

Unit 3. Materials and Processes

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POSSIBLY the most critical and time-consuming aspect of your duties as an aerospace technician will be preparing, inspecting, and repairing various portions of the launch vehicle. This section is designed to familiarize you with the materials and processes associated with the aerospace industry. We will begin with a look at the various processes utilized for developing both metallic and nonmetallic materials followed by a brief look at welding and soldering techniques. As you progress in this unit, you will also learn about the behavioral characteristics of ferrous and nonferrous metals, and how to identify, prevent, and repair corrosion-affected areas. Finally, the unit will conclude with an overview of the types and installation of fluid lines and fittings.

3-1. Structural Metals

Knowledge and understanding of the uses, strengths, limitations, and other characteristics of structural metals is vital to properly construct and maintain any equipment, especially airframes. In aerospace maintenance and repair, even a slight deviation from design specification, or the substitution of inferior materials, may result in the loss of both lives and equipment. The use of unsuitable materials can readily erase the finest craftsmanship. The selection of the correct material for a specific repair job demands familiarity with the most common physical properties of various metals.

220. Properties and selection factors of metals

Metallurgy is an important component for aerospace engineers and maintainers to be knowledgeable of. This allows for the best metals to be selected and used because of their various properties contributing to system success. Let us start with a review of the properties of metal followed by some selection factors.

Properties

Of primary concern in aerospace maintenance are such general properties of metals and their alloys as hardness, malleability, ductility, elasticity, toughness, density, brittleness, fusibility, conductivity

contraction and expansion, and so forth. These terms are explained to establish a basis for further discussion of structural metals.

Hardness

This term refers to the ability of a metal to resist abrasion, penetration, cutting action, or permanent distortion. Hardness may be increased by cold working the metal and, in the case of steel and certain aluminum alloys, by heat treatment. Structural parts are often formed from metals in their soft state and are then heat-treated to harden them so that the finished shape will be retained. Hardness and strength are closely associated properties of metals.

Brittleness

Brittleness is the property of a metal that allows little bending or deformation without shattering. A brittle metal is apt to break or crack without change of shape. Because structural metals are often subjected to shock loads, brittleness is not a very desirable property. Cast iron, cast aluminum, and very hard steel are examples of brittle metals.

Malleable

A metal that can be hammered, rolled, or pressed into various shapes without cracking, breaking, or leaving some other detrimental effect is said to be malleable. This property is necessary in sheet metal that is worked into curved shapes such as cowlings, fairings, or wingtips. Copper is an example of a malleable metal.

Ductility

Ductility is the property of a metal that permits it to be permanently drawn, bent, or twisted into various shapes without breaking. This property is essential for metals used in making wire and tubing. Ductile metals are greatly preferred for aerospace use because of their ease of forming and resistance to failure under shock loads. Chrome molybdenum steel is also easily formed into desired shapes. Ductility is similar to malleability.

Elasticity

This property enables a metal to return to its original shape when the force that causes the change of shape is removed. This property is extremely valuable because it would be highly undesirable to have a part permanently distorted after an applied load was removed. Each metal has a point known as the elastic limit beyond which it cannot be loaded without causing permanent distortion. In spacecraft construction, members and parts are so designed that the maximum loads to which they are subjected will not stress them beyond their elastic limits. This desirable property is present in spring steel.

Toughness

A material that possesses toughness will withstand tearing or shearing and may be stretched or otherwise deformed without breaking. Toughness is a desirable property in spacecraft metals.

Density

This is the weight of a unit volume of a material. In the aerospace industry, the specified weight of a material per cubic inch is preferred since this figure can be used in determining the weight of a part before actual manufacture. Density is an important consideration when choosing a material to be used in the design of a component [of a spacecraft] in order to maintain the proper weight and balance.

Fusibility

The ability of a metal to become liquid by the application of heat is fusibility. Metals are fused in welding. For example, steels fuse around 2,600° F and aluminum alloys at approximately 1,100° F.

Conductivity

Conductivity is the property that enables a metal to carry heat or electricity. The heat conductivity of a metal is especially important in welding because it governs the amount of heat that will be required for proper fusion. Conductivity of a metal, to a certain extent, determines the type of jig to be used to control expansion and contraction. To eliminate radio interference in spacecraft, electrical conductivity must also be considered in conjunction with bonding.

Contraction and expansion

Reactions produced in metals as the result of heating or cooling are known as contraction and expansion. Heat applied to a metal will cause it to expand or become larger. Cooling and heating affect the design of welding jigs, castings, and tolerances necessary for hot-rolled material.

Selection factors

Strength, weight, and reliability are three factors that determine the requirements to be met by any material used in airframe construction and repair. Airframes must be strong and yet as light in weight as possible. There are very definite limits to which increases in strength can be accompanied by increases in weight. An airframe so heavy that it could not support a few hundred pounds of additional weight would be of little use.

All metals, in addition to having a good strength/weight ratio, must be thoroughly reliable. The inherent reliability of a metal minimizes the possibility of dangerous and unexpected failures. In addition to these general properties, the material selected for a definite application must possess specific qualities suitable for the purpose.

Strength

The material must possess the strength required by the dimensions, weight, and use. There are five basic stresses that metals may be required to withstand. These are tension, compression, shear, bending, and torsion.

Tension

The tensile strength of a material is its resistance to a force that tends to pull it apart. Tensile strength is measured in psi and is calculated by dividing the load, in pounds, required to pull the material apart by its cross-sectional area, in square inches.

Compression

The compression strength of a material is its resistance to a crushing force that is the opposite of tensile strength. Compression strength is also measured in psi.

Shear

When a piece of metal is cut, the material is subjected, as it comes in contact with the cutting edge, to a force known as shear. Shear is the tendency on the part of parallel members to slide in opposite directions. It is like placing a cord or thread between the blades of a pair of scissors. The shear strength is the shear force in psi at which a material fails. It is the load divided by the shear area.

Bending

Bending can be described as the deflection or curving of a member due to forces acting upon it. The bending strength of material is the resistance it offers to deflecting forces.

Torsion

This is a twisting force. Such action would occur in a member fixed at one end and twisted at the other. The torsional strength of material is its resistance to twisting.

Weight

The relationship between the strength of a material and its weight per cubic inch, expressed as a ratio, is known as the strength/weight ratio. This ratio forms the basis for comparing the desirability of various materials for use in airframe construction and repair. Neither strength nor weight alone can be used as a means of true comparison. In some applications, the material with the lightest weight for a given thickness or gauge is best. Thickness or bulk is necessary to prevent bucking or damage caused by careless handling.

Reliability

Due to the extreme environments encountered by a space-lift system, either awaiting launch at a coastal, salt-air rich spaceport or during post-launch flight through the atmosphere into space, the materials used must be carefully chosen to combine the best mix of corrosion resistance and workability.

Stress resistance

Metals used in space-lift applications are subjected to both shock and fatigue (vibrational) stresses. Fatigue occurs in materials that are exposed to frequent reversals of loading or repeatedly applied loads, if the fatigue limit is reached or exceeded. Repeated vibration or bending will ultimately cause a minute crack to occur at the weakest point. As vibration or bending continues, the crack lengthens until the part completely fails. This is termed shock and fatigue failure. Resistance to this condition is known as shock and fatigue resistance. It is essential that materials used for critical parts be resistant to these stresses.

Corrosion resistance

Corrosion is the eating away or pitting of the surface or the internal structure of metals. Because of the thin sections used in spacecraft design and construction, it would be unwise to select a material possessing poor corrosion-resistant characteristics.

Cold working

Another significant factor to consider in maintenance and repair is the ability of a material to be formed, bent, or machined to required shapes. The hardening of metals by cold working or forming is termed work hardening. If a piece of metal is formed (shaped or bent) while cold, it is said to be cold-worked. Practically all the work an aerospace mechanic does on metal is cold-work. While this is convenient, it causes the metal to become harder and more brittle.

If the metal is cold-worked too much, that is, if it is bent back and forth or hammered at the same place too often, it will crack or break. Usually, the more malleable and ductile a metal is, the more cold working it can withstand.

Heat treatment

Any process that involves controlled heating and cooling of metals to develop certain desirable characteristics (such as hardness, softness, ductility, tensile strength, or refined grain structure) is called heat treatment or heat treating. With steels the term heat treating has a broad meaning and includes such processes as annealing, normalizing, hardening, and tempering.

In the heat treatment of aluminum alloys, only two processes are included: (1) the hardening/toughening process, and (2) the softening process. The hardening/toughening process is called heat treating, and the softening process is called annealing.

221. Metalworking processes

The primary methods of metalworking are known as hot working, cold working, extruding, and welding/soldering. The method used will depend on the metal involved and the part required, although in some instances multiple methods may be used to make a single part.

Hot working

Almost all steel is hot worked from the ingot into some form, from which it is either hot or cold worked to the finished shape. When an ingot is stripped from its mold, its surface is solid, but the interior is still molten. The ingot is then placed into a soaking pit that retards loss of heat, and the molten interior gradually solidifies. After soaking, the temperature is equalized throughout the ingot, then it is reduced to intermediate size by rolling, making it more readily handled.

Rolling

The rolled shape is called a bloom when its section dimensions are 6 x 6 inches or larger and approximately square. The section is called a billet when it is approximately square and less than 6 x 6 inches. Rectangular sections that have a width greater than twice their thickness are called slabs. The slab is the intermediate shape from which sheets are rolled.

Blooms, billets, or slabs are heated above the critical range and rolled into a variety of shapes of uniform cross section. The more common of these rolled shapes are sheet, bar, channels, angles, I-beams, and the like. As will be discussed later in this unit, hot-rolled material is frequently finished by cold rolling or drawing to obtain accurate finish dimensions and a bright, smooth surface.

Forging

Complicated sections that cannot be rolled, or sections of which only a small quantity is required, are usually forged. Forging of steel is a mechanical working at temperatures above the critical range to shape the metal as desired. Forging is done either by pressing or hammering the heated steel until the desired shape is obtained.

Pressing

Pressing is used when the parts to be forged are large and heavy; this process also replaces hammering where high-grade steel is required. Since a press is slow acting, its force is uniformly transmitted to the center of the section, thus affecting the interior grain structure as well as the exterior to give the best possible structure throughout.

Hammering

Hammering can be used only on relatively small pieces. Since hammering transmits its force almost instantly, its effect is limited to a small depth. Thus, it is necessary to use a very heavy hammer or to subject the part to repeated blows to ensure complete working of the section. If the force applied is too weak to reach the center, the finished forged surface will be concave. If the center was properly worked, the surface will be convex or bulged. The advantage of hammering is that the operator has control over both the amount of pressure applied and the finishing temperature and is able to produce small parts of the highest grade. This type of forging is usually referred to as smith forging. It is used extensively where only a small number of parts are needed. Considerable machining time and material are saved when a part is smith forged to approximately the finished shape.

Tempering

Steel is often harder than necessary and too brittle for most practical uses when put under severe internal strain. To relieve the internal strain and reduce brittleness, it is tempered after being hardened. This consists of heating the steel in a furnace to a specified temperature and then cooling it in air, oil, water, or a special solution. Temper condition refers to the condition of metal or metal alloys with respect to hardness or toughness. Rolling, hammering, or bending these alloys, or heat-treating and aging them, causes them to become tougher and harder. At times these alloys become too hard for forming and have to be re-heat-treated or annealed.

Annealing

Metals are annealed to relieve internal stresses, soften the metal, make it more ductile, and refine the grain structure. Annealing consists of heating the metal to a prescribed temperature, holding it there

for a specified length of time, and then cooling the metal back to room temperature. To produce maximum softness, the metal must be cooled very slowly. Some metals must be furnace cooled; others may be cooled in air.

Normalizing

Normalizing applies to iron-base metals only. Normalizing consists of heating the part to the proper temperature, holding it at that temperature until it is uniformly heated, and then cooling it in still air. Normalizing is used to relieve stresses in metals.

Cold working

Cold working applies to mechanical working performed at temperatures below the critical range. It results in a strain hardening of the metal. In fact, the metal often becomes so hard that it is difficult to continue the forming process without softening the metal by annealing.

Since the errors attending shrinkage are eliminated in cold working, a much more compact and better metal is obtained. The strength and hardness, as well as the elastic limit, are increased; but the ductility decreases. Since this makes the metal more brittle, it must be heated from time to time during certain operations to remove the undesirable effects of the working.

Bending

When metals are bent, the material on the outside of a curve stretches, while the material on the inside of the curve compresses. There is a location near the middle of the metal thickness that neither shrinks nor stretches. This is called the neutral line, or the neutral axis, of the material.

A closed angle is an angle that has been bent beyond 90 degrees. In order to form a closed angle of 15 degrees, the sheet must be bent through an angle of 165 degrees ($180 \text{ degrees} - 15 \text{ degrees} = 165 \text{ degrees}$).

Cold rolling

Cold rolling usually refers to the working of metal at room temperature. In this operation, the materials that have been rolled to approximate sizes are pickled to remove the scale, after which they are passed through chilled finishing rolls. This gives a smooth surface and also brings the pieces to accurate dimensions. The principal forms of cold-rolled stocks are sheets, bars, and rods.

Cold drawing

Cold drawing is used in making seamless tubing, wire, streamlined tie rods, and other forms of stock. Wire is made from hot-rolled rods of various diameters. These rods are pickled in acid to remove scale, dipped in lime water, and then dried in a steam room where they remain until ready for drawing. The lime coating adhering to the metal serves as a lubricant during the drawing operation.

The size of the rod used for drawing depends upon the diameter wanted in the finished wire. To reduce the rod to the desired size, it is drawn cold through a die. One end of the rod is filed or hammered to a point and slipped through the die opening. Here it is gripped by the jaws of the drawing block and pulled through the die. This series of operations is done by a mechanism known as a draw bench.

In order to reduce the rod gradually to the desired size, it is necessary to draw the wire through successively smaller dies. Because each of these drawings reduces the ductility of the wire, it must be annealed from time to time before further drawings can be accomplished. Although cold working reduces the ductility, it increases the tensile strength of the wire.

In making seamless steel tubing, the tubing is cold drawn through a ring-shaped die with a mandrel or metal bar inside the tubing to support it while the drawing operations are being performed. This forces the metal to flow between the die and the mandrel and affords a means of controlling the wall thickness and the inside and outside diameters.

Extruding

The extrusion process involves the forcing of metal through an opening in a die, thus causing the metal to take the shape of the die opening. Some metals such as lead, tin, and aluminum may be extruded cold; but generally metals are heated before the operation is begun.

The principal advantage of the extrusion process is its flexibility. Aluminum, because of its workability and other favorable properties, can be economically extruded to more intricate shapes and larger sizes than is practicable with many other metals.

Extruded shapes are produced in very simple as well as extremely complex sections. In this process a cylinder of aluminum, for instance, is heated to 750° F to 850° F and is then forced through the opening of a die by a hydraulic ram. The opening is the shape desired for the cross section of the finished extrusion.

Many structural parts, such as channels, angles, T-sections, and Z-sections are formed by the extrusion process.

Welding and brazing

With the development of new techniques during the first half of the 20th century, welding replaced bolting and riveting in the construction of many types of structures. It is also a basic process in the automotive and aircraft industries and in the manufacture of machinery. Along with soldering, it is essential in the production of virtually every manufactured product involving metals. The use of electron beams and lasers for welding has grown during the second half of the 20th century. These methods produce high-quality welded products at a rapid rate. Laser welding and electron-beam welding have valuable applications in the aerospace industry.

When making a good weld, the heat should be concentrated in the area being welded. If oxides are formed much more than 1/2 inch from the weld it is likely that too much heat was put into the metal and the metal may have been weakened.

As was mentioned previously, heat causes metal to expand. Cooling causes it to contract. If a metal is cooled too quickly after it is welded, it will contract unevenly and stresses will remain in the metal. These stresses produce cracks adjacent to the weld.

The most important consideration when selecting a welding rod is its compatibility with the material being welded.

Although there is a popular belief that brazing and soldering are inferior substitutes for welding, they have advantages over welding in many situations. For example, brazing brass has a strength and hardness near that of mild steel and is much more corrosion resistant. In some applications, brazing is highly preferred. For example, silver brazing is the customary method of joining high-reliability, controlled-strength, corrosion-resistant piping such as seawater coolant pipes. Silver brazed parts can also be precisely machined after joining, to hide the presence of the joint to all but the most discerning observers, whereas it is nearly impossible to machine welds having any residual slag present and still hide joints.

222. Ferrous metals

Many different metals are required in the repair of space-lift vehicles. This is a result of the varying needs with respect to strength, weight, durability, and resistance to deterioration of specific structures of parts. In addition, the particular shape or form of the material plays an important role. In selecting materials for repair, these factors plus many others are considered in relation to the mechanical and physical properties. Among the common materials used are ferrous metals. The term *ferrous* applies to the group of metals having iron as their principal constituent.

Identification

If carbon is added to iron, in percentages ranging up to approximately 1 percent, the product is vastly superior to iron alone and is classified as carbon steel. Carbon steel forms the base of those alloy steels produced by combining carbon steel with other elements known to improve the properties of steel. A base metal (such as iron) to which small quantities of other metals have been added is called an alloy. The addition of other metals changes or improves the chemical or physical properties of the base metal for a particular use.

Nomenclature and chemical compositions of steels

In order to facilitate the discussion of steels, some familiarity with their nomenclature is desirable. A numerical index, sponsored by the Society of Automotive Engineers (SAE) and the American Iron and Steel Institute (AISI), is used to identify the chemical compositions of the structural steels. The list of standard steels is altered from time to time to accommodate steels of proven merit and to provide for changes in the metallurgical and engineering requirements of industry.

Nomenclature

A four numeral series is used to designate the plain carbon and alloy steels; five numerals are used to designate certain types of alloy steels. The first two digits indicate the type of steel, the second digit also generally (but not always) gives the approximate amount of the major alloying element, and the last two (or three) digits are intended to indicate the approximate amount of carbon. However, a deviation from the rule of indicating the carbon range is sometimes necessary.

Composition

Small quantities of certain elements are present in alloy steels that are not specified as required. These elements are considered as incidental and may be present to the maximum amounts as follows: copper, 0.35 percent; nickel, 0.25 percent; chromium, 0.20 percent; molybdenum, 0.06 percent.

Metal stock

Metal stock is manufactured in several forms and shapes, including sheets, bars, rods, tubings, extrusions, forgings, and castings. Sheet metal is made in a number of sizes and thicknesses. Specifications designate thicknesses in thousandths of an inch. Bars and rods are supplied in a variety of shapes, such as round, square, rectangular, hexagonal, and octagonal. Tubing can be obtained in round, oval, rectangular, or streamlined shapes. The size of tubing is generally specified by outside diameter and wall thickness.

The sheet metal is usually formed cold in such machines as presses, bending brakes, draw benches, or rolls. Forgings are shaped or formed by pressing or hammering heated metal in dies. Castings are produced by pouring molten metal into molds. The casting is finished by machining.

Testing

Spark testing is a common means of identifying various ferrous metals. In this test the piece of iron or steel is held against a revolving grinding stone and the metal is identified by the sparks thrown off. Each ferrous metal has its own peculiar spark characteristics. The spark streams vary from a few tiny shafts to a shower of sparks several feet in length. (Few nonferrous metals give off sparks when touched to a grinding stone. Therefore, these metals cannot be successfully identified by the spark test.)

Identification by spark testing is often inexact unless performed by an experienced person, or the test pieces differ greatly in their carbon content and alloying constituents.

Wrought iron produces long shafts that are straw colored as they leave the stone and white at the end. Cast iron sparks are red as they leave the stone and turn to a straw color. Low-carbon steels give off long, straight shafts having a few white sprigs. As the carbon content of the steel increases, the

number of sprigs along each shaft increases, and the stream becomes whiter in color. Nickel steel causes the spark stream to contain small white blocks of light within the main burst.

Types, characteristics, and uses of alloyed steels

The following section identifies the three main types of alloyed steels used in the aerospace industry: carbon, nickel, and chromium.

Carbon steels

The first type of steel derives its physical properties from the presence of varying quantities of carbon. Arguably the most common type of steel produced worldwide, the carbon steels are used in almost every aspect of our daily lives.

Low-carbon steel

Steel containing carbon in percentages ranging from 0.10 to 0.30 percent is classed as low-carbon steel. The equivalent SAE numbers range from 1010 to 1030. Steels of this grade are used for making such items as safety wire, certain nuts, cable bushings, or threaded rod ends. This steel in sheet form is used for secondary structural parts and clamps and in tubular form for moderately stressed structural parts.

Medium-carbon steel

Steel containing carbon in percentages ranging from 0.30 to 0.50 percent is classed as medium-carbon steel. This steel is especially adaptable for machining or forging, and where surface hardness is desirable. Certain rod ends and light forgings are made from SAE 1035 steel.

High-carbon steel

Steel containing carbon in percentages ranging from 0.50 to 1.05 percent is classed as high-carbon steel. The addition of other elements in varying quantities adds to the hardness of this steel. In the fully heat-treated condition, it is very hard, will withstand high shear and wear, and will have little deformation.

Nickel steel

The various nickel steels are produced by combining nickel with carbon steel. Steels containing from 3 to 3.75 percent nickel are commonly used. Nickel increases the hardness, tensile strength, and elastic limit of steel without appreciably decreasing the ductility. It also intensifies the hardening effect of heat treatment. SAE 2330 steel is used extensively for spacecraft parts, such as bolts, terminals, keys, clevises, and pins.

Chromium steel

Chromium steels are high in hardness, strength, and corrosion-resistant properties and are particularly adaptable for heat-treated forgings that require greater toughness and strength than may be obtained in plain-carbon steel. It can be used for such articles as the balls and rollers of antifriction bearings.

Chrome-nickel (stainless) steel

Chrome-nickel or stainless steels are the corrosion-resistant metals. The anticorrosive degree of this steel is determined by the surface condition of the metal as well as by the composition, temperature, and concentration of the corrosive agent. The principal alloy of stainless steel is chromium. The corrosion-resistant steel most often used in construction is known as 18-8 steel because of its content of 18 percent chromium and 8 percent nickel. One of the distinctive features of 18-8 steel is that its strength may be increased by cold working.

Stainless steel may be rolled, drawn, bent, or formed to any shape. Because these steels expand about 50 percent more than mild steel and conduct heat only about 40 percent as rapidly, they are more difficult to weld. Stainless steel can be used for almost any part of a spacecraft. Some of its common

applications are in the fabrication of exhaust collectors, stacks and manifolds, structural and machined parts, springs, castings, tie rods, and control cables.

Chrome-vanadium steel

The chrome-vanadium steels are made of approximately 18 percent vanadium and about 1 percent chromium. When heat-treated, they have strength, toughness, and resistance to wear and fatigue. A special grade of this steel in sheet form can be cold formed into intricate shapes. It can be folded and flattened without signs of breaking or failure. SAE 6150 is used for making springs; and chrome-vanadium with high-carbon content, SAE 6195, is used for ball and roller bearings.

Chrome-molybdenum steel

Molybdenum in small percentages is used in combination with chromium to form chrome-molybdenum steel, which has various uses. Molybdenum is a strong alloying element. It raises the ultimate strength of steel without affecting ductility or workability. Molybdenum steels are tough and wear resistant, and they harden throughout when heat-treated. They are especially adaptable for welding and, for this reason, are used principally for welded structural parts and assemblies. This type steel has practically replaced carbon steel in the fabrication of fuselage tubing, engine mounts, and other structural parts. For example, a heat-treated SAE X4130 tube is approximately four times as strong as an SAE 1025 tube of the same weight and size.

A series of chrome-molybdenum steel most used in spacecraft construction is that series containing 0.25 to 0.55 percent carbon, 0.15 to 0.25 percent molybdenum, and 0.50 to 1.10 percent chromium. These steels, when suitably heat-treated, are deep hardening, easily machined, readily welded by either gas or electric methods, and are especially adapted to high-temperature service.

Inconel

Inconel is a nickel-chromium-iron alloy closely resembling stainless steel (corrosion-resistant steel, CRES) in appearance. Exhaust systems use both alloys interchangeably. Because the two alloys look very much alike, a distinguishing test is often necessary. One method of identification is to use an electrochemical technique to identify the nickel (Ni) content of the alloy. Inconel has nickel content greater than 50 percent, and the electrochemical test detects Ni. The tensile strength of Inconel is 100,000 psi annealed and 125,000 psi, when hard rolled. It is highly resistant to salt water and is able to withstand temperatures as high as 1,600° F. Inconel welds readily and has working qualities quite similar to those of corrosion-resistant steels.

223. Nonferrous metals

The term *nonferrous* refers to all metals that have elements other than iron as their base or principal constituent. This group includes such metals as aluminum, titanium, copper, and magnesium, as well as such alloyed metals as Monel and Babbitt.

Aluminum and aluminum alloys

Commercially pure aluminum is a white lustrous metal that stands second in the scale of malleability, sixth in ductility, and ranks high in its resistance to corrosion. Aluminum combined with various percentages of other metals forms alloys that are used in spacecraft construction.

Aluminum alloys, in which the principal alloying ingredients are either manganese, chromium, or magnesium and silicon, show little attack in corrosive environments. Alloys in which substantial percentages of copper are used are more susceptible to corrosive action. The total percentage of alloying elements is seldom more than 6 or 7 percent in the wrought alloys.

Aluminum

Aluminum is one of the most widely used metals in modern construction. It is vital to the space-lift industry because of its high strength-to-weight ratio and its comparative ease of fabrication. The

outstanding characteristic of aluminum is its light weight. Aluminum melts at the comparatively low temperature of 1,250° F. It is nonmagnetic and is an excellent conductor.

Commercially pure aluminum has a tensile strength of about 13,000 psi, but by rolling or other cold-working processes, its strength may be doubled, more or less. By alloying with other metals, or by using heat-treating processes, the tensile strength may be raised to as high as 65,000 psi or to within the strength range of structural steel.

Aluminum alloys

Aluminum alloys, although strong, are easily worked because they are malleable and ductile. They may be rolled into sheets as thin as 0.0017 in. or drawn into wire 0.004 in. in diameter. Most aluminum-alloy sheet stock used in spacecraft construction ranges from 0.016 to 0.096 in. in thickness.

The various types of aluminum alloys may be divided into two general classes, wrought and casting.

Wrought alloys

Wrought alloys (those that may be shaped by rolling, drawing, or forging) are the most widely used in spacecraft construction and are being used for stringers, bulkheads, skin, rivets, and extruded sections. Wrought aluminum alloys are divided into two general classes, non-heat-treatable alloys and heat-treatable alloys.

- Non-heat-treatable alloys are those in which the mechanical properties are determined by the amount of cold work introduced after the final annealing operation. The mechanical properties obtained by cold working are destroyed by any subsequent heating and cannot be restored except by additional cold working, which is not always possible. The “full hard” temper is produced by the maximum amount of cold work that is commercially practicable. Metal in the “as fabricated” condition is produced from the ingot without any subsequent controlled amount of cold working or thermal treatment. There is, consequently, a variable amount of strain hardening, depending upon the thickness of the section.
- For heat-treatable aluminum alloys, the mechanical properties are obtained by heat treating to a suitable temperature, holding at that temperature long enough to allow the alloying constituent to enter into solid solution, and then quenching the constituent in solution. The metal is left in a supersaturated, unstable state and is then age hardened either by natural aging at room temperature or by artificial aging at some elevated temperature.

Casting alloys

The casting alloys (those suitable for casting in sand, permanent mold, or die castings) are further divided into two basic groups. In one, the physical properties of the alloys are determined by the alloying elements and cannot be changed after the metal is cast. In the other, the alloying elements make it possible to heat-treat the casting to produce the desired physical properties.

The casting alloys are identified by a letter preceding the alloy number. When a letter precedes a number, it indicates a slight variation in the composition of the original alloy. This variation in composition is simply to impart some desirable quality. In casting alloy 214, for example, the addition of zinc to improve its pouring qualities is indicated by the letter A in front of the number, thus creating the designation A214.

When castings have been heat-treated, the heat treatment and the composition of the casting are indicated by the letter T, followed by an alloying number. An example of this is the sand-casting alloy 355, which has several different compositions and tempers and is designated by 355-T6, 355-T51, or C355-T51.

Aluminum alloy designations

Wrought aluminum and wrought aluminum alloys are designated by a four-digit index system. The system is broken into three distinct groups: 1xxx group, 2xxx–8xxx group, and 9xxx group (unused).

1xxx group

This 99 percent pure (or higher) aluminum has excellent corrosion resistance, high thermal and electrical conductivity, low mechanical properties, and excellent workability. Iron and silicon are major impurities.

The first digit of a designation identifies the alloy type.

The second digit indicates specific alloy modifications. Should the second number be zero, it would indicate no special control over individual impurities. Digits 1–9, however, when assigned consecutively as needed for the second number in this group, indicate the number of controls over individual impurities in the metal.

The last two digits of the 1xxx group are used to indicate the hundredths of 1 percent above the original 99 percent designated by the first digit. If the last two digits were 30, the alloy would contain 99 percent plus 0.30 percent of pure aluminum or a total of 99.30 percent pure aluminum.

Examples of alloys in this group are as follows:

- 1100 - 99.00 percent pure aluminum with one control over individual impurities.
- 1130 - 99.30 percent pure aluminum with one control over individual impurities.
- 1275 - 99.75 percent pure aluminum with two controls over individual impurities.

2xxx–8xxx groups

The first digit indicates the major alloying element used in the formation of the alloy as follows:

- 2xxx - Copper is the principle alloying element. Solution heat treatment, optimum properties equal to mild steel, poor corrosion-resistance unclad. It is usually clad with 6000 or high purity alloy. Its best known alloy is 2024.
- 3xxx - Manganese is the principle alloying element of this group, which is generally non-heat-treatable. The percentage of manganese that will be alloy effective is 1.5 percent. The most popular is 3003, which is of moderate strength and has good working characteristics.
- 4xxx - Silicon is the principle alloying element. This lowers the melting temperature. Its primary use is in welding and brazing. When used in welding heat-treatable alloys, this group will respond to a limited amount of heat treatment.
- 5xxx - Magnesium is the principle alloying element. It has good welding and corrosion-resistant characteristics. High temperatures (over 150° F) or excessive cold working will increase susceptibility to corrosion.
- 6xxx - Silicon and magnesium form magnesium silicide, which makes alloys heat treatable. It is of medium strength, is good forming, and has corrosion-resistant characteristics.
- 7xxx - Zinc is the principle alloying element. The most popular alloy of the series is 6061. When coupled with magnesium, it results in heat-treatable alloys of very high strength. It usually has copper and chromium added. The principle alloy of this is 7075.
- 8xxx - other elements.

The second digit in the alloy designation indicates alloy modifications. If the second digit is zero, it indicates the original alloy, while digits 1–9 indicate alloy modifications.

Hardness identification

Alloying is not the only method of increasing the strength of aluminum. Like other materials, aluminum becomes stronger and harder as it is rolled, formed, or otherwise cold worked. Since the hardness depends on the amount of cold working done, 1100 and some wrought aluminum alloys are available in several strain-hardened tempers. The soft or annealed condition is designated “O.” If the material is strain hardened, it is said to be in the “H” condition.

Where used, the temper designation follows the alloy designation and is separated from it by a dash (i.e., 7075-T6, 2024-T4, etc.). The temper designation consists of a letter indicating the basic temper which may be more specifically defined by the addition of one or more digits. These designations are as follows:

- 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 partially annealed.
- H3 - (plus one or more digits) Strain hardened and stabilized.

The digit following the designations H1, H2, and H3 indicate the degree of strain hardening, no. 8 representing the ultimate tensile strength equal to that achieved by a cold reduction of approximately 75 percent following a full anneal, O representing the annealed state.

Heat-treatment identification

In the wrought form, commercially pure aluminum is known as 1100. It has a high degree of resistance to corrosion and is easily formed into intricate shapes. It is relatively low in strength and does not have the properties required for structural aircraft parts. High strengths are generally obtained by the process of alloying. The resulting alloys are less easily formed and, with some exceptions, have lower resistance to corrosion than 1100 aluminum.

The most widely used alloys are hardened by heat treatment rather than by cold work. These alloys are designated by a somewhat different set of symbols:

- W - Solution heat-treated, unstable temper.
- 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.

Aluminum-alloy sheets are marked with the specification number on approximately every square foot of material. If for any reason this identification is not on the material, it is possible to separate the heat-treatable alloys from the non-heat-treatable alloys by immersing a sample of the material in a 10 percent solution of caustic soda (sodium hydroxide). The heat-treatable alloys will turn black due to the copper content, whereas the others will remain bright. In the case of clad material, the surface will remain bright, but there will be a dark area in the middle when viewed from the edge.

Alclad aluminum

The terms *alclad* and *pureclad* are used to designate sheets that consist of an aluminum-alloy core coated with a layer of pure aluminum to a depth of approximately 5.5 percent on each side. The pure aluminum coating affords a dual protection for the core—preventing contact with any corrosive agents and protecting the core electrolytically by preventing any attack caused by scratching or from other abrasions.

Titanium and titanium alloys

The use of titanium is widespread. It is used in many commercial enterprises and is in constant demand for such items as pumps, screens, and other tools and fixtures where corrosion attack is prevalent. In spacecraft construction and repair, titanium is used for fuselage skins, engine shrouds, firewalls, frames, fittings, and fasteners.

Titanium, in appearance, is similar to stainless steel. One quick method used to identify titanium is the spark test. Titanium gives off a brilliant white trace ending in a brilliant white burst. Also, identification can be accomplished by moistening the titanium and using it to draw a line on a piece of glass. This will leave a dark line similar in appearance to a pencil mark.

Titanium falls between aluminum and stainless steel in terms of elasticity, density, and elevated temperature strength. It has a melting point of 2,730° F to 3,155° F, low thermal conductivity, and a low coefficient of expansion. It is light, strong, and resistant to stress-corrosion cracking. Titanium is approximately 60 percent heavier than aluminum and about 50 percent lighter than stainless steel.

Because of the high melting point of titanium, high temperature properties are disappointing. The ultimate yield strength of titanium drops rapidly above 800° F. The absorption of oxygen and nitrogen from the air at temperatures above 1,000° F makes the metal so brittle on long exposure that it soon becomes worthless. However, titanium does have some merit for short-time exposure up to 3,000° F where strength is not important.

Titanium is nonmagnetic and has an electrical resistance comparable to that of stainless steel. Some of the base alloys of titanium are quite hard. Heat treating and alloying do not develop the hardness of titanium to the high levels of some of the heat-treated alloys of steel. It was only recently that a heat-treatable titanium alloy was developed. Prior to the development of this alloy, heating and rolling was the only method of forming that could be accomplished. However, it is possible to form the new alloy in the soft condition and heat-treat it for hardness.

Iron, molybdenum, and chromium are used to stabilize titanium and produce alloys that will quench harden and age harden. The addition of these metals also adds ductility. The fatigue resistance of titanium is greater than that of aluminum or steel.

Titanium becomes softer as the degree of purity is increased. It is not practical to distinguish between the various grades of commercially pure or unalloyed titanium by chemical analysis; therefore, the grades are determined by mechanical properties.

Titanium designations

The A, B, C classifications of titanium alloys were established to provide a convenient and simple means of describing all titanium alloys. Titanium and titanium alloys possess three basic types of crystals: A (alpha), B (beta), and C (combined alpha and beta). Their characteristics are as follows:

- A (alpha) - All-around performance; good weldability; tough and strong both cold and hot, and resistant to oxidation.
- B (beta) - Bendability; excellent bend ductility; strong both cold and hot, but vulnerable to contamination.

- C (combined alpha and beta for compromise performances) - Strong when cold and warm, but weak when hot; good bendability; moderate contamination resistance; excellent forgeability.

Titanium is manufactured for commercial use in two basic compositions: commercially pure titanium and alloyed titanium. A-55 is an example of commercially pure titanium. It has yield strength of 55,000 to 80,000 psi and is a general purpose grade for moderate to severe forming. It is sometimes used for nonstructural aircraft parts and all types of corrosion-resistant applications, such as tubing. Type A-70 titanium is closely related to type A-55 but has yield strength of 70,000 to 95,000 psi. It is used where higher strength is required, and it is specified for many moderately stressed aircraft parts. For many corrosion applications, it is used interchangeably with type A-55. Both type A-55 and type A-70 are weldable.

One of the widely used titanium-base alloys is designated as C-110M. It has 110,000 psi minimum-yield strength, and contains 8 percent manganese.

Type A-110AT is a titanium alloy that contains 5 percent aluminum and 2.5 percent tin. It also has high minimum-yield strength at elevated temperatures with the excellent welding characteristics inherent in alpha-type titanium alloys.

Corrosion characteristics

The corrosion resistance of titanium deserves special mention. The resistance of the metal to corrosion is caused by the formation of a protective surface film of stable oxide or chemi-absorbed oxygen. Film is often produced by the presence of oxygen and oxidizing agents.

Corrosion of titanium is uniform. There is little evidence of pitting or other serious forms of localized attack. Normally, it is not subject to stress corrosion, corrosion fatigue, intergranular corrosion, or galvanic corrosion. Its corrosion resistance is equal or superior to 18-8 stainless steel.

Laboratory tests with acid and saline solutions show titanium polarizes readily. The net effect, in general, is to decrease current flow in galvanic and corrosion cells. Corrosion currents on the surface of titanium and metallic couples are naturally restricted. This partly accounts for good resistance to many chemicals. Also, the material may be used with some dissimilar metals with no harmful galvanic effect on either.

Copper

Copper is one of the most widely distributed nonferrous metals. It is the only reddish-colored metal and is second only to silver in electrical conductivity. Its use as a structural material is limited because of its great weight. However, some of its outstanding characteristics, such as its high electrical and heat conductivity, in many cases overbalance the weight factor.

Because it is very malleable and ductile, copper is ideal for making wire. It is corroded by salt water but is not affected by fresh water. The ultimate tensile strength of copper varies greatly. For cast copper, the tensile strength is about 25,000 psi, and when cold rolled or cold drawn, its tensile strength increases to a range of 40,000 to 67,000 psi.

Copper alloys

Small amounts of alloying elements are added to copper to improve certain characteristics of the metal. Alloying copper can increase or reduce its strength, hardness, electrical or thermal conductivity, and corrosion resistance. The addition of a substance to improve one property may have unintended effects on other properties. This section describes the effects of various alloying elements with copper to create copper alloys.

Beryllium copper

Beryllium copper is one of the most successful of all the copper-base alloys. It is a recently developed alloy containing about 97 percent copper, 2 percent beryllium, and sufficient nickel to increase the

percentage of elongation. The most valuable feature of this metal is that the physical properties can be greatly stepped up by heat treatment, the tensile strength rising from 70,000 psi in the annealed state to 200,000 psi in the heat-treated state. The resistance of beryllium copper to fatigue and wear makes it suitable for diaphragms, precision bearings and bushings, ball cages, and spring washers.

Brass

Brass is a copper alloy containing zinc and small amounts of aluminum, iron, lead, manganese, magnesium, nickel, phosphorous, and tin. Brass with a zinc content of 30 to 35 percent is very ductile, but that containing 45 percent has relatively high strength.

Muntz metal

Muntz metal is a brass composed of 60 percent copper and 40 percent zinc. It has excellent corrosion-resistant qualities in salt water. Its strength can be increased by heat treatment. As cast, this metal has an ultimate tensile strength of 50,000 psi, and it can be elongated 18 percent. It is used in making bolts and nuts, as well as parts that come in contact with salt water.

Red brass

Red brass, sometimes termed bronze because of its tin content, is used in fuel and oil-line fittings. This metal has good casting and finishing properties and machines freely.

Bronze

Bronzes are copper alloys containing tin. The true bronzes have up to 25 percent tin, but those with less than 11 percent are most useful, especially for such items as tube fittings.

Aluminum bronze

These copper-base alloys contain up to 16 percent aluminum (usually 5 to 11 percent), to which other metals such as iron, nickel, or manganese may be added. Aluminum bronzes have good tearing qualities, great strength, hardness, and resistance to both shock and fatigue. Because of these properties, they are used for diaphragms, gears, and pumps. Aluminum bronzes are available in rods, bars, plates, sheets, strips, and forgings.

- Wrought aluminum bronzes are almost as strong and ductile as medium-carbon steel, and they possess a high degree of resistance to corrosion by air, salt water, and chemicals. They are readily forged, hot- or cold-rolled, and many react to heat treatment.
- Cast aluminum bronzes, using about 89 percent copper, 9 percent aluminum, and 2 percent of other elements, have high strength combined with ductility and are resistant to corrosion, shock, and fatigue. Because of these properties, cast aluminum bronze is used in bearings and pump parts. These alloys are useful in areas exposed to salt water and corrosive gases.

Manganese bronze

Manganese bronze is an exceptionally high-strength, tough, corrosion-resistant copper-zinc alloy containing aluminum, manganese, iron, and occasionally nickel or tin. This metal can be formed, extruded, drawn, or rolled to any desired shape. In rod form, it is generally used for machined parts, for aircraft landing gears, and brackets.

Silicon bronze

Silicon bronze is a more recent development composed of about 95 percent copper, 3 percent silicon, and 2 percent manganese, zinc, iron, tin, and aluminum. Although not a bronze in the true sense because of its small tin content, silicon bronze has high strength and great corrosion resistance.

Monel

Monel, the leading high-nickel alloy, combines the properties of high strength and excellent corrosion resistance. This metal consists of 68 percent nickel, 29 percent copper, 0.2 percent iron, 1 percent manganese, and 1.8 percent of other elements. It cannot be hardened by heat treatment.

Monel, adaptable to casting and hot or cold working, can be successfully welded. It has working properties similar to those of steel. When forged and annealed, it has a tensile strength of 80,000 psi. This can be increased to 125,000 psi by cold working, sufficient for classification among the tough alloys.

Monel has been successfully used for gears and chains to operate retractable landing gears and structural parts subject to corrosion. In aircraft, Monel is used for parts demanding both strength and high resistance to corrosion (such as exhaust manifolds and carburetor needle valves and sleeves).

K-Monel

K-Monel is a nonferrous alloy containing mainly nickel, copper, and aluminum. It is produced by adding a small amount of aluminum to the Monel formula. It is corrosion resistant and capable of being hardened by heat treatment. K-Monel has been successfully used for gears, and structural members in aircraft that are subjected to corrosive attacks. This alloy is nonmagnetic at all temperatures. K-Monel sheet has been successfully welded by both oxyacetylene and electric-arc welding.

Magnesium and magnesium alloys

Magnesium, the world's lightest structural metal, is a silvery white material weighing only two-thirds as much as aluminum. Magnesium does not possess sufficient strength in its pure state for structural uses, but when alloyed with zinc, aluminum, and manganese, it produces an alloy having the highest strength-to-weight ratio of any of the commonly used metals.

Magnesium alloys possess good casting characteristics. Their properties compare favorably with those of cast aluminum. In forging, hydraulic presses are ordinarily used; although, under certain conditions, forging can be accomplished in mechanical presses or with drop hammers.

Magnesium alloys are subject to such treatments as annealing, quenching, solution heat treatment, aging, and stabilizing. Sheet and plate magnesium are annealed at the rolling mill. The solution heat treatment is used to put as much of the alloying ingredients as possible into solid solution, which results in high tensile strength and maximum ductility. Aging is applied to castings following heat treatment where maximum hardness and yield strength are desired.

Magnesium embodies fire hazards of an unpredictable nature. When in large sections, its high thermal conductivity makes it difficult to ignite and prevents it from burning. It will not burn until the melting point is reached, which is 1,204° F. However, magnesium dust and fine chips are ignited easily. Precautions must be taken to avoid this if possible. Should a fire occur, it can be extinguished with an extinguishing powder, such as powdered soapstone or graphite powder. Water or any standard liquid or foam fire extinguishers cause magnesium to burn more rapidly and can cause explosions. Magnesium alloys produced in the United States consist of magnesium alloyed with varying proportions of aluminum, manganese, and zinc. These alloys are designated by a letter of the alphabet, with the no. 1 indicating high purity and maximum corrosion resistance.

224. Heat treatment

The deliberate and controlled process of heating and cooling metal affects its strength. During this lesson, you will learn about the principles of heat treatment and the heat treatment of ferrous metals and nonferrous metals.

Principles of heat treatment

Heat treatment is a series of operations involving the heating and cooling of metals in the solid state. Its purpose is to change a mechanical property or combination of mechanical properties so that the metal will be more useful, serviceable, and safe for a definite purpose. By heat treating, a metal can be made harder, stronger, and more resistant to impact. Heat treating can also make a metal softer and more ductile. No one heat-treating operation can produce all of these characteristics. In fact, some properties are often improved at the expense of others. In being hardened, for example, a metal may become brittle.

The various heat-treating processes are similar in that they all involve the heating and cooling of metals. They differ, however, in the temperatures to which the metal is heated, the rate at which it is cooled, and, of course, in the final result.

The most common forms of heat treatment for ferrous metals are hardening, tempering, normalizing, annealing, and case-hardening. Most nonferrous metals can be annealed, and many of them can be hardened by heat treatment. However, titanium is only one nonferrous metal that can be case-hardened, and none can be tempered or normalized.

Successful heat treating requires close control over all factors affecting the heating and cooling of metals.

Internal structure of metals

The results obtained by heat treatment depend to a great extent on the structure of the metal and on the manner in which the structure changes when the metal is heated and cooled. A pure metal cannot be hardened by heat treatment because little change occurs in its structure when heated. The two primary internal structures result from alloying or mechanical mixture.

Alloying

An alloy may be in the form of a solid solution, a mechanical mixture, or a combination of a solid solution and a mechanical mixture. When an alloy is in the form of a solid solution, the elements and compounds that form the alloy are absorbed, one into the other, in much the same way that salt is dissolved in a glass of water, and the constituents cannot be identified even under a microscope.

Mechanical mixtures

When two or more elements or compounds are mixed but can be identified by microscopic examination, a mechanical mixture is formed. A mechanical mixture can be compared to the mixture of sand and gravel in concrete—the sand and gravel are both visible. Just as the sand and gravel are held together and kept in place by the matrix of cement, the other constituents of an alloy are embedded in the matrix formed by the base metal.

Heat treatment of ferrous metals

The first, and most important, consideration in the heat treatment of a steel part is to determine its critical points. The critical points of steel are the temperatures at which certain changes in the chemical composition of the steel take place, during both heating and cooling. Steel at normal temperatures has its carbon (which is the chief hardening element) in a certain form called *pearlite* carbon; and if the steel is heated to a certain temperature, a change occurs, and the pearlite becomes *martensite* or hardening carbon. If the steel is allowed to cool slowly, the hardening carbon changes back to pearlite. The points at which these changes occur are the *decalescence* and *recalescence* or critical points, and the effect of these molecular changes is as follows: When a piece of steel is heated to a certain point, it continues to absorb heat without appreciably rising in temperature, although its immediate surroundings may be hotter than the steel. This is the *decalescence* point. Similarly, steel cooling slowly from a high heat will, at a certain temperature, actually increase in temperature, although its surroundings may be colder. This takes place at the *recalescence* point. When the upper critical point is known, the next consideration is the rate of heating and cooling to be used. Carrying

out these operations involves the use of uniform heating furnaces, proper temperature controls, and suitable quenching mediums.

Behavior of steel during heating and cooling

Changing the internal structure of a ferrous metal is accomplished by heating it to a temperature above its upper critical point, holding it at that temperature for a time sufficient to permit certain internal changes to occur, and then cooling to atmospheric temperature under predetermined, controlled conditions.

At ordinary temperatures, the carbon in steel exists in the form of particles of iron carbide scattered throughout an iron matrix known as “ferrite.” The number, size, and distribution of these particles determine the hardness of the steel. At elevated temperatures, the carbon is dissolved in the iron matrix in the form of a solution called “austenite,” and the carbide particles appear only after the steel has been cooled. If the cooling is slow, the carbide particles are relatively coarse and few. In this condition, the steel is soft. If the cooling is rapid, as by quenching in oil or water, the carbon precipitates as a cloud of very fine carbide particles, and the steel is hard. The fact that the carbide particles can be dissolved in austenite is the basis of the heat treatment of steel. The temperatures at which this transformation takes place are called the critical points and vary with the composition of the steel. The element normally having the greatest influence is carbon.

Hardening

Pure iron, wrought iron, and extremely low-carbon steels cannot be appreciably hardened by heat treatment, since they contain no hardening element. Cast iron can be hardened, but its heat treatment is limited. When cast iron is cooled rapidly, it forms white iron, which is hard and brittle. When cooled slowly, it forms gray iron, which is soft but brittle under impact.

In plain-carbon steel, the maximum hardness depends almost entirely on the carbon content of the steel, as carbon content increases, the ability of the steel to be hardened increases. However, this increase in hardenability with an increase in carbon content continues only to a certain point. In practice, that point is 0.85 percent carbon content. When the carbon content is increased beyond 0.85 percent, there is no increase in wear resistance.

For most steels, the hardening treatment consists of heating the steel to a temperature just above the upper critical point, soaking or holding for the required length of time, and then cooling it rapidly by plunging the hot steel into oil, water, or brine. Although most steels must be cooled rapidly for hardening, a few may be cooled in still air. Hardening increases the hardness and strength of the steel but makes it less ductile.

Because of the high internal stresses in the “as quenched” condition, steel must be tempered just before it becomes cold. The part should be removed from the quenching bath at a temperature of approximately 200° F, since the temperature range from 200° F down to room temperature is the cracking range.

Tempering

Tempering reduces the brittleness imparted by hardening and produces definite physical properties within the steel. Tempering always follows, never precedes, the hardening operation. In addition to reducing brittleness, tempering softens the steel.

Tempering is always conducted at temperatures below the low critical point of the steel. In this respect, tempering differs from annealing, normalizing, or hardening, all of which require temperatures above the upper critical point. When hardened steel is reheated, tempering begins at 212° F and continues as the temperature increases toward the low critical point. By selecting a definite tempering temperature, the resulting hardness and strength can be predetermined. The minimum time at the tempering temperature should be one hour. If the part is over one inch in thickness, the time should be increased by one hour for each additional inch of thickness.

Annealing

Annealing of steel produces a fine-grained, soft, ductile metal without internal stresses or strains. In the annealed state, steel has its lowest strength. In general, annealing is the opposite of hardening.

Annealing of steel is accomplished by heating the metal to just above the upper critical point, soaking at that temperature, and then cooling very slowly in the furnace. Soaking time is approximately one hour per inch of thickness of the material. To produce maximum softness in steel, the metal must be cooled very slowly. Slow cooling is obtained by shutting off the heat and allowing the furnace and metal to cool together to 900° F or lower, and then removing the metal from the furnace and cooling in still air. Another method is to bury the heated steel in ashes, sand, or other substance that does not readily conduct heat.

Normalizing

Normalizing of steel removes the internal stresses set up by heat treating, welding, casting, forming, or machining. Stress, if not controlled, will lead to failure. Because of the better physical properties, aircraft steels are often used in the normalized state but seldom, if ever, in the annealed state.

One of the most important uses of normalizing is on welded parts. Welding causes strains to be set up in the adjacent material. In addition, the weld itself is a cast structure as opposed to the wrought structure of the rest of the material. These two types of structures have different grain sizes, and to refine the grain as well as to relieve the internal stresses, all welded parts should be normalized after fabrication.

Normalizing is accomplished by heating the steel above the upper critical point and cooling in still air. The more rapid quenching obtained by air cooling, as compared to furnace cooling, results in a harder and stronger material than that obtained by annealing.

Case-hardening

Case-hardening produces a hard wear-resistant surface or case over a strong, tough core. Case-hardening is ideal for parts that require a wear-resistant surface and, at the same time, must be tough enough internally to withstand the applied loads. The steels best suited to case-hardening are the low-carbon and low alloy steels. If high-carbon steel is case-hardened, the hardness penetrates the core and causes brittleness. In case-hardening, the surface of the metal is changed chemically by introducing a high carbide or nitride content. The core is unaffected chemically.

Heat treatment of nonferrous metals

Nonferrous metals are heat-treated for many of the same reasons that ferrous metals are. The temperatures and processes, however, differ due to the differing compositions of the nonferrous group of metals. The next couple pages will focus on the more common nonferrous metals: aluminum, magnesium, titanium, and their alloys.

Aluminum alloys

There are two types of heat treatments applicable to aluminum alloys. One is called solution heat treatment, and the other is known as precipitation heat treatment. Some alloys, such as 2017 and 2024, develop their full properties as a result of solution heat treatment followed by about four days of aging at room temperature. Other alloys, such as 2014 and 7075, require both heat treatments.

Solution heat treatment

The term *solution heat treatment* means heat treatment of a metal with the purpose to dissolve particles precipitated in the matrix. It is done by heating the material to a temperature above the solution temperature of the actual particles and soaking the material for a period of time.

Temperature

The temperatures used for solution heat treating vary with different alloys and range from 825° F to 980° F. As a rule, they must be controlled within a very narrow range (plus or minus 10° F) to obtain specified properties.

If the temperature is too low, maximum strength will not be obtained. When excessive temperatures are used, there is danger of melting the low-melting constituents of some alloys with consequent lowering of the physical properties of the alloy. Even if melting does not occur, the use of higher than recommended temperatures promotes discoloration and increases quenching strains.

Time at temperature

The time at temperature, referred to as soaking time, is measured from the time the coldest metal reaches the minimum limit of the desired temperature range. The soaking time varies, depending upon the alloy and thickness, from 10 minutes for thin sheets to approximately 12 hours for heavy forgings. For the heavy sections, the nominal soaking time is approximately one hour for each inch of cross-sectional thickness.

The soaking time is chosen so that it will be the minimum time necessary to develop the required physical properties. The effect of an abbreviated soaking time is obvious. An excessive soaking period aggravates high-temperature oxidation. With clad material, prolonged heating results in excessive diffusion of copper and other soluble constituents in the protective cladding and may defeat the purpose of cladding.

Quenching

After the soluble constituents are in solid solution, the material is quenched to prevent or retard immediate reprecipitation. Three distinct quenching methods are employed: cold, hot, and spray. The one to be used in any particular instance depends upon the part, the alloy, and the properties desired.

- Cold-water quenching - Parts produced from sheet, extrusions, tubing, small forgings, and similar type material are generally quenched in a cold-water bath. The temperature of the water before quenching should not exceed 85° F. A sufficient quantity of water should be used to keep the temperature rise under 20° F. Such a drastic quench ensures maximum resistance to corrosion. This is particularly important when working with such alloys as 2017, 2024, and 7075. This is the reason a drastic quench is preferred, even though a slower quench may produce the required mechanical properties.
- Hot-water quenching - Large forgings and heavy sections can be quenched in hot or boiling water. This type of quench minimizes distortion and alleviates cracking that may be produced by the unequal temperatures obtained during the quench. The use of a hot-water quench is permitted with these parts because the temperature of the quench water does not critically affect the resistance to corrosion of the forging alloys. In addition, the resistance to corrosion of heavy sections is not as critical a factor as for thin sections.
- Spray quenching - High-velocity water sprays are useful for parts formed from clad sheet and large sections of almost all alloys. This type of quench also minimizes distortion and alleviates quench cracking. However, many specifications forbid the use of spray quenching for bare 2017 and 2024 sheet materials because of the effect on their resistance to corrosion.

Lag between soaking and quenching

The time interval between the removal of the material from the furnace and quenching is critical for some alloys and should be held to a minimum. When solution heat-treating 2017 or 2024 sheet material, the elapsed time must not exceed 10 seconds. The allowable time for heavy sections may be slightly greater.

Allowing the metal to cool slightly before quenching promotes reprecipitation from the solid solution. The precipitation occurs along grain boundaries and in certain slip planes causing poorer formability. In the case of 2017, 2024, and 7075 alloys, their resistance to intergranular corrosion is adversely affected.

Reheat treatment

The treatment of material that has been previously heat-treated is considered a reheat treatment. The unclad heat-treatable alloys can be solution heat-treated repeatedly without harmful effects.

The number of solution heat treatments allowed for clad sheet is limited due to increased diffusion of core and cladding with each reheating. Existing specifications allow one to three reheat treatments of clad sheet depending upon cladding thickness.

Straightening after solution heat treatment

During solution heat treatment, some warping occurs, producing kinks, buckles, waves, and twists. These imperfections are generally removed by straightening and flattening operations.

Where the straightening operations produce an appreciable increase in the tensile and yield strengths and a slight decrease in the percent of elongation, the material is designated T3 temper. When the above values are not materially affected, the material is designated T4 temper.

Precipitation heat treating

As previously stated, the aluminum alloys are in a comparatively soft state immediately after quenching from a solution heat-treating temperature. To obtain their maximum strengths, they must be either naturally aged or precipitation hardened.

During this hardening and strengthening operation, precipitation of the soluble constituents from the supersaturated solid solution takes place. As precipitation progresses, the strength of the material increases, often by a series of peaks, until a maximum is reached. Further aging (overaging) causes the strength to steadily decline until a somewhat stable condition is obtained. The submicroscopic particles that are precipitated provide the keys or locks within the grain structure and between the grains to resist internal slippage and distortion when a load of any type is applied. In this manner, the strength and hardness of the alloy are increased.

Precipitation hardening produces a great increase in the strength and hardness of the material with corresponding decreases in the ductile properties. The process used to obtain the desired increase in strength is therefore known as aging or precipitation hardening.

Precipitation practices

The temperatures used for precipitation hardening depend upon the alloy and the properties desired, ranging from 250° F to 375° F. They should be controlled within a very narrow range (plus or minus 5°) to obtain best results.

The time at temperature is dependent upon the temperature used, the properties desired, and the alloy. It ranges from eight to 96 hours. Increasing the aging temperature decreases the soaking period necessary for proper aging. However, a closer control of both time and temperature is necessary when using the higher temperatures.

After receiving the thermal precipitation treatment, the material should be air cooled to room temperature. Water quenching, while not necessary, produces no ill effects. Furnace cooling has a tendency to produce overaging.

Annealing of aluminum alloys

The annealing procedure for aluminum alloys consists of heating the alloys to an elevated temperature, holding or soaking them at this temperature for a length of time depending upon the mass of the metal, and then cooling in still air. Annealing leaves the metal in the best condition for cold working. However, when prolonged forming operations are involved, the metal will take on a condition known as "mechanical hardness" and will resist further working. It may be necessary to anneal a part several times during the forming process to avoid cracking. Aluminum alloys should not be used in the annealed state for parts or fittings.

Clad parts should be heated as quickly and carefully as possible since long exposure to heat tends to cause some of the constituents of the core to diffuse into the cladding. This reduces the corrosion resistance of the cladding.

Magnesium alloys

Magnesium-alloy castings respond readily to heat treatment, and about 95 percent of the magnesium used in construction is in the cast form. The heat treatment of magnesium-alloy castings is similar to the heat treatment of aluminum alloys in that there are two types of heat treatment:

1. Solution heat treatment
2. Precipitation (aging) heat treatment.

Magnesium, however, develops a negligible change in its properties when allowed to age naturally at room temperatures

Solution heat treatment

Magnesium-alloy castings are solution heat-treated to improve tensile strength, ductility, and shock resistance. This heat-treatment condition is indicated by using the symbol T4 following the alloy designation. Solution heat treatment plus artificial aging is designated-T6. Artificial aging is necessary to develop the full properties of the metal.

Solution treatment temperatures for magnesium-alloy castings range from 730° F to 780° F, the exact range depending upon the type of alloy. The temperature range for each type of alloy is listed in Specification MIL-H-6857, *Heat Treatment of Castings*. The upper limit of each range listed in the specification is the maximum temperature to which the alloy may be heated without danger of melting the metal.

The soaking time ranges from 10 to 18 hours, the exact time depending upon the type of alloy as well as the thickness of the part. Soaking periods longer than 18 hours may be necessary for castings over two inches in thickness. Magnesium alloys must NEVER be heated in a salt bath as this may result in an explosion.

A serious potential fire hazard exists in the heat treatment of magnesium alloys. If through oversight or malfunctioning of equipment, the maximum temperatures are exceeded, the casting may ignite and burn freely. Air quenching is used after solution heat treatment of magnesium alloys since there appears to be no advantage in liquid cooling.

Precipitation heat treatment

After solution treatment, magnesium alloys may be given an aging treatment to increase hardness and yield strength. Generally, the aging treatments are used merely to relieve stress and stabilize the alloys in order to prevent dimensional changes later, especially during or after machining. Both yield strength and hardness are improved somewhat by this treatment at the expense of a slight amount of ductility. The corrosion resistance is also improved, making it closer to the “as cast” alloy.

Precipitation heat-treatment temperatures are considerably lower than solution heat-treatment temperatures and range from 325° F to 500° F. Soaking time ranges from four to 18 hours.

Titanium

Titanium is heat-treated for the following purposes:

- Relief of stresses set up during cold forming or machining.
- Annealing after hot working or cold working or to provide maximum ductility for subsequent cold working.
- Thermal hardening to improve strength.

Stress relieving

Stress relieving is generally used to remove stress concentrations resulting from forming of titanium sheet. It is performed at temperatures ranging from 650° F to 1,000° F. The time at temperature varies from a few minutes for a very thin sheet to an hour or more for heavier sections. A typical stress relieving treatment is 900° F for 30 minutes followed by an air cool.

The discoloration or scale that forms on the surface of the metal during stress relieving is easily removed by pickling in acid solutions. The recommended solution contains 10 to 20 percent nitric acid and 1 to 3 percent hydrofluoric acid. The solution should be at or slightly above room temperature.

Full annealing

The annealing of titanium and titanium alloys provides toughness, ductility at room temperature, dimensional and structural stability at elevated temperatures, and improved machinability.

The full annealing is usually called for as preparation for further working. It is performed at 1,200° F to 1,650° F. The time at temperature varies from 16 minutes to several hours, depending on the thickness of the material and the amount of cold work to be performed. The usual treatment for the commonly used alloys is 1,300° F for one hour followed by an air cool. A full annealing generally results in sufficient scale formation to require the use of caustic descaling, such as sodium-hydride salt bath.

Thermal hardening

Unalloyed titanium *cannot* be heat-treated, but the alloys commonly used in spacecraft construction can be strengthened by thermal treatment, usually at some sacrifice in ductility. For best results, a water quench from 1,450° F, followed by reheating to 900° F for eight hours, is recommended.

Case-hardening

The chemical activity of titanium and its rapid absorption of oxygen, nitrogen, and carbon at relatively low temperatures make case-hardening advantageous for special applications. Nitriding, carburizing, or carbonitriding can be used to produce a wear-resistant case of 0.0001 to 0.0002 inch in depth.

225. Hardness testing

Hardness testing is a method of determining the results of heat treatment as well as the state of a metal prior to heat treatment. Since hardness values can be tied in with tensile-strength values and, in part, with wear resistance, hardness tests are a valuable check of heat-treat control and of material properties.

Practically all hardness-testing equipment now uses the resistance to penetration as a measure of hardness. Included among the better known hardness testers are the Brinell and Rockwell—both are described in this section. Also included is a popular portable-type hardness tester currently being used, the Barcol tester.

Brinell tester

The Brinell tester (fig. 3-1) uses a hardened spherical ball, which is forced into the surface of the metal. This ball is 10 millimeters (0.3937 inch) in diameter. A pressure of 3,000 kilograms is used for ferrous metals and 500 kilograms for nonferrous metals. The pressure must be maintained at least 10 seconds for ferrous metals and at least 30 seconds for nonferrous metals. The load is applied by hydraulic pressure. The hydraulic pressure is built up by a hand pump or an electric motor, depending on the model of tester. A pressure gauge indicates the amount of pressure. There is a release mechanism for relieving the pressure after the test has been made, and a calibrated microscope is provided for measuring the diameter of the impression in millimeters. The machine has various

shaped anvils for supporting the specimen and an elevating screw for bringing the specimen in contact with the ball penetrator. These are attachments for special tests.

In order to determine the Brinell-hardness number for a metal, the diameter of the impression is first measured, using the calibrated microscope furnished with the tester. After measuring the diameter of the impression, the measurement is converted into the Brinell-hardness number on the conversion table furnished with the tester



Figure 3-1. Brinell tester. (Reproduced by permission of Newage Testing Instruments, Inc., Southampton, PA, <http://www.hardnesstesters.com/brinell-hardness-tester.htm>.)



Figure 3-2. Rockwell tester. (Reproduced by permission of Newage Testing Instruments, Inc., Southampton, PA, <http://www.hardnesstesters.com/rockwell-hardness-tester.com>.)

Rockwell tester

The Rockwell tester (fig. 3-2) measures the resistance to penetration, as does the Brinell tester. Instead of measuring the diameter of the impression, the Rockwell tester measures the depth, and the hardness is indicated directly on a dial attached to the machine. The dial numbers in the outer circle are black, and the inner numbers are red. Rockwell-hardness numbers are based on the difference between the depth of penetration at major and minor loads. The greater this difference is, the less the hardness number and the softer the material.

Two types of penetrators are used with the Rockwell tester, a diamond cone and a hardened steel ball. The load that forces the penetrator into the metal is called the major load and is measured in kilograms. The results of each penetrator and load combination are reported on separate scales, designated by letters. The penetrator, the major load, and the scale vary with the kind of metal being tested.

The Rockwell tester is equipped with a weight pan, and two weights are supplied with the machine. One weight is marked in red; the other weight is marked in black. With no weight in the weight pan, the machine applies a major load of 60 kilograms. If the scale setup calls for a 100-kilogram load, the red weight is placed in the pan. For a 150-kilogram load, the black weight is added to the red weight. The black weight is always used with the red weight; it is never used alone.

The metal to be tested in the Rockwell tester must be ground smooth on two opposite sides and be free of scratches and foreign matter. The surface should be perpendicular to the axis of penetration, and the two opposite ground surfaces should be parallel. If the specimen is tapered, the amount of

error will depend on the taper. A curved surface will also cause a slight error in the hardness test. The amount of error depends on the curvature (i.e., the smaller the radius of curvature, the greater the error). To eliminate such error, a small flat should be ground on the curved surface if possible.

Clad aluminum-alloy sheets cannot be tested directly with any accuracy with a Rockwell hardness tester. If the hardness value of the base metal is desired, the pure aluminum coating must be removed from the area to be checked prior to testing.

Barcol tester

The Barcol tester (fig. 3-3) is a portable unit designed for testing aluminum alloys, copper, brass, or other relatively soft materials. It should not be used on steels. The approximate range of the tester is 25 to 100 Brinell. The unit can be used in any position and in any space that will allow for the operator's hand. It is of great value in the hardness testing of assembled or installed parts, especially to check for proper heat treatment. The hardness is indicated on a dial conveniently divided into 100 graduations.



Figure 3-3. Barcol tester.
(Reproduced by permission of Plastics Technology Laboratories, Inc.,
Pittsfield, MA, <http://www.ptli.com>.)

The design of the Barcol tester is such that specialized operator training is not necessary. It is only necessary to exert a light pressure against the instrument to drive the spring-loaded indenter into the material being tested. The hardness reading is instantly indicated on the dial.

Each tester is supplied with a test disk for checking the condition of the point. To check the point, press the instrument down on the test disk. When the downward pressure brings the end of the lower plunger guide against the surface of the disk, the indicator reading should be within the range shown on the test disk.

226. Nondestructive inspection (NDI) fundamentals

The inspection of parts for cracks or casting irregularities is critical. With few exceptions, the failure of a part following launch will have catastrophic consequences to the mission. Your ability to utilize the various inspection processes will be the key to your success or failure as a technician.

Magnetic particle inspection

Magnetic particle inspection is a method of detecting invisible cracks and other defects in ferromagnetic materials, such as iron and steel. This method of inspection is a nondestructive test, which means it is performed on the actual part without damage to the part. It is not applicable to nonmagnetic materials.

In rapidly rotating, reciprocating, vibrating, and other highly stressed parts, small defects often develop to the point that they cause complete failure of the part. Magnetic particle inspection has proved extremely reliable for the rapid detection of such defects located on or near the surface. In using this method of inspection, the location of the defect is indicated and the approximate size and shape are outlined.

The inspection process consists of magnetizing the part and then applying ferromagnetic particles to the surface area to be inspected. The ferromagnetic particles (indicating medium) may be held in suspension in a liquid (wet process) that is flushed over the part; the part may be immersed in the suspension liquid; or the particles, in dry powder form, (dry process) may be dusted over the surface of the part. The wet process is more commonly used in the inspection of airframe parts.

If a discontinuity is present, the magnetic lines of force will be disturbed, and opposite poles will exist on either side of the discontinuity. The magnetized particles thus form a pattern in the magnetic field between the opposite poles. This pattern, known as an "indication," assumes the approximate shape of the surface projection of the discontinuity. A discontinuity may be defined as an interruption in the normal physical structure or configuration of a part such as a crack, forging lap, seam, inclusion, porosity, and the like. A discontinuity may or may not affect the usefulness of a part.

Preparation of parts for testing

Grease, oil, and dirt must be cleaned from all parts before they are tested. Cleaning is very important, since any grease or other foreign material present can produce nonrelevant indications due to magnetic particles adhering to the foreign material as the suspension drains from the part. Grease or foreign material in sufficient amount over a discontinuity may also prevent the formation of a pattern at the discontinuity. It is not advisable to depend upon the magnetic particle suspension to clean the part. Cleaning by suspension is not thorough, and any foreign materials so removed from the part will contaminate the suspension, thereby reducing its effectiveness.

In the dry procedure, cleaning it is absolutely necessary. Grease or other foreign material would hold the magnetic powder, resulting in nonrelevant indications and making it impossible to distribute the indicating medium evenly over the part's surface.

All small openings and oil holes leading to internal passages or cavities should be plugged with paraffin or other suitable nonabrasive material. Coatings of cadmium, copper, tin, and zinc do not interfere with the satisfactory performance of magnetic particle inspection, unless the coatings are unusually heavy or the discontinuities to be detected are unusually small.

Chromium and nickel plating generally will not interfere with indications of cracks open to the surface of the base metal but will prevent indications of fine discontinuities, such as inclusions. Because it is more strongly magnetic, nickel plating is more effective than chromium plating in preventing the formation of indications.

Magnetizing methods

When a part is magnetized, the field strength in the part increases to a maximum for the particular magnetizing force and remains at this maximum as long as the magnetizing force is maintained. When the magnetizing force is removed, the field strength decreases to a lower residual value depending on the magnetic properties of the material and the shape of the part. These magnetic characteristics determine whether the continuous or residual method is used in magnetizing the part.

Continuous method

In the continuous inspection method, the part is magnetized and the indicating medium applied while the magnetizing force is maintained. The available flux density in the part is thus at a maximum. The maximum value of flux depends directly upon the magnetizing force and the permeability of the material of which the part is made.

The continuous method may be used in practically all circular and longitudinal magnetization procedures. The continuous procedure provides greater sensitivity than the residual procedure, particularly in locating subsurface discontinuities.

Inasmuch as the continuous procedure will reveal more nonsignificant discontinuities than the residual procedure, careful and intelligent interpretation and evaluation of discontinuities revealed by this procedure are necessary.

Residual method

The residual inspection procedure involves magnetization of the part and application of the indicating medium after the magnetizing force has been removed. This procedure relies on the residual or permanent magnetism in the part and is more practical than the continuous procedure when magnetization is accomplished by flexible coils wrapped around the part. In general, the residual procedure is used only with steels that have been heat-treated for stressed applications.

Identification of indications

The correct evaluation of the character of indications is extremely important but is sometimes difficult to make from observation of the indications alone. The principal distinguishing features of indications are shape, buildup, width, and sharpness of outline. These characteristics, in general, are more valuable in distinguishing between types of discontinuities than in determining their severity. However, careful observation of the character of the magnetic particle pattern should always be included in the complete evaluation of the significance of an indicated discontinuity.

Cracks

The most readily distinguished indications are those produced by cracks open to the surface. These discontinuities include fatigue cracks, heat-treat cracks, shrink cracks in welds and castings, and grinding cracks.

- Fatigue cracks give sharp, clear patterns, generally uniform and unbroken throughout their length and with good buildup. They are often jagged in appearance, as compared with the straight indications of a seam, and may also change direction slightly in localized areas. Fatigue cracks are found in parts that have been in service but are never found in new parts. They are usually in highly stressed areas of the part or where a stress concentration exists for some reason. It is important to recognize that even a small fatigue crack indicates positively that failure of the involved parts is in progress.
- Heat-treat cracks have a smooth outline but are usually less clear and have less buildup than fatigue cracks. On thin sections, such as cylinder barrel walls, heat-treat cracks may give very heavy patterns. These heat-treat cracks have a characteristic form consisting of short, jagged lines grouped together.
- Shrink cracks give a sharp, clear pattern, and the line is usually very jagged. Since the walls of shrink cracks are close together, their indications generally build up to less extent than do indications of fatigue cracks.
- Grinding cracks are fine and sharp but seldom have a buildup because of their limited depth. Grinding cracks vary from single-line indications to a heavy network of lines. Grinding cracks are generally related to the direction of grinding. For example, the crack usually begins and continues at right angles to the motion of a grinding wheel, giving a rather symmetrical pattern. Indications of grinding cracks can frequently be identified by means of this relation.

Seams

Indications of seams are usually straight, sharp, and fine. They are often intermittent and sometimes have very little buildup.

Hairlines are very fine seams in which the faces of the seam have been forced very close together during fabrication. Hairline indications are very fine and sharp, with very little buildup. Discontinuities of this type are normally considered detrimental only in highly stressed parts.

Inclusions

Inclusions are nonmetallic materials, such as slag materials and chemical compounds, which have been trapped in the solidifying ingot. They are usually elongated and strung out as the ingot is worked in subsequent processing operations.

Inclusions appear in parts in varying sizes and shapes, from stringers easily visible to the eye to particles only visible under magnification. In a finished part, they may occur as either surface or subsurface discontinuities.

Indications of subsurface inclusions are usually broad and fuzzy. They are seldom continuous or of even width and density throughout their length. Larger inclusions, particularly those near or open to the surface, appear more clearly defined. Close examination, however, will generally reveal their lack of definition and the fact that the indication consists of several parallel lines rather than a single line. These characteristics will usually distinguish a heavy inclusion from a crack.

Cavities

When cavities are located considerably below the surface of a part, the magnetic particle test is not a reliable method of detecting them. If any indication is obtained, it is likely to be an indistinct and inexact outline of the cavity, with the magnetic substance tending to distribute over the whole area rather than to outline clearly the boundary of the discontinuity. Defects of this type are detected more easily by radiographic procedures.

Laps

Laps may be identified by their form and location. They tend to occur at the ends or flash line of a forging. The indications are usually heavy and irregular. Islands and short branch indications usually break a lap indication of any length, and the scale included in the lap invariably gives fuzzy or small fernlike patterns stemming from the main indication.

Banding

When an ingot solidifies, the distribution of the various elements or compounds, generally, is not uniform throughout the mass of the ingot. Marked segregations of some constituents may thus occur. As the ingot is forged and then rolled, these segregations are elongated and reduced in cross section. Upon subsequent processing, they may appear as very thin parallel lines or bands, known as banding.

Segregation

Segregation in the form of banding is sometimes revealed by magnetic particle inspection, particularly when high field strengths are used. Banding is not normally considered significant.

The most serious forms of segregation probably occur in castings. Here the basic condition of the metal remains unaltered in the finished part, and any segregations occur as they were originally formed. They may vary in size and will normally be irregular in shape. They may occur on or below the surface.

Magnetic dye inspection

This type of inspection may be used for nonferrous metals and is similar to the preceding methods, except that a fluorescent/magnetic particle solution is used instead of a dry particle and the inspection is made under black light. Efficiency of inspection is increased by the neon-like glow of defects, and smaller flaw indications are more readily seen. This is an excellent method for use on gears, threaded parts, and engine components. After inspection, the part must be demagnetized and rinsed with a cleaning solvent.

Demagnetization

The permanent magnetism remaining after inspection must be removed by a demagnetization operation if the part is to be returned to service. Parts of operating mechanisms must be demagnetized to prevent magnetized parts from attracting filings, grindings, or chips inadvertently left in the system, or steel particles resulting from operational wear. An accumulation of such particles on a magnetized part may cause scoring of bearings or other working parts. Parts of the airframe must be demagnetized so they will not affect instruments.

Demagnetization between successive magnetizing operations is not normally required unless experience indicates that omission of this operation results in decreased effectiveness for a particular application. Previously, this operation was considered necessary to completely remove the existing field in a part before it was magnetized in a different direction. Demagnetization may be accomplished in a number of different ways. Possibly the most convenient procedure involves subjecting the part to a magnetizing force that is continually reversing in direction and, at the same time, gradually decreasing in strength. As the decreasing magnetizing force is applied first in one direction and then the other, the magnetization of the part also decreases.

Dye penetrant inspection

Penetrant inspection is a nondestructive test for defects open to the surface in parts made of any nonporous material. It is used with equal success on such metals as aluminum, magnesium, brass, copper, cast iron, stainless steel, and titanium. It may also be used on ceramics, plastics, molded rubber, and glass. Penetrant inspection will detect such defects as surface cracks or porosity. These defects may be caused by fatigue cracks, shrinkage cracks, shrinkage porosity, cold shuts, grinding and heat-treat cracks, seams, forging laps, and bursts. Penetrant inspection will also indicate a lack of bond between joined metals.

The main disadvantage of penetrant inspection is that the defect must be open to the surface in order to let the penetrant get into the defect. For this reason, if the part in question is made of material that is magnetic, the use of magnetic particle inspection is generally recommended.

Penetrant inspection depends upon a penetrating liquid entering the surface opening and remaining in that opening, making it clearly visible to the operator. It calls for visual examination of the part after it has been processed, but the visibility of the defect is increased so that it can be detected. Visibility of the penetrating material is increased by the addition of dye that may be either one or two types—visible or fluorescent. The visible penetrant kit consists of dye penetrant, dye remover emulsifier, and developer. The fluorescent penetrant inspection kit contains a black-light assembly as well as spray cans of penetrant, cleaner, and developer. The light assembly consists of a power transformer, a flexible power cable, and a handheld lamp. Due to its size, the lamp may be used in almost any position or location.

Briefly, the steps to be taken when performing a penetrant inspection are as follows:

1. Thorough cleaning of the metal surface.
2. Applying penetrant.
3. Removing penetrant with remover emulsifier or cleaner.
4. Drying the part.
5. Applying the developer.
6. Inspecting and interpreting results.

Radiography

Because of their unique ability to penetrate material and disclose discontinuities, X and gamma radiation, have been applied to the radiographic (X-ray) inspection of metal fabrications and nonmetallic products.

The penetrating radiation is projected through the part to be inspected and produces an invisible or latent image in the film. When processed, the film becomes a radiograph or shadow picture of the object. This inspection medium, in a portable unit, provides a fast and reliable means for checking the integrity of airframe structures

Radiographic inspection techniques are used to locate defects or flaws in airframe structures with little or no disassembly. This is in marked contrast to other types of nondestructive testing, which usually require removal, disassembly, and stripping of paint from the suspected part before it can be inspected. Due to the nature of X-ray, extensive training is required to become a qualified radiographer, and only qualified radiographers are allowed to operate the X-ray units.

Ultrasonic inspection

Ultrasonic detection equipment has made it possible to locate defects in all types of materials without damaging the material being inspected. Minute cracks, checks, and voids, too small to be seen by X-ray, are located by ultrasonic inspection. An ultrasonic test instrument requires access to only one surface of the material to be inspected and can be used with either straight-line or angle-beam testing techniques. Two basic methods are used for ultrasonic inspection.

1. The first of these methods is immersion testing. In this method of inspection, the part under examination and the search unit are totally immersed in a liquid couplant, which may be water or any other suitable fluid.
2. The second method is called contact testing, which is readily adapted to field use, and is the method discussed in this lesson. In this method the part under examination and the search unit are coupled with a viscous material, liquid, or paste, which wets both the face of the search unit and the material under examination.

There are two basic ultrasonic systems: pulsed and resonance. The pulsed system may be either echo or through transmission; the echo is the most versatile of the two pulse systems.

Pulse echo

Flaws are detected by measuring the amplitude of signals reflected and the time required for these signals to travel between specific surfaces and the discontinuity.

The time base, which is triggered simultaneously with each transmission pulse, causes a spot to sweep across the screen of the CRT (cathode-ray tube). The spot sweeps from left to right across the face of the scope 50 to 5,000 times per second, or higher if required for high-speed automated scanning. Due to the speed of the cycle of transmitting and receiving, the picture on the oscilloscope appears to be stationary.

A few microseconds after the sweep is initiated, the rate generator electrically excites the pulsar, and the pulsar in turn emits an electrical pulse. The transducer converts this pulse into a short train of ultrasonic sound waves. If the interfaces of the transducer and the specimen are properly orientated, the ultrasound will be reflected back to the transducer when it reaches the internal flaw and the opposite surface of the specimen. The time interval between the transmission of the initial impulse and the reception of the signals from within the specimen is measured by the timing circuits. The reflected pulse received by the transducer is amplified and then transmitted to the oscilloscope, where the pulse received from the flaw is displayed on the CRT screen. The pulse is displayed in the same relationship to the front and back pulses as the flaw is in relation to the front and back surfaces of the specimen.

Resonance system

This system differs from the pulse method in that the frequency of transmission is, or can be, continuously varied. The resonance method is principally used for thickness measurements when the two sides of the material being tested are smooth and parallel. The point at which the frequency matches the resonance point of the material being tested is the thickness determining factor.

It is necessary that the frequency of the ultrasonic waves, corresponding to a particular dial setting, be accurately known. Checks should be made with standard test blocks to guard against possible drift of frequency. If the frequency of an ultrasonic wave is such that its wavelength is twice the thickness of a specimen (fundamental frequency), then the reflected wave will arrive back at the transducer in the same phase as the original transmission so that strengthening of the signal, or a resonance, will occur. If the frequency is increased so that three times the wavelength equals four times the thickness, then the reflected signal will return completely out of phase with the transmitted signal and cancellation will occur. Further increase of the frequency, so that the wavelength is equal to the thickness again, gives a reflected signal in phase with the transmitted signal and resonance occurs once more.

By starting at the fundamental frequency and gradually increasing the frequency, the successive cancellations and resonances can be noted and the readings used to check the fundamental frequency reading.

In some instruments, the oscillator circuit contains a motor-driven capacitor that changes the frequency of the oscillator. In other instruments, the frequency is changed by electronic means. The change in frequency is synchronized with the horizontal sweep of a CRT. The horizontal axis thus represents a frequency range. If the frequency range contains resonances, the circuitry is arranged to present these vertically. Calibrated transparent scales are then placed in front of the tube, and the thickness can be read directly. The instruments normally operate between 0.25 mc. and 10 mc. in four or five bands.

The resonant-thickness instrument can be used to test the thickness of such metals as steel, cast iron, brass, nickel, copper, silver, lead, aluminum, and magnesium. In addition, areas of corrosion or wear on tanks, tubing, airplane wing skins, and other structures or products can be located and evaluated.

Direct reading, dial-operated units are available that measure thickness between 0.025 inch and 3 inches with an accuracy of better than ± 1 percent.

Ultrasonic inspection requires a skilled operator who is familiar with the equipment being used as well as the inspection method to be used for the many different parts being tested.

Eddy current testing

Electromagnetic analysis is a term that describes the broad spectrum of electronic test methods involving the intersection of magnetic fields and circulatory currents. The most widely used technique is the eddy current. Eddy currents are composed of free electrons, which are made to “drift” through metal under the influence of an induced electromagnetic field. Eddy currents are used to detect cracks, heat, or frame damage in conductive materials. In manufacturing plants, eddy current is used to inspect castings, stampings, machine parts, forgings, and extrusions.

Visual inspection

Nondestructive testing by visual means is the oldest method of inspection. Defects that would escape the naked eye can be magnified so they will be visible. Microscopes, borescopes, lasers, and magnifying glasses aid in performing visual inspection. It’s important to remember that in order to correctly perform a visual inspection, the item being inspected must be clean of all foreign contamination, and the area must be well illuminated.

The discussion of visual inspection will be confined to judging the quality of completed welds by visual means. Regardless of the item being inspected, it is paramount that the inspector knows the criteria for that item. For example, a properly welded joint has the following characteristics:

- Is uniform in width.
- Have ripples that are even and well feathered into the base metal.
- Shows no burn due to overheating in the base metal.
- Has good penetration.

227. Nonmetallic materials and processes

Burt Rutan is considered a pioneer in the development of hollow aircraft structures. These structures typically have self-supporting single skin; three-thickness core sandwiches; and extended, gently curved surfaces. Modern composite materials use materials, procedures, and special precautions that are different from those used with conventional aircraft fiberglass.

Characteristics

With composite materials, it is the fibers that carry the strength in a structure. Research has shown that a 60:40 fiber-to-resin ratio provides the best strength. It is important to remember that carbon is the best choice of composite material when stiffness is the prime requirement. The following are some key terms and practices to remember when working with composite materials.

- The basic two-part mix for epoxy matrix material is resin and hardener.
- One of the best ways of being sure that the matrix resin for a composite repair has been properly mixed is to mix enough extra resin of each batch to make an identical layup.
- Pot life is the length of time a catalyzed resin will remain in a workable state.
- Unidirectional tape laying is an automated fabrication process in which preimpregnated tape is laid side by side and/or overlapped to form a structure.
- Molds hold the surface in place while materials cure and harden; they are called male/female.
- When replacing honeycomb core material, the ribbon direction of the insert must be the same as the ribbon direction of the original core.
- You can use a ring (coin) tap test on composite structures. A change in the sound made by the coin being tapped on a piece of composite structure may be caused by damage or by a transition to a different type of internal structure.
- A quick and easy way to distinguish between cellulosed acetate plastic and acrylic plastic is to put a drop of zinc chloride on them. Zinc chloride has no effect on acrylic plastic, but it causes cellulose acetate plastic to turn milky.
- The strength and stiffness of a properly constructed composite buildup depends primarily on the orientation of the plies to the load direction.
- Water is the only fluid normally approved for use in machining composite materials. Any other fluid would contaminate the material and prevent subsequent bonding.
- Hole-filling fasteners such as conventional rivets should not be used in composite structures because of the probability of causing delaminating. When a conventional rivet is driven, its shank expands to completely fill the hole. The force applied by the expanded shank will cause the material to delaminate around the edges of the hole.
- When repairing damaged fastener holes in composite panels, chopped fibers or flox cane is added to the wet resin to strengthen the repair. Micro-balloons do not add any strength.
- Superficial scars, scratches, surface abrasions, or rain erosion can generally be repaired by applying one or more coats of a suitable resin, catalyzed to cure at room temperature, to the abraded surface.
- The preferred way of making a permanent repair to a composite structure is to remove the damaged area and lay in new repair plies, observing the choices of materials, the overlap dimensions, ply orientation, and curing procedures.
- Methyl ethyl ketone (MEK) is used in cleaning an area of a fiberglass structure to be repaired by bonding.

Nonmetallic materials

Nonmetallic materials, also known as composite materials, offer many advantages over other materials. Within aerospace markets, where exceptional performance is required but weight is critical,

composites continue to grow in importance. Some of the many advantages of composites are as follows:

- Stronger and stiffer than metals on a density basis - For the same strength they are lighter than steel by 80 percent and aluminum by 60 percent.
- Highly corrosion resistant - Most composites are essentially inert in the most corrosive environments.
- Outstanding durability - Well-designed composites have exhibited apparent infinite life characteristics, even in extremely harsh environments.
- Low investment in fabrication equipment - The inherent characteristics of composites typically allows production to be established for a fraction of the cost required in metallic fabrication.

The next few paragraphs focus on the most common composite materials within the aerospace industry.

Carbon/graphite

Carbon/graphite fiber composites are noted for their stiffness and high-compressive strength. One of the problems with carbon/graphite as a structural material is the fact that aluminum alloys in contact with it will corrode. For this reason, fasteners used with carbon/graphite must be made of a corrosion-resistant material such as titanium or corrosion-resistant steel.

When a repair to a metal honeycomb structure is made, the repair should be primed with a corrosion-inhibiting primer and should be sealed so no moisture or air can get to the inside of the repair.

Fiberglass

There are two types of glass fibers used in aircraft composite structure: E glass and S glass. E, or electrical glass, has a high resistivity and is designed primarily for electrical insulation. Its low cost makes it the more widely used type of glass where high strength is not required. S, or structural glass, has a high tensile strength and is used for critical structural applications.

Fiberglass honeycomb structure can be inspected for entrapped water by either X-ray or backlighting method. The backlighting method of inspection is done by removing all the paint from the surface and shining a strong light on one side of a panel and examining from the other side for any dark areas that would indicate entrapped water. When replacing honeycomb core material, the ribbon direction of the insert must be the same as the ribbon direction of the original core.

Kevlar

Kevlar is an aramid fiber that is noted for its flexibility and high-tensile strength. It does not conduct electricity and does not cause aluminum to corrode when it is held in contact with it.

Thermoset plastic

Thermoset plastic is a class of plastics that, when cured by thermal and/or chemical means, becomes substantially infusible and insoluble. Once cured, a thermoset cannot be returned to the uncured state. Some of the more common thermosets include:

- Epoxies.
- Polyurethanes.
- Phenolic and amino resins.
- Bismaleimides.
- Polyamides.

Nonmetallic processes

The processes used in the fabrication of composite materials differ depending upon the specific type of material being used. This section will concentrate on the three primary methods: Prepeg, vacuum bagging, and vacuum-assisted resin transfer molding (VARTM).

Preimpregnated layup

Preimpregnated layup or prepreg is a combination of mat, fabric, nonwoven material, or roving with resin that is usually cured to an intermediate stage where it is ready for molding. This intermediate stage is also called the B-stage. It can be redesignated as standard or net-resin prepregs:

- Standard prepreg contains more resin than is desired in the finished part; excess resin is bled off during cure.
- Net-resin prepreg contains the same resin content that is desired in the finished part—no resin bleed.

Prepreg containing a chemical thickening agent is called a mold mat, and those in sheet form are called sheet molding compounds.

Vacuum bagging

Vacuum bagging is a technique employed to create mechanical pressure on a laminate during its cure cycle. Pressurizing a composite lamination serves several functions:

- It removes trapped air between layers.
- It compacts the fiber layers for efficient force transmission among fiber bundles and prevents shifting of fiber orientation during cure. Vacuum bagging pressures can be as high as 2,000 pounds per square foot.
- It reduces humidity.
- The vacuum bagging technique optimizes the fiber-to-resin ratio in the composite part.

For years these advantages have enabled aerospace and racing industries to maximize the physical properties of advanced composite materials such as graphite (carbon), aramid, and epoxy.

All laminates are bagged in essentially the same way. Once you know the basics, you can bag just about any structure. There are some tricks to handle complicated geometry, but the bags all look alike.

Release agent

Before you even start laying up the part, you apply a release agent to the tool. This may be a liquid release coating, a wax, or even a solid barrier such as Teflon tape. When applying the release, be sure to mask off the edges of the tool so the bag sealant tape (BST) will stick to the tool.

Bag sealant tape

BST is a putty-like material that comes in rolls, usually 1/2 in. wide, with a release paper on one side. You press the tape against the tool, leaving the release paper on until you are ready to apply the bag itself. The tape usually goes on after the part is laid up, especially if it is a wet layup.

Caul plate

The caul plate is placed in immediate contact with the layup during curing to transmit normal pressure and provide a smooth surface on the finished part.

Peel ply

Once the laminate is in place, it's time to apply the bag. The first item to go down is a peel ply. Peel plies are a tightly woven fabric, often nylon, and impregnated with some type of release agent. The peel ply will stick to the laminate, but it will pull away without too much difficulty.

Peel ply is optional. Most often it is used to give the laminate a rough, rather than smooth, finish. Many engineers consider this a bondable finish, and it usually passes a wet-out test.

If peel ply is used, it will absorb a small amount of resin, and this must be accounted for. A net-resin prepreg may end up too dry. Peel ply specs should say how much resin will be absorbed, in ounces per square foot or grams per square meter.

Release film

After the peel ply comes a layer of release film. This is a thin plastic that has been treated so it won't bond to the laminate. It is highly stretchable so it can conform to complex geometries.

Peel ply can be either a solid sheet, or it can have perforations (in the latter case, it is often called perf ply). The perforations might be like pin-pricks, or they might be small holes that are punched out. The spacing can also vary from two inches to eight inches. Choose spacing based on the amount of resin that needs to be bled out: wet layups can use close spacing; prepreg manufacturers can recommend spacing for their particular products; and net-resin systems, of course, use unperforated release films.

Not all release films are compatible with every resin system. You can get release film treated so it will bond to the laminate (bondable one side [BOS] or bondable both sides [BBS]). BOS can be used to create a permanent release layer on composite tools or as a moisture barrier on laminates.

Bleeder and breather

At least one layer of bleeder cloth goes above the release film. Bleeder is a thick, felt-like cloth. Its purpose is to absorb excess resin.

The bleeder also acts as a breather, providing a continuous air path for pulling the vacuum. If the bag wrinkles against the hard laminate, it will trap air. The breather prevents this from happening.

The breather must be thick enough so that it doesn't become fully saturated with resin. A thick breather is also desirable to keep resin from coming in contact with the bag. It doesn't hurt anything if that happens, but preventing it makes the bag easier to remove.

Bag

The bag is the last item to be placed. It's a relatively thick plastic layer, available in different amounts of conformability. The bag is usually applied along one edge at a time. Start at one corner and press the bag into the BST, removing the release paper from the tape as you move along the edge.

Be careful not to get any wrinkles in the bag or it will leak. Pleats will be required for anything but flat or simply curved structures.

Make sure you remember to attach the vacuum port before closing the bag. The base of the port goes inside the bag—cut a small cross in the bag for the attachment flange to fit through. If the tool has an area for the port, make sure there is a breather path from the port to the part. If the port goes on the part itself, put several layers of breather under the port to prevent print-through.

General considerations

In addition to making sure all materials are compatible with the resin system, also make sure they can handle the cure temperature. Also remember that oven or autoclave temperatures will likely approach 375°–400° F during a 350° F cure, and bagging materials must be compatible with these higher temperatures.

How much vacuum is too much? In general, you can't get too much vacuum. Always try for a full 14.7 psi; the only exception would be if you are worried about crushing a core or dimpling face sheets over honeycomb.

Vacuum-assisted resin transfer molding

Parts created by VARTM are made by placing dry-fiber reinforcing fabrics into a mold, applying a vacuum bag to the open surface, and pulling a vacuum while at the same time infusing a resin to saturate the fibers until the part is fully cured. This process allows for easy visual monitoring of the resin to ensure complete coverage to produce good parts without defects.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

220. Properties and selection factors of metals

1. Match the description in column A with the item in column B. Items in column B may be used once, more than once, or not at all.

*Column A**Column B*

- | | |
|--|-----------------|
| <p>____ (1) This property enables a metal to return to its original shape when the force that causes the change of shape is removed.</p> | a. Hardness |
| <p>____ (2) The weight of a unit volume of a material.</p> | b. Brittleness |
| <p>____ (3) The ability of a metal to become liquid by the application of heat.</p> | c. Malleable |
| <p>____ (4) This property is necessary in sheet metal that is worked into curved shapes.</p> | d. Ductility |
| <p>____ (5) The ability of a metal to resist abrasion, penetration, cutting action, or permanent distortion.</p> | e. Elasticity |
| <p>____ (6) The property of a metal that allows little bending or deformation without shattering.</p> | f. Toughness |
| <p>____ (7) The property of a metal that permits it to be permanently drawn, bent, or twisted into various shapes without breaking.</p> | g. Density |
| | h. Fusibility |
| | i. Conductivity |

2. What are the five basic stresses that metals may be required to withstand?
3. How many processes are used in the heat treatment of aluminum alloys?

221. Metalworking processes

1. Why is steel tempered after being hardened?
2. Describe the annealing process of steel and the resulting property after it has been annealed.
3. Normalizing applies to what type(s) of metal(s)?
4. Cold drawing is used to create what types of stock.

5. What is the result if a welded joint is cooled too quickly?

222. Ferrous metals

1. How many numerals are used to identify plain-carbon steel?

2. Match the spark identification/color in column A with the type of steel in column B. Items in column B may be used once, more than once, or not at all.

<i>Column A</i>	<i>Column B</i>
____ (1) Spark stream contains small white blocks of light within the main burst.	a. Cast iron
____ (2) Gives off long, straight shafts having a few white sprigs.	b. Wrought iron
____ (3) Sparks are red as they leave the stone and turn to a straw color.	c. Low-carbon steel
____ (4) Long shafts that are straw colored as they leave the stone and white at the end.	d. Nickel steel
	e. Stainless steel

3. What are the four main types of chromium steel?

223. Nonferrous metals

1. Why is aluminum vital to the space-lift industry?

2. The aluminum code number 1100 identifies what type of aluminum?

3. In the four-digit aluminum index system number 2024, the first digit indicates what

4. What is alclad aluminum?

5. Why does titanium have a high resistance to corrosion?

6. Which of the copper alloys has excellent corrosion-resistant qualities in salt water?

7. How should fire involving magnesium be extinguished?

224. Heat treatment

1. What is the only nonferrous metal that can be case-hardened?
2. How does an alloy differ from a mechanical mixture?
3. Describe the effects of annealing steel.
4. Which heat-treating process for steel removes the internal stresses set up by heat treating, welding, casting, forming, or machining?
5. Which heat-treating process of metal produces a hard, wear-resistant surface over a strong, tough core?
6. What are the two types of heat treatments applicable to aluminum alloys?
7. What are the three methods used to quench an aluminum alloy following heat treatment?
8. Why are magnesium alloy castings solution heat-treated?
9. What are the advantages of fully annealed titanium?

225. Hardness testing

1. What are the three types of hardness testers?
2. Which of the hardness testers is portable and should only be used on relatively soft materials?

226. Nondestructive inspection fundamentals

1. What materials may be inspected using the magnetic particle inspection method?

2. What flaws is the magnetic particle inspection extremely reliable in detecting?
3. What two types of indicating mediums are available for magnetic particle inspection?
4. Which magnetization method is generally used with steels that have been heat-treated for stressed applications?
5. What must be accomplished following any magnetization procedure?
6. Dye penetrant inspection methods may be used on what types of surfaces?
7. Which inspection methods may be suitable to use to detect cracks open to the surface in aluminum forgings and castings?

227. Nonmetallic materials and processes

1. What fiber-to-resin ratio provides the best strength?
2. A change in the sound made by a coin being tapped on a piece of composite structure may be caused by damage or what else?
3. What is the only fluid normally approved for use in machining composite materials?
4. What is used when cleaning an area of a fiberglass structure to be repaired by bonding?
5. What is one of the problems with carbon/graphite as a structural material?
6. What are the two types of glass fibers used in airframe composite structures?
7. What are the types of thermoset plastic?

8. What is the difference between standard prepreg and net-resin prepreg?
9. Before you even start laying up a part for vacuum bagging, what must you apply to the tool?
10. What is the purpose of the “bleeder”?

3-2. Corrosion Control

Metal corrosion is the deterioration of the metal by chemical or electrochemical attack and can take place internally as well as on the surface. As in the rotting of wood, this deterioration may change the smooth surface, weaken the interior, or damage or loosen adjacent parts.

Water or water vapor containing salt combines with oxygen in the atmosphere to produce the main source of corrosion. Corrosion can cause eventual structural failure if left unchecked. The appearance of the corrosion varies with the metal. On aluminum alloys and magnesium, it appears as surface pitting and etching, often combined with a grey or white powdery deposit. On copper and copper alloys the corrosion forms a greenish film; on steel, a reddish rust. When the grey, white, green, or reddish deposits are removed, each of the surfaces may appear etched and pitted, depending upon the length of exposure and severity of attack. If these surface pits are not too deep, they may not significantly alter the strength of the metal; however, the pits may become sites for crack development. Some types of corrosion can travel beneath surface coatings and can spread until the part fails.

228. Types, forms, and factors of corrosion

Corrosion, if not stopped, can result in catastrophic failure of components, systems, or even compromise a complete mission or structure. This lesson covers the types, forms, and factors of corrosion.

Types of corrosion

There are two general classifications of corrosion that cover most of the specific forms. These are direct chemical attack and electrochemical attack. In both types of corrosion, the metal is converted into a metallic compound such as an oxide, hydroxide, or sulfate. The corrosion process always involves two simultaneous changes: The metal that is attacked or oxidized suffers what may be called anodic change, and the corrosive agent is reduced and may be considered as undergoing cathodic change.

Direct chemical attack

Direct chemical attack, or pure chemical corrosion, is an attack resulting from a direct exposure of a bare surface to caustic liquid or gaseous agents. Unlike electrochemical attack where the anodic and cathodic changes may be taking place a measurable distance apart, the changes in direct chemical attack are occurring simultaneously at the same point. The most common agents causing direct chemical attack are the following:

- Spilled battery acid or fumes from batteries.
- Residual flux deposits resulting from inadequately cleaned, welded, brazed, or soldered joints.
- Entrapped caustic cleaning solutions.

Spilled battery acid

Spilled battery acid is becoming less of a problem with the advent of nickel-cadmium batteries that are usually closed units. The use of these closed units lessens the hazards of acid spillage and battery fumes.

Residual flux

Many types of fluxes used in brazing, soldering, and welding are corrosive, and they chemically attack the metals or alloys with which they are used. Therefore, it is important that residual flux be removed from the metal surface immediately after the joining operation. Flux residues are hygroscopic in nature; that is, they are capable of absorbing moisture and, unless carefully removed, tend to cause severe pitting.

Caustic cleaning solutions

Caustic cleaning solutions in concentrated form should be kept tightly capped and as far from airframes as possible. Some cleaning solutions used in corrosion removal are, in themselves, potentially corrosive agents, and particular attention should be directed toward their complete removal after use. Where entrapment of the cleaning solution is likely to occur, a noncorrosive cleaning agent should be used even though it is less efficient.

Electrochemical attack

An electrochemical attack may be likened, chemically, to the electrolytic reaction that takes place in electroplating, anodizing, or in a dry-cell battery. The reaction in this corrosive attack requires a medium, usually water, which is capable of conducting a tiny current of electricity. When a metal comes in contact with a corrosive agent and is also connected by a liquid or gaseous path through which electrons may flow, corrosion begins as the metal decays by oxidation. During the attack, the quantity of corrosive agent is reduced and, if not renewed or removed, may completely react with the metal (become neutralized). Different areas of the same metal surface have varying levels of electrical potential and if connected by a conductor, such as salt water, will set up a series of corrosion cells and corrosion will commence. The electrochemical attack is responsible for most forms of corrosion on structures and component parts.

All metals and alloys are electrically active and have a specific electrical potential in a given chemical environment. The constituents in an alloy also have specific electrical potentials that are generally different from each other. Exposure of the alloy surface to a conductive, corrosive medium causes the more active metal to become anodic and the less active metal to become cathodic, thereby establishing conditions for corrosion. These are called local cells. The greater the difference in electrical potential between the two metals, the greater will be the severity of a corrosive attack if the proper conditions are allowed to develop.

The conditions for these corrosion reactions are a conductive fluid and metals having a difference in potential (dissimilar metals). If, by regular cleaning and surface refinishing, the medium is removed and the minute electrical circuit eliminated, corrosion cannot occur; this is the basis for effective corrosion control.

Forms of corrosion

There are many forms of corrosion. The form of corrosion depends on the metal involved, its size and shape, its specific function, atmospheric conditions, and the corrosion-producing agents present. Those described in this section are the more common forms found on airframe structures.

Surface corrosion

Surface corrosion appears as a general roughening, etching, or pitting of the surface of a metal, frequently accompanied by a powdery deposit of corrosion products. Surface corrosion may be caused by either direct chemical or electrochemical attack. Sometimes corrosion will spread under the surface coating and cannot be recognized by either the roughening of the surface or the powdery

deposit. Instead, the paint or plating will be lifted off the surface in small blisters that result from the pressure of the underlying accumulation of corrosion products.

Galvanic

Galvanic corrosion, or dissimilar metal corrosion, results in extensive pitting damage from contact between dissimilar metal parts in the presence of a conductor. While surface corrosion may or may not be taking place, a galvanic action, not unlike electroplating, occurs at the points or areas of contact where the insulation has broken down or been omitted. This electrochemical attack can be very serious because the action is, in many instances, taking place out of sight, and the only way to detect it prior to structural failure is by disassembly and inspection.

Intergranular

Intergranular corrosion is an attack along the grain boundaries of an alloy and commonly results from a lack of uniformity in the alloy structure. Aluminum alloys and some stainless steels are particularly susceptible to this form of electrochemical attack. The lack of uniformity is caused by changes that occur in the alloy during heating and cooling. Intergranular corrosion may exist without visible surface evidence.

Very severe intergranular corrosion may sometimes cause the surface of a metal to “exfoliate.” This is a lifting or flaking of the metal at the surface due to delamination of the grain boundaries caused by the pressure of corrosion-residual product buildup. This type of corrosion is difficult to detect in its original stage. Ultrasonic and eddy current inspection methods are being used with a great deal of success.

Stress

Stress corrosion occurs as the result of the combined effect of sustained tensile stresses and a corrosive environment. Stress-corrosion cracking is found in most metal systems; however, it is particularly characteristic of aluminum, copper, certain stainless steels, and high-strength alloy steels (over 240,000 psi). It usually occurs along lines of cold working and may be transgranular or intergranular in nature. Aluminum-alloy bell cranks with pressed-in bushings, clevis pin joints, shrink fits, and overstressed tubing B-nuts are examples of parts that are susceptible to stress-corrosion cracking.

Fretting

Fretting corrosion is a particularly damaging form of corrosive attack that occurs when two mating surfaces are subject to slight relative motion. It is characterized by pitting of the surfaces and the generation of considerable quantities of finely divided debris. Since the restricted movements of the two surfaces prevent the debris from escaping very easily, an extremely localized abrasion occurs. The presence of water vapor greatly increases this type of deterioration. If the contact areas are small and sharp, deep grooves resembling Brinell markings (which is a form of surface fatigue caused from repeated impact or overloading pressure) or indentations may be worn in the rubbing surface. As a result, this type of corrosion (on bearing surfaces) has also been called false Brinelling.

Factors affecting corrosion

Many factors affect the type, speed, cause, and seriousness of metal corrosion. Some of these factors can be controlled and some cannot.

Climate

The environmental conditions greatly affect corrosion characteristics. In a predominately marine environment (with exposure to sea water and salt air), moisture-laden air is considerably more detrimental to an airframe than it would be if all operations were conducted in a dry climate. Temperature considerations are important because the speed of electrochemical attack is increased in a hot, moist climate.

Size and type of metal

It is a well-known fact that some metals will corrode faster than others. It is a less-known fact that variations in size and shape of a metal can indirectly affect its corrosion resistance.

Thick structural sections are more susceptible to corrosive attack than thin sections because variations in physical characteristics are greater. When large pieces are machined or chemically milled after heat treatment, the thinner areas will have different physical characteristics than the thicker areas.

From a corrosion-control standpoint, the best approach is to recognize the critical nature of the integrity and strength of major structural parts and to maintain permanent protection over such areas at all times to prevent the onset of deterioration.

Foreign material

Among the controllable factors that affect the onset and spread of corrosive attack is foreign material that adheres to the metal surfaces. Such foreign materials include:

- Soil and atmospheric dust.
- Oil and grease.
- Salt water and salt-moisture condensation.
- Spilled battery acids and caustic cleaning solutions.
- Welding and brazing flux residues.

It is important that airframes be kept clean. How often and to what extent depends on several factors, such as location and type of operation.

229. Preventive maintenance

Much has been done to improve corrosion-resistance aerospace materials: improvement in materials, surface treatments, insulation, and protective finishes. All of these have been aimed at reducing maintenance effort as well as improving reliability. In spite of these improvements, corrosion and its control is a very real problem that requires continuous preventive maintenance.

Corrosion preventive maintenance includes the following specific functions:

- Adequate cleaning.
- Detailed inspection for corrosion and failure of protective systems.
- Prompt treatment of corrosion and touch-up of damaged paint areas.
- Keeping drain holes free of obstruction.
- Daily wipe down of exposed critical areas.
- Making maximum use of protective covers.

Inspection

Inspection for corrosion is a continuing problem and should be handled on a daily basis.

Overemphasizing a particular corrosion problem when it is discovered and then forgetting about corrosion until the next crisis is an unsafe, costly, and troublesome practice. Most checklists are complete enough to cover all parts, and no part should go unchecked. Use these checklists as a general guide when an area is to be inspected for corrosion. Through experience it will be learned that most vehicles have trouble areas where corrosion will set in despite routine inspection and maintenance.

Corrosion-prone areas

Discussed briefly in this section are most of the trouble areas common to all space-lift vehicles. However, this coverage is not necessarily complete and may be amplified and expanded to cover the

special characteristics of the particular model involved by referring to the applicable maintenance manual.

Battery compartments and battery vent openings

Despite improvements in protective paint finishes and in methods of sealing and venting, battery compartments continue to be corrosion-problem areas. Fumes from overheated electrolyte are difficult to contain and will spread to adjacent cavities and cause a rapid corrosive attack on all unprotected metal surfaces. Battery vent openings on the skin should be included in the battery-compartment inspection and maintenance procedure. Regular cleaning and neutralization of acid deposits will minimize corrosion from this cause.

Water entrapment areas

Design specifications require that aircraft have drains installed in all areas where water may collect. Daily inspection of low-point drains should be a standard requirement. If this inspection is neglected, the drains may become ineffective because of accumulated debris, grease, or sealants.

External skin areas

External surfaces are readily visible and accessible for inspection and maintenance. Even here, certain types of configurations or combinations of materials become troublesome under certain operating conditions and require special attention.

Relatively little corrosion trouble is experienced with magnesium skins if the original surface finish and insulation are adequately maintained. Trimming, drilling, and riveting destroy some of the original surface treatment that is never completely restored by touch-up procedures. Any inspection for corrosion should include all magnesium skin surfaces with special attention to edges, areas around fasteners, and cracked, chipped, or missing paint.

Piano-type hinges are prime spots for corrosion due to the dissimilar metal contact between the steel pin and aluminum hinge. They are also natural traps for dirt, salt, and moisture. Inspection of hinges should include lubrication and actuation through several cycles to ensure complete lubricant penetration.

Corrosion of metal skin joined by spot welding is the result of the entrance and entrapment of corrosive agents between the layers of metal. This type of corrosion is evidenced by corrosion products appearing at the crevices through which the corrosive agents enter. More advanced corrosive attack causes skin buckling and eventual spot-weld fracture. Skin buckling in its early stages may be detected by sighting along spot-welded seams or by using a straightedge. The only technique for preventing this condition is to keep potential moisture entry points, including seams and holes created by broken spot welds, filled with a sealant or a suitable preservative compound.

Corrosion-prevention processes

One key to preventing corrosion is eliminating the electrolyte (usually in the form of water) from the equation. Each of the following processes is designed to do just that. The following lesson describes some of the more common processes and provides information on how to protect and maintain that coating to ensure future corrosion resistance.

Electroplating

Electroplating is the process of transferring metal from one object to another by chemical and electrical means. Several reasons for applying plated coatings are as follows:

1. To protect the base metal (metal being plated) against corrosion. Tin, zinc, nickel, and cadmium are some of the metals used to form a protective coating on another metal by electrolytic action.

2. To protect the base metal against wear caused by abrasion or fretting corrosion. Chromium plating is extensively used for wear resistance on gauges, dies, oleo pistons, and cylinder barrels. Nickel plating can also be used for this purpose.
3. To produce and retain a desired appearance (color and luster), as well as improve resistance to tarnish. Gold, nickel, or chromium plating can be used in this application.
4. To protect a base metal against some special chemical reaction; for example, copper plating is sometimes used to prevent certain parts of a component manufactured of steel from absorbing carbon during case-hardening.
5. To increase the dimensions of a part. This process, known as “building up,” may be applied to parts accidentally made undersize or to worn parts. Nickel or chromium plating is commonly used for this purpose.
6. To serve as a base for further plating operations, reduce buffing costs, and ensure bright deposits of nickel or nickel and chromium. Copper is commonly used for this purpose.

All electroplating processes are basically similar. The equipment used consists of a tank or bath containing a liquid solution called an electrolyte, a control panel, and a source of direct current.

When a current is passed through the circuit, the plating material is the positive electrode or anode of the circuit. The part on which the plating is deposited is the negative electrode or cathode of the circuit. The source of power anode, cathode, and electrolyte form the plating electrical circuit and cause tiny particles of the plating material to be deposited on the surface of the part being plated. The process is continued until a plating of the required thickness is obtained. The electrolyte, anode, cathode, and current setting will vary with the type of plating material being used.

Some plating operations do not use anodes of the metal being deposited but obtain the metal from the electrolyte alone. Chromium plating is an example of this type plating. Lead anodes instead of chromium anodes, which are unsatisfactory, are employed to complete the electrical circuit. The chromium for the plating comes from the chromic acid in the electrolyte.

Metal spraying

Metal spraying, or metallizing, is the surface application of molten metal on any solid-base material. It is possible to spray aluminum, cadmium, copper, nickel, steel, or any of several metals using this process. In aircraft work the process is used primarily to spray a coat of pure aluminum on steel parts to improve their corrosion resistance.

The base material must be roughened (usually by sandblasting) and perfectly clean in order for the sprayed metal to adhere to the surface of the base material. Metal spraying equipment consists of a supply of oxygen and acetylene piped to the spray gun, which ends in a nozzle. At this point they can be ignited as in a welding torch. A supply of compressed air is also piped to the spray gun. This compressed air operates a feeding mechanism that draws the wire through the spray gun. The wire is melted by the hot oxyacetylene flame and is thrown against the surface being metallized by the compressed air.

Parco lubricizing

Parco lubricizing is a chemical treatment for iron and steel parts that converts the surface to a nonmetallic, oil-absorptive phosphate coating. It is designed primarily to reduce wear on moving parts.

The process is a modification of parkerizing and consists of a precleaning treatment in which vapor degreasing, acid pickle, or spray emulsion is used, followed by a 15-minute dip in a solution of water and 10 percent by volume of Parco Lubrite. This is followed by a water rinse and a dip in water-soluble oil. The phosphate surface soaks up oil and retains it.

Anodizing

Anodizing is the most common surface treatment of nonclad aluminum-alloy surfaces. The aluminum-alloy sheet or casting is the positive pole in an electrolytic bath in which chromic acid or other oxidizing agent produces an aluminum oxide film on the metal surface. Aluminum oxide is naturally protective, and anodizing merely increases the thickness and density of the natural oxide film. When this coating is damaged in service, it can only be partially restored by chemical surface treatments. Therefore, any processing of anodized surfaces, including corrosion removal, should avoid unnecessary destruction of the oxide film.

The anodized coating provides excellent resistance to corrosion. The coating is soft and easily scratched, making it necessary to use extreme caution when handling it prior to coating it with primer.

Aluminum wool, nylon webbing impregnated with aluminum-oxide abrasive or fiber-bristle brushes, are the approved tools for cleaning anodized surfaces. The use of steel wool, steel-wire brushes, or harsh abrasive materials on any aluminum surfaces is prohibited. Producing a buffed or wire-brush finish by any means is also prohibited. Otherwise, anodized surfaces are treated in much the same manner as other aluminum finishes.

In addition to its corrosion-resistant qualities, the anodic coating is also an excellent bond for paint. In most cases, parts are primed and painted as soon as possible after anodizing. The anodic coating is a poor conductor of electricity; therefore, if parts require bonding, the coating is removed where the bonding wire is to be attached. Alclad surfaces that are to be left unpainted require no anodic treatment; however, if the alclad surface is to be painted, it is usually anodized to provide a bond for the paint.

Alodizing

Alodizing is a simple chemical treatment for all aluminum alloys to increase their corrosion resistance and to improve their paint-bonding qualities. Because of its simplicity, alodizing is rapidly replacing anodizing in aircraft work.

The process consists of precleaning with an acidic or alkaline metal cleaner that is applied by either dipping or spraying. The parts are then rinsed with fresh water under pressure for 10–15 seconds. After thorough rinsing, alodine is applied by dipping, spraying, or brushing. A thin, hard coating results that ranges in color from light, bluish green with a slight iridescence on copper-free alloys to an olive green on copper-bearing alloys. The alodine is first rinsed with clear cold or warm water for a period of 15–30 seconds. An additional 10- to 15-second rinse is then given in a Deoxylyte bath. This bath is to counteract alkaline material and to make the alodized aluminum surface slightly acid on drying.

Surface treatment and inhibitors

As previously described, aluminum and magnesium alloys in particular are protected originally by a variety of surface treatments. Steels may have been Parco lubrized or otherwise oxidized on the surface during manufacture. Most of these coatings can only be restored by processes that are completely impractical in the field. But corroded areas where such protective films have been destroyed require some type of treatment prior to refinishing. The following inhibiting materials are particularly effective in the field treatment of aluminum, are beneficial to bare magnesium, and are of some value even on bare steel parts.

The labels on the containers of surface-treatment chemicals will provide a warning if a material is toxic or flammable. However, the label might not be large enough to accommodate a list of all the possible hazards that may ensue if the materials are mixed with incompatible substances. For example, some chemicals used in surface treatments will react violently if inadvertently mixed with paint thinners. Chemical surface-treatment materials must be handled with extreme care and mixed exactly according to directions.

Chromic-acid inhibitor

A 10 percent solution by weight of chromic acid, activated by a small amount of sulfuric acid, is particularly effective in treating exposed or corroded aluminum surfaces. It may also be used to treat corroded magnesium.

This treatment tends to restore the protective oxide coating on the metal surface. Such treatment must be followed by regular paint finishes as soon as practicable and never later than the same day as the latest chromic acid treatment. Chromium trioxide flake is a powerful oxidizing agent and a fairly strong acid. It must be stored away from organic solvents and other combustibles. Wiping cloths used in chromic-acid pickup should either be rinsed thoroughly after use or disposed of.

Sodium dichromate solution

A less-active chemical mixture for surface treatment of aluminum is a solution of sodium dichromate and chromic acid. Entrapped solutions of this mixture are less likely to corrode metal surfaces than chromic-acid inhibitor solutions.

Chemical surface treatments

Several commercial, activated chromate acid mixtures are available under Specification MIL-C-5541, *Chemical Conversion Coatings on Aluminum and Aluminum Alloys*, for field treatment of damaged or corroded aluminum surfaces. Precautions should be taken to make sure sponges or cloths used are thoroughly rinsed to avoid a possible fire hazard after drying.

Protective paint finishes

A good, intact paint finish is the most effective barrier between metal surfaces and corrosive media. The three most common finishes are a nitrocellulose finish, an acrylic nitrocellulose finish, and an epoxy finish. In addition, high-visibility fluorescent materials may also be used, along with a variety of miscellaneous combinations of special materials. There may also be rain-erosion-resistant coatings on metal leading edges and several different baked-on enamel finishes.

230. Corrosion removal

In general, any complete corrosion treatment involves the following:

- Cleaning and stripping of the corroded area.
- Removing as much of the corrosion products as practicable.
- Neutralizing any residual materials remaining in pits and crevices.
- Restoring protective surface films.
- Applying temporary or permanent coatings or paint finishes.

The following paragraphs deal with the correction of corrosive attack on surfaces and components where deterioration has not progressed to the point requiring rework or structural repair of the part involved.

Surface cleaning and paint removal

The removal of corrosion necessarily includes removal of surface finishes covering the attacked or suspected area. To assure maximum efficiency of the stripping compound, the area must be cleaned of grease, oil, dirt, or preservatives. This preliminary cleaning operation is also an aid in determining the extent of corrosion spread since the stripping operation will be held to the minimum, consistent with full exposure of the corrosion damage. Extensive corrosion spread on any panel should be corrected by fully treating the entire section.

The selection of the type of materials to be used in cleaning will depend on the nature of the matter to be removed. Dry-cleaning solvent should be used for removing oil, grease, or soft preservative

compounds. For heavy-duty removal of thick or dried preservatives, other compounds of the solvent-emulsion type are available.

The use of a general purpose, water-rinsable stripper is recommended for most applications. Wherever practicable, paint removal from any large area should be accomplished outside (in open air) and preferably in shaded areas. If inside removal is necessary, adequate ventilation must be assured. Synthetic rubber surfaces must be thoroughly protected against possible contact with paint remover. Care must also be exercised in using paint remover around gas or watertight seam sealants since this material will tend to soften and destroy the integrity of these sealants.

Mask off any opening that would permit the stripping compound to get into interior or critical cavities. Paint stripper is toxic and contains ingredients harmful to both skin and eyes. Rubber (nitrile) gloves, aprons of acid-repellent material, and goggle-type eyeglasses should be worn if any extensive paint removal is to be accomplished.

Mechanical removal of iron rust

The most practicable means of controlling the corrosion of steel is the complete removal of corrosion by mechanical means and restoring corrosion-preventive coatings. Except on highly stressed steel surfaces, the use of abrasive papers and compounds, small power buffers and buffing compounds, hand-wire brushing, or steel wool are all acceptable cleanup procedures. However, it should be recognized that in any such use of abrasives, residual rust usually remains in the bottom of small pits and other crevices. It is practically impossible to remove all corrosion products by abrasive or polishing methods alone. As a result, once a part has rusted, it usually corrodes again more easily than it did the first time

Chemical surface treatment of steel

There are approved methods for converting active rust to phosphates and other protective coatings. Parco lubricizing and the use of other phosphoric acid proprietary chemicals are examples of such treatments. However, these processes require shop-installed equipment and are impracticable for field use. Other commercial preparations are effective rust converters where tolerances are not critical and where thorough rinsing and neutralizing of residual acid is possible. These situations are generally not applicable to assembled craft, and the use of chemical inhibitors on installed steel parts is not only undesirable but very dangerous. The danger of entrapment of corrosive solutions and the resulting uncontrolled attack that could occur when such materials are used under field conditions outweigh any advantages to be gained from their use.

Removal of corrosion from highly stressed steel parts

Any corrosion on the surface of a highly stressed steel part is potentially dangerous, and the careful removal of corrosion products is required. Surface scratches or change in surface structure from overheating can also cause sudden failure of these parts. Corrosion products must be removed by careful processing, using mild abrasive papers such as rouge or fine-grit aluminum oxide, or fine buffing compounds on cloth buffing wheels. It is essential that steel surfaces not be overheated during buffing. After careful removal of surface corrosion, protective paint finishes should be reapplied immediately. If the corrosion cannot be safely removed from the part, it will be necessary to replace the part with a new one.

Treatment of unpainted and anodized aluminum surfaces

Relatively pure aluminum has considerably more corrosion resistance compared with the stronger aluminum alloys. Advantage is taken of this by laminating a thin sheet of relatively pure aluminum over the base aluminum alloy. The protection obtained is good, and the alclad surface can be maintained in a polished condition. In cleaning such surfaces, however, care must be taken to prevent staining and marring of the exposed aluminum and, more important from a protection standpoint, to avoid unnecessary mechanical removal of the protective alclad layer and the exposure of the more susceptible aluminum-alloy-base material.

As previously stated, applying an oxide film or anodizing is a common surface treatment of aluminum alloys. When this coating is damaged in service, it can be only partially restored by chemical surface treatment. Therefore, any corrosion correction of anodized surfaces should avoid destruction of the oxide film in the unaffected area.

For both materials, avoid the use of steel wool, steel-wire brushes, or severe abrasive materials. Aluminum wool, aluminum-wire brushes, or fiber-bristle brushes are the approved tools for cleaning corroded aluminum surfaces. Care must be exercised in any cleaning process to avoid unnecessary breaking of the adjacent protective film. Take every precaution to maintain as much of the protective coating as practicable. Otherwise, treat anodized surfaces in the same manner as other aluminum finishes. Chromic acid and other inhibitive treatments tend to restore the oxide film.

Treatment of intergranular corrosion in heat-treated aluminum-alloy surfaces

In its most severe form, actual lifting of metal layers (exfoliation) occurs. More severe cleaning is a must when intergranular corrosion is present. The mechanical removal of all corrosion products and visible delaminated metal layers must be accomplished to determine the extent of the destruction and to evaluate the remaining structural strength of the component.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

228. Types, forms and factors of corrosion

1. What are the most common causes for direct-chemical-attack corrosion?

2. What conditions must exist for electrochemical corrosion attack?

3. Match the corrosion description in column A with the type of corrosion in column B. Items in column B may be used once, more than once, or not at all.

Column A

- ____ (1) General roughening, etching, or pitting of the surface of a metal, frequently accompanied by a powdery deposit of corrosion products.
- ____ (2) Extensive pitting damage from contact between dissimilar metal parts in the presence of a conductor.
- ____ (3) Attacks along the grain boundaries of an alloy, commonly results from a lack of uniformity in the alloy structure.
- ____ (4) Results from the combined effect of sustained tensile stresses and a corrosive environment.
- ____ (5) Occurs when two mating surfaces are subject to slight relative motion.

Column B

- a. Galvanic corrosion
- b. Stress corrosion
- c. Surface corrosion
- d. Fretting corrosion
- e. Intergranular corrosion
- f. Caustic corrosion

4. Why is temperature an important factor for corrosion?

5. What are the three main factors affecting corrosion?

229. Preventive maintenance

1. What are three trouble areas that are more prone to corrosion?
2. Match the description in column A with the corrosion-prevention process in column B. Items in column B may be used once, more than once, or not at all.

Column A

- ___ (1) Transferring metal from one object to another by chemical and electrical means.
- ___ (2) The surface application of molten metal on any solid-base material.
- ___ (3) A simple chemical treatment for all aluminum alloys, rapidly replacing anodizing.
- ___ (4) The chemical treatment for iron and steel parts that converts the surface to a nonmetallic oil-absorptive phosphate coating.
- ___ (5) The three most common are a nitrocellulose finish, an acrylic nitrocellulose finish, and an epoxy finish.
- ___ (6) The most common surface treatment of nonclad aluminum-alloy surfaces.
- ___ (7) This treatment tends to restore the protective oxide coating on the metal surface.

Column B

- a. Chemical surface treatments
- b. paint finishes
- c. metallizing
- d. Alodizing
- e. Parco lubricizing
- f. Chromic acid inhibitor
- g. Electroplating
- h. Sodium dichromate solution
- i. Anodizing

230. Corrosion removal

1. What must be done to assure maximum efficiency of the stripping compound?
2. On what type of surface should abrasive papers and compounds, small power buffers and buffing compounds, hand wire brushing, or steel wool *not* be used to remove corrosion?
3. What are the approved tools for cleaning corroded aluminum surfaces?

3-3. Fluid Lines and Fittings

The term *plumbing* refers not only to the hose, tubing, fittings, and connectors, but also to the processes of forming and installing them. Occasionally it may be necessary to repair or replace damaged plumbing lines. Very often the repair can be made simply by replacing the tubing; however, if replacements are not available, the needed parts may have to be fabricated. Replacement tubing should be of the same size and material as the original line. All tubing is pressure tested prior to initial installation and is designed to withstand several times the normal operating pressure to which it will

be subjected. If a tube bursts or cracks, it is generally the result of excessive vibration, improper installation, or damage caused by collision with an object. All tubing failures should be carefully studied, and the cause of the failure determined.

231. Plumbing components

When we think of plumbing, we often think of the pipes in our homes that bring water to our sinks, tubs, and toilets or take waste water and other materials through the drains into the waste system. Plumbing in air and space systems works on the same basic principle. Air or liquids are transported through a plumbing system. The next couple of pages discuss plumbing lines and connectors.

Plumbing lines

Plumbing lines usually are made of metal tubing and fittings or of flexible hose. Metal tubing is widely used for fuel, instrument, and hydraulic lines. Flexible hose is generally used with moving parts or where the hose is subject to considerable vibration.

Generally, aluminum-alloy or corrosion-resistant steel tubing has replaced copper tubing. The high fatigue factor of copper tubing is the chief reason for its replacement. It becomes hard and brittle from vibrations and finally breaks; however, it may be restored to its soft-annealed state by heating it red hot and quenching it in cold water. Cooling in air will result in a degree of softness but not equal to that obtained with the cold-water quench. This annealing process must be accomplished if copper tubing is removed for any reason. Inspection of copper tubing for cracks, hardness, brittleness, and general condition should be accomplished at regular intervals to preclude failure. The workability, resistance to corrosion, and lightweight of aluminum alloy are major factors in its adoption for plumbing.

In some high-pressure (3,000 psi) hydraulic installations, corrosion-resistant steel tubing is used. Corrosion-resistant steel tubing is better suited for these applications because it does not have to be annealed for flaring or forming; in fact, the flared section is somewhat strengthened by the cold working and strain hardening during the flaring process. Its higher tensile strength permits the use of tubing with thinner walls; consequently the final installation weight is not much greater than that of the thicker wall aluminum-alloy tubing.

Identification of materials

Before making repairs to any plumbing, it is important to make accurate identification of plumbing materials. Aluminum-alloy or steel tubing can be identified readily by sight where it is used as the basic plumbing material. However, it is difficult to determine whether a material is carbon steel or stainless steel, or whether it is 1100, 3003, 5052-O, or 2024-T aluminum alloy.

It may be necessary to test samples of the material for hardness by filing or scratching with a scribe. The magnet test is the simplest method for distinguishing between the annealed austenitic and the ferritic stainless steels. The austenitic types are nonmagnetic unless heavily cold worked, whereas the straight chromium carbon and low-alloy steels are strongly magnetic.

By comparing code markings of the replacement tubing with the original markings on the tubing being replaced, it is possible to identify definitely the material used in the original installation.

The alloy designation is stamped on the surface of large aluminum-alloy tubing. On small aluminum-alloy tubing, the designation may be stamped on the surface, but more often it is shown by a color code. Bands of the color code (not more than four inches in width) are painted at the two ends and approximately midway between the ends of most tubing. When the band consists of two colors, one-half the width is used for each color.

Painted color codes used to identify aluminum-alloy tubing are as follows:

Aluminum-Alloy Number	Color of Band
1100	White
3003	Green
2014	Gray
2024	Red
5052	Purple
6053	Black
6061	Blue and Yellow
7075	Brown and Yellow

Aluminum-alloy tubing, 1100 or 3003, is used for general purpose lines of low or negligible fluid pressures, such as instrument lines and ventilating conduits. The 2024-T and 5052-O aluminum-alloy materials are used in general purpose systems of low and medium pressures, such as hydraulic and pneumatic 1,000 to 1,500 psi systems and fuel and oil lines. Occasionally, these materials are used in high-pressure (3,000 psi) systems.

Tubing made from 2024-T and 5052-O materials will withstand a fairly high pressure before bursting. These materials are easily flared and are soft enough to be formed with hand tools. They must be handled with care to prevent scratches, dents, and nicks.

Corrosion-resistant steel tubing, either annealed or 1/4 hard, is used extensively in high-pressure hydraulic systems. External lines should always be made of corrosion-resistant steel to minimize damage. Although identification markings for steel tubing differ, each usually includes the manufacturer's name or trademark, the SAE number, and the physical condition of the metal.

Metal tubing is sized by outside diameter, which is measured fractionally in sixteenths of an inch. Thus, no. 6 tubing is 6/16 (or 3/8) inch and no. 8 tubing is 8/16 (or 1/2) inch, and so forth.

In addition to other classification or means of identification, tubing is manufactured in various wall thicknesses. Thus, it is important when installing tubing to know not only the material and outside diameter but also the thickness of the wall.

Flexible hose

Flexible hose is used to connect moving parts with stationary parts in locations subject to vibration or where a great amount of flexibility is needed. It can also serve as a connector in metal-tubing systems.

Synthetics

Synthetic materials most commonly used in the manufacture of flexible hose are buna-N, neoprene, and butyl.

- Buna-N (the "N" standing for nitrile) is a synthetic rubber compound that has excellent resistance to petroleum products. Buna-N should not be confused with Buna-S (the "S" standing for styrene). Buna-S, which is a newer rubber compound having a much better wear resistance in its raw form than even the highest quality natural rubber, cannot be compounded and vulcanized easily on the machines made for natural rubber.
- Neoprene is a synthetic rubber compound that has an acetylene base. Its resistance to petroleum products is not as good as Buna-N but has better abrasive resistance.
- Butyl is a synthetic rubber compound made from petroleum raw materials.

Rubber hose

Flexible rubber hose consists of a seamless synthetic-rubber inner tube covered with layers of cotton braid and wire braid and an outer layer of rubber-impregnated cotton braid. This type of hose is suitable for use in fuel, oil, coolant, and hydraulic systems. These types of hose are normally

classified by the amount of pressure they are designed to withstand under normal operating conditions.

- Low pressure, any pressure below 250 psi. Fabric-braid reinforcement.
- Medium pressure, pressures up to 3,000 psi. One wire-braid reinforcement. Smaller sizes carry pressure up to 3,000 psi. Larger sizes carry pressure up to 1,500 psi.
- High pressure (all sizes up to 3,000 psi operating pressures).

Identification markings consisting of lines, letters, and numbers are printed on the hose. These code markings show such information as hose size, manufacturer, date of manufacture, and pressure and temperature limits. Code markings assist in replacing a hose with one of the same specification or a recommended substitute. In some instances, several types of hose may be suitable for the same use. Therefore, in order to make the correct hose selection, always refer to the maintenance or parts manual.

Size designation

The size of flexible hose is determined by its inside diameter. Sizes are in 1/16 in. increments and are identical to corresponding sizes of rigid tubing with which it can be used.

Identification of fluid lines

Fluid lines are often identified by markers made up of color codes, words, and geometric symbols. These markers identify each line's function, content, and primary hazard, as well as the direction of fluid flow.

In addition to the above mentioned markings, certain lines may be further identified as to specific function within a system; for example, DRAIN, VENT, PRESSURE, or RETURN.

Lines conveying fuel may be marked FLAM; lines containing toxic materials are marked TOXIC in place of FLAM. Lines containing physically dangerous materials, such as oxygen, nitrogen, or refrigerant, are marked PHDAN.

Manufacturers are responsible for the original installation of identification markers, but the mechanic is responsible for their replacement when it becomes necessary.

Generally, tapes and decals are placed on both ends of a line and at least once in each compartment through which the line runs. In addition, identification markers are placed immediately adjacent to each valve, regulator, filter, or other accessory within a line. Where paint or tags are used, location requirements are the same as for tapes and decals.

Assembly precautions

Make certain that the material used in the fittings is similar to that of the tubing; for example, use steel fittings with steel tubing and aluminum-alloy fittings with aluminum-alloy tubing. Brass fittings plated with cadmium may be used with aluminum-alloy tubing.

For corrosion prevention, aluminum-alloy lines and fittings are usually anodized. Steel lines and fittings, if not stainless steel, are plated to prevent rusting or corroding. Brass and steel fittings are usually cadmium plated, although some may come plated with nickel, chromium, or tin.

To ensure proper sealing of hose connections and to prevent breaking hose clamps or damaging the hose, follow the hose-clamp tightening instructions carefully. When available, use the hose-clamp torque-limiting wrench. These wrenches are available in calibrations of 15 and 25 inch pounds. In the absence of torque-limiting wrenches, the finger-tight-plus-turns method should be followed.

Support clamps

Support clamps are used to secure the various lines to the airframe or power-plant assemblies. Several types of support clamps are used for this purpose. The rubber-cushioned and plain clamps are the

most commonly used. The rubber-cushioned clamp is used to secure lines subject to vibration; the cushioning prevents chafing of the tubing. The plain clamp is used to secure lines in areas not subject to vibration.

Use bonded clamps to secure metal hydraulic, fuel, and oil lines in place. Unbonded clamps should be used only for securing wiring. Remove any paint or anodizing from the portion of the tube at the bonding-clamp location. Make certain that clamps are of the correct size. Clamps or supporting clips smaller than the outside diameter of the hose may restrict the flow of fluid through the hose.

Plumbing connectors

Plumbing connectors, or fittings, attach one piece of tubing to another or to system units. There are many types, but the two most common in airframe maintenance are the flared fitting and flareless fitting. The amount of pressure that the system carries is usually the deciding factor in selecting a connector. The beaded type of joint, which requires a bead and a section of hose and hose clamps, is used only in low- or medium-pressure systems, such as vacuum and coolant systems. The flared, flareless, and swaged types may be used as connectors in all systems, regardless of the pressure.

Flared tube fittings

A flared tube fitting consists of a sleeve and a nut. The nut fits over the sleeve and, when tightened, draws the sleeve and tubing flare tightly against a male fitting to form a seal. Tubing used with this type of fitting must be flared before installation.

The male fitting has a cone shaped surface with the same angle as the inside of the flare. The sleeve supports the tube so that vibration does not concentrate at the edge of the flare and distributes the shearing action over a wider area for added strength. Tube flaring and the installation of flared tube fittings are discussed in detail later in this unit.

The AN standard fitting is the most commonly used flared tubing assembly for attaching the tubing to the various fittings required in aircraft plumbing systems. The AN standard fittings include the AN818 nut and AN819 sleeve. The AN819 sleeve is used with the AN818 coupling nut. All these fittings have straight threads, but they have different pitch for the various types.

Flared tube fittings are made of aluminum alloy, steel, or copper-base alloys. For identification purposes, all AN steel fittings are colored black, and all AN aluminum-alloy fittings are colored blue. The AN 819 aluminum bronze sleeves are cadmium plated and are not colored. The size of these fittings is given in dash numbers, which equal the nominal tube outside diameter (OD) in sixteenths of an inch.

Threaded flared tube fittings have two types of ends referred to as male and female. The male end of a fitting is externally threaded, whereas the female end of a fitting is internally threaded.

Flareless tube fittings

The MS (military standard) flareless tube fittings are finding wide application in plumbing systems. Using this type fitting eliminates all tube flaring yet provides a safe, strong, dependable tube connection. The fitting consists of three parts: a body, a sleeve, and a nut. The body has a counterbored shoulder against which the end of the tube rests. The angle of the counterbore causes the cutting edge of the sleeve to cut into the outside of the tube when the two are joined. Installation of flareless tube fittings is discussed later in this unit.

232. Rigid tube forming processes

Damaged tubing and fluid lines should be replaced with new parts whenever possible. Sometimes replacement is impractical and repair is necessary. Scratches, abrasions, and minor corrosion on the outside of fluid lines may be considered negligible and can be smoothed out with a burnishing tool or aluminum wool. If a fluid line assembly is to be replaced, the fittings can often be salvaged, and then the repair will involve only tube forming and replacement.

Tube forming

Tube forming consists of five processes:

1. Cutting.
2. Bending.
3. Flaring.
4. Beading.
5. Presetting.

If the tubing is small and of soft material, the assembly can be formed by hand bending during installation. If the tubing is 1/4 in. in diameter, or larger, hand bending without the aid of tools is impractical.

Tube cutting

When cutting tubing, it is important to produce a square end, free of burrs. Tubing may be cut with a tube cutter or a hacksaw.

Tube cutter

A cutter can be used with any soft metal tubing, such as copper, aluminum, or aluminum alloy. A new piece of tubing should be cut approximately 10 percent longer than the tube to be replaced to provide for minor variations in bending. Place the tubing in the cutting tool with the cutting wheel at the point where the cut is to be made. Rotate the cutter around the tubing, applying a light pressure to the cutting wheel by intermittently twisting the thumbscrew. Too much pressure on the cutting wheel at one time could deform the tubing or cause excessive burring. After cutting the tubing, carefully remove any burrs from inside and outside the tube. Use a knife or the burring edge attached to the tube cutter.

When performing the deburring operation, use extreme care. Ensure that the wall thickness of the end of the tubing is not reduced or fractured. Very slight damage of this type can lead to fractured flares or defective flares that will not seal properly. A fine-tooth file can be used to file the end square and smooth.

Hacksaw

If a tube cutter is not available or if tubing made of hard material is to be cut, use a fine-tooth hacksaw, preferably one having 32 teeth per inch. The use of a saw will decrease the amount of work hardening of the tubing during the cutting operation. After sawing, file the end of the tube square and smooth, removing all burrs.

An easy way to hold small-diameter tubing when cutting it is to place the tube in a combination flaring tool and clamp the tool in a vise. Make the cut about 1/2 inch from the flaring tool. This procedure keeps sawing vibrations to a minimum and prevents damage to the tubing if it is accidentally hit with the hacksaw frame or file handle while cutting. Be sure all filings and cuttings are removed from the tube.

Tube bending

The objective in tube bending is to obtain a smooth bend without flattening the tube. Tubing less than 1/4 in. in diameter usually can be bent without the use of a bending tool.

Hand bending

To bend tubing with the hand-tube bender, insert the tubing by raising the slide-bar handle as far as it will go. Adjust the handle so that the full length of the groove in the slide bar is in contact with the tubing. The zero mark on the radius block and the mark on the slide bar must align. Make the bend by rotating the handle until the desired angle of bend is obtained, as indicated on the radius block.

Bend the tubing carefully to avoid excessive flattening, kinking, or wrinkling. A small amount of flattening in bends is acceptable, but the small diameter of the flattened portion must not be greater than 75 percent of the original outside diameter. Tubing with flattened, wrinkled, or irregular bends should not be installed. Wrinkled bends usually result from trying to bend thin-wall tubing without using a tube bender.

Machine bending

Tube-bending machines for all types of tubing are generally used in repair stations and large maintenance shops. With such equipment, proper bends can be made on large-diameter tubing and on tubing made from hard material. The production-tube bender is an example of this type of machine.

The ordinary production-tube bender will accommodate tubing ranging from 1/2 inch to 1½ inch outside diameter. Benders for larger sizes are available, and the principle of their operation is similar to that of the hand-tube bender. The radius blocks are so constructed that the radius of bend will vary with the tubing diameter. The radius of bend is usually stamped on the block.

Filler method

When hand- or production-tube benders are not available or are not suitable for a particular bending operation, a filler of fusible alloy or of dry sand is used to facilitate bending. When using this method, cut the tube slightly longer than is required. The extra length is for inserting a plug (which may be wooden) in each end.

After plugging one end, fill and pack the tube with fine, dry sand and plug tightly. Both plugs must be tight so they will not be forced out when the bend is made. The tube can also be closed by flattening the ends or by soldering metal disks in them. After the ends are closed, bend the tubing over a forming block shaped to the specified radius.

In a modified version of the filler method, a fusible alloy is used instead of sand. In this method, the tube is filled under hot water with a fusible alloy that melts at 160° F. The alloy-filled tubing is then removed from the water, allowed to cool, and bent slowly by hand around a forming block or with a tube bender. After the bend is made, the alloy is again melted under hot water and removed from the tubing.

When using either filler method, make certain that all particles of the filler are removed so that none will be carried into the system in which the tubing is installed.

Store the fusible-alloy filler where it will be free from dust or dirt. It can be remelted and reused as often as desired. Never heat this filler in any other method than the prescribed method, as the alloy will stick to the inside of the tubing, making them both unusable.

Tube flaring

Two kinds of flares are generally used in plumbing systems, the single flare and the double flare. Flares are frequently subjected to extremely high pressures; therefore, the flare on the tubing must be properly shaped, or the connection will leak or fail.

A flare made too small produces a weak joint, which may leak or pull apart; if made too large it interferes with the proper engagement of the screw thread on the fitting and will cause leakage. A crooked flare is the result of the tubing not being cut squarely. If a flare is not made properly, flaws cannot be corrected by applying additional torque when tightening the fitting. The flare and tubing must be free from cracks, dents, nicks, scratches, or any other defects.

The flaring tool used for airframe tubing has male and female dies ground to produce a flare of 35° to 37°. Under no circumstances is it permissible to use an automotive-type flaring tool that produces a flare of 45°.

A hand-flaring tool is used for flaring tubing. The tool consists of a flaring block or grip die, a yoke, and a flaring pin. The flaring block is a hinged double bar with holes corresponding to various sizes

of tubing. These holes are countersunk on one end to form the outside support against which the flare is formed. The yoke is used to center the flaring pin over the end of the tube to be flared.

Single flare

To prepare a tube for flaring, cut the tube squarely and remove all burrs. Slip the fitting nut and sleeve on the tube and place the tube in the proper size hole in the flaring tool. Center the plunger or flaring pin over the end of the tube. Then project the end of the tubing slightly from the top of the flaring tool, about the thickness of a dime, and tighten the clamp bar securely to prevent slippage.

Make the flare by striking the plunger several light blows with a lightweight hammer or mallet. Turn the plunger a half turn after each blow and be sure it seats properly before removing the tube from the flaring tool. Check the flare by sliding the sleeve into position over the flare. The outside diameter of the flare should extend approximately 1/16 in. beyond the end of the sleeve, but should not be larger than the major outside diameter of the sleeve.

Double flare

A double flare should be used on 5052-O and 6061-T aluminum-alloy tubing for all sizes from 1/8 in. to 3/8 in. outside diameter. This is necessary to prevent cutting off the flare and failure of the tube assembly under operating pressures. Double flaring is not necessary on steel tubing. The double flare is smoother and more concentric than the single flare and therefore seals better. It is also more resistant to the shearing effect of torque.

To make the double flare, separate the clamp blocks of the double-flaring tool and insert and clamp the tubing with the burred end flush with the top of the clamp. Insert the starting pin into the flaring-pin guide and strike the pin sharply with a hammer until the shoulder of the pin stops against the clamp blocks. Remove the starting pin and insert the finishing pin; hammer it until its shoulder rests on the clamp block.

Beading

Beads can be used to dampen vibration in solid lines or to increase the effectiveness of the seal when a rubber or fabric sleeve is clamped to a metal duct. Typical applications include low-pressure air, exhaust, and liquid systems. There are two types of beads, rotary and compression.

Rotary beading

Rotary beading is a versatile form of end forming that can be used in a variety of industrial applications. For example, beaded joints can be used for O-rings, or they can be used to connect hoses to tube ends.

Compression beading

Compression beading is used in different applications than a rotary bead and does not keep as tight of a tolerance. Compression beads typically act as a stop or as a means of containing another part within an area on the tube. This type of beading process is created by compressing two sides of the tube together by forcing the two tube ends towards one another. The trick is to leave a small gap open in-between a clamp that holds one end and a tube-forming die that supports the other end. As the two tools hit their end point, the tube collapses at the gap, creating the bead.

Presetting

Although the use of flareless tube fittings eliminates all tube flaring, another operation, referred to as presetting, is necessary prior to installation of a new flareless tube assembly.

1. Cut the tube to the correct length, with the ends perfectly square. Deburr the inside and outside of the tube. Slip the nut, then the sleeve, over the tube.
2. Lubricate the threads of the fitting and nut with hydraulic fluid. Place the fitting in a vise.

3. Hold the tubing firmly and squarely on the seat in the fitting. (Tube must bottom firmly in the fitting.)
4. Tighten the nut until the cutting edge of the sleeve grips the tube. This point is determined by slowly turning the tube back and forth while tightening the nut.
5. When the tube no longer turns, the nut is ready for final tightening.
6. Final tightening depends upon the tubing.
 - a) For aluminum-alloy tubing up to and including 1/2 in. outside diameter, tighten the nut from 1 to 1 1/6 turns.
 - b) For steel tubing and aluminum-alloy tubing over 1/2 in. outside diameter, tighten from 1 1/6 to 1 1/2 turns.

After presetting the sleeve, disconnect the tubing from the fitting and check the following points:

- The tube should extend 3/32 in. to 1/8 in. beyond the sleeve pilot; otherwise, blow off may occur.
- The sleeve pilot should contact the tube or have a maximum clearance of 0.005 in. for aluminum-alloy tubing or 0.015 in. for steel tubing.
- A slight collapse of the tube at the sleeve cut is permissible. No movement of the sleeve pilot, except rotation, is permissible.

233. Installation, fabrication, and replacement of tubes and hoses

This last lesson covers some basic knowledge you need to know about installing, fabricating, and replacing various tubes and hoses. We'll start by providing information on metal tubes and rap up with flexible hose.

Rigid metal tube lines

When inspecting rigid metal tubing, you must be able to identify unacceptable damage and know if it is necessary to replace an entire section or simply repair the damage.

Replacement criteria

Scratches or nicks no deeper than 10 percent of the wall thickness in aluminum-alloy tubing may be repaired, if they are not in the heel of a bend. Replace lines with severe die marks, seams, or splits in the tube. Any crack or deformity in a flare is also unacceptable and is cause for rejection. A dent of less than 20 percent of the tube diameter is not objectionable on straight sections of tubing, unless it is in the heel of a bend. Dents can be removed by drawing a bullet of proper size through the tube by means of a length of cable.

A severely damaged line should be replaced. However, the line can be repaired by cutting out the damaged section and inserting a tube section of the same size and material. Flare both ends of the undamaged and replacement tube sections and make the connection by using standard unions, sleeves, and tube nuts. If the damaged portion is short enough, omit the insert tube and repair by using one union and two sets of connecting fittings.

When repairing a damaged line, be very careful to remove all chips and burrs. Any open line that is to be left unattended for some time should be sealed using metal, wood, rubber, or plastic plugs or caps.

When repairing a low-pressure line using a flexible fluid connection assembly, position the hose clamps carefully in order to prevent overhang of the clamp bands or chafing of the tightening screws on adjacent parts. If chafing can occur, the hose clamps should be repositioned on the hose.

Layout of lines

Remove the damaged or worn assembly, taking care not to further damage or distort it, and use it as a forming template for the new part. If the old length of tubing cannot be used as a pattern, make a wire

template, bending the pattern by hand as required for the new assembly. Then bend the tubing to match the wire pattern.

A tube must be cut or flared accurately enough so that it can be installed without undue bending and mechanical strain. Bends are sometimes necessary to permit the tubing to expand or contract under temperature changes and to absorb vibration. If the tube is small (under 1/4 in.) and can be hand formed, casual bends may be made to allow for this. If the tube must be machine formed, definite bends must be made to avoid a straight assembly.

Start all bends a reasonable distance from the fittings because the sleeves and nuts must be slipped back during the fabrication of flares and during inspections. In all cases, the new tube assembly should be formed prior to installation so that it will not be necessary to pull or deflect the assembly into alignment by means of the coupling nuts.

Installation of rigid tubing

Before installing a line assembly, inspect the line carefully. Remove dents and scratches, and be sure all nuts and sleeves are snugly mated and securely fitted by proper flaring of the tubing. The line assembly should be clean and free of all foreign matter. Ensure that no electrical lines are located below the line(s) being installed.

Connection and torque

Never apply compound to the faces of the fitting or the flare, for it will destroy the metal-to-metal contact between the fitting and flare, a contact that is necessary to produce the seal. Be sure that the line assembly is properly aligned before tightening the fittings. Do not pull or apply tension to move the installation into place with torque on the nut. It must be remembered that these torque values are for flared-type fittings only. Always use two wrenches to tighten fittings to the correct torque value when installing a tube assembly. Overtightening a fitting may damage the threads, completely cut off the tube flare, or it may ruin the sleeve or fitting nut. Failure to tighten sufficiently also can be serious, as this condition may allow the line to blow out of the assembly or to leak under system pressure.

The use of torque wrenches and the prescribed torque values prevent overtightening or undertightening. If a tube fitting assembly is tightened properly, it can be removed and retightened many times before reflairing is necessary.

Flareless tube installation

Tighten the nut by hand until an increase in resistance to turning is encountered. Should it be impossible to run the nut down with the fingers, use a wrench, but be alert for the first signs of bottoming. It is important that the final tightening commence at the point where the nut just begins to bottom.

Using a wrench, turn the nut 1/6 turn (one flat on a hex nut). Use a wrench on the connector to prevent it from turning while tightening the nut. After the tube assembly is installed, the system should be pressure tested. Should a connection leak, it is permissible to tighten the nut an additional 1/6 turn (making a total of 1/3 turn). If, after tightening the nut a total of 1/3 turn, leakage still exists, the assembly should be removed and the components of the assembly inspected for scores, cracks, and presence of foreign material, or damage from over tightening.

NOTE: Overtightening a flareless tube nut drives the cutting edge of the sleeve deeply into the tube, causing the tube to be weakened to the point where normal in-flight vibration could cause the tube to shear. After inspection (if no discrepancies are found), reassemble the connections and repeat the pressure test procedures.

CAUTION: Do not in any case tighten the nut beyond 1/3 turn (two flats on the hex nut); this is the maximum the fitting may be tightened, after beginning to bottom, without the possibility of permanently damaging the sleeve and nut.

Common faults are as follows:

- Flare distorted into nut threads.
- Sleeve cracked.
- Flare cracked or split.
- Flare out of round.
- Inside of flare rough or scratched.
- Fitting cone rough or scratched.
- Threads of nut or union dirty, damaged, or broken.

Some manufacturers' service instructions will specify wrench-torque values for flareless tubing installations.

Flexible hose

Hose and hose assemblies should be checked for deterioration at each inspection period. Leakage, separation of the cover or braid from the inner tube, cracks, hardening, lack of flexibility, and excessive "cold flow" are apparent signs of deterioration and reason for replacement. The term *cold flow* describes the deep, permanent impressions in the hose produced by the pressure of hose clamps or supports.

When failure occurs in a flexible hose equipped with swaged end fittings, the entire assembly must be replaced. Obtain a new hose assembly of the correct size and length, complete with factory installed end fittings.

When failure occurs in a hose equipped with reusable end fittings, a replacement line can be fabricated with the use of such tooling as may be necessary to comply with the assembly instructions of the manufacturer.

Assembly of sleeve-type fittings

Sleeve-type end fittings for flexible hoses are detachable and may be reused if determined to be serviceable. The inside diameter of the fitting is the same as the inside diameter of the hose to which it is attached.

To make a hose assembly, select the proper size hose and end fittings. Cut the hose to the correct length using a fine-tooth hacksaw. Place the socket in a vise. Screw the hose into the socket counterclockwise until the hose bottoms on the shoulder of the socket, then back off one-quarter turn. Lubricate the inside of the hose and nipple threads liberally.

Mark the hose position around the hose at the rear of the socket using a grease pencil or painted line. Insert the nipple into the nut and tighten the nipple and nut on the assembly tool. If an assembly tool is not available, a mating AN815 adapter may be used. A 1/32 in. to 1/16 in. clearance between the nut and sleeve is required so that the nut will swivel freely when the assembly tool is removed. After assembly, always make sure all foreign matter is removed from inside the hose by blowing out with compressed air.

Proof test after assembly

All flexible hose must be proof tested after assembly by plugging or capping one end of the hose and applying pressure to the inside of the hose assembly. The proof-test medium may be a liquid or a gas. For example, hydraulic, fuel, and oil lines are generally tested using hydraulic oil or water, whereas air or instrument lines are tested with dry, oil-free air or nitrogen. When testing with a liquid, all

trapped air is bled from the assembly prior to tightening the cap or plug. Hose tests, using a gas, are conducted underwater. In all cases, follow the hose manufacturer's instructions for proof-test pressure and fluid to be used when testing a specific hose assembly.

Place the hose assembly in a horizontal position and observe for leakage while maintaining the test pressure. Proof-test pressures should be maintained for at least 30 seconds.

Installation of flexible hose assemblies

Flexible hose must not be twisted on installation, since this reduces the life of the hose considerably and may also loosen the fittings. Twisting of the hose can be determined from the identification stripe running along its length. This stripe should not spiral around the hose.

Flexible hose should be protected from chafing by wrapping it with tape, but only where necessary.

The minimum bend radius for flexible hose varies according to size and construction of the hose and the pressure under which the hose is to operate. Bends that are too sharp will reduce the bursting pressure of flexible hose considerably below its rated value.

Flexible hose should be installed so that it will be subject to a minimum of flexing during operation. Although hose must be supported at least every 24 inches, closer supports are desirable. A flexible hose must never be stretched tightly between two fittings. From 5 percent to 8 percent of its total length must be allowed for freedom of movement under pressure. When under pressure, flexible hose contracts in length and expands in diameter.

Protect all flexible hose from excessive temperatures, either by locating the lines so they will not be affected or by installing shrouds around them.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

231. Plumbing components

1. Why is corrosion-resistant steel tubing better suited for high-pressure applications?
2. What is the simplest method for distinguishing between the annealed austenitic and the ferritic stainless steels?
3. What aluminum-alloy materials are used on general purpose systems of low and medium pressure (1,000 to 1,500 pounds per square inch [psi]) systems? What are their color codes?
4. How is metal tubing sized?
5. When may flexible hose be used?
6. What are the three most commonly used synthetics in the manufacture of flexible hose?

7. How are flexible hoses sized?
8. In the absence of torque-limiting wrenches, what method of tightening hose clamps should be used?
9. When should rubber support clamps be used and why?
10. What are the two most common types of plumbing connectors?
11. What are the three materials flared tube fittings are made out of, and how are they identified?
12. What are the three parts of a military standard (MS) flareless tube fitting?

232. Rigid tube forming processes

1. Match the description in column A with the rigid tube forming process in column B. Items in column B may be used once, more than once, or not at all.

<i>Column A</i>	<i>Column B</i>
___ (1) During this process, applying too much pressure at one time could deform the tubing or cause excessive burring.	g. Flaring
___ (2) This process involves filling the tube with fine, dry sand.	h. Cutting
___ (3) This process, if made too small, produces a weak joint that may leak or pull apart.	i. Double flaring
___ (4) Perform this process carefully to avoid excessive flattening, kinking, or wrinkling.	j. Bending
___ (5) This process is not necessary on steel tubing.	k. Beading
___ (6) This process is necessary prior to installation of a new flareless tube assembly.	l. Presetting
___ (7) This process is used to dampen vibration in solid lines or to increase the effectiveness of the seal when a rubber or fabric sleeve is clamped to a metal duct.	

233. Installation, fabrication and replacement of tubes and hoses

1. Scratches or nicks no deeper than 10 percent of the wall thickness in aluminum-alloy tubing may be repaired unless they are located where?
2. A dent on straight sections of tubing is not objectionable so long as it is less than what percent of the tube diameter?

3. During rigid tube installation, what must not be located below the tubing?
4. Explain the “finger-tight-plus-turns” method of flareless tube installation.
5. What does the term *cold flow* refer to?
6. After hose assembly, what should be done to make sure all foreign matter is removed from inside the hose?
7. For how long should proof-test pressures be maintained?
8. How do you determine if twisting of a hose has occurred?

Answers to Self-Test Questions

220

1. (1) e.
(2) g
(3) h.
(4) c.
(5) a.
(6) b.
(7) d.
2. Tension, compression, shear, bending, torsion.
3. 2 processes: heat-treating and annealing.

221

1. To relieve the internal strain and reduce brittleness.
2. Heating the metal to a prescribed temperature, holding it there for a specified length of time, and cooling the metal back to room temperature. Relieves internal stress, softens the metal, makes it more ductile, and refines the grain structure.
3. Iron-base metals only.
4. Seamless tubing, wire, streamlined tie rods.
5. Cracks adjacent to the weld.

222

1. 4.
2. (1) d.
(2) c.

- (3) a.
- (4) b.
- 3. Chrome nickel, chrome vanadium, chrome molybdenum, Inconel.

223

- 1. High-strength-to-weight ratio and its comparative ease of fabrication.
- 2. 99 percent commercially pure aluminum.
- 3. The major alloying element (copper).
- 4. Sheets that consist of an aluminum-alloy core coated with a layer of pure aluminum.
- 5. Due to the formation of a protective surface film of stable oxide or chemi-absorbed oxygen.
- 6. Muntz metal.
- 7. Using an extinguishing powder, such as powdered soapstone or graphite powder.

224

- 1. Titanium.
- 2. Alloy constituents cannot be identified under a microscope; mechanical mixture compounds can be identified by microscopic examination.
- 3. Produces fine-grained, soft, ductile metal without internal stresses or strains.
- 4. Normalizing.
- 5. Case-hardening.
- 6. Solution and precipitation heat treatment.
- 7. Cold water, hot water, and spray.
- 8. To improve tensile strength, ductility, and shock resistance.
- 9. Provides toughness, improved machinability, ductility at room temperature, and dimensional and structural stability at elevated temperatures.

225

- 1. Brinell, Rockwell, Barcol.
- 2. Barcol.

226

- 1. Ferromagnetic materials.
- 2. Flaws on or near the surface.
- 3. Wet and dry process materials.
- 4. Residual method.
- 5. Demagnetization.
- 6. Any nonporous material.
- 7. Dye penetrant inspection, eddy current inspection, ultrasonic inspection, and visual inspection.

227

- 1. 60:40.
- 2. A transition to a different type of internal structure.
- 3. Water.
- 4. Methyl-ethyl-ketone (MEK).
- 5. Aluminum alloys in contact with it will corrode.
- 6. E glass and S glass.
- 7. Epoxies, polyurethanes, bismaleimides, polyamides, phenolic and amino resins.
- 8. Standard prepreg contains more resin than is desired in the finished part; excess resin is bled off during cure, and net-resin prepreg contains the same resin content that is desired in the finished part; no resin bleed.

9. Release agent.
10. Absorb excess resin.

238

1. Spilled battery acid, residual flux deposits, and entrapped caustic cleaning solutions.
2. Conductive fluid and metals having a difference in potential (dissimilar metals).
3. (1) c.
(2) a.
(3) e.
(4) b.
(5) d.
4. Speed of electrochemical attack is increased in a hot, moist climate.
5. Climate, size and type of metal, foreign material.

229

1. Battery compartments and battery vent openings, water entrapment areas, and external skin areas.
2. (1) g.
(2) c.
(3) d.
(4) e.
(5) b.
(6) i.
(7) f.

230

1. The area must be cleaned of grease, oil, dirt, or preservatives.
2. Highly stressed steel surfaces.
3. Aluminum wool, aluminum-wire brushes, or fiber-bristle brushes.

231

1. It does not have to be annealed for flaring or forming.
2. Magnet test.
3. 2024-T (red) and 5052-O (purple).
4. By outside diameter.
5. When connecting moving parts with stationary parts in locations subject to vibration, where a great amount of flexibility is needed, may also serve as a connector in metal tubing systems.
6. Buna-N, neoprene, and butyl.
7. By inside diameter.
8. The finger-tight-plus-turns method.
9. To secure lines subject to vibration; the cushioning prevents chafing of the tubing.
10. Flared and flareless.
11. Aluminum alloy, steel, or copper-base alloys; steel fittings are colored black, aluminum-alloy fittings are colored blue, aluminum bronze sleeves are cadmium plated and are not colored.
12. Body, sleeve, nut.

232

1. (1) b.
(2) d.
(3) a.
(4) d.

- (5) c.
- (6) f.
- (7) e.

233

1. In the heel of a bend.
2. 20 percent.
3. Electrical lines.
4. After tightening by hand (finger tight), use a wrench to turn the nut $1/6$ turn (one flat on a hex nut), if the connection leaks, it is permissible to tighten the nut an additional $1/6$ turn (making a total of $1/3$ turn), after tightening the nut a total of $1/3$ turn, if leakage still exists, the assembly should be removed and the components of the assembly inspected for scores, cracks, presence of foreign material, or damage from overtightening.
5. Deep, permanent impressions in hose produced by pressure from hose clamps or supports.
6. Blow out with compressed air.
7. At least 30 seconds.
8. The stripe is spiraled around the hose.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to ECI (AFIADL) Form 34, Field Scoring Answer Sheet.

Do not return your answer sheet to AFIADL.

78. (220) What term refers to the property of a metal which enables it to return to its original shape when the force which causes the change of shape is removed?
- Hardness.
 - Elasticity.
 - Brittleness.
 - Ductility.
79. (220) What term refers to the property which enables a metal to carry heat or electricity?
- Fusibility.
 - Toughness.
 - Conductivity.
 - Density.
80. (220) Why is the conductivity of a metal important to consider when welding?
- It governs the time required to properly cool the piece.
 - It governs the amount of heat required for proper fusion.
 - It is the determining factor for calculating the speed of the weld.
 - It is the determining factor for identifying the hardness of the material.
81. (220) What term includes such processes as annealing, normalizing, hardening, and tempering?
- Tensioning.
 - Corrosion treating.
 - Cold working.
 - Heat treating.
82. (221) What process involves the forcing of metal through an opening in a die, thus causing the metal to take the shape of the die opening?
- Extruding.
 - Cold rolling.
 - Cold drawing.
 - Annealing.
83. (221) What is the customary method of joining high-reliability, controlled-strength corrosion-resistant piping?
- Mig welding.
 - Silver Brazing.
 - Tig welding.
 - Brass brazing.
84. (222) What metal sparks are red as they leave the stone and turn to a straw color?
- Nickel steel.
 - Cast iron.
 - Low-carbon steel.
 - Wrought iron.

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85. (222) What is the principal alloy of stainless steel?
- Molybdenum.
 - Vanadium.
 - Nickel.
 - Chromium.
86. (223) What is the percentage purity level of the 1xxx group of aluminum alloys?
- 99 to 100.
 - 75 to 98.99.
 - 50 to 74.99.
 - 25 to 49.99.
87. (224) What is heat treatment?
- Heating and cooling of metals in the solid state.
 - Heating and cooling of metals in the molten state.
 - Heating of metals from the solid to the molten state.
 - Cooling of metals from the molten to the solid state.
88. (224) Which nonferrous metal can be casehardened?
- Monel.
 - Magnesium.
 - Titanium.
 - Bronze.
89. (224) When two or more elements or compounds are combined but can be identified by microscopic examination, it is known as what?
- Unstable.
 - Stable.
 - Alloy.
 - Mechanical mixture.
90. (224) What is the first, and most important, consideration in the heat treatment of a steel part?
- Determining the upper critical point.
 - To know its chemical composition.
 - How to control the rate of heating.
 - How to control the rate of cooling.
91. (224) What do the number, size, and distribution of ferrite particles determine for steel?
- Hardness.
 - Ductility.
 - Brittleness.
 - Conductivity.
92. (224) What process is always conducted at temperatures below the low critical point of the steel?
- Annealing.
 - Normalizing.
 - Tempering.
 - Hardening.
93. (224) Which type of quench minimizes distortion and alleviates quench cracking of most alloys?
- Spray.
 - Hot water.
 - Cold Water.
 - Steam.

94. (225) What measurement, if any, does a Brinell hardness tester use?
- There is no measurement, the hardness is indicated on the dial.
 - Radius of the impression.
 - Diameter of the impression.
 - Depth of the impression.
95. (225) What are the two types of penetrators used with a Rockwell tester?
- Hardened steel ball and diamond cone.
 - Hardened steel ball and silica cone.
 - Diamond cone and silica cone.
 - Silica sphere and Hardened steel ball.
96. (226) Dye penetrant inspection tests for defects open to the surface in parts made of what type of material?
- Any nonporous material.
 - Any porous material.
 - Ceramics only.
 - Nonferrous metals only.
97. (226) What nondestructive method detects minute cracks, checks, and voids, too small to be seen by X-ray?
- Magnetic particle.
 - Eddy current.
 - Dye penetrant.
 - Ultrasonic.
98. (227) What are the basic two parts mixed for epoxy matrix material?
- Hardener and pitch.
 - Hardener and accelerant.
 - Resin and accelerant.
 - Resin and hardener.
99. (227) How are superficial scars, scratches, surface abrasions, or rain erosion to composite materials repaired?
- By sanding and painting the area.
 - By removing the affected area and replacing it with a patch.
 - By applying one or more coats of a suitable resin.
 - By laying additional repair tiles over the area.
100. (227) What type of fiberglass has a high tensile strength and is used for critical structural applications?
- S glass.
 - L glass.
 - K glass.
 - E glass.
101. (227) What is the name of the class of plastics that, when cured by thermal and/or chemical means becomes substantially infusible and insoluble?
- Kevlar.
 - Hydroset.
 - Aramid.
 - Thermoset.

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102. (227) During vacuum bagging, how high can pressures reach?
- 10,000 pounds per square foot.
 - 8,000 pounds per square foot.
 - 4,000 pounds per square foot.
 - 2,000 pounds per square foot.
103. (227) Once a laminate is in place during vacuum bagging, what is the first item to go down when applying the bag?
- Bleeder.
 - Release film.
 - Peel ply.
 - Release agent.
104. (228) What cause of corrosion is *not* the result of direct exposure of a bare surface to liquid or gaseous agents?
- Caustic cleaning solutions.
 - Residual flux.
 - Spilled battery acid.
 - Electrochemical attack.
105. (228) When entrapment of the cleaning solution is likely to occur, what type of cleaning agent should be used?
- Corrosive.
 - Noncorrosive
 - Powdered.
 - Aerosol.
106. (228) An electrochemical attack may be likened, chemically, to what process?
- Tempering.
 - Annealing.
 - Acid etching.
 - Electroplating.
107. (228) What type of corrosion is frequently accompanied by a powdery deposit of corrosion products?
- Galvanic.
 - Surface.
 - Intergranular.
 - Stress.
108. (228) Exfoliation is a severe form of what type of corrosion?
- Galvanic.
 - Surface.
 - Intergranular.
 - Stress.
109. (228) What type of corrosion has also been called false brinelling?
- Galvanic.
 - Surface.
 - Fretting.
 - Stress.

110. (228) The speed of electrochemical attack is increased in what type of climate?
- Cool, dry.
 - Cool, moist.
 - Hot, dry.
 - Hot, moist.
111. (228) What type of structural sections is more susceptible to corrosive attack?
- Thick.
 - Thin.
 - Vertical.
 - Horizontal.
112. (229) What should be used as a general guide when an area is to be inspected for corrosion?
- Civil engineering manual.
 - Memory.
 - Checklist.
 - Manufacturer data sheet.
113. (229) What corrosion control process involves the surface application of molten metal on any solid base material?
- Metallizing.
 - Anodizing.
 - Alodizing.
 - Electroplating.
114. (230) What should be used for removing oil, grease, or soft preservative compounds?
- Steam.
 - Dry cleaning solvent.
 - Water rinsable stripper.
 - Paint remover.
115. (230) What should be used to remove corrosion on the surface of a highly stressed steel part?
- Small power buffers.
 - Mild abrasive papers.
 - Steel wool.
 - Wire brush.
116. (231) What is the color code for 1100 aluminum alloy tubing?
- White.
 - Green.
 - Gray.
 - Red.
117. (231) Unbonded clamps should only be used to secure what?
- Hydraulic lines.
 - Wiring.
 - Fuel lines.
 - Oil lines.
118. (231) What is usually the deciding factor in selecting a connector for a plumbing system?
- Gas type.
 - Fluid type.
 - System location.
 - System pressure.

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119. (231) For identification purposes, what color are steel AN fittings?
- White.
 - Green.
 - Gray.
 - Black.
120. (231) A flareless tube fitting consists of how many parts?
- 5.
 - 4.
 - 3.
 - 2.
121. (232) The small diameter of the flattened portion of a bend must not be greater than what percent of the original outside diameter?
- 75.
 - 80.
 - 85.
 - 90.
122. (232) A double flare should be used on what type of tubing?
- Titanium.
 - Aluminum.
 - Stainless steel.
 - Copper.
123. (233) If they are not in the heel of a bend, scratches or nicks no deeper than what percent of the wall thickness in aluminum alloy tubing may be repaired?
- 10 percent.
 - 7 percent.
 - 5 percent.
 - 2 percent.
124. (233) If an old length of tubing cannot be used as a pattern, what should be used as a template?
- Manufactures schematic.
 - Another piece of tube.
 - Layout jig.
 - Wire.

When you complete this course, please complete the student survey on the Internet at this URL:

http://www.maxwell.af.mil/au/afiadl/operation/survey_fr.htm

Student Notes

Glossary

Abbreviations and Acronyms

AC	alternating current
AISI	American Iron and Steel Institute
AN	Air Force–Navy
APC	angled physical contact
AWG	American Wire Gauge
BBS	bondable both sides
BOS	bondable one side
BST	bag sealant tape
CRES	corrosion resistant steel
CRO	cathode-ray oscilloscope
CRT	cathode-ray tube
DC	direct current
DMM	digital multimeter
DPDT	double-pole double-throw
DUT	device under test
DVM	digital volt meter
EMF	electromotive force
EMI	electromagnetic interference
ESD	electrostatic discharge
ESDS	electrostatic discharge sensitive
hp	horse power
IC	integrated circuit
ID	inside diameter
LED	light emitting diode
LH	left-hand
MEK	methyl-ethyl-ketone
MMC	maximum material condition
MS	military standard
NAS	National Aerospace Standard
NC	normally closed

NDI	nondestructive inspection
NO	normally open
OD	outside diameter
OL	out of limits or overload
PC	physical contact
PCB	printed circuit board
psi	pounds per square inch
PSU	power supply unit
PWB	printed wiring board
RFI	radio frequency interference
RH	right-hand
rpm	revolution per minute
SAE	Society of Automotive Engineers
SI	International System of Units
SPDT	single-pole double-throw
SPST	single-pole single-throw
SSU	Saybolt seconds universal
TDR	time domain reflectometer
VARTM	vacuum assisted resin transfer molding
VOM	volt-ohm-milliammeter

<u>Unit</u>	<u>Symbol</u>
capacitance	C
capacitance unit of measure	F
capacitive resistance	X_C
cubic centimeters	cc
current	I
current unit of measure	A
decible	dB
degrees Celsius or centigrade	C
degrees Fahrenheit	F
gram(s)	g
inductance	L
inductance unit of measure	H
inductive reactance	X_L
micrometer	μm
micron	mc.
nickel	Ni
pole	P
reactance	X
reactance unit of measure	Ω
resistance	R
resistance/impedance unit of measure	Ω
throw	T
total current	I_t
total resistance	R_t
voltage	E
voltage unit of measure	V
watt	P
watt unit of measure	W

Student Notes

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