3215
10/31/63

NAA-SR-8578
COPY

MASTER

JOINING OF APM ALUMINUM ALLOYS FOR REACTOR FUEL APPLICATIONS

AEC Research and Development Report

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

Price $0.50
Available from the Office of Technical Services
Department of Commerce
Washington 25, D. C.

NAA-SR-8578
METALS, CERAMICS,
AND MATERIALS
23 PAGES

JOINING OF APM ALUMINUM ALLOYS FOR REACTOR FUEL APPLICATIONS

By

E. C. SUPAN
W. H. FRISKE
G. V. ALM

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.
P.O. BOX 309 CANOGA PARK, CALIFORNIA

CONTRACT: AT(11-1)-GEN-8
ISSUED:

DISTRIBUTION

This report has been distributed according to the category "Metals, Ceramics, and Materials" as given in "Standard Distribution Lists for Unclassified Scientific and Technical Reports" TID-4500 (21st Ed.), June 1, 1963. A total of 625 copies was printed.

CONTENTS

TABLE

FIGURES

FIGURES

ABSTRACT

Atomics International has been engaged in the development of aluminum powder metallurgy alloys (APM or SAP), for both fuel cladding and structural components in organic-cooled reactors. Due to the dispersed oxide phase in APM alloys, these materials have been difficult to join by common fusion welding and brazing techniques. This report discusses eutectic bonding, flash welding, and cold pressure bonding, the specialized joining techniques which have been found suitable for joining this unconventional and difficult-to-weld material. Silver eutectic bonding is the principal method now being used for making helium leaktight end closures in finned APM tubing. Flash welding is the best alternate method thus far investigated.

I. INTRODUCTION

Atomics International has been engaged in the development of aluminum powder metallurgy alloys (APM or SAP), for both fuel cladding and structural components in organic-cooled reactors. APM alloys, containing 4 to 7 wt % Al_2O_3, have received the greatest attention, due to their favorable nuclear, thermal, and physical characteristics. Fuel elements, consisting of UO_2 pellets clad in extruded APM finned tubes, have been fabricated and irradiated. However, because of the dispersed oxide phase in APM alloys, common fusion welding and brazing techniques have proven unsatisfactory as joining methods. This report discusses the specialized joining techniques which Atomics International has found to be suitable for joining this unconventional and difficult-to-weld material.

Comparative elevated-temperature tensile properties of two APM alloys and wrought Type 7075 T-6 alloy are illustrated in Figure 1. The M257 alloy consists essentially of a highly dispersed phase of Al_2O_3 (4 to 7 wt %) in pure aluminum. It is the dispersed oxide phase which, by its dispersion-strengthening mechanism, imparts the good elevated-temperature strength properties. In the organic-cooled reactor, the APM fuel cladding reaches temperatures up to 900°F, which necessitates these elevated-temperature strength properties. M486* is a prealloyed APM alloy that is strengthened by a dispersion of intermetallic compounds. However, these intermetallics are soluble above 800°F, and mechanical strength properties are reduced, limiting its application as a cladding alloy.

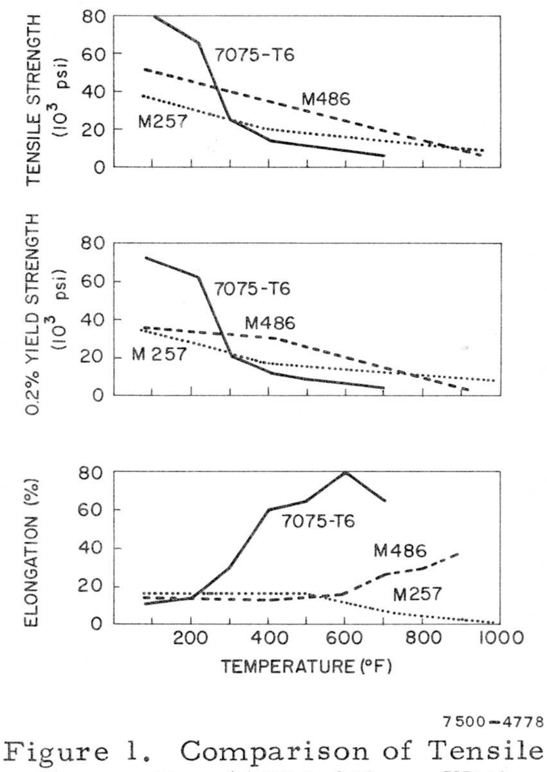
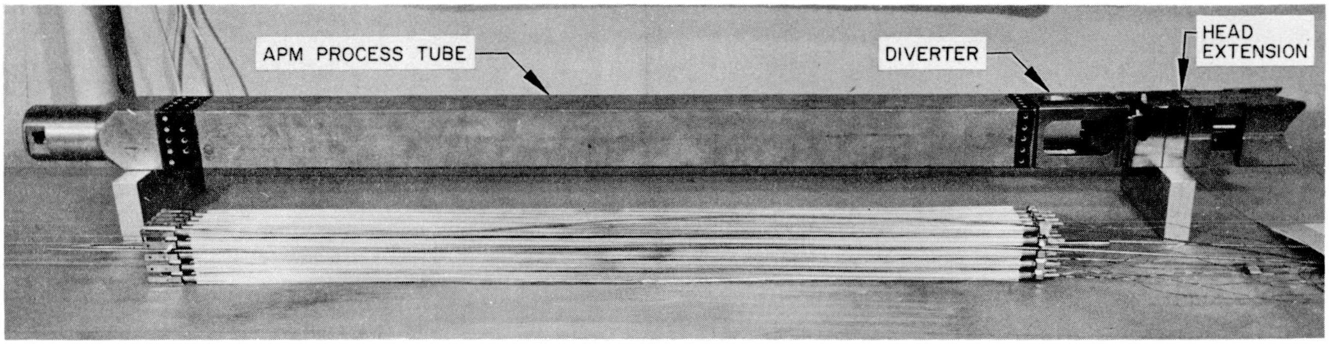


Figure 1. Comparison of Tensile Properties (APM Alloys With Wrought Alloy Type 7075 T-6)

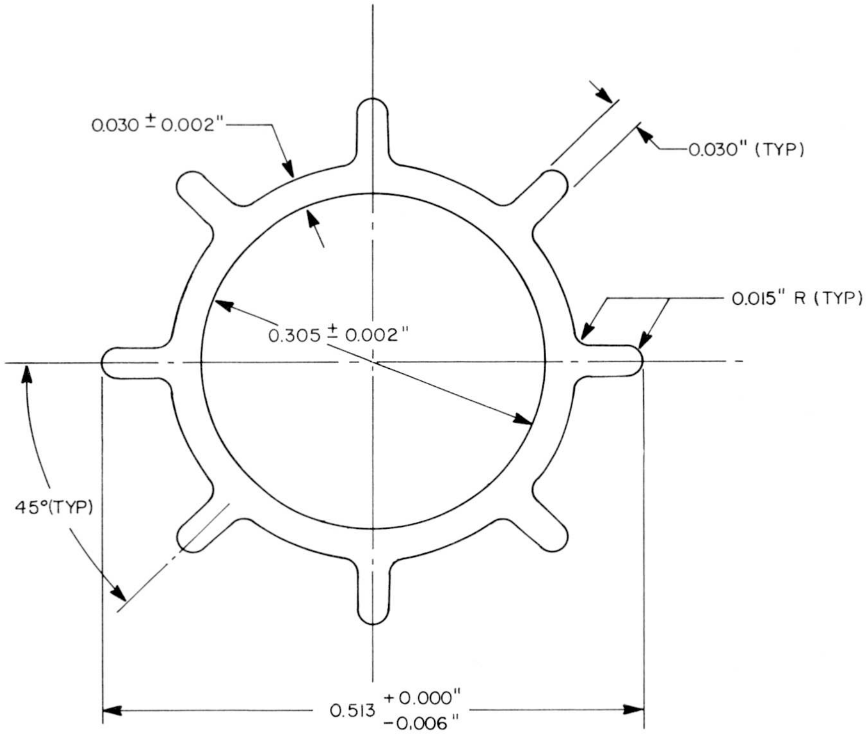
A typical APM-clad UO_2 fuel rod and test fuel element are shown in Figure 2. The joining problem is restricted to the end closures in the tube, a cross section of

*M486 Nominal Composition: 7.8% Fe, with 0.2% each of Cr, Ti, V, and Zr.



7600-5162E

Figure 2. APM-UO_2 Irradiation Test Element for OMRE

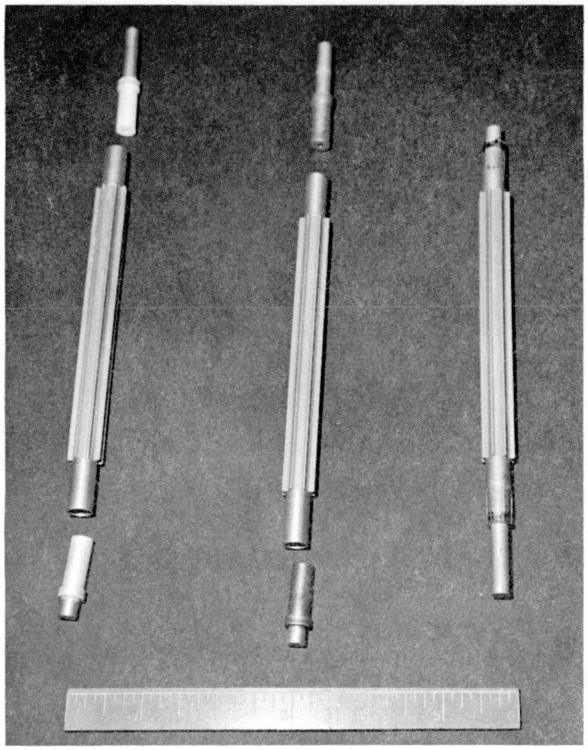


7500-51625

Figure 3. Eight-Finned M257 Fuel Tube

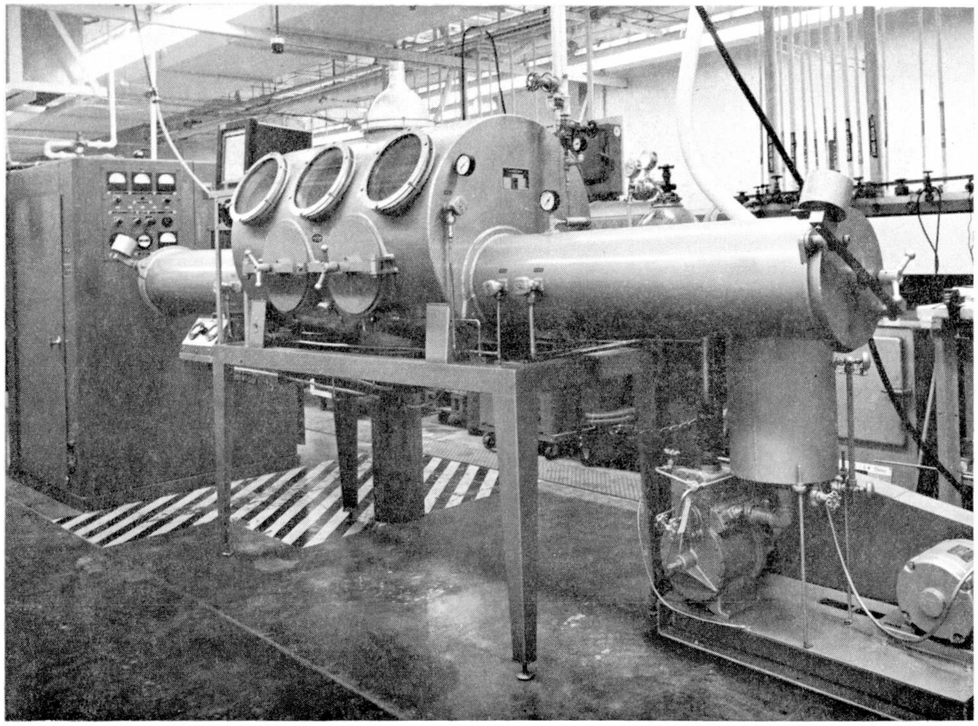
which is shown in Figure 3. Joining of end-closure components by fusion welding results in destruction of the dispersed oxide. The oxide phase segregates in the fusion zone, leaving the weld strength, at best, near that of unalloyed aluminum. On the other hand, at the operating temperatures of the fuel cladding, brazed joints are mechanically weak. Joints made in APM alloys by these techniques are not only undesirable, with respect to strength, but also are extremely difficult to produce.

It is evident that those techniques which cause essentially no disruption of the oxide dispersion offer the most promise for promoting high-efficiency joints. Solid-state bonding falls into this category. The techniques which appear to be most suitable for APM end closures include eutectic bonding, flash welding, cold pressure welding, magnetic force welding, and friction welding. Three of these techniques which have been investigated at AI, in varying degrees, are discussed here. These are eutectic bonding, flash welding, and cold welding.



7500-4128B

Figure 4. Experimental Fuel Rods



7600-51160C

Figure 5. Glove Box for Eutectic Bonding of End Closures

II. EUTECTIC BONDING

Silver eutectic bonding is the principal method now being used by Atomics International for making helium leaktight end closures in finned APM tubing. This process represents a specialized case of hot pressure bonding.

Figure 4 illustrates the end-closure design used for eutectic bonding. The Type 1100 aluminum alloy end plug is electroplated with a 0.0001-in. thick coating of silver, in preparation for bonding. A silver-aluminum eutectic occurs at 1050°F, with the eutectic composition at 29.5 wt % silver. The end closure assembly is heated, under pressure, to a temperature above the 1050°F eutectic, wherein the formation of the eutectic is followed by rapid diffusion of silver away from the joint area.

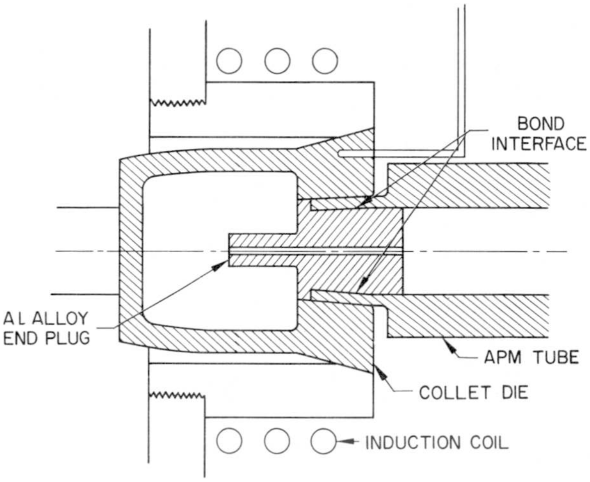
Eutectic bonding is carried out in a helium-filled glove box, as shown in Figure 5. The parts are introduced into either of the evacuation chambers, which are located at each end of the glove box. The air in the chamber is removed by a vacuum pump, followed by back-filling with helium to atmospheric pressure. The parts are then transferred to the helium-filled working chamber for eutectic bonding.

The apparatus used for eutectic bonding is shown in Figures 6a and 6b. Pressure is applied to the end-closure assembly by a six-segment collet die, in conjunction with a pneumatic pressure cylinder. The collet die is heated by high-frequency induction. A thermocouple is located in the collet, and the temperature is continuously recorded during the entire bonding operation.

Prior to assembly of the components for bonding, the joint area of the APM tube is wire-brushed in the glove box, to remove surface oxide contamination. Eutectic bonding is effected by heating the assembly to 1140°F under pressure, and holding it at temperature for 3 to 5 min, followed by cooling (under pressure) to 300°F. The process requires about 15 min of heating and cooling time per joint. The microstructure of a typical eutectic-bonded end-closure joint is shown in Figure 7.

A. PEEL TESTS

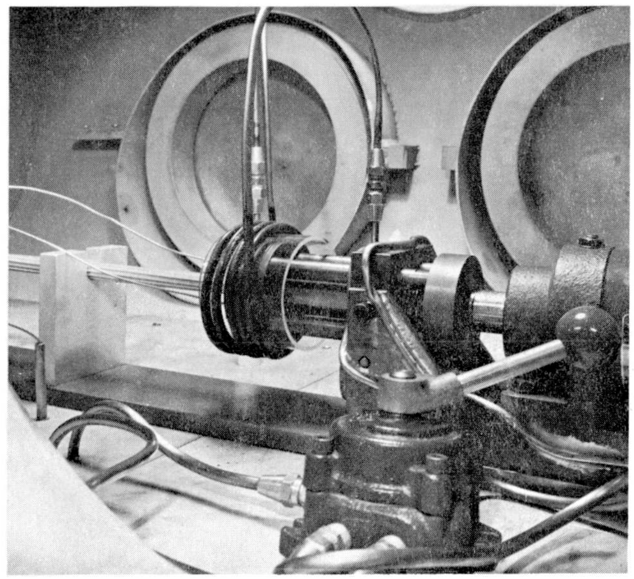
Evaluation of bond integrity is made by a simple "peel test" (i.e., separating the joint by prying the components apart with a hammer and chisel). Three levels of bond quality are recognized:



7600-5170

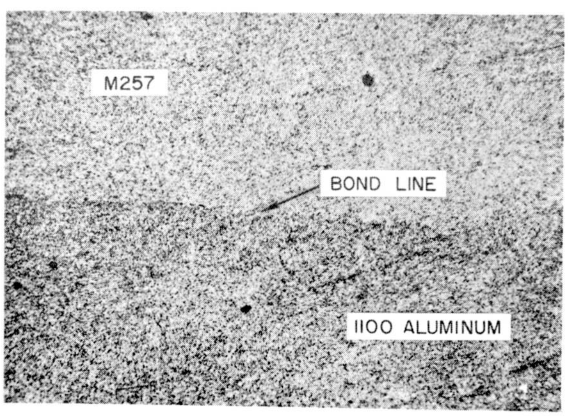
a. Schematic

b. Photograph



7600-51160B

Figure 6. Eutectic-Bonding Apparatus



250 X

7500-51626

Figure 7. Microstructure of a Eutectic Bond

1) "A" bonds are those which cannot be separated with a chisel.

2) "B" bonds are those which can be partially separated, only with considerable difficulty.

3) "C" bonds are those which can be separated fairly easily.

Only the "A" and "B" bonds are considered acceptable for fuel-rod end closures.

When producing end closures in fuel rods, peel tests are made on dummy specimens, before and after each day's run and after every 3 or 4 end closures, to ensure that "B" bonds, or better, are being consistently obtained.

B. LEAK TESTS

The eutectic-bonded end closures are tested for helium leaktightness while being thermally cycled between 350 and 900°F. The fuel rod is enclosed in a vacuum retort, and is continuously monitored for leaks. Thus, the helium atmosphere contained in the fuel rod facilitates leak testing. Each end closure is subjected to a minimum of three heating cycles. The criterion for leak-tightness is a helium leak rate less than 1×10^{-8} std. cc/sec during the final cycle.

C. OPERATIONAL TESTS

The eutectic-bonding process has been used in the fabrication of five test elements for the OMRE test reactor. Four of these have completed the scheduled irradiation in the reactor core, while the fifth was removed prior to irradiation, because of a malfunction in the instrumentation. There have been no failures in the eutectic-bonded end closures of the fuel rods in any of the five test elements.

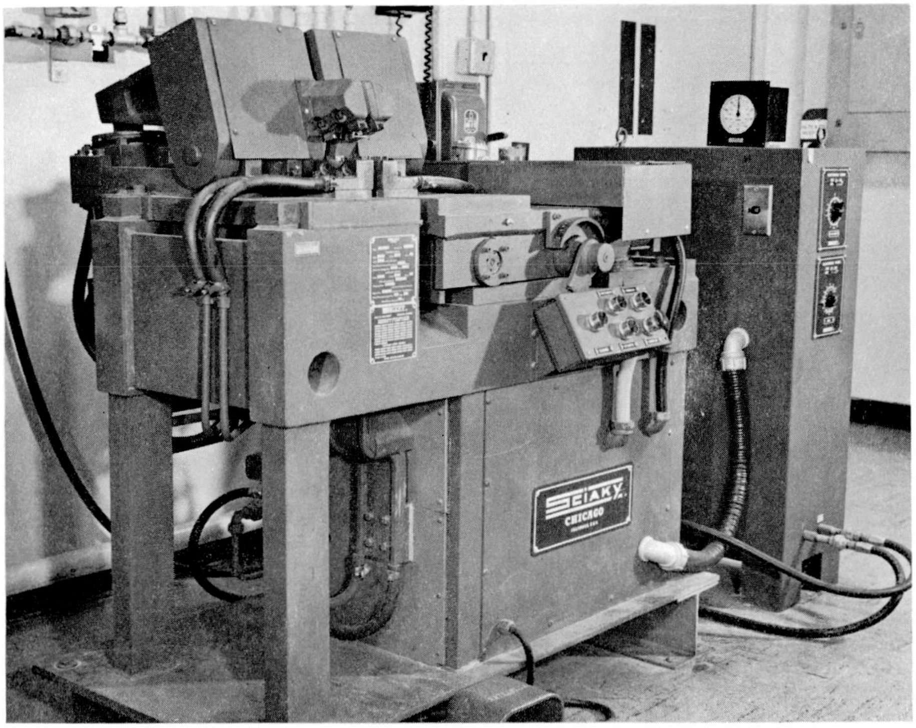
D. LIMITATIONS

There are two notable limitations to the eutectic bonding process:

1) End closures have not been obtained with APM end plugs. It is desirable to use APM for its elevated temperature strength. Successful bonds were produced only with such commercial alloys as Type 6061 and Type 1100 aluminum. The Type 1100 alloy is preferred, due to its nonaging characteristics during heat treatment.

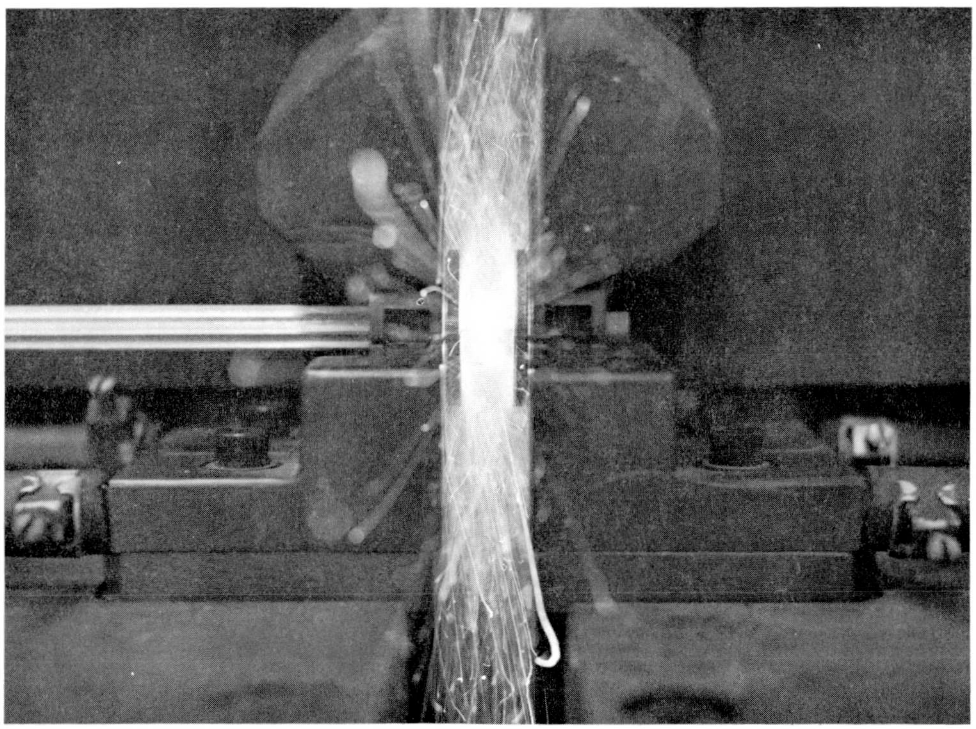
2) The process is relatively slow, compared to other joining techniques, which is an economic consideration.

For these reasons, our development efforts have been directed toward other solid-state bonding techniques.



7500-1869B

a. General View



7500-1869D

b. Closeup View of Flashing

Figure 8. Flash Butt-Welding Machine

III. FLASH WELDING

Flash butt welding is the best alternate method for producing APM end closures that has thus far been investigated at Atomics International. This was concluded from an initial evaluation phase of a continuing development effort, which is described here in some detail.

The flash butt-welding machine (Sciaky Bros., Inc.) used for this work is shown in Figure 8a. It has a power rating of 20 kva at 50% duty cycle, which is sufficient for butt welding aluminum alloys up to 0.100 in.^{2} in cross section. The upset force is adjustable to a maximum of 2500 lb. Figure 8b is a closeup view of the flashing operation.

A simple tube-end plug joint design was utilized in producing end closures, as illustrated in Figure 9. The fins are machined back, 3/32 in. from the end of the tube, to give a cross section matching that of the counterbored end plug. After flashing and upsetting, 3/32 in. of material is lost from each component, giving a total material loss of 3/16 in.

A considerable number of flash welds were made, using various combinations of machine settings. The most promising combination of values found for the flash-welding parameters are listed in Table I.

The microstructure of a typical joint area is shown in Figure 10.

The results of tensile tests, with the upset removed by machining, are presented in Figure 11. Ultimate tensile strength values for finned tubing and end plug material are plotted for comparison. Joint efficiency was estimated at better than 85%, over the temperature range from 72 to 1000°F.

Burst tests, at room temperature and 900°F, using argon gas pressure, have always resulted in failures which originated in the tube wall, as shown in Figure 12.

Flash-welded joints have also been shown to be helium leaktight, while thermal cycling between 350 and 900°F, in the same manner as the tests already described for eutectic-bonded end closures.

Flash-welded end closures of even higher integrity have been obtained, using the joint design shown in Figure 13. The cup-shaped insert is mechanically

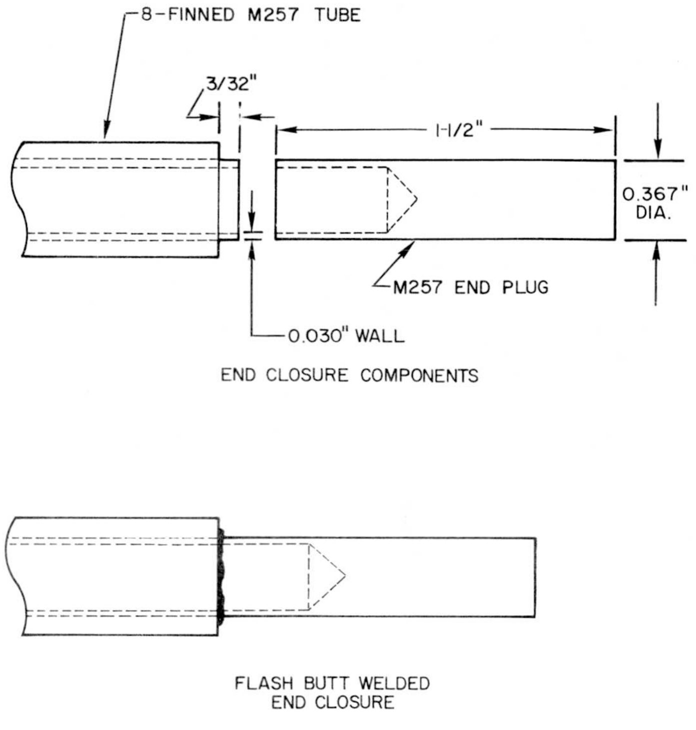
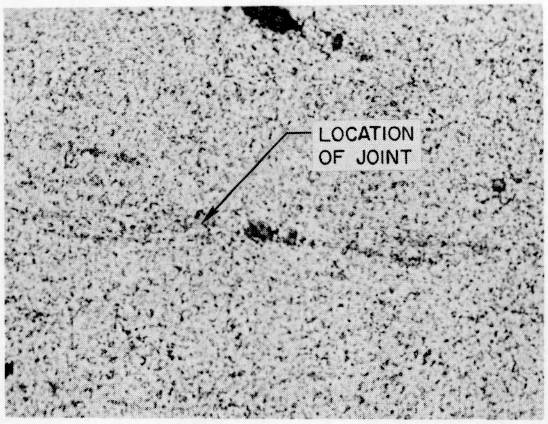


Figure 9. Tube-End Plug Design for Flash Butt Welding

TABLE I

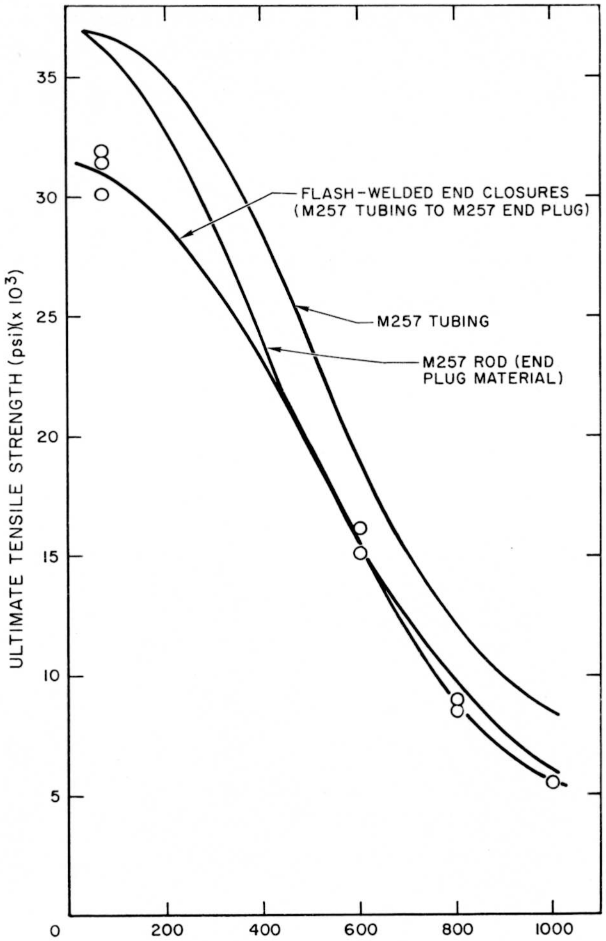
FLASH WELDING PARAMETERS

Flash Time (sec)	0.75
Flash Distance (in.)	0.103
Flash Voltage (v)	3.05
Upset Current Time (ac cycles)	2
Hold Time (ac cycles)	225
Die Clamping Force (lb)	1360
Upset Force (lb)	1155
Final Die Spacing (in.)	0.016



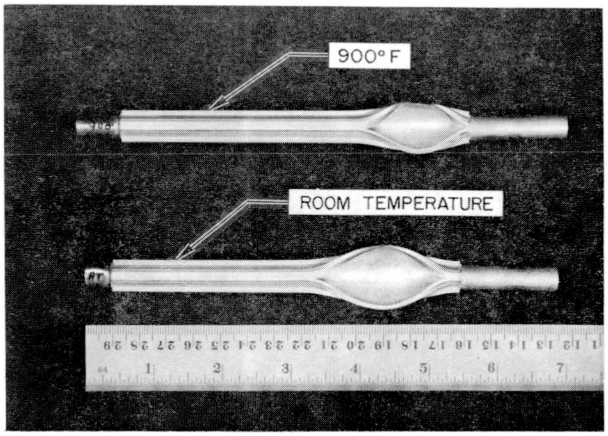
500X 7500-51617

Figure 10. Microstructure of a Typical Flash-Welded Joint



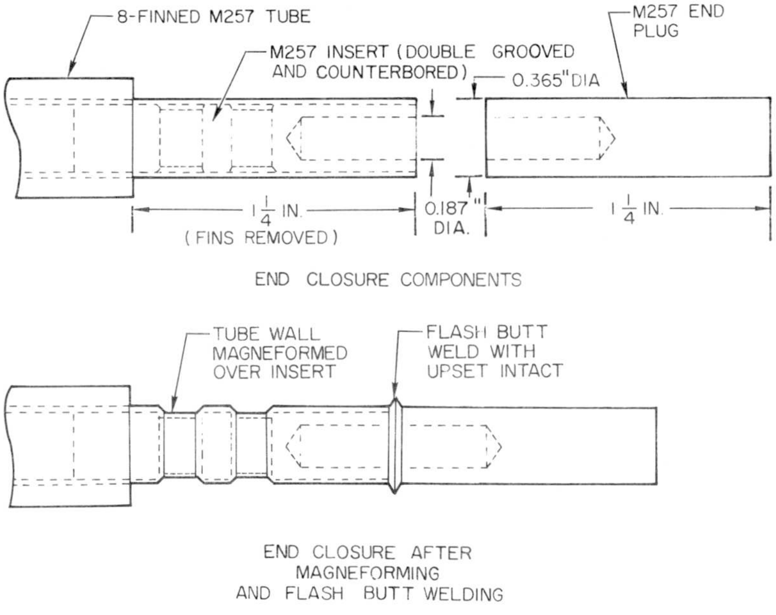
7500-51618

Figure 11. Comparative Tensile Strength of Flash-Welded End Closures and Parent Metal Components



7500-51619

Figure 12. Burst Tests of Flash-Welded Tubes



7500-51620

Figure 13. Heavy Wall Joint Design for Flash Welding

locked into the tube end, so that the open end of the insert is flush with the tube end. A heavy-walled end plug of matching cross section is flash butt welded to the tube-insert assembly.

Mechanical locking of the insert is accomplished by the use of a machine known as "Magneform," which is manufactured by General Atomic Division of General Dynamics Corporation. The tube is collapsed over the insert by the action of electromagnetic forces in the Magneform coil, in pulses of 10 to 20 μsec. Good electrical contact, as well as mechanical strength, is established between the APM tube and insert, which allows the assembly to act as a single mass during flash welding. The values of the flash-welding parameters listed in Table I were adjusted to accommodate this joint design. Tensile tests of heavy-walled flash-welded end closures have resulted in failure on the diameter at the base of the fins, with the ultimate stress at about 1200 lb. The ultimate strength of the joint is of the order of 2000 lb.

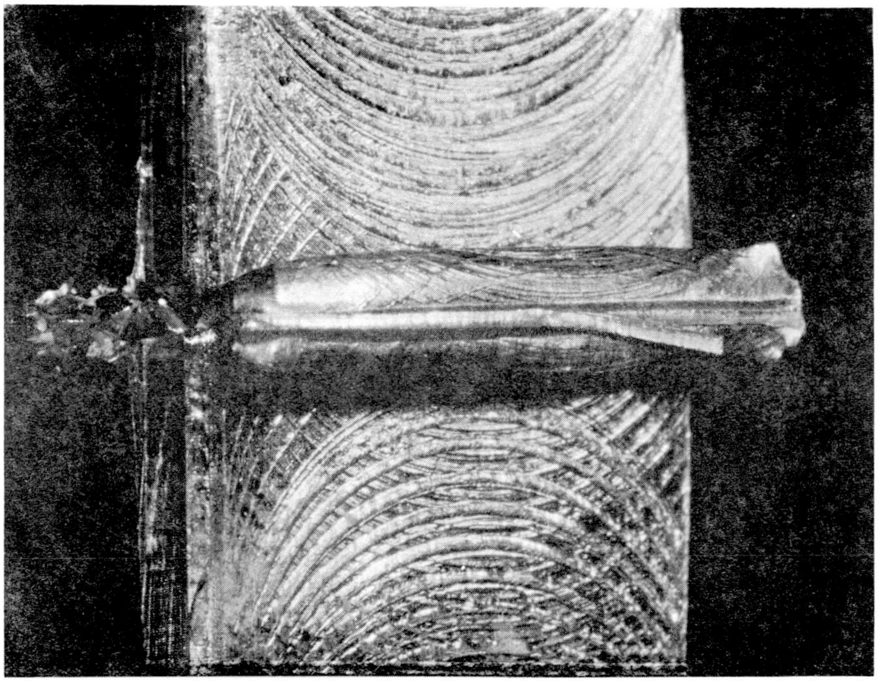
This type of end-closure design is considerably more promising than the simple tube-end plug design, not only because it is inherently stronger, but it is more adaptable to the fuel-rod fabrication scheme as a whole. Therefore, development work is continuing with this type of APM end closure.

IV. COLD WELDING

Cold pressure welding is a potential alternate method of producing end closures in APM finned tubes. A preliminary evaluation of cold welding was made, to determine whether the process was applicable to APM, and to ascertain the mechanical properties that could be expected in such joints.

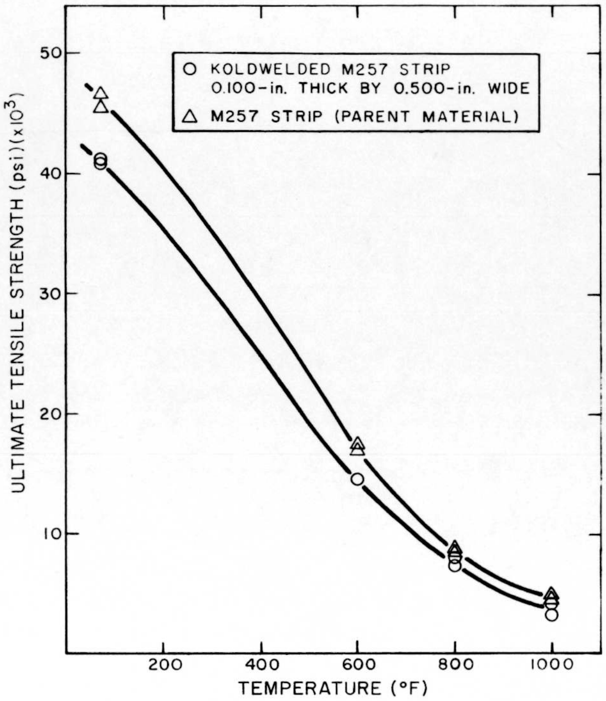
Trial welds in M257 alloy were made for Atomics International by Utica Division of Kelsey-Hayes Company, using their proprietary "Koldweld" process. Cold butt welds were made in 0.100-in. thick by 0.500-in. wide strips, and 3/8-in. diameter rods. The components were annealed 1 hr at 900°F, prior to Koldwelding. Koldwelds were effected at estimated pressures of 250,000 to 300,000 psi, using a double upset technique. A typical strip butt weld is illustrated in Figure 14.

Tensile data for machined tensile specimens are plotted in Figure 15. The ultimate tensile strength of the component materials is included for comparison. The 3/8-in. diameter M257 rod is identical to the end plug material used for flash welding. Typical tensile failures at room temperature were



7500-51621

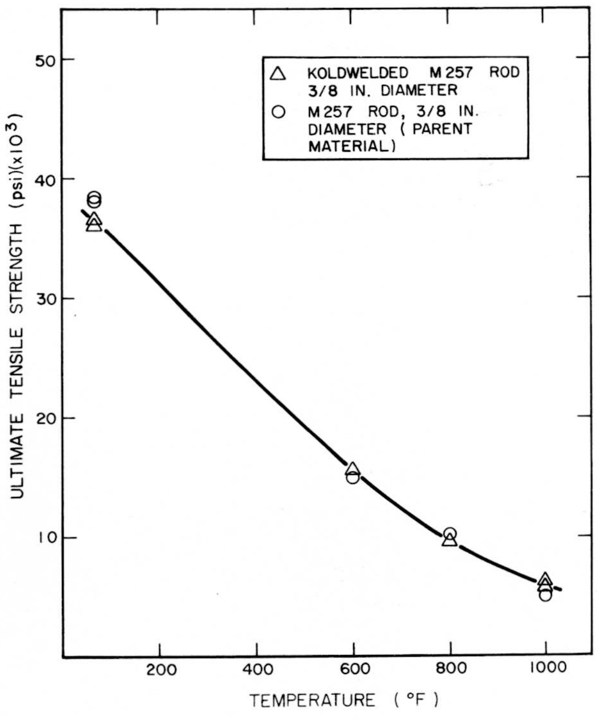
Figure 14. Cold Butt-Welded M257 Alloy Strip



7500-51622

a. M257 Strip and Parent Metal

b. M257 Rod and Parent Metal



7500-51623

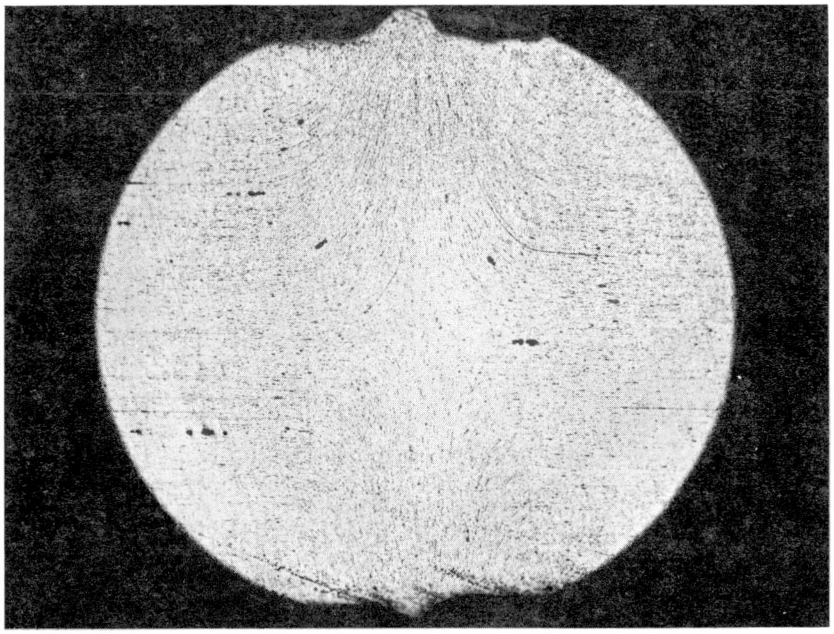
Figure 15. Comparative Tensile Strength of Cold Butt-Welded Joints

ductile in nature, with the fracture located in both the joint and parent metals, representing a joint efficiency of nearly 100%. Elevated temperature failures were typically in the joint.

The microstructure of a cold-welded joint in strip material is shown, at low magnification, in Figure 16. The joint is described by extrusion flow lines.

It was concluded, from this work, that the strength properties of cold-welded joints in APM are adequate for producing end closures of high integrity. It remains to be shown, however, that such end closures can be made.

The development of cold-welded end closures is currently being pursued, as an alternate to flash butt welding. The cold-welding technique appears attractive, from the standpoint of joint quality and process economy.



7500-51624
30 X

Figure 16. Microstructure of Cold Butt-Welded Joint in M257 Alloy Strip

V. SUMMARY

From the work conducted under this program, silver eutectic bonding is the established reference process for making helium leaktight end closures in finned APM tubing. However, this process has its limitations, and a continuing effort is being made to find other acceptable methods of making such joints. Flash welding is the best alternate method thus far investigated, but cold welding is being considered as a further alternate method.

Some work has been carried out on eutectic bonding of APM to APM. As yet, no reportable results have been obtained.