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OXY-ACETYLENE WELDING OF CHROMIUM-MOLYBDENUM STEEL TUBING

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THE LINDE AIR PRODUCTS COMPANY

A DATA book on steel tubing would not be complete unless it contained some information on the methods used for fabricating structures from tubing. Welding is undoubtedly the most important means by which tubing is joined in the structures and this section of this data book is therefore devoted to a discussion of the oxy-acetylene, electric arc and atomic-hydrogen techniques of welding. In fabricating S.A.E. X4130 tubing into aircraft structures, on which the main emphasis of this article will be placed, oxy-acetylene welding is widely used and is the only welding method used on complicated joints in light-gauge materials.

In this article important factors in the oxy-acetylene welding of aircraft structures are described. The information presented is divided so as to be treated under the following general subtitles: Design, Welding Technique, and Production. In an effort to make the information more useful, the division of the subject matter under these subtitles has not been rigid. For instance, there is considerable discussion of welding technique under the subject of joint design, since it is at that point that the material is of most value and most directly applicable.

DESIGN

Oxy-acetylene welding is fundamentally simple. The edges of two pieces of metal are brought close together, heated to a molten state by means of the oxy-acetylene flame and after an intermingling of the molten metal allowed to cool down. Upon reaching room temperature there is but one piece of metal with, in effect, no joint at all. In practical application, of course, it is not as simple as that, but this fundamental simplicity does make it possible to produce excellent results with proper design and welding technique.

In the preparation of this text, Mr. Morrison thanks the following for their generous assistance:

Messrs. MacCart, Brewster Corp.; *Thieblot and Blumenthal*, Fairchild; *Johnson and Craig*, Grumman; *Falk, Badgley and Borchers*, Kellett; *Vollmer and Barrett*, Martin; *Lescher*, Republic; *Runde*, Vought-Sikorsky.

EDITORS

The Two Divisions of Joint Design: In welding, the subject of joint design is usually considered as consisting of two parts. The first and simpler is the design of the weld cross section. The second is the design of the joint between two or more parts.

Weld Cross Section

Edge Preparation: With material less than ⅛″ thick no special preparation is necessary except to make sure a good fit is obtained and that the edges are cleaned of scale, grease and other dirt. For material ⅛″ thick and heavier, the edges to be welded together should be beveled so as to provide an included angle of at least 75°, if possible.

Spacing: Most welds in aircraft work are fillet welds of one form or another and for this type of weld no spacing is needed. For butt-type welds the edges to be joined should be spaced somewhat to facilitate thorough penetration. This spacing at the point of welding should be at least $\frac{1}{32}$″ for the lighter gauges to ⅛″ for plate material.

Weld Penetration: Thorough fusion between the base metal and metal added from the welding rod

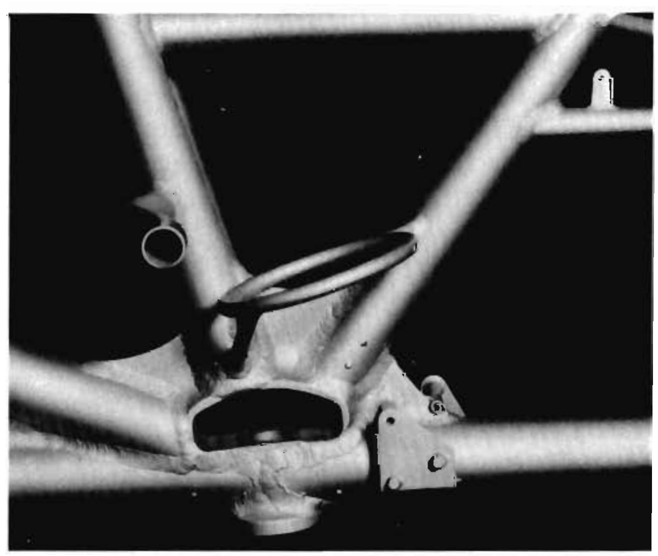
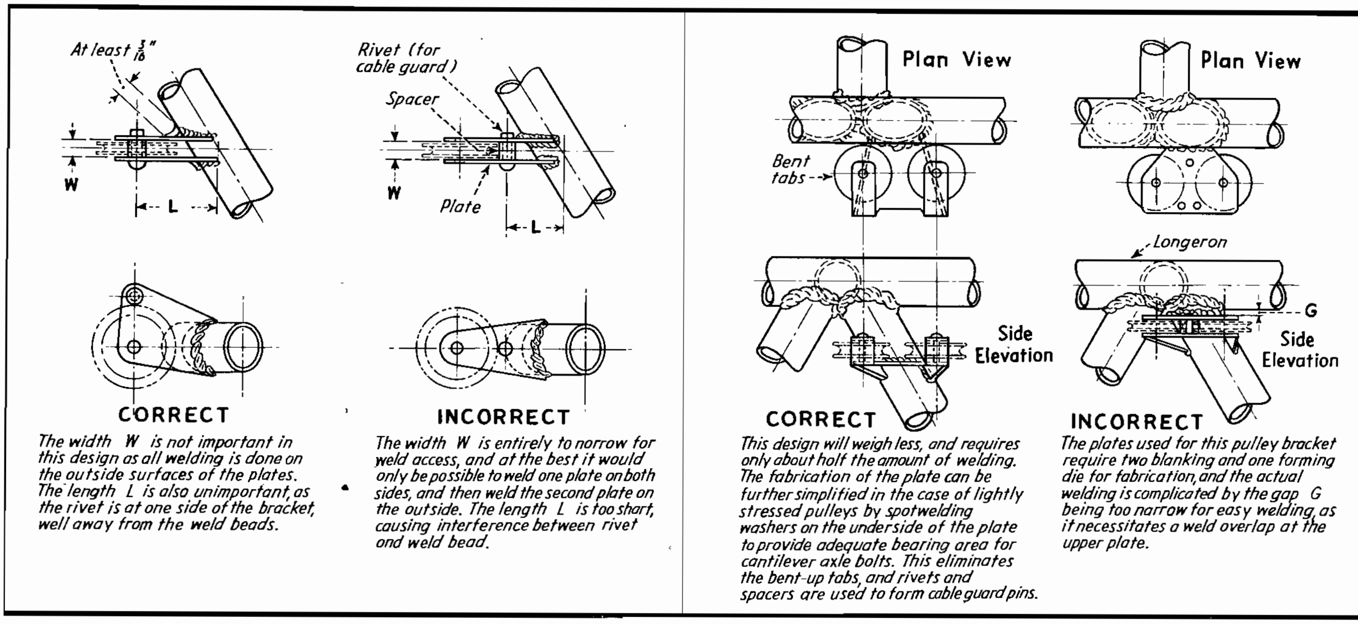


Figure No. 1. **Good example of welded joint design with special fitting at cluster for controls.**



CORRECT: *The width W is not important in this design as all welding is done on the outside surfaces of the plates. The length L is also unimportant, as the rivet is at one side of the bracket, well away from the weld beads.*

INCORRECT: *The width W is entirely to narrow for weld access, and at the best it would only be possible to weld one plate on both sides, and then weld the second plate on the outside. The length L is too short, causing interference between rivet and weld bead.*

CORRECT: *This design will weigh less, and requires only about half the amount of welding. The fabrication of the plate can be further simplified in the case of lightly stressed pulleys by spotwelding washers on the underside of the plate to provide adequate bearing area for cantilever axle bolts. This eliminates the bent-up tabs, and rivets and spacers are used to form cable guard pins.*

INCORRECT: *The plates used for this pulley bracket require two blanking and one forming die for fabrication, and the actual welding is complicated by the gap G being too narrow for easy welding, as it necessitates a weld overlap at the upper plate.*

Figure No. 2. THOMPSON & LOWE—VULTEE

at all points in the weld is a necessary requirement of all fusion welding.

Weld Reinforcement: By reinforcement is meant the amount by which the weld is built up above the top surfaces of the parts being joined. Such reinforcement should merge smoothly into the top surfaces without undercutting or excessive build-up at any point. For butt welds in S.A.E. X4130 sheet or tubing welded with low-carbon or medium-carbon welding rod, the weld should be built up so as to be about 1¼ times the base-metal thickness.

Welding Rod: Curiously enough, better results are frequently obtained in the oxy-acetylene welding of low-alloy steels when the welding rod has an analysis which is different from that of the base metal. For X4130 this takes the direction of a lower alloy content in the rod. With thin sections which are not to be subsequently heat-treated, a rod* with the analysis 0.06% carbon max., 0.25% manganese max., and not over 0.05% silicon has been used a great deal with completely satisfactory results. For parts which are subsequently to be heat-treated or in which somewhat higher strengths are desired in the weld, a welding rod somewhat higher in carbon is recommended. A rod** having 0.14 to 0.18% carbon, approximately 1.10% manganese and 0.37% silicon has found wide acceptance for some time and its use seems to be expanding. The manganese and silicon in this rod have a fluxing action which is advantageous.

Welding Technique: This subject is abstracted here and more completely discussed in a later section. A slightly excess acetylene flame adjustment is recommended for welding with either of the welding rods mentioned and X4130 base metal. One important reason for this is that the slight amount of carbon in the flame has a fluxing action which is of considerable aid in reducing surface oxides; yet such a flame adjustment does not cause carbon pick-up by the base metal.

A purely theoretical analysis of the metallurgy of the base metal and of the welding action may indicate a neutral flame as desirable. However, the presence of surface oxide and the fact that the flame adjustment may fluctuate slightly strengthen the argument in favor of a slight excess acetylene feather in the flame.

Design of Joinings Between Structural Parts

The design of the joinings between two or more pieces of tubing is dictated in most cases by the final structure desired. There are certain basic designs, of course, such as those between two pieces of tubing whose axes are to be in the same straight line or, in another case, perpendicular to each other. The Army and Navy authorities and the Civil Aeronautics Board, singly or in combination, have

*Oxweld No. 7 Drawn Iron Welding Rod (copper-coated) meets this specification.

**Oxweld No. 1 High Test Steel Welding Rod (patented).

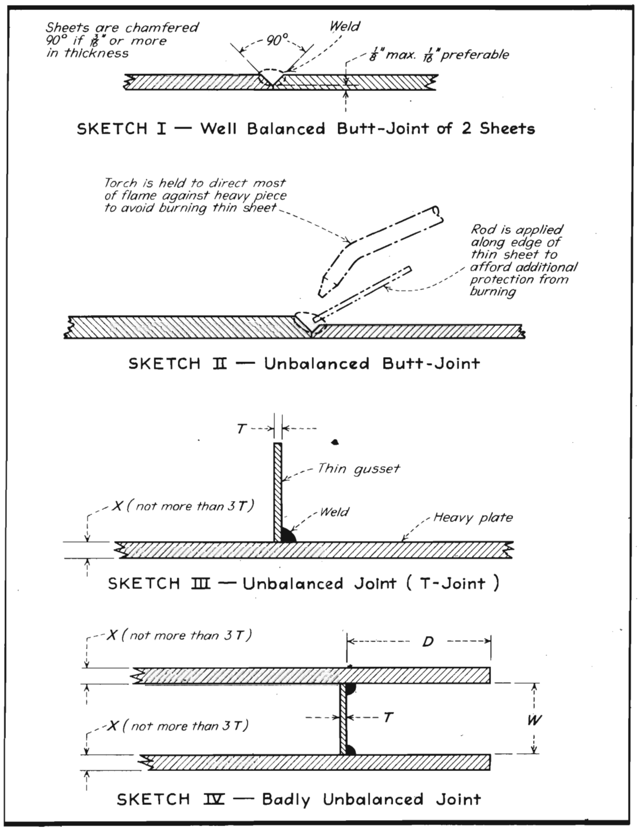


Figure No. 3. THOMPSON & LOWE—VULTEE

formulated specifications* regarding designs and materials covering these basic designs and it does not seem to be necessary for this article to repeat those regulations. Although there is not always complete accord with such specifications, more investigating work is continually in progress and they will undoubtedly be revised from time to time.

Designers of aircraft structures are undoubtedly already familiar with the specifications necessary. It is believed more to the point, therefore, if this article gives an explanation of the effect of welding on tubing and thus provides the designer with some material with which to reason.

Effect of Welding Heat on S.A.E. X4130

Most tubing used in aircraft is purchased in the normalized condition or, in other words, it has been heated to a temperature above the critical, soaked there a sufficiently long time to be certain the metal has reached a uniform temperature throughout, and then allowed to cool to room temperature in still air. Since X4130 is an air-hardening steel, such normalized tubing possesses higher strength and hardness and slightly lower ductility than if it had been cooled slowly in a furnace.**

During welding the edges to be joined are heated to a molten condition and allowed to cool in air. Because of the nature of the welding operation, in a relatively narrow zone adjacent to the weld there will be metal which was heated (1) considerably above the critical, (2) just above the critical, (3) not quite up to the critical, and (4) only slightly heated. After welding the hot metal will cool down more rapidly than if the whole tube was heated, since nearby cool metal will have a quenching effect. That gives three important effects to be considered, namely, expansion and contraction, air-hardening, and annealing.

Expansion and Contraction: Of course, when a weld area is heated, the metal expands, and upon cooling, contracts. Out of this come two factors of importance to the designer as well as the welding operator—distortion and locked-up stresses—and a third factor which is a property of the particular steel being considered—"white-shortness."

Distortion: The elimination of distortion is largely a function of the welding shop, but the designer must consider it in order to decide how completely he can expect it to be eliminated. During the years that aircraft tubing has been welded, the welding

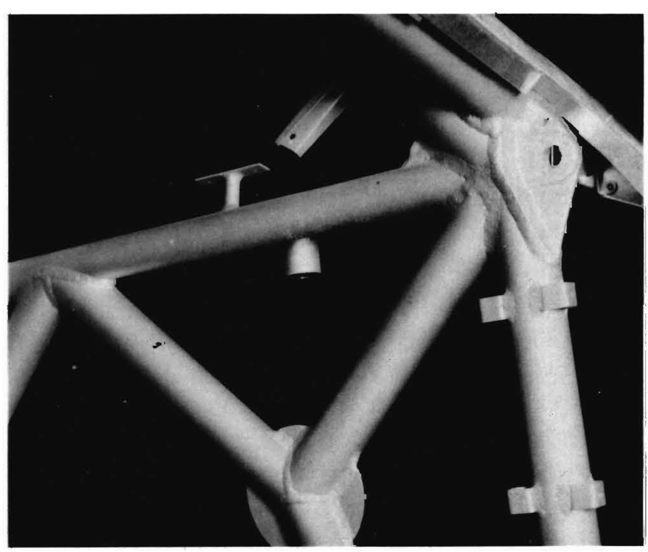


Figure No. 4. Close-up of a section of finished tubular structure to show types of welded joints.

*ANC-5, Strength of Aircraft Elements, Air Commerce Manual No. 18.
**See Section I for details on heat treatment.

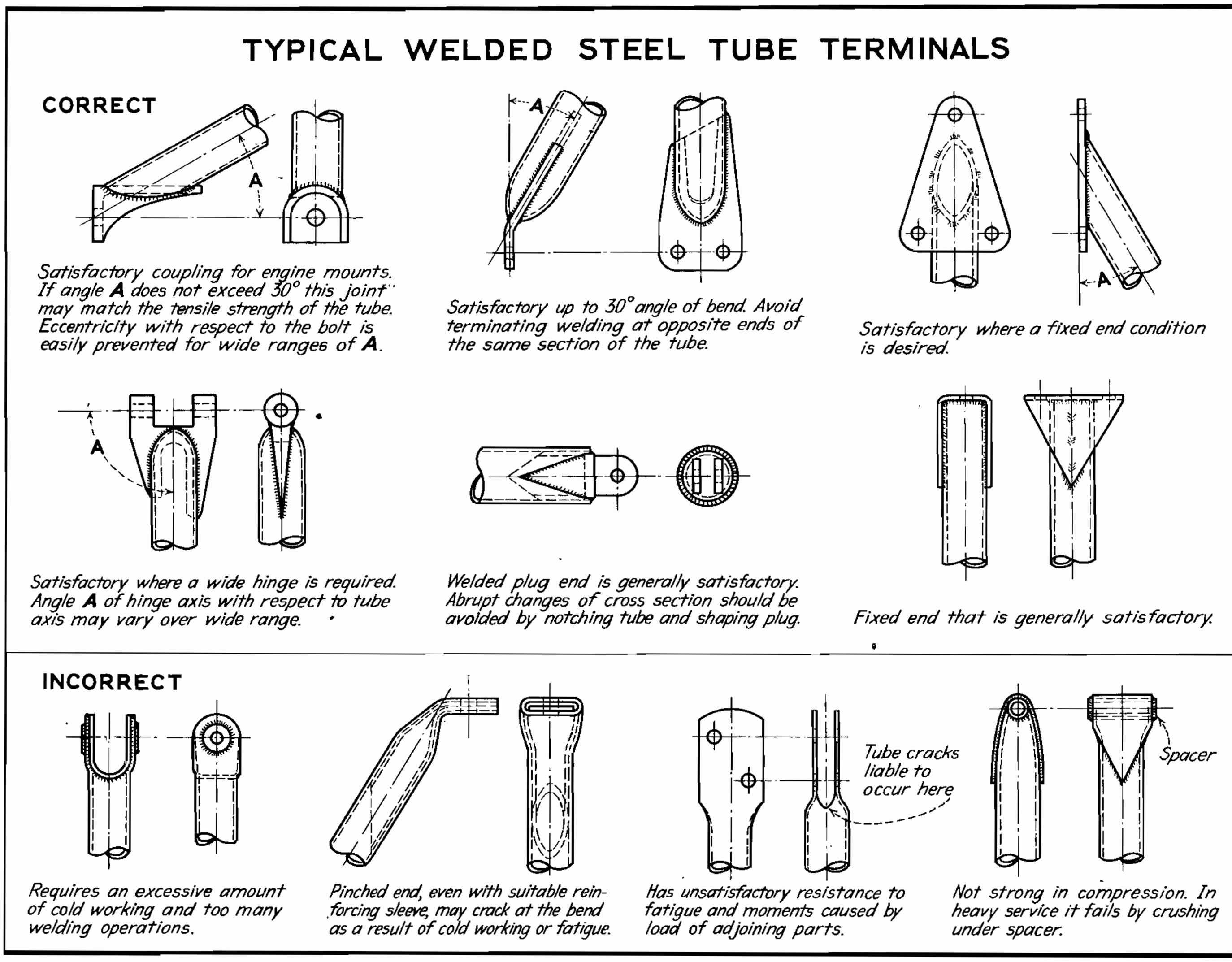


Figure No. 5.

THOMPSON & LOWE—VULTEE

shops have become particularly clever in eliminating distortion. The amount of shrinkage to be expected has been estimated and proper allowances made. The designer must realize, however, that the amount of angular distortion and the amount of lateral distortion which result from the last weld in a closed structure vary with the amount of heat the welding operator uses, and there is, therefore, a limit to the closeness of the tolerances to be expected. An instance which illustrates a design calling for too small a tolerance concerns the fabrication of a motor mount on which it was expected also to support a small oil tank. The welding shop was able to hold the face-to-face dimension of the mount to extremely close tolerance. Fixed brackets for the mounting of the oil tank added the requirement of keeping accurate angular alignment and straightness of the motor mount ring supporting tubes, and this caused considerable difficulty in the welding shop. A slight redesign to provide a small adjustment in the bracket would have met the condition with far less effort and better final results.

Locked-Up Stresses: There are two sources of locked-up stresses. When cold-work, such as bending or flattening, is performed on tubing, stresses are locked up in the metal. Practically all stresses caused by the manufacture of the tubing are relieved by the normalizing treatment.

During the contraction which follows welding, rather high stresses are locked up in the metal which was heated. However, in static tension, compression, or torsion, these stresses do not cause any particular difficulty (provided there has not been any serious impairment of ductility), unless there is but little unstressed material adjacent to the weld. When a part is loaded, the internal stresses induced seem to continue to move about until all the metal which is available to carry the load has been stressed to its yield point. Then permanent deformation begins.

For the designer this means that he should avoid placing welds too closely together. For instance, a short tube welded at both ends into a rigid structure cannot absorb a great deal of additional stress (in the same direction as those induced by welding). It becomes necessary for the designer to consider, therefore, where stresses induced by cold-work or by welding will be located, so that they may be distributed as uniformly as possible throughout the structure. Frequently it will be found advisable to remove the effects of cold work on bent and formed tubes by renormalizing or annealing before welding.

White-Shortness: S.A.E. X4130 has the property of being white-short or, in other words, it has extremely low strength at a white heat, above 2,000° F. In general, care during the welding operation to avoid subjecting the white-hot metal to any tension stress is sufficient. Frequently, however, the designer can avoid specifying a condition in which this property may become important. A small assembly with numerous welds in several directions, for instance, places a considerable burden on the welding shop to avoid distortion and locked-up stresses, as well as avoiding any stress at all on any section that happens to be at a white heat.

Air-Hardening: It was pointed out under the subject of locked-up stresses that the stresses locked up in the weld do not cause particular difficulty provided there has not been an impairment of ductility. When a weld is made in cold tubing and the welding is performed too rapidly, the quenching effect of the cold metal in an air-hardening steel like X4130 may create a brittle zone along the edge of the weld. The elimination of this, however, is definitely a function of the welding shop and not of the design department.

Annealing: Somewhat the same situation exists regarding annealing as has just been described for air-hardening. A zone adjacent to the weld is heated below the critical and cooled, and naturally a certain amount of annealing takes place. This, however, is not serious and specifications for design take it into consideration.

In general, the factors which have been discussed are mutual problems of the design and production departments. It is important, therefore, that the designer be acquainted with the welding problems in order that he may avoid welding difficulties by slight changes in design.

WELDING TECHNIQUE

To make an oxy-acetylene weld, a small area at the edges of the two parts being joined is heated until a small pool of molten metal is formed. Then, as this pool is made to progress along the junction

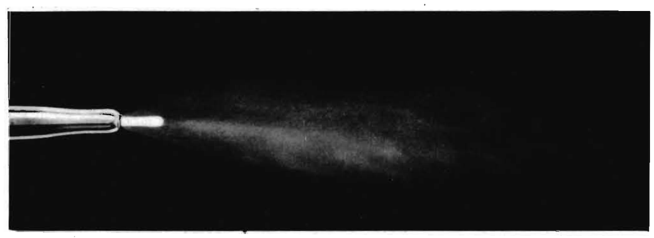


Figure No. 6. **The neutral flame has an approximately one-to-one mixture of oxygen and acetylene.**

of the two parts, additional metal is added from a welding rod. The rear edge of the puddle is continuously solidifying while additional metal is becoming molten at the leading edge of the puddle. There are three important parts to the welding operation—the flame, the welding rod, and the method of making the weld.

The Flame

Oxygen and acetylene pass through a suitable mixing device and the mixed gases burn at the blowpipe tip. This furnishes the source of heat for the welding.

The oxy-acetylene flame is the hottest flame known. This fact is explained by a consideration of the chemistry of the flame and, since the chemistry of the flame has an important bearing on the weld, it is worth at least brief consideration.

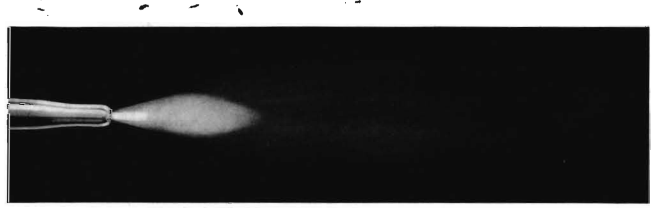


Figure No. 7. **This flame is variously called an excess acetylene, a reducing, or a carburizing flame.**

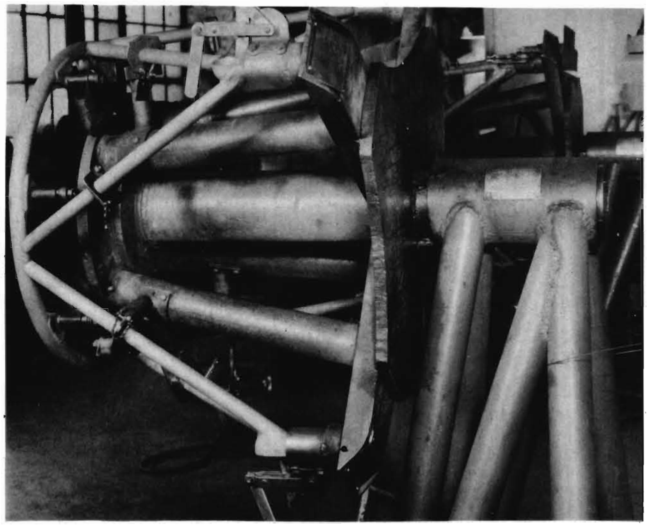


Figure No. 8. **Complete engine mount assembly and welding jig mount set up ready for welding. In this design the mount can be rotated around the center permitting 2 men to work at same time and both in best position for good work. (Note heavy tubes used in jig and toggle clamps for quickly fastening and releasing legs.)**

Acetylene gas is a compound of two parts carbon and two parts hydrogen. The complete oxidation of acetylene takes place in two complete steps.

$$C_2H_2 + O_2 \rightarrow 2CO + H_2 + \text{Heat} \quad (1)$$

The products of this primary combustion, carbon monoxide and hydrogen, are both combustible.

$$\left.\begin{array}{l} 2CO + O_2 \rightarrow 2CO_2 + \text{Heat} \\ 2H_2 + O_2 \rightarrow 2H_2O + \text{Heat} \end{array}\right\} (2)$$

From this it becomes evident that 2½ volumes of oxygen are required to burn completely one volume of acetylene.

$$C_2H_2 + 2\tfrac{1}{2}O_2 \rightarrow 2CO_2 + H_2O + \text{Heat} \quad (1) \text{ and } (2)$$

In the oxy-acetylene process approximately one volume of oxygen is supplied from the cylinder as pure oxygen. This is sufficient for the primary combustion—equation (1). The oxygen for the secondary combustion—(2)—is supplied from the air.

When exactly equal quantities of pure oxygen and acetylene are supplied to the blowpipe, a neutral flame results. In the inner cone of this flame the primary combustion is taking place. In the outer envelope oxygen from the air is causing the secondary combustion.

If the one-to-one mixture is varied to give an excess of acetylene, a third cone appears in the flame—the excess acetylene feather. Then part of the oxygen for the primary reduction must be supplied from the air.

If, on the other hand, the one-to-one mixture is varied to give an excess of oxygen, the inner cone becomes shorter, is necked in and acquires a purplish tinge. With this type of flame, some of the oxygen for the secondary combustion is supplied through the blowpipe.

The Welding Rod

As explained earlier, X4130 steel is usually welded with an ordinary steel welding rod. In light sections there is an actual pick-up of alloying elements by the weld metal from the base metal. In heavier sections this pick-up is not so uniform in its effect upon the weld, which indicates the reason for using a somewhat stronger metal for the welding rod. In addition, parts to be heat-treated require a higher carbon content in the weld metal.

One other important factor regarding welding rods is the need for rods of uniform analysis. Reputable manufacturers of welding rods make certain that the analysis of rods which they sell is within narrow limits.

Welding Technique

There are three techniques of weld-metal deposition in use in aircraft welding—forehand ripple, backhand, and "scale" welding.

Forehand Ripple Welding: In this method the blowpipe is held in the right hand and rod in the left (for a right-handed operator) and the direction of welding is from right to left, thus placing the flame between the completed portion of the weld and the welding rod tip. The puddle is maintained continuously and, in light gauges, metal from the welding rod is added intermittently as needed.

There are one or two things regarding this technique which should be pointed out. The edges of the base metal should be melted first and the puddle thus moved forward. The molten puddle should never be allowed to flow forward onto solid edges as the metal will then not weld. In butt welds this melting of the edges ahead of welding must be done all the way through to the underside of the base metal.

In any welding the flame should be held so that the inner cone no more than just touches the surface of the puddle. It is in the inner cone that the primary combustion is taking place and "digging" the inner cone into the molten puddle will cause oxidation of the steel.

At no time during welding should the air be allowed to touch the white-hot or molten metal. The outer envelope of the flame provides a protection against oxidation and this protection should not be removed until the weld has cooled down at least to a red heat. Drawing the inner cone back away from the weld allows the metal to cool, yet still provides protection against oxidation.

Backhand Technique: In this method the blowpipe and rod are held the same way, but the direction of welding is from left to right. The advantage is that the flame can be made to play more directly on the base-metal edges ahead of the welding puddle, speeding the welding. The ripple effect at the top of the weld, produced more by the welding rod than the flame, may be somewhat coarser than with forehand welding but not excessively so. The same general precautions as to thorough fusion and avoidance of oxide apply as in forehand welding.

"Scale" Welding: In this welding method, which can be performed either forehand or backhand, the welding puddle is not maintained continuously. A puddle is created, some welding rod added and the puddle enlarged, and then the flame is withdrawn and the puddle allowed to solidify. Thereupon, a new puddle, overlapping the first, is created and the operation repeated.

"Scale" welding is a special-purpose technique developed for use in making fillet welds in which distortion or overheating of a thin section becomes a problem. An example of a circumstance for which it is desirable is the attachment of a thin gusset plate by means of a fillet weld. "Scale" welding is naturally slower than either forehand or backhand, but does have the advantage of causing less distortion. *It should not be used except for those special purposes for which it was developed.*

The most important precaution regarding "scale" welding is to keep the weld protected by the flame envelope at all times. When allowing each succeeding weld to solidify, draw the flame *back along the line of the flame*. Do not flick it off to one side.

PRODUCTION

An important factor which has been more or less neglected in certain aircraft plants is a managerial control of the procedure followed in the welding department.

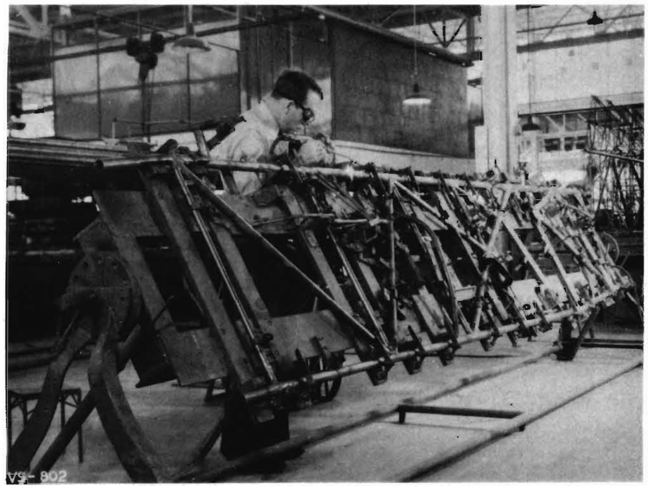


Figure No. 9. **Welding jig for fuselage side member. Note how jig is suspended on end pivots to permit turning work to best position for the welder.**

Procedure Control

The idea of a procedure control by means of which the welding operation may be brought under the close control of management, where it belongs, is of paramount importance in an industry such as aircraft manufacture where accelerated production with no sacrifice of safety is the theme. Curiously enough, however, relatively few aircraft plants employ a well-planned procedure control in their welding departments.

Briefly a procedure control consists of the following:

1. Design for welding.
2. Selection and inspection of materials.
3. Establishment of a procedure which will give the results desired.
    a. Preparation of material.
    b. The welding procedure.
4. Qualification of the welding operator to follow the procedure.
5. Inspection and testing of completed work.

1. Design for Welding: A number of factors in this have already been discussed under the subject of design. The subject is repeated here for emphasis and to show its relationship in the procedure control.

2. Selection and Inspection of Materials: This includes base metal, welding rods, gases and apparatus. The affidavits of reputable manufacturers are generally acceptable for the first three items. Periodic inspection of apparatus should be performed.

3. Establishment of a Procedure Which Will Give the Results Desired: It is here and in part (4) that a greater amount of effort should be expended. All too frequently the establishment of a procedure is left up to the welding foreman or a man who is considered a "good welder." When the welding has been completed, it is visually examined, checked for measurement, and usually tested by magnaflux. From that it is assumed that the part is what the designer expected.

In those shops in which a procedure control is used and which, consequently, are getting the most consistently good results, the line of attack is somewhat different. A conference is held to discuss the production of each new design. Estimates of the amount of allowance for expansion and contraction are made, the direction of welding is decided upon as well as the starting and stopping points.

The parts entering the design are then prepared carefully to give a close fit, and welds are made in accordance with the plan. If the distortion is then within allowable limits the part is ready for testing. If the distortion is too great, the welding sequence is restudied and a new part welded.

Testing is done by more than just magnaflux. The part is subjected to tension, compression, torsion, or a combination of these—depending upon the type of stress it is designed to withstand. The severity and completeness of each test depends upon available testing equipment and the individual circumstances.

Again any difficulties which may arise are analyzed and any necessary changes in procedure are made. Suitable jigs are designed and built and the welding procedure marked on the blueprint. These markings include the starting and stopping points of all welds, the direction of welding and the welding technique. All operators are then required to follow that procedure exactly.

4. Qualification of the Welding Operator to Follow the Procedure: In many respects this is the most important part of the procedure control. In welding shops of plants not using a procedure control, practically every welding operator uses a slightly different technique from the rest. Some always use forehand welding, others always "scale" weld. Flame adjustment is far from uniform and ranges all the way from slight excess acetylene to definitely oxidizing adjustments. Some operators allow the puddle to flow forward onto solid metal and then attempt to "dig it in" by dipping the inner cone deep into the puddle. Some operators start a puddle and, instead of keeping it uniform in size, allow it to grow continuously larger. When it appears that the puddle will get out of control, they flick the flame off to the side to allow it to cool, and, of course, thus expose the molten metal to the oxygen of the air. Frequently operators doing "scale" welding expose each successive weld puddle to the air. After observing such variations in welding technique, it becomes no longer a source of wonder that the welding results are not uniform. The fault lies in the lack of definite control. The proof in this statement is that in those plants having a definite procedure control, consistently good results are obtained.

5. Inspection and Testing of Completed Work: The most widely used testing method for completed work in aircraft is the magnaflux test. This subject is rather completely covered in another article in this Section so space will not be devoted to it here.

Jigs and Fixtures: As has already been discussed, the design of jigs and fixtures is rightfully a part of procedure control. This function should be performed under the direction of the welding supervisor, even if the actual construction work is performed by a separate department.

Jig design is a broad subject, perhaps as broad as the subject of design of the structural parts. Therefore, a few general suggestions are all that can be given here.

A jig should be designed with thought to the properties of the material being welded. S.A.E. X4130 is air-hardening. Any large masses of jig close to a weld will serve to hasten the quenching of the weld and, sometimes, may increase the tendency to form brittle zones.

Oxy-acetylene welding can be done in any position, but the most consistent results will be found in those welds which are made in the flat position. It becomes advisable, therefore, to make all jigs so that they are also positioning fixtures.

The design of jigs for motor mounts, for instance, varies widely from plant to plant. Some jigs require the operator to make some welds lying on his back, welding in the overhead position through a small hole in the bed plate of the jig. In others the man must crawl into the most awkward positions to complete the work.

The best jigs for motor mounts are those which make it possible to weld in the flat position, or nearly so, at all times while the operator is in a comfortable position. Such jigs cost somewhat more but are justified from the standpoint both of the amount and the quality of the work done in them.

The subject of operator comfort receives considerable attention in those plants doing consistently good work. It is inefficient to require a man to assume awkward and tiring positions. He obviously cannot do his best work. Stools of various heights best suited to the work should be provided wherever possible.

Another point regarding jigs which should be stressed is the method of clamping. Quick-acting clamps are best. These require less time for mounting materials and often make it possible to hold parts quite rigidly during welding itself but to release the stress while the material cools through the brittle range.

In one plant small box-like parts are tack-welded in a jig but removed for welding. To minimize distortion during welding, short lengths of welding rod are added to support the parts. After welding, these are melted off. This method is excellent when welded to the edges of sheets, but should not be used to support tubular structures. The amount of welding performed on any tube should be kept to a minimum. Also, the designer may have taken care to locate the welds at the point of least service stress, and his efforts would be nullified by any welding done at other points.

As a final point in the ways to achieve the results desired: make it easy for the welding operator to get new blowpipe tips. The use of a bad tip may spoil the weld. More trouble from tips is, of course, experienced with bad welding technique.

SUMMARY

To assemble additional data for this article, the author made special trips to a number of aircraft plants. It became immediately evident that the most important purpose which this article could accomplish was to reaffirm the idea of a procedure control as a means of assuring consistently good work in the welding department.

In some instances during these visits, additional material was suggested for this article, such as data on the subjects of cracking after heat-treatment and the effect of fatigue on welds in parts subsequently heat-treated. Unfortunately, time has not been available to assemble any concrete data on these subjects as yet. It has been felt that a presentation of the fundamentals of oxy-acetylene welding with some suggestions for the use of these fundamentals in aircraft production is the primary purpose of this article.

In conclusion it should be stressed that consistently good results from a welding department are assured when management: (1) designs for welding; (2) establishes a procedure which will give the results expected; and (3) qualifies the welding operators to follow that procedure.

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ARC WELDING OF TUBULAR AIRCRAFT STRUCTURES

By FRANK B. BOLTE, *Process Engineer*

BOEING AIRCRAFT CORPORATION

Arc welding has been successfully used on aircraft structure by some of the American manufacturers for the past 19 years and is gaining more widespread usage as its economies and advantages become more apparent to the designer and the production departments. But in order to take full advantage of this method of assembly, many things must be considered. The first of which is:

DESIGN

Care should be taken in the design of all tubular joints, to make all welds as accessible as possible. Joints requiring torch heating and hand forming should be avoided. Where telescoping joints of tubes are made, the outer tube should be fish-mouthed, with the opposing sections at a 30° angle or greater to each other; see Figure 1. Where plate fittings are installed in tubes, they should be designed approximately as shown in Figure 2. In cluster fittings where tubes are connected by or reinforced with gussets, their arrangement and the intersecting plane of the gussets in the tubes should be as shown in Figure 3.

If the 30° angle rule for opposing sides of tubular joints is remembered in design, many of the troubles caused by stress concentration and the effect of welding on alloy tubing can be eliminated, because structures designed in this manner have better stress distribution characteristics. This is particularly true of arc welding on X4130 and other high alloy tubing, as the amount of base metal affected by the welding heat is approximately ⅓ that of the zone affected by gas welding on the same part. As the heating time during welding is reduced, grain growth and decarburization are largely eliminated, producing a much better structure from a metallurgical standpoint, with greatly reduced shrinkage and warping problems. Since the amount of shrinkage and warpage caused by arc welding is not as great as in gas welding, different allowances must be made for close tolerance parts requiring machining after welding.

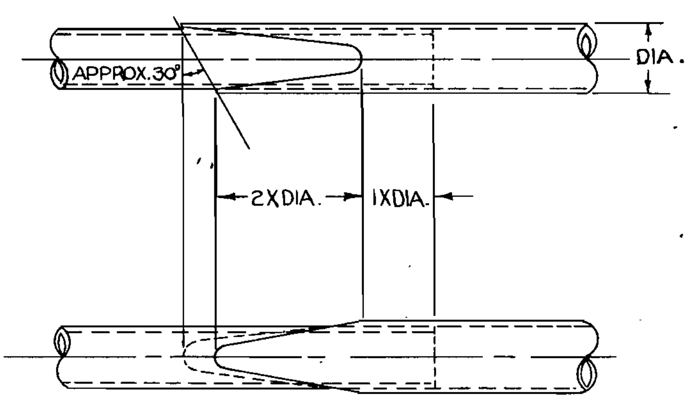


Figure No. 1

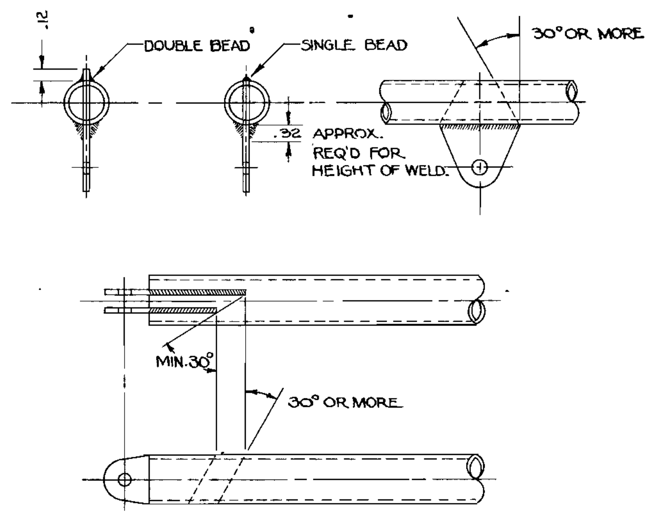


Figure No. 2

Usually welding warpage can be controlled by the adoption of a set welding sequence for each assembly. An allowance of $\frac{1}{16}''$ is usually sufficient for machine finish on most assemblies.

Recent developments in arc welding equipment make it possible and practical to design for arc welding of sections as thin as .016 which will unquestionably increase the usage of arc welding on aircraft structures. See Arc Welding in Design, Manufacture and Construction, published by The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio. American Welding Society Handbook.

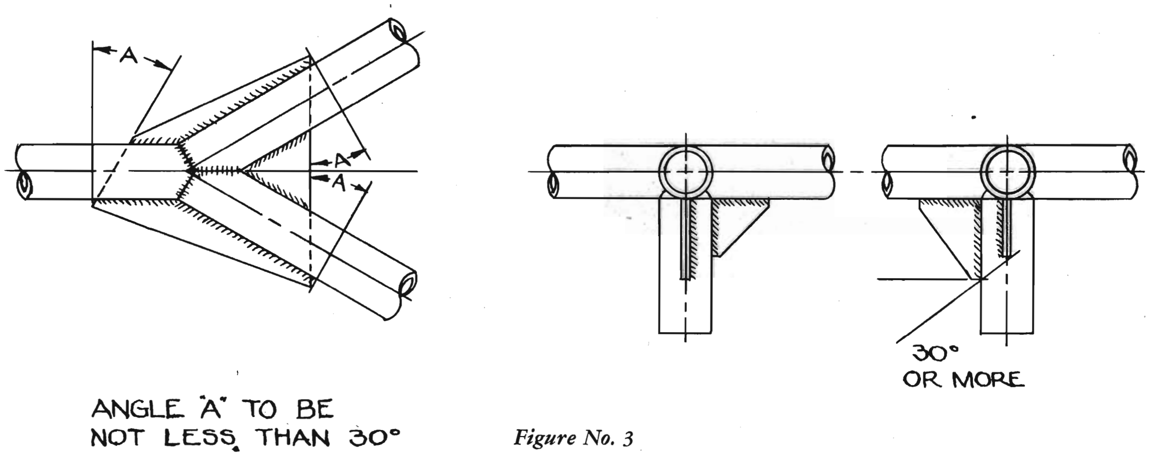


Figure No. 3

MATERIALS

In the arc welding of X4130 tubing, experience has shown that the most satisfactory filler rod is a low carbon rod, with reasonable tensile strength and high ductility.

Very satisfactory crack-free welds can be made on normalized X4130 tubing without preheating or stress relieving the assembly when this type of filler rod is used.

In the arc welding of stainless steels, stabilized materials are necessary in order to retain their corrosion resistance properties after welding. Very ductile Columbiam bearing coated electrodes seem to be the best material developed to date for this type of weld.

SHOP FABRICATION OF TUBULAR STRUCTURES

All joints of tubular assemblies to be arc welded must be rather closely fitted, if the full benefit of this process is to be attained. To obtain this type of fit by hand cutting and filing is a slow and expensive procedure, but the following methods can be used with speed and economy.

Jigs and Fixture of Tubing or Pipe

Where low carbon tubes or pipe (2″ dia. or larger) are used, very satisfactory scarfed or developed tube joints can be made by the use of templates to mark the tubes so that they can be cut with Acetylene or Butane cutting torches. This can be

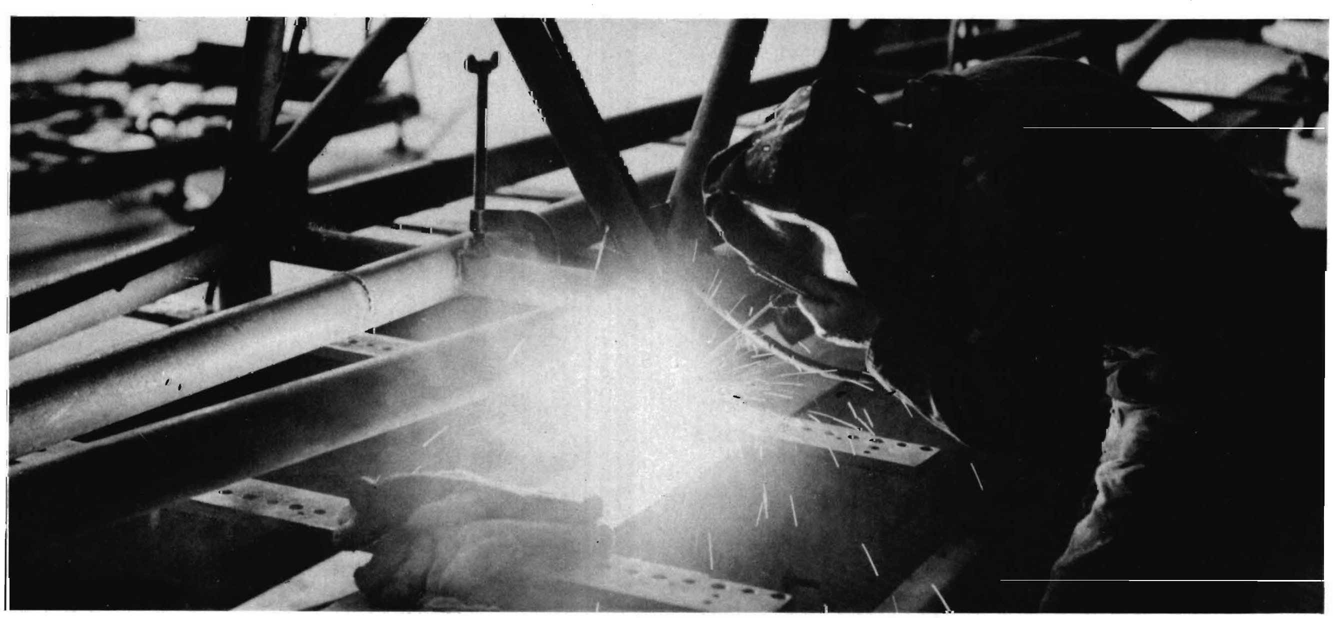


Figure No. 4—**Lifting Fixture for Flying Fortress Fuselage.**

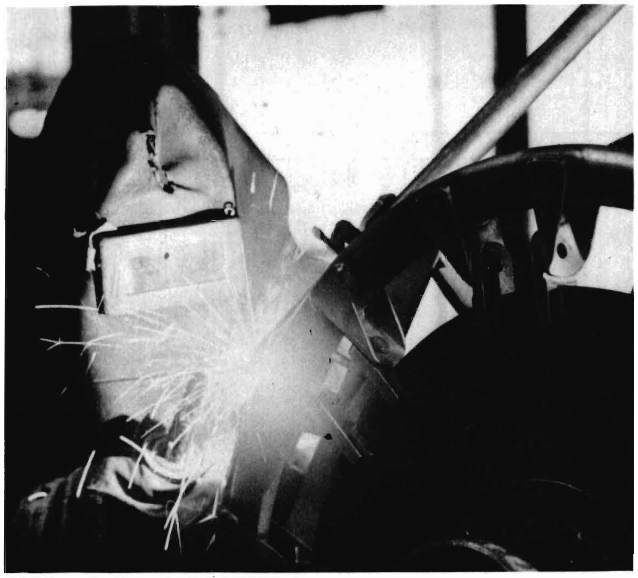


Figure No. 5—**Welding Engine Mount Support Tubes to Completed Engine Ring for Boeing Stratoliner.**

done by hand but if large quantities of tubes are to be cut, it is advisable to make a motor driven device to rotate the tube while using cams or templates to guide the torch. This, followed by a small amount of grinding will develop satisfactory joints for jigs and fixtures, see Figure 4, but it must be remembered that torch cutting cannot be used on aircraft structural tubing.

Structural Tubes

To obtain good results and low production costs, tubular designs to be arc welded should be tooled approximately as follows:

1. *Jig Design*

a. To eliminate the possibilities of arc blow, good clearance between the holding fixtures and the parts to be welded should always be maintained; if this is not done, considerable difficulty will be experienced in the actual welding operation. See Figure 4.

b. Wherever possible, the jig should be built as a trunnion jig so that the part can be turned to a convenient position for all welds, and eliminate as far as possible the necessity for overhead welding.

c. As soon as the jig has been completed (which, by the use of preliminary drawings, can sometimes be ahead of design) a complete set of parts should be hand fitted in the jig and then used as templates for the manufacture of the tools to shape the tube ends blank or shear the gussets, etc.

2. *Tooling of Individual Parts*

a. Straight cuts on tubes can be made by any of the conventional methods, of which probably the best is the wet abrasive cutoff saw.

b. Due to the importance of close fits and the elimination of gaps in the welded areas, the selection of a method for forming tube ends to be assembled in cluster fittings, deserves careful consideration. The quantity of parts to be produced has an important bearing on the method to be selected.

1. *Slots in Tube Ends. See Figures 2 and 3.*

a. Can be made by milling saws, which is rather slow and expensive, but a satisfactory method for small quantities.

b. A slitting shear can be constructed for cutting slots in tube ends over ¾" ID and having wall thicknesses not exceeding .072. This shear is constructed on the old-fashioned principle employed in the tinsmith's stovepipe shear. The tube is passed under the double blades while the single blade enters the tube to shear out a strip of the desired width. The removed strip should always stop in a drilled hole and milled slots should have radii ends to prevent cracking of the tubes in welding.

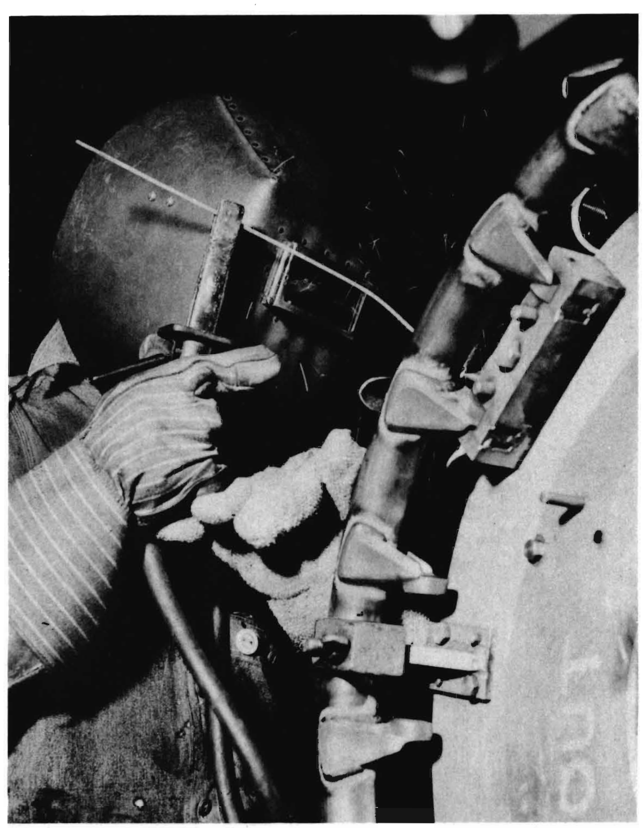


Figure No. 6—**Welding Drop Forged Shockmount Lugs on Engine Ring.**

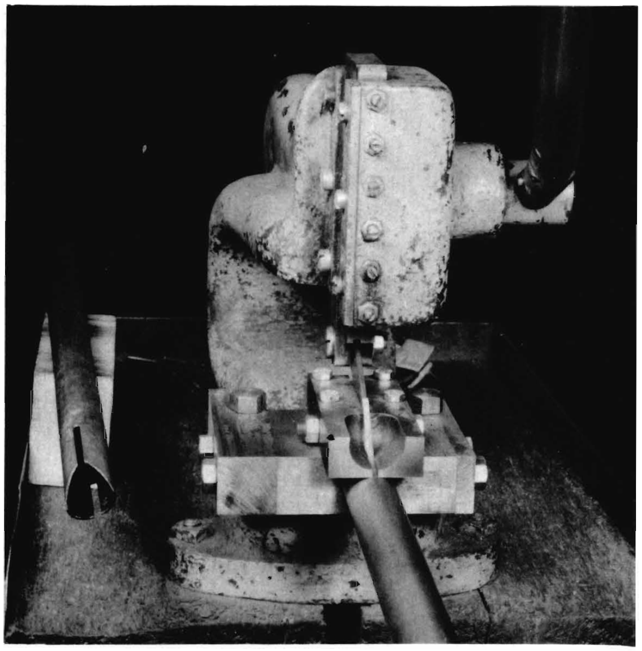


Figure No. 7—Tube Slitting Shear

The above described slitting shear can be designed and made as a power tool or the jaws can be mounted in and actuated by a bench type hand press, see Figure No. 7. No tools of this nature are available for purchase and must be designed and manufactured by anyone desiring to use them.

c. The *shaping of tube ends* for cluster fittings, see Figures 3 and 6.

Tubes forming cluster fittings develop rather odd shapes at their points of intersection and to hand cut and file them for proper fits is a slow and expensive operation. This should only be done where small quantities are desired or to develop the first samples for a new prototype going into production. The following methods have been used to shape tube ends correctly for cluster assembly:

1. *Milling and Drilling*

Special fixtures can be constructed to hold and index the tubes so that they can be radius milled to matching shapes or drilled along their intersecting planes with special drills or hole saws of the same diameter as the intersecting tube. But both of these methods are slow and expensive and the following method is considerably less expensive and faster.

2. *Nibbling Tube Ends to Shape*

Tubes from $\frac{3}{4}$ ID up having wall thicknesses of .081 and less can be correctly shaped to very difficult matching contours in from 30 seconds to 1 minute each by the following method:

A conventional Campbell Nibbler is reworked to mount post dies under the nibbling punch, see Figure No. 8. These post dies are approximately .010 under the minimum ID of the tubes to be shaped and incorporate a replaceable cutting die mounted in the post. It is also necessary to have the post drilled along its length (if the nibbling die used is $\frac{1}{4}$", the hole should be at least $\frac{5}{16}$ for chip clearance) so that the chips can be ejected through the tube being nibbled by compressed air.

This tube end nibbler is used in the following manner:

From the sample tubes developed in the welding jig, nibbler templates are made from tubing of approximately $\frac{3}{16}$" wall thickness that has an ID approximately .015 over the OD of the tube to be nibbled. These templates are made as single end or double end templates, so that one or both ends can be shaped in the same template with the proper rotational alignment of the shapes desired on the tube end. A locking device is provided to hold the tube in place inside the template while it is being nibbled.

The tube is inserted in the template locked in place, and is ready to be shaped, which is accomplished as follows:

Compressed air is forced through from the back side of the hole in the post die. The tube with its template is placed on the post die and forced under the nibbling punch until the template contacts the punch. The tube is then rotated with the template in contact with the punch for one complete revolution, at which time the shaping operation is complete. A small amount of clean-up may be necessary in some cases, but usually the tube can be used "as is" after the nibbling operation. This type of tube end forming is the most satisfactory for arc welding as it leaves no feathered edges to cause welding troubles or cracks.

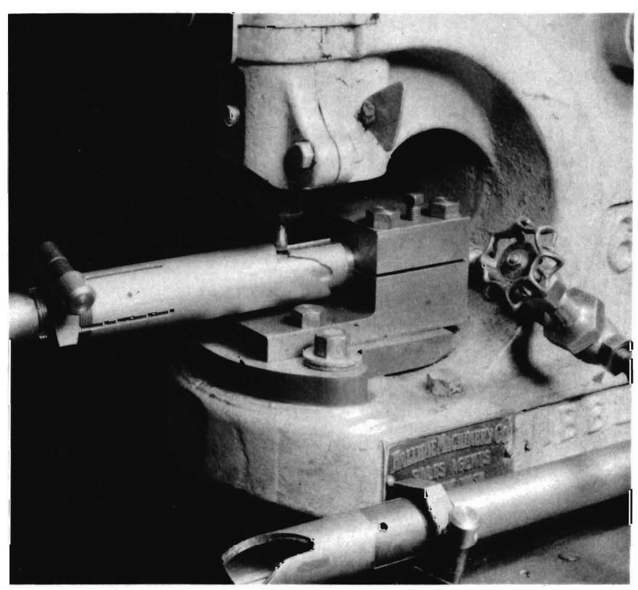


Figure No. 8—Tube Nibbler

3. *Die Cutting of Tube Ends*

When large quantities of small tubes are shaped for cluster assembly, the best method of shaping the tube ends seems to be by a clipping operation using special dies in punch presses. If this type of tube cutting operation is contemplated, care should be taken, in the design and manufacture of the tube clipping dies, to prevent the formation of feathered sections on the tube in the clipping operation.

EQUIPMENT

In order to obtain the best results, all arc welding machines used on aircraft structures should be equipped with Dual continuous controls of current and voltage; this will allow the delicate adjustment of both current and voltage that is absolutely necessary to obtain the high quality welds required for aircraft structures.

For small light gauge work, it is necessary to have current control down to and sometimes below 5 amperes. This can be obtained on both motor generator DC machines (such as built by the Lincoln Electric Co. of Cleveland, Ohio) or for light work only, the Electronic Arc Welder (Weld-O-Tron, manufactured by Allis-Chalmers) is also a satisfactory machine.

WELDING TECHNIQUE

Welding technique is largely a matter of properly training operators in the methods of obtaining correct machine adjustments and speed of laying filler rod to obtain good welds.

A good arc weld can be generally defined as having the following characteristics:

1. Good penetration.

Where the filler rod has been melted properly to the desired depth into the material being welded.

2. The welded bead should be reasonably smooth without excessively large craters or lumps where the weld is started and stopped.

3. The weld should be homogeneous and with low porosity.

4. There should be no overlap of the bead. Overlapping is usually caused by improper fusion of the welding rod with the parent metal.

5. The parent metal should not be undercut at the edge of the welded bead. Undercuts are usually caused by using too high a current for the welding rod size being used, and too high speed of travel of the electrode across the plate.

This article is too short to attempt to give much more information on operator technique but if the instruction of operators is contemplated, very good information can be obtained from the publications listed at the end of this article.

CLEANING PROTECTIVE COATINGS AND INSPECTION OF ARC WELDED ASSEMBLIES

When bare electrodes are used to arc weld assemblies, they are discolored and slightly scaled. When coated electrodes are used, the coating from the electrode is deposited in the form of a slag over the weld and welded area. To properly inspect welded assemblies, all discoloration, flux and tube scale must be removed.

The best method of cleaning arc welded assemblies is by sand or steel blasting of the completed units. This also furnishes a good surface for the application of protective coatings.

1. *Cadmium Plated Assemblies*

The procedure to be followed for the finishing and inspection of cadmium plated assemblies is as follows:

a. Sand or steel blast after welding, keep the parts as clean as possible, grease and oil free.

b. Cadmium plate and completely neutralize.

c. Magnetically inspect parts for cracks in the welding or adjacent metal.

d. Oil and drain inside of close tube assemblies. Plug oil holes with drive screws.

2. *Primed or Metal-Sprayed Assemblies*

a. Sand or steel blast parts after welding.

b. Magnetically inspect parts for cracks in the welding or adjacent metal.

c. Oil and drain inside of close tube assemblies. Plug oil holes with drive screws.

d. Clean parts thoroughly and keep grease free.

e. If a metallic spray protective coating such as aluminum is used, the parts should be primed immediately after being metal-sprayed.

Interpretation of Magnetic Inspection Results

Magnetic inspection of welded tubular assemblies is a very successful method of detecting cracked areas not apparent to the naked eye.

The process consists of the following steps:

1. The assembly to be inspected is magnetized either as a unit or in sections.

2. The parts are then submerged in a bath of kerosene in which a Para-Magnetic Substance (either black, or white for dark backgrounds) is kept in suspension by agitation of the bath. If the parts are too large to dip they are set on a drain tray and a stream of kerosene bearing the Para-Magnetic Substance is flooded over them from a hose.

3. The Para-Magnetic Substance will collect over and around sections in which there are either inclusions or cracks in the material.

Some experience is necessary to properly interpret the results of this type of inspection.

4. Typical examples of magnetic inspection results are shown in the attached sketches.

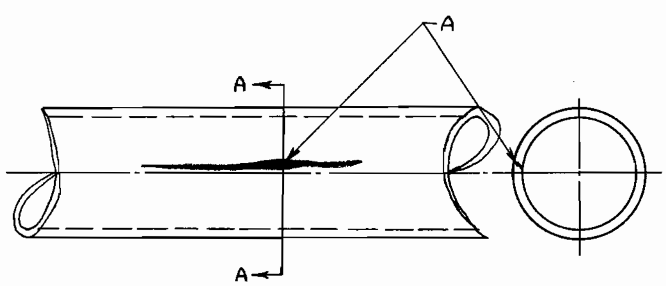


Figure No. 9

The shaded area at section A.A. indicates large crack or lap at an angle to the tube wall at that point.

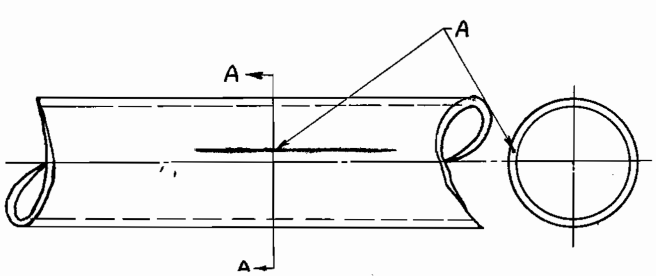


Figure No. 10

This type of result in the powder deposit usually indicates an internal threadlike inclusion in the material.

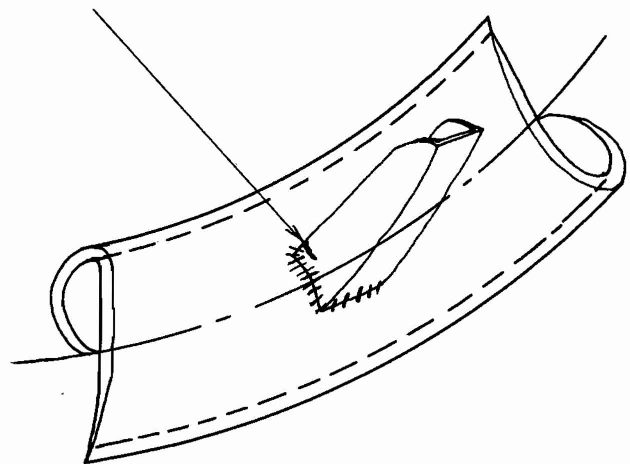


Figure No. 11

This is an example of a small area light section welded to a heavier piece of stock containing much more mass for heat dissipation. Unless care is used in the welding excessive grain growth, stress concentration and shrinkage cracks will be found as shown in the minor section. This is particularly true if attempts are made to straighten the minor section after welding.

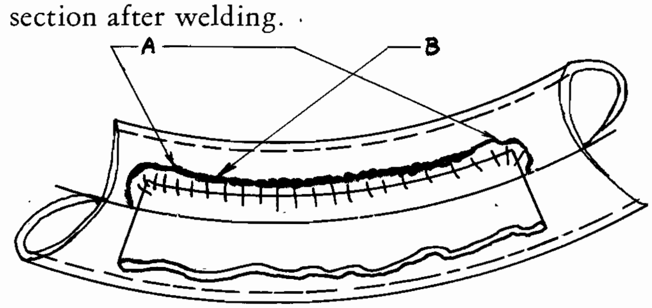


Figure No. 12

The cracks shown at A at the ends of the welded plate are the results of what is known as a "Hot Weld." Changes in the metallic structure of the material in the form of excessive grain growth and air hardening have promoted the cracking conditions. Arc welds made with bare electrodes have a tendency to build up excessively large beads which are sometimes slightly overlapped even in a good weld. When this condition exists, a diffused collection of the Para-Magnetic Substance will be seen all along the edge of the weld, as shown in Figure No. 12, section 12B. This does not indicate a cracked condition, and a small amount of experience with magnetic inspection will soon enable inspectors to differentiate between this condition and a cracked section.

For references to other text on Aircraft Welding, see Sec. II—9.

A PRACTICAL AND THEORETICAL PROCEDURE IN THE ART OF ATOMIC-HYDROGEN WELDING

By H. P. REIBER
LYCOMING DIV.—AVIATION MANUFACTURING CORP.

BASICALLY, Atomic-Hydrogen Arc Welding embodies two sources of heat energy, primarily an electric arc used to disassociate the molecules of the hydrogen into their atoms and secondly the inherent property of these hydrogen atoms to recombine into hydrogen molecules.

The process derives its name from the atomic state of the hydrogen gas incidental to the electric arc molecular disassociation.

The typical atomic hydrogen torch and equipment shown in Figure No. 1 will exemplify the practical and theoretical characteristics that produce an outstanding and efficient performance when used in conjunction with good welding technique.

The hydrogen gas, which is usually furnished in 200 cu. ft. capacity bottles at 2000 lb. pressure, is piped to a solenoid operated valve, the purpose of which is to stop the flow of the gas when the torch is not in use. From this valve the gas flows to the torch and thence to each of the two tungsten electrode holders. These holders are arranged such that the gas completely surrounds the tungsten electrode and emerges through a gas tip.

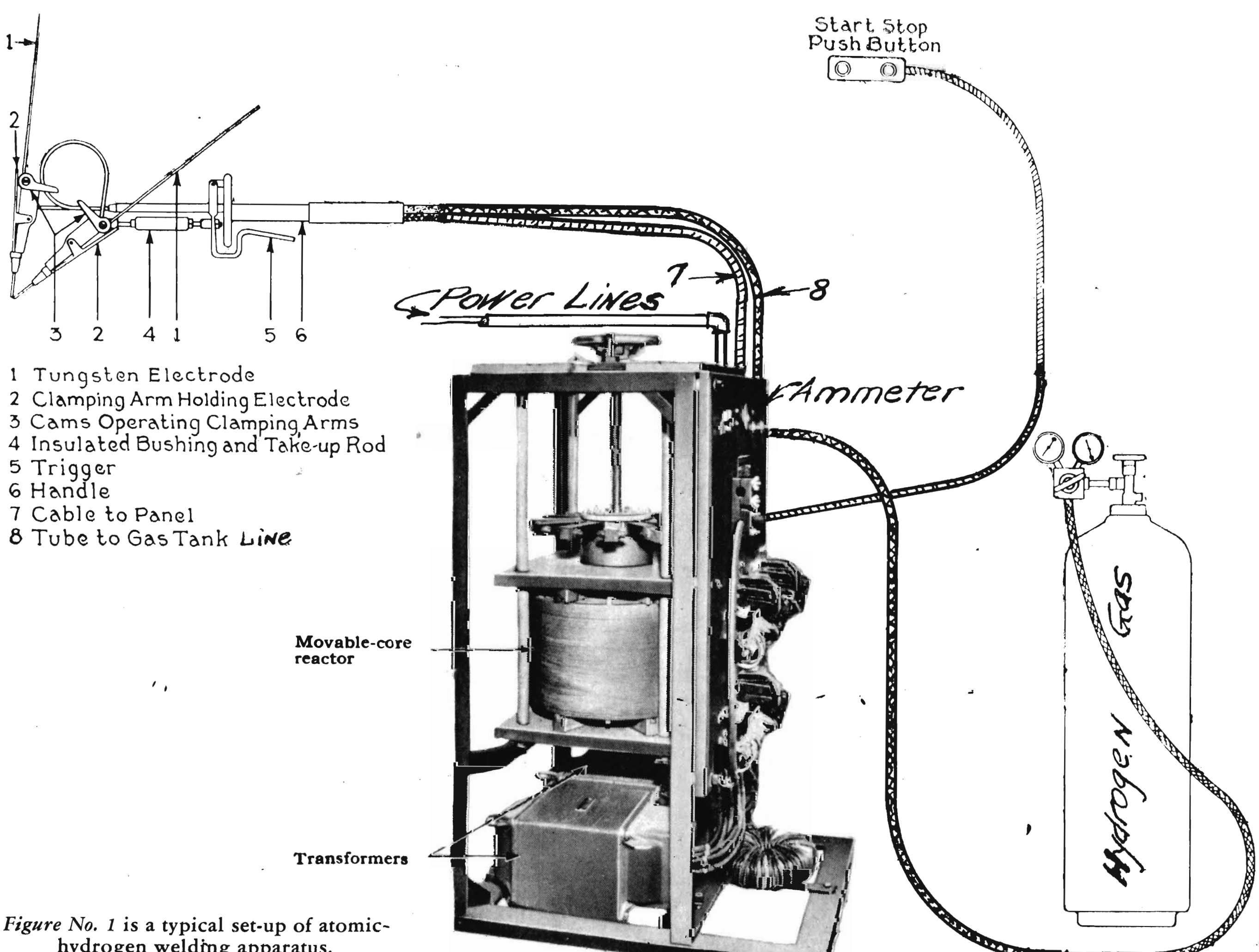


Figure No. 1 is a typical set-up of atomic-hydrogen welding apparatus.

The line voltage is stepped up to 300 volts for the welding circuit through a suitable transformer and in the latest type of equipment a movable core reactor provides a continuous current control for the welding circuit.

Assuming that the reducing valve on the hydrogen gas bottle has been set at about 10 lbs., and that an arc has been produced between the two tungsten electrodes and the current reactor has been set to the proper amperage, an intensely brilliant arc stream will be evidenced at the ends of the electrodes.

The phenomenon of molecular to atomic change of state in the hydrogen gas by virtue of the electric arc is accepted. A considerable amount of energy has been thus absorbed and a view of the arc stream will reveal a definite circular outline to this gaseous envelope. As the atoms escape the arc stream, they recombine to form molecules again at the outer edge of the arc fan or envelope and the energy is released as heat. This extra heat, added to the normal temperature of the electric arc, produces a temperature concentration at the boundary of the arc stream somewhere in the range of 7000 to 10,000° F.

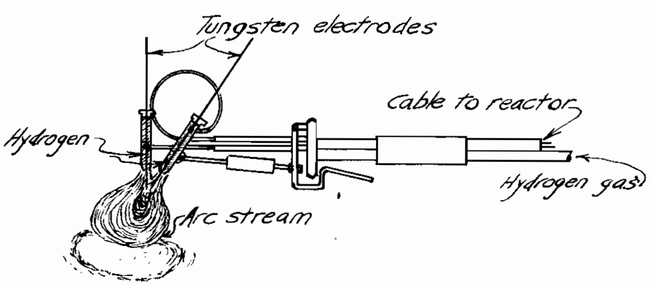


***Figure No. 2* shows a typical torch with attendant arc stream and molten pool of the work.**

Noteworthy features in connection with the atomic torch phenomena are the concentration of a high temperature in the small volume of the arc fan and outer edge, which just touches the work, excellent and rapid heat transfer to the work, complete shielding of the molten metal directly under the arc stream from porosity and brittleness produced by oxygen and nitrogen from the air and a detergent to surface oxidation after the weld is completed. The arc fan or envelope also shields the melting filler rod as it is used in the welding process again aiding in the prevention of oxidation. Facility for protected welding is thus on hand, now the feature of weldability of the product should be considered.

Weldability may be defined as the ability of the steel to tolerate the heating or thermal cycle of a particular welding process without the formulation of hard, brittle or porous zones. Hardenability is not strictly a criterion of a weldability but it does offer a fair measuring standard.

Metallurgical, chemical, physical and thermal factors influence weldability so that with these agents in mind it will be found that only by experiment as to acceptability of the weld can the selection of proper weld material be accomplished.

A weld may be defined as a localized union or consolidation of metals. Three characteristics in common exist in the welding process—the union or consolidation of metals is localized, metal in the joint is at a temperature above the critical value, and the weld is accomplished in a comparatively short period of time. Thus a small volume of metal is heated from room temperature to above the critical and cooled to below a black heat in rapid succession with the result of a rapid change in volume to create expansion stresses.

Internal stresses are propagated in the spread of heat by thermal conductivity, the work becomes ductile, soft and weak and in rapid cooling of the molten metal the effect of the dissolved gases entrapped in the weld is to produce porosity.

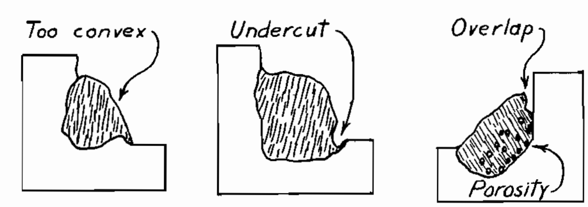


***Figure No. 3* shows examples of poor welding and can be used as examples in the determination of weldability of the parent metal and filler rod.**

Obviously in determining weldability the operator will observe gas bubbles, presence of alloying elements and impurities, dispersement or undercutting of metal, overlapping, porosity, hair-line cracks, and hardening. The examples shown in Figure No. 3 can be used in the determination of weldability of the parent metal or filler rod, either metal alone should not produce the results indicated. Proper welding technique sometimes will improve the low weldability features.

Welding Technique

As with any other art, welding technique is essentially a matter of craftsmanship. The resultant technique is not more difficult or involved than any other welding process, but ultimately the skill rests with the individual. Some observations from good, sound practice are offered: the electrodes for any torch should be so selected that they do not gas, melt, or spawl off too rapidly; many instances of excessive costs begin here and small particles of tungsten have

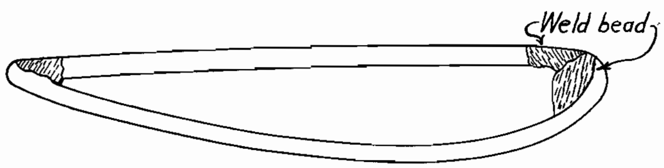


Figure No. 4 **is a typical hollow steel blade weld.**

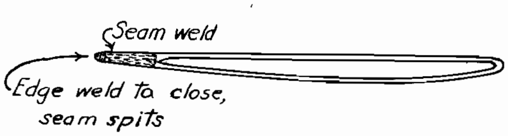


Figure No. 5 **is an edge weld adjacent to an electric seam weld.**

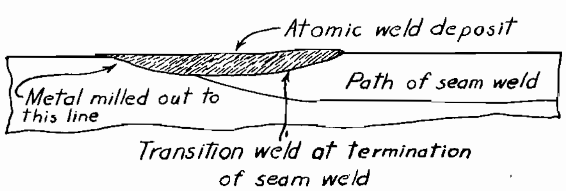


Figure No. 6 **is a transition weld at the termination of an electric seam weld.**

been found in the weld bead. The electrodes should extend beyond the gas tip of the torch 7/8" for 1/16" x 3/32" diameter electrodes and be again extended to this distance when worn down to 1/2". Similarly for 1/8" and 3/16" diameter extend 1 1/8" and reset at 5/8". Set electrodes just tight enough to permit movement by tapping with a wooden block.

The hydrogen gas pressure adjustment is best made by reducing the pressure until small beads, indicating rapid tungsten evaporation, begin to appear on the ends of the electrodes and the definite arc stream disappears; now increase the pressure on the reducing valve until the beads disappear and a well-defined arc stream is produced.

Proper welding current, resultant size of arc stream, gas pressure, size of electrodes are factors easily and quickly determined by reference to torch performance in creating the molten pool of metal, obviously the thinner the metal the lower the current and smaller the other factors. Equipment manufacturers have reliable data available for welding adjustments.

The metal should be melted away ahead of the molten pool with the electrodes about 3/8" from the work, cooling behind it and the puddling technique common to acetylene welding is most essential. Bring the filler rod into the arc stream close to the pool and permit this melted metal to drop into the pool, never permitting the rod to touch the electrodes. Good practice dictates a slow puddling and rotary motion to the torch and constantly plying the arc stream over the pool while it solidifies and cools down to a black heat. When depositing additional beads or layers, the first application should be at a black temperature.

Where possible the rate of cooling should be retarded and a convenient method is to preheat the material to be welded. A top temperature of 200° to 300° for low carbon content and 500 to 600° F. for higher carbon content, which, if at all possible, should be maintained during the welding process. The work should never be constrained from expansion movement and never subjected to extreme assembly pressure, supports should be provided to prevent distortion under the elevated temperature.

A neutral or reducing gas should be passed through the work while welding to prevent undesirable scale accumulations at the molten pool. Where a reducing gas is not available hydrogen gas is quite satisfactory; the sketch herewith offers a simple method of visible gas flow apparatus. See Figure No. 8 for Flow Bottle sketch.

Recommendations and Examples

The filler rod should be of the same chemical analysis as the parent metal with exception of an increase of approximately 5% in the carbon content to provide for inevitable carbon loss in depositing the filler rod metal.

Too much emphasis cannot be placed on the necessity of preheating the work, maintaining this temperature during the welding process, steady, not too rapid torch manipulation, slowly reducing the temperature of the welded joint to a black heat. Where possible the work should be given a thermal bath or heat treatment to relieve welding and cooling stresses and to eliminate the hard structures in the weld. The furnace temperature for low carbon, low alloy steels should be 1100 to 1200° F. and the work to remain at this degree for 1 hour, thence allowed to cool slowly; for low carbon, higher alloy, and air hardening steels such as S.A.E. 6130 and 4330 the furnace temperature range should be 1275 to 1300° F. and the work held for 1½ hours, thence cooled slowly. During this stress relieving cycle a constant flow of non-oxidizing gas through the work should be maintained.

In normal use the arc stream or fan shape varies in diameter between ⅜″ and ¾″ and emits a hissing sound. For light gauge or thin section stock the electrodes would be closer together, reducing the arc stream fan diameter below ⅜″ to a pointed silent arc. The fan stream is held practically vertical and in line with the weld seam for material $\frac{1}{16}$″ and

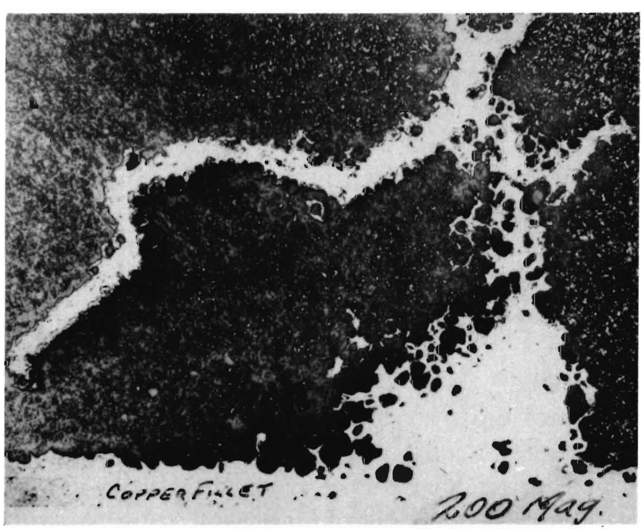


Figure No. 7 **shows a transition weld failure due to rapid deposit or cooling of the weld. Note the entry of copper, which is used as a fillet, into the cracks or voids. At this magnification (200x) the grain structure is quite satisfactory.**

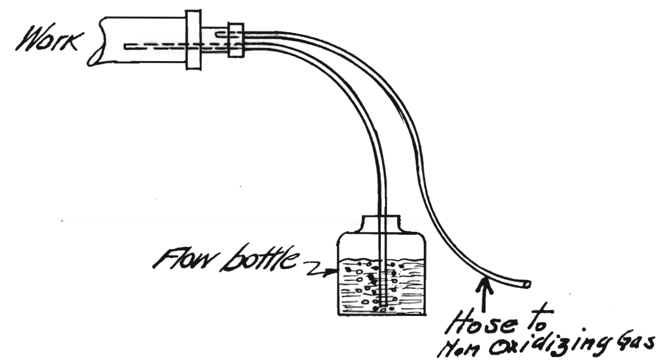


Figure No. 8 **is a typical gas flow bottle used during the application of non-oxidizing gas into the interior of the work.**

less in thickness to about 30° for material over ⅜″ thick.

Penetration of the molten pool is quite important so that in the case of a butt weld close observation should be made for the point at which the surface of the molten pool becomes almost quiescent and coupled with a bead width of about 3 times the plate thickness, the welder will have acquired good penetration. For edge welds the arc stream fan is carried more nearly parallel to the seam, inclined slightly from the vertical and satisfactory penetration is acquired when the molten pool flows to the outer edges and is well rounded. Penetration of corner welds is judged by the action of the molten metal and the bead displays no undercutting, overlapping, porosity, or holes as are indicated in the drawing under weldability, Figure No. 3.

After welding S.A.E. 4130-X steel and in fact any composition of steel, the rate of cooling from welding temperature and hence the hardness attained will vary with the process employed. Steep temperature gradients occur with spot welding and likewise low gradients or slower cooling transpire with acetylene and atomic hydrogen. It is recommended that in tubular structures a manipulation of the torch be maintained until a black heat is evident, care being taken to prolong the process consistently with efficiency.

It is essential in the last analysis of all ferrous welded joints that they be checked by the magnaflux method for the determination of proper and sound welds.

For references to additional articles on Aircraft Welding, see Sec. II—9.

NON-DESTRUCTIVE INSPECTION

By H. J. HUESTER, *Bureau of Aeronautics*

Note—The opinions or assertions contained herein are the private ones of the writer and are not to be construed as official or reflecting the views of the Navy Department or the naval service at large.

Magnaflux Inspection

The magnaflux test is a non-destructive method of locating the presence of cracks, laps, seams, large inclusions and similar defects in ferromagnetic materials such as iron and steel. This test has the particular advantage in that it will locate defects which are so small that they are invisible to the eye and which, in many cases, remain undetectable at magnifications of 50 diameters unless specially prepared. Under favorable conditions, it will locate defects below the surface of the piece being examined.

Metallographic examination and physical tests are established and reliable methods of determining the properties and quality of the materials used in construction. However, it is impractical to test by these methods every piece of material used, because these tests are in most cases destructive, and would result in the loss of the material or part required for construction. Nevertheless, it is vitally important that material or parts containing undesirable defects be identified and eliminated from use.

Many methods have been devised for non-destructive testing of materials and finished parts and structures. Among the most important are X-Ray, Gamma Ray, acid etching, ringing test for soundness, air pressure, hydraulic pressure, magnetic analysis and most recently, the magnaflux test and the electric defect detector developed by the Speery Products Company. None of these tests have unlimited application due to the characteristics inherent in each type of test. However, for the rapid, dependable and sensitive non-destructive testing of ferromagnetic materials, the magnaflux test offers many advantages over other tests developed to date. The electric defect detector for tubes is confined to tubing of uniform diameter and cross section and is used in the tube mill to insure products free of defects.

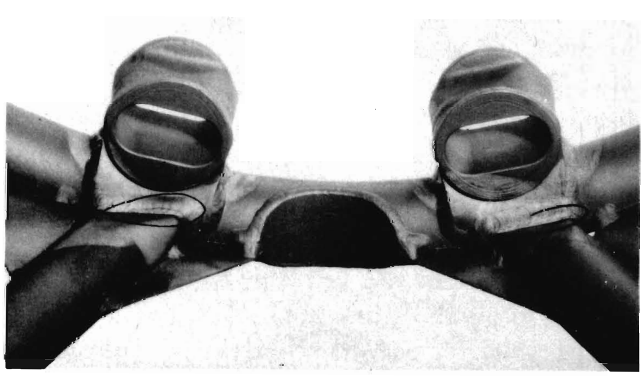


Figure No. 1A—**Welding Cracks on Engine Mount Shown Up by Magnaflux Inspection.**

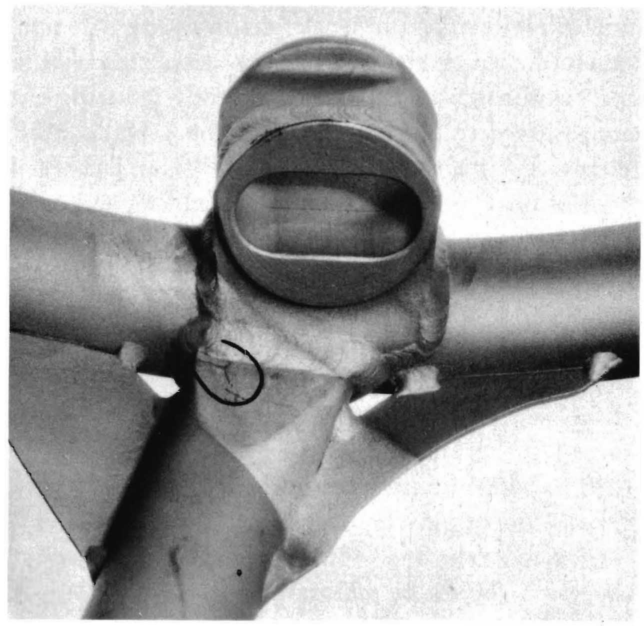


Figure No. 1B

Application

The general requirements governing inspection of magnetizable materials and parts for cracks, seams, laps, non-metallic inclusions, and other injurious defects by the magnetic flux method are covered by Army-Navy Aeronautical Specification AN-QQ-M-181. This specification is obtainable from the U. S. Army Air Corps or the Bureau of Aeronautics, Navy Department, Washington, D. C.

Equipment

Standard units have been developed by the Army and Navy to comply with the requirements of this specification. These units are commercially known as Army-Navy Standard Units and are obtainable under U. S. Air Corps Specification No. 50220-D dated 22 May, 1940 and Navy Aeronautical Specification M-6a dated 10 October, 1940.

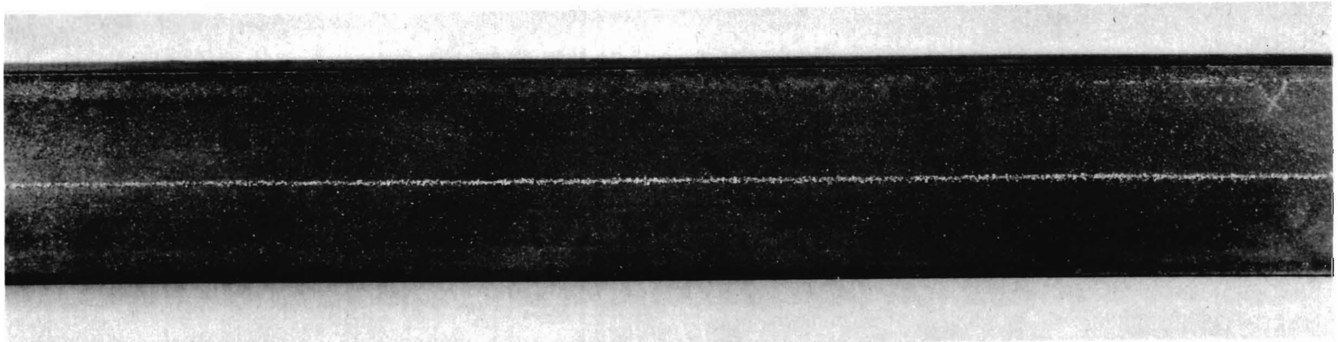


Figure No. 2 **shows the Magnaflux indication of a seam in a piece of bar stock.**

Fabricated Parts

Magnaflux inspection is conducted on all highly-stressed aircraft structural parts such as:

- Engine mounts.
- Landing gear including struts, bolts, etc.
- Wing hinge fittings.
- Arresting gear hook.
- Arresting gear buffer piston.
- Displacing gear.
- Tail wheel fittings and piston.
- Catapult hold down link.
- Hydraulic system.
- All springs.
- All welded primary structure fittings and welded joints which do not appear to have been properly welded.
- Any part which in the opinion of the inspector should be investigated.
- Armament installation supports.

Raw Material

The raw material or stock from which the above parts are fabricated is usually purchased as steel of aircraft quality which requires this material to be magnafluxed or otherwise tested to insure high quality product. This means that if latent defects in the steel are discovered during magnaflux inspection of the fabricated parts, the supplier of the raw material may be required to provide replacements.

Types of Defects

The indication of defects most commonly found in members of aircraft and aircraft engines and which are capable of detection by the magnaflux test may be classified under the following two major groups in order of their diminishing importance.

1. Cracks
2. Inclusions

Cracks—Under this group are included only those defects that represent actual rupture of the metal. They may be again subdivided into two classes: (a) Cracks developed in service by fatigue; (b) Cracks developed in manufacturing processes. This latter covers a host of defects too broad to discuss here but among which are laps, bursts, splits, pipes, shrink cracks in welds, hardening cracks, grinding cracks, etc. Cracks form the most serious class of all defects since they represent an actual parting of the metal which cannot be healed and are a nucleus for further growth and spreading of the crack under the action of repeated stresses and may ultimately lead to failure of the part.

Inclusions—This includes all types of what are usually classified by metallurgists as non-metallics. Among these are the sulfides, oxides, and silicates and particles of slag and refractory materials. When such inclusions are of appreciable size they may be detected by the magnaflux. In some cases, they are

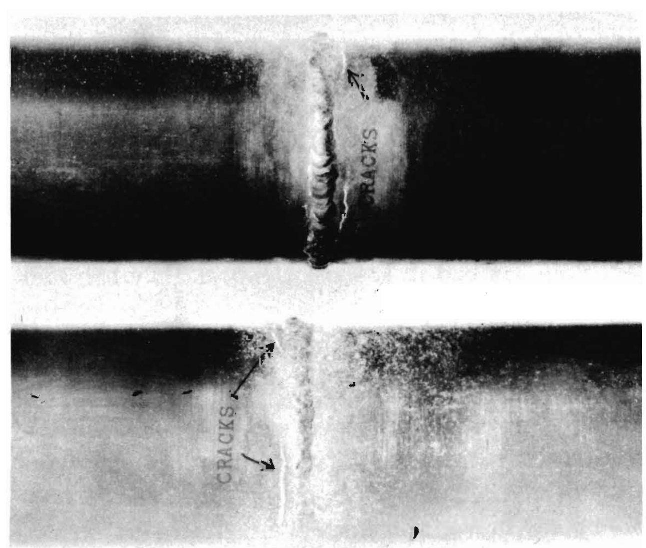


Figure No. 3. **Reproductions of welded sections photographed after Magnaflux Inspection which showed up small internal cracks in the welds as indicated by arrows.**

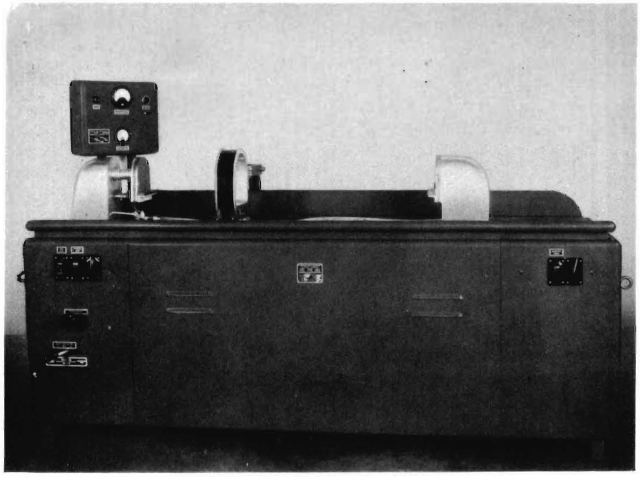


Figure No. 4 shows a model AN Magnaflux unit which is the one referred to on first page under "Equipment."

rolled out and appear in steel as the familiar seams and hairlines. This class of defect is often dangerous depending upon its size, its location in the part and the conditions of stress in the part.

Since the surface is the vulnerable location under repeated stress, and any sort of surface roughness or discontinuity has an effect on stress distribution, it follows that a non-metallic inclusion lying at the surface may be deleterious. As in all other instances, the discontinuities are more serious the harder the steel. In soft steels, the effect of the ordinary inclusions is very minor.

Wherever the difference between a mirror-lapped surface and a rough ground surface would affect the service life under repeated stress sufficiently to demand polishing the surface, then avoidance of even ordinarily small inclusions and the selection of extraordinarily clean steel of "aircraft quality" is fully justified. Big inclusions on the surface, such as cannot fail to be shown by magnaflux inspection methods, are bad in any steel, especially when they happen to coincide with an external stress-raiser such as a poor fillet. In such a case the inclusion may be the last straw on the camel's back.

By and large, the effect of inclusions as inherent stress-raisers in steel is very minor indeed compared to the imposed stress-raisers in the form of poor fillets, oil holes, and discontinuities of that character which are so common in neglectful design. Between inclusions and keyways, the comparison is as the mote and the beam!

Failures

The types of failures found in aircraft parts are usually due to minute welding cracks which have their origin adjacent to the weld as shown in accompanying photographs. This is usually caused by faulty welding technique. The minute cracks progress under vibratorial stresses and cause complete separation of the member.

The failure to the engine mount shown in the photographs progressed from a minute crack, which apparently originated during the welding operation. A large percentage of these cracks cannot be detected with the unaided or aided eye alone. This conclusion can be confirmed by examination of the samples shown in photograph, Figure No. 3. The arrows in the photographs point to cracks, which have been revealed by the use of iron dust and which could not be detected visually. These minute cracks apparently developed during the welding operation.

Welded assemblies can be conveniently inspected by being properly magnetized, with the portable magnetizing unit furnished with the AN units.

Magnaflux locates seams and stringers in tubing and internal die scratches are located from the outside surface. The largest field of magnaflux inspection in connection with tubing is in the inspection of welds in tubular structures and the welds attaching fittings to tubing.

This inspection is for the location of lack of fusion or slag inclusions in the welds and also cracks in the tubing, adjacent to the weld.

Method of Rating Magnaflux Indications

In order to clarify and simplify description of inclusions in steel a special subcommittee of the Iron and Steel Division of the Society of Automotive Engineers has prepared a method of rating magnaflux indications. The rating system is not intended as a direct index of quality, but rather as a shorthand description of the indications observed on the surface of the sample.

The accompanying rating system is a simple code whereby the number, length and distribution of the magnaflux lines may be expressed on the basis of a square foot of surface examined, regardless of the size of the sample. In general, it is suggested that for convenience in handling and counting, the sample should be not less than 5″ long.

CODE FACTORS

(1) The total number of lines per square foot;

(2) the aggregate length of all the lines per square foot;

(3) the length (inches of the longest single line);

(4) a letter, A, B, C, or D indicating the uniformity of distribution.

The length of the longest line is given to the nearest 0.1 in. and the aggregate length to the nearest inch.

The letter "A" indicates uniform distribution, "B" a slight tendency toward grouping, "C" an arrangement of discernible groups and "D" indicates well defined or concentrated groups or clusters.

To distinguish indications of exceptionally heavy nature, the letter "H" may be added to the figure giving the length of the longest line, item (3). In case the average lines rather than only the longest line, might be heavy, the letter "H" might be added to the aggregate length of all the lines, item (2).

Indications of "pepper and salt" nature, less than 0.1 in. in length are not to be counted as lines but are regarded as background, and unless in large numbers, will be disregarded. When in large numbers, their presence will be mentioned after the form rating items, by appropriate descriptive words.

Where indications of less than 0.1 in. length occur in "ranks," or strung out end to end they will be counted as lines whenever the spaces or interruptions between them are less than 0.1 in. across. When the spaces or interruptions are more than 0.1 in. across, these short indications will be disregarded.

SOME REFERENCES ON MAGNAFLUX INSPECTION

Non-Destructive Tests. Magnetic Dust (Magnaflux) Method; Magnetizing Field, Ferro-Magnetic Material, Wet Method, Demagnetization, Equipment, by A. V. DeForrest, F. B. Doane and C. A. McCune. In Welding Handbook; American Welding Society, New York, 1938, pages 702–707. (New edition due to be published in late 1941.)

Magnetic Testing. In Metals Handbook; American Society for Metals, 1939, pages 770–772.

Principles of Magnaflux Inspection, F. B. Doane.

General View of Glenn L. Martin Welding Department

TUBE BENDING

By H. M. WILLIAMS and C. G. A. SWANSON
WILLIAMS, WHITE & CO., MOLINE, ILL.

Beginning with tubular frames for bicycles and for piping plumbing fixtures, the use of bent tubing has grown so tremendously that new high speed methods for bending must be employed in the production of household and office equipment, agricultural implements, and especially in the airplane, automobile and motorcycle industries. The old method of filling the tube or pipe with powdered rosin or sand and plugging the ends before bending, so as to prevent collapse, has some merit, but is extremely slow and is now used only in miscellaneous special work where only a few pieces are required. The three high production methods are as follows:

1. ***Revolving die form with stationary ironing die and mandrel:*** The tubing is inserted in bending dies and over a stationary mandrel which is withdrawn after making the bend. The tube is clamped and then clamp and bending die revolve, pulling the tube around the bending die and over the mandrel. The purpose of the mandrel of course is to prevent collapsing. See photographs Nos. 1 and 3.

2. ***Floating wiping die:*** Tubing is inserted in a set of stationary bending dies and clamped, whereupon a swinging arm to which the sliding die is attached carries it around the stationary die, wiping the tubing into the groove. This type of die is used principally when a bend of changing radius is to be made. See photographs Nos. 4, 5 and 6.

3. ***Presses:*** Of the many methods employed in tube bending on presses and bulldozers, the three most generally used in production are:

   (a) The common male-female forming die construction, which is particularly adapted to the bending of large radii and irregular curves.

   (b) The male forming die with either floating or pivoted rollers or shoes, which is used mainly in bending of heavy pipe or tubing. See photograph No. 2.

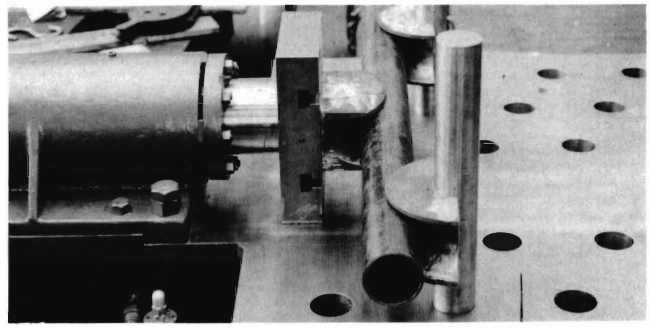


Figure No. 2

   (c) The wing die and cushion construction. A vertical mechanical or hydraulic press is fitted with a radius die on the upper ram, with two rocking type dies on the table, which is supported on a pressure pad which gives downward as the upper ram descends, carrying the tubing with it. The rocking dies on the table have the effect of wrapping the tube around the upper bending die. See photograph No. 7.

With methods 1 and 2, either hydraulic or mechanically operated machines are used, and even hand operated on light work where production is not high.

Selection of the type of production bending equipment must be based upon the mechanical and physical properties of the tubing itself. In general it is desired to have tubing with high elongation, a low ratio of yield strength to tensile strength, and a sufficiently high ratio of wall thickness to tube diameter. It must be ductile to take the necessary stretch in the outer wall. However, it must have sufficient stiffness to prevent buckling or failure by compression on the inside of the bend. Also, it must have sufficient strength to stand the combined tensile and flattening stresses. In bending the decreased strength caused by the thinning of the outer wall is somewhat offset by work hardening due to cold stretching. In ductile material the flattening stresses are relieved by the natural flow of metal. Rather complex stress analyses are used to determine the required power for bending tubing without depending on experimental results.

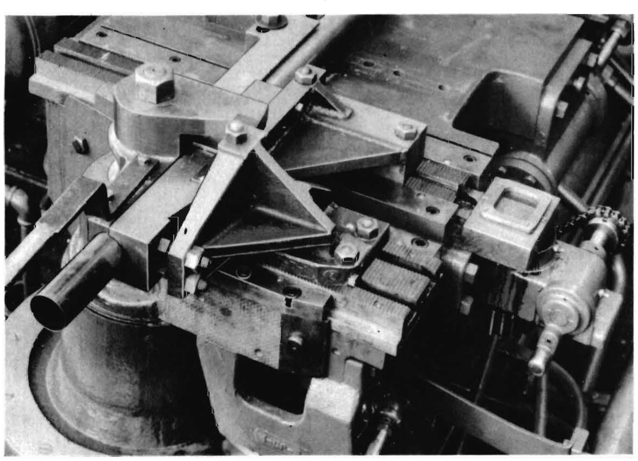


Figure No. 1

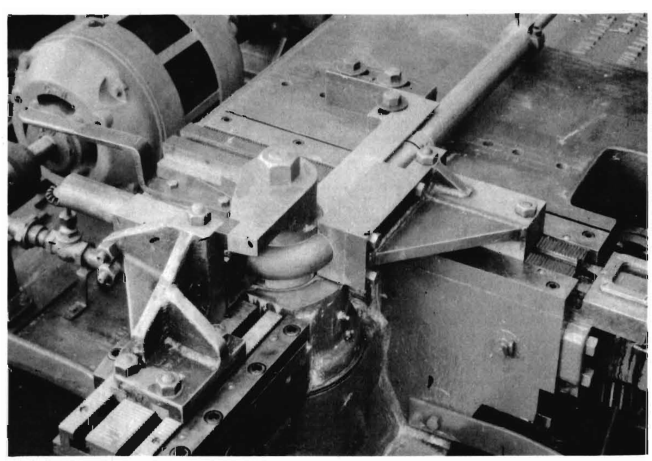


Figure No. 3

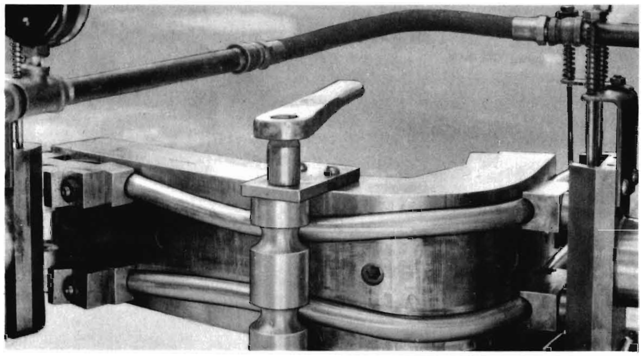


Figure No. 4

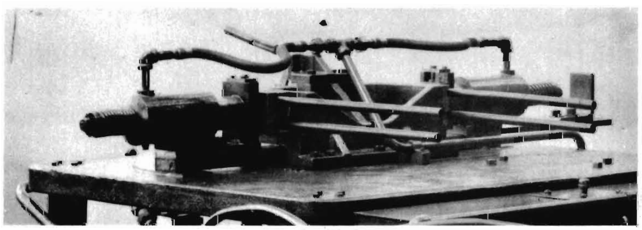


Figure No. 5

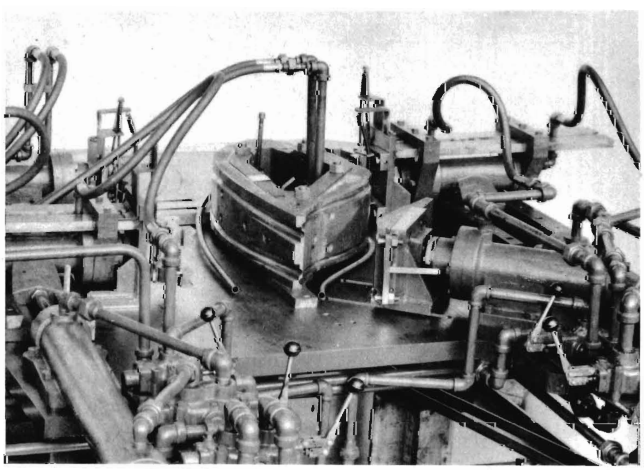


Figure No. 6

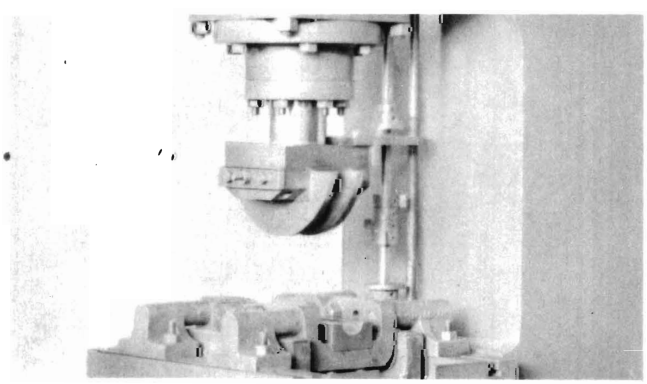


Figure No. 7

In bending tubing the following conditions must be considered:

(a) The quality of the tubing must be such that it will take a bend of the required radius and degree—that is, it must bend without breaking or tearing. No matter how carefully the dies and mandrels are made and fitted to the tubing, the tubing itself must be of such quality as to stand the various bending stresses.

(b) With tubing of the proper quality, the bend is only as good as the fit of the bending dies and arbor or mandrel, therefore the dies must fit the stated size of the tubing, and in production the tubing must come to that size within very close tolerances.

(c) In making small radius bends in large diameter thin-walled tubing, such as grease traps, half hard tubing is generally used and the section to be bent is annealed before bending; with such annealing held very close as to the length of the section of the tube to be bent and the temperature and time of the annealing.

(d) With methods 1 and 2 the clamping die must be of such a construction that the tube positively cannot slip, as any slippage causes wrinkling and breakage of the tubing. With thin-walled tubing teeth are often cut in the clamping dies to prevent slipping, as it is not possible to put sufficient clamping pressure on thin-walled tubing without collapsing it.

(e) Various types of mandrels are used in bending thin-walled tubing. The solid type and the jointed type are the most commonly used. The selection of the type to be used depends upon the nature of the material to be bent, the radius and degree of bend, the smoothness required and amount of flattening permissible in the bend.

(f) Inner shoes are used on the inside of the bend ahead of the bending die in bending thin-walled tubing to prevent inside wrinkles.

(g) In bending tubing hot, care must be given to keep the temperature as low as possible so that the strength of the tubing is not decreased any more than necessary. Greater plastic flow naturally results at elevated temperatures and is often employed in difficult production bending.

In bending square tubing, split dies must be used, because the upset on the inside of the bend swells the tube in the dies so tightly that it cannot be removed without separating the die. Therefore the dies are closed, the tubing bent, the clamp released, which allows the die to open so that the bent tube can be removed.

Thin flat material may be bent edgewise in the same sort of die as is used for square tubing—that is, dies split so that the piece may be freed after bending.

Bending small angles and extruded shapes requires special dies, depending on the size and shape of the material and the radius and degree of bend.

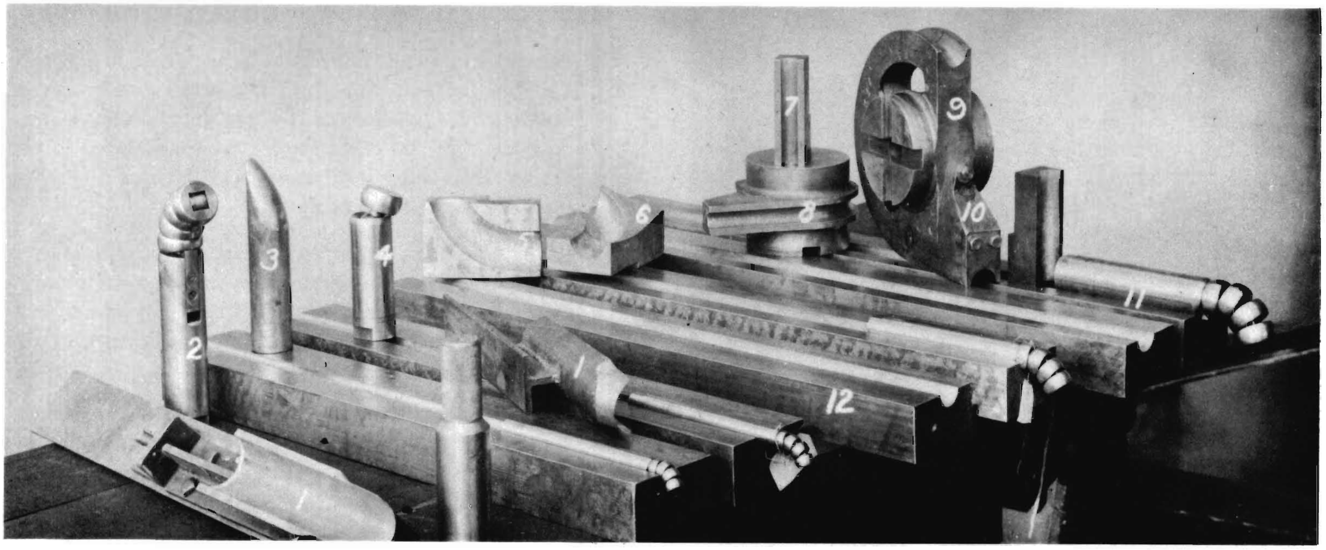


Figure No. 8

TOOLS

Photograph Fig. No. 8 shows a number of typical standard tools used for bending different diameters, wall thicknesses and radii, as well as tubes of various material, such as seamless steel, brass, aluminum, welded steel, stainless steel clad, lock joint, or any tube the physical and chemical qualities of which will permit bending by any method.

The two parts numbered "1" in photograph Fig. No. 8 show stationary inner shoes, sometimes called wiper dies, that are usually needed when bending thin walled tubing to short radius without wrinkling the inside of the bend.

Part No. 2 shows a jointed ball mandrel used with Part No. 1 inner shoe.

Part No. 3 shows a solid type mandrel used on heavy wall tube with long radius bend, which does not require the more expensive jointed ball mandrel for satisfactory results.

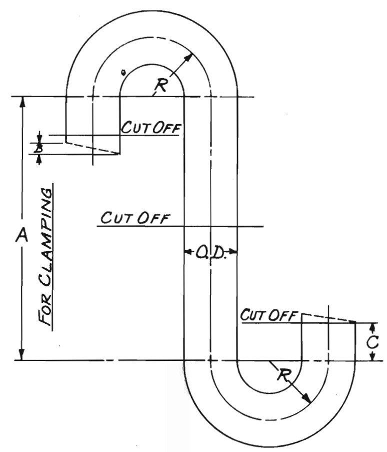
Part No. 4 shows a single ball mandrel which may be used instead of No. 3 for work coming between jobs requiring No. 2 or No. 3 mandrels—especially in making a bend within a bend —that is, in two planes—with the type clamp shown by Parts No. 5 and No. 6.

Parts No. 8 and No. 9 show various types of revolving dies or "wheels" which are used according to the class of work to be done: No. 8 is a solid revolving die and No. 9 is a similar die but with the clamp die section No. 10 removable so that it can be used on practically all radii of bends in tubing of the same outside diameter.

Part No. 7 shows one design of clamp die to clamp the tubing to the revolving dies No. 8 and No. 9.

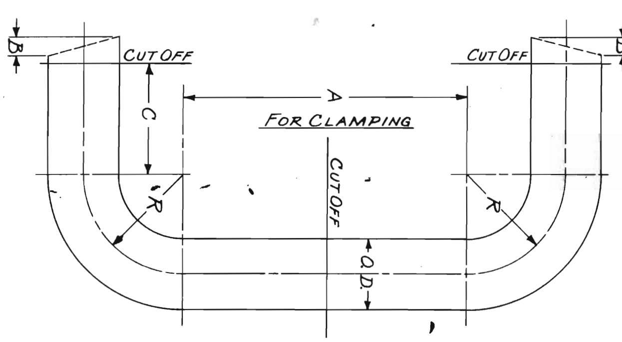
Part No. 12 shows the outside die which holds the tubing tight against the revolving die. This outside or sliding die generally moves ahead with the tube and prevents scratches as well as excessive tool wear. In some cases this outside die is stationary if the material in the tubing and the diameter, radius and wall thickness permit.

For high production it is important that the machine have extreme rigidity, flexibility of adjustment, and convenience of operation.



Sketch No. 1

Soft Annealed Tubing.
1½" OD, 17 and 20 Gauge, 1¾" Radius.
A. Approx. 7". B. Approx. ⅝". C. Approx. 1".



Sketch No. 2

Soft Annealed Tubing.
2" OD, 17 Gauge, 2⅝" Radius.
A. Approx. 7½". B. Approx. ¼". C. Approx. 3½".

CORROSION PROTECTION

By CHARLES W. WOODROW

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The opinions or assertions contained herein are the private ones of the writer and are not to be construed as official or as reflecting the views of the Navy Department or the naval service at large.

EVEN in this day, insidious, wasting corrosion which is synonymous with rust is taking its toll through improperly protected metal. These costly losses are not confined to the loss of the material but they likewise cause loss of sales in a highly competitive market.

This article is written with the purpose of centering the discussion upon the causes of corrosion and how to prevent such corrosion during the process of manufacture, in transit, or storage prior to use. After the metal is fabricated, other protective coatings or coverings may have to be relied upon to prevent corrosion.

In the instance of tubular structures, the tubing must be thoroughly protected against corrosion following the cleaning prior to the burning off of the original preservative during welding, heat treating and sandblasting. General practice calls for protecting the internal walls of the tubing with an oil type of preservative, while the outer exposed surfaces are primed and finished with at least two coats of a durable hard drying organic protective coating.

THE WHEREFORE OF CORROSION

The corrosion of metals, either surface or along the grain boundaries, is the process of gradual disintegration or decomposition of a chemical nature. Many destructive elements or compounds are the cause for the change of the processed iron to its stable form, that of iron oxide. The most destructive of these agents are acids, certain gases, salts and the ever abundant moisture.

The study for the prevention of corrosion has been long and arduous and through this study many theories dealing with the causes of corrosion have been evolved. Of these the following merit comment:

The Acid Theory
The Colloid Theory
The Direct Chemical Attack Theory
The Biological Theory
The Peroxide Theory
The Electro-Chemical Theory

The acid theory assumes that some acid is formed through dissolved carbon dioxide. However, later work has shown that corrosion will take place in the absence of carbon dioxide.

The colloid theory has been evolved around the idea that iron, coming in contact with liquid water and in the presence of air or oxygen, slowly oxidizes to ferrous hydroxide in a colloidal state. Through the catalytic action of oxygen, the chemical action continues until the iron hydroxide precipitates out.

The theory of direct chemical attack by oxygen maintains that the metal is directly attacked by dissolved oxygen.

The biological theory contends that corrosion is caused by the presence of micro-organisms. Organic by-products of these organisms are considered the cause of oxide formation.

The peroxide theory states that the corrosion of iron is due to the decomposition of water by the corroding metal, so that the hydrogen is liberated to react with the dissolved oxygen to form hydrogen peroxide.

The electro-chemical theory is based on the separation of the ions, a chemical action resulting from electrolysis or the decomposition of a substance. This theory has been substantiated by extensive research and represents the most modern thought on the study of corrosion. According to the theory, the different potential of dissimilar particles of the case metal in the presence of water sets up a small electric current. The H^+ cations and the O^{++} anions of slightly dissociated water migrate to the cathode and anode portions of the metal respectively If no dissolved oxygen is present in the water, the reaction is immediately stopped by the accumulation of the H^+ cations at the cathode. However, in the presence of the dissolved oxygen, the cations combine to form water and the reaction proceeds, insoluble iron oxides precipitating from the anode.

Aside from the foregoing theories, extensive research has proven the following important fact: Iron will not appreciably corrode in the absence of moisture.

Tests made by accredited laboratories seem to indicate that iron will not corrode if a humidity level below 30% is maintained. Relative humidity and the temperature are controlling factors. Relative humidity is the amount of moisture present given as percent of the total water vapor which could occupy the considered space at the prevailing conditions of temperature and pressure. The relative humidity thus varies inversely with the temperature. Official weather bureau reports show that it is very unusual for the relative humidity of outside air to drop below the critical value of 30%. Even under normal weather and storage conditions, the manufacturer and the fabricator will always be confronted with the likelihood of corrosion due to the ever possible condensation of vapor. Take note of a simple example: You know many people who wear spectacles. You have been with them many times in the cold of winter when you have passed into a warm interior from the intense cold outdoors. What has happened? Immediately their spectacles fogged as the moisture in the air of the warm interior suddenly chilled by the cold glass surface reached the dew point and condensed. This is what is meant by insidious condensation which will often precipitate upon the metal to cause corrosion during many sudden changes of temperature through short periods of time.

RUST PREVENTATIVES

The many years of research have produced voluminous data and methods for combating corrosion. These methods have included—

- The development of alloys highly resistant to corrosion
- The conversion of metal surfaces with chemicals
- The application of metallic coatings
- The application of non-metallic coatings
- The use of packing materials

Alloys highly resistant to corrosion

The uses for corrosion resistant alloys are many. Their need is vital in chemical plants where utmost resistance to corrosive chemicals is important to the economical operation of the factory.

Conversion of metal surfaces with chemicals

The conversion of the metal surfaces through the action of chemical compounds has become widely known. This method of protection against corrosion is especially adaptable for iron and steel. After the metal has been thoroughly cleaned, and, if necessary, pickled or sandblasted, the fabricated parts are dipped in the chemical solutions for the required and stipulated period of time. Upon completion of the coating operation, the parts are thoroughly rinsed, dried, and then coated with a rust preventative.

Metallic coatings

The application of metallic protective coatings is widespread. Data describing each metallic coating and the methods for the application of these metals can be found written in many technical books and articles. The metals usually applied for commercial use as metallic coatings are copper, lead, aluminum, zinc, cadmium, tin and nickel.

Non-metallic coatings

The non-metallic coatings can be divided into two classes. In the first class or group are included paints and the modern synthetic lacquers, varnishes and enamels, classified as organic protective coatings. These coatings are derived from the processing of oxidizing oils, synthetic and natural resins, cellulose derivatives and pigments.

The second class of non-metallic coatings include the hard drying and the non-drying oil types of coatings or rust preventatives.

The hard drying oil type compounds can be applied by a spray gun or brush, such as is commonly used in applying paints. These coatings dry hard in a short time. They cannot be removed, however, with ease. These coatings are practical for rapid handling with this limitation on their selection—they must be free from cracking, peeling, or slipping from the metal surface. The hard drying film forming coat is carried in solution by a volatile. After application, the volatile evaporates, leaving the hard coating capable of withstanding heavy wear and resistant to the corrosive action of air and water. The film should also have sufficient flexibility to withstand any subsequent formings of the metal. When it is necessary to remove this coating, it should be readily soluble in a solvent.

The non-drying oil type coatings have widespread application as they give excellent protection against corrosion. They are a type of coating, if properly formulated, that does not harden or lend itself to cracking, peeling or slipping from the metal surface. This class of coating should be readily soluble in solvents when it is necessary to remove the oil coating for subsequent operations or protection.

The essential properties necessary in a rust preventative are those which will (a) wet the metal and displace the water adhering to the metal surface, (b) not corrode the metal, (c) adhere to the metal in a solid homogeneous film throughout the storage period without running away from the surface, (d) not oxidize over the long storage period, (e) be easy and economical to remove, and (f) not have a toxic effect upon the operating personnel.

The preservative must thoroughly wet the metal surface and displace or absorb the water adhering to the metal surface. This type of compound is essentially a very excellent grade of mineral oil to which additives having active polar characteristics have been incorporated in the oil. A polar compound, according to Langmuir, is an organic compound which possesses the ability to readily orient itself in close proximity to the molecular surface of the metal to preferentially wet the metal surface in relation to the water. This type of compound is defined as having atomic electro-magnetic properties in the presence of a metal.

Included in this polar active oil preservative are additional anti-corrosive materials or chemical inhibitors which can either be an amine (an alkaline reactive organic compound derived from ammonia) or a dichromate salt. These anti-corrosive materials must be slightly water soluble, as is the amine, to help take up the water adhering to the metal and neutralize any weak acids formed or to have the properties of a dichromate compound to unite with the adhering water to form an oxide protective coating to the metal.

These compounds must adhere to the metal in a solid homogeneous film throughout the storage period without running away from the surface. They, therefore, must be true homogeneous compounds. The consistencies of this class of rust preventative vary from heavy grease-like consistencies requiring heat for application to consistencies which can be applied by dipping, brushing or spraying at normal temperatures. The desired flowability for the rust preventative compound is dependent upon the type of product to be preserved. Some of the compounds are diluted with a solvent which evaporates off and leaves a protective coating or film.

Protective compounds must not oxidize over the long storage period. Oxidation may produce a brittle film which may be chipped from the metal during handling, thus exposing the metal to corrosive elements.

The preservative should be easily as well as economically removed by means of solvents or degreasing compounds so that a chemically clean metal surface is obtained for any subsequent rust preventative which may be applied to the metal.

The health of the operators must be taken into consideration. Particular attention must be paid to good ventilation, especially if the compounds contain volatiles. Protective measures must be taken to insure against both respiratory and skin disorders of operating personnel.

Packaging materials

The use of packaging materials, such as packing paper or transparent film materials, represents an added method of protection against corrosion. It is essential that the material selected have the following characteristics:

1. It must be of such a character as to be impermeable and impervious to moisture. It may be a parchment grade of paper impregnated with a preservative or coated with a moisture impermeable coating or moisture-proof transparent film.
2. It must be treated in a manner so as to prevent the absorption of the preservative on the metal into the paper.
3. It must not contain any harmful chemicals which, while in contact with the metal, will cause corrosion.
4. It must resist breakdown of the above desired characteristics in prolonged contact with the surface preservative to be used.

Surface preparation

In the interest of economy the following steps are essential toward arresting and preventing corrosion:

1. Be sure that the metal is reasonably dry, clean and free from mill scale, dirt and rust. As stated in the beginning of this article, iron will not corrode if the relative humidity is maintained below 30%. However, as this ideal situation is not always available, care must be exercised in handling the metal prior to preservation.
2. If the metal has just been drawn, have room as dry as possible while cooling. When metal is at

room temperature, preserve against corrosion by the method selected. It is important that all surface oxygen and moisture be removed before applying the preservative.

3. If the metal has been previously preserved and is badly corroded, wire brush, if feasible, to remove any corroded particles. Pass metal through a degreasing bath or use other effective cleaners, then preserve by the method selected.

Applying a rust preservative to moist metal will seal the moisture between the preservative and the metal permitting rust or corrosion to take place beneath the surface of the preservative.

LABORATORY TESTS

Salt Spray Test

The following salt spray test may be used, in part, for evaluating the protective characteristics of a preservative. A complete detailed description is in the tentative method of salt spray testing of non-ferrous metals (and ferrous metals) A.S.T.M. Designation B 117-39T, page 1169 of the A.S.T.M. Standards 1939, Part 1. The construction of the salt spray chamber is described in detail. Either a 3.5% or a 20% solution by weight of sodium chloride in distilled water may be used. The pH of the solution should be from 6 to 7. The salt should be at least 99.8% sodium chloride. The operating temperature for this test should be room temperature.

The panels, after preservation, are usually hung vertically. The spray, highly atomized by impingement against a baffle plate, passes over the panels. The salt stimulates corrosion, as it provides an excellent medium for electro-chemical corrosion.

Method for Determining the Water Vapor Permeability of Wrapping Materials

The following method for determining the degree of water vapor which will permeate commercial wrapping and packaging materials has been prepared by the technical staff of the Davison Chemical Company.

"Stender dishes having a diameter of 60 millimeters and a height of 35 millimeters are used for the test. Disks of the sample under examination are cut to fit these dishes fairly accurately. A sharp edged steel device similar to a cake cutter has been found to work advantageously for the cutting. The dishes are fitted with a stainless steel ring, the circumference of which is arranged so as to easily fit inside of the dishes. These rings are open and arranged so that the slight tension of the spring will hold the ring in position. This ring is placed about ¼″ below the top of the dish. The fiber disk is then placed on the steel ring which serves as a support. The membrane is then sealed to the edge of the dish with beeswax.

"These permeability tests are run so that the driving force through the membrane will be equivalent to 60% relative humidity. When devising the method it was felt that this would be of a more practical application than to use a desiccating agent over a saturated atmosphere. For the purpose of maintaining this driving force with the greatest amount of simplicity, it was decided to use a saturated solution of ammonium sulphate in the chamber surrounding the stender dishes. Such a solution gives an 80% relative humidity over a wide range of temperatures.

"Before sealing the membrane in the dish, a slurry of saturated solution of potassium acetate and crystals equivalent to a depth of about ¼″ is placed in the stender dish. The dishes are then placed under a large bell jar over the ammonium sulphate solution and the pick up in weight is noted at regular intervals of about 24 hours until a regular rate of rise is obtained.

"The equation below expresses the permeability in pounds of water vapor per square foot of area, per hour, per millimeter of mercury:

$$P = c\left[\frac{\triangle W_f - \triangle W_i}{A} \times \frac{1}{T_f - T_i} \times \frac{1}{(\text{a.v.p.d.})}\right]$$

where P is the permeability; c is a constant needed to change from the c.g.s. system of units to the British system; $\triangle W_f$ and $\triangle W_i$ are the final and initial changes in weight expressed in grams, respectively, found at times T_f and T_i expressed in hours; A is the area in square inches; (a.v.p.d.) is the average vapor pressure difference expressed in millimeters of Hg between the outside and the inside of the cell.

"The area, A, is obtained accurately to two decimal places with a planimeter.

"A continuous recording thermometer indicates the room temperature throughout the test. By taking the temperature reading at 2-hour intervals (an arbitrarily chosen figure), the vapor pressure of the saturated solutions of both ammonium sulphate and potassium acetate can be obtained by reference to proper tables. (See International Critical Table, Vol. 1, pp. 67–68.) The difference is obtained by subtraction. These various differences are then averaged over the entire period of the test.

"Substitution of these values in the Equation gives the desired result. The weights are read to four places, the area to two, the average vapor pressure difference to two, and the final result is carried to nine places."

OTHER LABORATORY TESTS

For Rust Preventative Compounds

Other tests have been developed by many laboratories, some of which are a partial immersion of the panels in a 4% salt water solution, the alternate immersion of the panels in a 4% salt water solution and the subjection of the preserved metal to high humidity and high temperature followed by rapid chilling of the atmosphere.

However, it is wrong and unfair to evaluate rust preventative compounds on the basis of tests which reproduce a condition which will never prevail.

MANUFACTURERS OF PRESERVATIVES AND PACKAGING MATERIALS

There are many manufacturers at the present time furnishing protective materials which will effectively inhibit corrosion of metal parts under most conditions. The preservative used should be selected for the specific application. It is not to be expected that a material suitable for preserving the mechanism of a watch should be equally effective for protecting "I" beams in shipment.

Further, the preservative must not be expected to do the whole job. The importance of a surface free from oxygen, residual moisture and acids cannot be overemphasized.

It, therefore, behooves the manufacturer, when he considers the subject of preservation of metal structures, to spend a little time in investigating all of the phases of his problem rather than save a few dollars' worth of time at the risk of losing many dollars' worth of material.

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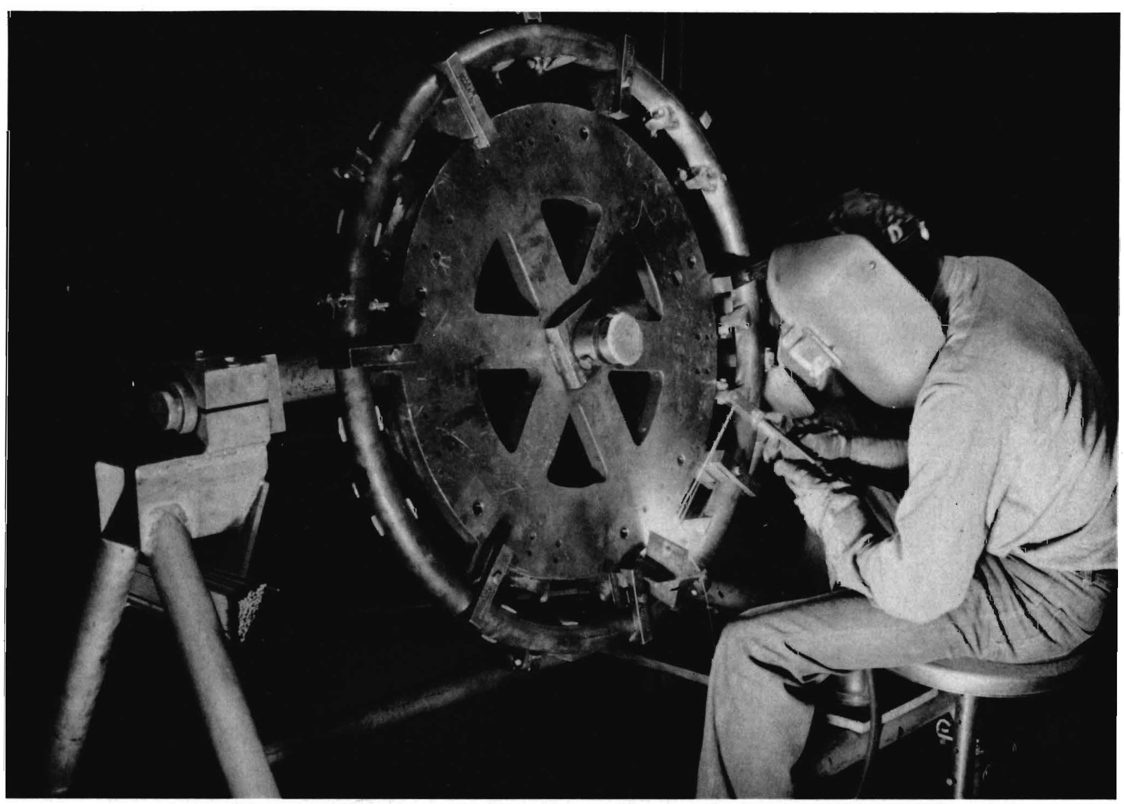
View in Douglas Engine Mount Welding Department

COURTESY KELLETT AUTOGIRO

Gas Welding Engine Mount forgings to tubular ring.



Arc Welding Engine Mount forgings to tubular ring at Douglas. Note how welding fixture is pivoted at two axes so welder can move work into one position for best work.