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Metallurgy and Ceramics

SIGMA PLUG WELDING OF SPUN-OVER FUEL CANS

by

F. J. Winsor

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Development Engineering Division
Engineering Research Laboratory

[redacted]

December 1952

E. I. du Pont de Nemours & Co. (Inc.)
Explosives Department
Atomic Energy Division
Wilmington, Delaware

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F. J. Winsor
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Engineering Department

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ABSTRACT

Efforts made to employ the sigma welding process for plug welding closures in spun-over fuel cans were unsuccessful. No combination of welding conditions was found which would produce satisfactory, leak-tight, plug welds in aluminum.

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SIGMA PLUG WELDING OF SPUN-OVER FUEL CANS

I. SUMMARY

A. PURPOSE OF INVESTIGATION

Previous work at this Laboratory dealt with the development of groove welding techniques in an effort to improve the peripheral welding of the brazed joint at the top of aluminum-sheathed fuel slugs. In a further effort to increase the resistance to failure of the canned slugs the production of a closure made by forming the can over the top of the cap and welding the resulting center opening has been considered. Such a closure, in effect, increases the length of the braze layer between the cap and the can wall without greatly increasing the length of the sheathed slug (see Figures 1 and 2). The purpose of this investigation was to determine the applicability of the inert-gas-shielded, consumable electrode process, using commercially available equipment, for producing a welded closure in spun-over fuel cans.

B. RESULTS AND CONCLUSIONS

1. Using commercially available sigma welding equipment, no practical combination of welding conditions was found which resulted in satisfactory leak-tight closures in spun-over canned fuel slugs.

2. Excessive weld metal porosity and intergranular cracking were encountered in efforts to plug weld these closures. Porosity appeared to be related largely to the inherent characteristics of arc initiation. Intergranular cracking was believed to result from the high solidification shrinkage of aluminum, silicon segregation at the grain boundaries, and excessive restraint imposed by the joint design.

C. RECOMMENDATIONS

1. It is recommended that plug welding of spun-over closures by the sigma welding process be dismissed from consideration for start-up at the Savannah River Plant.

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2. Research may be expected eventually to improve the sigma welding process itself from the standpoint of reducing, or eliminating, porosity which apparently is associated with arc initiation. However, further research on the plug welding of spun-over closures by the sigma welding process should not be undertaken unless related studies indicate possible methods for overcoming the fundamental difficulties arising from the high solidification shrinkage of aluminum and the excessive restraint due to the joint design.

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II. DISCUSSION

A. INTRODUCTION

A previous report on this project (5) described a peripheral-groove, welding technique which was developed in an effort to improve the reliability of the seal weld between the cap and the can at the top of bonded fuel cans.

The work described in the present report was based upon the idea of increasing the length of braze layer between the cap and can wall, and thereby, presumably, decreasing the possibility of having a continuous path of defects in the braze layer which could expose the uranium slug to the process fluid. This can be done without greatly increasing the length of the fuel element by providing a thick cap, counterboring it to a suitable depth, and spinning the remaining material down against the bottom surface of the counterbore. Preparation of the top of the element in this manner necessitates the closing of an opening at the center of the spun-over material. One method of closure, which was developed by the American Machine and Foundry Co. for sealing die-formed target cans, consists of accurately boring out the center opening, pressing into it a tightly fitting knurled botton, and welding the button around its periphery by means of the inert-gas, tungsten arc process (3).

In an effort to obtain a simplified method of welding, the consumable-electrode, inert-gas-shielded welding process was considered for plug welding this central opening. The results of preliminary experiments on sigma (shielded inert gas metal arc) plug welding of die-formed target cans at the Development Laboratory of Linde Air Products Co., Newark, N. J. were indefinite. It was felt that these tests were not sufficiently thorough to permit a proper evaluation of the potentialities of sigma plug welding. Consequently, further work to evaluate this type of welding for closing the aluminum-sheathed slug was undertaken at this Laboratory.

B. EXPERIMENTAL PROCEDURES

1. MATERIAL: This investigation was performed with material supplied by the Argonne National Laboratory. Preliminary experiments established that there was no significant difference between plug welding closures in cans containing dummy aluminum slugs and in cans containing uranium slugs. Consequently, in order to facilitate handling, most of the experiments were made with canned dummy slugs, consisting of 2S aluminum rod brazed into aluminum cans and capped with hollow, plugged, 2S caps. (See Figure 1). Approximately 300 plug welds were made in such material. In addition, approximately 25 welds were made on uranium fuel slugs canned by the triple-dip process.

Most of the welds were made with 2S aluminum wire, obtained from the Air Reduction Sales Co. A few welds were made also with 43S (5% silicon) alloy wire. The wire was obtained with a type C surface finish which is recommended by Airco as being suitable for welding without requiring any further pretreatment.

2. LATHE SPINNING: In preparing new slugs for spinning, the upper part of the hollow cap was cut off in a lathe, and the remaining cap wall, braze layer, and can wall was machined back to a distance of 0.290 in. above the bottom of the hole in the cap. A recess in the top of the assembly was then bored with a 0.931 in. diam. flat end mill. This resulted in an average recess diameter of 0.939 in. and left an average wall thickness of approximately 0.073 in. for spinning. Slug dimensions, prior to spinning, are shown in Figure 1.

In order to conserve material, dummy slugs were reused several times for spinning and for welding. In preparing used dummy pieces, the tops were cut back, and the caps were counterbored to a depth of 0.290 in. from the top surface, using the 0.931 in. diam. end mill.

Spinning over the ends of the cans was performed on a lathe using a tool designed by the Aluminum Company of America (4). The spinning tool was mounted on the lathe carriage, and the tool axis was positioned at an angle of 46° from the face of the lathe chuck. The contact edge of the spinning tool was located 0.078 in. above the bottom of the recess in the can top. This tool setting provided a nominal clearance of 0.005 in. above the bottom of the recess, based upon an average wall thickness of 0.073 in. prior to spinning. With this clearance it was possible to spin the metal flush against the cap without reducing the wall thickness during spinning. Experience indicated that this procedure prevented binding of the spinning tool against the work. Consequently overloading the carriage and shifting of the tool or damage to the lathe were prevented.

For spinning, the lathe speed was 200 rev./min. and the cross-feed speed was 0.0315 in. per revolution.

Figure 2 is a sketch showing the characteristic features of a spun-over can top.

3. WELDING EQUIPMENT: Welding was performed with a Linde FSM-1 automatic sigma welding machine, manufactured by the Linde Air Products Co. Sigma welding is a consumable-electrode, inert-gas shielded arc welding process.* This process is characterized by high current

* This process is also known as "Aircomatic" welding, a registered trade mark of the Air Reduction Co., Inc.

densities on the electrode wire in order to provide adequate arc stability. This results in high rates of metal deposition. For this reason, the sigma welding process is especially suited for high-speed welding of relatively thick materials.

The welding electrode consists of wire, provided in coil form, having a suitable chemical composition and a suitable diameter depending upon the type of material to be welded and its thickness. In welding with the Linde FSM-1 machine the wire is pulled from the reel by knurled feed rolls in the drive head, and it is fed through a current-collecting guide tube and thence into the welding arc. The recommended power supply for sigma welding is direct current, reverse polarity (electrode positive), obtained either from a welding generator or a rectifier. The recommended shielding gas is argon, at a flow rate of about 45 cu.ft./hr.

In the Linde FSM-1 machine, control of the welding arc is provided, as desired, either by electronic control of the arc voltage or by means of the self-regulating feature of the arc which results from the proper selection of a constant rate of wire feed in combination with the drooping volt-ampere characteristic of a d.c. welding power supply. Because of the high rate of metal deposition in sigma welding, only a very short weld time was required for plug welding the can tops. In order to control this weld time accurately, a General Electric electronic timer (range 0.16 to 2.4 sec.) was employed to energize the welding relay in the Linde machine.

Figure 3 is a photograph showing the sigma welding machine used in this investigation.

4. VACUUM BUBBLE TESTS: Welds were tested for leakage by a vacuum bubble test. In this test, the cans were submerged in kerosene in a glass cylinder, and a vacuum of 28-29 inches of mercury was drawn on the top of the cylinder. Air bubbles issuing from the top surface of the can revealed the presence of leaks.

C. RESULTS

1. LATHE SPINNING OPERATION: Little difficulty was encountered in the lathe spinning operation for forming over the can tops once it had been established that a small amount of tool relief (mentioned in the Experimental Procedures, page 9) was required.

Variations in the depth of the recess and the wall thickness before spinning, and also in the position of the spinning tool, affected the diameter of the opening at the center of the spun-over top, and also affected the amount of space between the cap and the formed-over metal.

A thorough study of the factors associated with the spinning of can tops was rendered superfluous by the failure of the sigma welding process to produce satisfactory welds in this investigation. However, it is believed that service failures might be encountered due to cracking of the braze layers near the top of the element by the machining and spinning operations. This should be investigated before developing other methods of welding a spun-over closure.

2. <u>STUDY OF WELDING VARIABLES</u>: The major variables in the sigma welding process are (1) wire size, (2) current, (3) wire feed rate and (4) travel speed, or in this case, weld time.

In this investigation the wire size was maintained constant at 1/16 in. diameter. Previous experiments at the Linde Development Laboratory have indicated no significant effect of varying the wire diameter between 3/64 in. and 3/32 in.

The current was varied from 150 to 210 amperes. At each current setting, it was necessary to make a coarse adjustment on the wire feed rate controls in order to keep the automatic voltage control within operating range. No effect of the welding current on the weld soundness was observed over the range investigated. Herbst and McElrath (1) report that, in sigma welding carbon steels, current densities should be well under 98,000 amp./sq.in. to eliminate porosity. In this investigation, current densities ranged from 50,000 to 70,000 amp./sq.in.

For any particular value of welding current, there was a narrow range of wire feed rate (or voltage setting on the automatic voltage control) over which satisfactory operation could be obtained. This variation in wire feed rate had no effect on weld soundness. The optimum rate of wire feed for a current of 180 amp. was about 170 in./min.

With the short weld times involved, the automatic voltage control was found to be ineffective for maintaining a constant arc length. The circuit is reported to be capable of maintaining the arc voltage within $\pm$ 0.1 volt (2); however, this rating may apply to the steady-state condition which is reached only after a considerably longer period of time than that required to produce the plug welds in this investigation. With the control circuit in operating range, the average arc voltage was about 22 volts. Efforts to change the arc voltage by varying the control potentiometer setting resulted in unsatisfactory machine operation. In operating the machine on automatic voltage control the arc length was observed to vary considerably more than it did when operating with a constant rate of wire feed. However, this difference had no apparent effect on weld soundness.

During this investigation, welds were made over a time range of approximately 0.5 to 4.0 seconds. Although variations in the weld time appreciably affected the weld size, no relationship between weld time and weld soundness was observed. The majority of welds were made with weld times of 1.0-1.4 seconds.

3. EFFORTS TO ELIMINATE POROSITY AND CRACKING: In addition to studying the inherent variables in the sigma welding process, several other factors were investigated to reduce porosity and cracking of the welds. These factors are summarized below. None of these efforts produced any significant improvement in weld soundness.

a. Preheating: Preheating of cans to temperatures ranging from 400°F. to 1,000°F., by means of a flame torch, was investigated. Temperatures were measured with "Tempilstiks." Preheating followed by partial cooling was also attempted.

b. Use of Chill Blocks: From preliminary experiments at the Linde Development Laboratory, it appeared that a copper chill block clamped around the can near the top might be effective in reducing the severe shrinkage which occurred at the periphery of the weld. Further investigation was made of the use of chill blocks in this project. In addition to the edge-type, chill block used at Linde, experiments were made with a flat-top, chill block, 2 in. x 2 in. x 1/4 in. thick, with a 1/2-in. diam. hole located over the opening to be welded in the can top. Despite the apparent effect which the chill blocks had in altering the heat flow during welding, there was no evidence from bubble tests or metallographic examinations that their use improved the weld soundness.

c. Machining of Opening in Can Top: Because of the deformation gradient across the can wall during spinning, the diameter of the opening in the spun-over top was smallest at the outside surface and increased below the surface. Several experiments were made on cans in which the hole was machined to a constant diameter throughout its depth and also in which the underneath cap was counterbored beneath the opening. There was no evidence that weld quality was improved by these measures.

d. Preplacing Sheet over the Opening and Melting Through It: In order to circumvent some of the difficulties which were suspected to be due to the arc starting characteristics, an attempt was made to start the arc on an aluminum sheet placed over the top opening and melt through it to make the plug weld. One fairly dense, but cracked, weld was made in this manner. Further attempts were even less satisfactory. In most cases, the metal which dropped through, froze before it flowed enough to fill the opening, and in all cases, shrinkage cracks occurred. Preheating of the cans prior to placing the starting sheet did not improve the results.

e. Alternate Melting and Freezing: Welds made with a series of intermittent short pulses of current showed no improvement in quality over welds made with a single pulse of current, longer in duration.

f. Retract Starting vs. Manual Starting: The Linde FSM-1 machine provides for either retract starting or manual starting of the arc. In retract starting, the wire is jogged down until it touches the work. Then when the arc starting switch is depressed, a current-sensitive relay in the control circuit causes the wire feed motor to reverse momentarily until the arc is established. In manual starting, the wire is fed to within about 1/4 in. of the work, and then, with the arc starting switch on, the arc is ignited by inserting a carbon pencil between the wire and the work. Although it might be expected that the method of manual starting would result in less-transient starting conditions, there was no evidence that the difference in starting technique affected the results.

g. Annealing of Cans Before Welding: A series of experiments was made with cans which were annealed for one hour at 700°F. after spinning and before welding. The annealing treatment failed to improve the weld quality.

h. Rotation of Cans During Welding: Several experiments were made to determine the effect of rotating the cans at various speeds during welding. The cans were rotated with an air-operated stirring motor. At high speeds (greater than 100 rpm) practically all of the weld metal was expelled by the centrifugal force. At an intermediate speed (approximately 60 rpm) there was some evidence that rotation occasionally produced denser welds, but the results were not reproducible, and all of the closures leaked.

i. Sigma Welding and Remelting with Tungsten Arc: In preliminary experiments with plug welding of die-formed cans at the Air Reduction Research Laboratories it was suggested that the weld defects which were present after "Aircomatic" (or sigma) welding might be eliminated by remelting the weld with an inert-gas-shielded tungsten arc. This procedure was tried without success. Even with the manual addition of filler metal it was not possible to satisfactorily eliminate porosity in the weld.

j. Variation of Electrode Position from Center of Opening: Many of the sigma welds which were made with the electrode wire centered in the opening in the can top leaked severely from the central shrinkage cavity. In an attempt to avoid this, some welds were made with the electrode wire positioned off center and with the can slowly rotated. These welds also leaked because of shrinkage-porosity and -cracking.

k. Etching of Cans After Machining and Prior to Spinning: The procedure which had been adopted for cleaning the cans after machining and prior to spinning consisted of degreasing in acetone. In order to provide further assurance that the welding difficulties which had been encountered were not due to the presence of dirt and grease picked up during machining, a series of twelve cans was degreased in acetone, etched in 2% hydrofluoric acid at room temperature for 3 min., rinsed in cold water, and wiped dry. There was no evidence that the prior etching procedure improved the subsequent weld soundness of these cans.

l. Use of Argon-Helium Mixtures: Although most of the welds were made with argon as the shielding gas, a few welds were made with mixtures of 65% helium - 35% argon and 10% helium - 90% argon (by volume). The results obtained with argon-helium mixtures showed no improvement over those obtained with argon alone. This was to be expected, since it has been reported that in welding carbon steel, helium increases the spatter rate and reduces arc stability (1).

4. METALLOGRAPHIC EXAMINATION: It was quite obvious from observations during welding, from vacuum bubble tests, and from examinations of machined weld surfaces that very inferior plug welds were produced by the sigma process. However, metallographic examinations were made of several weld sections, and photomicrographs were taken of a typical section to provide a permanent record of the defects which were encountered. These photomicrographs are presented in Figures 4-9. Figure 4 is a macrograph showing radial and vertical cross-sections of a weld. The remaining photomicrographs clearly show the very poor weld quality resulting from porosity and intergranular shrinkage cracks.

D. CONCLUSIONS

As a result of this investigation it is concluded that sound, leak-tight, plug welds in aluminum cannot be produced by the sigma welding process using presently available commercial equipment.

There appear to be at least four factors which have rendered it practically impossible to produce satisfactory plug welds in aluminum. They are:

1. High solidification shrinkage of pure aluminum: During solidification, aluminum undergoes a 6.6% contraction in volume, which is very high as compared with 0.6-1.0% volume contraction for iron and steel. The high solidification shrinkage of aluminum increases the tendency for intergranular cracking in highly restrained welds such as plug welds.

2. Restraint introduced by joint design: A plug weld in the center of a plate or disc of metal is prevented from shrinking freely during solidification, and in the case of aluminum, this restraint is sufficient to cause intergranular cracking during solidification.

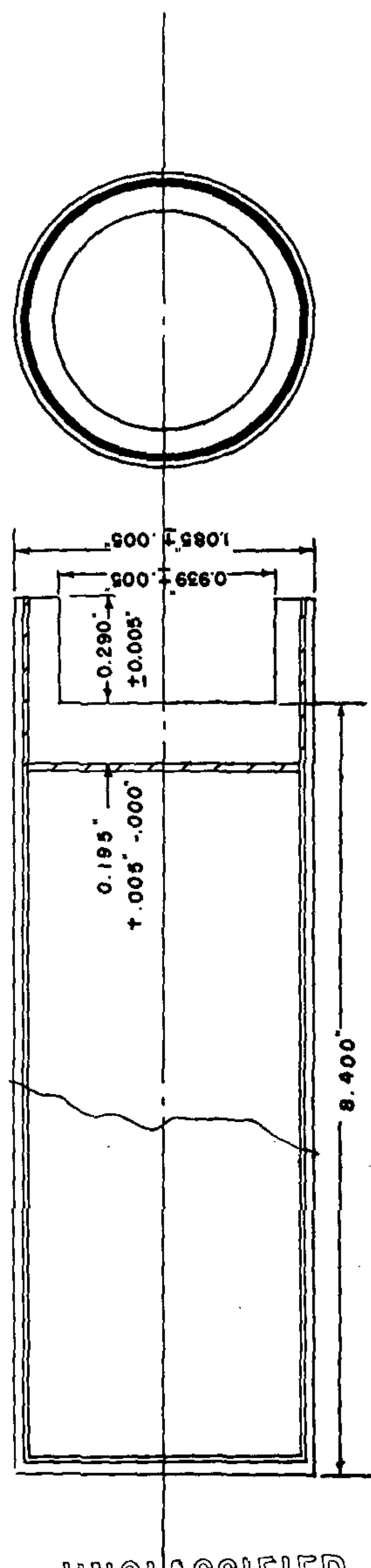
3. Starting characteristics of an inert-gas shielded, consumable-electrode arc: It is believed that metal transfer is very erratic during the first few seconds after arc ignition until a satisfactory weld pool has been established. This initial erratic deposition of metal results in a cellular weld structure having numerous voids. According to Linde representatives, porosity at the start of the weld is frequently a problem in sigma welding. A few bead-on-plate welds made in this Laboratory showed considerable porosity at the start and severe crater cracking at the end of the welds. For many applications these problems may be solved in a practical manner by providing separate starting and finishing tabs attached to the joint, or by chipping out the defective regions and rewelding manually.

4. Air beneath the spun-over can top and in the opening to be welded: It is believed that expansion of air trapped beneath the spun-over top may aggravate the porosity problem. However, this is probably only a minor factor since a plug weld made in a drilled hole in the end of a solid bar was also found to be extremely porous. Another undesirable situation with this type of joint is that it is difficult to provide adequate protection against oxidation of the initially deposited metal because there is inadequate opportunity for the inert shielding gas to displace the air which is present initially.

III. APPENDIX

[redacted]

FIGURE 1

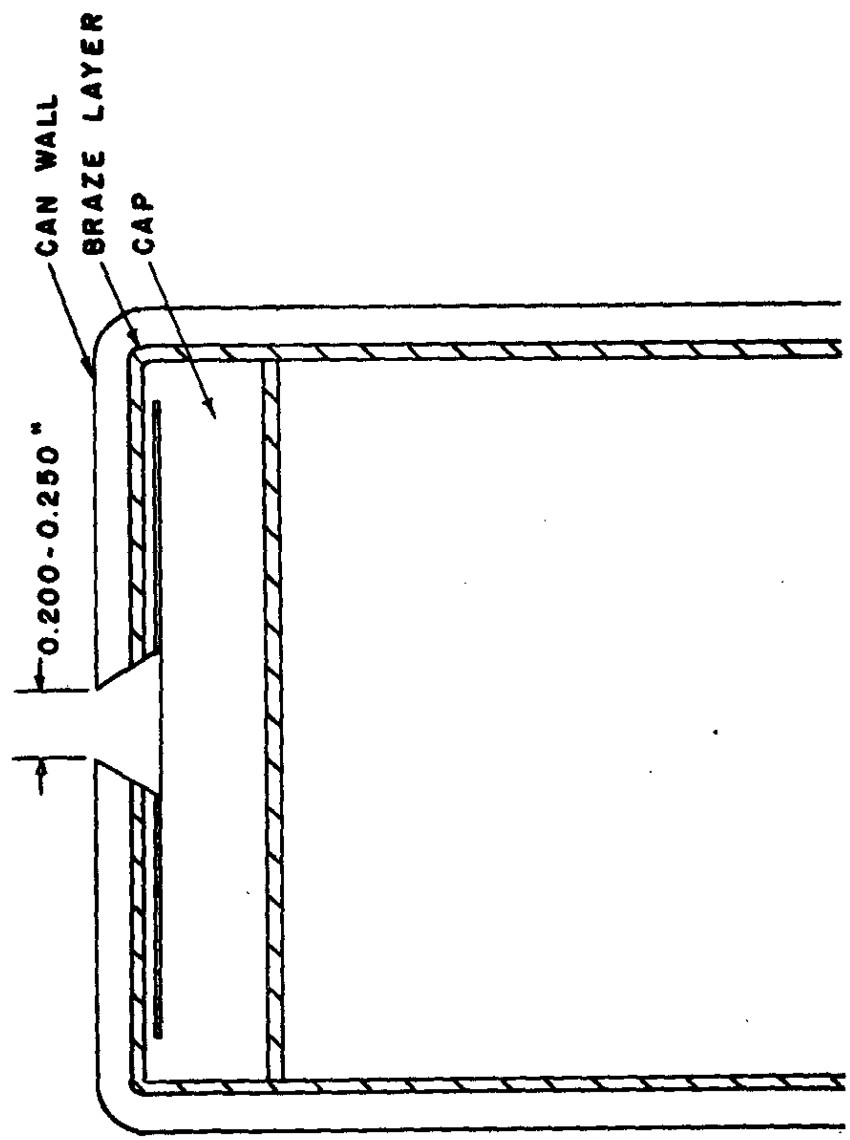


SLUG DIMENSIONS BEFORE SPINNING

[redacted]

FIGURE 2

[redacted]



DETAILS OF SPUN-OVER FUEL CAN

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FIGURE 3

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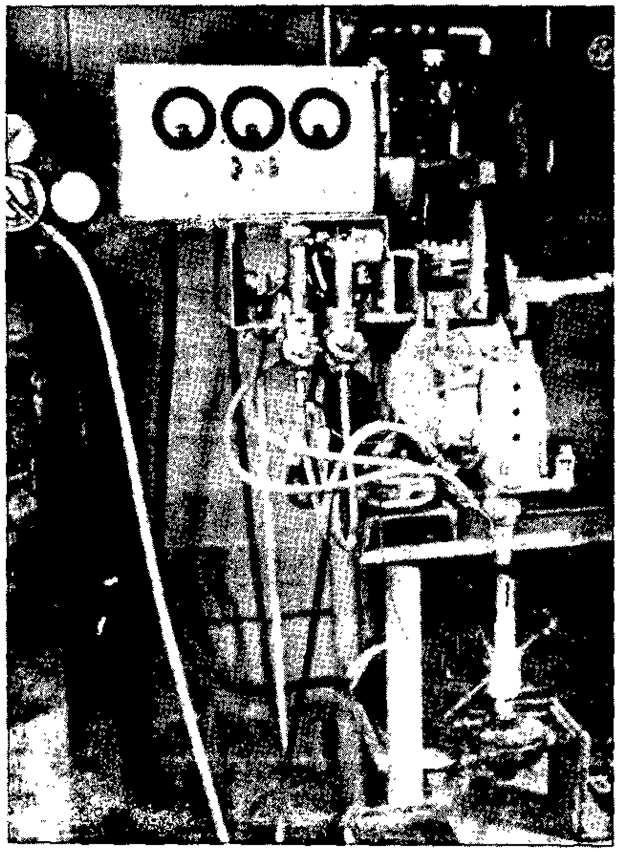

LINDE FSM-1 AUTOMATIC SIGMA WELDING MACHINE

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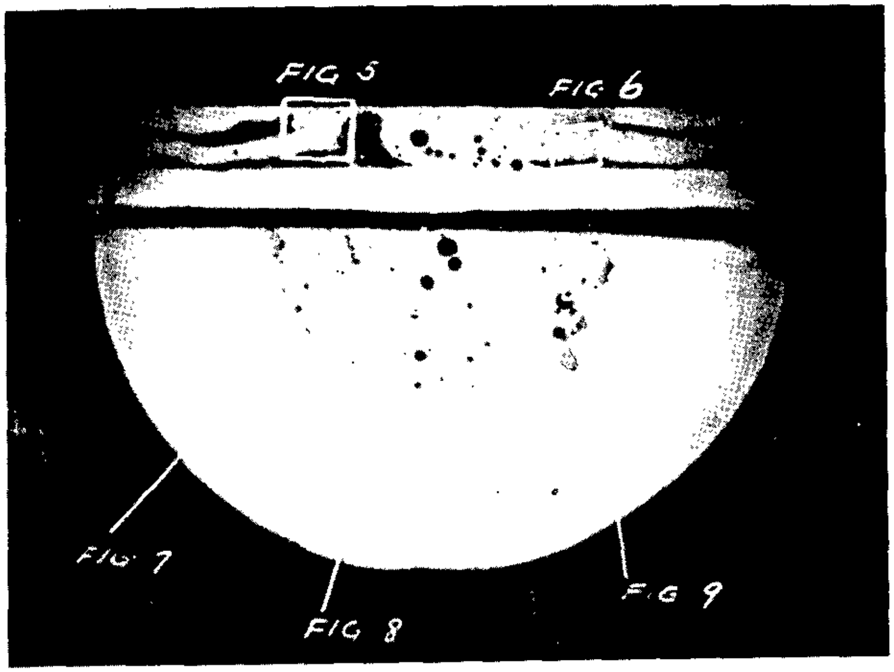
[redacted]

FIGURE 4

UNCLASSIFIED



VERTICAL AND RADIAL SECTIONS THROUGH A TYPICAL

SIGMA PLUG WELD, 3.6X

(Locations of sections shown in Figure 5, 6, 7, 8 and 9 are indicated)

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[redacted]

[redacted]

FIGURE 5

UNCLASSIFIED

SECTION OF PLUG WELD SHOWING FUSED AREA

AT END OF BRAZE LAYER, 50X

(See Figure 4)

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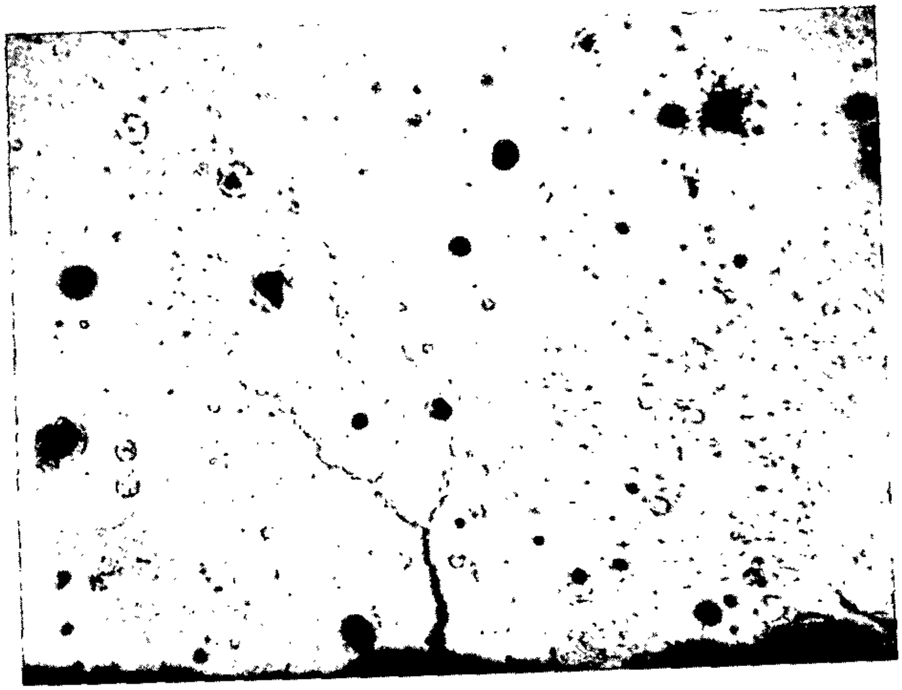
[redacted]

FIGURE 6

UNCLASSIFIED



SECTION OF PLUG WELD SHOWING REGION NEAR INNER SURFACE, 50X

(See Figure 4)

(Note Intergranular Cracking)

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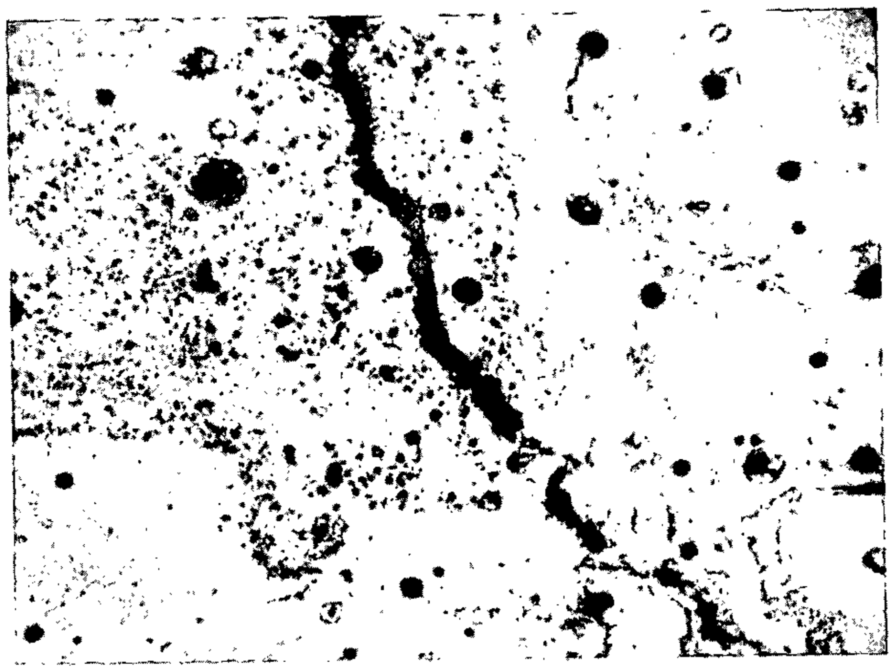

SECTION OF PLUG WELD SHOWING REGION OF

HIGH SILICON CONTENT EXPOSED TO SURFACE, 50X

(See Figure 4)

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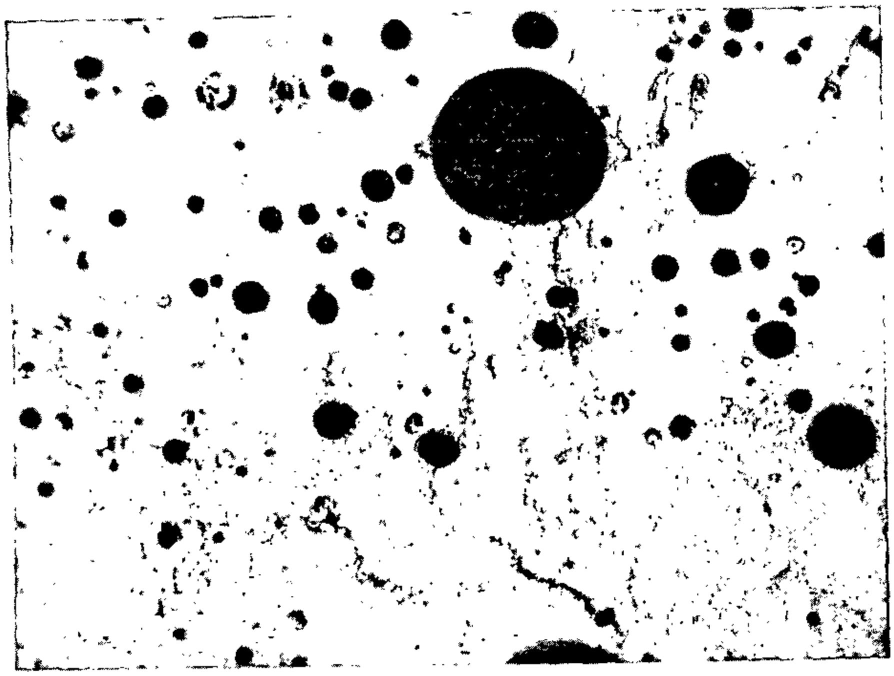
[redacted]

FIGURE 8

UNCLASSIFIED



SECTION OF PLUG WELD SHOWING POROSITY NEAR PERIPHERY, 50X

(See Figure 4)

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[redacted]

FIGURE 9

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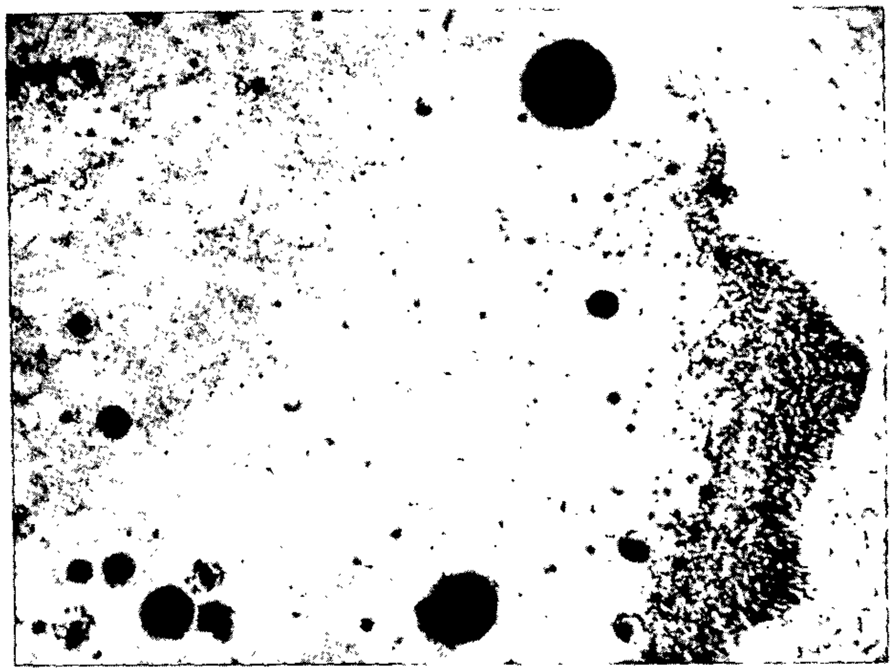

SECTION OF PLUG WELD SHOWING POROSITY AND HIGH SILICON CONTENT ALONG FUSION LINE, 50X

(See Figure 4)

(Dark Area at Right is High in Silicon)

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[redacted]

[redacted]

IV. BIBLIOGRAPHY

1. Herbst, H. T. and McElrath, T., Jr., "Sigma Welding of Carbon Steels," The Welding Journal, 30, No. 12, 1084-1091, 1951.

2. Linde Air Products Co., "Instructions and Parts Data for Linde FSM-1 (Series 2) Machine," Form 9136-B, New York.

3. Millenson, M. B., "Project 8980 - SRP Can Welding, Development of the Fold-Over Closure for 'T' Cans," J. O. 79004-3.04-15, American Machine and Foundry Co., New York, June 16, 1952.

4. Smith, C. D. and Wick, E. A., "Trip Report to Alcoa, New Kensington, Pa.," DPW 5220, April 16, 1952.

5. Winsor, F. J., "The Peripheral Groove Welding of Fuel Cans," DP-10, Engineering Research Laboratory, August 1952.

[redacted]