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# WELDING AND BRAZING OF BERYLLIUM TO ITSELF AND TO OTHER METALS

by

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## ABSTRACT

Welding and brazing techniques for joining QMV beryllium to itself and to several other metals have been studied. Specific joining problems were studied, but the data collected are applicable to many of the design problems where beryllium must be joined to itself or another metal.

The inert-gas-shielded consumable-electrode welding process and aluminum-alloy filler metals can be used to join beryllium plate to other beryllium plate or aluminum plate. Cracking of the beryllium may prevent welding of highly restrained joints. Furnace brazing in vacuum or protective atmospheres can be used to join beryllium to itself and to copper, Monel, nickel, and stainless steel. Monel is the easiest of these metals to braze to beryllium. Aluminum alloys, silver, and the silver-copper eutectic alloy can be used as brazing materials.

## INTRODUCTION

Beryllium possesses properties which make it a potentially useful material in various applications. Many of the applications require that beryllium be joined either to itself or to other metals. In some cases, the joints must be liquid or gas tight. Methods of producing such joints have been reported, but in a great many cases the techniques were applicable only to small assemblies. In other cases, the joints did not have sufficient strength to be useful in structural application.

The objective of the investigation reported here was to develop improved methods of joining beryllium to itself and to other metals.

The results of the investigation show that it is possible to join beryllium to itself and to other metals by both welding and brazing techniques. The joints produced are useful in that they have at least as good ductility as the beryllium and adequate strengths. Notch effects produced by certain types of welded or brazed joints are serious because of the severe notch sensitivity of beryllium. Joint designs which involve notches should be avoided.

The first sections of this report cover the tests made to develop welding procedures and to determine the strengths of welded joints. The final sections of the report cover tests made to develop furnace-brazing procedures.

## MATERIALS

Beryllium plate used in this investigation was standard Brush QMV metal furnished in hot-pressed, hot-pressed and rolled, and hot-pressed and sintered forms. The plates were received machined to assorted sizes with nominal thicknesses of 1/8, 1/4, and 1/2 in. Each plate was identified with the Brush heat number (Y-4XXX). The approximate composition of the QMV metal is given in the following tabulation:

| Composition of QMV Metal, wt % | |
|---|---|
| Beryllium | 98.0 |
| BeO | 1.0 |
| Aluminum | 0.1 to 0.2 |
| Iron | 0.1 to 0.2 |
| Magnesium | 0.05 |
| Silicon | 0.05 |

In tests to develop methods of joining beryllium to other metals, the following plate materials were used in addition to beryllium.

| 1/8 In. Thick | 1/4 In. Thick | 1/2 In. Thick |
|---|---|---|
| 3S Aluminum | 3S Aluminum | 3S Aluminum |
| Phosphorus-deoxidized copper | Phosphorus-deoxidized copper | |
| Monel | Monel | |
| "A" nickel | "A" nickel | |
| Type 347 stainless | Type 302 stainless | |

Filler metals that were tried with the various base metals are listed below:

| Group 1 | | Group 2 | |
|---|---|---|---|
| Filler Metals | Base Metals | Filler Metals | Base Metals |
| Aluminum alloys | Beryllium | Copper alloys | Beryllium |
| | Aluminum | Nickel alloys | Copper |
| | | Silver alloys | Monel |
| | | | Nickel |
| | | | Stainless steel |

Beryllium structures joined with a filler metal in one group cannot be joined directly to base metals in the other group.

The strong tendency of beryllium to oxidize at elevated temperatures precluded its use as a filler metal for the inert-gas-shielded welding processes.

## WELDING WITH BERYLLIUM FILLER METALS

In past work, attempts have been made to weld beryllium directly to beryllium. These attempts were not successful, but it was thought at the time that the quality of the metal available might be responsible for the lack of success. Consequently, a few tests were made to determine if the QMV plates could be welded using beryllium as the filler metal.

These tests were carried out by making bead welds on 1/2-in.-thick plates of beryllium about 3 in. square. The welds were made with a tungsten-arc torch using argon as the shielding gas. All welds cracked while they were being made. The cracks opened up just behind the molten pool. A few attempts were made to eliminate cracking with preheat, but none were successful.

It was apparent that the improvement in the quality of the beryllium over that available earlier had no effect on the hot-cracking tendencies of the metal. Consequently, the balance of the work was devoted to the investigation of joining beryllium with nonberyllium base materials.

## WELDING WITH ALUMINUM FILLER METALS

Procedures for the use of aluminum alloys for welding a 3 per cent aluminum-beryllium alloy were developed earlier. These welds were made using a commercial, coated-aluminum electrode. Additional tests with aluminum-alloy filler metals were necessary to develop methods suitable for welding of beryllium structures and beryllium-aluminum structures.

### Welding Procedures

Techniques for manual and automatic welding of butt joints and fillet joints were developed. Welding was done in a closed hood exhausted with a blower which gave a complete air change every three minutes. The hood was divided into two chambers. The welder stood in one chamber and performed the actual welding through access holes into the second chamber. A partial view of the hood is shown in Figure 1.

A Model 2 Aircomatic hand-gun assembly was used for inert-gas-shielded consumable-electrode welding tests. Automatic tests were made with this equipment by holding the welding gun stationary and moving the joint assembly under the arc on a carriage or turning jig.

#### Butt Joints

Butt joints were used to study the influence of joint design, filler metal shielding gas, and other welding variables on penetration, porosity, and strength properties of the joints. Tests were made on joints prepared from hot-pressed beryllium plates, 1/4 x 2-7/8 x 2- 7/8 in., hot-pressed and sintered beryllium plates, 1/2 x 2 x 3 in., and 3S aluminum plates of like size.

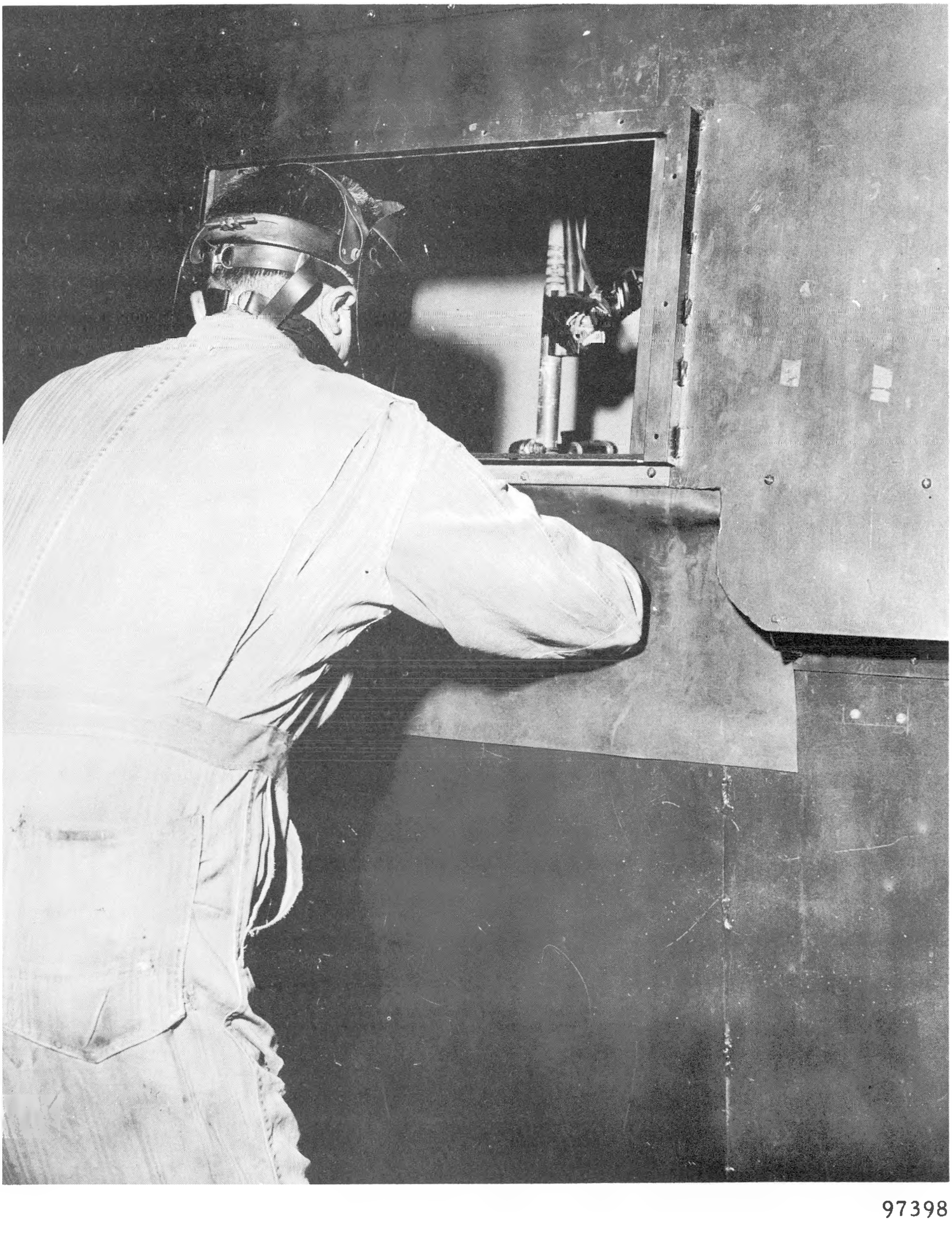

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FIGURE 1. VIEW OF WELDING HOOD SHOWING OPERATOR IN POSITION TO MAKE AUTOMATIC WELD

The inert-gas-shielded tungsten-arc and consumable-electrode welding processes were tested as possible methods of joining beryllium to itself and to aluminum. Welding with tungsten electrodes was not satisfactory, because oxidation of the beryllium joint surfaces occurred ahead of the weld pool outside of the area covered by the shielding gases. Supplementary shielding did not reduce this oxidation to any great extent. The consumable-electrode process produced good welds. Welding speed is greatly increased with this process, and the beryllium does not oxidize appreciably ahead of the weld pool.

Four aluminum alloys were used as 1/16-in.-diameter filler wire in the consumable-electrode welding equipment. Compositions of these alloys are given in the tabulation below:

| | Composition, wt % | | |
|---|---|---|---|
| Alcoa Alloy No. | Al | Si | Cu |
| 2S | 99 min | -- | -- |
| 43S | 95 | 5 | -- |
| 716 | 86 | 10 | 4 |
| 716* | 83.3 | 12 | 4.7 |
| 718** | 88 | 12 | -- |

*Battelle analysis; others are manufacturers' specification.
**718 alloy has replaced the 716 alloy, because of better corrosion resistance; 716 alloy is not manufactured at present.

Welding conditions which produced the best joints are listed in Table 1. Porosity was never completely eliminated from the welds. However, the use of low current, helium shielding gas, and filler-metal Alloys 716 and 718 did reduce porosity considerably. High currents, argon shielding gas, and Alloys 2S and 43S tended to produce excessive porosity. Figure 2 shows typical radiographs of test welds. Porosity was divided into fine and coarse classes, as shown in Figure 2.

No procedure which would insure complete penetration when welding from one side of the joint was found. A small pass on the back of the joint was found necessary to eliminate points of incomplete penetration. In multi-pass welds, the pass on the back of the joint should be made after the first pass on the front side of the joint.

The importance of eliminating incomplete penetration in beryllium weldments should not be overlooked, since beryllium is very notch sensitive. Incomplete penetration of the weld joint acts as a notch, which may cause cracking of the beryllium plate.

TABLE 1. OPTIMUM WELDING CONDITIONS FOR BUTT JOINTS BETWEEN BERYLLIUM AND ITSELF AND BETWEEN BERYLLIUM AND ALUMINUM, MADE WITH THE INERT-GAS-SHIELDED CONSUMABLE-ELECTRODE PROCESS

Filler Wire: 1/16-in.-diameter 718 alloy
Feed: 210 in./min

Shielding Gas: Grade A helium
Flow: 200 cfh

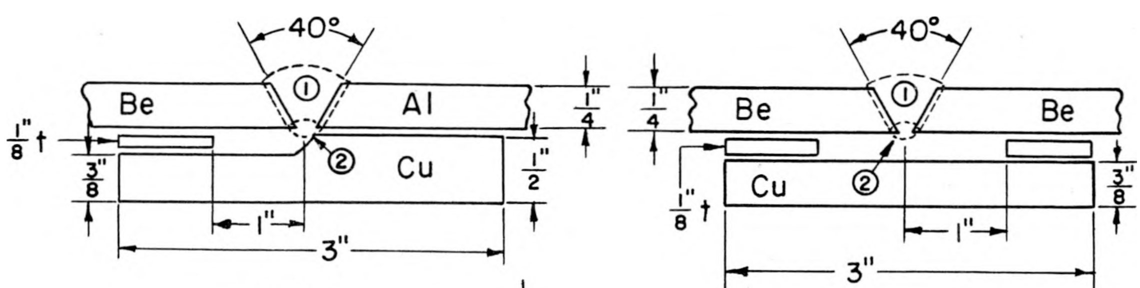
Direct Current: Reverse polarity
Current: 175 amp
Arc Voltage: 28 v

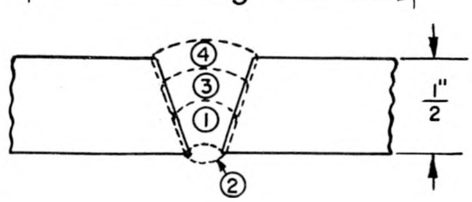
Travel Speed:

1/4 Inch
Pass 1: 6 in./min
Pass 2: 32 in./min

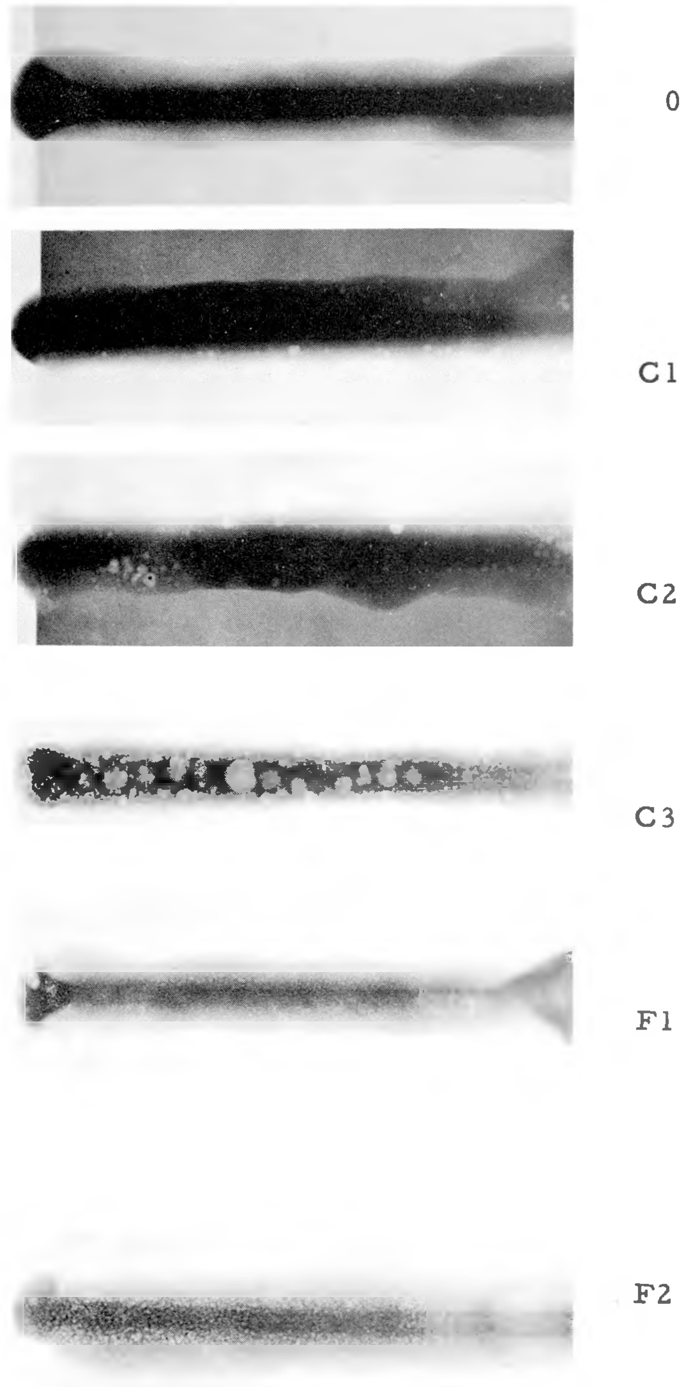
1/2 Inch
Pass 1: 6 in./min
Pass 2: 32 in./min
Pass 3: 16 in./min
Pass 4: 28 in./min

Joint Design:
Root Gap: 1/8 in.
Aluminum plates used for starting and ending welds




Backing as above for each joint type.




1X N4972

FIGURE 2. POROSITY IN BERYLLIUM WELDS MADE WITH ALUMINUM ALLOYS

Either a 40- or a 60-deg included angle can be used satisfactorily. The 40-deg angle is preferred, since it reduces the volume of weld metal in any beryllium assembly.

Attempts to use double-vee butt joints were unsuccessful. The second passes in such joints invariably cracked.

Metallographic examination of weld cross sections showed that only a little beryllium was actually melted during welding, when the proper conditions were used. Figures 3 and 4 show the beryllium-weld-metal bond areas of welds made with 2S and 716 alloys, respectively. The particles dispersed in the weld metal, as shown in Figure 3, are beryllium. The ideal situation is to get bonding of the beryllium and aluminum filler metal with minimum melting of the beryllium.

## Fillet Joints

Tests were made to determine the welding conditions necessary to produce fillet joints at the junction of aluminum ribs and beryllium plates. The best joints were made using the joint design shown in Figure 5. All other welding conditions were the same as those recommended for butt joints, except the travel speed, which was 28 in./min. Figure 6 shows a transverse section cut through a joint made under the above conditions.

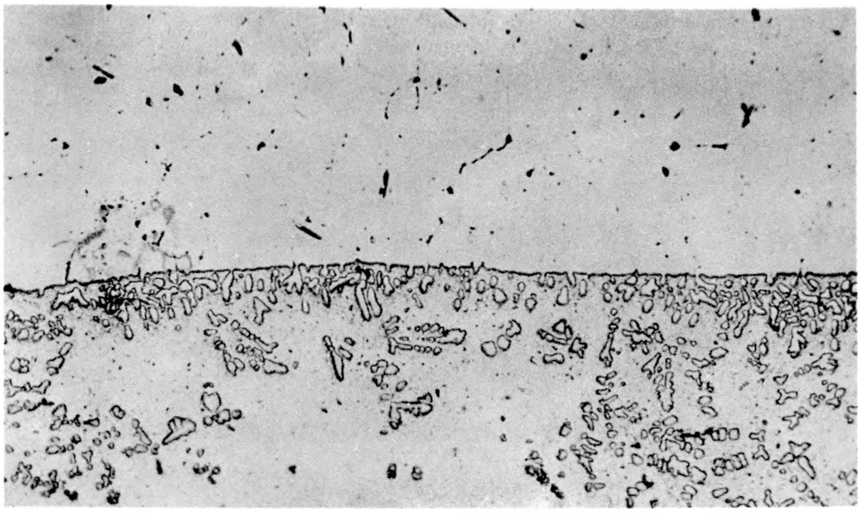
## Fabricating Structures

The fabrication of structures by welding generally involves making one or more welds between plates which are not free to move during welding. This lack of free movement results in stresses being imposed on the plates during the thermal cycle characteristic of the welding process. Distortion and weld- or base-metal cracking may occur if these stresses become sufficiently high.

A series of tests was made to determine if beryllium could be welded to aluminum under conditions similar to those encountered in fabricating structures.

The test selected for this was a circular weld between a beryllium disk and an aluminum plate containing a hole for the disk. The plate and disk edges were machined to form a single-vee butt joint around the circumference of the disk. This type of joint is one of the most difficult welds to make and is sometimes used as a test to determine the cracking tendencies of weld metal.

Beryllium disks were machined from square weldments containing one or two crosswelds. A typical disk is shown in Figure 7. Disks of two sizes



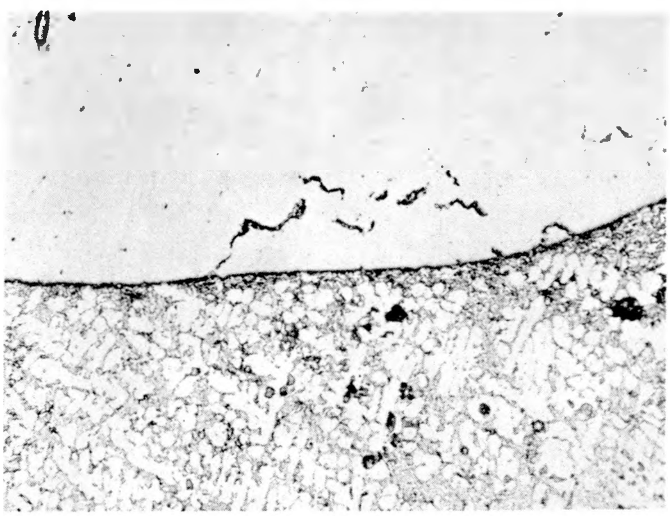
Beryllium

Weld Metal

250X 91032

FIGURE 3. BOND BETWEEN BERYLLIUM AND 2S ALUMINUM WELD METAL

Dispersed particles are beryllium



Beryllium

Weld Metal

250X 93202

FIGURE 4. BOND BETWEEN BERYLLIUM AND 716 ALUMINUM WELD METAL

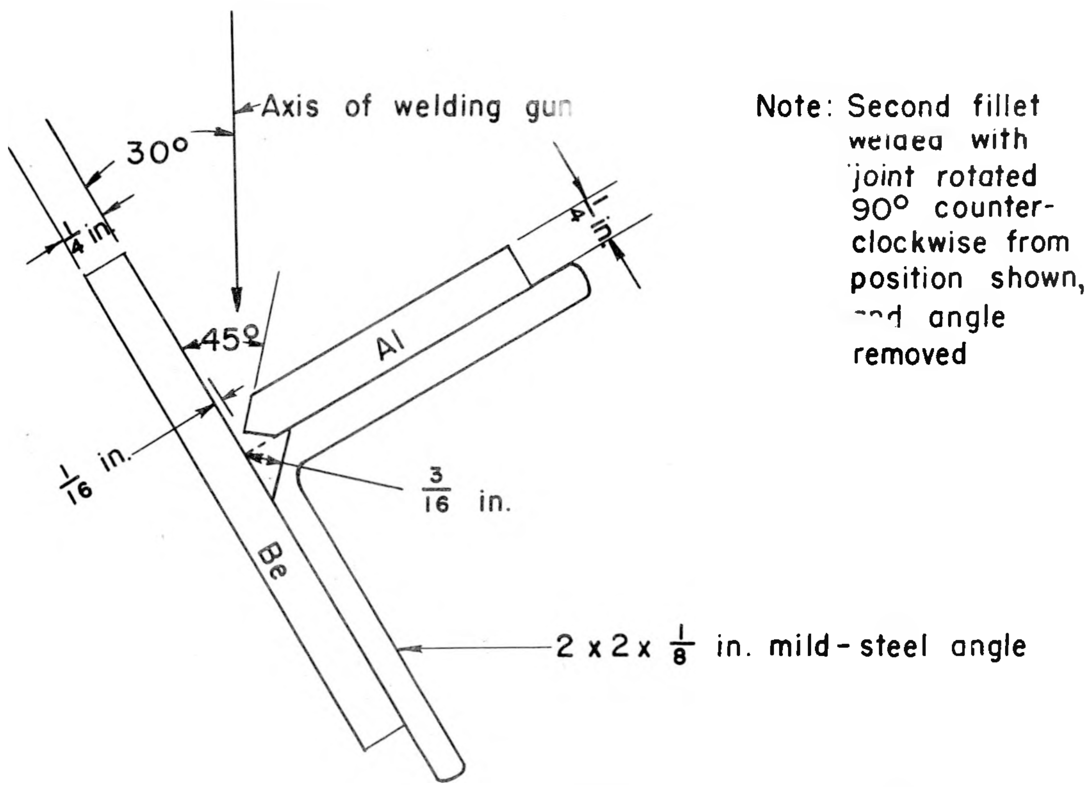



FIGURE 5. CROSS SECTION OF RIB JOINT IN POSITION FOR WELDING FIRST FILLET

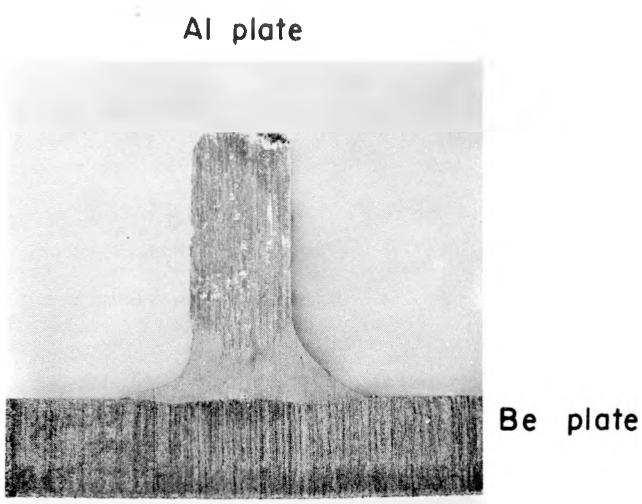
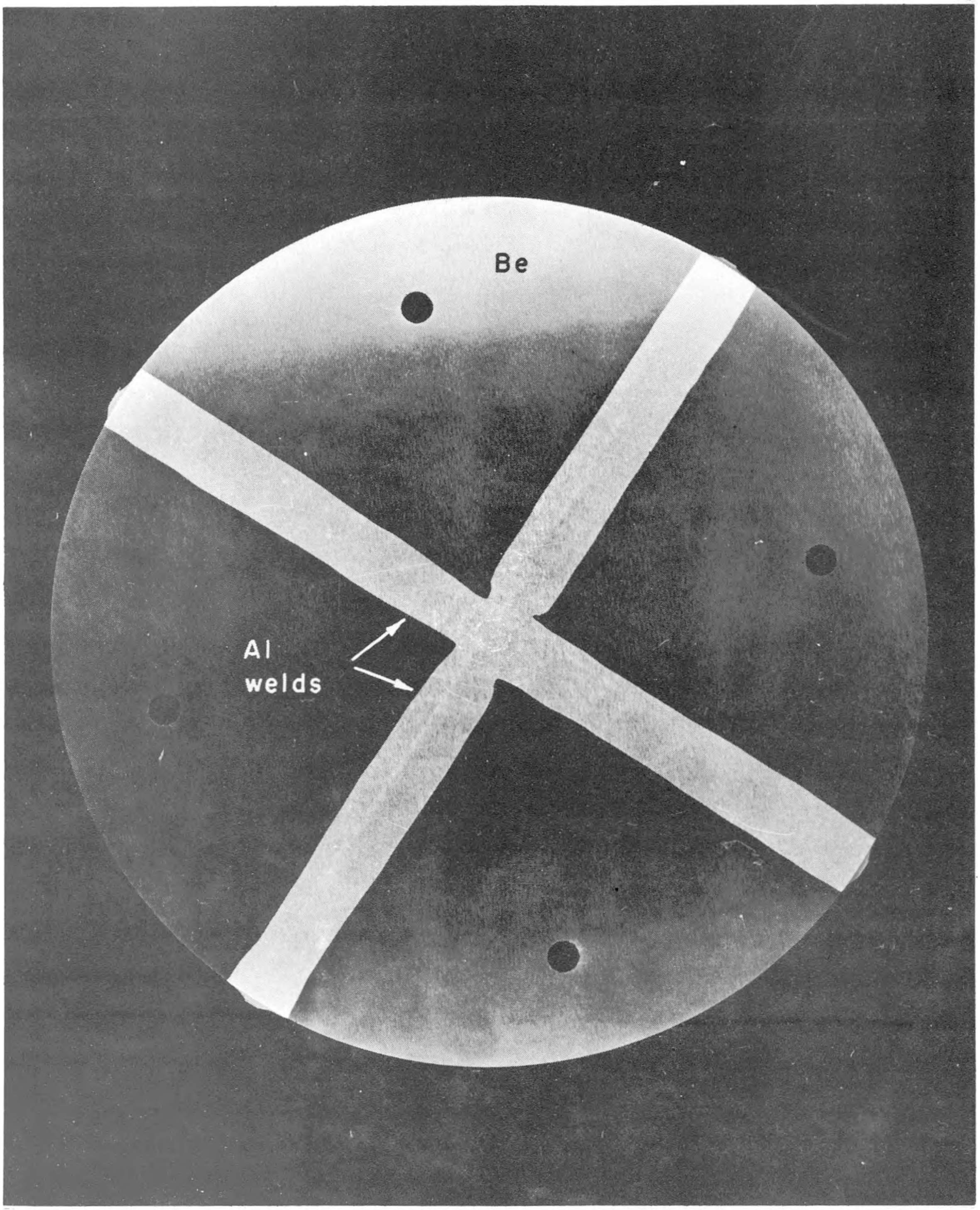



FIGURE 6. TRANSVERSE SECTION OF DOUBLE-VEE FILLET WELD MADE AT RECOMMENDED CONDITIONS

A- 5907




1X

97708

FIGURE 7. DISK FABRICATED FROM FOUR BERYLLIUM PLATES BY WELDING

094-015

were used, 1/4 in. thick by 5-3/4-in. diameter and 1/2 in. thick by 7-3/4-in. diameter. Welding conditions and joint designs developed for single-vee butt joints were used in these tests.

In the first tests, the disks were welded manually into large aluminum plates. Under these conditions, the beryllium plate in the disk cracked. The cracks in the beryllium plate initiated at points of incomplete penetration in the welds. No cracking occurred in the weld metal. Figure 8 shows one of these welds. Additional tests were made using 1-in.-wide aluminum rings and automatic welding equipment. It was hoped that use of a narrow ring of aluminum would reduce the stresses on the beryllium disk and prevent cracking of the beryllium plates.

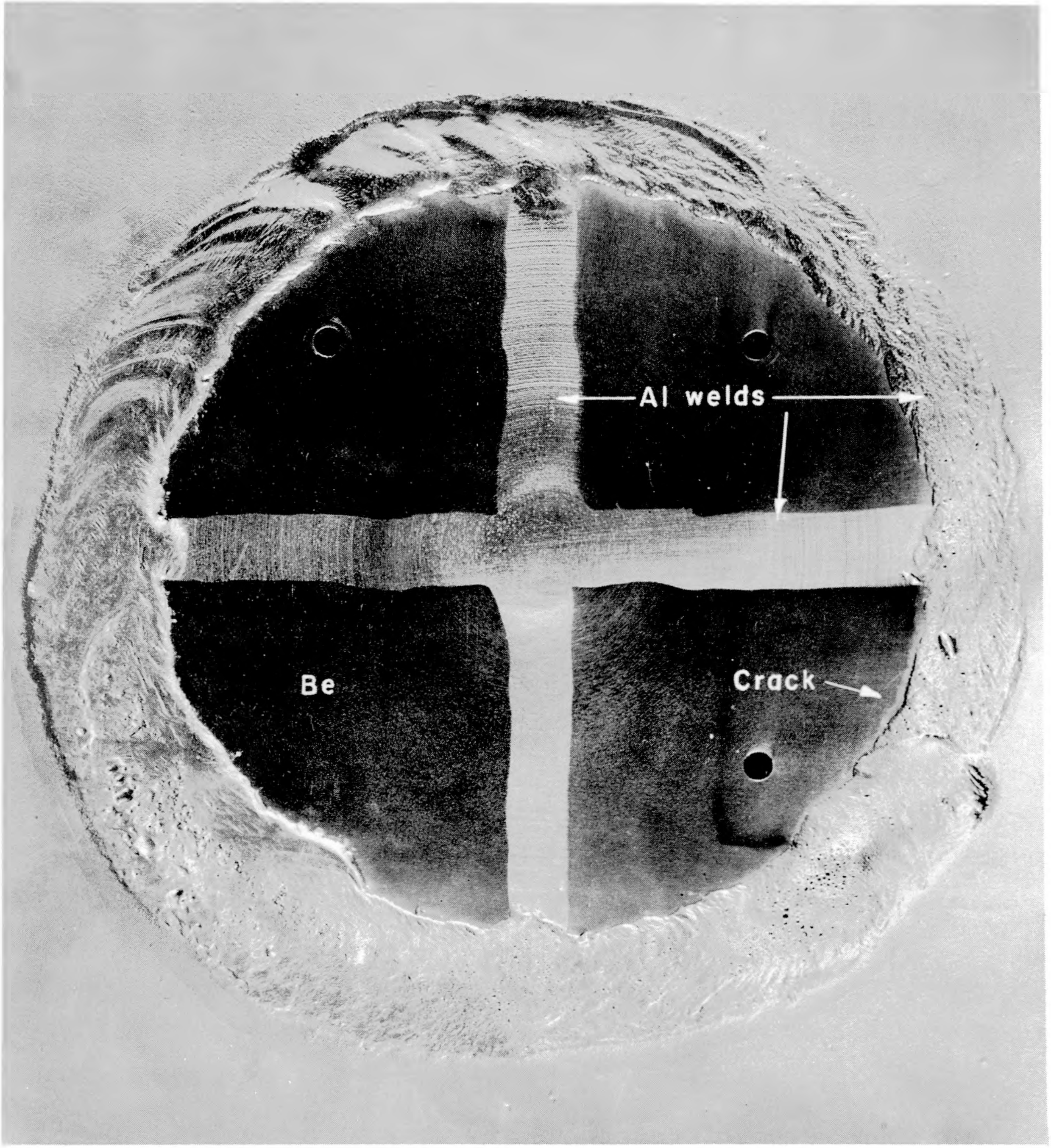
Three 1/4-in. disks were welded into 1-in. aluminum rings. Examination of these welds disclosed cracks along the fusion line of the crosswelds near the edges of the disks, but no cracks in the beryllium plates. Evidently, remelting the crosswelds at the ends produced weak points in the structure which were unable to resist the stresses resulting from shrinkage of the circumferential weld.

A final 1/2-in. disk was welded manually into an aluminum ring using the sequence shown in Figure 9. Short tack welds were made across the ends of the crossweld to prevent remelting of the crossweld ends during the deposition of the circumferential weld. The tack welds were completed in three passes. The remainder of the circumferential weld was welded by depositing a weld pass around half of the circumference, then around the other half. Three passes were made in this manner to complete the joint. After the first pass was deposited, the root side of the joint was examined. Penetration of the weld was excellent except at three points. Short weld beads were deposited at these points to insure good penetration.

Examination of the 1/2-in. disk at 30X showed no cracks in the welds or on the plate surfaces. Radiographs of the completed assembly indicate a short crack at one end of the crossweld. A recheck of the visual examination using a dye penetrant did not reveal any cracks. Apparently, the crack does not extend to the surface of the joint; however, its presence would make the assembly useless. A photograph of the completed disk weld is shown in Figure 10.

## Strength Properties of Welded Joints

Beryllium plate and weldments were tested using tensile, bend, and impact tests. Figure 11 shows the dimensions of the specimens and methods of loading.




1X 97802

FIGURE 8. BERYLLIUM DISK WELDED INTO ALUMINUM PLATE WITH CIRCUMFERENTIAL WELD

(Note crack in Be plate at lower right.)

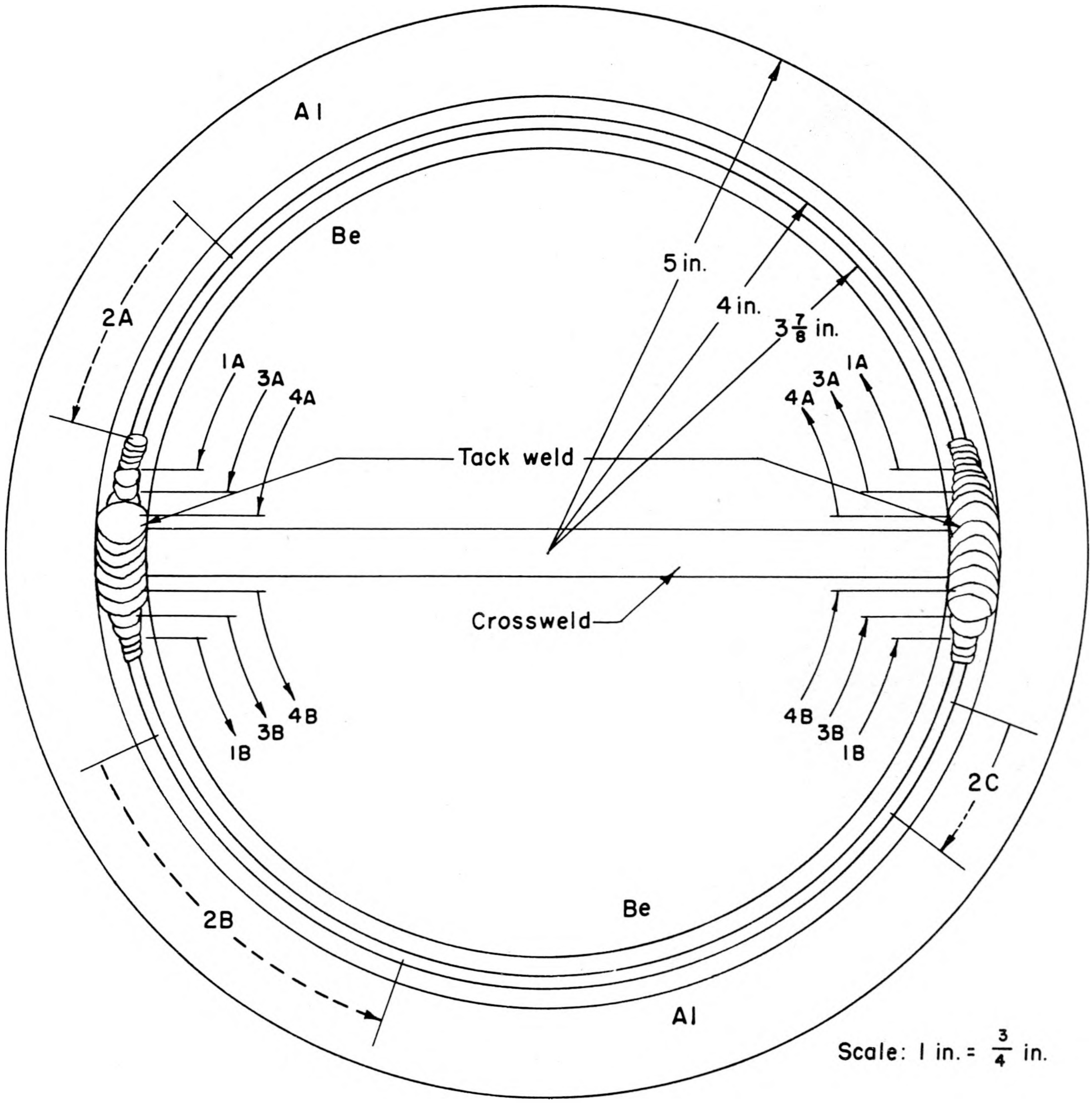
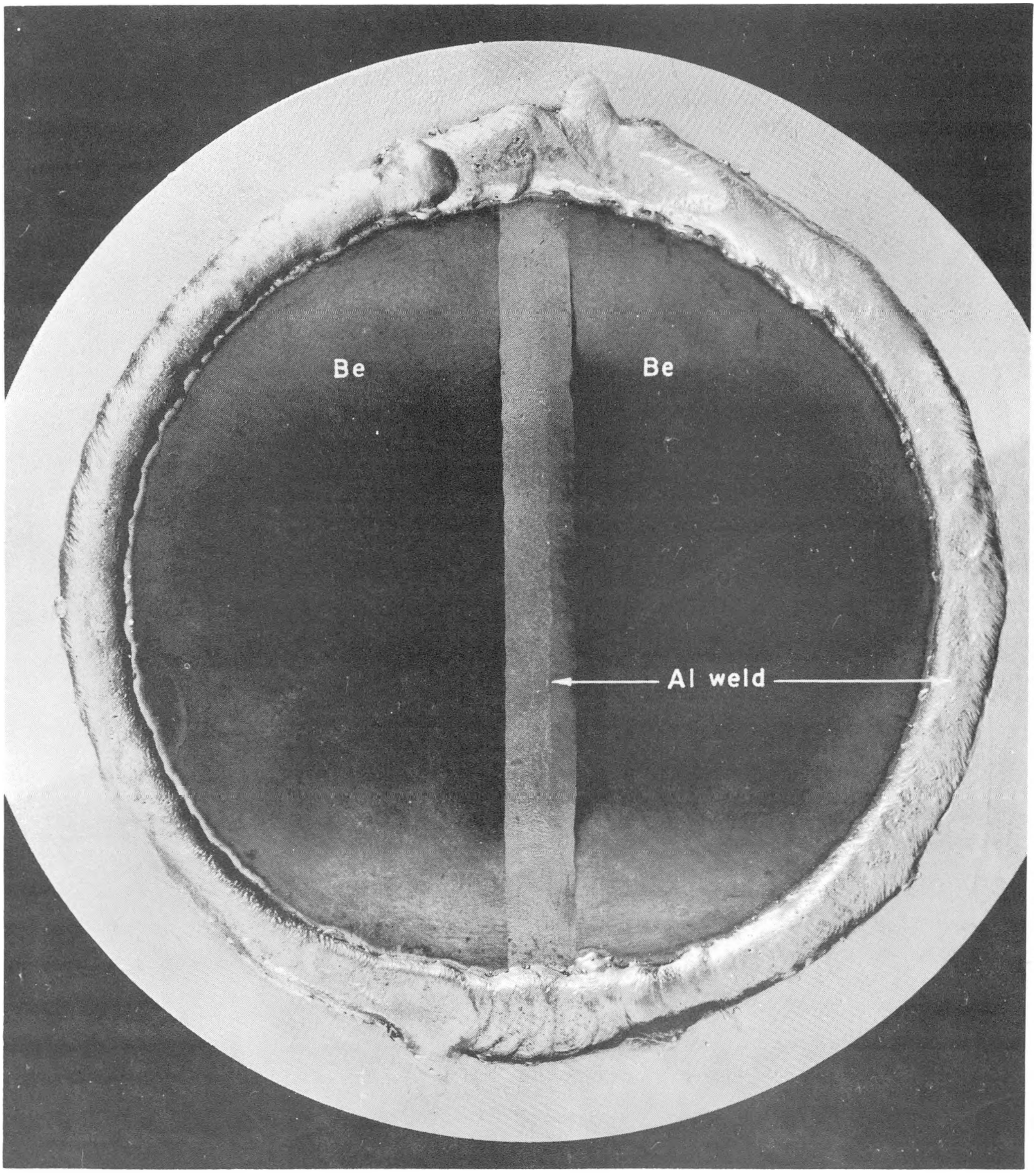


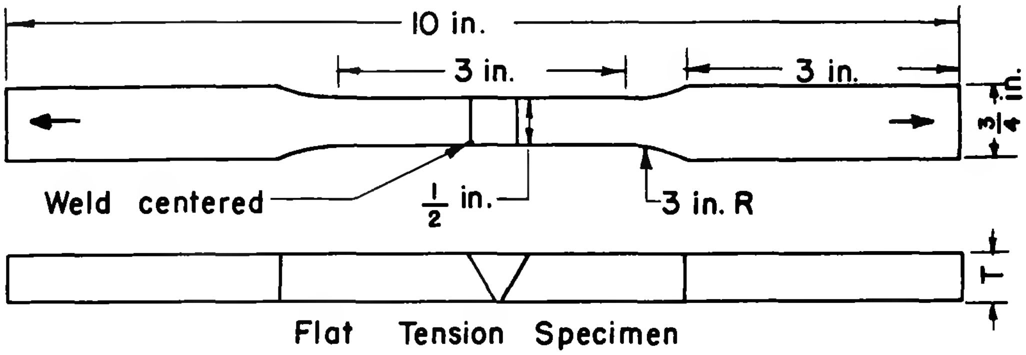

FIGURE 9. WELDING SEQUENCE FOR SPECIMEN No. Be 80, $\frac{1}{2}$ IN. THICK

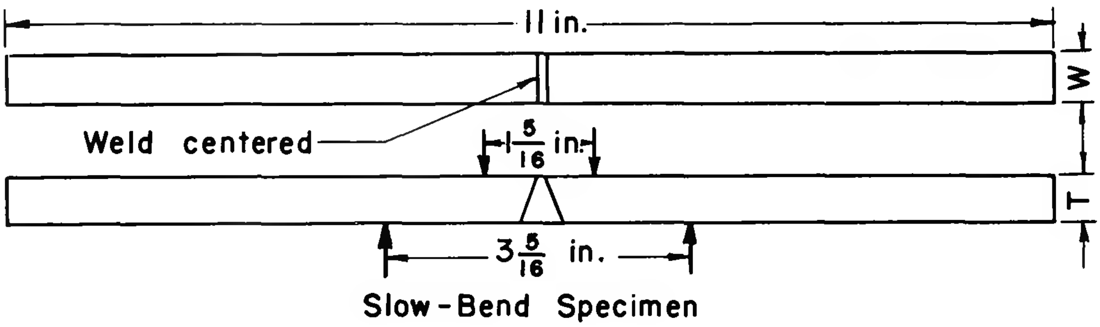
A - 5906




2/3X 97801

FIGURE 10. COMPLETED DISK WELD IN 1/2-IN.-THICK PLATE



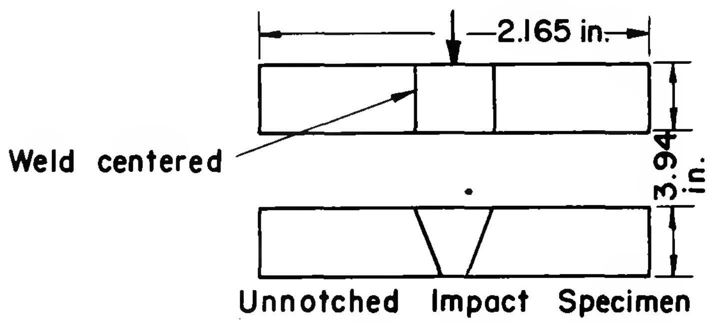




FIGURE II. SPECIMENS FOR DETERMINING STRENGTH PROPERTIES

Heavy arrows indicate direction of loading

A- 5905

The 1/4-in. beryllium plate used was hot pressed and hot rolled; the 1/2-in. beryllium plate was hot pressed and sintered. All of the aluminum plate used was 3S alloy.

Weld specimens were machined from single-vee butt joints made by manual welding.

The weldments from which specimens were machined were made before all of the optimum welding conditions given in Table 1 were known. In fact, several of the conditions were changed because of weaknesses discovered in the tests to determine strength properties. The differences in the welding conditions of these welds from the conditions given in Table 1 are listed below:

1. Welds in 1/4-in. plate — 1 pass only,

2. Welds in 1/2-in. plate — 2 passes only,

3. Specimens Be43A and Be43B — argon shielding at 50 cfh, and

4. All specimens except Be56B — 716 aluminum filler wire.

Tension specimens were prepared using all the steps given in Table 2. Bend and impact specimens were prepared using Steps 1, 2, 4, and 5 given in Table 2.

Tensile tests were made using a Baldwin-Southwark universal testing machine and Templin grips. The platen speed during testing was 0.01 inch per minute. Load-deflection diagrams were plotted from strain readings taken with the SR-4 strain gages attached to the specimens. Yield points were determined from these diagrams by the 0.2 per cent offset method. Elongation was measured from 0.1-in. grid lines stamped on the specimens.

Slow-bend tests of the constant-moment type were made to determine the weakest point in the weldments under bending loads. Welded specimens were bent with the face of the weld in tension. The platen speed during the tests was from 0.01 to 0.03 in./min. Elongation was measured from 0.1-in grid lines stamped on the specimens. Bend angles were measured with a protractor.

Impact tests were made in a Riehle 110-ft-lb machine. Welded specimens were stuck on the center of the weld cross section. Specimens tested at low temperatures (-318 F) were placed in a bath of liquid nitrogen until boiling stopped. The specimens were then removed, placed on the anvil, and fractured within 10 sec.

Radiographs of the machined specimens showed the presence of slight porosity in all the weld joints.

TABLE 2. PROCEDURE FOR PREPARATION OF BERYLLIUM TENSION, BEND, AND IMPACT SPECIMENS

1. Saw cut to length and width.

2. Grind flat surfaces using the following schedule:

   a. Norton Wheel No. 57A46-G-12V BEP, No. 24 treated, or De Sanno Radiac Wheel 9A36-12 VOS.

   b. Cuts of 0.0005 in. with fairly fast cross feed.

3. Mill reduced section and radii using the following schedule:

   a. 6 x 1 high-speed stagger cutter.

   b. Spindle speed - 30 rpm.

   c. Table feed - 2 in./min for roughing
      -3/4 to 1 in./min for finishing.

   c. Depth of successive cuts:

      Roughing - 0.010 in. or less.

      Finishing:

      First pass - 0.006 in.
      Second pass - 0.004 in.
      Third pass - 0.002 in.

4. Chemical polish for one minute at 240 F in the following bath:

   | | |
   |---|---|
   | Concentrated orthophosphoric acid | - 450 ml |
   | Concentrated sulfuric acid | - 26-1/2 ml |
   | Chromic anhydride | - 53-1/4 g |

5. Visual and radiographic examination.

6. Application of SR-4 strain gage.

Results of the tensile tests are presented in Table 3. Beryllium picked up by the weld metal increases its strength and lowers its ductility. Apparently, this is necessary to obtain strong bonds between the beryllium and the weld metal, since two-pass welds in 1/2-in. plate did not have consistently strong bonds. The relative amount of beryllium picked up during the second pass of the welds in 1/2-in.-thick plate was small because of the larger volume of weld metal deposited and the smaller area of contact with the beryllium plate.

Results of the bend tests are presented in Table 4. The ductility of the unwelded beryllium varied considerably, but appears to be better than the ductility of beryllium-to-beryllium welds. The 1/4-in.-thick beryllium-to-aluminum weld specimens bent entirely in the aluminum heat-affected zone.

Results of the impact tests are presented in Table 5. Except for Specimen Be59B-5, all fractures in weld specimens occurred in the beryllium plate and weld metal near the fusion line.

Changes in the recommended welding procedures for 1/2-in.-thick plates were made after studying the results of the tensile, bend, and impact tests. More consistent and possibly better strength properties should be obtained with these procedures (given in Table 1).

## WELDING WITH COPPER- AND NICKEL-ALLOY FILLER METALS

Joining beryllium to copper, Monel, nickel, and stainless steel requires some filler metal other than aluminum. The alloys listed below were tested as filler wire, with the inert-gas-shielded consumable-electrode equipment for welding these metals to beryllium.

| Name | Manufacturer and Alloy | Composition, wt % |
|---|---|---|
| Copper | Anaconda 372 | 98 Cu, +Mn, Sn, and Si |
| Silver-copper | Handy and Harman BT | 72 Ag, 28 Cu |
| Aluminum bronze | Airco 928 | 92 Cu, 8 Al, < 1 Fe |
| Nickel | International Nickel "A" | 99 Ni, +C, Cu, Fe, Mn, and Si |
| Monel | Moline Monel | 67 Ni, 30 Cu, 1 to 4 Fe, 1 Mn, +C, S, and Si |
| Nichrome | Hoskins 717 | 78 Ni, 20 Cr, 1 Fe, +C, Mn, and Si |

TABLE 3. RESULTS OF TENSION TESTS ON BERYLLIUM PLATE AND WELDMENTS MADE WITH ALUMINUM ALLOYS

| Specimen | Brush Heat | Thickness and Included Angle | Yield Strength, psi | Ultimate Strength, psi | Elongation, per cent in 2 In. | Elongation, per cent in 0.5 In. | Reduction in Area, % | Location of Fracture[a] | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| **Beryllium-Beryllium Welds** | | | | | | | | | |
| Be-46A-1 | Y-4778 | 1/4 in. | -- | 21,400 | 1 | -- | 1 | Comb. | |
| Be-46A-2 | | 60° | -- | 23,300 | 1 | -- | 1 | Be | |
| Be-56B-1 | Y-4795 | 1/4 in. | 20,200 | 21,900 | 1 | -- | 1 | Weld | SR-4 gage across weld root |
| Be-56B-2 | | 60° | 19,500 | 24,100 | 1 | -- | 1 | Be | SR-4 gage across weld face |
| Be-56B-3 | | | -- | 23,500 | 1 | -- | 1 | Weld | |
| Be-57A-1 | Y-4783 | 1/4 in. | 29,600 | 31,000 | 1 | -- | 1 | Comb. | SR-4 gage across weld root |
| Be-57A-2 | | 40° | -- | 27,400 | 1 | -- | 1 | Comb. | |
| Be-57A-3 | | | -- | 23,200 | 1 | -- | 1 | Comb. | |
| Be-58A-1 | Y-4710 | 1/2 in. | -- | 19,900 | 1 | -- | 1 | Comb. | SR-4 gage across weld root |
| Be-58A-2 | | 40° | -- | 16,800 | 1 | -- | 1 | Comb. | |
| Be-58A-3 | | | -- | 10,100 | 1 | -- | 1 | F. L. | |
| **Beryllium-Aluminum Welds** | | | | | | | | | |
| Be-46B-1 | Y-4778 | 1/4 in. | -- | 14,500 | 10 | 40 | 80 | HAZ | |
| Be-46B-2 | | 60° | -- | -- | -- | -- | -- | --- | Broken in machining |
| Be-56A-1 | Y-4783 | 1/4 in. | -- | 12,500 | 12 | 50 | 89 | HAZ | SR-4 gage on beryllium |
| Be-56A-2 | | 60° | 9,100 | 12,500 | 12 | 50 | 87 | HAZ | SR-4 gage on aluminum |
| Be-56A-3 | | | -- | 12,900 | 11 | 50 | 86 | HAZ | |
| Be-57B-1 | Y-4783 | 1/4 in. | -- | -- | -- | -- | -- | --- | Cracked in machining |
| Be-57B-2 | | 40° | -- | 12,900 | 10 | 40 | 80 | HAZ | |
| Be-57B-3 | | | -- | 11,900 | 12 | 50 | 87 | HAZ | |
| Be-58B-1 | Y-4710 | 1/2 in. | -- | 16,800 | 11 | 2 | 10 | Be and F. L. | |
| Be-58B-2 | | 40° | -- | 11,300 | 1 | -- | 1 | F. L. | |
| Be-58B-3 | | | -- | -- | -- | -- | -- | --- | Fusion line tore during machining |
| **Unwelded[b]** | | | | | | | | | |
| Be-1 | Y-4795 | 1/4 in. | 38,600 | 41,200 | 1 | -- | 1.0 | --- | Specimens not prepared by listed procedure. After machining, specimens were hand polished with 240-, 400-, and 600- grit metallographic paper |
| Be-2 | | | 36,800 | 54,600 | 1 | -- | 4.5 | --- | |
| Be-3 | | | 42,500 | 55,000 | 1 | -- | 2.5 | --- | |
| Be-4 | | | 37,500 | 44,500 | 1.5 | -- | 2.0 | --- | |
| Be-60 | Y-4781 | 1/4 in. | 30,500 | 30,600 | 1 | -- | 1 | --- | |
| Be-61 | | | 31,400 | 33,000 | 1 | -- | 1 | --- | |
| Be-62 | | | -- | 30,000 | 1 | -- | 1 | --- | |
| Be-63 | | | -- | 30,200 | 1 | -- | 1 | --- | |
| Be-64 | Y-4805 | 1/8 in. | -- | 54,700 | 1 | -- | 1 | --- | |
| Be-65 | | | -- | 55,000 | 1 | -- | 1 | --- | |
| Be-66-1 | Y-4820 | 1/2 in. | 29,500 | 34,100 | 1 | -- | 1 | --- | |
| Be-66-2 | | | -- | 31,200 | 1 | -- | 1 | --- | |
| Be-66-3 | | | 29,000 | 33,200 | 1 | -- | 1 | --- | |

(a) Be - Beryllium plate
F. L. - Beryllium fusion line
Weld - Weld center

(a) Comb. - Beryllium plate and weld
HAZ - Aluminum heat-affected zone

(b) SR-4 gage in center of all specimens.

TABLE 4. RESULTS OF BEND TESTS ON BERYLLIUM PLATE AND WELDMENTS MADE WITH ALUMINUM ALLOYS

| Specimen | Brush Heat | Included Angle[a], deg, or Original Number | Dimensions, in. Thickness | Dimensions, in. Width | Bend Angle, deg | Elongation, % in 1 in. | Breaking or Maximum Load, lb | Location of Fracture |
|---|---|---|---|---|---|---|---|---|
| | | | | Beryllium-Beryllium Welds | | | | |
| Be46A-3 | Y-4778 | 60 | | Cracked in machining | | | | |
| Be56B-4 | Y-4795 | 60 | 0.210 | 0.737 | 10 | < 1 | 335 | Weld |
| Be57A-4 | Y-4783 | 40 | 0.226 | 0.728 | 8 | < 1 | 525 | Weld |
| Be58A-4 | Y-4710 | 40 | 0.433 | 0.731 | 3 | < 1 | 1600 | Fusion line |
| | | | | Beryllium-Aluminum Welds | | | | |
| Be46B-3 | Y-4778 | 60 | | Broke during sawing | | | | |
| Be56A-4 | Y-4783 | 60 | 0.226 | 0.711 | 70 | 7 | 225 | None (Bent in Al) |
| Be57B-4 | Y-4783 | 40 | 0.232 | 0.734 | 68 | 7 | 240 | None (Bent in Al) |
| Be58B-4 | Y-4710 | 40 | 0.453 | 0.764 | 8 | 1 | 2300 | Fusion line & Be |
| | | | | Unwelded | | | | |
| Be66-4 | Y-4820 | -- | 0.498 | 0.578 | 16 | 2 | 4450 | -- |
| Be66-5 | Y-4820 | 66-1 | 0.498 | 0.578 | 12 | -- | 3900 | -- |
| Be66-6 | Y-4820 | 66-1 | 0.498 | 0.578 | 7 | < 1 | 3500 | -- |
| Be79-1 | Y-4783 | 57A-4 | 0.226 | 0.728 | 7 | < 1 | 575 | -- |
| Be79-2 | Y-4783 | 57A-4 | 0.226 | 0.728 | 24 | 2 | 875 | -- |
| Be79-3 | Y-4783 | 57B-4 | 0.232 | 0.734 | 72 | 9 | 1040 | Load point |
| Be79-4 | Y-4783 | 56A-4 | 0.226 | 0.711 | 92 | 10 | 925 | None |
| Be79-5 | Y-4795 | 56B-4 | 0.210 | 0.737 | 33 | -- | 750 | Load point |
| Be79-6 | Y-4795 | 56B-4 | 0.210 | 0.737 | 44 | 4 | 775 | Load point |
| Be79-7 | Y-4710 | 58A-4 | 0.437 | 0.731 | 7 | 1 | 3000 | -- |
| Be79-8 | Y-4710 | 58A-4 | 0.437 | 0.731 | 5 | < 1 | 2800 | -- |

(a) Three specimens were bent from one machined strip 11 in. long. Original numbers refer to the strip from which the specimens were taken.

TABLE 5. RESULTS OF UNNOTCHED CHARPY IMPACT TESTS[a] ON BERYLLIUM PLATE AND WELDMENTS MADE WITH 716 ALUMINUM ALLOY

| Specimen | Included Angle, deg | Test Temp | Energy Absorbed, ft-lb | Specimen | Test Temp | Energy Absorbed, ft-lb |
|---|---|---|---|---|---|---|
| Beryllium-Beryllium Welds[b] | | | | Unwelded | | |
| Be-43A-1 | | 76 F | 2 | Be-5[b, e] | 78 F | 8.2 |
| Be-43A-2 | 60 | 76 F | 2 | Be-6[b, e] | 78 F | 11.2 |
| Be-43A-3 | | Liq. $N_2$ | 1.5 | Be-7[b, e] | 78 F | 17.6 |
| | | | | Be-8[b, e] | Liq. $N_2$ | 4 |
| Be-43D-1 | | 76 F | 1.5 | Be-9[b, e] | Liq. $N_2$ | 4.5 |
| Be-43D-2 | | 76 F | 1.5 | Be-10[b, e] | Liq. $N_2$ | 7.5 |
| Be-43D-3 | 40 | Liq. $N_2$ | 1.5 | | | |
| Be-43D-4 | | Liq. $N_2$ | 1 | Be-69A[b] | 76 F | 2 |
| Be-43D-5 | | 76 F | 2 | Be-69B[b] | 76 F | 1.5 |
| | | | | Be-69C[b] | 76 F | 2.5 |
| Beryllium-Aluminum Welds[b] | | | | Be-69D[b] | Liq. $N_2$ | 1.5 |
| | | | | Be-69E[b] | Liq. $N_2$ | 1 |
| Be-59A-1 | | 76 F | 3 | Be-69F[b] | Liq. $N_2$ | 1.5 |
| Be-59A-2 | | 76 F | 7 | | | |
| Be-59A-3 | 40 | Liq. $N_2$ | 1.5 | Be-70A[c] | 76 F | 3 |
| Be-59A-4 | | Liq. $N_2$ | 1.5 | Be-70B[c] | 76 F | 2 |
| Be-59A-5 | | 76 F | 7 | Be-70C[c] | 76 F | 2 |
| | | | | Be-70D[c] | Liq. $N_2$ | 3 |
| Be-59B-1 | | 76 F | 3 | Be-70E[c] | Liq. $N_2$ | 1.5 |
| Be-59B-2 | | 76 F | 3 | Be-70F[c] | Liq. $N_2$ | 1 |
| Be-59B-3 | 60 | Liq. $N_2$ | 2.5 | | | |
| Be-59B-4 | | Liq. $N_2$ | 2.5 | | | |
| Be-59B-5 | | 76 F | 35 (d) | | | |

(a) Specimens machined from 1/2-in. plate and weldments.
(b) Beryllium from Brush Heat Y-4536.
(c) Beryllium from Brush Heat Y-4820.
(d) Fractured in aluminum heat-affected zone.
(e) Specimens not prepared by listed procedure. No additional treatment after machining.

The same equipment and general procedures described in the previous sections were used in investigating this phase of the program.

Test welds were made manually; the operator attempted to prevent melting of the beryllium plates and produce a braze-type bond. None of the filler wires produced joints which could be considered useful. Copper was the only filler wire used which produced crack-free joints. Cracking occurred during or shortly after welding when using the other filler wires.

Single-vee butt joints between beryllium and copper were sound as welded. Radiographs showed no porosity or cracks in these welds. The welds had appreciable resistance to fracture when bent. The fractures occurred near the beryllium-weld-metal interface, with very smooth fracture surfaces. Metallographic examination of sections from the welds indicated several brittle, intermetallic-compound bands, as shown in Figure 12. A postweld heat treatment was effective in diffusing some of these compounds but did not eliminate all of them.

Where only low stresses are imposed in use or where little more than a metal-to-metal seal is required, welding with copper might be used to join beryllium to itself or to copper.

## FURNACE BRAZING

Preliminary brazing tests were made with simple lap-joint specimens. It was soon learned that these specimens were not suitable for beryllium because of the metal's notch sensitivity. Double-shear specimens were brazed with some success. Later work was devoted to brazing large specimens from which flat tensile specimens could be machined. Proper jigging and clamping of all of these specimens were difficult and would present an intricate problem in brazing any large assemblies.

Brazes were made in both vacuum and controlled-atmosphere retorts. The atmosphere retort was constructed with a hot and a cold zone. Equipment for making the brazing tests is shown in Figure 13.

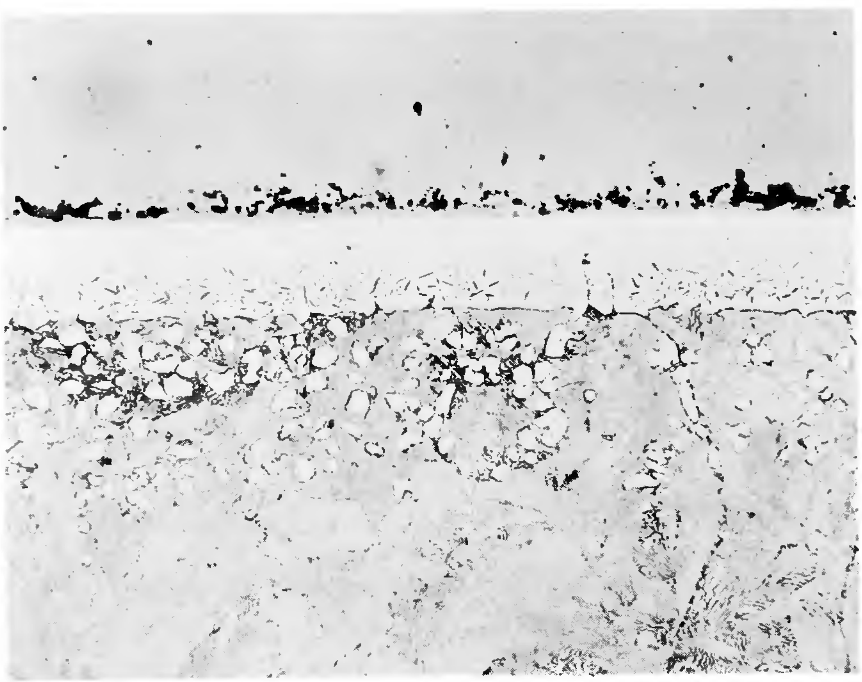
Beryllium surfaces could not be kept completely clean in any atmosphere or at pressures as low as 5 microns of mercury. However, silver and the silver-copper eutectic alloy (72 per cent silver - 28 per cent copper) wet the beryllium despite this oxidation. The predominant factor in oxide formation was the time at elevated temperatures. A rapid heating and cooling cycle (less than 15 min above 1200 F) was used to limit this time.

Brazing-alloy foil was preplaced in the joints. The joint assemblies were supported with special jigs and clamps.

Beryllium

Be-Cu compounds

250X As Welded 90254

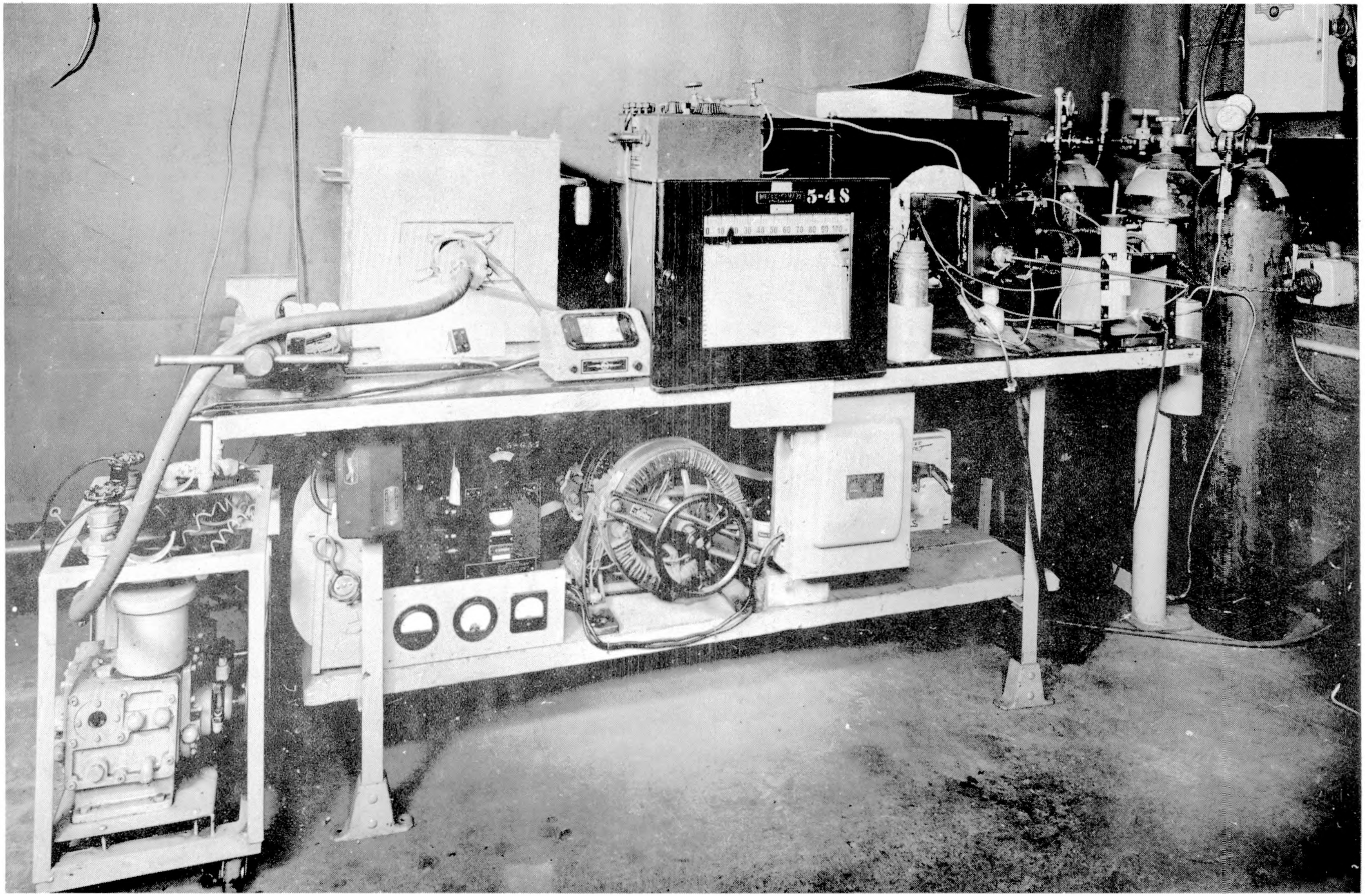


Beryllium

Be-Cu compounds

250X Heated 4 Hr at 1400 F in Helium 90255

FIGURE 12. BERYLLIUM AND COPPER WELD-METAL BOND AREAS




97318

FIGURE 13. BRAZING FURNACES AND EQUIPMENT

Discussion of the test techniques and results is presented under two filler- and base-metal groupings.

## Brazing With Aluminum Alloys

Brazing of beryllium with aluminum alloys has been investigated previously by H. A. Saller and others at Battelle. In this previous work, the best brazes were obtained with a 24-hr heating time at 1500 F. Intergranular diffusion of the aluminum into the beryllium during this cycle strengthened the bonds of these joints. Tests were made to determine if the diffusion rate could be speeded up by increasing the temperature to 1600 F or 2000 F. Shorter heating times (6 hr maximum) were used in these tests. Lap-joint brazes made with these conditions were easily broken at the bond lines.

The use of long times at 1500 F is recommended for brazing beryllium to itself with aluminum. Aluminum cannot be joined to beryllium by this method, but aluminum-brazed assemblies could be welded to aluminum.

## Brazing With Copper and Silver Alloys

Copper- and silver-base alloys are usually used to braze copper, Monel, nickel, and stainless steel. Survey tests were made with many copper- and silver-base alloys as brazing materials, to determine if they would be useful in brazing beryllium to itself and to the other metals mentioned above.

### Preliminary Tests

Lap-joint brazes were made with base-metal strips, 1/8 x 1/4 x 2 in. The beryllium strips were cleaned before brazing by etching one minute in a chemical bath* held at 235 F. Surface films were removed from the brazing foils by polishing with 400-grit metallographic paper. All brazing foil used was 0.003 in. thick. Specimens were set up in small stainless steel clamps with a 1/4-in. overlap.

The braze assemblies were placed in the vacuum or controlled-atmosphere retort. To facilitate outgassing, the vacuum retort was preheated to 800 F outside the furnace. The braze assembly was placed in the

| | | |
|---|---|---|
| *Concentrated orthophosphoric acid | - | 450 ml |
| Concentrated sulfuric acid | - | 26-1/2 ml |
| Chromic anhydride | - | 53-1/4 g |

hot zone of the furnace, which was heated well above the brazing temperature. When the assembly reached the desired temperature, it was removed rapidly for cooling.

This procedure was used to obtain the rapid heating and cooling cycles that are believed to be necessary in brazing beryllium. Diffusion of beryllium into copper alloys is known to embrittle the alloys, and there is reason to believe that other alloys would also be embrittled by beryllium pickup.

Brazing alloys with a narrow melting range (pure metals or eutectics) produced better brazes than alloys with wide melting ranges.

A dry hydrogen atmosphere with a dew point -40 F or lower was necessary to obtain good bonds to stainless steel. The other base metals, including beryllium, could be brazed in argon, helium, and hydrogen atmospheres or in vacuum.

Lap joints brazed with copper-base alloys in the temperature range from 1650 to 2000 F were brittle. The brazes fractured at the beryllium-copper interface at low loads. The fractures were of the smooth type typical of fractures obtained in welds made in beryllium with copper and discussed in a preceding section.

Lap joints brazed with silver and some of its alloys broke in the beryllium plates. Silver and the silver-copper eutectic alloy (72 per cent silver - 28 per cent copper) were selected for further testing to determine the strength properties of the brazes.

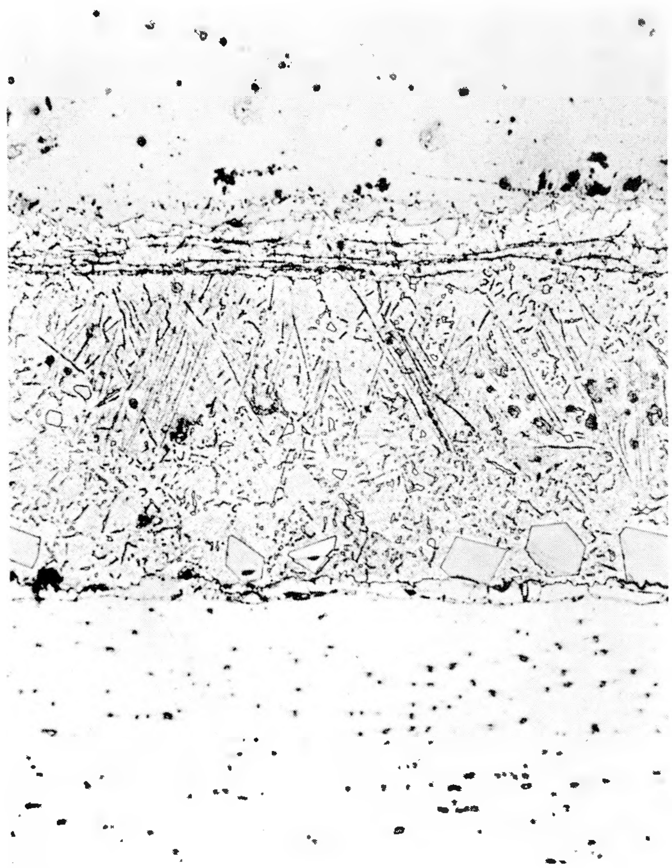
Metallographic examination of the brazes made with silver and silver brazing alloys showed that the bonds between the beryllium and the brazing alloy were good. Figures 14 and 15 show photomicrographs of brazes made with silver and the silver-copper eutectic alloy.

It has been reported* that successful brazes of metals to refractory oxides have been made using an 85 per cent silver - 15 per cent zirconium alloy and induction brazing. These alloys might wet oxidized beryllium surfaces more readily than other silver alloys. Tests were made in which foils of silver and zirconium were placed in lap joints and heated to 1950 F. The amount of each foil used was adjusted to give an alloy with a composition of 85 per cent silver and 15 per cent zirconium. This method resulted in the alloy melting over a wide temperature range, and poor brazes were obtained. Further work with this alloy system might be advisable.

## Strength Properties of Braze Joints

Figure 16 shows the specimens used for preparing silver and silver-copper eutectic brazes for strength tests.

*Pearsall, C. S., and Zingesen, P. K., "Metal to Nonmetallic Brazing", Technical Report No. 104, MIT, April 5, 1949.



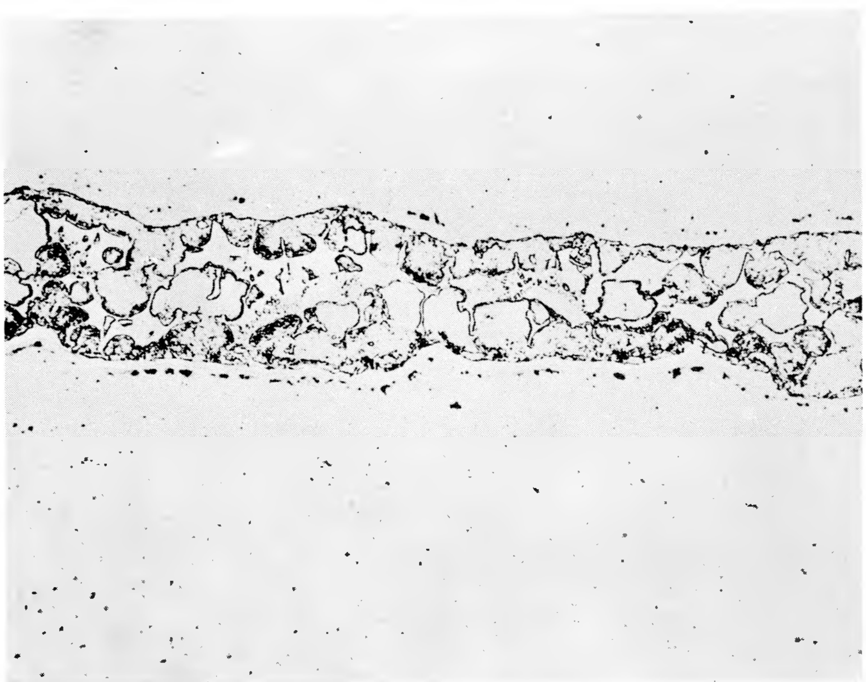
Beryllium

Silver braze

Type 347 stainless steel

250X 91034

FIGURE 14. BERYLLIUM-TO-STAINLESS BRAZE MADE WITH SILVER



Beryllium

72% silver-
28% copper braze

Beryllium

250X 91028

FIGURE 15. BERYLLIUM-TO-BERYLLIUM BRAZE MADE WITH SILVER-COPPER EUTECTIC ALLOY

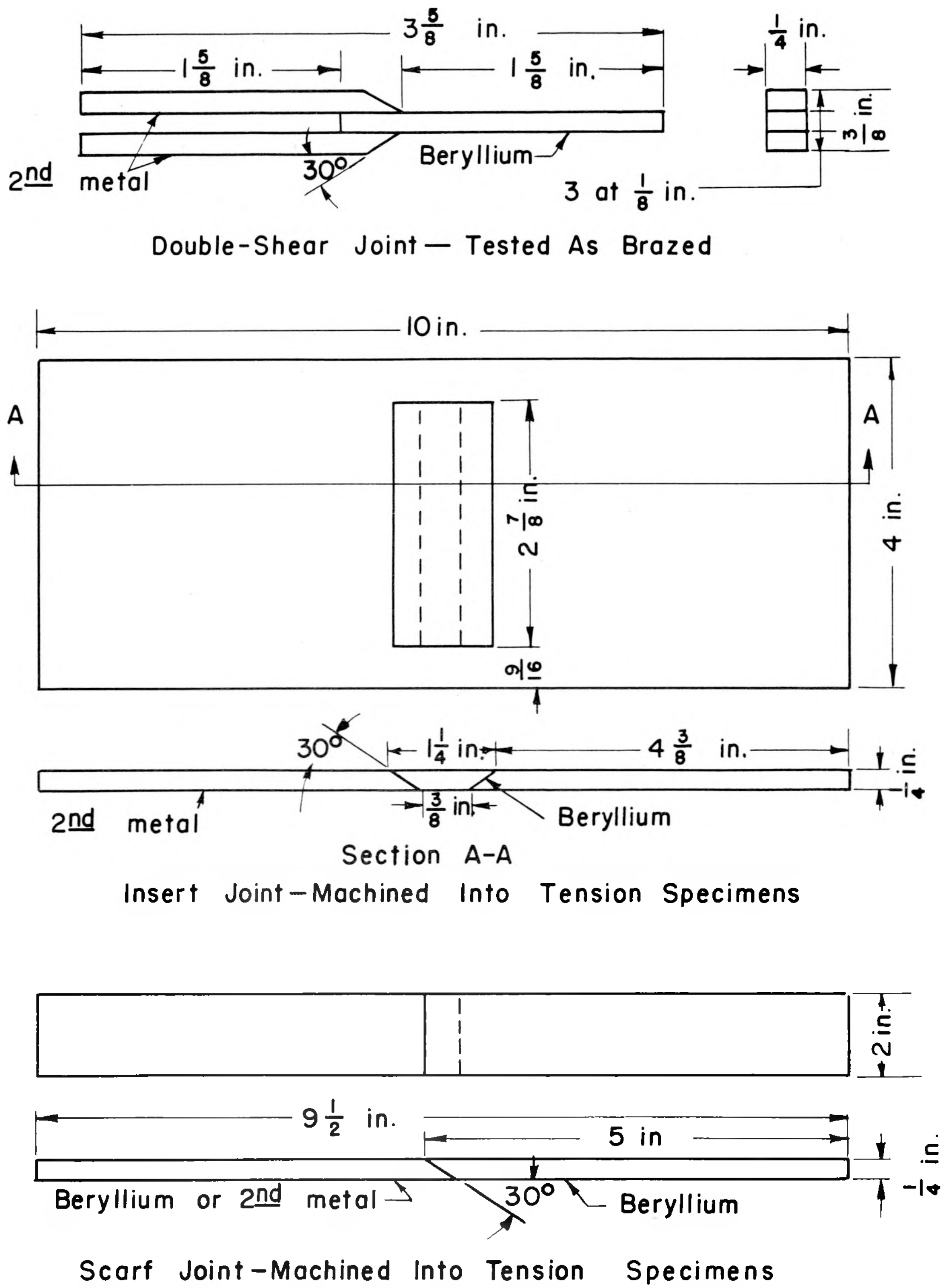



FIGURE 16. BRAZE SPECIMENS FOR DETERMINING STRENGTH PROPERTIES

A-5908

Double-shear joints were brazed using the same procedures used for lap joints. After brazing, the specimens were pulled in tension in a Dillon testing machine. Platen speed used for these tests was 0.05 in. per minute. Data and results of these tests are given in Table 6.

Insert joints were brazed in the atmosphere retort. A supporting jig attached to a stainless steel tube was used to push the specimen into the hot zone for brazing and to remove it for cooling. A thermocouple was placed inside this tube. The beryllium insert plates were clamped into position.

Scarf joints were also brazed in the atmosphere retort. A combination clamping and supporting jig was used for positioning these joints in the retort.

Both the insert and the scarf joints were difficult to braze. The major problem was in designing suitable jigs for holding the joint surfaces in contact throughout the brazing cycle. Table 7 lists the brazing data and test results of insert and scarf-joint specimens which were machined into tension specimens. The same procedures used for machining and testing weld specimens were used for these braze specimens.

## Discussion

The large temperature range through which the plates must be heated and cooled during a brazing cycle results in dimensional changes which make proper jigging difficult. Considering this effect alone, the ease with which the other metals investigated can be brazed to beryllium is ranked as follows:

1. Monel,
2. Nickel,
3. Type 302 stainless steel, and
4. Copper.

By using a ferritic stainless steel, instead of the austenitic Type 302 used in this investigation, brazes could be made as easily as they can be made to Monel.

Lap joints are much easier to braze than any type of butt joint. The inherent discontinuities and resulting stress concentrations in lap joints can be lessened by proper design, but they cannot be eliminated completely. For this reason, the effects of lap joints on the properties of a brazed joint should be considered carefully before such joints are used.

Induction heating would be the best method of producing a short brazing cycle and minimizing diffusion of beryllium into the brazing alloys. However, its usefulness is limited to small assemblies.

REM:DCM:CBV/bep
June 9, 1953

TABLE 6. BRAZING CONDITIONS AND TEST RESULTS FOR DOUBLE-SHEAR BRAZES

Beryllium to nickel, Monel, or Type 347 stainless steel

| Specimen | Base Metal | Atmosphere | Brazing Material[a] | Max Temp, F | Time Above Alloy Melting Point, min | Appearance | Load[b], lb | Area, sq in. | Breaking Stress[c], psi |
|---|---|---|---|---|---|---|---|---|---|
| Be133 | Monel | Vacuum | 72 Ag, 28 Cu | 1520 | 3 | Good | 1525 | 0.036 | 42,400 |
| Be134 | Nickel | " | Ditto | 1510 | 3 | Fair | 700 | 0.035 | 20,000 |
| Be135 | 347 stainless steel | " | " | 1510 | 3 | Poor | 225 | 0.034 | 6,600 |
| Be136A | 347 stainless steel | " | " | 1530 | 3 | Poor | 110 | 0.036 | 3,100 |
| Be152 | Nickel | Argon | " | 1570 | 1 | Poor | 200 | 0.028 | 7,100 |
| Be143 | 347 stainless steel | Hydrogen | 100 Ag | 1795 | 1 | Poor | 800 | 0.033 | 24,200 |
| Be145A | Nickel | Vacuum | " | 1850 | 3 | Poor | 1025 | 0.034 | 30,000 |
| Be145B | Monel | Vacuum | " | 1850 | 3 | Poor | 375 | 0.034 | 11,000 |

(a) Melting points: 72 per cent silver - 28 per cent copper - 1435 F
100 per cent silver - 1760 F

(b) All fractures occurred in the beryllium.

(c) Stress calculated using area of beryllium.

TABLE 7. BRAZING CONDITIONS AND TENSION-TEST RESULTS FOR INSERT AND SCARF-JOINT SPECIMENS

Beryllium to itself, copper, Monel, or Type 302 stainless steel

| Specimen | Type | Base Metal | Atmosphere | Brazing Alloy[a] | Max Temp, F | Time Above Alloy Melting Point, min | Thickness Machined[b], in. | Load, lb | Breaking Stress[c], psi | Location of Fracture |
|---|---|---|---|---|---|---|---|---|---|---|
| Be165A | | | | | | | 0.086 | 330 | 7,700 | Bond |
| Be165B | Insert | Copper | $H_2$ | 72 Ag, 28 Cu | 1545 | 2 | | Broken during machining | | |
| Be165C | | | | | | | 0.136 | 525 | 7,700 | Bond |
| Be168A | Scarf | Copper | $H_2$ | 72 Ag, 28 Cu | 1445 | < 1 | 0.153 | 690 | 9,000 | Bond |
| Be168B | | | | | | | 0.140 | 710 | 10,100 | Bond |
| Be173A | Scarf | Monel | $H_2$ | 100 Ag | 1790 | 1 | 0.148 | 2020 | 27,500 | Beryllium |
| Be173B | | | | | | | 0.173 | 2350 | 27,200 | Bond and Beryllium |
| Be176 | Scarf | 302 stainless steel | $H_2$ | 100 Ag | 1850 | 6 | | Broken during machining | | |
| Be180 | Scarf | Beryllium | He + $H_2$ | 72 Ag, 28 Cu | 1600 | 3.5 | | Broken during machining | | |
| Be181A | Scarf | Beryllium | He + $H_2$ | 100 Ag | 1775 | 1 | 0.180 | 490 | 5,500 | Bond and Beryllium |

(a) Melting points: 72 per cent silver - 28 per cent copper – 1435 F
100 per cent silver – 1760 F

(b) All specimens – 0.501 ± .001 in. wide.

(c) Stress calculated using normal area of reduced section.