

SLAC-PUB-1095
(ACC)
August 1972

BRAZING WITH COPPER AND COPPER-BASE ALLOYS*

G. P. Fritzke

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

(Paper to be presented at the Conference on Copper,
Metal Show and Materials Engineering Conference,
Cleveland, Ohio Oct. 16-19, 1972)

* Supported by the U. S. Atomic Energy Commission.

The purpose of this paper is to present a variety of topics associated with brazing — especially brazing of copper with copper-base alloys. These topics are drawn from the experiences of fabricating the accelerating components and related experimental hardware for the world's longest and most powerful electron accelerator, better known as SLAC (Stanford Linear Accelerator Center*). As its name implies, the useful function of SLAC is to produce high-energy electrons which are used either to "map" the profile of a proton or neutron, or to bombard targets and to study these reactions. The production of these high-energy electrons takes place through an in-line series of accelerating sections, called disc-loaded waveguides, which are manufactured by machining and brazing. To facilitate handling, waveguide sections are manufactured in 10-foot long lengths — each length contains over 200 braze joints, all of which must be vacuum tight since leaking air into the system would interfere with the bunches of electrons as they speed past (reaching, by the way, 99.999996% of the speed of light). These disc-loaded waveguides are coupled to powerful klystron tubes which produce the bursts of energy necessary for electron acceleration. The matching of the energy paths from the klystrons to the disc-loaded waveguides must be carried out with precision and repeatability since almost one thousand sections, each 10-feet long, had to be made. Such precision was partially achieved by manufacturing each 10-foot section in a series of brazing steps. Since rebrazing a part containing an already-brazed joint must be carried out at successively lower temperatures to avoid remelting the joint, step-brazing was employed as the means to produce each section. The first section describes this process. Subsequent sections then describe some problem areas that are of interest since they are relatively uncommon and may be frustratingly encountered by most brazing shops.

A. Step Brazing of Accelerator Disc-loaded Waveguides

Ideally, an entire waveguide assembly might be brazed in a single step. However, the needs for vacuum integrity, internal inspection (boroscope) of the cavity surfaces for signs of excess braze alloy, and precise alignment of sections that "couple" the high-frequency energy to the disc-loaded waveguides from klystron tubes precludes a one step operation.

To produce one accelerator section, at least 5 separate braze steps were required. As shown in Figure 1, Step 1 joined a stainless-steel weld flange (to facilitate welding of adjacent accelerator sections) to a stiffening ring with pure copper (melting point of 1083°C). Two parts were joined in Step 2 — the braze alloy used here was 65% copper and 35% gold with a melting point of 1010°C. Part 1 joined a stainless steel flange to a rectangular piece of copper that formed the transition from the klystron-produced energy to the disc-loaded waveguide sections. The second part of Step 2 was to join the previously-brazed weld flange from Step 1 to a cavity, called a "coupler" cavity. Step 3 joined these two parts with several cavity sections to facilitate the next step. The braze alloy used for Step 3 was 50% copper 50% gold, with a melting point of 970°C. These steps produced an "input" coupler and an "output" coupler. Step 4 joined these two couplers at the end of a stack of disc-loaded waveguide sections by using a braze alloy of 72% silver and 28% copper — the eutectic alloy with a melting point of 780°C. Finally, Step 5 (not shown in Fig. 1) joined eight copper water-cooling

* Operated by Stanford University for the USAEC.

tubes to the outside of the waveguide. These tubes are necessary to maintain the accelerator at a constant temperature ($113^{\circ} \pm 1.25^{\circ}\text{F}$). This last braze was performed with an alloy consisting of 63% silver, 27% copper and 10% indium which has a melting point of 730°C . Repair operations, when necessary could be carried out with a similar alloy — 61% silver, 24% copper and 15% indium — with a melting point of 705°C . Brazing was an ideal technique for step 5 since maximum heat-transfer surface could be assured with the flow of this alloy.

Once production started, not one failure was encountered due to brazing. Most of this success could be attributed to excellent quality control of the braze alloy material by the outside vendors and the careful numbering system and material control maintained internally.

Figure 2 shows a typical inlet-coupler portion with the stainless steel flange and transition piece as they are supported by a fixture required for alignment. Figure 3 is an overall view of a 10-foot long section — note the many braze interfaces of this section.

B. Alloying of Braze Metal

As a braze alloy melts and starts to flow into the joint, factors such as joint clearance, base metal alloy, temperature of the part and hold time at temperature all play an important part on joint quality. Another result of these factors is that the braze alloy may react with the base metal to form either a higher or lower melting point material. Two examples are given here where errors occurred when this fact was not taken into account.

In the first example, a BAG-1 brazing alloy was used which, although not a copper-base alloy, entered from the wide joint at the upper left to fill the narrow gap at the lower right and it interacted with the base metal which was oxygen-free copper. Two steps of this interaction may be noted in this figure. First, as shown on the curved portion at the upper right, the braze material alloyed with the copper. Then, this alloy was either mechanically lifted or became chemically incompatible with the oxygen-free copper and separated to float into the braze stream, as shown at the bottom of the wide joint. The flow of the brazing alloy carried this copper-rich material into the narrow gap, the sides of which also interacted with the braze alloy.

Finally, as shown in the narrow portion of the joint, the braze alloy was overburdened with sluggish copper-rich alloy. This "new" braze alloy melted at a higher temperature and shortly downstream plugged the narrow, cold (for this new braze alloy) joint to result in incomplete filling and poor joint strength.

A brazing adage states that "The remelt temperature of a braze joint increases". However, when such knowledge is depended upon, failures can occur. One type of failure occurred when we tried to repair a vacuum leak in a braze joint between a stainless-steel flange and a copper transition section. Dilution of the 65% copper, 35% gold braze alloy (melting point of 1010°C) with copper always provided a higher temperature safety margin of 10 to 20°C when repair brazes were made in all-copper joints.

However, no effective dissolution of stainless-steel alloying elements by the braze alloy had taken place and, when repair brazing was underway, the thin layer of undiluted braze alloy next to the stainless steel melted and the stainless flange "floated" off to one side. Repairs were eventually made, but with a new copper transition section, new alloy, etc.

C. Ordering Problems with Copper-Gold Braze Alloy

The type of "ordering" referred to does not mean a purchasing procedure with a brazing vendor. As shown in Figure 5 low-temperature reactions called "ordered" reactions may occur between copper and gold if the time and temperatures are suitable. While not common, such reactions may provide headaches to facilities where high-production operations are necessary. During cleaning of the stainless-steel flange which was mentioned in the above section, the normal operations used to prepare stainless steel for hydrogen brazing did not remove the copper-gold braze material from the flange. Figure 6 shows the rejected stainless steel flange — the rectangular cutout is surrounded by a rim of braze alloy left behind by an unsuccessful repair braze. Metallography showed the residual braze alloy to be enclosed by an envelope of 90 to 95% pure gold. Figure 7 is a metallographic cross section of some of the residual braze alloy — the light-colored zone on the surface of this section is the high-gold content envelope that would not dissolve in our normal cleaning solutions.

Microprobe analyses were performed to determine the ratio of gold and copper in some of the particles. For example, Figure 8 shows the etched sample and Figures 9 and 10 show the same area where microprobe scan pictures were taken which were sensitive to gold-rich (Figure 9) and copper-rich (Figure 10) areas. Thus, small islands of gold-rich particles were caused to separate from the matrix during the ordering reaction that took place during furnace cooldown.

Other flanges, afflicted with similar "undesolvable" braze residues, were saved from the scrap bin by sanding the surface to expose the copper-rich alloy which easily dissolved during routine cleaning.

D. Stress Cracking

Four brazing operations were required to produce a leak-tight stainless steel housing for a liquid-hydrogen target. The first brazing material was pure copper, which melts at 1083°C — just below the maximum temperature reached by our hydrogen-brazing furnace. Thus, this high-temperature brazement would permit us to step braze with a wide range of braze alloys if additional brazes or repairs became necessary.

As shown in Figure 11, the short sides of the stainless steel target were set into milled slots cut into the inside surfaces of the longer top and bottom pieces. Tack welds were used to jig the plates. Copious quantities of copper powder were spread along the joint with a brazing cement. The part was inserted into an Inconel retort which was purged with nitrogen and hydrogen and lowered into a large furnace at a temperature of 1100°C. Every joint cracked, as shown in Figure 12. Metallographically, the joint area showed numerous copper-filled cracks similar to Figure 13.

Interestingly, the etched sample revealed not only grain boundary penetration by the copper but also considerable interaction by the copper with grain-boundary materials associated with 304 stainless steel. Figure 14 illustrates this grain-boundary interaction as a broadening of the grain boundaries. Also of interest was the moderate dissociation of the stainless steel at the surface where excess amounts of copper braze alloy resided. Figure 15 shows many islands of "stainless steel" as they float away from the parent material. Additional grain-boundary interaction of copper and stainless steel may also be seen in this figure.

To cause cracking of the stainless steel, a large stress gradient had to be present when the copper melted. In this instance, the stress gradient was caused by a too-rapid heating of the assembly when the cold part and retort were inserted

into the hot furnace. Subsequent brazes were successful when the idling temperature of the furnace was lowered to 1000°C and then brought to 1100°C when the retort and parts to be brazed had reached thermal equilibrium.

E. Failure of Inconel Retort

Within a week after the above hydrogen-target assembly cracks had occurred, a failure occurred in the large (2 feet in diameter by 13 foot long) Inconel retort that contained the hydrogen atmosphere used for brazing. Many brittle cracks, such as shown in a section of the retort wall (Figure 16) transected the retort near the bottom flange in several areas. Metallographically (Figure 17), the cracks again had the brittle, intergranular appearance of stress cracking.

In this instance, microprobe analysis showed numerous tramp elements (all associated with brazing alloys) to predominate the composition of the inside surface of the retort. Figure 18 illustrates the complicated microstructure associated with the splashed braze alloy that fell away from parts being brazed. Again, this failure was attributed to the combination of high stress around the bottom flange, excess liquid — metal braze alloy that dripped onto this area and the high temperature (1100°C) required to braze stainless steel with pure copper.

F. Related Stress-Cracking Problem

Recently, a stress cracking problem was encountered when "all of the facts were known" and steps had been taken to prevent stress cracking. A small expansion and alignment fixture, called a drift-tube eyelet, had already been successfully hydrogen-furnace brazed with an alloy of 65% copper and 35% gold (See Figure 19 and note the prior braze joints. The top weld cracked whereas the bottom weld was successfully welded). The welder already knew that a braze-alloy contaminated weld would crack and had scraped the inside of the tubing to remove all traces of excess braze alloy that might blush to the weld area. Metallography showed that no braze alloy was directly involved with the weld, but the weld was close enough to the joint to cause braze-alloy melting and cracking of the outer sleeve (see Figure 20). The circumferential weld apparently caused enough O.D. tensile stress during solidification and thermal contraction to cause stress cracking.

The successful weld was also examined to determine why it had not cracked, since the weld-to-braze distances were about the same. Figure 21 illustrates that cracking did occur and although the piece may have been vacuum tight, it could be expected to be brittle and fail during operation. An all-welded structure was hurriedly fabricated and inserted.

Here, then, was an instance where precautions were still not sufficient to prevent a failure. Even though the braze alloy was not intimately connected with the weld region, thermal input and stress application was sufficient to cause stress cracking at some distance from the weld.

Conclusions

Although hundreds of thousands of successful brazes pass by unnoticed, the unsuccessful braze receives almost undue attention. The examples shown here present a variety of case histories of brazes and their problem areas. It is hoped that this information may prove useful to others who are brazing copper and using copper-base brazing alloys.

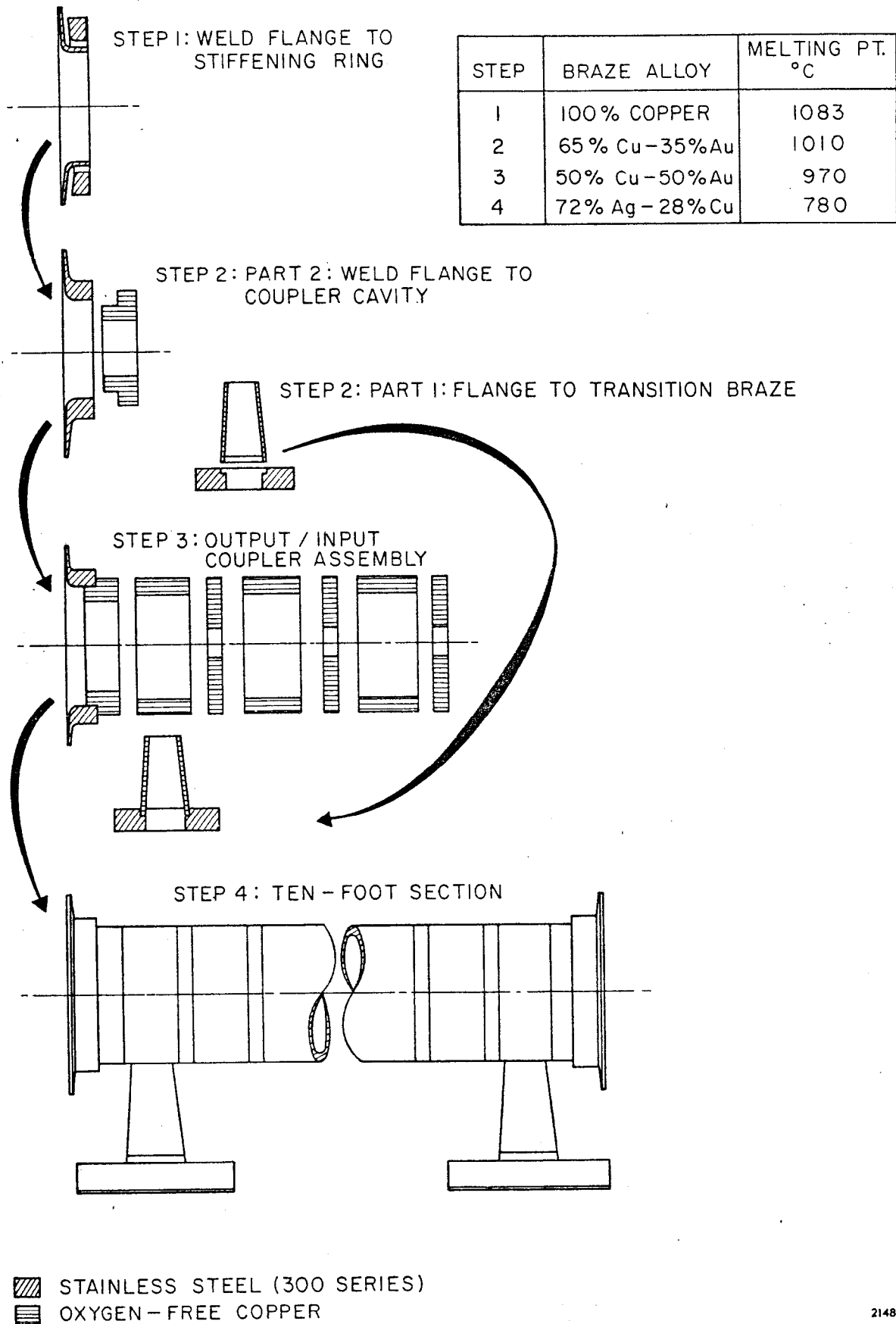


FIG. 1--Four of five step-brazing operations used to manufacture one disc-loaded waveguide.

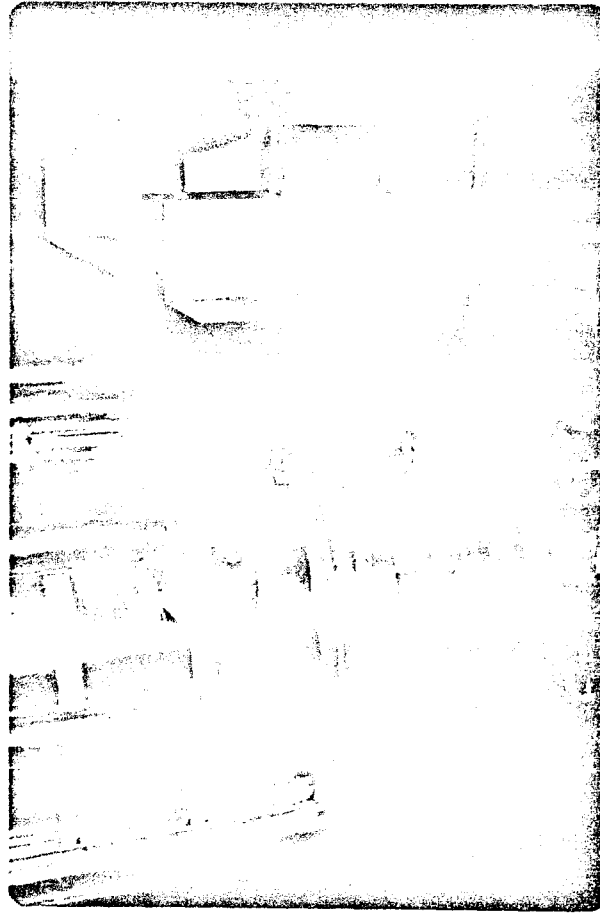


FIG. 2--Stainless steel flange and end coupler assembly.

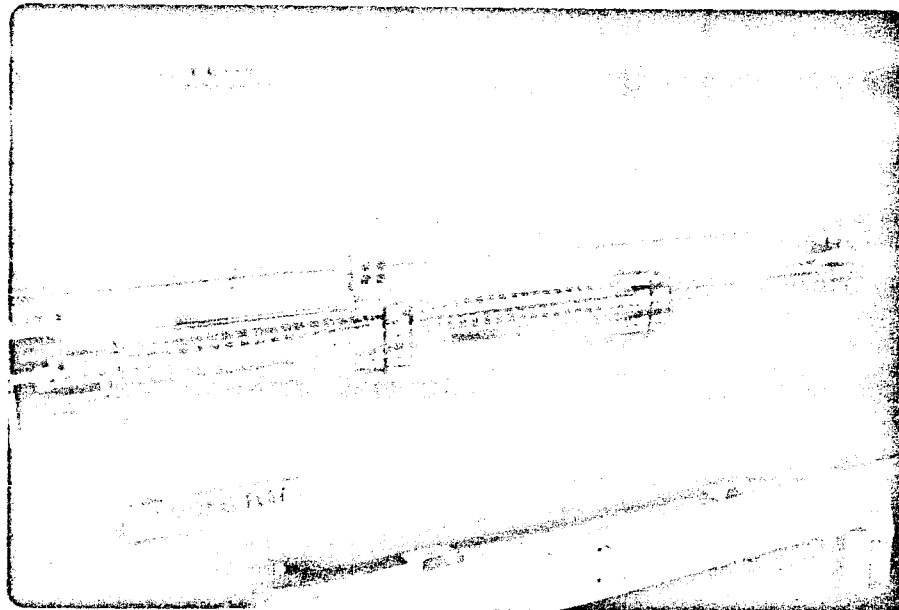


FIG. 3--Overall view of accelerator section.

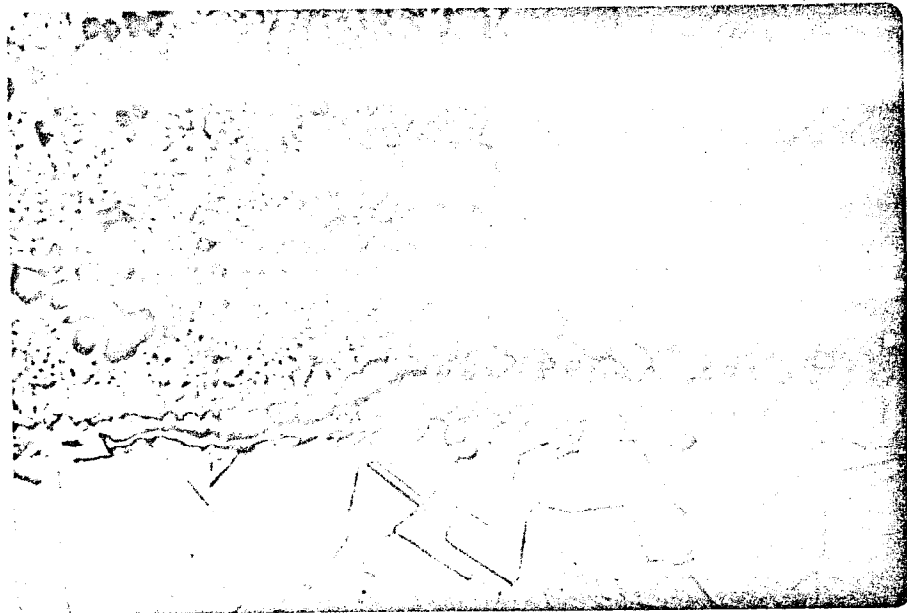


FIG. 4--Copper braze showing alloying. Magnification: 400X.

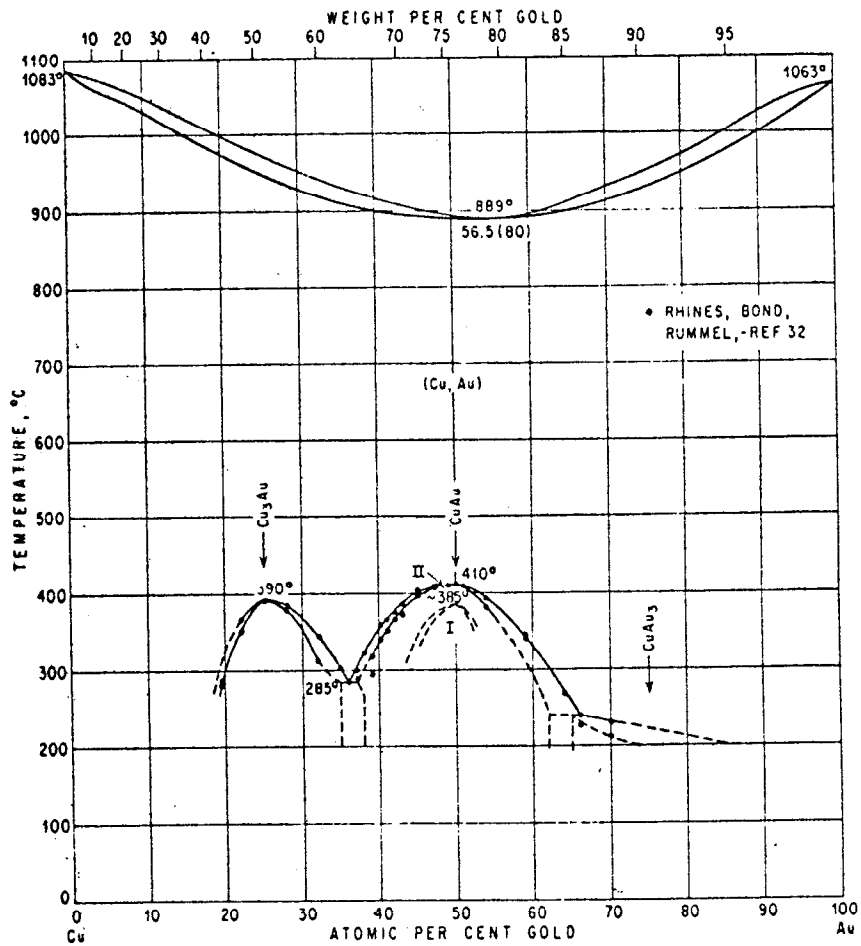


FIG. 5--Gold-copper phase diagram.

2148A10

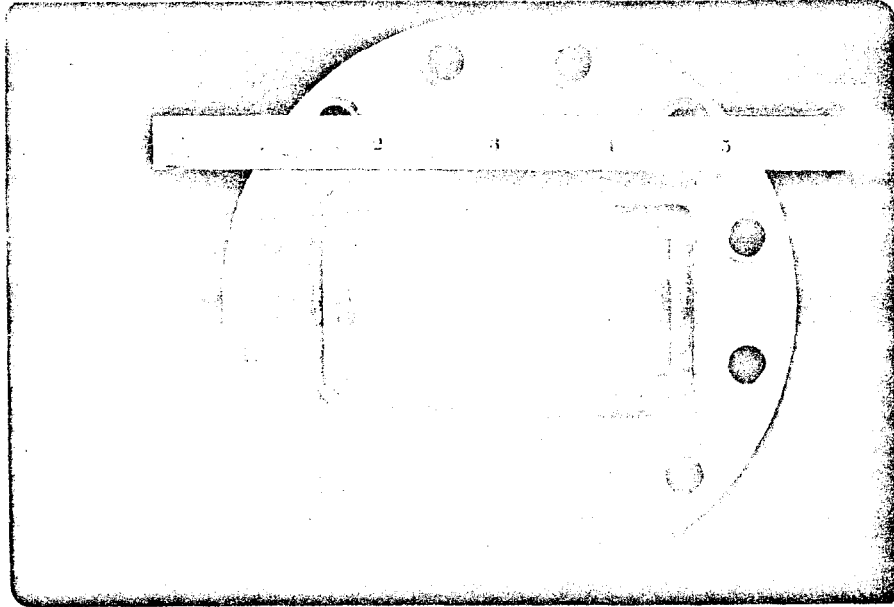


FIG. 6--Stainless steel flange reject -- undersolvable braze.

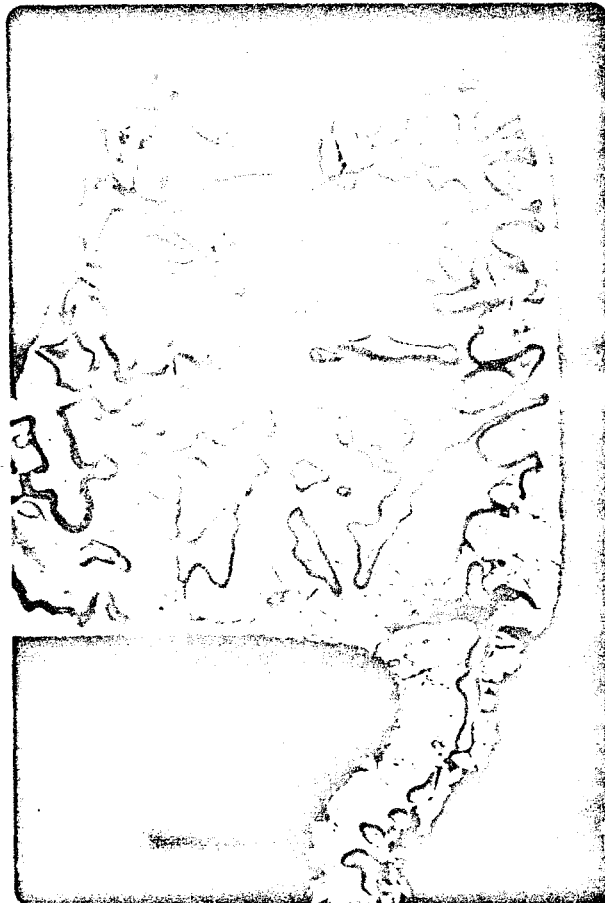


FIG. 7--Metallographic cross section of residual braze from stainless steel flange. Magnification: 50X.

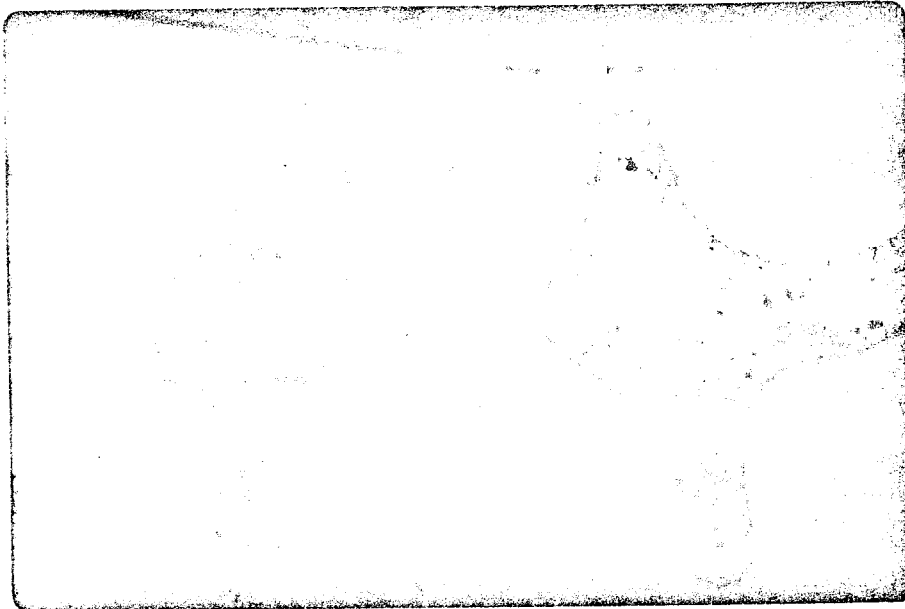


FIG. 8--Metallographic cross section in center of residual braze section. Magnification: 400X.



FIG. 9--Microprobe scan showing gold-rich configuration. Magnification: 750X.

2148A4



FIG. 10--Microprobe scan showing copper-rich background.
Magnification: 750X.

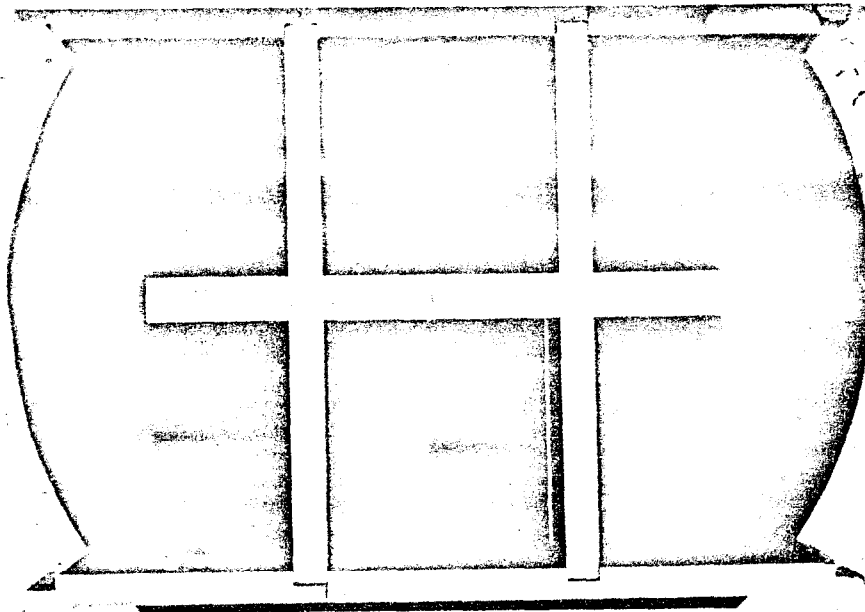


FIG. 11--Cross section through stainless steel target.

2148A5

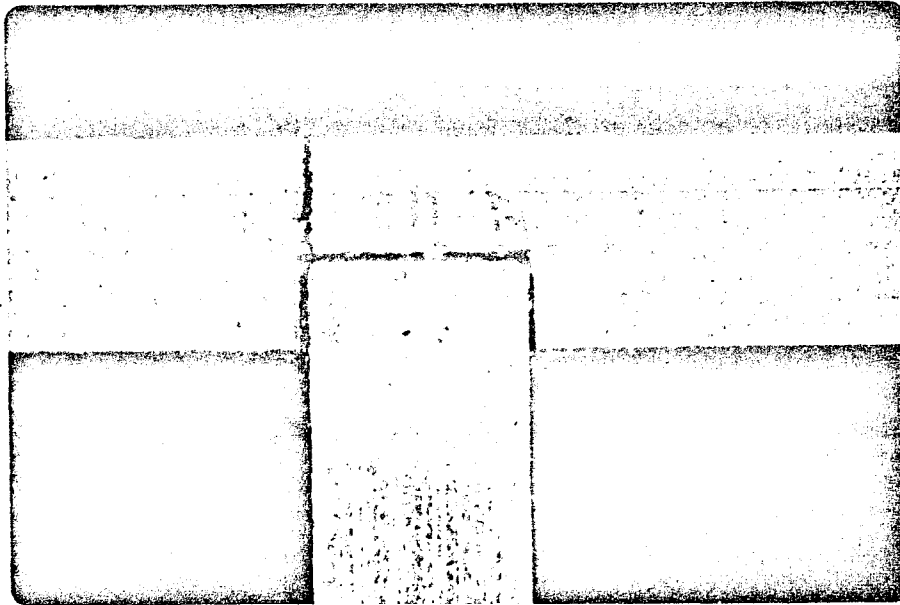


FIG. 12--Stress crack in corner of stainless steel target.
Magnification: 3X.

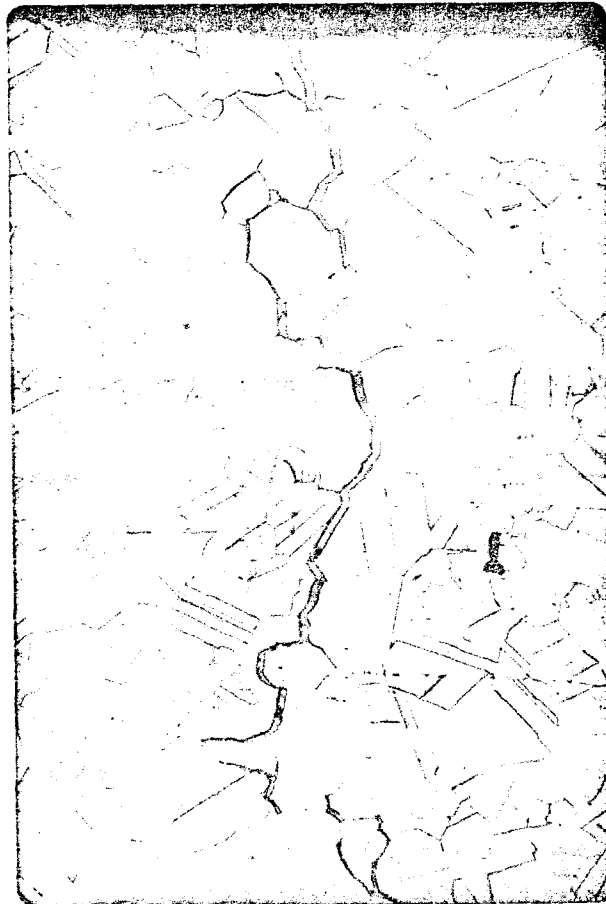


FIG. 13--Stress crack in stainless steel target. Magnification: 50X.

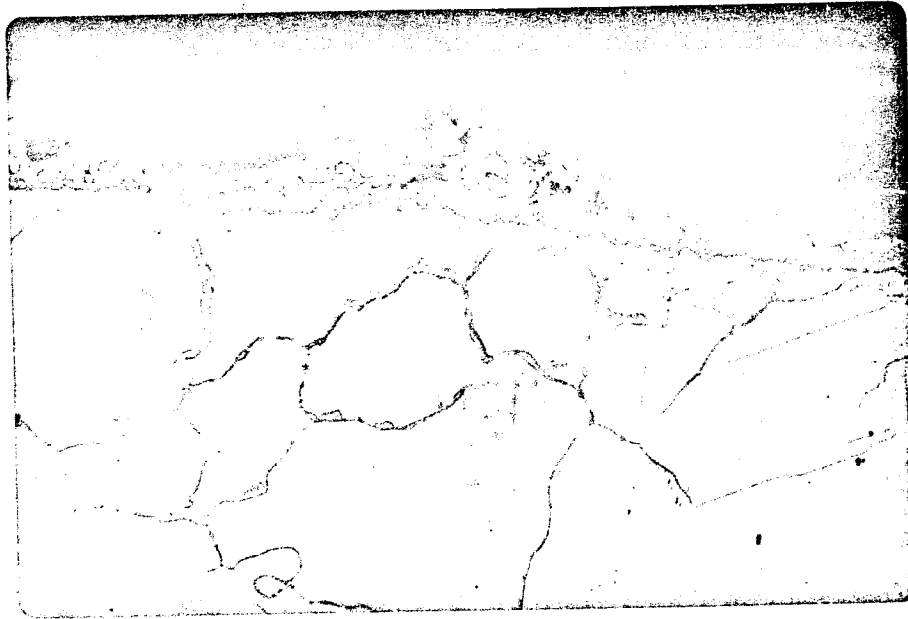


FIG. 14--Grain-boundary attack by copper braze. Magnification: 200X.

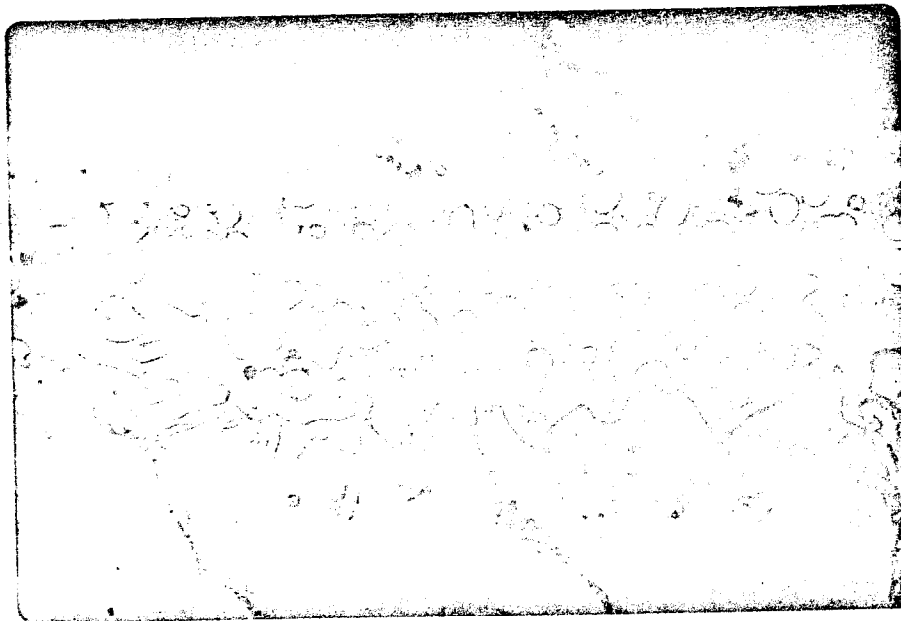


FIG. 15--Dissolution of stainless steel by copper braze material.
Magnification: 400X.

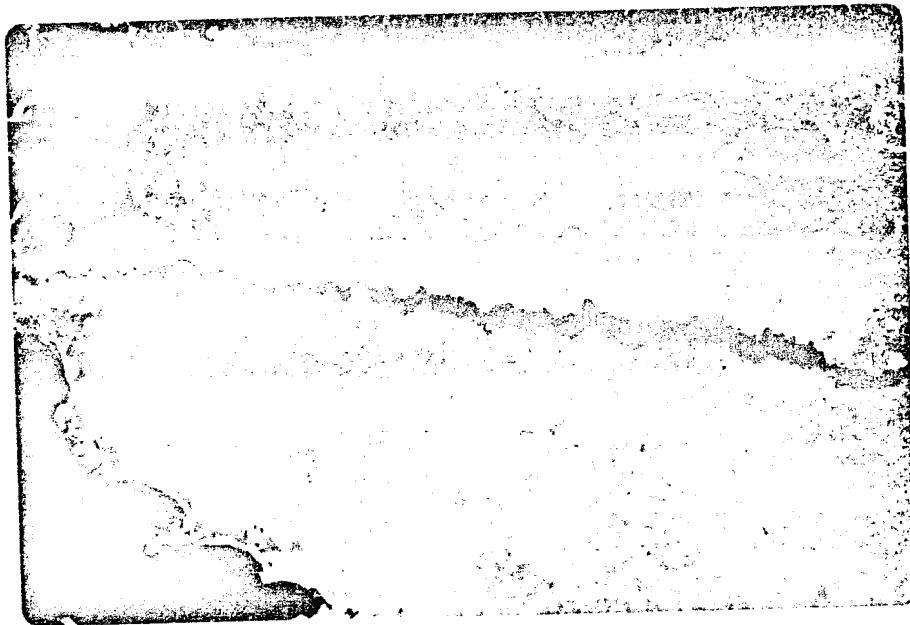


FIG. 16--Shell section of inconel retort — note crack through center.

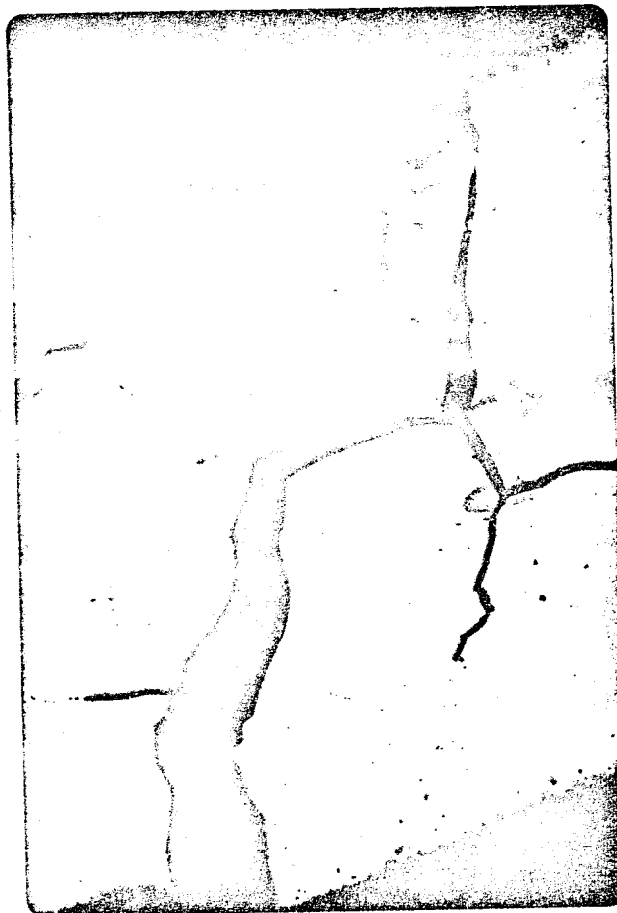


FIG. 17--Brittle crack pattern through inconel retort shell.
Magnification: 50X.



FIG. 18--Inside surface of inconel retort -- note splashed braze alloy.
Magnification: 400X.

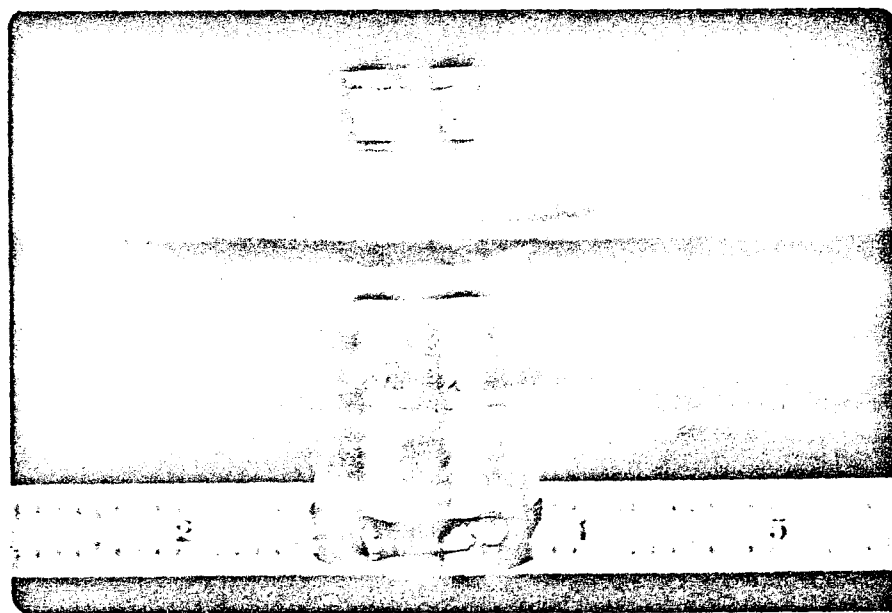


FIG. 19--Drift-tube eyelet -- note crack near top of piece.

2148A9

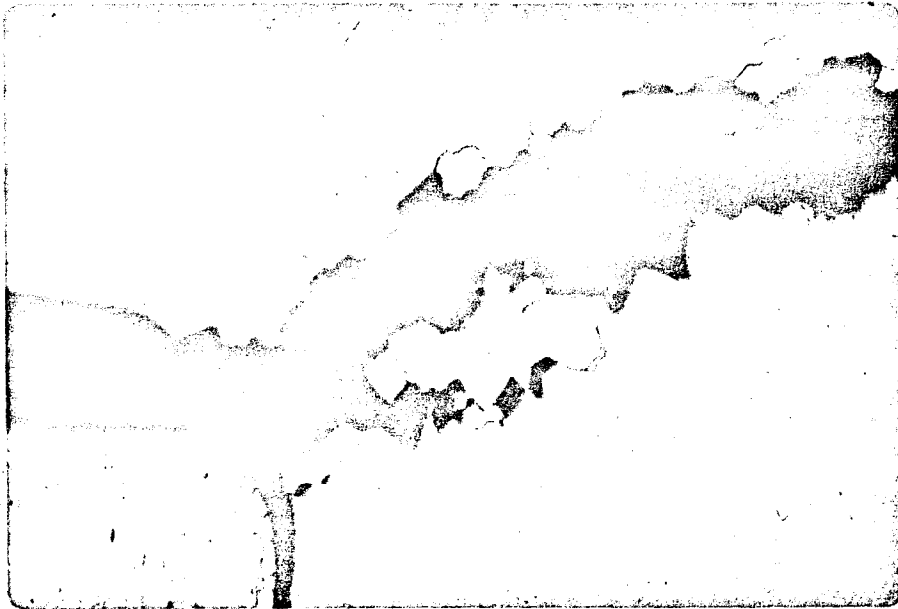


FIG. 20--Crack in outer sleeve in weld heat affected zone.
Magnification: 100X.

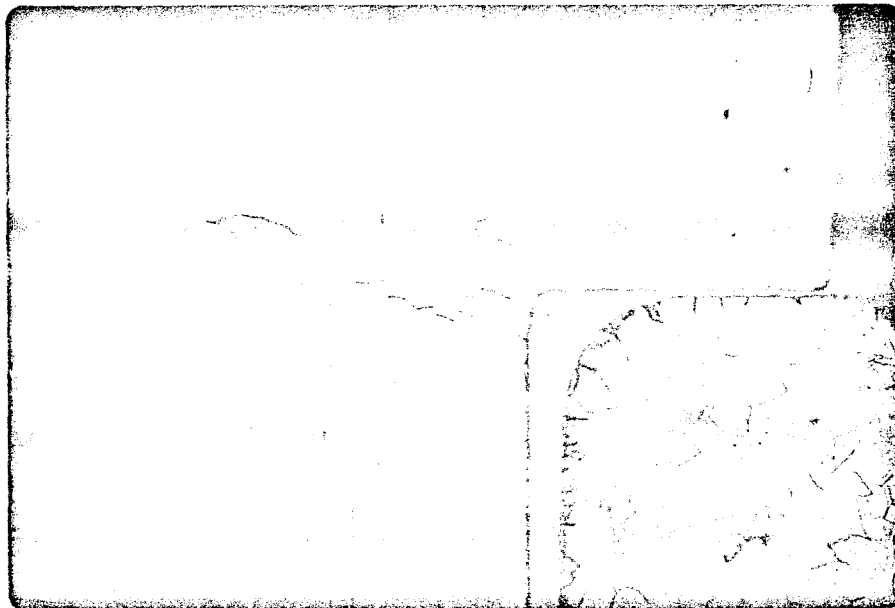


FIG. 21--Crack, filled with copper braze alloy, in "uncracked"
side of eyelet. Magnification: 50X.

2148A11