outside of the buffing wheel. Renew the compound frequently.

When you buff large, flat sheets, don't use too much pressure, and don't hold the work too long in one position. When buffing small plastic parts, be careful that the wheel does not seize the piece and pull it out of your grasp.