Electrochemical Attack

An electrochemical attack may be likened chemically to the electrolytic reaction which 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.

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 which 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.

As can be seen, the conditions for these corrosion reactions are a conductive fluid and metals having a difference in potential. 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.

The electrochemical attack is responsible for most forms of corrosion on aircraft structure and component parts.

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 which result from the pressure of the underlying accumulation of corrosion products.

Dissimilar Metal Corrosion

Extensive pitting damage may result 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 Corrosion

This type of 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 Corrosion

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 p.s.i.). It usually occurs along lines of cold working and may be transgranular or intergranular in nature. Aluminum alloy bellcranks with pressed-in bushings, landing gear shock struts with pipe-thread type grease fittings, clevis pin joints, shrink fits, and overstressed tubing B-nuts are examples of parts which are susceptible to stress corrosion cracking.

Fretting Corrosion

Fretting corrosion is a particularly damaging form of corrosive attack which occurs when two mating surfaces, normally at rest with respect to one another, 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 or pressure 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

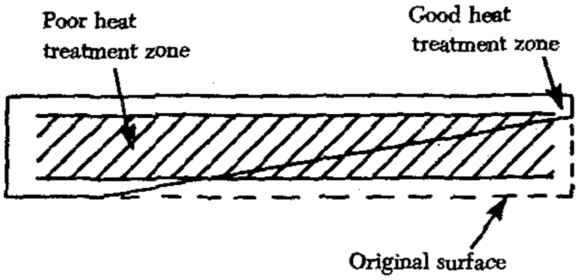
Many factors affect the type, speed, cause, and seriousness of metal corrosion. Some of these factors can be controlled and some cannot.

Climate

The environmental conditions under which an aircraft is maintained and operated 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 aircraft 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.



Tapering exposes zone of poor heat treatment to corrosive environment

FIGURE 6–59. The effect of machining thick heat-treated wrought aluminum alloys.

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. (See figure 6–59.)

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 which affect the onset and spread of corrosive attack is foreign material which adheres to the metal surfaces. Such foreign material includes:

(1) Soil and atmospheric dust.
(2) Oil, grease, and engine exhaust residues.
(3) Salt water and salt moisture condensation.
(4) Spilled battery acids and caustic cleaning solutions.
(5) Welding and brazing flux residues.

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

PREVENTIVE MAINTENANCE

Much has been done to improve the corrosion resistance of aircraft: 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:

(1) An adequate cleaning.
(2) Thorough periodic lubrication.
(3) Detailed inspection for corrosion and failure of protective systems.
(4) Prompt treatment of corrosion and touchup of damaged paint areas.
(5) Keeping drainholes free of obstruction.
(6) Daily draining of fuel cell sumps.
(7) Daily wipe-down of exposed critical areas.
(8) Sealing of aircraft against water during foul weather and proper ventilation on warm, sunny days.
(9) Making maximum use of protective covers on parked aircraft.

After any period during which regular corrosion-preventive maintenance is interrupted, the amount of maintenance required to repair accumulated corrosion damage and bring the aircraft back up to standard will usually be quite high.

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 scheduled maintenance checklists are complete enough to cover all parts of the aircraft or engine, and no part of the aircraft 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 aircraft have trouble areas where corrosion will set in despite routine inspection and maintenance.

In addition to routine maintenance inspections, amphibians or seaplanes should be checked daily and critical areas cleaned or treated, as necessary.

CORROSION-PRONE AREAS

Discussed briefly in this section are most of the trouble areas common to all aircraft. However, this coverage is not necessarily complete and may be amplified and expanded to cover the special characteristics of the particular aircraft model involved by referring to the applicable maintenance manual.

Exhaust Trail Areas

Both jet and reciprocating engine exhaust deposits are very corrosive and give particular trouble where gaps, seams, hinges, and fairings are located down the exhaust path and where deposits may be trapped and not reached by normal cleaning methods. Special attention should be paid to areas around rivet heads and in skin crevices. Fairings and access plates in the exhaust areas should be removed for inspection. Exhaust deposit buildup in remote areas such as the empennage surfaces should not be overlooked. Buildup in these areas will be slower and sometimes completely absent, but it has become a problem on some currently operating aircraft.

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 aircraft 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.

Bilge Areas

These are natural sumps for waste hydraulic fluids, water, dirt, and odds and ends of debris. Residual oil quite often masks small quantities of water which settle to the bottom and set up a hidden chemical cell. Seaplane and amphibian aircraft bilge areas are protected by small bags of potassium dichromate inhibitor suspended near the low point in each bilge compartment. These crystals dissolve in any waste water and tend to inhibit the attack on exposed metal surfaces.

Inspection procedures should include replacement of these bags when most of the chemical has been dissolved. Particular attention must be paid to areas located under galleys and lavatories and to human waste disposal openings on the aircraft exteriors. Human waste products and the chemicals used in lavatories are very corrosive to the common aircraft metals. Clean these areas frequently and keep the paint touched up.

Wheel Well and Landing Gear

This area probably receives more punishment due to mud, water, salt, gravel, and other flying debris than any other area on the aircraft.

Because of the many complicated shapes, assemblies, and fittings, complete area paint film coverage is difficult to attain. A partially applied preservative tends to mask corrosion rather than prevent it. Due to heat generated by braking action, preservatives cannot be used on some main landing gear wheels. During inspection of this area, pay particular attention to the following trouble spots:

1. Magnesium wheels, especially around boltheads, lugs, and wheel web areas, particularly for the presence of entrapped water or its effects.
2. Exposed rigid tubing, especially at B-nuts and ferrules, under clamps and tubing identification tapes.
3. Exposed position indicator switches and other electrical equipment.
4. Crevices between stiffeners, ribs, and lower skin surfaces, which are typical water and debris traps.

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.

Engine Frontal Areas and Cooling Air Vents

These areas are being constantly abraded with airborne dirt and dust, bits of gravel from runways, and rain erosion which tend to remove the protective finish. Inspection of these areas should include all sections in the cooling air path, with special attention to places where salt deposits may be built up during marine operations. It is imperative that incipient corrosion be inhibited and that paint touchup and hard film preservative coatings be maintained intact on seaplane and amphibian engine surfaces at all times.

Wing Flap and Spoiler Recesses

Dirt and water may collect in flap and spoiler recesses and go unnoticed because they are normally retracted. For this reason these recesses are potential corrosion problem areas.

External Skin Areas

External aircraft 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 which is never completely restored by touchup 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.

Miscellaneous Trouble Areas

Helicopter rotor heads and gearboxes, in addition to being constantly exposed to the elements, contain bare steel surfaces, many external working parts, and dissimilar metal contacts. These areas should be inspected frequently for evidence of corrosion. The proper maintenance, lubrication, and the use of preservative coatings can prevent corrosion in these areas.

All control cables, whether plain carbon steel or corrosion-resistant steel, should be inspected to determine their condition at each inspection period. Cables should be inspected for corrosion by random cleaning of short sections with solvent-soaked cloths. If external corrosion is evident, tension should be relieved and the cable checked for internal corrosion. Cables with internal corrosion should be replaced. Light external corrosion should be removed with a steel-wire brush. When corrosion products have been removed, re-coat the cable with preservative.

CORROSION REMOVAL

In general, any complete corrosion treatment involves the following: (1) Cleaning and stripping of the corroded area, (2) removing as much of the corrosion products as practicable, (3) neutralizing any residual materials remaining in pits and crevices, (4) restoring protective surface films, and (5) applying temporary or permanent coatings or paint finishes.

The following paragraphs deal with the correction of corrosive attack on aircraft 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. In order 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. Drycleaning solvent may 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, including aircraft tires, fabric, and acrylics, 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 aircraft interiors or critical cavities. Paint stripper is toxic and contains ingredients harmful to both skin and eyes. Rubber gloves, aprons of acid-repellent material, and goggle-type eyeglasses should be worn if any extensive paint removal is to be accomplished. The following is a general stripping procedure:

1. Brush the entire area to be stripped with a cover of stripper to a depth of 1/32 to 1/16 inch. Any paint brush makes a satisfactory applicator, except that the bristles will be loosened by the effect of paint remover on the binder, and the brush should not be used for other purposes after being exposed to paint remover.
2. Allow the stripper to remain on the surface for a sufficient length of time to wrinkle and lift the paint. This may be from 10 minutes to several hours, depending on both the temperature and humidity, and the condition of the paint coat being removed. Scrub the surface with a bristle brush saturated with paint remover to further loosen finish that may still be adhering to the metal.
3. Reapply the stripper as necessary in areas that remain tight or where the material has dried, and repeat the above process. Only nonmetallic scrapers may be used to assist in removing persistant paint finishes.
4. Remove the loosened paint and residual stripper by washing and scrubbing the surface with water and a broom or brush. If water spray is available, use a low-to-medium pressure stream of water directly on the scrubbing broom or brush. If steam cleaning equipment is available and the area is sufficiently large, cleaning may be accomplished using this equipment together with a solution

of steam cleaning compound. On small areas, any method may be used that will assure complete rinsing of the cleaned area.

CORROSION OF FERROUS METALS

One of the most familiar types of corrosion is ferrous oxide (rust), generally resulting from atmospheric oxidation of steel surfaces. Some metal oxides protect the underlying base metal, but rust is not a protective coating in any sense of the word. Its presence actually promotes additional attack by attracting moisture from the air and acting as a catalyst in causing additional corrosion to take place. As a result, all rust must be removed from steel surfaces, if complete control of the corrosive attack is to be realized.

Rust first shows on boltheads, holddown nuts, or other unprotected aircraft hardware. Its presence in these areas is generally not dangerous and has no immediate effect on the structural strength of any major components. However, it is indicative of a need for maintenance and of possible corrosive attack in more critical areas. It is also a factor in the general appearance of the equipment. When paint failures occur or mechanical damage exposes highly stressed steel surfaces to the atmosphere, even the smallest amount of rusting is potentially dangerous in these areas and must be removed and controlled.

Mechanical Removal of Iron Rust

The most practicable means of controlling the corrosion of steel is the complete removal of corsion products 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 Lubrizing 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 aircraft, 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 which 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 re-applied immediately.

CORROSION OF ALUMINUM AND ALUMINUM ALLOYS

Corrosion attack on aluminum surfaces is usually quite obvious, since the products of corrosion are white and generally more voluminous than the original base metal. Even in its early stages, aluminum corrosion is evident as general etching, pitting, or roughness of the aluminum surfaces. NOTE: Aluminum alloys commonly form a smooth surface oxidation which is from .001 in. to .0025 in. thick. This is not considered detrimental as such a coating provides a hard shell barrier to the introduction of corrosive elements. Such oxidation is not to be confused with the severe corrosion discussed in this paragraph.

General surface attack of aluminum penetrates relatively slowly, but is speeded up in the presence of dissolved salts. Considerable attack can usually take place before serious loss of structural strength develops. However, at least three forms of attack on aluminum alloys are particularly serious: (1) The penetrating pit-type corrosion through the walls of aluminum tubing, (2) stress-corrosion cracking of materials under sustained stress, and (3) the intergranular attack which is characteristic of certain improperly heat-treated aluminum alloys.

In general, corrosion of aluminum can be more effectively treated in place than corrosion occuring on other structural materials used in aircraft. Treatment includes the mechanical removal of as much of the corrosion products as practicable, and the inhibition of residual materials by chemical means, followed by the restoration of permanent surface coatings.

Treatment of Unpainted Alumium 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. A typical aluminum corrosion treatment sequence follows:

1. Remove oil and surface dirt with any suitable mild cleaner prior to abrasive cleaning of aluminum surfaces.
2. Hand polish the corroded areas with fine abrasives or with metal polish. Metal polish intended for use on clad aluminum aircraft surfaces must not be used on anodized aluminum since it is abrasive enough to actually remove the protective anodized film. It effectively removes stains and produces a high, lasting polish on unpainted alclad. If a surface is particularly difficult to clean, a cleaner and brightener compound for aluminum, can be used before polishing to shorten the time and lessen the effort necessary to get a clean surface.
3. Treat any superficial corrosion present, using an inhibitive wipe-down material. An alternate treatment is processing with a solution of sodium dichromate and chromium trioxide. Allow these solutions to remain on the corroded area for 5 to 20 minutes, and then remove the excess by rinsing and wiping the surface dry with a clean cloth.
4. Overcoat the polished surfaces with waterproof wax.

Aluminum surfaces that are to be subsequently painted can be exposed to more severe cleaning procedures and can also be given more thorough corrective treatment prior to painting. The following sequence is generally used:

1. Thoroughly clean the affected surfaces of all soil and grease residues prior to processing. Any general aircraft cleaning procedure may be used.
2. If residual paint films remain, strip the area to be treated. Procedures for the use of paint removers, and the precautions to observe, were previously mentioned in this chapter under "Surface Cleaning and Paint Removal."
3. Treat superficially corroded areas with a 10 percent solution of chromic acid and sulphuric acid. Apply the solution by swab or brush. Scrub the corroded area with the brush while it is still damp. While chromic acid is a good inhibitor for aluminum alloys, even when corrosion products have not been completely removed, it is important that the solution penetrate to the bottom of all pits and underneath any corrosion that may be present. Thorough brushing with a stiff fiber brush should loosen or remove most existing corrosion and assure complete penetration of the inhibitor into crevices and pits. Allow the chromic acid to remain in place for at least 5 minutes, then remove the excess by flushing with water or wiping with a wet cloth. There are several commercial chemical surface treatment compounds, similar to the type described above, which may also be used.
4. Dry the treated surface and restore recommended permanent protective coatings as required in accordance with the aircraft manufacturer's procedures. Restoration of paint coatings should immediately follow any surface treatment performed. In any case, make sure that corrosion treatment is accomplished or is re-applied on the same day that paint refinishing is scheduled.

Treatment of Anodized Surfaces

As previously stated, 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. 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 anodized 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

As previously described, intergranular corrosion is an attack along grain boundaries of improperly or inadequately heat-treated alloys, resulting from precipitation of dissimilar constituents following heat treatment. 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.

Corrosion depth and removal limits have been established for some aircraft. Any loss of structural strength should be evaluated prior to repair or replacement of the part.

CORROSION OF MAGNESIUM ALLOYS

Magnesium is the most chemically active of the metals used in aircraft construction and is, therefore, the most difficult to protect. When a failure in the protective coating does occur, the prompt and complete correction of the coating failure is imperative if serious structural damage is to be avoided. Magnesium attack is probably the easiest type of corrosion to detect in its early stages, since magnesium corrosion products occupy several times the volume of the original magnesium metal destroyed. The beginning of attack shows as a lifting of the paint films and white spots on the magnesium surface. These rapidly develop into snowlike mounds or even "white whiskers." Reprotection involves the removal of corrosion products, the partial restoration of surface coatings by chemical treatment, and a re-application of protective coatings.

Treatment of Wrought Magnesium Sheet and Forgings

Magnesium skin attack will usually occur around edges of skin panels, underneath holddown washers, or in areas physically damaged by shearing, drilling, abrasion, or impact. If the skin section can be removed easily, this should be done to assure complete inhibition and treatment. If insulating washers are involved, screws should be loosened, at least sufficiently to permit brush treatment of the magnesium under the insulating washer. Complete mechanical removal of corrosion products should be practiced insofar as practicable. Such mechanical cleaning should be limited to the use of stiff, hog-bristle brushes and similar nonmetallic cleaning tools, particularly if treatment is to be performed under field conditions. Any entrapment of steel particles from steel-wire brushes or steel tools, or contamination of treated surfaces by dirty abrasives, can cause more trouble than the initial corrosive attack. Corroded magnesium may generally be treated as follows:

1. Clean and strip the paint from the area to be treated. (Paint stripping procedures were discussed earlier in this chapter.)
2. Using a stiff, hog-bristle brush, break loose and remove as much of the corrosion products as practicable. Steel-wire brushes, carborundum abrasives, or steel cutting tools should not be used.
3. Treat the corroded area liberally with a chromic acid solution, to which has been added sulphuric acid, and work into pits and crevices by brushing the area while still wet with chromic acid, again using a nonmetallic brush.
4. Allow the chromic acid to remain in place for 5 to 20 minutes before wiping up the excess with a clean, damp cloth. Do not allow the excess solution to dry and remain on the surface, as paint lifting will be caused by such deposits.

5. As soon as the surfaces are dry, restore the original protective paint.

Treatment of Installed Magnesium Castings

Magnesium castings, in general, are more porous and more prone to penetrating attack than wrought magnesium skins. However, treatment is, for all practical purposes, the same for all magnesium areas. Engine cases, bellcranks, fittings, numerous covers, plates, and handles are the most common magnesium castings.

When attack occurs on a casting, the earliest practicable treatment is required if dangerous corrosive penetration is to be avoided. In fact, engine cases submerged in salt water overnight can be completely penetrated. If it is at all practicable, parting surfaces should be separated to effectively treat the existing attack and prevent its further progress. The same general treatment sequence in the preceding paragraph for magnesium skin should be followed.

If extensive removal of corrosion products from a structural casting is involved, a decision from the manufacturer may be necessary to evaluate the adequacy of structural strength remaining. Specific structural repair manuals usually include dimensional tolerance limits for critical structural members and should be referred to, if any question of safety is involved.

TREATMENT OF TITANIUM AND TITANIUM ALLOYS

Attack on titanium surfaces is generally difficult to detect. Titanium is, by nature, highly corrosion resistant, but it may show deterioration from the presence of salt deposits and metal impurities, particularly at high temperatures. Therefore, the use of steel wool, iron scrapers, or steel brushes for cleaning or for the removal of corrosion from titanium parts is prohibited.

If titanium surfaces require cleaning, hand polishing with aluminum polish or a mild abrasive is permissable, if fiber brushes only are used and if the surface is treated following cleaning with a suitable solution of sodium dichromate. Wipe the treated surface with dry cloths to remove excess solution, but do not use a water rinse.

PROTECTION OF DISSIMILAR METAL CONTACTS

Certain metals are subject to corrosion when placed in contact with other metals. This is commonly referred to as electrolytic or dissimilar metals corrosion. Contact of different bare metals creates an electrolytic action when moisture is present. If this moisture is salt water, the electrolytic action is accelerated. The result of dissimilar-metal contact is oxidation (decomposition) of one or both metals. The chart shown in figure 6–60 lists the metal combinations requiring a protective separator. The separating materials may be metal primer, aluminum tape, washers, grease, or sealant, depending on the metals involved.

Contacts Not Involving Magnesium

All dissimilar joints not involving magnesium are protected by the application of a minimum of two coats of zinc chromate primer in addition to normal primer requirements. Primer is applied by brush or spray and allowed to air-dry 6 hours between coats.

Contacts Involving Magnesium

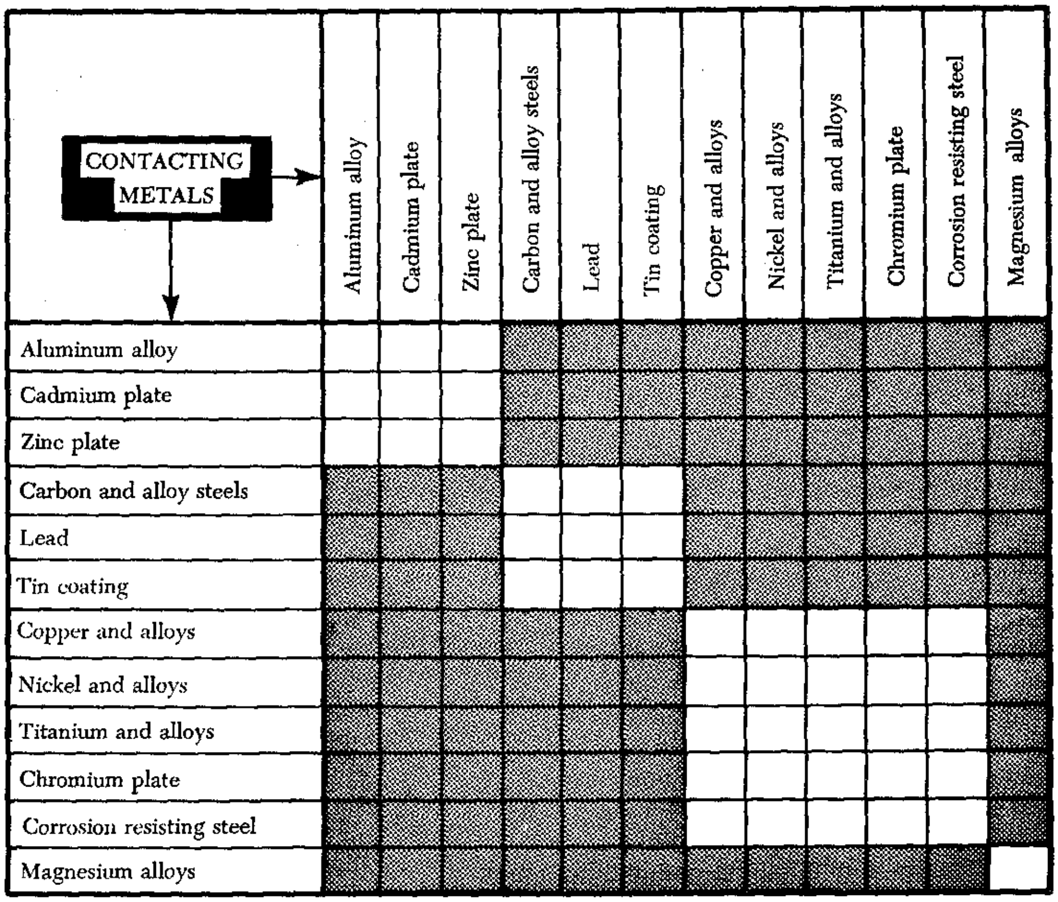
To prevent corrosion between dissimilar-metal joints in which magnesium alloy is involved, each surface is insulated as follows:

At least two coats of zinc chromate are applied to each surface. Next, a layer of pressure-sensitive vinyl tape 0.003-inch thick is applied smoothly and firmly enough to prevent air bubbles and wrinkles. To avoid creep-back, the tape is not stretched during application. When the thickness of the tape interferes with the assembly of parts, where relative motion exists between parts, or when service temperatures above 250° F. are anticipated, the use of tape is eliminated and extra coats (minimum of three) of primer are applied.

CORROSION LIMITS

Corrosion, however slight, is damage. Therefore, corrosion damage is classified under the four standard types, as is any other damage. These types are: (1) Negligible damage, (2) damage repairable by patching, (3) damage repairable by insertion, and (4) damage necessitating replacement of parts.

The term "negligible," as used here, does not imply that little or nothing should be done. The corroded surface should be cleaned, treated, and painted as appropriate. Negligible damage, generally, is corrosion which has scarred or eaten away the surface protective coats and begun to etch the metal.



CONTACTING METALS	Aluminum alloy	Cadmium plate	Zinc plate	Carbon and alloy steels	Lead	Tin coating	Copper and alloys	Nickel and alloys	Titanium and alloys	Chromium plate	Corrosion resisting steel	Magnesium alloys
Aluminum alloy				▨	▨	▨	▨	▨	▨	▨	▨	▨
Cadmium plate				▨	▨	▨	▨	▨	▨	▨	▨	▨
Zinc plate				▨	▨	▨	▨	▨	▨	▨	▨	▨
Carbon and alloy steels	▨	▨	▨				▨	▨	▨	▨	▨	▨
Lead	▨	▨	▨				▨	▨	▨	▨	▨	▨
Tin coating	▨	▨	▨				▨	▨	▨	▨	▨	▨
Copper and alloys	▨	▨	▨	▨	▨	▨						▨
Nickel and alloys	▨	▨	▨	▨	▨	▨						▨
Titanium and alloys	▨	▨	▨	▨	▨	▨						▨
Chromium plate	▨	▨	▨	▨	▨	▨						▨
Corrosion resisting steel	▨	▨	▨	▨	▨	▨						▨
Magnesium alloys	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	

Shaded areas indicate dissimiliar metal contacts

FIGURE 6-60. Dissimilar metal contacts that will result in electrolytic corrosion.

Corrosion damage extending to classifications of "repairable by patching" and "repairable by insertion" should be rapaired in accordance with the applicable structural repair manual.

When corrosion damage exceeds the damage limits to the extent that repair is not possible, the component or structure should be replaced.

PROCESSES AND MATERIALS USED IN CORROSION CONTROL

Metal Finishing

Aircraft parts are almost always given some type of surface finish by the manufacturer. The main purpose is to provide corrosion resistance; however, surface finishes may also be applied to increase wear resistance or to provide a suitable base for paint.

In most instances the original finishes cannot be restored in the field due to nonavailability of equipment or other limitations. However, an understanding of the various types of metal finishes is necessary if they are to be properly maintained in the field and if the partial restoration techniques used in corrosion control are to be effective.

Surface Preparation

Original surface treatments for steel parts usually include a cleaning treatment to remove all traces of dirt, oil, grease, oxides, and moisture. This is necessary to provide an effective bond between the metal surface and the final finish. The cleaning process may be either mechanical or chemical. In mechanical cleaning the following methods are employed: wire brush, steel wool, emery cloth, sandblasting, or vapor blasting.

Chemical cleaning is preferred over mechanical since none of the base metal is removed by cleaning. There are various chemical processes now in use, and the type used will depend on the material being cleaned and the type of foreign matter being removed.

Steel parts are pickled to remove scale, rust, or other foreign matter, particularly before plating. The pickling solution can be either muriatic (hydrochloric) or sulfuric acid. Cost-wise, sulfuric acid is preferable, but muriatic acid is more effective in removing certain types of scale.

The pickling solution is kept in a stoneware tank and is usually heated by means of a steam coil. Parts not to be electroplated after pickling are immersed in a lime bath to neutralize the acid from the pickling solution.

Electrocleaning is another type of chemical cleaning used to remove grease, oil, or organic matter. In this cleaning process, the metal is suspended in a hot alkaline solution containing special wetting agents, inhibitors, and materials to provide the necessary electrical conductivity. An electric current is then passed through the solution in a manner similar to that used in electroplating.

Aluminum and magnesium parts are also cleaned by using some of the foregoing methods. Blast cleaning is not applicable to thin aluminum sheets, particularly alclad. Steel grits are not used on aluminum or corrosion-resistant metals.

Polishing, buffing, and coloring of metal surfaces play a very important part in the finishing of metal surfaces. Polishing and buffing operations are sometimes used when preparing a metal surface for electroplating, and all three operations are used when the metal surface requires a high-luster finish.

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:

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 gages, 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 casehardening.
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.

CHEMICAL TREATMENTS

Parco Lubrizing

Parco Lubrizing is a chemical treatment for iron and steel parts which 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, it 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 to 15 seconds. After thorough rinsing, alodine is applied by dipping, spraying, or brushing. A thin, hard coating results which 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 to 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 alodyzed aluminum surface slightly acid on drying.

Chemical 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 which 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 warnings if a material is toxic or flammable. However, the label might not be large enough to accommodate a list of all the possible hazards which 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 for field treatment of damaged or corroded aluminum surfaces. Precautions should be taken to make sure that sponges or cloths used are thoroughly rinsed to avoid a possible fire hazard after drying. (See figure 6–61)

TYPE OF CORROSION	STEP 1 CLEANING TO REMOVE FOREIGN MATTER	STEP 2 PAINT STRIPPING (WHEN APPLICABLE)	STEP 3 CORROSION REMOVAL	STEP 4 SURFACE TREATMENT (WHEN APPLICABLE)
Light or heavy pitting or etching of aluminum (clad)	Remove foreign matter with cleaner, Spec MIL-C-25769	Readily accessible areas: Strip with stripper, Spec MIL-R-25134 Confined areas: Strip with solvent	Remove corrosion with brightener, Spec MIL-C-25378	Chromate conversion coating Spec MIL-C-5541
Light or heavy pitting or etching of aluminum (clad)	As above	As above	Remove corrosion by mechanical method — or — Remove corrosion with brightener, Spec MIL-C-25378	As above
Intergranular or exfoliation corrosion of aluminum	As above	As above	Remove corrosion by mechanical method	As above
Light or heavy corrosion on small aluminum parts which can be removed for treatment	**Painted Parts** Clean and strip in solution of paint and varnish remover, Spec MIL-R-7751 **Unpainted Parts** Clean with compound, Spec P-C-426, MIL-C-5543 or vapor degrease	**Not Required** If cleaning accomplished with paint and varnish remover Spec MIL-R-7751	Remove corrosion and oxide film by immersion of parts in phosphoric-chromate acid solution	Immersion chromate conversion coating, Spec MIL-C-5541
Stress corrosion cracking of aluminum	**Not Applicable**	See Step 1	See Step 1	See Step 1

FIGURE 6-61. Typical corrosion removal and treatment procedures for aluminum alloys.

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 enamel finishes on engine cases and wheels.

AIRCRAFT CLEANING

Cleaning an aircraft and keeping it clean are extremely important. A cracked landing gear fitting covered with mud and grease may be easily overlooked. Dirt can hide cracks in the skin. Dust and grit cause hinge fittings to wear excessively. A film of dirt if left on the aircraft's outer surface, reduces flying speed and adds extra weight. Dirt or trash blowing or bouncing around the inside of the aircraft is annoying and dangerous. Small pieces of dirt blown into the eyes of the pilot at a critical moment can cause an accident. A coating of dirt and grease on moving parts makes a sort of grinding compound that can cause excessive wear. Salt water has a serious corroding effect on exposed metal parts of the aircraft, and should be washed off immediately.

There are many different kinds of cleaning agents approved for use in cleaning aircraft. It is impractical to cover each of the various types of cleaning agents since their use varies under different conditions, such as the type of material to be removed, the aircraft finish, and whether the cleaning is internal or external.

In general, the types of cleaning agents used on aircraft are solvents, emulsion cleaners, soaps, and synthetic detergents. Their use must be in accordance with the applicable maintenance manual. The types of cleaning agents named above are also classed as light- or heavy-duty cleaners. The soap and synthetic detergent type cleaners are used for light-duty cleaning, while the solvent and emulsion type cleaners are used for heavy-duty cleaning. The light-duty cleaners, which are nontoxic and nonflammable, should be used whenever possible.

Exterior Cleaning

There are three methods of cleaning the aircraft exterior: (1) Wet wash, (2) dry wash, and (3) polishing. Polishing can be further broken down into hand polishing and mechanical polishing. The type and extent of soiling and the final desired appearance determine the cleaning method to be used.

Wet wash removes oil, grease, or carbon deposits and most soils, with the exception of corrosion and oxide films. The cleaning compounds used are usually applied by spray or mop, after which high-pressure running water is used as a rinse. Either alkaline or emulsion cleaners can be used in the wet-wash method.

Dry wash is used to remove airport film, dust, and small accumulations of dirt and soil when the use of liquids is neither desirable nor practical. This method is not suitable for removing heavy deposits of carbon, grease, or oil, especially in the engine exhaust areas. Dry-wash materials are applied with spray, mops, or cloths, and removed by dry mopping or wiping with clean, dry cloths.

Polishing restores the luster to painted and unpainted surfaces of the airplane, and is usually performed after the surfaces have been cleaned. Polishing is also used to remove oxidation and corrosion. Polishing materials are available in various forms and degrees of abrasiveness. It is important that the aircraft manufacturer's instructions be used in specific applications.

The washing of aircraft should be performed in the shade whenever possible as cleaning compounds tend to streak the surface if applied to hot metal, or permitted to dry on the area. Install covers over all openings where water or cleaners might enter and cause damage.

Various areas of aircraft, such as the sections housing radar and the area forward of the cockpit that are finished with a dull paint, should not be cleaned more than necessary and should never be scrubbed with stiff brushes or coarse rags. A soft sponge or cheesecloth with a minimum of manual rubbing is advisable. Any oil or exhaust stains on the surface should first be removed with a solvent such as kerosene or other petroleum-base solvent. The surfaces should be rinsed immediately after cleaning to prevent the compound from drying on the surface.

Before applying soap and water to plastic surfaces, flush the plastic surfaces with fresh water to dissolve salt deposits and wash away dust particles. Plastic surfaces should be washed with soap and water, preferably by hand. Rinse with fresh water and dry with chamois or absorbent cotton. In view of the soft surface, do not rub plastic with a dry cloth since this is not only likely to cause scratches, but it also builds up an electrostatic charge which attracts dust particles to the surface. The charge as well as the dust may be removed by patting or gently blotting with a clean, damp chamois. Do not use scouring powder or other material which can mar the finish. Remove oil and grease by rubbing gently with a cloth wet with soap and water. Do not use acetone, benzene, carbon tetrachloride, lacquer thinners, window cleaning sprays, gasoline, fire extinguisher or deicer fluid on plastics because they soften the plastic and cause crazing.

Surface oil, hydraulic fluid, grease, or fuel can be removed from aircraft tires by washing with a mild soap solution.

After cleaning, lubricate all grease fittings, hinges, etc., where removal, contamination, or dilution of the grease is suspected during washing of the aircraft.

INTERIOR CLEANING

Keeping the interior of the aircraft clean is just as important as maintaining a clean exterior surface. Corrosion can establish itself on the inside structure to a greater degree because it is difficult to reach some areas for cleaning. Nuts, bolts, bits of wire, or other metal objects carelessly dropped and neglected, combined with moisture and dissimilar-metal contact, can cause electrolytic corrosion.

When performing structural work inside the aircraft, all metal particles and other debris should be cleaned up as soon as possible. To make cleaning easier and prevent the metal particles and debris from getting into inaccessible areas, a dropcloth can be used in the work area to catch this debris.

A vacuum cleaner can be used to pick up dust and dirt from the interior of the cockpit and cabin.

Aircraft interior present certain problems during cleaning operations. The following is taken from The National Fire Protection Association (NFPA) Bulletin #410F "Aircraft Cabin Cleaning Operation".

Basic to an understanding of the problem is the fact that aircraft cabin compartments constitute relatively small enclosures as measured by their cubic footage. This presents the possibility of restricted ventilation and the quick build-up of flammable vapor-air mixtures where there is any indiscriminate use of flammable cleaning agents or solvents. Within the same volume there may also exist the possibility of an ignition source in the form of an electrical fault, a friction or static spark, an open flame device, or some other potential introduced by concurrent maintenance work.

Wherever possible, nonflammable agents should be used in these operations to reduce to the minimum the fire and explosion hazards.

Types of Cleaning Operations

The principal areas of aircraft cabins which may need periodic cleaning are:

(1) Aircraft passenger cabin areas (seats, carpets, side panels, headliners, overhead racks, curtains, ash trays, windows, doors, decorative panels of plastic, wood or similar materials).

(2) Aircraft flight station areas (similar materials to those found in passenger cabin areas plus instrument panels, control pedestals, glare shields, flooring materials, metallic surfaces of instruments and flight control equipment, electrical cables and contacts, etc.).

(3) Lavatories and buffets (similar materials to those found in passenger cabin areas plus toilet facilities, metal fixtures and trim, trash containers, cabinets, wash and sink basins, mirrors, ovens, etc.).

Nonflammable Aircraft Cabin Cleaning Agents and Solvents

(1) *Detergents and Soaps.* These have widespread application for most aircraft cleaning operations involving fabrics, headliners, rugs, windows and similar surfaces that are not damageable by water solutions since they are colorfast and nonshrinkable. Care is frequently needed to prevent leaching of water soluble fire-retardant salts which may have been used to treat such materials in order to reduce their flame spread characteristics.

(2) *Alkaline Cleaners.* Most of these agents are water soluble and thus have no fire hazard properties. They can be used on fabrics, headliners, rugs and similar surfaces in the same manner as detergent and soap solutions with only minor added limitations resulting from their inherent caustic character which may increase their efficiency as cleaning agents but result in somewhat greater deteriorating effects on certain fabrics and plastics.

(3) *Acid Solutions.* A number of proprietary acid solutions are available for use as cleaning agents. They are normally mild solutions designed primarily to remove carbon smut or corrosive stains. As water based solutions, they have no flash point but may require more careful and judicious use not only to prevent damage to fabrics, plastics, or other surfaces but also to protect the skin and clothing of those using the materials.

(4) *Deodorizing or Disinfecting Agents.* A number of proprietary agents useful for aircraft cabin deodorizing or disinfecting are nonflammable. Most of these are designed for spray application (aerosol type) and have a nonflammable pressurizing agent but it is well to check this carefully as some may contain a flammable compressed gas for pressurization.

(5) *Abrasives.* Some proprietary nonflammable mild abrasive materials are available for rejuvenating painted or polished surfaces. They present no fire hazard.

(6) *Dry Cleaning Agents.* Perchlorethylene and trichlorethylene as used at ambient temperatures are examples of nonflammable dry cleaning agents. These materials do have a toxicity hazard requiring care in their use. Fire retardant treated materials may be adversely affected by the application of these agents as is true of the water-soluble agents.

Flammable and Combustible Agents

(1) *High Flash Point Solvents.* Specially refined petroleum products, first developed as "Stoddard Solvent" but now sold under a variety of trade names by different companies, have solvent properties approximating gasoline but have fire hazard properties similar to those of kerosene as commonly used (not heated). Most of these are stable products having a flash point from 100° F. to 140° F. with a comparatively low degree of toxicity.

(2) *Low Flash Point Solvents.* Class I (flash point at below 100° F.) flammable liquids should not be used for aircraft cleaning or refurbishing. Common materials falling into this "Class" are acetone, aviation gasoline, methyl ethyl ketone, naphtha and toluol.

In cases where it is absolutely necessary to use a flammable liquid, high flash point liquids (those having a flash point of 100° F. or more) should be used.

(3) *Mixed Liquids.* Some commercial solvents are mixtures of liquids with differing rates of evaporation such as a mixture of one of the various naphthas and a chlorinated material. The different rates of evaporation may present problems from both the toxicity and fire hazard viewpoints and such mixtures should not be used unless they are stored and handled with full knowledge of these hazards and appropriate precautions taken.

Container Controls

Flammable liquids should be handled only in approved containers or safety cans appropriately labeled.

Fire Prevention Precautions

During aircraft cleaning or refurbishing operations where flammable or combustible liquids are used, the following general safeguards are recommended:

(1) Aircraft cabins should be provided with ventilation sufficient at all times to prevent the accumulation of flammable vapors. To accomplish this, doors to cabins shall be open to secure maximum advantage of natural ventilation. Where such natural ventilation is insufficient under all conditions to prevent the accumulation of flammable vapors, approved mechanical ventilation equipment shall be provided and used. The accumulation of flammable vapors above 25 percent of the lower flammability limit of the particular vapor being used, measured at a point five feet from the location of use, shall result in emergency revisions of operations in progress.

(2) All open flame and spark producing equipment or devices that might be brought within the vapor hazard area should be shut down and not operated during the period when flammable vapors may exist.

(3) Electrical equipment of a hand portable nature used within an aircraft cabin shall be of the type approved for use in Class I, Group D, Hazardous Locations as defined by the National Electrical Code.

(4) Switches to aircraft cabin lighting and to the aircraft electrical system components within the cabin area should not be worked on or switched on or off during cleaning operations.

(5) Suitable warning signs should be placed in conspicuous locations at aircraft doors to indicate that flammable liquids are being or have been used in the cleaning or refurbishing operation in progress.

Fire Protection Recommendations

During aircraft cleaning or refurbishing operations where flammable liquids are used the following *general* fire protection safeguards are recommended:

(1) Aircraft undergoing such cleaning or refurbishing should preferably be located outside of the hangar buildings when weather conditions permit. This provides for added natural ventilation and normally assures easier access to the aircraft in the event of fire.

(2) It is recommended that during such cleaning or refurbishing operations in an aircraft outside of the hangar that portable fire extinguishers be provided at cabin entrances having a minimum rating of 20–B and, at minimum, a booster hoseline with an adjustable water spray nozzle be available capable of reaching the cabin area for use pending the arrival of airport fire equipment. As an alternate to the previous recommendations a Class A fire extinguisher having a minimum rating of 4–A plus or a Class B fire extinguisher having a minimum rating of 20–B should be placed at aircraft cabin doors for immediate use if required.

NOTE 1: All-purpose (dry chemical) type extinguishers should not be used in situations where aluminum corrosion is a problem.

NOTE 2: Portable and semi-portable fire detection and extinguishing equipment has been developed, tested and installed to provide protection to aircraft during construction and maintenance operations. Operators are urged to investigate the feasibility of utilizing such equipment during aircraft cabin cleaning and refurbishing operations.

(3) Aircraft undergoing such cleaning or refurbishing where the work must be done under cover should be in hangars equipped with automatic fire protection equipment.

POWERPLANT CLEANING

Cleaning the powerplant is an important job and should be done thoroughly. Grease and dirt accumulations on an air-cooled engine provide an effective insulation against the cooling effect of air flowing over it. Such an accumulation can also cover up cracks or other defects.

When cleaning an engine, open or remove the cowling. Beginning with the top, the engine and accessories are washed down with a fine spray of kerosene or solvent. A bristle brush may be used to help clean some of the surfaces.

Fresh water and soap, and approved cleaning solvents may be used for cleaning propeller and rotor blades. Except in the process of etching, caustic material should not be used on a propeller. Scrapers, power buffers, steel brushes, or any tool or substances that will mar or scratch the surface should not be used on propeller blades, except as recommended for etching and repair.

Water spray, rain, or other airborne abrasive material strikes a whirling propeller blade with such force that small pits are formed in the blade's leading edge. If preventive measures are not taken, corrosion causes these pits to rapidly grow larger. The pits may become so large that it is necessary to file the blade's leading edge until it is smooth.

Steel propeller blades have more resistance to abrasion and corrosion than aluminum alloy blades. Steel blades, if rubbed down with oil after each flight, retain a smooth surface for a long time.

Propellers should be examined regularly because cracks in steel or aluminum alloy blades can become filled with oil which tends to oxidize. This can readily be seen when the blade is inspected. Keeping the surface wiped with oil serves as a safety feature by helping to make cracks more obvious.

Propeller hubs must be inspected regularly for cracks and other defects. Unless the hubs are kept clean, defects may not be found. Steel hubs should be cleaned with soap and fresh water, or with an approved cleaning solvent. These cleaning solvents may be applied by cloths or brushes. Tools and abrasives that scratch or otherwise damage the plating should be avoided.

In special cases in which a high polish is desired, the use of a good grade of metal polish is recommended. Upon completion of the polishing, all traces of polish must be removed immediately, the blades cleaned, and then coated with clean engine oil.

All cleaning substances must be removed immediately after completion of the cleaning of any propeller part. Soap in any form can be removed by rinsing repeatedly with fresh water. After rinsing, all surfaces should be dried and coated with clean engine oil.

After cleaning the powerplant, all control arms, bellcranks, and moving parts should be lubricated according to instructions in the applicable maintenance manual.

SOLVENT CLEANERS

In general, solvent cleaners used in aircraft cleaning should have a flashpoint of not less than 105° F., if explosion proofing of equipment and other special precautions are to be avoided. Chlorinated solvents of all types meet the nonflammable requirements but are toxic, and safety precautions must be observed in their use. Use of carbon tetrachloride should be avoided.

Dry-cleaning Solvent

Stoddard solvent is the most common petroleum-base solvent used in aircraft cleaning. Its flashpoint is slightly above 105° F. and can be used to remove grease, oils, or light soils. Drycleaning solvent is preferable to kerosene for all cleaning purposes, but like kerosene it leaves a slight residue upon evaporation which may interfere with the application of some final paint films.

Aliphatic and Aromatic Naphtha

Aliphatic naphtha is recommended for wipe-down of cleaned surfaces just before painting. This material can also be used for cleaning acrylics and rubber. It flashes at approximately 80° F. and must be used with care.

Aromatic naphtha should not be confused with the aliphatic material. It is toxic and attacks acrylics and rubber products, and must be used with adequate controls.

Safety Solvent

Safety solvent, trichloroethane (methyl chloroform), is used for general cleaning and grease removal. It is nonflammable under ordinary circumstances, and is used as a replacement for carbon tetrachloride. The use and safety precautions necessary when using chlorinated solvents must be observed. Prolonged use can cause dermatitis on some persons.

Methyl Ethyl Ketone (MEK)

MEK is also available as a solvent cleaner for metal surfaces and paint stripper for small areas. This is a very active solvent and metal cleaner, with a flashpoint of about 24° F. It is toxic when inhaled, and safety precautions must be observed during its use.

Kerosene

Kerosene is mixed with solvent-emulsion type cleaners for softening heavy preservative coatings. It is also used for general solvent cleaning, but its use should be followed by a coating or rinse with some othes type of protective agent. Kerosene does not evaporate as rapidly as dry cleaning solvent and generally leaves an appreciable film on cleaned surfaces, which may actually be corrosive. Kerosene films may be removed with safety solvent, water emulsion cleaners, or detergent mixtures.

Cleaning Compound For Oxygen Systems

Cleaning compounds for use in the oxygen system are anhydrous (waterless) ethyl alcohol, isopropyl (anti-icing fluid) alcohol, or a mixture of freon and isopropyl alcohol. These may be used to clean accessible components of the oxygen system such as crew masks and lines. Fluids should not be put into tanks or regulators.

Do not use any cleaning compounds which may leave an oily film when cleaning oxygen equipment. Avoid prolonged skin contact with the freon-alcohol mixture or breathing of the vapors. Instructions of the manufacturer of the oxygen equipment and cleaning compounds must be followed at all times.

EMULSION CLEANERS

Solvent- and water-emulsion compounds are used in general aircraft cleaning. Solvent emulsions are particularly useful in the removal of heavy deposits, such as carbon, grease, oil, or tar. When used in accordance with instructions, these solvent emulsions do not affect good paint coatings or organic finishes.

Water-Emulsion Cleaner

Material available under Specification MIL-C-22543A is a water-emulsion cleaning compound intended for use on both painted and unpainted aircraft surfaces. This material is also acceptable for cleaning fluorescent painted surfaces and is safe for use on acrylics. However, these properties will vary with the material available, and a sample application should be checked carefully before general uncontrolled use.

Solvent-Emulsion Cleaners

One type of solvent-emulsion cleaner is nonphenolic and can be safely used on painted surfaces without softening the base paint. Repeated use may soften acrylic nitrocellulose lacquers. It is effective, however, in softening and lifting heavy preservative coatings. Persistent materials should be given a second or third treatment as necessary.

Another type of solvent-emulsion cleaner has a phenolic base which is more effective for heavy-duty application, but it also tends to soften paint coatings. It must be used with care around rubber, plastics, or other nonmetallic materials. Rubber gloves and goggles should be worn for protection when working with phenolic-base cleaners.

SOAPS AND DETERGENT CLEANERS

A number of materials are available for mild cleaning use. In this section, some of the more common materials are discussed.

Cleaning Compound, Aircraft Surfaces

Specification MIL-C-5410 Type I and II materials are used in general cleaning of painted and unpainted aircraft surfaces for the removal of light-to-medium soils, operational films, oils, or greases. They are safe to use on all surfaces, including fabrics, leather, and transparent plastics. Nonglare finishes should not be cleaned more than necessary and should never be scrubbed with stiff brushes.

Nonionic Detergent Cleaners

These materials may be either water-soluble or oil-soluble. The oil-soluble detergent cleaner is effective in a 3- to 5-percent solution in dry-cleaning solvent for softening and removing heavy preservative coatings. This mixture's performance is similar to the emulsion cleaners mentioned previously.

MECHANICAL CLEANING MATERIALS

Mechanical cleaning materials must be used with care and in accordance with directions given, if damage to finishes and surfaces is to be avoided.

Mild Abrasive Materials

No attempt is made in this section to furnish detailed instructions for using various materials listed. Some do's and don'ts are included as an aid in selecting materials for specific cleaning jobs.

Powdered pumice is used for cleaning corroded aluminum surfaces. Similar mild abrasives may also be used.

Impregnated cotton wadding material is used for removal of exhaust-gas stains and polishing corroded aluminum surfaces. It may also be used on other metal surfaces to produce a high reflectance.

Aluminum metal polish is used to produce a high-luster, long-lasting polish on unpainted aluminum clad surfaces. It should not be used on anodized surfaces because it will remove the oxide coat.

Three grades of aluminum wool, coarse, medium, and fine, are used for general cleaning of aluminum surfaces. Impregnated nylon webbing material is preferred over aluminum wool for the removal of corrosion products and stubborn paint films and for the scuffing of existing paint finishes prior to touchup.

Lacquer rubbing compound material can be used to remove engine exhaust residues and minor oxidation. Heavy rubbing over rivet heads or edges where protective coatings may be worn thin should be avoided.

Abrasive Papers

Abrasive papers used on aircraft surfaces should not contain sharp or needlelike abrasives which can imbed themselves in the base metal being cleaned or in the protective coating being maintained. The abrasives used should not corrode the material being cleaned. Aluminum oxide paper, 300 grit or finer, is available in several forms and is safe to use on most surfaces. Type I, Class 2 material under Federal Specification P-C-451 is available in 1½- and 2-inch widths. The use of carborundum (silicon carbide) papers should be avoided, particularly on aluminum or magnesium. The grain structure of carborundum is sharp, and the material is so hard that individual grains will penetrate and bury themselves even in steel surfaces. The use of emery paper or crocus cloth on aluminum or magnesium can cause serious corrosion of the metal by imbedded iron oxide.

CHEMICAL CLEANERS

Chemical cleaners must be used with great care in cleaning assembled aircraft. The danger of entrapping corrosive materials in faying surfaces and crevices counteracts any advantages in their speed and effectiveness. Any materials used must be relatively neutral and easy to remove. It is emphasized that all residue must be removed. Soluble salts from chemical surface treatments such as chromic acid or dichromate treatment will liquefy and promote blistering in the paint coatings.

Phosphoric-Citric Acid

A phosphoric-citric acid mixture (Type I) for cleaning aluminum surfaces is available and is ready to use as packaged. Type II is a concentrate which must be diluted with mineral spirits and water. Skin contact should be avoided by wearing rubber gloves and goggles. Any acid burns may be neutralized by copious water washing, followed by treatment with a diluted solution of baking soda (sodium bicarbonate).

Baking Soda

Baking soda may be used to neutralize acid deposits in lead-acid battery compartments and to treat acid burns from chemical cleaners and inhibitors.

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 aircraft 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.

Properties of Metals

Of primary concern in aircraft 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.

Explanation of Terms

Hardness refers to the ability of a metal to resist abrasion, penetration, cutting action, or permanent distortion. Hardness may be increased by coldworking 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 is the property of a metal which 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.

A metal which can be hammered, rolled, or pressed into various shapes without cracking, breaking, or having 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 is the property of a metal which 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 aircraft use because of their ease of forming and resistance to failure under shock loads. For this reason, aluminum alloys are used for cowl rings, fuselage and wing skin, and formed or extruded parts, such as ribs, spars, and bulkheads. Chrome molybdenum steel is also easily formed into desired shapes. Ductility is similar to malleability.

Elasticity is that property which enables a metal to return to its original shape when the force which 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 aircraft 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.

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

Density is the weight of a unit volume of a material. In aircraft work, 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 part in order to maintain the proper weight and balance of the aircraft.

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

Conductivity is the property which 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 the metal, to a certain extent, determines the type of jig to be used to control expansion and contraction. In aircraft, electrical conductivity must also be considered in conjunction with bonding, to eliminate radio interference.

Contraction and expansion are reactions produced in metals as the result of heating or cooling. 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 which 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, thus minimizing 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.

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

The tensile strength of a material is its resistance to a force which tends to pull it apart. Tensile strength is measured in p.s.i. (pounds per square inch) and is calculated by dividing the load, in pounds, required to pull the material apart by its cross-sectional area, in square inches.

The compression strength of a material is its resistance to a crushing force which is the opposite of tensile strength. Compression strength is also measured in p.s.i.

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 p.s.i. at which a material fails. It is the load divided by the shear area.

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 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.

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, such as the skin of monocoque structures, thickness is more important than strength, and, in this instance, the material with the lightest weight for a given thickness or gage is best. Thickness or bulk is necessary to prevent buckling or damage caused by careless handling.

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

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 aviation 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 stand. Any process which 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 and toughening process, and (2) the softening process. The hardening and toughening process is called heat treating, and the softening process is called annealing.

Aircraft metals are subjected to both shock and fatigue (vibrational) stresses. Fatigue occurs in materials which 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.

METALWORKING PROCESSES

There are three methods of metalworking: (1) Hot-working, (2) cold-working, and (3) extruding. The method used will depend on the metal involved and the part required, although in some instances both hot- and cold-working 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 in a soaking pit which 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.

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 which 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 chapter, hot-rolled material is frequently finished by cold-rolling or drawing to obtain accurate finish dimensions and a bright, smooth surface.

Complicated sections which 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 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 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.

Steel is often harder than necessary and too brittle for most practical uses when put under severe internal strain. To relieve such 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.

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 applies to iron-base metals only. Normalizing consists of heating the part to the proper temperature, holding it at that temperature until it is uniformaly 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.

While there are several cold-working processes, the two with which the aviation mechanic will be principally concerned are cold-rolling and cold-drawing. These processes give the metals desirable qualities which cannot be obtained by hot-working.

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 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 drawbench.

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 aircraft 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.

FERROUS AIRCRAFT METALS

Many different metals are required in the repair of aircraft. 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 aircraft 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. In this system, 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 middle of the carbon range. However, a deviation from the rule of indicating the carbon range is sometimes necessary.

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.

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. Refer to the numerical index table in figure 6–62.

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, drawbenches, 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.

Series designation	Types
100xx	Nonsulphurized carbon steels
11xx	Resulphurized carbon steels (free machining)
12xx	Rephosphorized and resulphurized carbon steels (free machining)
13xx	Manganese 1.75%
*23xx	Nickel 3.50%
*25xx	Nickel 5.00%
31xx	Nickel 1,25%, chromium 0.65%
33xx	Nickel 3.50%, chromium 1.55%
40xx	Molybdenum 0.20 or 0.25%
41xx	Chromium 0.50 or 0.95%, molybdenum 0.12 or 0.20%
43xx	Nickel 1.80%, chromium 0.50 or 0.80%, molybdenum 0.25%
44xx	Molybdenum 0.40%
45xx	Molybdenum 0.52%
46xx	Nickel 1.80%, molybdenum 0.25%
47xx	Nickel 1.05%, chromium 0.45%, molybdenum 0.20 or 0.35%
48xx	Nickel 3.50%, molybdenum 0.25%
50xx	Chromium 0.25, or 0.40 or 0.50%
50xxx	Carbon 1.00%, chromium 0.50%
51xx	Chromium 0.80, 0.90, 0.95, or 1.00%
51xxx	Carbon 1.00%, chromium 1.05%
52xxx	Carbon 1.00%, chromium 1.45%
61xx	Chromium 0.60, 0.80, or 0.95%, vanadium 0.12%, 0.10% min., or 0.15% min.
81xx	Nickel 0.30%, chromium 0.40%, molybdenum 0.12%
86xx	Nickel 0.55%, chromium 0.50%, molybdenum 0.20%
87xx	Nickel 0.55%, chromium 0.05%, molybdenum 0.25%
88xx	Nickel 0.55%, chromium 0.05%, molybdenum 0.35%
92xx	Manganese 0.85%, silicon 2.00%, chromium 0 or 0.35%
93xx	Nickel 3.25%, chromium 1.20%, molybdenum 0.12%
94xx	Nickel 0.45%, chromium 0.40%, molybdenum 0.12%
98xx	Nickel 1.00%, chromium 0.80%, molybdenum 0.25%

*Not included in the current list of standard steels.

FIGURE 6–62. SAE numerical index.

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

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.

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.

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. It has limited use in aircraft. SAE 1095 in sheet form is used for making flat springs and in wire form for making coil springs.

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 aircraft parts, such as bolts, terminals, keys, clevises, and pins.

Chromium steel is high in hardness, strength, and corrosion-resistant properties, and is particularly adaptable for heat-treated forgings which 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 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 aircraft 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 an aircraft. 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.

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.

Molybdenum in small percentages is used in combination with chromium to form chrome-molybdenum steel, which has various uses in aircraft. 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, landing gears, 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 aircraft 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 is a nickel-chromium-iron alloy closely resembling stainless steel (corrosion resistant steel, CRES) in appearance. Aircraft 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 a nickel content greater than 50 percent, and the electrochemical test detects Ni.

Prepare a wiring assembly as shown in Figure 6-2A, and prepare the two reagents (ammonium fluoride and dimethylglyoxime solutions) placing them in separate dedicated dropper solution bottles. Before testing, the metal must be thoroughly cleaned in order for the electrolytic deposition to take place. You may use nonmetallic hand scrubbing pads or 320 to 600 grit "crocus cloth" to remove deposits and corrosion products (thermal oxide).

Connect the alligator clip of the wiring assembly to the bare metal being tested. Place one drop of a 0.05 percent reagent grade ammonium fluoride solution in deionized water on the center of a (1 by 1 inch) sheet of filter paper. Lay the moistened filter paper over the bare metal alloy being tested. Firmly press the end of the aluminum rod over the center of the moist paper. Maintain connection for 10 seconds while rocking the aluminum rod on the filter paper. Ensure that the light emitting diode (LED) remains lit (indicating good electrical contact and current flow) during this period. Disconnect the wiring assembly, and set it aside. Remove the filter paper and examine it to determine that a light spot appears where the connection was made.

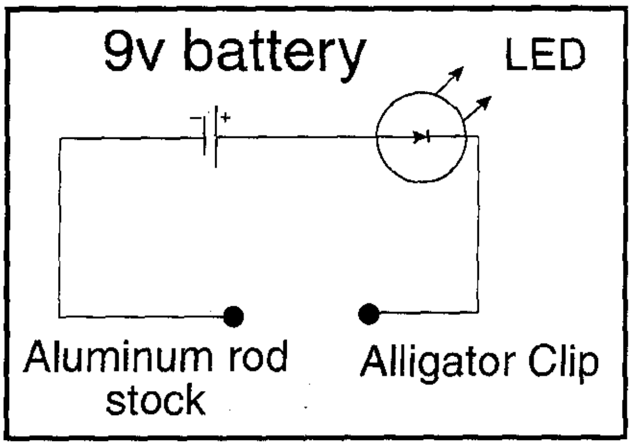


FIGURE 6-2A. Wiring assembly schematic.

Deposit one drop of 1.0 percent solution of reagent grade dimethylglyoxime in ethyl alcohol on the filter paper (same side that was in contact with the test metal). A bright distinctly pink spot will appear within seconds on the filter paper if the metal being tested is Inconel. A brown spot will appear if the test metal is stainless steel. Some stainless steel alloys may leave a very light pink color. However, the shade and depth of color will be far less than would appear for Inconel. For flat surfaces the test spot will be circular while for curved surfaces, such as the outside of a tube or pipe, the test spot may appear as a streak. (See Figure 6-2B for sample test results.) This procedure should not be used in the heat affected zone of weldments and on nickel coated surfaces.

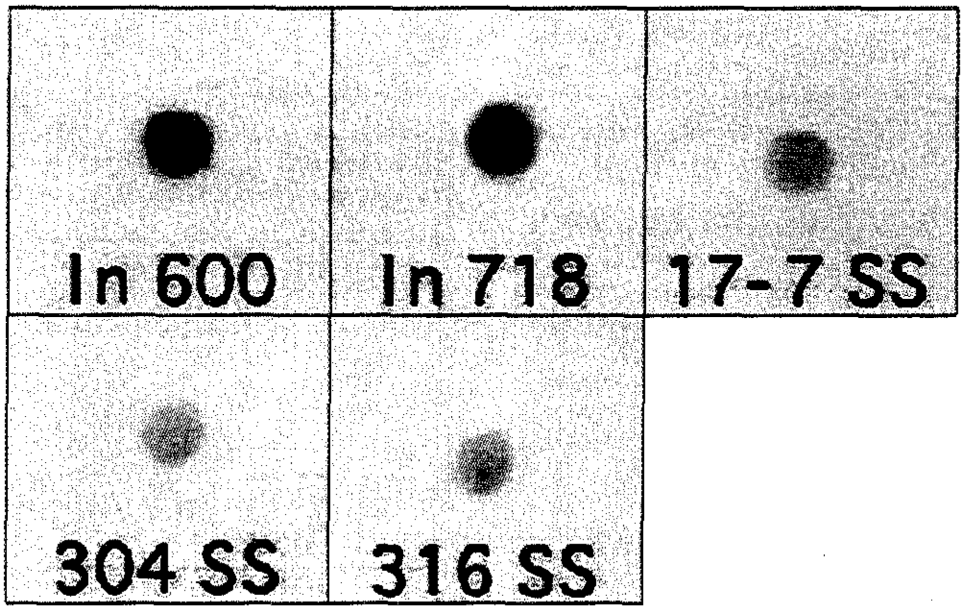


FIGURE 6-2B. Electrochemical test results, Inconel and stainless steel alloys.

The tensile strength of Inconel is 100,000 p.s.i., annealed, and 125,000 p.s.i., 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.

NONFERROUS AIRCRAFT METALS

The term "nonferrous" refers to all metals which 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 babbit.

Aluminum and Aluminum Alloys

Commercially pure aluminum is a white lustrous metal which 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 which are used in aircraft 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 is one of the most widely used metals in modern aircraft construction. It is vial to the aviation 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 metals 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 p.s.i., but by rolling or other cold-working processes its strength may be approximately doubled. By alloying with other metals, or by using heat-treating processes, the tensile strength may be raised to as high as 65,000 p.s.i. or to within the strength range of structural steel.

Aluminum alloys, although strong, are easily worked because they are malleable and ductile. They may be rolled into sheets as thin as .0017 inch or drawn into wire .004 inch in diameter. Most aluminum alloy sheet stock used in aircraft construction ranges from .016 to .096 inch in thickness; however, some of the larger aircraft use sheet stock which may be as thick as .356 inch.

The various types of aluminum may be divided into two general classes: (1) The casting alloys (those suitable for casting in sand, permanent mold, or die castings), and (2) the wrought alloys (those which may be shaped by rolling, drawing, or forging). Of these two, the wrought alloys are the most widely used in aircraft construction, being used for stringers, bulkheads, skin, rivets, and extruded sections.

Aluminum casting alloys are divided into two basic groups. In one, the physical properties of the alloys are determined by the alloying elements and cannot be 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 is 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 castings are produced by one of three basic methods: (1) Sand mold, (2) permanent mold, or (3) die cast. In casting aluminum, it must be remembered that in most cases different types of alloys must be used for different types of castings. Sand castings and die castings require different types of alloys than those used in permanent molds.

Sand and permanent mold castings are parts produced by pouring molten metal into a previously prepared mold, allowing the metal to solidify or freeze, and then removing the part. If the mold is made of sand, the part is a sand casting; if it is a metallic mold (usually cast iron) the part is a permanent mold casting. Sand and permanent castings are produced by pouring liquid metal into the mold, the metal flowing under the force of gravity alone.

The two principal types of sand casting alloys are 112 and 212. Little difference exists between the two metals from a mechanical properties standpoint, since both are adaptable to a wide range of products.

The permanent mold process is a later development of the sand casting process, the major difference being in the material from which the molds are made. The advantage of this process is that there are fewer openings (called porosity) than in sand castings. The sand and the binder, which is mixed with the sand to hold it together, give off a certain amount of gas which causes porosity in a sand casting.

Permanent mold castings are used to obtain higher mechanical properties, better surfaces, or more accurate dimensions. There are two specific types of permanent mold castings: (1) The permanent metal mold with metal cores, and (2) the semipermanent types containing sand cores. Because finer grain structure is produced in alloys subjected to the rapid cooling of metal molds, they are far superior to the sand type castings. Alloys 122, A132, and 142 are commonly used in permanent mold castings, the principal uses of which are in internal combustion engines.

Die castings used in aircraft are usually aluminum or magnesium alloy. If weight is of primary importance, magnesium alloy is used because it is lighter than aluminum alloy. Aluminum alloy is frequently used since it is stronger than most magnesium alloys.

A die casting is produced by forcing molten metal under pressure into a metallic die and allowing it to solidify; then the die is opened and the part removed. The basic difference between permanent mold casting and die casting is that in the permanent mold process the metal flows into the die under gravity. In the die casting operation, the metal is forced under great pressure.

Die castings are used where relatively large production of a given part is involved. Remember, any shape which can be forged can be cast.

Wrought aluminum and wrought aluminum alloys are divided into two general classes, nonheat-treatable alloys and heat-treatable alloys.

Nonheat-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 to hold 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.

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 through 8xxx group, and 9xxx group (which is at present unused).

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 through 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. Thus, 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:

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.

In the 2xxx through 8xxx groups, the first digit indicates the major alloying element used in the formation of the alloy as follows:

2xxx—copper.
3xxx—manganese.
4xxx—silicon.
5xxx—magnesium.
6xxx—magnesium and silicon.
7xxx—zinc.
8xxx—other elements.

In the 2xxx through 8xxx alloy groups, the second digit in the alloy designation indicates alloy modifications. If the second digit is zero, it indicates the original alloy, while digits 1 through 9 indicate alloy modifications.

The last two of the four digits in the designation identify the different alloys in the group (figure 6–63).

Effect of Alloying Element

1000 series. 99% or higher, excellent corrosion resistance, high thermal and electrical conductivity, low mechanical properties, excellent workability. Iron and silicon are major impurities.

2000 series. 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.

3000 series. Manganese is the principle alloying element of this group which is generally non-heat-treatable. The percentage of manganese which will be alloy effective is 1.5%. The most popular is 3003 which is of moderate strength, and has good working characteristics.

4000 series. 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.

5000 series. 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.

6000 series. Silicon and magnesium form magnesium silicide which makes alloys heat-treatable. It is of medium strength, good forming and has corrosion resistant characteristics.

Alloy	Per cent of alloying elements—aluminum and normal impurities constitute remainder								
	Copper	Silicon	Manganese	Magnesium	Zinc	Nickel	Chromium	Lead	Bismuth
1100	......	......	......	......	......	......	......	......	......
3003	......	......	1.2	......	......	......	......	......	......
2011	5.5	......	......	......	......	......	......	0.5	0.5
2014	4.4	0.8	0.8	0.4	......	......	......	......	......
2017	4.0	......	0.5	0.5	......	......	......	......	......
2117	2.5	......	......	0.3	......	......	......	......	......
2018	4.0	......	......	0.5	......	2.0	......	......	......
2024	4.5	......	0.6	1.5	......	......	......	......	......
2025	4.5	0.8	0.8	......	......	......	......	......	......
4032	0.9	12.5	......	1.0	......	0.9	......	......	......
6151	......	1.0	......	0.6	......	......	0.25	......	......
5052	......	......	......	2.5	......	......	0.25	......	......
6053	......	0.7	......	1.3	......	......	0.25	......	......
6061	0.25	0.6	......	1.0	......	......	0.25	......	......
7075	1.6	......	......	2.5	5.6	......	0.3		......

FIGURE 6-63. Nominal composition of wrought aluminum alloys.

7000 series. 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.

Hardness Identification

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, number 8 representing the ultimate tensile strength equal to that achieved by a cold reduction of approximately 75% following a full anneal, 0 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.

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.

The most widely used alloys in aircraft construction are hardened by heat treatment rather than by cold-work. These alloys are designated by a somewhat different set of symbols: —T4 and W indicate solution heat treated and quenched but not aged, and T6 indicates an alloy in the heat treated hardened condition.

—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.

Additional digits may be added to T1 through T10 to indicate a variation in treatment which significantly alters the characteristics of the product.

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, however, and does not have the strength required for structural aircraft parts. Higher 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.

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.

The most widely used alloys in aircraft construction are hardened by heat treatment rather than by cold-work. These alloys are designated by a somewhat different set of symbols: —T4 and W indicate solution heat treated and quenched but not aged, and T6 indicates an alloy in the heat treated hardened condition.

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 nonheat-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 5½ 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

Titanium was discovered by an English priest named Gregot. A crude separation of titanium ore was accomplished in 1825. In 1906 a sufficient amount of pure titanium was isolated in metallic form to permit a study. Following this study, in 1932, an extraction process was developed which became the first commercial method for producing titanium. The United States Bureau of Mines began making titanium sponge in 1946, and 4 years later the melting process began.

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 aircraft construction and repair, titanium is used for fuselage skins, engine shrouds, firewalls, longerons, frames, fittings, air ducts, and fasteners,

Titanium is used for making compressor disks, spacer rings, compressor blades and vanes, through bolts, turbine housings and liners, and miscellaneous hardward for turbine engines.

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 from 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. Aircraft firewalls demand this requirement.

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 classification of titanium alloys was 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:

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 a commercially pure titanium. It has a yield strength of 55,000 to 80,000 p.s.i. and is a general-purpose grade for moderate to severe forming. It is sometimes used for nonstructural aircraft parts and for all types of corrosion-resistant applications, such as tubing.

Type A-70 titanium is closely related to type A-55 but has a yield strength of 70,000 to 95,000 p.s.i. 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 is used for primary structural members and aircraft skin, has 110,000 p.s.i. minimum yield strength, and contains 8 percent manganese.

Type A-110AT is a titanium alloy which contains 5 percent aluminum and 2.5 percent tin. It also has a 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 and Copper Alloys

Copper is one of the most widely distributed 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 p.s.i., and when cold rolled or cold drawn its tensile strength increases to a range of 40,000 to 67,000 p.s.i.

In aircraft, copper is used primarily in the electrical system for bus bars, bonding, and as lockwire.

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 p.s.i. in the annealed state to 200,000 p.s.i. 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 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 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 p.s.i., 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, 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.

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 in aircraft.

Among the copper alloys are the copper aluminum alloys, of which the aluminum bronzes rank very high in aircraft usage. They would find greater usefulness in structures if it were not for their strength-to-weight ratio as compared with alloy steels. 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.

These copper-base alloys contain up to 16 percent of 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.

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 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 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 p.s.i. This can be increased by cold-working to 125,000 p.s.i., sufficient for classification among the tough alloys.

Monel has been successfully used for gears and chains to operate retractable landing gears, and for 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 which 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 is probably more widely distributed in nature than any other metal. It can be obtained from such ores as dolomite and magnesite, and from sea water, underground brines, and waste solutions of potash. With about 10 million pounds of magnesium in 1 cubic mile of sea water, there is no danger of a dwindling supply,

Some of today's aircraft require in excess of one-half ton of this metal for use in hundreds of vital spots. Some wing panels are fabricated entirely from magnesium alloys, weigh 18 percent less than standard aluminum panels, and have flown hundreds of satisfactory hours. Among the aircraft parts that have been made from magnesium with a substantial savings in weight are nosewheel doors, flap cover skin, aileron cover skin, oil tanks, floorings, fuselage parts, wingtips, engine nacelles, instrument panels, radio masts, hydraulic fluid tanks, oxygen bottle cases, ducts, and seats.

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 number 1 indicating high purity and maximum corrosion resistance.

Many of the magnesium alloys manufactured in this country are produced by the Dow Chemical Company and have been given the trade name of Dowmetal alloys. To distinguish between these alloys, each is assigned a letter. Thus, we have Dowmetal J, Dowmetal M, and so forth.

Another manufacturer of magnesium alloys is the American Magnesium Corporation, a subsidiary of the Aluminum Company of America. This company uses an identification system similar to that used for aluminum alloys, with the exception that magnesium alloy numbers are preceded with the letters AM. Thus, AM240C is a cast alloy, and AM240C4 is the same alloy in the heat-treated state. AM3S0 is an annealed wrought alloy, and AM3SRT is the same alloy rolled after heat treatment.

SUBSTITUTION OF AIRCRAFT METALS

In selecting substitute metals for the repair and maintenance of aircraft, it is very important to check the appropriate structural repair manual. Aircraft manufacturers design structural members to meet a specific load requirement for a particular aircraft. The methods of repairing these members, apparently similar in construction, will thus vary with different aircraft.

Four requirements must be kept in mind when selecting substitute metals. The first and most important of these is maintaining the original strength of the structure. The other three are: (1) Maintaining contour or aerodynamic smoothness, (2) maintaining original weight, if possible, or keeping added weight to a minimum, and (3) maintaining the original corrosion-resistant properties of the metal.

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 casehardening. Most nonferrous metals can be annealed and many of them can be hardened by heat treatment. However, there is only one nonferrous metal, titanium, that can be casehardened, and none can be tempered or normalized.

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 there is little change in its structure when heated. On the other hand, most alloys respond to heat treatment since their structures change with heating and cooling.

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 which 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.

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.

An alloy in the form of a mechanical mixture at ordinary temperatures may change to a solid solution when heated. When cooled back to normal temperature, the alloy may return to its original structure. On the other hand, it may remain a solid solution or form a combination of a solid solution and mechanical mixture. An alloy which consists of a combination of solid solution and mechanical mixture at normal temperatures may change to a solid solution when heated. When cooled, the alloy may remain a solid solution, return to its original structure, or form a complex solution.

HEAT-TREATING EQUIPMENT

Successful heat treating requires close control over all factors affecting the heating and cooling of metals. Such control is possible only when the proper equipment is available and the equipment is selected to fit the particular job. Thus, the furnace must be of the proper size and type and must be so controlled that temperatures are kept within the limits prescribed for each operation. Even the atmosphere within the furnace affects the condition of the part being heat treated. Further, the quenching equipment and the quenching medium must be selected to fit the metal and the heat-treating operation. Finally, there must be equipment for handling parts and materials, for cleaning metals, and for straightening parts.

Furnaces and Salt Baths

There are many different types and sizes of furnaces used in heat treatment. As a general rule, furnaces are designed to operate in certain specific temperature ranges and attempted use in other ranges frequently results in work of inferior quality. In addition, using a furnace beyond its rated maximum temperature shortens its life and may necessitate costly and time-consuming repairs.

Fuel-fired furnaces (gas or oil) require air for proper combustion and an air compressor or blower is therefore necessary. These furnaces are usually of the muffler type: that is, the combustion of the fuel takes place outside of and around the chamber in which the work is placed. If an open muffler is used, the furnace should be designed so as to prevent the direct impingement of flame on the work.

In furnaces heated by electricity the heating elements are generally in the form of wire or ribbon. Good design requires incorporation of additional heating elements at locations where maximum heat loss may be expected. Such furnaces commonly operate up to a maximum temperature of about 2,000° F. Furnaces operating at temperatures up to about 2,500° F. usually employ resistor bars of sintered carbides.

Temperature Measurement and Control

Temperature in the heat-treating furnace is measured by a thermoelectric instrument known as a pyrometer. This instrument measures the electrical effect of a thermocouple and, hence, the temperature of the metal being treated. A complete pyrometer consists of three parts—a thermocouple, extension leads, and meter.

Furnaces intended primarily for tempering may be heated by gas or electricity and are frequently equipped with a fan for circulating the hot air.

Salt baths are available for operating at either tempering or hardening temperatures. Depending on the composition of the salt bath, heating can be conducted at temperatures as low as 325° F. to as high as 2,450° F. Lead baths can be used in the temperature range of 650° F. to 1,700° F. The rate of heating in lead or salt baths is much faster in furnaces.

Heat-treating furnaces differ in size, shape, capacity, construction, operation, and control. They may be circular or rectangular and may rest on pedestals or directly on the floor. There are also pit-type furnaces, which are below the surface of the floor. When metal is to be heated in a bath of molten salt or lead, the furnace must contain a pot or crucible for the molten bath.

The size and capacity of a heat-treating furnace depends on the intended use. A furnace must be capable of heating rapidly and uniformly, regardless of the desired maximum temperature or the mass of the charge. An oven-type furnace should have a working space (hearth) about twice as long and three times as wide as any part that will be heated in the furnace.

Accurate temperature measurement is essential to good heat treating. The usual method is by means of thermocouples: the most common base-metal couples are copper-constantan (up to about 700° F.), iron-constantan (up to about 1,400° F.), and chromel-alumel (up to about 2,200° F.). The most common noble-metal couples (which can be used up to about 2,800° F.) are platinum coupled with either the alloy 87 percent platinum—13 percent rhodium or the alloy 90 percent platinum—10 percent rhodium. The temperatures quoted are for continuous operation.

The life of thermocouples is affected by the maximum temperature (which may frequently exceed those given above) and by the furnace atmosphere. Iron-constantan is more suited for use in reducing and chromel-alumel in oxidizing atmospheres. Thermocouples are usually encased in metallic or ceramic tubes closed at the hot end to protect them from the furnace gases. A necessary attachment is an instrument, such as a millivoltmeter or potentiometer, for measuring the electromotive force generated by the thermocouple. In the interest of accurate control, the hot junction of the thermocouple should be placed as close to the work as possible. The use of an automatic controller is valuable in controlling the temperature at the desired value.

Pyrometers may have meters either of the indicating type or recording type. Indicating pyrometers give direct reading of the furnace temperature. The recording type produces a permanent record of the temperature range throughout the heating operation by means of an inked stylus attached to an arm which traces a line on a sheet of calibrated paper or temperature chart.

Pyrometer installations on all modern furnaces provide automatic regulation of the temperature at any desired setting. Instruments of this type are called controlling potentiometer pyrometers. They include a current regulator and an operating mechanism such as a relay.

Heating

The object in heating is to transform pearlite (a mechanical mixture of iron carbide that exists in a finely mixed condition) to austenite as the steel is heated through the critical range. Since this transition takes time, a relatively slow rate of heating must be used. Ordinarily, the cold steel is inserted when the temperature in the furnace is from 300° F. to 500° F. below the hardening temperature. In this way, too rapid heating through the critical range is prevented.

If temperature-measuring equipment is not available, it becomes necessary to estimate temperatures by some other means. An inexpensive, yet fairly accurate method involves the use of commercial crayons, pellets, or paints that melt at various temperatures within the range of 125° F. to 1,600° F. The least accurate method of temperature estimation is by observation of the color of the hot hearth of the furnace or of the work. The heat colors observed are affected by many factors, such as the conditions of artificial or natural light, the character of the scale on the work, etc.

Steel begins to appear dull red at about 1,000° F., and as the temperature increases the color changes gradually through various shades of red to orange, to yellow, and finally to white. A rough approximation of the correspondence between color and temperature is indicated in figure 6–64.

It is also possible to secure some idea of the temperature of a piece of carbon or low-alloy steel, in the low temperature range used for tempering, from the color of the thin oxide film that forms on the cleaned surface of the steel when heated in this range. The approximate temperature-color relationship for a time at temperature of about one-half is indicated on the lower portion of the scale in figure 6–64.

Protective Atmospheres

It is often necessary or desirable to protect steel or cast iron from surface oxidation (scaling) and loss of carbon from the surface layers (decarburization). Commercial furnaces, therefore, are generally equipped with some means of atmosphere control. This usually is in the form of a burner for burning controlled amounts of gas and air and directing the products of combustion into the furnace muffle. Water vapor, a product of this combustion, is detrimental and many furnaces are equipped with a means for eliminating it. For furnaces not equipped with atmosphere control, a variety of external atmosphere generators are available. The gas so generated is piped into the furnace and one generator may supply several furnaces. If no method of atmosphere control is available, some degree of protection may be secured by covering the work with cast iron borings or chips.

Since the work in salt or lead baths is surrounded by the liquid heating medium, the problem of preventing scaling or decarburization is simplified.

Vacuum furnaces also are used for annealing steels, especially when a bright non-oxidized surface is a prime consideration.

Soaking

The temperature of the furnace must be held constant during the soaking period, since it is during this period that rearrangement of the internal structure of the steel takes place. Soaking

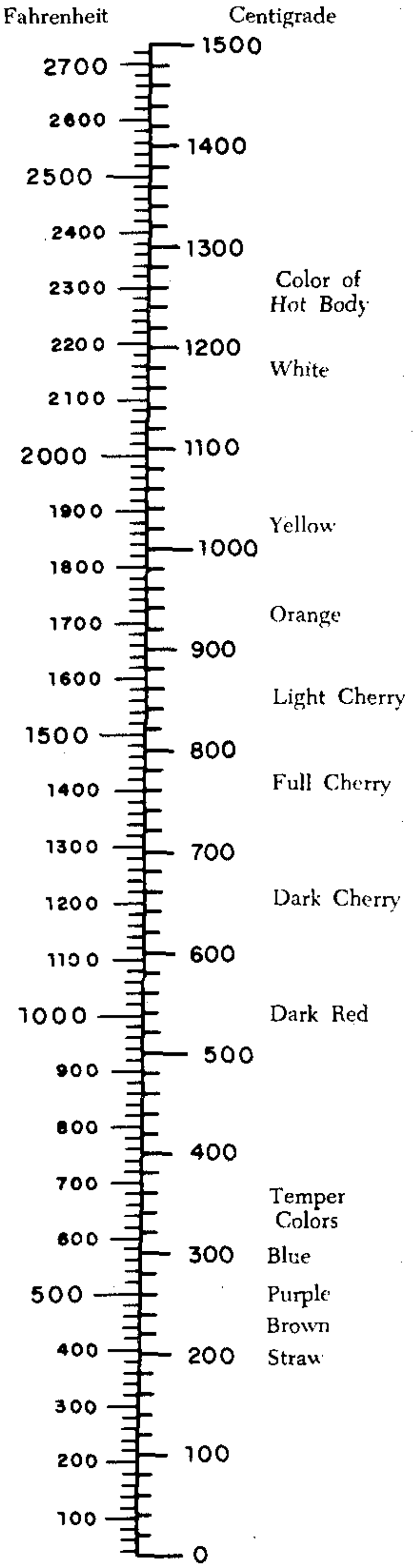


FIGURE 6–64. Temperature chart indicating conversion of Centigrade to Fahrenheit or visa versa, color temperatures scale for hardening-temperature range, and tempering-temperature range.

temperatures for various types of steel are specified in ranges varying as much as 100° F. (See figure 6–65.) Small parts are soaked in the lower part of the specified range and heavy parts in the upper part of the specified range. The length of the soaking period depends upon the type of steel and the size of the part. Naturally, heavier parts require longer soaking to ensure equal heating throughout. As a general rule, a soaking period of 30 minutes to 1 hour is sufficient for the average heat-treating operation.

Cooling

The rate of cooling through the critical range determines the form that the steel will retain. Various rates of cooling are used to produce the desired results. Still air is a slow cooling medium, but is much faster than furnace cooling. Liquids are the fastest cooling media and are therefore used in hardening steels.

There are three commonly used quenching liquids—brine, water, and oil. Brine is the most severe medium, water is next, and oil is the least severe. Generally an oil quench is used for alloy steels, and brine or water for carbon steels.

Quenching Media

Quenching solutions act only through their ability to cool the steel. They have no beneficial chemical action on the quenched steel and in themselves impart no unusual properties. Most requirements for quenching media are met satisfactorily by water or aqueous solutions of inorganic salts such as table salt or caustic soda, or by some type of oil. The rate of cooling is relatively rapid during quenching in brine, somewhat less rapid in water, and slow in oil.

Brine usually is made of a 5- to 10-percent solution of salt (sodium chloride) in water. In addition to its greater cooling speed, brine has the ability to "throw" the scale from steel during quenching. The cooling ability of both water and brine, particularly water, is considerably affected by their temperature. Both should be kept cold—well below 60° F. If the volume of steel being quenched tends to raise the temperature of the bath appreciably, the quenching bath should be cooled by adding ice or by some means of refrigeration.

There are many specially prepared quenching oils on the market; their cooling rates do not vary widely. A straight mineral oil with a Saybolt viscosity of about 100 at 100° F. is generally used. Unlike brine and water, the oils have the greatest cooling velocity at a slightly elevated temperature—about 100 to 140° F.—because of their decreased viscosity at these temperatures.

When steel is quenched, the liquid in immediate contact with the hot surface vaporizes; this vapor reduces the rate of heat abstraction markedly. Vigorous agitation of the steel or the use of a pressure spray quench is necessary to dislodge these vapor films and thus permit the desired rate of cooling.

The tendency of steel to warp and crack during the quenching process is difficult to overcome because certain parts of the article cool more rapidly than others. The following recommendations will greatly reduce the warping tendency.

1. A part should never be thrown into the quenching bath. By permitting it to lie on the bottom of the bath, it is apt to cool faster on the top side than on the bottom side, thus causing it to warp or crack.
2. The part should be agitated slightly to destroy the coating of vapor which might prevent it from cooling rapidly. This allows the bath to convey its heat to the atmosphere.
3. Irregular-shaped parts should be immersed in such a way that the heavy end enters the bath first.

Quenching Equipment

The quenching tank should be of the proper size to handle the material being quenched. Circulating pumps and coolers may be used to maintain approximately constant temperatures when a large amount of quenching is to be done. To avoid building up a high concentration of salt in the quenching tank, provision must be made to add fresh water to the quench tank used for molten salt baths.

Tank location in reference to the heat-treating furnace is very important. The tank should be situated to permit rapid transfer of the part from the furance to the quenching medium. A delay of more than a few seconds will, in many instances, prove detrimental to the effectiveness of the heat treatment. When material of thin section is being heat treated, guard sheets should be employed to retard the loss of heat during transfer to the quench tank. A rinse tank must be provided to remove all salt from the material after quenching if the salt has not been adequately removed in the quenching tank.

HEAT TREATMENT OF FERROUS METALS

The first important consideration in the heat treatment of a steel part is to know its chemical

Steel No.	Temperatures			Quenching medium (n)	Tempering (drawing) temperature for tensile strength (p.s.i.)				
	Normalizing air cool	Annealing	Hardening		100,000	125,000	150,000	180,000	200,000
	°F	°F	°F		°F	°F	°F	°F	°F
1020	1,650–1,750	1,600–1,700	1,575–1,675	Water	—	—	—	—	—
1022(x1020)	1,650–1,750	1,600–1,700	1,575–1,675	Water	—	—	—	—	—
1025	1,600–1,700	1,575–1,650	1,575–1,675	Water	(a)	—	—	—	—
1035	1,575–1,650	1,575–1,625	1,525–1,600	Water	875	—	—	—	—
1045	1,550–1,600	1,550–1,600	1,475–1,550	Oil or water	1,150	—	—	(n)	—
1095	1,475–1,550	1,450–1,500	1,425–1,500	Oil	(b)	—	1,100	850	750
2330	1,475–1,525	1,425–1,475	1,450–1,500	Oil or water	1,100	950	800	—	—
3135	1,600–1,650	1,500–1,550	1,475–1,525	Oil	1,250	1,050	900	750	650
3140	1,600–1,650	1,500–1,550	1,475–1,525	Oil	1,325	1,075	925	775	700
4037	1,600	1,525–1,575	1,525–1,575	Oil or water	1,225	1,100	975	—	—
4130(x4130)	1,600–1,700	1,525–1,575	1,575–1,625	Oil (c)	(d)	1,050	900	700	575
4140	1,600–1,650	1,525–1,575	1,525–1,575	Oil	1,350	1,100	1,025	825	675
4150	1,550–1,600	1,475–1,525	1,500–1,550	Oil	—	1,275	1,175	1,050	950
4340(x4340)	1,550–1,625	1,525–1,575	1,475–1,550	Oil	—	1,200	1,050	950	850
4640	1,675–1,700	1,525–1,575	1,500–1,550	Oil	—	1,200	1,050	750	625
6135	1,600–1,700	1,550–1,600	1,575–1,625	Oil	1,300	1,075	950	800	750
6150	1,600–1,650	1,525–1,575	1,550–1,625	Oil	(d)(e)	1,200	1,000	900	800
6195	1,600–1,650	1,525–1,575	1,500–1,550	Oil	(f)	—	—	—	—
NE8620	—	—	1,525–1,575	Oil	—	1,000	—	—	—
NE8630	1,650	1,525–1,575	1,525–1,575	Oil	—	1,125	975	775	675
NE8735	1,650	1,525–1,575	1,525–1,575	Oil	—	1,175	1,025	875	775
NE8740	1,625	1,500–1,550	1,500–1,550	Oil	—	1,200	1,075	925	850
30905	—	(g)(h)	(i)	—	—	—	—	—	—
51210	1,525–1,575	1,525–1,575	1,775–1,825	Oil	1,200	1,100	(k)	750	—
51335	—	1,525–1,575	(j) 1,775–1,850	Oil	—	—	—	—	—
52100	1,625–1,700	1,400–1,450	1,525–1,550	Oil	(f)	—	—	—	—
Corrosion resisting (16–2) (1)	—	—	—	—	(m)	—	—	—	—
Silicon chromium (for springs)	—	—	1,700–1,725	Oil					

NOTES

(a) Draw at 1150° F. for tensile strength of 70,000 p.s.i.

(b) For spring temper draw at 800° to 900° F. Rockwell Hardness C-40-45.

(c) Bars or forgings may be quenched in water from 1,500°–1,600° F.

(d) Air-cooling from the normalizing temperature will produce a tensile strength of approximately 90,000 p.s.i.

(e) For spring temper draw at 850° to 950° F. Rockwell Hardness C-40-45.

(f) Draw at 350° to 450° F. to remove quenching strains. Rockwell Hardness C-60-65.

(g) Anneal at 1,600° to 1,700° F. to remove residual stresses due to welding or cold work. May be applied only to steel containing titanium or columbium.

(h) Anneal at 1,900° to 2,100° F. to produce maximum softness and corrosion resistance. Cool in air or quench in water.

(i) Harden by cold work only.

(j) Lower side of range for sheet 0.06 inch and under. Middle of range for sheet and wire 0.125 inch. Upper side of range for forgings.

(k) Not recommended for intermediate tensile strengths because of low impact.

(l) AN-QQ-S-770.—It is recommended that, prior to tempering, corrosion-resisting (16 Cr-2 Ni) steel be quenched in oil from a temperature of 1,875° to 1,900° F., after a soaking period of 1/2 hour at this temperature. To obtain a tensile strength at 115,000 p.s.i., the tempering temperature should be approximately 525° F. A holding time at these temperatures of about 2 hours is recommended. Tempering temperatures between 700° and 1,100° F. will not be approved.

(m) Draw at approximately 800° F. and cool in air for Rockwell Hardness of C-50.

(n) Water used for quenching shall not exceed 65° F. Oil used for quenching shall be within the temperature range of 80°–150° F.

FIGURE 6–65. Heat treatment procedures for steels.

composition. This, in turn, determines its upper critical 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 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 solid 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 the 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.

When hardening carbon steel, it must be cooled to below 1,000° F. in less than 1 second. Should the time required for the temperature to drop to 1,000° F. exceed 1 second, the austenite begins to transform into fine pearlite. This pearlite varies in hardness, but is much harder than the pearlite formed by annealing and much softer than the martensite desired. After the 1,000° F. temperature is reached, the rapid cooling must continue if the final structure is to be all martensite.

When alloys are added to steel, the time limit for the temperature drop to 1,000° F. increases above the 1-second limit for carbon steels. Therefore, a slower quenching medium will produce hardness in alloy steels.

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.

Hardening temperatures and quenching mediums for the various types of steel are listed in figure 6–65.

Hardening Precautions

A variety of different shapes and sizes of tongs for handling hot steels is necessary. It should be remembered that cooling of the area contacted by the tongs is retarded and that such areas may not harden, particularly if the steel being treated is very shallow hardening. Small parts may be wired together or quenched in baskets made of wire mesh.

Special quenching jigs and fixtures are frequently used to hold steels during quenching in a manner to restrain distortion.

When selective hardening is desired, portions of the steel may be protected by covering with alundum cement or some other insulating material. Selective hardening may be accomplished also by the use of water or oil jets designed to direct quenching medium on the areas to be hardened. This also is accomplished by the induction and flame-hardening procedures previously described, particularly on large production jobs.

Shallow hardening steels, such as plain carbon and certain varieties of alloy steels, have such a high critical cooling rate that they must be quenched in brine or water to effect hardening. In general, intricately shaped sections should not be made of shallow hardening steels because of the tendency of these steels to warp and crack during hardening. Such items should be made of deeper hardening steels capable of being hardened by quenching in oil or air.

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 re-heated, 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. Approximate temperatures for various tensile strengths are listed in figure 6–65. The minimum time at the tempering temperature should be 1 hour. If the part is over 1 inch in thickness, the time should be increased by 1 hour for each additional inch of thickness. Tempered steels used in aircraft work have from 125,000 to 200,000 p.s.i. ultimate tensile strength.

Generally, the rate of cooling from the tempering temperature has no effect on the resulting structure; therefore, the steel is usually cooled in still air after being removed from the furnace.

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 cooling very slowly in the furnace. (See figure 6–65 for recommended temperatures.) Soaking time is approximately 1 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, 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 conduct heat readily.

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 in aircraft work is in 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. Recommended normalizing temperatures for the various types of aircraft steels are listed in figure 6–65.

CASEHARDENING

Casehardening produces a hard wear-resistant surface or case over a strong, tough core. Casehardening is ideal for parts which 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 casehardening are the low-carbon and low-alloy steels. If high-carbon steel is casehardened, the hardness penetrates the core and causes brittleness.

In casehardening, the surface of the metal is changed chemically by introducing a high carbide or nitride content. The core is unaffected chemically. When heat treated, the surface responds to hardening while the core toughens. The common forms of casehardening are carburizing, cyaniding, and nitriding. Since cyaniding is not used in aircraft work, only carburizing and nitriding are discussed in this section.

Carburizing

Carburizing is a casehardening process in which carbon is added to the surface of low-carbon steel. Thus, a carburized steel has a high-carbon surface and a low-carbon interior. When the carburized steel is heat treated, the case is hardened while the core remains soft and tough.

A common method of carburizing is called "pack carburizing." When carburizing is to be done by this method, the steel parts are packed in a container with charcoal or some other material rich in carbon. The container is then sealed with fire clay, placed in a furnace, heated to approximately 1,700° F., and soaked at that temperature for several hours. As the temperature increases, carbon monoxide gas forms inside the container and, being unable to escape, combines with the gamma iron in the surface of the steel. The depth to which the carbon penetrates depends on the length of the soaking period. For example, when carbon steel is soaked for 8 hours, the carbon penetrates to a depth of about 0.062 inch.

In another method of carburizing, called "gas carburizing," a material rich in carbon is introduced into the furnace atmosphere. The carburizing atmosphere is produced by the use of various gases or by the burning of oil, wood, or other materials. When the steel parts are heated in this atmosphere, carbon monoxide combines with the gamma iron to produce practically the same results as those described under the pack-carburizing process.

A third method of carburizing is that of "liquid carburizing." In this method the steel is placed in a molten salt bath that contains the chemicals required to produce a case comparable with one resulting from pack or gas carburizing.

Alloy steels with low-carbon content as well as low-carbon steels may be carburized by either of the three processes. However, some alloys, such as nickel, tend to retard the absorption of carbon. As a result, the time required to produce a given thickness of case varies with the composition of the metal.

Nitriding

Nitriding is unlike other casehardening processes in that, before nitriding, the part is heat treated to produce definite physical properties. Thus, parts are hardened and tempered before being nitrided. Most steels can be nitrided, but special alloys are required for best results. These special alloys contain aluminum as one of the alloying elements and are called "nitralloys."

In nitriding, the part is placed in a special nitriding furnace and heated to a temperature of approximately 1,000° F. With the part at this temperature, ammonia gas is circulated within the specially constructed furnace chamber. The high temperature cracks the ammonia gas into nitrogen and hydrogen. The ammonia which does not break down is caught in a water trap below the regions of the other two gases. The nitrogen reacts with the iron to form nitride. The iron nitride is dispersed in minute particles at the surface and works inward. The depth of penetration depends on the length of the treament. In nitriding, soaking periods as long as 72 hours are frequently required to produce the desired thickness of case.

Nitriding can be accomplished with a minimum of distortion, because of the low temperature at which parts are casehardened and because no quenching is required after exposure to the ammonia gas.

HEAT TREATMENT OF NONFERROUS METALS

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 4 days of aging at room temperature. Other alloys, such as 2014 and 7075, require both heat treatments.

The alloys that require precipitation heat treatment (artificial aging) to develop their full strength also age to a limited extent at room temperature; the rate and amount of strengthening depends upon the alloy. Some reach their maximum natural or room-temperature aging strength in a few days, and are designated as −T4 or −T3 temper. Others continue to age appreciably over a long period of time. Because of this natural aging, the −W designation is specified only when the period of aging is indicated, for example, 7075-W (½ hour). Thus, there is considerable difference in the mechanical and physical properties of freshly quenched (−W) material and material that is in the −T3 or −T4 temper.

The hardening of an aluminum alloy by heat treatment consists of four distinct steps:

1. Heating to a predetermined temperature.
2. Soaking at temperature for a specified length of time.
3. Rapidly quenching to a relatively low temperature.
4. Aging or precipitation hardening either spontaneously at room temperature, or as a result of a low-temperature thermal treatment.

The first three steps above are known as solution heat treatment, although it has become common practice to use the shorter term, "heat treatment". Room-temperature hardening is known as natural aging, while hardening done at moderate temperatures is called artificial aging, or precipitation heat treatment.

SOLUTION HEAT TREATMENT

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°) 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 1 hour for each inch of cross-sectional thickness (see figure 6–66).

The soaking time is chosen so that it will be the minimum 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 into 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 re-precipitation. Three distinct quenching methods are employed. 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

Thickness, in.	Time, Minutes
Up to .032	30
.032 to 1/8	30
1/8 to 1/4	40
Over 1/4	60

NOTES: Soaking time starts when the metal (or the molten bath) reaches a temperature within the range specified above.

FIGURE 6–66. Typical soaking times for heat treatment.

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 which 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 for 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 re-precipitation 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.

Re-heat Treatment

The treatment of material which has been previously heat treated is considered a re-heat 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 re-heating. Existing specifications allow one to three re-heat treatments of clad sheet depending upon cladding thickness.

Straightening After Solution Heat Treatment

Some warping occurs during solution heat treatment, 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.

The strengthening of the heat-treatable alloys by aging is not due merely to the presence of a precipitate. The strength is due to both the uniform distribution of a finely dispersed submicro-

Alloy	Solution heat-treatment			Precipitation heat-treatment		
	Temp., °F	Quench	Temper desig.	Temp., °F	Time of aging	Temper desig.
2017	930-950	Cold water	T4			T
2117	930-950	Cold water	T4			T
2024	910-930	Cold water	T4			T
6053	960-980	Water	T4	445-455	1-2 hr	T5
				or		
				345-355	8 hr	T6
6061	960-980	Water	T4	315-325	18 hr	T6
				or		
				345-355	8 hr	T6
7075	870	Water		250	24 hr	T6

FIGURE 6–67. Conditions for heat treatment of aluminum alloys.

scopic precipitate and its effects upon the crystal structure of the alloy.

The aging practices used depend upon many properties other than strength. As a rule, the artificially aged alloys are slightly overaged to increase their resistance to corrosion. This is especially true with the artificially aged high-copper-content alloys that are susceptible to intergranular corrosion when inadequately aged.

The heat-treatable aluminum alloys are subdivided into two classes, those that obtain their full strength at room temperature and those that require artificial aging.

The alloys that obtain their full strength after 4 or 5 days at room temperature are known as natural aging alloys. Precipitation from the supersaturated solid solution starts soon after quenching, with 90 percent of the maximum strength generally being obtained in 24 hours. Alloys 2017 and 2024 are natural aging alloys.

The alloys that require precipitation thermal treatment to develop their full strength are artificially aged alloys. However, these alloys also age a limited amount at room temperature, the rate and extent of the strengthening depending upon the alloys.

Many of the artificially aged alloys reach their maximum natural or room temperature aging strengths after a few days. These can be stocked for fabrication in the −T4 or −T3 temper. High-zinc-content alloys such as 7075 continue to age appreciably over a long period of time, their mechanical property changes being sufficient to reduce their formability.

The advantage of −W temper formability can be utilized, however, in the same manner as with natural aging alloys; that is, by fabricating shortly after solution heat treatment, or retaining formability by the use of refrigeration.

Refrigeration retards the rate of natural aging. At 32° F., the beginning of the aging process is delayed for several hours, while dry ice (−50° F. to −100° F.) retards aging for an extended period of time.

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. (See figure 6–67.)

The time at temperature is dependent upon the temperature used, the properties desired, and the alloy. It ranges from 8 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.

HEAT TREATMENT OF ALUMINUM ALLOY RIVETS

Aluminum alloy rivets are furnished in the following compositions: Alloys 1100, 5056, 2117, 2017, and 2024.

Alloy 1100 rivets are used in the "as fabricated" condition for riveting aluminum alloy sheets where a low-strength rivet is suitable. Alloy 5056 rivets are used in the "as fabricated" condition for riveting magnesium alloy sheets.

Alloy 2117 rivets have moderately high strength and are suitable for riveting aluminum alloy sheets. These rivets receive only one heat treatment, which is performed by the manufacturer, and are anodized after being heat treated. They require no further heat treatment before they are used. Alloy 2117 rivets retain their characteristics indefinitely after heat treatment and can be driven anytime. Rivets made of this alloy are the most widely used in aircraft construction.

Alloy 2017 and 2024 rivets are high-strength rivets suitable for use with aluminum alloy structures. They are purchased from the manufacturer in the heat-treated condition. Since the aging characteristics of these alloys at room temperatures are such that the rivets are unfit for driving, they must be re-heat treated just before they are to be used. Alloy 2017 rivets become too hard for driving in approximately 1 hour after quenching. Alloy 2024 rivets become hardened in 10 minutes after quenching. Both of these alloys may be re-heat treated as often as required; however, they must be anodized before the first re-heat treatment to prevent intergranular oxidation of the material. If these rivets are stored in a refrigerator at a temperature lower than 32° F. immediately after quenching, they will remain soft enough to be usable for several days.

Rivets requiring heat treatment are heated either in tubular containers in a salt bath, or in small screen-wire baskets in an air furnace. The heat treatment of alloy 2017 rivets consists of subjecting the rivets to a temperature between 930° F. to 950° F. for approximately 30 minutes, and immediately quenching in cold water. These rivets reach maximum strength in about 9 days after being driven. Alloy 2024 rivets should be heated to a temperature of 910° F. to 930° F. and immediately quenched in cold water. These rivets develop a greater shear strength than 2017 rivets and are used in locations where extra strength is required. Alloy 2024 rivets develop their maximum shear strength in 1 day after being driven.

The 2017 rivet should be driven within approximately 1 hour and the 2024 rivet within 10 to 20 minutes after heat treating or removal from refrigeration. If not used within these times, the rivets should be re-heat treated before being refrigerated.

HEAT TREATMENT OF MAGNESIUM ALLOYS

Magnesium alloy castings respond readily to heat treatment, and about 95 percent of the magnesium used in aircraft 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 and (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 heat-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. 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 2 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. For this reason, the furnace used should be equipped with a safety cutoff that will turn off the power to the heating elements and blowers if the regular control equipment malfunctions or fails.

Some magnesium alloys require a protective atmosphere of sulfur dioxide gas during solution heat treatment. This aids in preventing the start of a fire even if the temperature limits are slightly exceeded.

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 4 to 18 hours.

HEAT TREATMENT OF TITANIUM

Titanium is heat treated for the following purposes:

1. Relief of stresses set up during cold forming or machining.
2. Annealing after hot working or cold working, or to provide maximum ductility for subsequent cold working.
3. 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 which 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 room temperature or slightly above.

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 anneal 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 1 hour, followed by an air cool. A full anneal 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 aircraft 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 re-heating to 900° F. for 8 hours is recommended.

Casehardening

The chemical activity of titanium and its rapid absorption of oxygen, nitrogen, and carbon at relatively low temperatures make casehardening 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.

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 of which are described and illustrated in this section. Also included is a popular portable-type hardness tester currently being used.

Brinell Tester

The Brinell tester (figure 6–68) 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 gage 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.

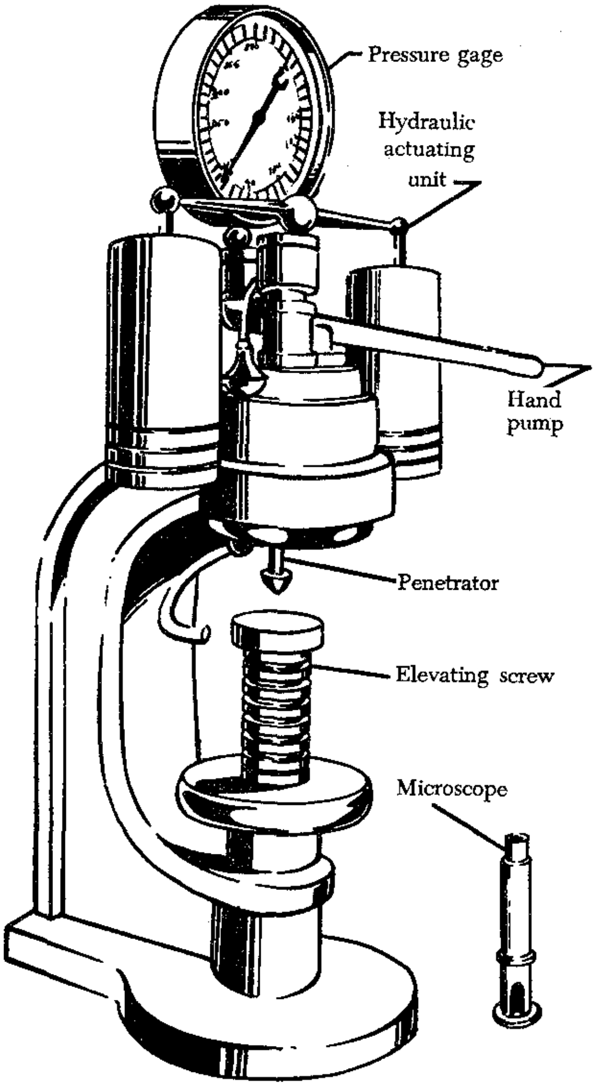


FIGURE 6–68. Brinell hardness tester.

Rockwell Tester

The Rockwell hardness tester (figure 6–69) 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

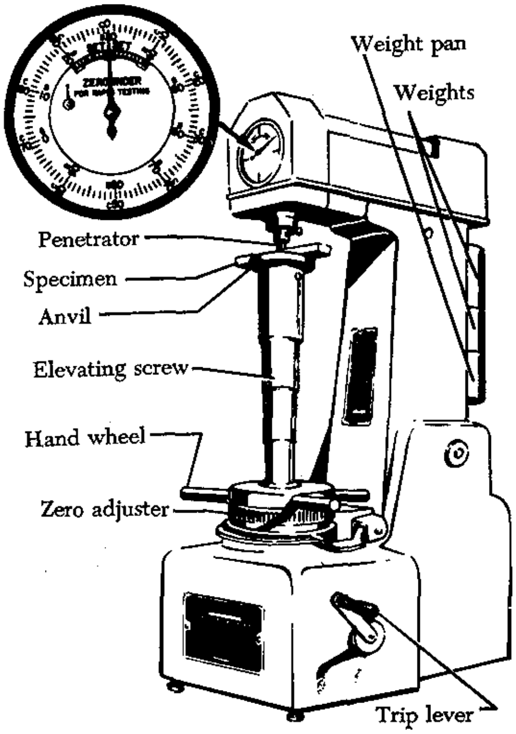


FIGURE 6–69. Rockwell hardness tester.

this difference, 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 which 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

For hardened steels, the diamond penetrator is used; the major load is 150 kilograms; and the hardness is read on the "C" scale. When this reading is recorded, the letter "C" must precede the number indicated by the pointer. The C-scale setup is used for testing metals ranging in hardness from C-20 to the hardest steel (usually about C-70). If the metal is softer than C-20, the B-scale setup is used. With this setup, the $\frac{1}{16}$-inch ball is used as a penetrator; the major load is 100 kilograms; and the hardness is read on the B-scale.

In addition to the "C" and "B" scales, there are other setups for special testing. The scales, penetrators, major loads, and dial numbers to be read are listed in figure 6-70.

Scale symbol	Penetrator	Major load (kg.)	Dial number
A	Diamond	60	Black
B	$\frac{1}{16}$-inch ball	100	Red
C	Diamond	150	Black
D	Diamond	100	Black
E	$\frac{1}{8}$-inch ball	100	Red
F	$\frac{1}{16}$-inch ball	60	Red
G	$\frac{1}{16}$-inch ball	150	Red
H	$\frac{1}{8}$-inch ball	60	Red
K	$\frac{1}{8}$-inch ball	150	Red

FIGURE 6–70. Standard Rockwell hardness scales.

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.

Practically all testing is done with either the B-scale setup or the C-scale setup. For these scales, the colors may be used as a guide in selecting the weight (or weights) and in reading the dial. For the B-scale test, use the red weight and read the red numbers. For a C-scale test, add the black weight to the red weight and read the black numbers.

In setting up the Rockwell machine, use the diamond penetrator for testing materials known to be hard. If the hardness is unknown, try the diamond, since the steel ball may be deformed if used for testing hard materials. If the metal tests below C-22, then change to the steel ball.

Use the steel ball for all soft materials, those testing less than B-100. Should an overlap occur at the top of the B-scale and the bottom of the C-scale, use the C-scale setup.

Before the major load is applied, the test specimen must be securely locked in place to prevent slipping and to seat the anvil and penetrator properly. To do this, a load of 10 kilograms is applied before the lever is tripped. This preliminary load is called the minor load. The minor load is 10 kilograms regardless of the scale setup.

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 (figure 6-71) is a portable unit designed for testing aluminum alloys, copper, brass, or other relatively soft materials. It should not be used on aircraft steels. 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.

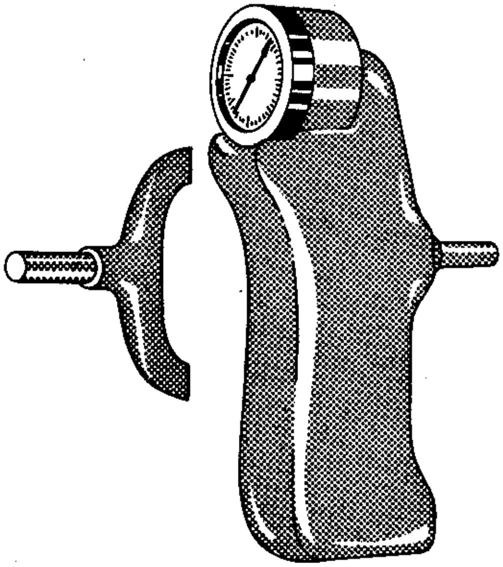


FIGURE 6–71. Barcol portable hardness tester.

Alloy and temper	Barcol number
1100-O	35
3003-O	42
3003-H14	56
2024-O	60
5052-O	62
5052-H34	75
6061-T	78
2024-T	85

FIGURE 6–72. Typical Barcol readings for aluminum alloy.

The design of the Barcol tester is such that operating experience is not necessary. It is only necessary to exert a light pressuse against the instrument to drive the spring-loaded indenter into the material to be tested. The hardness reading is instantly indicated on the dial.

Several typical readings for aluminum alloys are listed in figure 6-72. Note that the harder the material is, the higher the Barcol number will be.

To prevent damage to the point, avoid sliding or scraping when it is in contact with the material being tested. If the point should become damaged, it must be replaced with a new one. No attempt should be made to grind the point.

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.