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INTERIM REPORT ON THE ALUMINUM POWDER METALLURGY PRODUCT DEVELOPMENT PROGRAM

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34 PAGES

INTERIM REPORT ON THE ALUMINUM POWDER METALLURGY PRODUCT DEVELOPMENT PROGRAM

By
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CONTENTS

TABLES

FIGURES

ABSTRACT

Because of their good elevated temperature strength properties, aluminum powder metallurgy (APM) products have application in organic cooled reactors. Tensile and creep investigations have confirmed the superiority of APM alloys over conventional, wrought aluminum alloys, in the temperature range of 800 to 1000°F. However, the resultant strength values are significantly lower than previously reported. Cold working may also lower the elevated temperature strength of APM alloys. Alloy M257 has been successfully extruded into externally-finned, thin-walled, small-diameter tubing. End closures in M257 tubes have been successfully made by fusion welding unalloyed aluminum end plugs and by flash welding M257 end plugs. After prolonged heating at 1100°F, no evidence of a reaction between UO_2 pellets and M257 has been found. APM products are compatible with organic coolants at 750°F.

I. INTRODUCTION

In view of their improved elevated temperature properties, aluminum powder metallurgy (APM) alloys are being considered for cladding and structural applications in organic cooled reactors. Because of these properties, it is claimed that the usable service temperature of these products is some 200°F higher than for the best conventional wrought aluminum alloy. In addition, these products retain the low neutron absorption characteristic of aluminum, without substantial loss in corrosion resistance in organics or loss of thermal conductivity. Thus, fuel elements utilizing an aluminum powder metallurgy product as the cladding material would be capable of higher operating temperatures than those using conventional aluminum. This would enable a nuclear plant to produce higher temperature steam.

The principal areas for further evaluation of these products for application in organic reactor systems are in welding and joining, the fabrication of complex tubular shapes, and in the development of additional data on elevated temperature strength properties. It is the purpose of this report to present the current status of this development effort and to summarize the experimental data obtained to date.

The improved elevated temperature strength of aluminum powder metallurgy alloys is due primarily to the dispersion strengthening effect of submicroscopic particles. The strengthening effect is retained at elevated temperatures because of the insolubility and high melting point of this dispersed phase. Alloys utilizing a dispersion of aluminum oxide (Al_2O_3) in a matrix of aluminum as the strengthening media were originally developed in Europe by the Swiss firm, Aluminium Industrie Aktien Gesellschaft (AIAG), and are designated "Sintered Aluminum Products" or "SAP." In the USA, the Aluminum Company of America (Alcoa) produces products designated as "Aluminum Powder Metallurgy" products or "APM."

Alcoa markets two types of APM Products: (a) a dispersion of Al_2O_3 in Al, similar to the SAP alloys, and (b) a pre-alloyed atomized powder, utilizing insoluble intermetallic compounds as the dispersion strengthening mechanism. APM products commercially available from Alcoa are alloys M257, containing 5 to 8% Al_2O_3, and M486, an alloyed aluminum powder containing 7.8% Fe and

0.2% each of Ti, Zr, V, and Cr in Al, with Al_2O_3 present only as an impurity (0.5%). Commercial alloys produced by AIAG are designated as SAP895 and SAP865, and contain 10 to 11% and 13 to 14% Al_2O_3 respectively. The principle alloy under investigation has been Alcoa's M257, because it possesses the most desirable combination of strength and ductility.

In this report, "APM" will designate aluminum powder metallurgy products categorically, and specific alloys will be referred to by the appropriate alloy number, e.g., M257, M486, and SAP895.

II. MATERIALS

The APM materials tested were commercial products, procured from Alcoa and AIAG. The mechanical properties and chemical analyses reported by Alcoa for specific lots and products are tabulated below.

Alloy	Product	Mfr's Lot No.	Mechanical Properties TS (psi)	YS (psi)	Elongation (%)
M257	Extruded Rod 5/8-in. diam	458973	39,600	31,100	17.0
	Extruded Rod 3/4-in. diam	474443	37,200	29,300	18.0
	Extruded Rod 3/4-in. diam	482168	37,800	29,600	17.5
	Drawn Tubing, 0.678-in. OD x 0.020-in. Wall	360643	39,800	33,300	8.5
	Drawn Tubing, 0.678-in. OD x 0.020-in. Wall	363053	42,200	35,200	7.0
	Flat Sheet 0.064-in. thick	602307	44,400 45,700	38,600 40,900	11.0 (long.) 8.5 (trans.)
M486	Extruded Rod 3/4-in. diam	195625	Not Available		
	Extruded Rod 3/4-in. diam	195914	Not Available		

Alloy	Mfr's Lot No.	Chemical Composition (%) Fe + Si (max)	Other Impurities (max) Each	Other Impurities (max) Total	$Al + Al_2O_3$
M257	458973	1.0	0.05	0.15	Remainder
	474443	1.0	0.05	0.15	Remainder
	482168	1.0	0.05	0.15	Remainder
	360643	1.0	0.05	0.15	Remainder
	363053	1.0	0.05	0.15	Remainder
	602307	1.0	0.05	0.15	Remainder

The composition of SAP895 products reported by AIAG is as follows:

Lot Number	Chemical Composition of Powder			
	Al (Free) (%)	H_2O (%)	Fe (%)	Grease (%)
S64B	89.1	0.14	0.31	0.14

The mechanical properties reported by AIAG for SAP895, Lot S64B, at 20°C, are as follows:

Identification Numbers	Yield Proof Stress (psi)	Ultimate Tensile Strength (psi)	Elong. (% in 2 in.)	Brinell Hardness
S64B - 13R (0.064-in. thick sheet)	35,000	54,200	8	110
S64B - 13U (0.128-in. thick sheet)	35,200	53,000	9	107

III. MECHANICAL PROPERTIES

The mechanical properties of APM alloys M257 and M486, along with other experimental alloys, such as M430 and M470, have been published.[1-4] These data include tensile properties at temperatures up to 1000°F, stress-rupture data up to 900°F, and creep properties up to 600°F. All of these data were based on the results of tests of experimental material. The mechanical property studies undertaken in this program had the objectives of confirming published data and further developing the creep properties, in the temperature range above 600°F.

A. TENSILE RESULTS

The results of tensile tests of M257 extruded bars at 800, 900, and 1000°F are shown in Table I. These data confirm the superior elevated temperature properties of this alloy, compared to conventional aluminum alloys. However, the properties are some 10% lower than published values.

Smooth and notched tensile specimens of two alloys, M257 and SAP895, were tested, in order to determine the effect of stress concentrations on the tensile strength. Specimens were taken from 0.064-in. thick sheets of each alloy, in the longitudinal direction of rolling. The notch geometry is shown in Figure 1. Stress concentration factors of 2.5 and 5.0 were selected for the initial tests. The results of these tests are summarized in Table II. The data indicate that the materials are not notch sensitive for these notch geometries.

Alcoa[5] recently determined the notch strength of M257 and M486 extruded rod specimens, at temperatures up to 800°F. They reported the notch-strength ratio for M257 to be 1.07 at 400°F, decreasing to 0.90 at 800°F. For M486, Alcoa found the notch-strength ratio increased from 1.20 at 400°F to 1.39 at 800°F. These values were for specimens having a 60° V-notch, 0.073-in. deep with a 0.002-in. root radius. The stress concentration factor was not reported.

The effects of irradiation on the tensile properties of M-257 have recently been reported by AECL.[6] The differences between irradiated and unirradiated properties do not appear to be significant. The results of these tests are shown in Table III.

TABLE I

TENSILE PROPERTIES FOR M257 IN THE AS-EXTRUDED CONDITION*

Test Temp. (°F)	Source	UTS (psi)	YS 0.2% Offset (psi)	Elongation† (%)	$E(\times 10^6)$§ (psi)
800	AI	11,000	9,800	6.8	5.9
	Alcoa[1,2]	12,000	11,000	5.0	6.6
900	AI	9,500	8,500	6.7	6.9
	Alcoa[1,2]	11,000	10,500	4	6.1
1000	AI	6,900	5,900	**	**
	Alcoa[1,2]	7,500	7,000	2	5.5

* Values reported are the averages for two round specimens for each temperature. Specimens were held at temperature for 1 hr prior to testing at a load rate of 100 lb/min. All specimens were from Lot No. 458973

† AI data reported as "% in 2 in. gage length." Alcoa data reported as "% in 4 diam "

§ Read from autograph

** Not determined

TABLE II

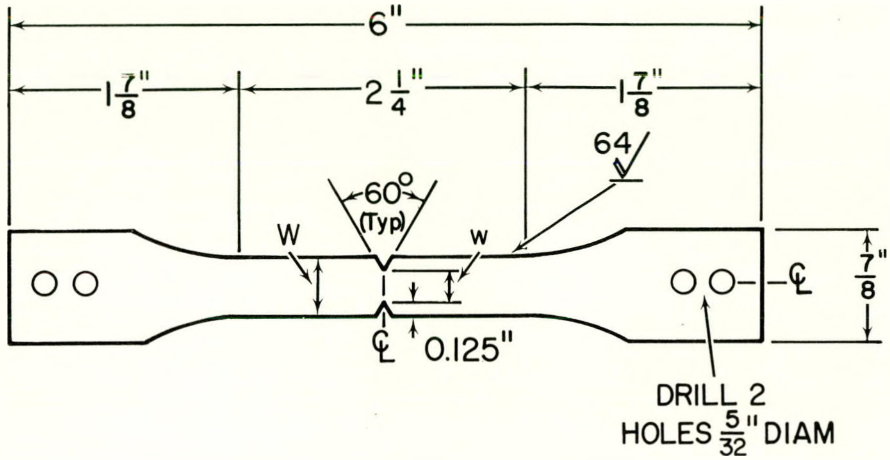
NOTCH-TENSILE PROPERTIES OF APM ALLOYS

Alloy	Specimen Type	Temp. (°F)	Tensile† Strength (psi)	Notch-Strength§ Ratio
M257*	Smooth	Room	43,000	
		900	7,500	
	Notched	Room	49,800	1.16
	$K_t = 2.5$	900	7,800	1.04
	$K_t = 5.0$	900	7,500	1.01
SAP895*	Smooth	Room	49,400	
		900	10,200	
	Notched	Room	57,000	1.15
	$K_t = 2.5$	900	10,500	1.03
	$K_t = 5.0$	900	10,200	1.00

* Rolled sheet, 0.064-in. thick. Specimens cut in longitudinal direction of rolling. M257 - Lot No. 602307, SAP895 - Lot No. S64B–13R

† Tensile tests, after 1 hr at temperature, at 100 lb/min loading rate

§ Ratio of ultimate tensile strength of notched specimen to that of smooth specimen



RATIO w/W = 0.50		NOTCH RADIUS (in.)	NOTCH FACTOR K_t
W (in.)	w (in.)		
0.50	0.250	0.036	2.5
		0.0069	5.0
		0.0016	10.0

Figure 1. Design of Specimen Used for Notch-Tensile Tests of APM Alloys

TABLE III

TENSILE PROPERTIES OF M257, PRE- AND POSTIRRADIATION[6]

Irradiation History	Testing Temp. (°C)	Proportional Limit (psi)	YS 0.2% Offset (psi)	UTS (psi)	Total Elong. (%)
Unirradiated	Room	25,000	30,000	37,400	16.8
"	270	15,500	19,000	21,200	11.5
Irrd. -1.22 x 10^{20} fast n/cm^2	Room	26,800	31,400	39,700	11.8
	270	16,600	20,000	21,500	11.6
Irrd. -1.53 x 10^{20} fast n/cm^2	Room	28,100	32,000	41,000	11.5
	270	17,000	20,100	22,000	10.5

Specimens irradiated at 50°C

TABLE IV

CREEP STRENGTH PROPERTIES OF APM ALLOYS

Alloy	Specimen Condition	Test Temp. (°F)	Specimen No.*	Stress (psi)	Hours to Rupture	Total Creep (%)	Primary Creep (%)	Secondary Creep Rate (%/hr)	Total Hours	Remarks
M257	Extruded	800	257-13	7000	62.3	0.42	0.42	0	62.3	
		800	257-3†	6000	-	0.75	0.65	-	263	Temp. increased to 900°F
		900		6000	120	-	-	-	120	
		900	257-1†	4000	-	0.65	0.6	-	172	Stress increased to 6000 psi
				6000	32	-	-	-	32	
		900	257-4	7000	0.9	2.0	-	-	0.9	
		900	257-19	6500	6.3	1.2	-	-	6.3	
		900	MCL-9	6500	7.3	-	-	-	7.3	
		900	257-2†	6000	15.5	0.65	0.6	-	15.5	
		900	257-5	6000	18.5	0.65	-	-	18.5	
		900	257-11	5500	1256	0.48	0.48	0	1256	
		900	257-6	5000	-	0.55	0.45	-	143	Discontinued
		900	257-9	4000	>1435	0.25	0.25	0	>1435	In process
		1000	257-16	5500	0.2	3.2	-	-	0.2	
		1000	MCL-10	5500	0.9	-	-	-	0.9	
		1000	257-17	5000	2.2	0.9	-	-	2.2	
		1000	257-18	4750	3.5	0.9	-	-	3.5	
		1000	257-24§	4500	3.4	1.0	-	-	3.4	
		1000	257-25§	4250	11.8	0.9	-	-	11.8	
		1000	257-12	4000	909	0.7	0.7	0	909	
		1000	257-8	3500	-	0.35	0.3	0	1320	Discontinued
M257	Swaged	900	MCL-1	7000	0.1	-	-	-	0.1	
		900	MCL-2	6500	0.4	3.0	-	-	0.4	
		900	257-21	6000	0.7	2.4	-	-	2.4	
		900	257-22	5500	3.1	-	-	-	3.1	
		900	MCL-3	5000	75.5	1.0	0.8	-	75.5	
		1000	MCL-4	4500	<0.1	11.5	-	-	<0.1	
		1000	MCL-5	4000	0.4	8.0	-	-	0.4	
		1000	MCL-6	3500	2.0	-	-	-	2.0	
		1000	MCL-8	3500	2.0	3.5	-	-	2.0	
		1000	257-20	3500	2.0	1.6	-	-	2.0	
		1000	257-23	3250	4.6	2.0	-	-	4.6	
		1000	MCL-7	3000	-	0.8	-	-	332.1	Discontinued
M257	Sheet	1000	257-14**	4000	<0.1	-	-	-	<0.1	Broke on loading
		1000	257-15**	3500	0.6	12.0	-	-	0.6	
M486	Extruded	800	486-4§§	4000	-	1.6	0.75	8.7×10^{-4}	1170.5	Discontinued
		850	486-3§§	4000	263.3	8.9	0.85	1.7×10^{-2}	263.3	
		900	486-2††	4000	64	9.0	1.0	7.4×10^{-2}	64	

* All M257 specimens are from Lot No. 474443 unless otherwise noted
† M257 Lot No. 458973
§ M257 Lot No. 482168
** M257 Lot No. 602307
†† M486 Lot No. 195914
§§ M486 Lot No. 195625

B. CREEP RESULTS

The results of creep tests on APM alloys are summarized in Table IV. Tests of M257 have been made on material in three conditions: (1) as-hot-extruded, (2) as-swaged (from 3/4 to 1/2-in. diam), and (3) as-rolled (0.064-in. sheet). For the as-extruded condition, round specimens with a 0.375-in. diam by 2.0-in. gage length reduced section were used. All swaged specimens had a 0.250-in. diam reduced section. However, those designated by the prefix "MCL" had a 1.0-in. gage length, while all others had a 2.0-in. gage length. Sheet specimens had a 0.500-in. wide by 2.0-in. gage length reduced section. Tests of M486 were in the as-extruded condition only. These specimens had a reduced section of 0.500-in. diam with a 2.0-in. gage length. The smaller, 0.375-in. diam, specimens were adapted for M257 when preliminary tests of 0.500-in. diam specimens resulted in failure in the threaded grip, rather than in the reduced section. The 1.0-in. gage length of certain swaged specimens was selected to allow a 2-in. extensometer to be positioned on the shoulders of the specimen, rather than on the reduced section. This was done to prevent any possible failure due to a notch effect by the knife edge of the extensometer grips.

Figure 2 is a plot of stress vs rupture time for the M257 specimens tested to date. These data indicate that the creep-rupture strength of extruded M257 at 900°F is significantly lower than as previously published[3] and that cold working of M257, as induced by swaging or rolling, significantly reduces creep-rupture strength.

Creep-strain vs time curves for APM alloys M486 and M257 as-extruded specimens are shown in Figure 3. These plots illustrate: (1) the superior creep strength of M257 over M486, and (2) the rapid loss of creep strength of M486 above 800°F. Figure 4 shows typical strain vs time plots obtained for M257 extruded specimens. The creep characteristics for this alloy are unique, in that practically all elongation occurs in the primary stage, with an insignificant secondary creep rate. Figure 5 shows the strain-time curves of creep-rupture tests of M257 in the as-swaged condition. These tests indicate that the swaged specimens may possess higher ductility than as-extruded.

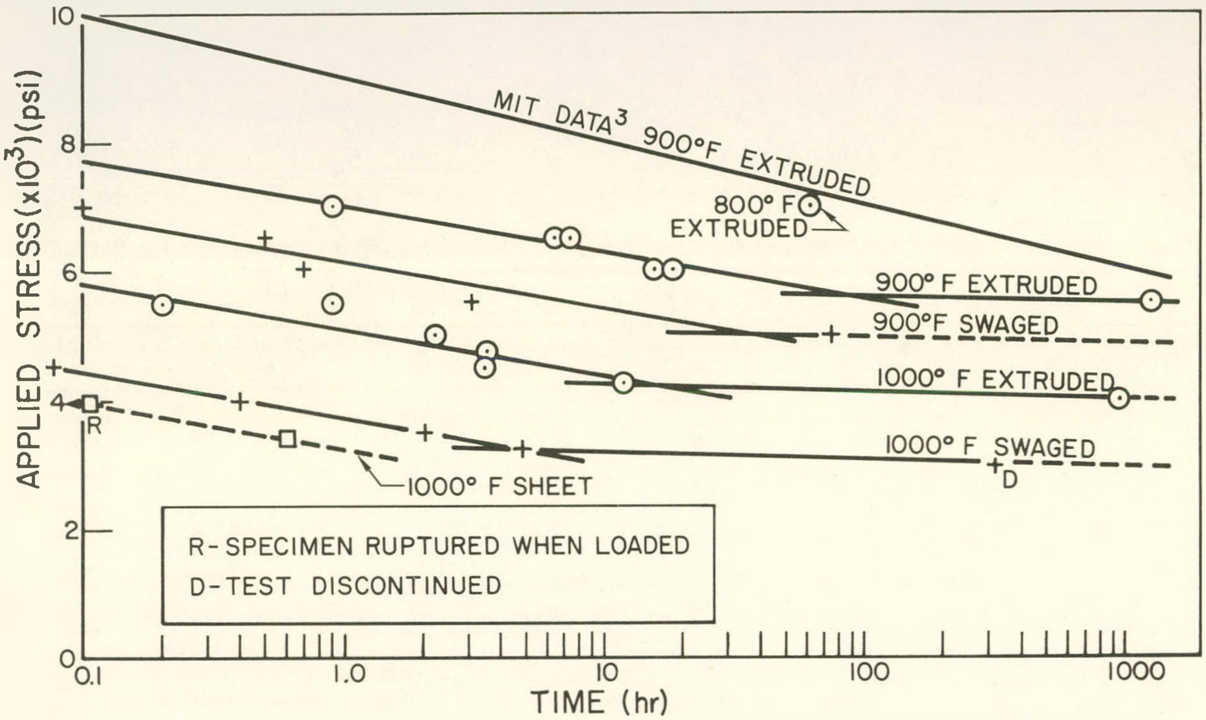


Figure 2. Creep-Rupture Data for APM Alloy M257

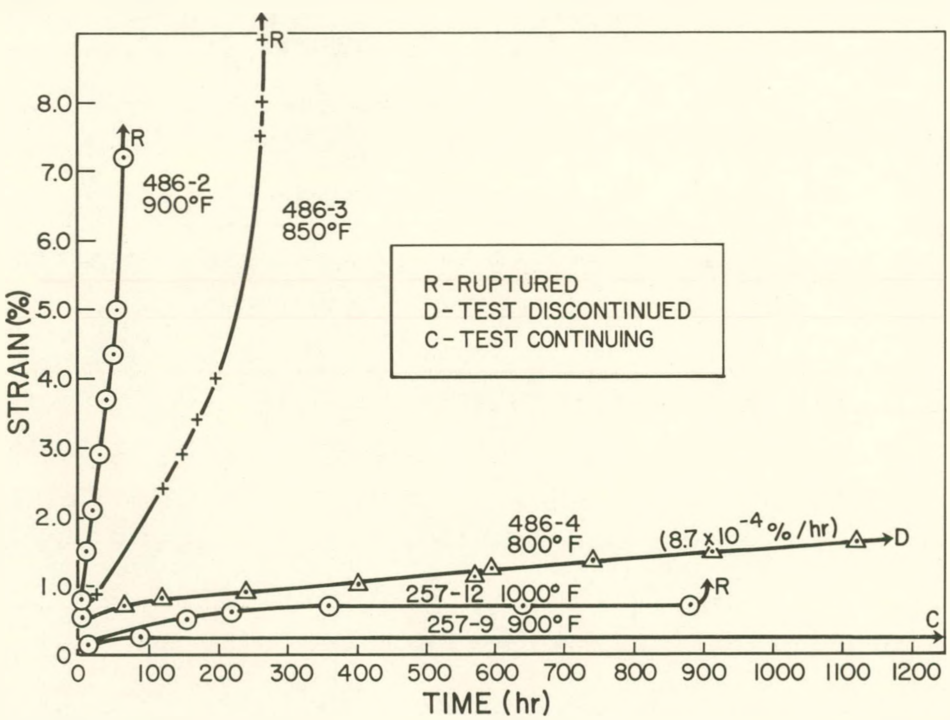


Figure 3. Creep Tests of As-Extruded APM Alloys at a Stress of 4000 psi

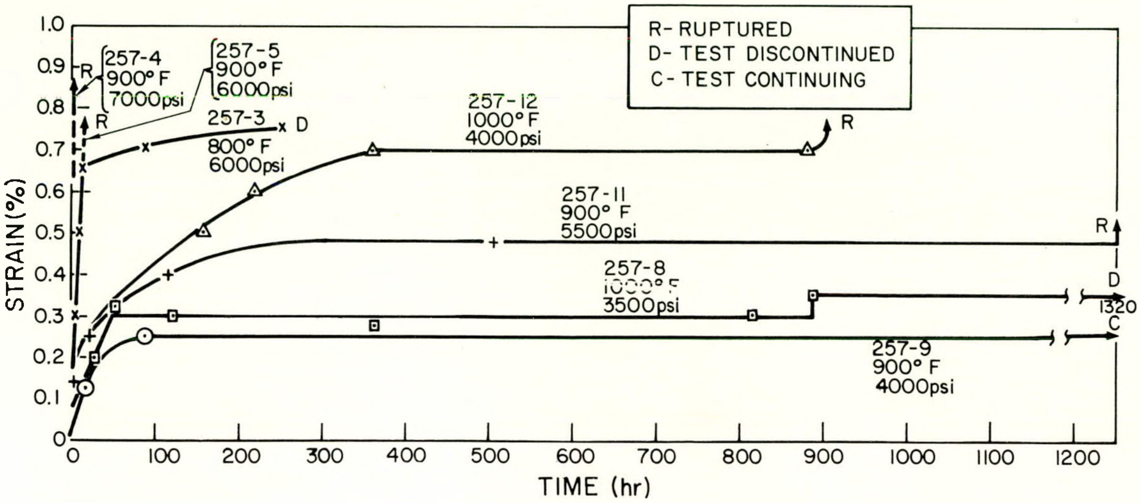


Figure 4. Creep Tests of M257 in As-Extruded Condition

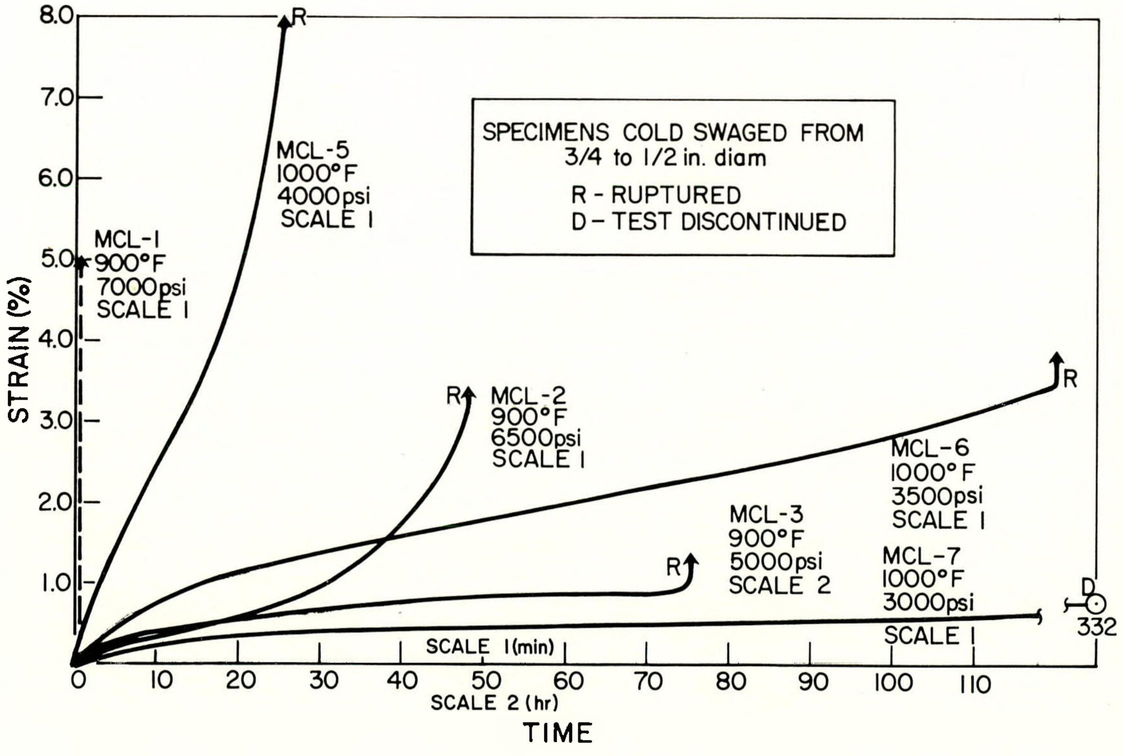
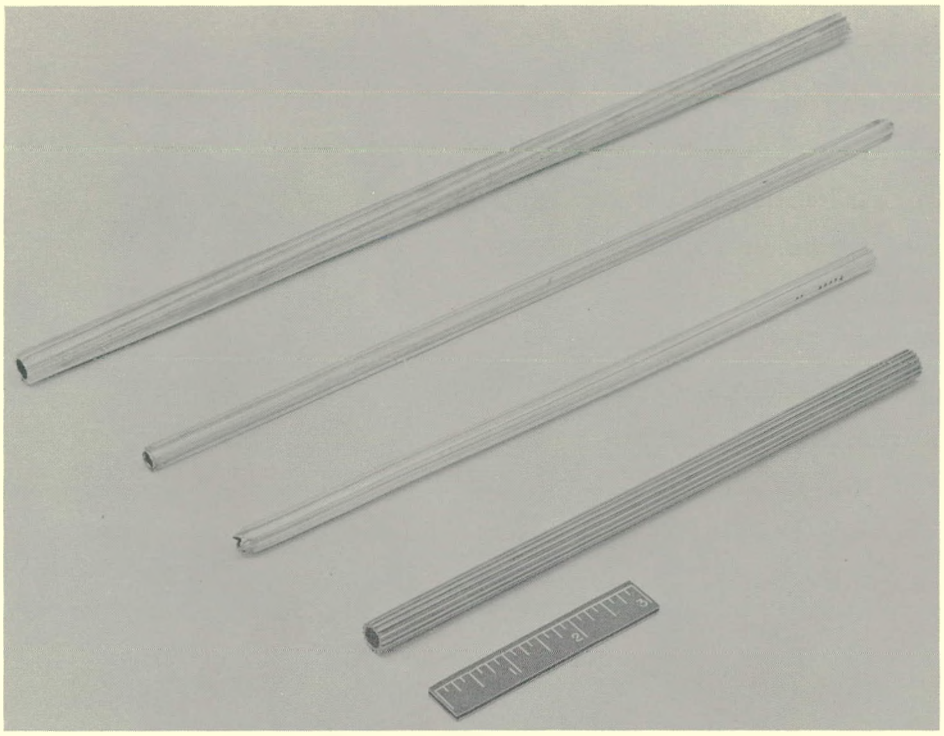


Figure 5. Creep-Rupture Tests of M257 in As-Swaged Condition

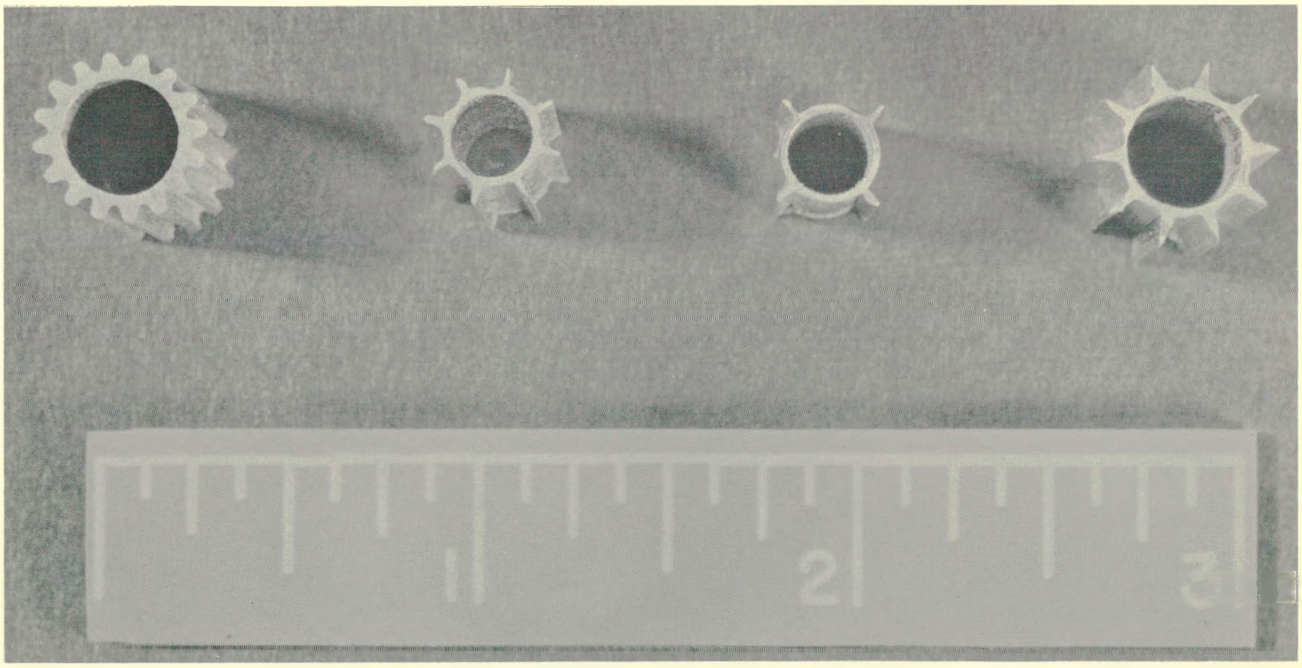
IV. FABRICATION

Finned tubes, simulating the configurations of potential fuel element designs for organic reactor concepts, have been produced from alloy M257 by three commercial fabricators of aluminum. Some of the tubular shapes extruded to date are shown in Figures 6a and 6b. In the initial feasibility studies, one fabricator produced the 4-fin and 8-fin tubes, 0.210-in. ID by 0.020-in. wall, with fins 0.020-in. wide and 0.050-in. high, in lengths up to 17 in. The cold impact extrusion process was employed, utilizing a production line press and a die that was modified to the desired fin design. Another fabricator produced the 16-fin tube, 0.300-in. ID by 0.015-in. wall (nominal dimension), by hot extruding from a temperature of 750°F. A third fabricator has recently made experimental extrusions of similar tubing, 0.300-in. ID by 0.015-in. wall, with ten external fins, in lengths up to 14 ft. This is the design proposed for the OCR fuel element.

In laboratory experimentation, lengths of both the 10-fin and 16-fin tubes have been successfully twisted to form a helical spiral of about 90° in 12 in. This spiral is shown in the 10-fin tube shown in Figure 6a.



a. Side View

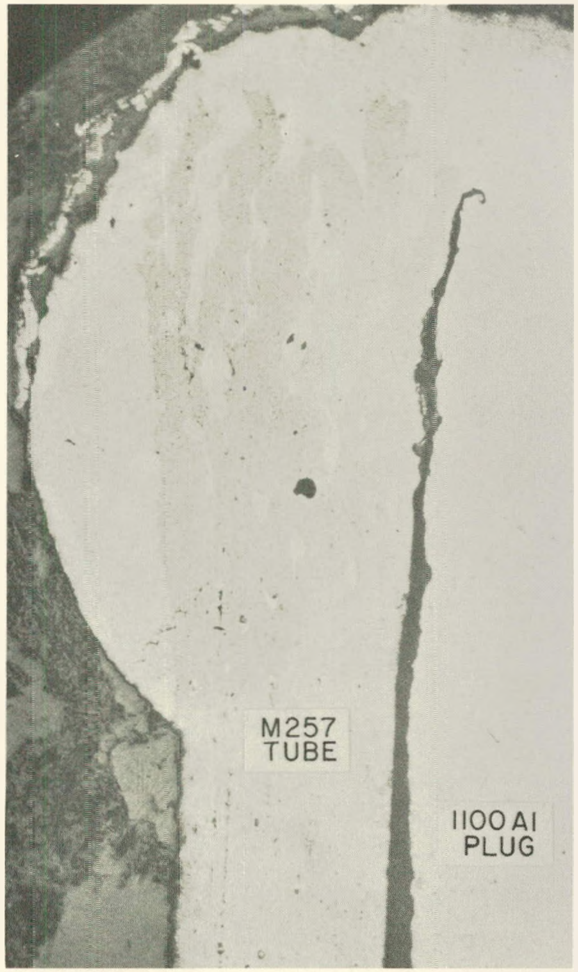


b. End View

Figure 6. Tubular Shapes Extruded from APM Alloy M257

50X

Figure 7. Fusion Welded End Closure of 1100 Al End Plug in M257 Tube



50X

Figure 8. Fusion Welded Joint of 1100 Al and M257, Showing Segregation of Oxide Induced by Overheating

V. JOINING

A. FUSION WELDING

Fusion welding of M257 is not generally satisfactory, because of the alloy's poor flowing characteristic and the resultant porosity, due to segregation of the oxide flakes. Nevertheless, end closures in simulated fuel tubes have been successfully accomplished by fusing 1100 Al end plugs to M257 tubing. An inert gas shielded tungsten electrode is used to melt a weld lip of the end plug and flow it around the joint. A water-cooled chill block extracts the heat from the tubing to prevent fusion of the M257 and subsequent oxide segregation. A photomicrograph of a satisfactory weld of this type is shown in Figure 7. While the weld itself may only have the strength of unalloyed aluminum, tests to date indicate that end closures of this type can have higher strength at elevated temperatures than the sidewalls of the 0.020-in. wall M257 tubing.

Figure 8 shows the weld area of a specimen that ruptured in the weld when pressurized in a routine burst test. In this weld, the M257 was overheated to fusion, resulting in the segregation of the oxide and an inferior joint.

Test assemblies with fusion-welded end closures, as-welded and after burst testing at 900°F, are shown in Figure 9. The results of all burst tests on specimens of this type are summarized in Table V.

Fusion welding of M486 has not been extensively evaluated. Examination of such welds has revealed considerable underbead porosity.

B. FLASH WELDING

Alcoa has previously reported that M257 sheet and plate have been successfully joined by the flash welding process. In one series of tests, average joint efficiencies for tensile and yield strengths were 96 and 89%, respectively, at all temperatures up to 600°F.[7]

The flash welding process has recently been adapted to the making of end closures in thin-wall (0.020-in.) M257 tubing with good success. A welding specialty company, working on a development order, developed a flash welding technique for butt welding a machined M257 end cap to M257 tubes. Fourteen assemblies, 0.680-in. OD by 0.020-in. wall by 6-in. long, were made. All of

TABLE V

GAS PRESSURE BURST TESTS OF END CLOSURES IN M257 TUBES

Type Joint	Type End Plug	Test No.	Test Temp. (°F)	Max. Pressure (psig)	Remarks
Fusion Weld	1100Al	1	Room	2350	Leaked at weld. Previously tested by thermal cycling and porosity tests at 1100°F
		2	900	300	Ruptured tube
		3	900	400	Ruptured tube
		4	900	400	Ruptured tube and tore around weld Assembly only 3-1/2" long
		5	900	400	Ruptured tube
		7	750	700	Ruptured tube and tore around weld
		8	750	700	Weld leaked
		11	750	950	Blew out end plug
		10	600	800	Ruptured tube
		12	600	950	Blew out end plug
Flash Weld	M257	6	900	800	Ruptured tube and tore around weld
		9	750	1100	Machined sidewall of end plug yielded Leak developed in adjacent weld joint
		13	Room	2400	Rupture occurred in weld and tore in reduced section of end plug Plug separated completely from tube
		14	600	900	Ruptured tube, tearing through the flash weld
Hot press	M257	15	900	900	Ruptured tube

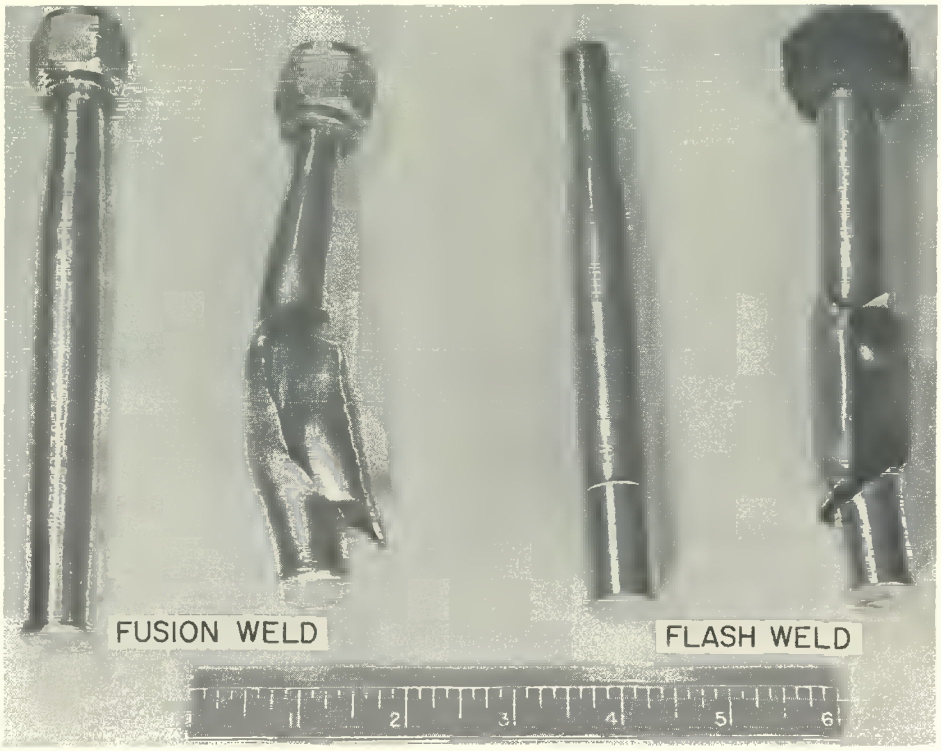


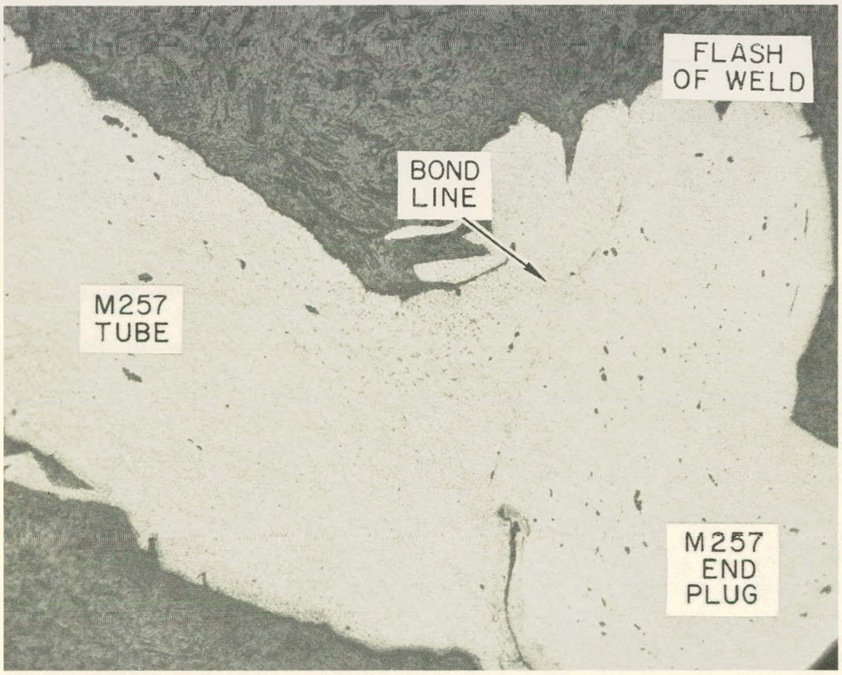
Figure 9. Fusion and Flash-Welded End Closures In M257 Tubing, As-Welded And After Pressurizing to Rupture

these were declared leak-tight when tested under 35 psi water pressure. However, two leaked when checked with a mass spectrometer leak detector. Destructive tests have been performed on four of these flash welded assemblies, the results of which are summarized in Table V. Typical assemblies, as-welded and after pressurizing to rupture, are shown in Figure 9. Figure 10a is a photomicrograph, showing the flash weld area at a magnification of 50X. Figure 10b shows the bond line at a higher magnification, 500X.

No flash welds have been made on M486, but it is believed that this alloy can also be successfully welded by this technique.

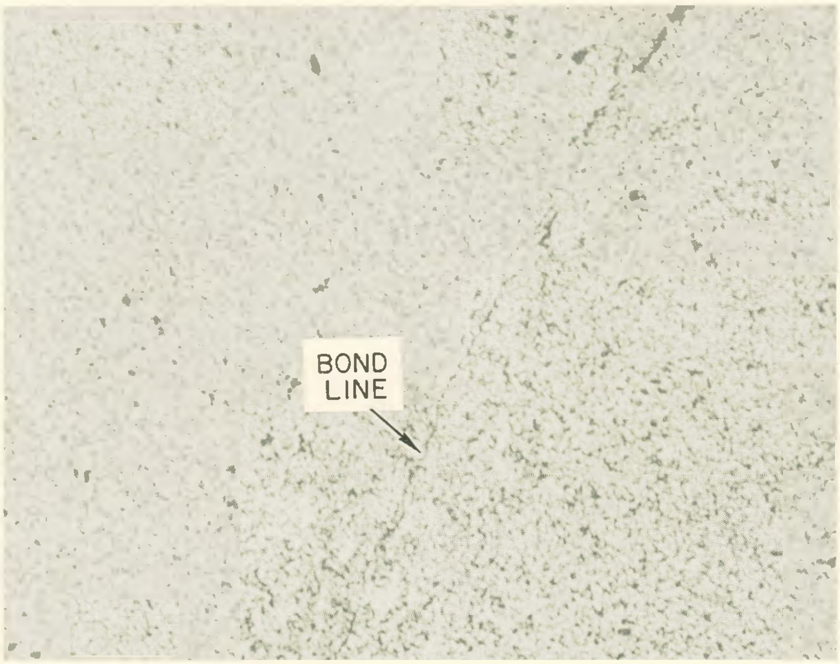
C. ULTRASONIC WELDING

APM alloys have been successfully joined by the ultrasonic welding technique. Lap welded joints of M257 to itself, and M486 to itself, have been evaluated to date. Samples, 3/4 in. wide and 9 in. long by 0.032 in. thick were



50X

a.



500X

b.

Figure 10. Photomicrographs of End Closure Made by Flash Welding M257 End Plug in M257 Tubing

joined by two ultrasonic spot welds about 3/16-in. in diam. Peel tests at room temperature showed that the spots tore out, indicative of sound welds. In tensile tests performed at room temperature, two specimens of each alloy failed in shear. At 800°F, failure occurred in the parent metal rather than in the weld. The results of these tests are summarized in Table VI.

TABLE VI

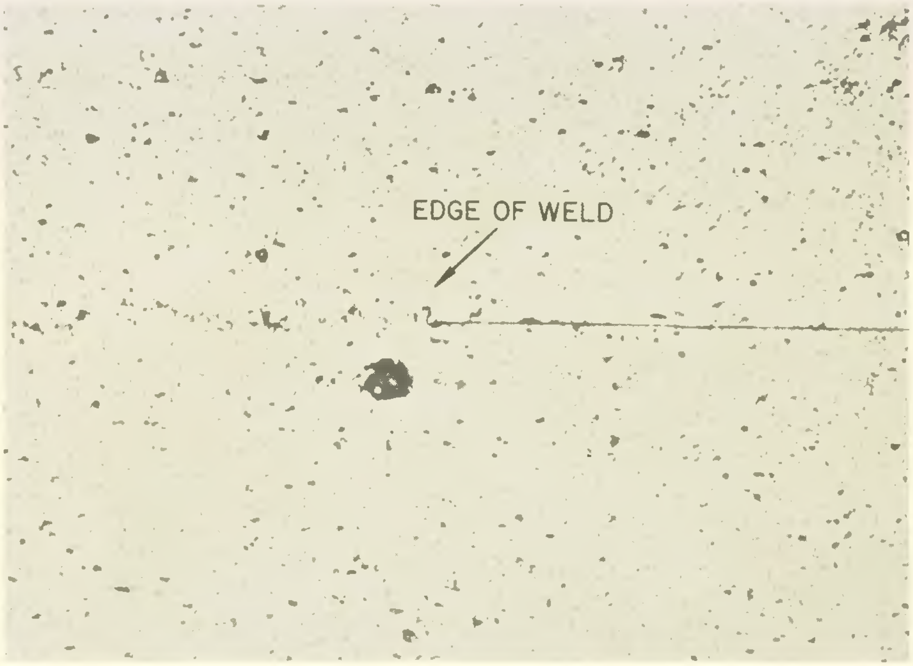
TENSILE TESTS OF ULTRASONICALLY WELDED APM STRIP SPECIMENS

Alloy	Test Temp. (°F)	Breaking Load (lb)
M257-1	Room	836
M257-2	Room	870
M257-3	800	170
M257-4	800	169
M486-1	Room	853
M486-2	Room	925
M486-3	800	221
M486-4	800	227

Figure 11 shows photomicrographs of typical ultrasonic welds in M257 and M486.

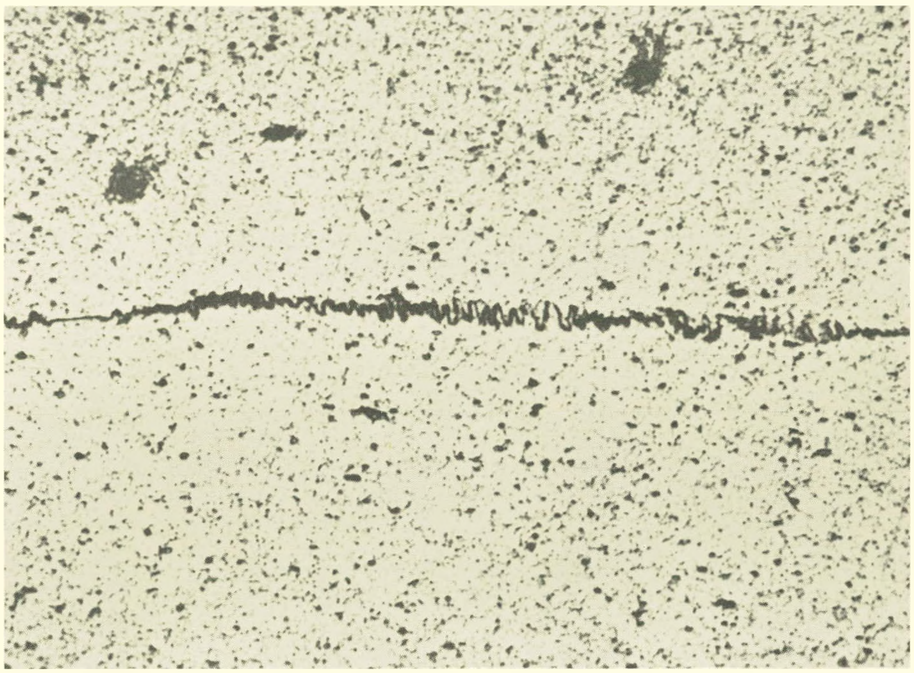
D. RESISTANCE SPOT WELDING

Strip samples of M257, M486, and SAP895 have been spot welded by conventional resistance spot welding techniques with some degree of success. For example, M486 and M257 tabs were spot welded to sheet tensile specimens, prior to elevated temperature tests, thus successfully preventing the holes of the grips from elongating. Such welds were tested at room temperature by the standard shop peel test, and the welds were found to pull out, indicative of a good joint. A photomicrograph of a resistance spot weld nugget in M257 is shown in Figure 12. Note the segregation of oxide which occurred during the short period the nugget was molten.



500X

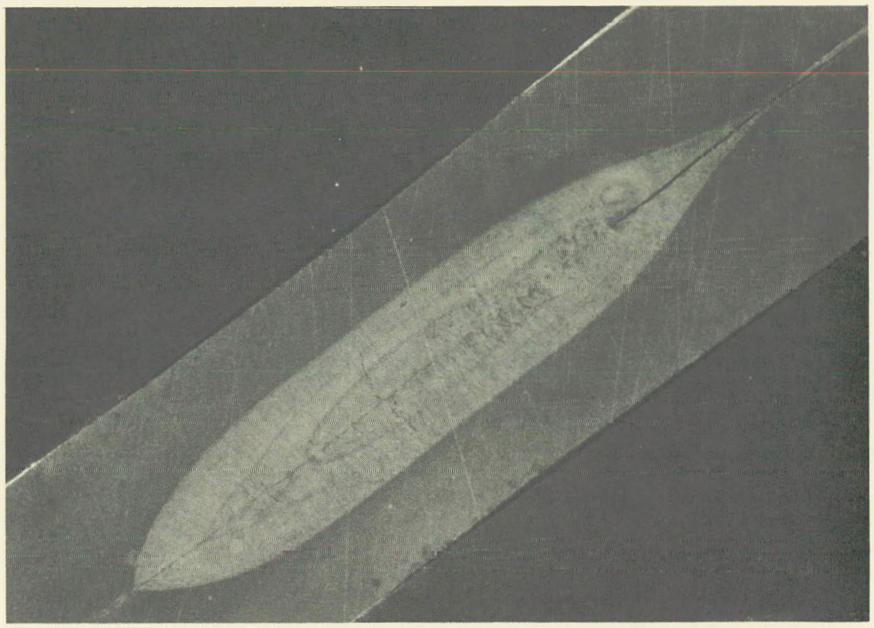
a. Edge of Spot Weld



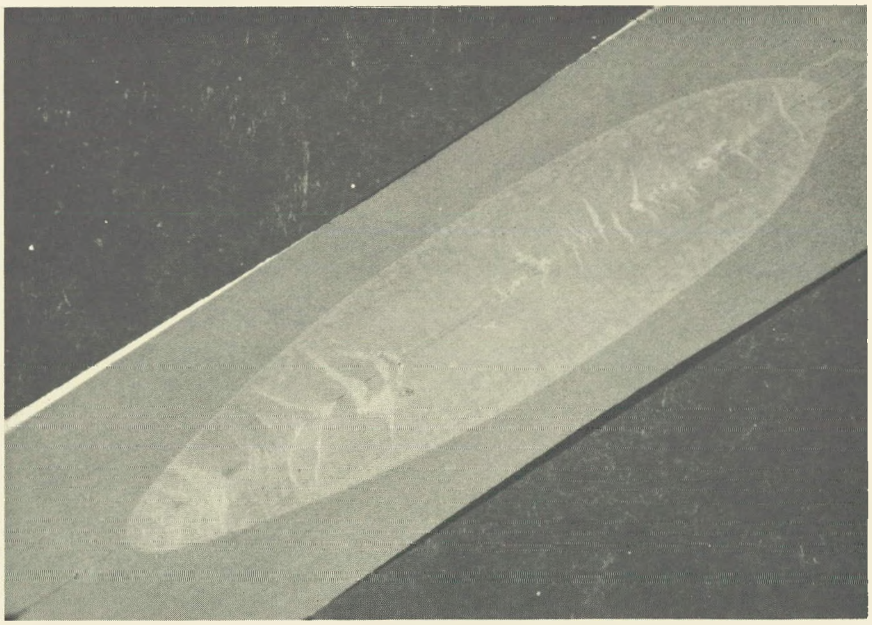
500X

b. Irregular Bond Line Induced by Ultrasonic Vibrations

Figure 11. Photomicrographs of Ultrasonic Spot Welds in APM Alloy M257



a. M257 14X



b. SAP895 14X

Figure 12. Photographs of Resistance Spot Welds in APM Alloys M257 and SAP895

E. HOT PRESSING

Hot die pressing has been used with some success in obtaining solid state bonding between various APM alloy combinations. To date, the systems studied have been M257 to M257, M257 to M486, and M257 to 1100 Al. Bond strengths of up to 25,000 psi at room temperature (75% joint efficiency) have been obtained for tensile studs of M257 to M257, and up to 30,000 psi for M257 to M486. Tensile studs of M257 to 1100 Al have failed in the aluminum, rather than at the bond line. The procedure used for this technique is to: (1) butt the alloy specimens, 1/4-in. diam by 1-1/2 in. long, in a die, (2) prepress at a pressure of 60,000 psi, and (3) heat to 1100°F at pressures of 40,000 to 70,000 psi for 10 min. The quality of the resultant bond is evaluated by pulling in tension to determine bond strength.

The adaptation of this hot die pressing technique to the making of end closures in M257 tubes is currently under investigation, and preliminary attempts have shown promising results.

VI. COMPATABILITY TESTS

A. APM - ORGANIC

M257 alloy has exhibited excellent resistance to corrosion when exposed to liquid polyphenyls at 750°F for 30 days. Its behavior is similar to that of 1100 aluminum. Tests of M486, along with additional samples of M257, are currently in progress.

B. APM - UO_2

An M257 fuel tube, containing sintered UO_2 pellets, was sized by isostatic pressurizing and heated for 4 weeks at 900°F with no evidence of interaction.[8]

Similarly, no evidence of any interaction was apparent when a 1100 Al-UO_2-M257 sandwich was enclosed in a stainless steel capsule and heated to 1100°F for 4 weeks. Tests of this type are continuing.

VII. MISCELLANEOUS TESTS

M257 tubes, 0.630-in. ID by 0.020-in. wall, were found to be vacuum tight at all temperatures up to 1000°F when tested with a helium mass-spectrometer leak detector. Also, the tubing was pressure tight, for internal pressures of 1 atm of helium, at temperatures up to 900°F.

Various APM products were annealed at temperatures up to 1185°F. M257 extruded tube and rod products have exhibited no blistering after 6-hr exposures at temperature. On sheet products, however, a few blisters have developed at 1150°F and, in one instance, a blister was observed on a specimen after a creep test at 1000°F. SAP895 sheet and tubular products have consistantly blistered at temperatures above 1125°F.

VIII. DISCUSSION AND CONCLUSIONS

Aluminum powder metallurgy products, Alcoa's M257 in particular, were selected for evaluation as a cladding material in organic reactor systems, in view of published data indicating improved elevated temperature strength. Mechanical property studies conducted in this program have confirmed the superiority of the APM alloy M257 over conventional wrought alloys. However, results to date indicate that tensile and creep strength properties, in the temperature range of 800 to 1000°F, are somewhat lower than previously reported. There is also a strong indication that the creep and tensile properties of APM alloys are significantly altered by cold working, as induced by swaging or rolling. A considerable test effort is required to establish the effects of fabrication and thermal histories and compositional variations on these elevated temperature properties. The indication of increased ductility of M257 over published values could conceivably render this alloy even more attractive as a cladding or structural element in organic systems. At this state in the program, no real effort has been made to analyze or extrapolate these data to the expected life of an organic reactor core.

Fabrication development efforts to date have established that finned tubular configurations, as required for organic-cooled reactors, are feasible. Future efforts are aimed at evaluating various commercial processes and establishing the practical dimensional tolerances and design limitations.

At the onset of this program, the joining of APM alloys was recognized as a major development area. Although end closures in test fuel tubes have been made with some degree of success, this field still requires a major effort. End closures made by the fusion welding of 1100 Al end plugs in M257 tubes have, in most cases, proven to be stronger than the 0.020 in. wall tubing.

Similarly, flash welding techniques show high promise, but a considerable effort is required to confirm or improve on the initial success. Other techniques, notably hot pressing and ultrasonic welding, remain to be fully exploited to establish their potential for making end closures. Electron beam welding will also be explored.

Although APM alloys are expected to be completely compatible with the coolant for organic systems, compatability with UO_2 in fuel tubes is not fully resolved. It has been reported that aluminum and UO_2 exhibit an interaction at temperatures of 500 to 600°C.[9] This reaction occurs within 10 hr at 600°C when UO_2 powder is dispersed and compacted in a matrix of aluminum. The results of tests being conducted in this program indicate that such a reaction is not probable in UO_2 fuel tube designs, since intimate contact between UO_2 and Al, such as in the compacted cermet plate, is not attained. Testing is continuing, however, by pressing fragments of a crushed UO_2 pellet into a sample of M257, prior to extended heating at 600°C.[8] This treatment will more nearly simulate actual conditions when a fuel tube is under irradiation.

Blistering of APM products is recognized as a serious potential problem that has occurred in both M257 and SAP895. The evaluation of all APM products will be continued to determine the full extent of this blistering phenomenon. If it is borne out that blistering is a common defect in tubular products, it may be necessary to require a blister anneal test on 100% of the products, prior to acceptance for fuel tube application.

In summary, the problems involved in the development of APM products for nuclear reactor application do not appear to be insurmountable. Continued development efforts will result in techniques suitable for making fuel rods and assembling them into prototype fuel elements for the in-pile and out-of-pile testing required for these designs.

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