

HEAT TREATING

www.plansforu.com

HEAT TREATMENT OF ALUMINUM ALLOYS



PREPARED BY
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.

Nº 2394

20

PROPERTY OF THE
BUREAU of AERONAUTICS
Manufacturing Operations Section
NAVY DEPARTMENT—WASHINGTON, D.C.

UNAUTHORIZED CIRCULATION OF THIS PAMPHLET
BY ANYONE IS PROHIBITED

HEAT-TREATMENT OF ALUMINUM ALLOYS

EQUIPMENT AND PRACTICE

THEORY OF HEAT-TREATMENT

1. Types of Aluminum Alloys.—The wrought aluminum alloys used in aircraft construction are of two general types: (1) Those alloys in which the harder tempers are produced by strain-hardening, or cold working; and (2) the heat-treatable alloys, which respond to thermal treatments to improve their mechanical properties. Alloys of the first type are *2S*, *3S*, and *52S*, and those of the second type are *17S*, *24S*, *53S*, and *61S*.

When severe forming is necessary, both types of alloys may be annealed to reduce the hardness resulting from either strain-hardening or previous heat-treatment. After fabrication, alloys of the second type are heat-treated to improve their strength, hardness, and resistance to corrosion. These alloys are never used in the annealed condition because of their inferior mechanical properties in that temper.

2. Crystalline Nature of Aluminum Alloys.—Aluminum and aluminum alloys, like other metals, are crystalline in their solid state. As metal cools, crystallization starts from many points in the liquid, but first from the exposed or contact surfaces. All these crystals have the same form, but may be turned with respect to each other, so that they will not fit together, and they therefore interfere with the growth of each other and limit their sizes. While all the addition of metal to the original nucleus takes place in the form of minute crystals of the regular pattern, growth may be stopped, because of interference from other groups, in certain directions sooner than in others. The group as a whole may then be irregular in shape, and turned, or oriented, at a different angle or direction from adjoining groups. These irregularly-shaped, polyhedral groups are called

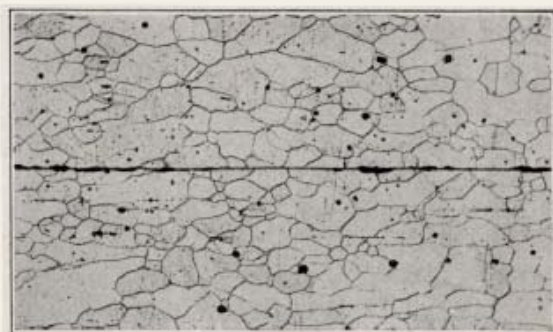


FIG. 1



FIG. 2

grains, which are visible with a microscope. The crystals forming the grains cannot be seen, since they are submicroscopic in size.

3. The grain structure of annealed aluminum sheet, 2SO, is shown in the 100x photomicrograph (magnification 100 times) in Fig. 1. The specimen was etched with a .5-per cent solution of hydrofluoric acid to bring out the condition of the structure. The varied shapes of the grains are shown by the dark grain boundaries. The small dark particles consist mostly of the iron-aluminum compound, $FeAl_3$. The horizontal line is the junction between two separate pieces of sheet.

www.plansforu.com

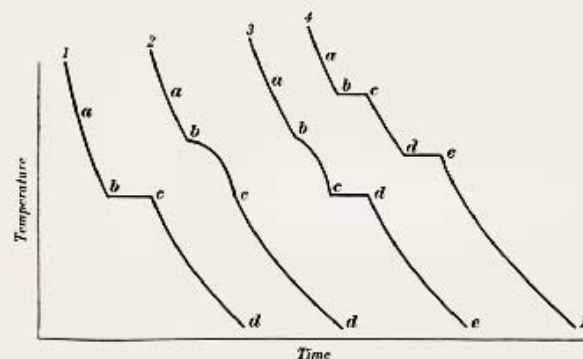


FIG. 3

By cold rolling, the sheet can be strain, or work, hardened. In this condition, as shown in the 100x photomicrograph in Fig. 2, the individual grains have been elongated and are no longer distinguishable, and the dark impurities have collected in the elongated areas. The tensile strength has been increased from 13,000 pounds per square inch for 2SO, to 24,000 pounds per square inch for 2SH.

4. **Cooling Curves.**—A metal, when pure, solidifies at a fixed temperature; whereas, an alloy may solidify either at a fixed temperature or over a range of temperatures. The cooling curves in Fig. 3 illustrate what may happen when a metal or an alloy passes from the liquid to the solid state. Curve 1 represents liquid cooling along the line ab , freezing at a constant temperature along bc as a pure metal or as a eutectic mixture, and cooling as a solid along cd . A eutectic mixture is the mixture resulting from the solidification of the lowest-freezing solution of two metals that are soluble in the liquid state and insoluble in the solid state. When the metals solidify, or freeze, a complete separation occurs and certain constituents, which depend on the proportions of the two metals, crystallize out first and leave a solution that has the lowest freezing point that can be made of all the liquid solutions of the two metals. If the original solution had the right proportions, it would solidify as

a eutectic mixture. Instead of two pure metals, the constituents of the eutectic may be solid solutions, chemical compounds, or a combination of any two.

5. Curve 2, Fig. 3, shows cooling as a liquid along ab , freezing along bc , such as would occur in a solid solution, and cooling as a solid along cd . Curve 3 shows liquid cooling along ab , gradual freezing of one constituent along bc , such as occurs when two metals are soluble in the liquid state but insoluble in the solid state, freezing of the remaining metal or eutectic mixture along cd at a constant temperature, and cooling of the solid along de . Curve 4 shows cooling of two metals completely insoluble in each other both as liquids and as solids. ab is cooling of the liquid mixture, bc freezing of the metal having the higher melting point, cd cooling of the liquid and solid mixture, de freezing of the second metal, and ef cooling of the solid mixture.

6. **Equilibrium Diagram.**—After the cooling curves for two metals soluble in the liquid state and partly soluble in the solid state have been drawn, as in Fig. 3, the corresponding points on the curves may be connected by lines to produce an equilibrium diagram, such as shown in Fig. 4. Whereas in Fig. 3 the temperature is plotted against the time, in Fig. 4 the temperature is plotted against the varying percentages of the two metals. The line abc joining the freezing points a and c of metals A and B , respectively, to the freezing point b of the eutectic is called the *liquidus*. The line $adbe$ joining the points at which complete solidification takes place is called the *solidus*. At temperatures above the liquidus line any composition of alloy is in a liquid state; whereas at temperatures below the solidus all constituents are solid. Between the liquidus and solidus both liquids and solids are present to give a mushy stage in the freezing or melting of alloys.

7. When an alloy cools from a temperature such as f , Fig. 4, solidification starts at point g on the liquidus, and the solid separating out is a solid solution of the two metals having a

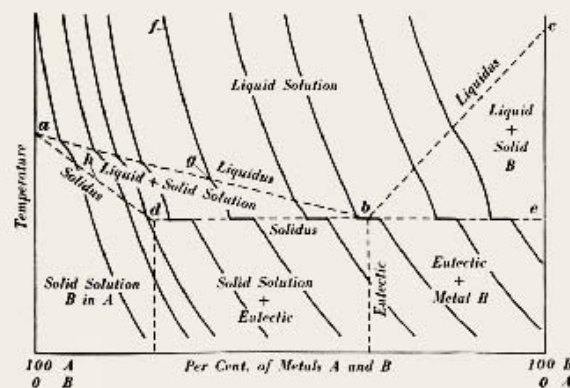


FIG. 4

composition represented by the point h on the solidus horizontally opposite the point g on the liquidus. As the metal continues to cool, more of the solid solution separates out along the line ad , with the percentage of metal B increasing to the composition d . However, since the solid solution has a smaller percentage of metal B than had the original liquid solution, the liquid increases in metal B until the composition b is reached. At that point all the remaining liquid solidifies as a eutectic mixture. Thus the final solid is a mixture of a solid solution and the eutectic. If the composition of the original solution had been within the range from a to d , that is, mostly of metal A , the resulting solid would have been all solid solution. If the composition had been greater than b , that is, mostly of metal B , the solid would have been a mixture of metal B and the eutectic. The conditions of the various phases are shown on the illustration.

8. **Theory of Solution and Precipitation Treatments.**—The heat-treatment of aluminum alloys consists of two steps, the solution and the precipitation heat-treatments, and can be understood readily by reference to Fig. 5, in which is shown the equilibrium diagram for aluminum-copper alloys, as originated by Stockdale, Dix, and Richardson. The diagram in the lower

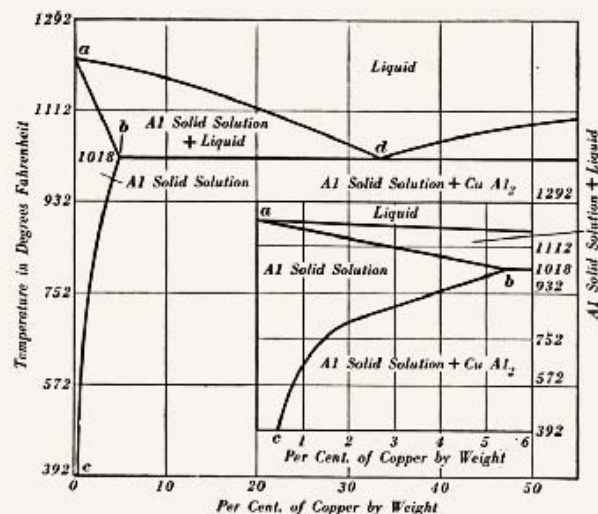


FIG. 5

right-hand corner of the large diagram is the upper left-hand section of the large diagram, drawn with a smaller scale for the temperature and a larger scale for the percentage of copper.

In the liquid condition aluminum and copper are completely soluble in each other. If the alloy contains less copper than indicated by point *b*, it solidifies as a solid solution of copper, in the form of CuAl_2 , and aluminum. At 1,018° F., which is the freezing point for the eutectic formed at point *d* by aluminum and CuAl_2 , about 5½ per cent of copper as CuAl_2 is soluble in aluminum; whereas, only about .5 per cent remains in solution when slowly cooled to the point *c* or on down to room temperature. The remaining CuAl_2 precipitates out along the line *bc*. By rapid cooling, however, the separation may be prevented and the CuAl_2 retained in solution down to room temperature. If such a structure stands at room temperature or is reheated, the CuAl_2 precipitates out of solution in a finely dispersed or scattered form. In this condition the particles act as keys and interfere with slippage along the crystallographic slip planes, thus increasing the hardness and strength of the alloy.

www.plansforu.com

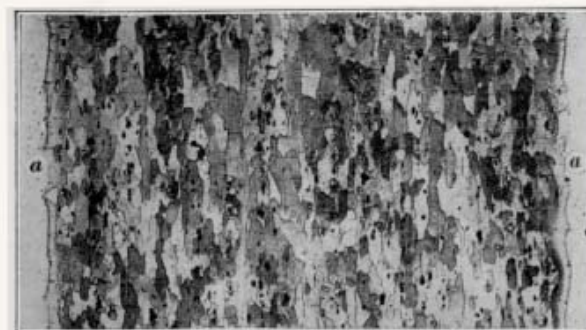


FIG. 6

9. If the CuAl_2 particles are large, which is their condition before heat-treatment, many of the slip planes would not be keyed. Therefore, the first step in heat-treating aluminum alloys consists in heating and rapid cooling to put the large particles of CuAl_2 into solution; this operation is known as the solution heat-treatment. The next step, involving precipitation of the fine particles of CuAl_2 , is known as aging when carried out at room temperature, and as artificial aging or the precipitation heat-treatment, when carried out at elevated temperatures. The alloys 1750 and 2450, after solution heat-treatment, age at room temperature to attain the 17ST and 24ST conditions.

10. The alloys 53S and 61S, when heated and quenched, age slowly and incompletely at room temperature and require artificial aging to attain their fully heat-treated temper. In the quenched condition the latter alloys are designated as 53SW and 61SW, and when artificially aged as 53ST and 61ST. Since 53S contains no copper and 61S only a small percentage, but both contain magnesium and silicon, the hardening of these alloys is the result of the precipitation of Mg_2Si particles from solid solution, just as in the case of CuAl_2 particles in 17S and 24S.

11. **Microstructure of Heat-Treated Dural.**—The microstructure of heat-treated dural is shown in the center section of the 100x photomicrograph in Fig. 6, which is a cross-section

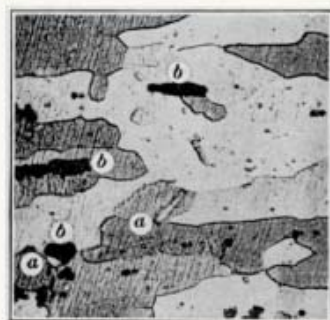


FIG. 7

of Alclad sheet having the aluminum coating *a*. At higher magnification, as shown by the 500x photomicrograph in Fig. 7, the constituents of the dural can be identified. Both photomicrographs were etched for 15 seconds in Keller's etch, composed of 1 per cent of concentrated hydrofluoric acid, 1½ per cent of concentrated hydrochloric acid, 2½ per cent of concentrated nitric acid, and 95 per cent of water. The structure is a solid solution, with white particles *a* of CuAl_2 and black particles *b* of the aluminum-copper-iron-manganese constituent. The variation in color from white to gray, by which the individual grains are distinguished, is the result of the variation in orientation and in concentration of copper atoms of the crystallographic planes exposed by etching. This microstructure is identical with that before aging has taken place. The few relatively large particles *a* of CuAl_2 were present in the same form before aging and cause little hardness. The precipitate of CuAl_2 that comes out of solution during aging and causes the increased hardness and strength of the alloy, is submicroscopic in size and cannot be seen or identified in the photomicrograph.

12. Theory of Annealing.—When annealed aluminum alloys are required by an aircraft manufacturer, they are bought in that condition. Material that has been strain-hardened however during forming, and requires still further forming must be annealed to reduce its hardness. The hardness caused by cold

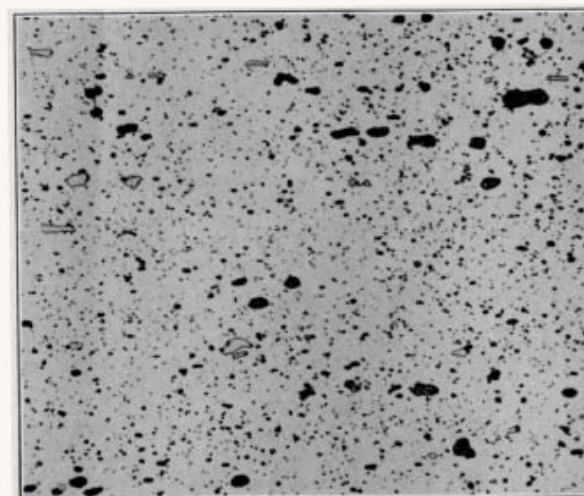


FIG. 8

working is regarded as the result of the deformation of the metallic structure and grain boundaries. The material is softened by heating it above a certain temperature, known as the recrystallization temperature, in order to replace the distorted structure by one having equiaxed, polygonal grains. Heating the metal below the recrystallization temperature causes no apparent change in the microstructure.

After annealing, the metal may be cooled at any rate. In the case of strain-hardened, heat-treatable alloys, the annealing temperature must be above the recrystallization temperature, but is kept as low as possible to avoid heat-treatment effects that would prevent complete softening of the alloy; otherwise, the cooling rate must be slow to counteract the effect of such heating by allowing the alloying constituents to precipitate out in large particles. When the heat-treatable alloys are annealed to reduce the hardness of a previous heat-treatment, they are heated to a somewhat higher temperature in order to bring the small particles of alloying constituents into solution, and are then cooled slowly to allow precipitation of large particles. This condition is shown in the 500x photomicrograph, Fig. 8.

HEAT-TREATING EQUIPMENT

13. Types of Heating Furnaces.—Two types of heating furnaces, the salt bath and the air furnace, are used for the heat-treatment of aluminum alloys. Salt baths may be heated by electricity, gas, or oil. Because of longer tank life, better working conditions, and less fire hazard resulting from decomposition of the salt in contact with hot spots caused by flame impingement, the electrical heating of salt baths is often preferred to fuel firing. In air furnaces the air is heated by electricity or gas, and is circulated by fans throughout the charge. Gas-fired air furnaces should be of the muffle type to prevent any contact of the parts with the products of combustion, and should be properly baffled and provided with means for recirculation of the air. Both types of furnaces should be regulated with automatic temperature controls that can maintain the temperature of the furnace within the comparatively narrow limits required for aluminum alloys. The pyrometers should be of the automatic and recording type, and should be checked at least once each month by calibrated pyrometers of known accuracy.

14. Salt Baths.—Salt baths are usually composed of molten sodium nitrate or equal parts of molten sodium and potassium nitrates. A bath consisting only of sodium nitrate is less stable and has a greater corrosive effect on the tank and the parts than the mixture of nitrates. When heat-treating only is to be done in a salt bath, sodium nitrate is satisfactory. When aluminum-alloy parts are to be annealed in a salt bath, however, a mixture of nitrates must be used, since the melting point of sodium nitrate alone is too high for annealing purposes. A bath of equal parts of sodium and potassium nitrates is molten at temperatures below the annealing temperatures, and is recommended for general use.

Either type of bath provides uniform heating, protection against oxidation, and faster heat transfer than is possible with an air furnace because of the high heat capacity of the salt. The saving in time, however, may be offset by the greater distortion resulting from the rapid and progressive changing in tempera-

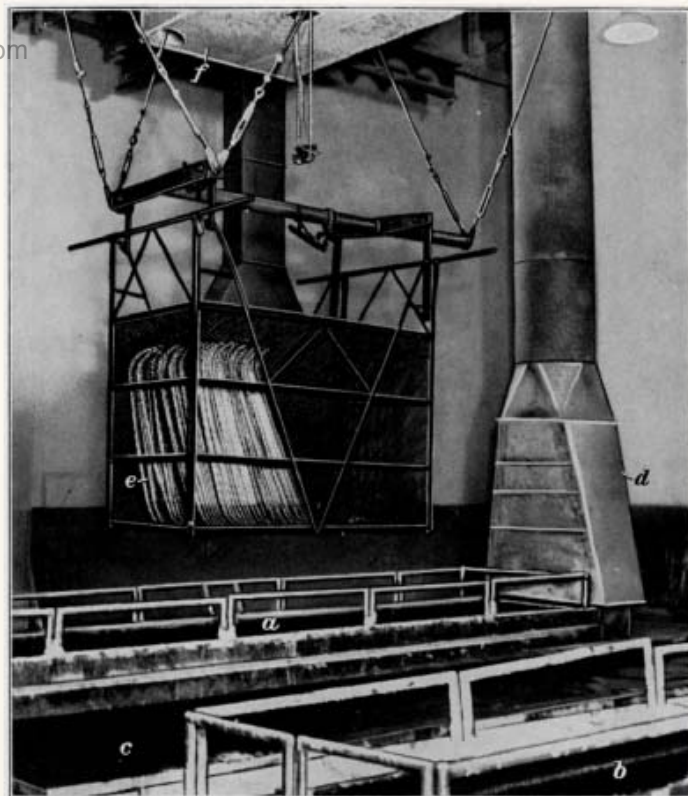


FIG. 9

ture of the parts. Since an appreciable percentage of the distortion that occurs during heat-treatment is supposed to take place when the parts are first charged into the furnace, distortion, especially of large parts, is considerably less with air furnaces because of the slower heating. The rapidity with which the charge is brought up to the heat-treating temperature in a salt bath is advantageous when Alclad sheet is being treated, since the shorter period in the furnace reduces diffusion of the alloying constituents of the core into the aluminum coating, and the consequent loss in corrosion resistance.

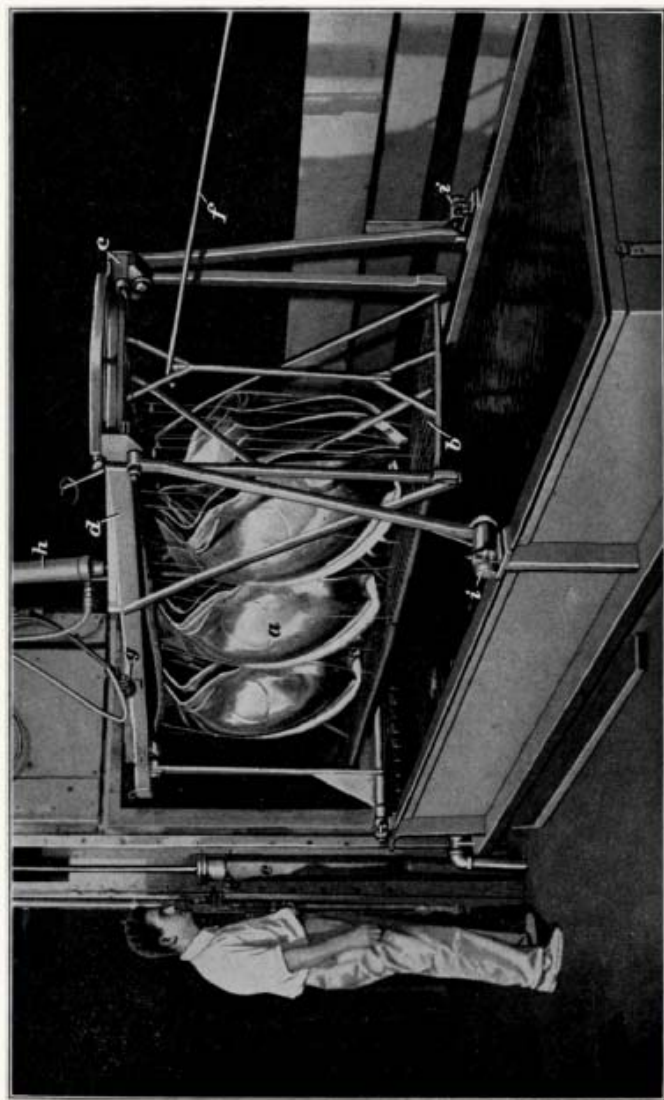


FIG. 10

15. Salt-Bath Furnaces.—A typical installation of a salt-bath furnace is shown in Fig. 9. The two end tanks *a* and *b* contain sodium nitrate and the middle tank *c* contains the quenching water. The salt baths are heated by gas burners, which are located beneath the floor level at the near end of each tank. The products of combustion from the burners pass through tubes running lengthwise through the tanks, and then out through stacks *d* at the end of each tank. By this arrangement a uniform temperature can be maintained throughout the bath. On some installations, the tanks containing the molten salt are provided with covers to reduce the heat loss and to improve working conditions.

The parts can be hung in the molten salt by wires suspended from rods laid across the tank, or they may be placed in racks and immersed. In the former case, the parts may be charged progressively from one end of the bath to the other, and quenched in the same progression without objectionable variation in the temperature of the bath. Since both charging and quenching are done by hand, the method is flexible and permits individual treatment in that the contour of the stock can be followed in the quenching operation in order to lessen distortion. When the charge consists of many small parts, such as spacers, washers, or clips, they may be placed in capped metal cylinders and suspended in the bath in order to avoid direct contact with the molten salt. They may then be quenched by pouring them into perforated or wire containers in the quench tank.

16. For a great number of fairly large parts, stacking them in racks, as at *e*, Fig. 9, is more convenient. Enough space should be maintained between adjacent parts to permit free circulation of the molten salt. The racks are handled by overhead cranes. The crane *f* in this case is operated by a pendant push-button control that provides vertical, lengthwise, and crosswise motion. If desired, automatic control is available whereby the rack can be lifted from the salt, moved crosswise over the quench tank, and lowered into the water. This means of transferring the parts from the bath to the quench tank, however, is slow and undesirable for parts that are to have maximum cor-

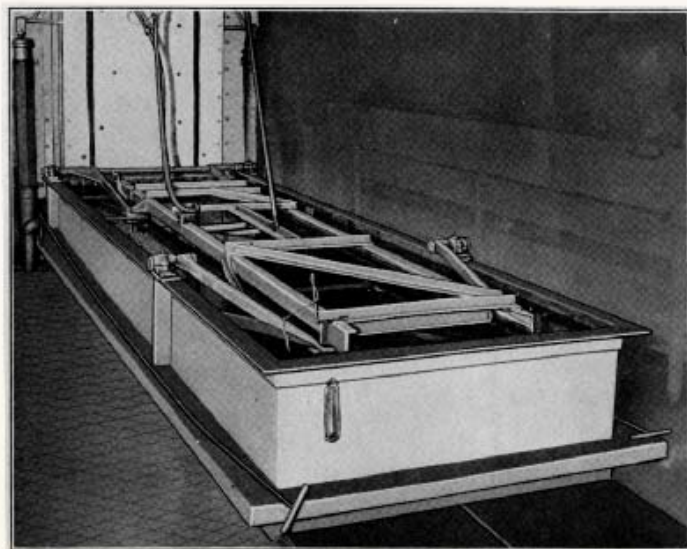


FIG. 11

rosion resistance. After the quench, the parts still contained in the rack, are rinsed in a separate tank of water to remove any adhering salt.

17. Electric Air Furnace.—An air furnace that is electrically heated and provided with a quick-quenching arrangement is shown in Fig. 10. Air is circulated by a fan past strip heating elements on the sides and top of the furnace, and then over the charge. A shield made of concrete, 2 inches thick, is placed in front of the elements to protect them from damage by the work rack or charge and to provide a duct for air circulation.

The parts *a* are suspended by wires in the rack *b* and are well separated in order to permit free circulation of the air between them. The work rack *b* has small wheels *c* that run in the channels *d* of the framework attached to the quench tank. These channels in the position shown are in line with channels fastened to the top of the furnace. Charging can be accomplished readily by running the rack along the framework and thence into the furnace. After the charge has been heated for the required

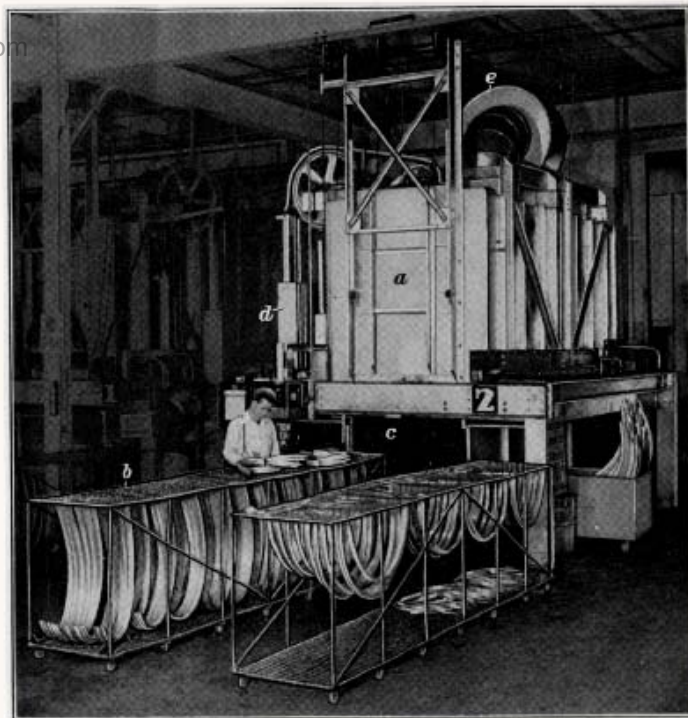


FIG. 12

period of time, the door is raised pneumatically by means of an air cylinder *e*, the channels *d* are alined with the channels in the furnace, and the rack is pulled out rapidly by a long hook *f*. As the rack moves out, it strikes and releases an air valve at *g* that is in the air line leading to the cylinder *h*, thereby allowing the framework to swing forward around its trunnions *i* and immerse the work rack and parts in the quenching water, as shown in Fig. 11. This arrangement permits a very rapid quench, approximately 5 seconds elapsing between the opening of the furnace door and the immersion of the charge.

18. Vertical Air Furnace.—The vertical air furnace shown in Fig. 12 is constructed so that the heating chamber *a* is directly

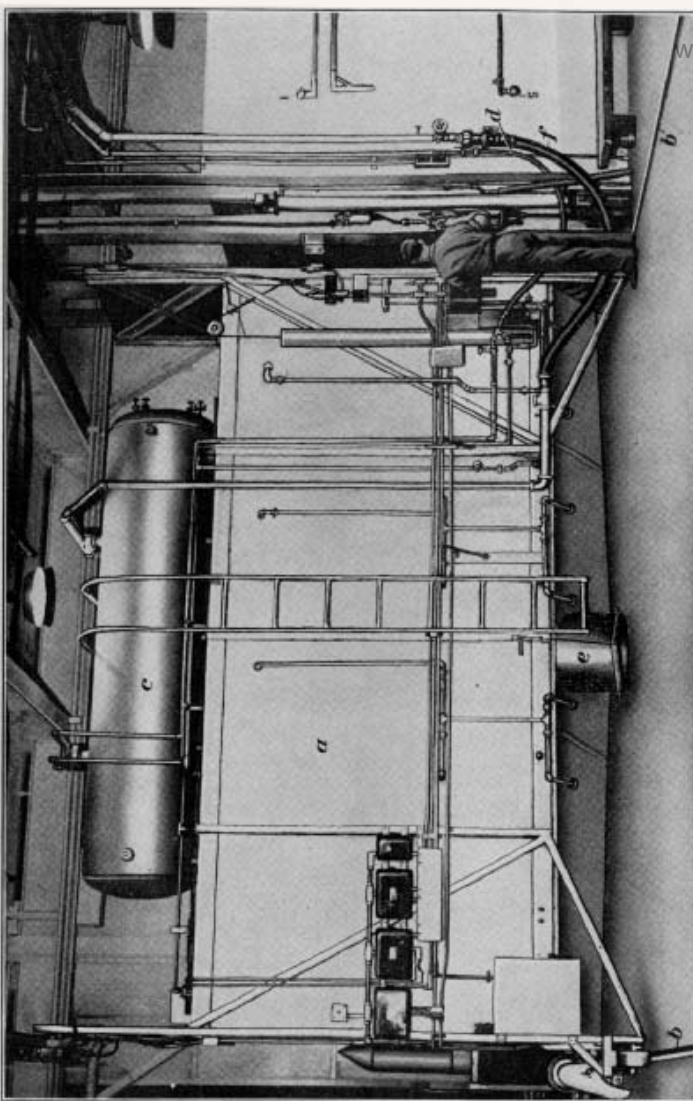


FIG. 13

over the quench tank, and the heated parts can be dropped into the water within a few seconds after leaving the furnace. The parts are loaded and rigidly wired on a work rack *b*, which is wheeled on tracks into a cage, or elevator, that is protected by side baffles *c* from air currents during the quench. The cage is hoisted into the furnace by a cable running over a set of pulleys to a pneumatic cylinder at one side of the furnace, counterweights *d* being provided to balance the weight of the cage and charge. The furnace is electrically heated, has a forced air circulation from a fan *e* on top of the furnace, and is entirely closed except for bottom doors that are opened and closed by pneumatic cylinders. When the doors are moved to their inward, or closed, positions, they run upon wedges and are held tightly against the opening.

After the charge is held within the furnace for the required period of time, the bottom doors are opened and the cage is dropped into the quenching tank. Instead of dropping with a splash, the cage slows momentarily at the surface of the water before being plunged, in order to reduce to some extent the severity of the quench and distortion of the parts.

With this type of furnace, as well as other air furnaces, trouble may be experienced from the formation of minute blisters on the surface of bare 24S. Moisture in the air is responsible for this condition. When a suitable chemical, such as Alorco Protective Compound, is placed in the furnace with the load, it will prevent the formation of blisters by volatilizing when heated and forming a protective, gaseous, coating on the surface of the parts.

19. Fog Quench Booth.—Large parts that would warp too badly when tank quenched may be spray or fog quenched with much less distortion. Some plants have an arrangement whereby a quench booth is located at the end of each air furnace. The rack carrying the charge is wheeled in at one end of the furnace, retained within the furnace for the required heating time, and then moved out of the other end of the furnace directly into the quench booth. An installation of this type requires a quench booth for each furnace.

On the installation shown in Fig. 13, however, only one quench booth *a* is needed to serve three furnaces and could be utilized to serve still more if necessary. The booth is mounted on wheels and can be driven by a small electric motor along the tracks *b*, to bring it into quenching position in front of any one of the three furnaces. Once the booth is in position and the door is opened, the operation is automatic. A chain conveyor, which is driven by a second electric motor, is arranged in the booth so as to pull the loaded work rack from the furnace into the booth. The rack travels on tracks provided in both the furnace and booth. An end section of the track within the booth swings downward to meet the track in the furnace and so span the distance between the furnace and the booth.

As soon as the push-button control is actuated, the conveyor moves into the furnace and a panel on the conveyor links with a crossbar on the rack. At that instant, a dog on the conveyor actuates a limit switch which reverses the conveyor and opens the water valve to start the sprays. As soon as the rack is drawn entirely within the booth, a second dog on the conveyor operates another limit switch, which stops the conveyor and closes the door of the quench booth.

20. The parts are sprayed from above, below, and on the sides, with water from the overhead tank *c*, Fig. 13. The water in the tank is under an air pressure of 90 pounds per square inch; an air line *d* leading to the tank maintains the pressure during the quenching cycle. An open pipe *e* at the bottom of the booth empties the water into a floor drain, from which it runs into a sump for reuse. A fan in the exhaust system pulls the water vapor and air through the charge to hasten the quenching effect.

After quenching is completed, the booth is rolled to a point opposite the space between two furnaces and the work rack is unloaded on to a carriage. The booth is then moved to the next furnace that is to be unloaded, and the water tank is refilled by a hose *f* that can be quickly coupled to a water line that leads to the sump.

HEAT-TREATING PROCEDURE

21. **Solution Heat-Treatment.**—Solution heat-treatment of aluminum alloys consists of three steps: heating to a specified temperature; holding, or soaking, at that temperature for the required length of time; and then quenching in water. The heat-treating temperatures, as shown in Table I, differ to some extent for the various alloys. These temperatures should be maintained rigidly within the ranges specified. A temperature that is too low causes an incomplete solution of the CuAl_2 into the aluminum and reduced physical properties; whereas, exceeding the upper limit results in incipient melting of the eutectic at the grain boundaries and serious blistering on the surface of the parts. It may appear that 17S and 24S could be heat-treated together at a temperature of 930° F. Theoretically it may be so, but practically it cannot be done since the pyrometric control of the temperature is not perfect and the temperature throughout the furnace is not uniform.

TABLE I
HEAT-TREATING TEMPERATURES

Material	Temperature in Degrees F.
17S, bare and Alclad	930-950
24S, bare and Alclad	910-930
53S	960-980
61S	960-980

22. **Soaking Period.**—When parts are charged into a furnace, it should be at heat-treating temperature. The temperature will immediately drop as much as 100 degrees or even more, depending on the type of furnace, the size of the charge and work rack, and, with an air furnace, on the time that the furnace door is open. The time required for the furnace temperature to rise again to the specified heat-treating temperature depends not only on the size of the charge, but also on the heating capacity of the bath or air furnace. Longer heating-up periods are required for air furnaces than for salt baths, because the rate of heat transfer in air is slower than in molten salt.

TABLE II
SOAKING PERIOD FOR SOLUTION HEAT-TREATMENT

Thickness of Material Inch	Time in Minutes for Soaking After Bath of Furnace Temperature Has Returned to Specified Value									
	Material in Annealed Condition				Material in Heat-Treated Condition					
	17S and 17S Alclad		24S and 24S Alclad		17S and 17S Alclad		24S and 24S Alclad		52S and 52S Alclad	
	Salt Bath	Air Furnace	Salt Bath	Air Furnace	Salt Bath	Air Furnace	Salt Bath	Air Furnace	Salt Bath	Air Furnace
.020 and less	10	15	15	20	10	10	10	10	15	15
.020 to .032	15	20	20	25	10	10	10	15	15	15
.032 to .063	15	25	25	30	15	15	15	20	15	15
.063 to .125	20	30	30	45	20	20	20	30	20	20
.125 to .250	30	50	45	60	25	30	25	60	30	30
.250 to .500	45	90	60	90	30	60	30	90	45	45
Over .500										

As required by the particular parts involved

www.plansforu.com If the weight of salt in a salt-bath furnace is large compared to the load, as is frequently the case with formed sheet-metal parts, the temperature of the bath may not even fall below the minimum heat-treating temperatures.

The soaking period is determined from the time the heat-treating temperature is reached. Its duration depends on the heating medium, the type of alloy, the previous thermal or mechanical treatment to which the alloy has been subjected, and the size and shape of the parts being treated. The soaking period is not extremely critical, except for Alclad stock, which should be brought up to temperature as quickly as possible and soaked for the shortest possible time. Prolonged heating of Alclad causes diffusion of the alloying constituents of the core into the aluminum coating, with consequent alteration of the composition of the coating material and impairment of the corrosion resistance, especially on light sheets where the clad coating is extremely thin.

23. Characteristic soaking periods for aluminum alloys are given in Table II for salt baths, and for air furnaces with natural air circulation. When furnaces are equipped with forced circulation, the soaking periods are shortened to nearly those recommended for salt baths. The times given are approximate only, and are subject to any adjustments that are necessary to allow for different types of furnaces and classes of work.

As shown in the table, the soaking time increases with the thickness of the part. When a charge includes parts of different thicknesses, whether in separate pieces or in assemblies where members overlap, the entire charge should be soaked for the period required for the greatest thickness. With air furnaces, the thickness differential between parts should be limited so that the soaking time required for the thickest parts is not more than four times the minimum time required for the thinnest parts. When Alclad is being treated, different thicknesses in one charge should be avoided as far as possible, in order to prevent the diffusion of alloying constituents into the clad coating.

The previous thermal treatment also affects the soaking time. When material has previously been heat-treated, the treatment

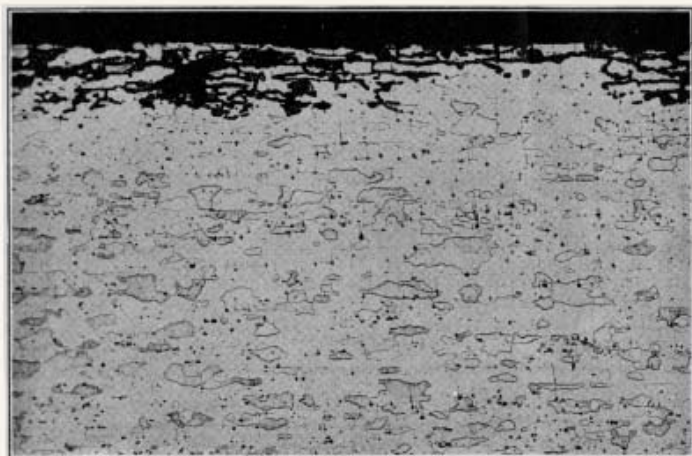


FIG. 14

is actually a reheat-treatment and generally requires a shorter soaking period than annealed material to dissolve all the CuAl_2 . When stock is purchased in the *ST* condition, the first heat-treatment in the aircraft plant is considered as a reheat-treatment.

24. Quenching Practice.—All aluminum-alloy parts after a solution heat-treatment must be quenched from the heat-treating temperature, or from one no lower than 900°F ., by immersion in cold water. The temperature of the quenching water for *17S* and *24S* should be maintained as low as practicable and should not exceed 85°F . at the time of quenching, or 100°F . at any time during the quench. A constant supply of running water is desirable in order to maintain a minimum temperature, and also to prevent a concentration of dissolved salts when the charge is heated in a salt bath. To obtain uniform distribution of temperature throughout the quenching tank, compressed air may be introduced into the water just before the quench is made. For *53S* and *61S* the temperature of the quenching water is not critical, since mild quenching has a negligible effect on the corrosion resistance and mechanical properties of these two alloys.

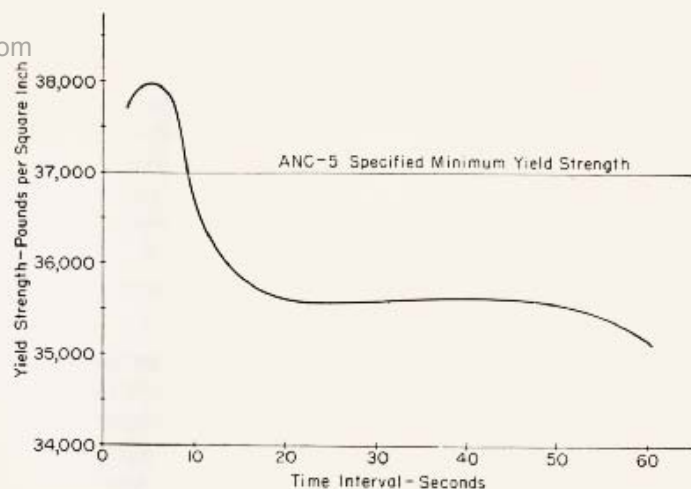


FIG. 15

25. The quenching tank should be located as near as possible to the salt bath or air furnace to avoid delay in transferring the parts to the tank. Any delay of more than a few seconds is detrimental to the effectiveness of the heat treatment, since a slow quench permits precipitation of CuAl_2 particles at the grain boundaries, leading to intergranular corrosion caused by an electrolytic reaction between the copper and aluminum in the presence of salt water. The appearance of intergranular corrosion is shown along the edges of the *24ST* sheet in the 100x photomicrograph in Fig. 14. This type of corrosion may result in serious embrittlement and failure of the part in service, when it is subjected to the severe corrosion conditions that are common for Naval aircraft. The time interval required for the transfer from the furnace to the quenching tank also affects the yield strength of the material. Research, conducted at the Lockheed Aircraft Corporation resulted in the development of the strength-time curve shown in Fig. 15. This curve, obtained from heat-treating .032-inch *24SO* Alclad in a salt bath, and quenching it in water at 70°F ., indicates that the time interval should be about 5 seconds for optimum strength, and must be

less than 9 seconds to obtain physical properties in excess of those specified in ANC-5 "Strength of Aircraft Elements." www.plansforu.com

As a further prevention against corrosion, that is, in addition to keeping the time interval as short as possible, parts that have been heated in salt baths must be thoroughly washed to remove all traces of adhering salt. Any salt allowed to remain on the surface of parts will absorb moisture and hasten corrosion. If rinsing in cold water does not remove the salt, the parts may be rinsed in warm water. Since hot water, over 150° F., accelerates aging, it should not be used, especially if the parts are to be formed before aging and hardening take place.

26. Spray and Fog Quenching.—Since sudden quenching by immersion in cold water has a tendency to warp the material, either spray or fog quenching may be used to reduce the distortion. These methods are similar in that they employ nozzles that direct sprays of water under pressure at the material from all directions. In fog-quenching equipment, however, the nozzles are restricted in size so that the water on issuing from the nozzles will atomize to a fine vapor, or fog. Neither spray nor fog quenching is permissible on parts for Naval aircraft, except on special permission from the Bureau of Aeronautics, because the use of either method reduces the corrosion resistance to salt-water attack. Fog quenching reduces the corrosion resistance to an even greater extent than does spray quenching, because the fine water vapor on striking the parts seems to form over their surface a blanket of steam that delays the quenching effect. Both fog and spray quenching however are used widely on Army and commercial aircraft, which are subject to much less severe corrosive conditions.

27. Prevention of Distortion.—The two general types of distortion that occur during heat-treatment are (1) misalignment such as twisting or bowing, and (2) "oil canning" wherein a portion of a flat part will snap back and forth on application of pressure. Since both types are difficult to eliminate by reworking, their prevention greatly accelerates production.

In general, distortion is caused by non-uniform cooling during quenching. The portion of the heated part that is first quenched

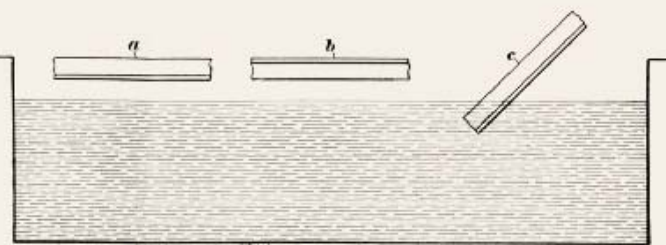


FIG. 16

contracts and plastically deforms the portion cooled last. Since the contraction of the latter portion is restricted by the greater rigidity of the first portion, compressive stresses are set up in the first portion quenched and tensile stresses in the last portion quenched, thereby producing distortion. Any method that produces a more uniform cooling tends to prevent distortion. Thus, in Fig. 16, hat sections are quenched in three positions, with flanges down at *a*, with flanges up at *b*, and at 45 degrees with flanges down at *c*. With this particular part the angular twist was about 45 degrees with method *a*, and 10 degrees with method *b*; whereas with method *c* no angular distortion occurred. The ideal method would have been to quench the part in a vertical position, but the length of the hat section prevented doing so. Even the 45-degree quench however equalized the cooling rate to such an extent that the temperature differential between the flanges and channel was reduced so that no angular distortion took place. The position of the strengthening flanges on the hat section is also important, since the flanges should enter the quench and cool first. This condition should also be observed when loading a rack for spray quenching, as the same effect is caused by the flanges on entering the quenching booth as on entering an immersion quench. Additional precautions that should be observed for the prevention of distortion during spray quenching are to allow sufficient space between the parts, to hang large parts vertical and parallel to the sides of the work rack, and not to place long parts on the bottom of the rack, since they would sag and distort because of the non-uniform support.

28. Age-Hardening.—When parts made of *17S* or *24S* are removed from the quenching water, they begin after a short period to age-harden. At room temperature, 70° F., precipitation of the $CuAl_2$ particles is practically complete in 4 days for *17S* and in 1 day for *24S*, but slight additional changes continue for 10 days or more. The ultimate tensile and yield strengths, as well as the hardness, increase as aging occurs. Thus, *24ST* attains at room temperature approximately one-quarter of its strength in 1 hour, one-half in 2 hours, and practically all in 1 day.

Alloys *53S* and *61S*, after quenching, must be reheated to a temperature of from 315° to 325° F., and held for a period of from 12 to 18 hours to obtain their maximum strength and hardness. This artificial aging is nearly always done in an air furnace, but can be carried out in ovens heated by electricity or steam coils. Whatever equipment is used, it must be capable of a uniform temperature distribution throughout the heating zone. When *53S* and *61S* are used for non-structural parts, such as fillets and fairings, no artificial aging need be done since their maximum strength is not required.

29. Refrigeration of Quenched Parts.—The characteristic of alloys *17S* and *24S* to remain soft for a short period after solution heat-treating, permits forming and straightening operations before the metal age-hardens. Whenever possible, forming should be done on material in the fully heat-treated and aged condition. Most forming of *ST* material is now being done on press brakes, stretch presses, and roll-forming equipment, but is also being applied to hydro-presses to an increasing extent. When forming of material in the *ST* condition is not possible, as on drop hammers, the parts are formed of *SO* stock. During heat-treatment, however, certain parts warp and require reforming after quenching to correct the warpage. Thus, some parts formed on drop hammers may be returned to the hammer and restruck to insure their conforming to the contour of the die.

Since alloys *17S* and *24S* become too hard for forming after aging for approximately an hour, and production conditions make such quick treatment inconvenient, the parts should be

refrigerated to retard age-hardening. The parts will maintain their formability for approximately 24 hours if stored at 32° F. and for longer periods at lower temperatures.

30. Annealing Procedure.—The annealing procedure depends on the alloy and on the purpose of annealing, that is, whether it is done to reduce the hardness resulting from cold working or from previous heat-treatment. Strain-hardening of the unheat-treatable alloys is removed by heating *2S* and *52S* to from 625° to 700° F., and *3S* from 725° to 775° F., and cooling in air immediately after the charge has reached the specified temperature.

The procedure to follow in annealing the heat-treatable alloys depends on whether a partial or a full anneal is desired. For a full anneal for relief of hardness caused by cold working, all the heat-treatable alloys may be heated to a temperature of from 640° to 670° F., and cooled slowly in air. Higher temperatures should be avoided since they produce a hardening effect. Quenching in water is not advisable as it involves danger of distortion.

For a partial anneal for the relief of hardness caused by previous heat-treatment, the same annealing procedure may be used or the alloys may be heated to from 750° to 800° F., and quenched in air or cold water. Either treatment will soften the material so that it is suitable for all except the most severe forming operations.

For a full anneal for the relief of hardness caused by previous heat-treatment, the alloys are heated to from 790° to 810° F., soaked for 2 hours, and cooled at an approximate rate of 50 degrees per hour to 450° F., when the cooling may be more rapid. The slow cooling may be accomplished in the furnace or salt bath, in a heat-insulated chamber, between sheets of asbestos, or by burying in heat-insulating material. If the parts are cooled in a salt bath, they must be removed before the bath begins to freeze. All traces of salt must then be rinsed from the parts. Quenching in water from a temperature below 450° F. may be used to avoid adhering salt, but there is less danger of distortion if the work cools in air. Because of the long soaking

period at which the parts are held at the relatively high temperature, full annealing is not permitted on Alclad material, as it would cause diffusion of the alloying constituents of the core into the clad coating and impairment of the corrosion resistance.

31. Reheat-Treatment.—Material other than Alclad may be reheat-treated any number of times in salt baths provided that the treatment is carefully performed, and in air furnaces provided that the material is anodized. The structure of the alloys is not damaged in any way. Unanodized 17S and 24S, however, may be reheat-treated only once in air furnaces. In the case of Alclad, certain limits on the number of treatments must be observed to avoid diffusion of the alloying constituents into the clad coating. On stock .032 inch or less in thickness, no reheat-treatment is allowed if the material has been purchased in the SO condition; and only one reheat-treatment is allowed if the material has been purchased in the ST condition. For greater thicknesses the same number of reheat-treatments are allowed in SO and ST material. One reheat-treatment is allowed for stock from .032 to .063 inch; two for stock from .063 to .125 inch; and three for stock over .125 inch.

HEAT-TREATMENT OF RIVETS

32. Requirements of Rivet Heat-Treating.—The heat-treatment of rivets does not differ essentially from that of other aluminum-alloy products. The requirements specified for general heat-treatment apply, except for the soaking times and the equipment, which should be especially adapted to handling rivets.

The rivets that must be heat-treated are those made of 17ST and 24ST. The 17ST rivets are distinguished by a small projection on the head, as shown at *a*, Fig. 17 (*a*), and the 24ST rivets by two raised dashes opposite each other and extending radially from the center of the head, as shown at *b*, view (*b*). These rivets are purchased in the heat-treated condition, given a solution heat-treatment, and then refrigerated to retard their age-hardening. If the rivets are not refrigerated after solution heat-treating, 17ST rivets, also designated as *D* rivets, should be driven within an hour after quenching, and 24ST, or *DD*,

rivets within approximately 10 minutes, if a high rate of riveting is to be maintained. Since the rivets, however, cannot be used as fast as they are heat-treated, refrigeration is required. When rivets are ice-boxed at 32° F. immediately after quenching, aging is partially retarded and satisfactory driving characteristics are maintained for as long as 3 days. With mechanical refrigeration or by the use of dry ice, which is solid carbon dioxide, temperatures of from -40° to -50° can be obtained. At such temperatures, age-hardening is retarded to such an extent that the rivets can be driven for a period of two weeks or more. However, the rivets in local storage boxes, which are located in various parts of the plant, are generally changed every 24 hours.

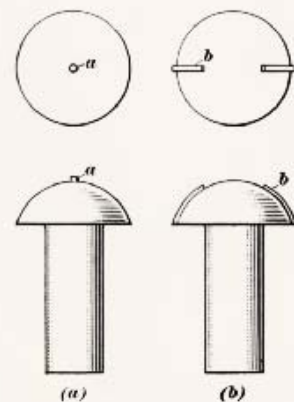


FIG. 17

33. Salt-Bath Equipment.—One important requisite of salt baths intended for use in the heat-treatment of rivets, is that direct contact between the rivets and molten salt be avoided. A typical installation of a salt bath is shown in Fig. 18. The furnace consists of a round pot installed within the outer casing *a*, and heated by gas burners *b* at opposite sides of the furnace. The top of the tank is fitted with a cover plate *c* through which the cylindrical rivet containers *d* extend into the salt bath. These containers are closed at the lower end and are immersed in the bath for nearly their full length. A close-fitting, insulated lid *e* covers the entire top of the tank and the containers. A thermocouple in the tube *f* is led into the bath from the control board. The two recording pyrometers *g* are provided to regulate the temperature of the furnace shown, and that of a similar furnace not shown in the illustration. After the rivets have been heated to the proper temperature and held at that temperature for the required soaking period, each container is removed by tongs and



FIG. 18

the rivets are poured immediately into cold circulating water. The container itself must not be quenched since the rivets must have direct contact with the water. Handling of the rivets in the quench tank *h* is facilitated by using perforated receptacles *i* immersed in the water. The rivets may then be dried before refrigeration by whirling them in a centrifugal drier, or by immersing them for a moment in alcohol which rinses off the water and then quickly evaporates.

34. Another type of salt bath that is particularly recommended for heat-treating rivets is similar, except that the salt

is electrically heated and the arrangement of the rivet containers is somewhat different. The containers are perforated tubes that fit into closed tubes extending from the top cover plate into the molten salt. The closed tubes are approximately 2 to 2½ inches in diameter, and are spaced to provide not less than ¼ inch separation, in order to permit free circulation of the bath in contact with their outer surfaces. Thus, neither the rivets nor the containers contact the molten salt and, as far as transfer of heat is concerned, this type of equipment is actually an air furnace in which the heat is supplied by the molten salt.

35. A salt-bath furnace designed to provide a quick quench is shown in Fig. 19. Muffles *a* closed at their inner end fit into and protect the closed tubes that extend horizontally into the molten bath, and are expanded into the front wall of the tank. Rivet containers, such as *b*, fit into these closed tubes and are pulled out by their handles for quenching and recharging. To quench a charge, the container *b* is pulled out as shown until its opening is over the funnel *c* of a perforated receptacle that is immersed in the quenching water, and is then turned so as to pour the rivets into the funnel and water. From the upper tier of muffles, the rivets fall through chutes *d* into their respective receptacles. After being entirely emptied, the container is turned to its upright position and another charge of rivets is made. In pouring the rivets into the container, care must be taken not to spill any into the quenching receptacles, since unheat-treated rivets must not be mixed with rivets in the heat-treated condition.

36. **Air-Furnace Equipment.**—Air-furnace equipment for heat-treating of rivets should be capable of maintaining accurate control of the range in temperature and of its distribution within the furnace. To assure good circulation of the heated air throughout the rivets and a uniform temperature in all parts of the charge during the soaking period, the rivets should be placed in mesh containers or perforated tubes. Quenching from these containers is accomplished in the same manner as from a vertical salt bath.



FIG. 19

37. Procedure for Heat-Treating Rivets.—The temperatures for the solution heat-treatment of rivets are the same as those for other products made of the same alloy, namely, from 930° to 950° F. for 17ST and from 910° to 930° F. for 24ST. The soaking period, determined for each size and arrangement of charge by placing a thermocouple in or near the charge, depends on the type of alloy, the diameter of the rivet, and the type and efficiency of the heat-treating equipment. For salt baths and for air furnaces having a forced circulation of air, the minimum time should be not less than 10 minutes for 24ST rivets. The most favorable soaking time required to produce the desired results should be carefully determined by experiment to suit the individual equipment used. Thus, for the salt-bath installation illustrated in Fig. 19, the soaking periods given in Table III were determined as satisfactory for 17ST rivets. These data apply to this particular installation and should not be regarded as a recommendation for other type rivets.

TABLE III
SOAKING PERIOD FOR 17ST RIVETS

Diameter of Rivet, Inch	Minimum Soaking Period, Minutes
$\frac{3}{8}$	20
$\frac{3}{8}$ to $\frac{5}{8}$	30
$\frac{3}{4}$ to 1	45
$1\frac{1}{8}$ to $1\frac{1}{2}$	60

38. Reheat-Treatment of Rivets.—When rivets are purchased by an aircraft company from a rivet manufacturer, they are supplied in the heat-treated condition. Therefore, the first heat-treatment in the aircraft plant is a reheat-treatment. As the unused rivets are brought back to the heat-treating department from the refrigerated storage boxes, additional reheat-treatments may be performed to soften them and so restore their workability. Rivets may generally be reheat-treated repeatedly without injury, provided the treatment is carefully and properly performed. Since an excessive number of reheat-treatments,

however, will result in a gradual hardening of the rivets and render them unfit for use, the number of such treatments is usually limited to fifteen.

When rivets are made by the aircraft manufacturer, the first heat-treatment must be preceded by anodizing in order to prevent high temperature oxidation and intergranular corrosion. The reheat-treatments may be carried on in the usual manner. When *A17ST*, or *AD*, rivets are manufactured in the aircraft plant, they are heat-treated at the same temperatures as *17ST* rivets, but need not be refrigerated since they remain relatively soft in the fully aged condition and may be driven at any time after quenching.

TESTING AND INSPECTION

39. Heat-Treating Specifications.—In the construction of Naval or Army aircraft, the Army-Navy Aeronautical Specification AN-QQ-H-186 on Process for Heat-treatment of Aluminum Alloys, must be followed. This specification, from which much of the information on heat-treating procedure contained in this paper was obtained, is practical and not difficult to follow. The process as it is carried on in the aircraft plants is checked carefully by government inspectors, to assure conformation to the requirements of the specification. The heat-treating equipment, the temperature-control devices, and all details of the procedure are subject to inspection.

40. Methods of Testing.—To determine the suitability of the equipment and procedure, physical, corrosion, and hardness tests are made each month on samples of the same alloys being treated. The samples represent the maximum and minimum of the range in thickness of the parts. For Alclad, a microscopic examination is also made to determine the extent of diffusion of the alloying constituents of the core into the clad coating.

The physical tests for ultimate tensile strength, yield strength, and elongation are conducted on alloys in their aged condition. Alloys *17ST* and *24ST* are tested not less than 4 days after solution heat treatment; whereas, alloys *53ST* and *61ST* may be tested at any time after completion of the aging treatment.

41. The corrosion test is made by immersing the sample in a salt solution for a specified period. First, the sample is washed in carbon tetrachloride, then in alcohol, and dried. In the case of Alclad, the coating is removed from one side of the sample before cleaning. The sample is then immersed in a solution of sodium chloride, hydrogen peroxide, and water for a period of from 16 to 24 hours depending on the thickness of the material. The sample is prepared for microscopic examination by etching in Keller's etch, and examined at a magnification of not less than 500x. Any high temperature oxidation indicating improper furnace atmosphere, and intergranular corrosion indicating slow quenching, can be detected by this examination.

42. Hardness tests can be used to determine whether parts have been properly heat-treated. They may be accepted as an indication of the strength developed by heat-treatment, but cannot be relied on as a complete check on the suitability of the process, since they provide inadequate information on such important factors as yield strength and elongation. The tests are conducted on a Rockwell Hardness Tester, whereby the hardness is determined by measuring the amount of indentation produced by a certain load acting on a penetrator which is pressed into the material. The depths of penetration are indicated directly on a dial gage having different scales for different loading pressures.

With a 100-kilogram load and a $\frac{1}{8}$ -inch ball as the penetrator, alloy *17ST* after aging for 24 hours should show a minimum hardness of 90 on the red scale on the dial. Alloy *24ST* under the same conditions should show a hardness of 95. On thin material, a lower load gives more accurate results. With a 60-kilogram load and a $\frac{1}{8}$ -inch ball, *17ST* should show a hardness of 105, and *24ST* a hardness of 108. The hardness of *17S* rivets aged for 24 hours should be from 73 to 83, depending on the rivet diameter, with a 60-kilogram load and a $\frac{1}{16}$ -inch ball.