NASA Technical Memorandum

NASA TM - 82552

IN-HOUSE WELDING STUDIES SUPPORTING THE PRELAUNCH ASSESSMENT OF THE STS-6 MAIN ENGINES

By Lisa L. Hawkins

Process Engineering Division
Metals Processing Branch

June 1983

(NASA-TM-82552) IN-HOUSE WELDING STUDIES SUPPORTING THE PRELAUNCH ASSESSMENT OF THE STS-6 MAIN ENGINES (NASA) 28 p HC A03/MF A01 CSCL 13H
N84-11499
Unclas
G3/37 42412

National Aeronautics and Space Administration

George C. Marshall Space Flight Center

MSFC - Form 3190 (Rev. May 1983)

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. NASA TM - 82552	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE In-House Welding Studies Supporting the Prelaunch Assessment of the STS-6 Main Engines		5. REPORT DATE June 1983 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Lisa L. Hawkins		8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. 13. TYPE OF REPORT & PERIOD COVERED
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D.C. 20546		Technical Memorandum 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES Prepared by Process Engineering Division, Metals Processes Branch		

16. ABSTRACT

This memorandum describes two in-house welding studies undertaken by the Materials and Processes Laboratory as a result of problems with the Challenger engines.

(1) Heat Exchanger Coils: Description of process used to perform these welds, sample test data, recommendations for process improvement.

(2) Weld 56; High-Pressure Fuel Turbo Pump: Description of effort to simulate problem welds, as well as good welds, test data, and conclusions.

17. KEY WORDS STS-6 Prelaunch Assessment - EH HEX/Weld 56 HPFTP Studies		18. DISTRIBUTION STATEMENT Unclassified – Unlimited	
19. SECURITY CLASSIF. (of this report) Unclassified	20. SECURITY CLASSIF. (of this page) Unclassified	21. NO. OF PAGES 27	22. PRICE NTIS

MSFC - Form 3292 (May 1969)

ACKNOWLEDGMENT

Many people played significant roles in the performance of these studies. Without the cooperation of each of them, these results could not have been obtained.

Members of the Advanced Manufacturing Technology Laboratory (MMA) who contributed significantly to the effort were Charles Brosemer and Joe Sexton. Members of the Metals Processes Branch, and the Metallurgy Research Branch of the Materials and Processes Laboratory (MSFC) who contributed significantly to the effort were Paul Munafo, Newton Tiller, Ed White, Ernie Bayless, Jack Reid, Sam Clark, and Terry Craig.

Because many people were involved in this effort, it is possible that these acknowledgments may overlook someone. Such omission is unintentional, and we wish to extend our thanks to all those who made a contribution.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TECHNICAL MEMORANDUM

IN-HOUSE WELDING STUDIES SUPPORTING PRELAUNCH ASSESSMENT OF THE STS-6 MAIN ENGINES

INTRODUCTION

Subsequent to the problems occurring in the Challenger main engines, which resulted in a delay in STS-6 launch, two welding studies were undertaken by the Materials and Processes Laboratory of Marshall Space Flight Center in an attempt to suggest possible solutions to these problems.

The first study involved investigation of the process used by Wintec to weld the heat exchanger coils. The second involved simulation of the weld 56 joint in the high pressure fuel turbo pump. These two in-house welding studies are summarized in this report.

AN EVALUATION OF THE WELDING PROCESS USED IN FABRICATION OF THE HEAT EXCHANGER COILS

The leak in the heat exchanger of Challenger engine 2016 stimulated program-wide examinations. Since the heat exchanger was known to fail due to lack of fusion in a weld, the welding procedures were of particular interest. Metals Processes Branch at MSFC fabricated several test specimens which closely represent the heat exchanger coil. Tubes of 316 stainless steel and Haynes 188 alloy were joined together with a filler insert. The configurations of the test specimens and the filler insert are shown in Figures 1 and 2, respectively. Figure 3 shows the initial components, and Figure 4 shows a completed specimen.

The welding system set-up is shown in Figure 5. The fixture and welding positioner proved to be very important in providing the necessary accessibility and controlled travel speed. Because the amperage used to weld was very low (3 to 4 amps), a sensitive ammeter was required to effectively record it. A helium flow meter was calibrated for determination of the argon shield gas flow (Figure 6), because an argon flow meter capable of measuring small flow rates was unavailable. The purge and back-up gas was fed into the inside diameter (ID) by means of an injector needle which acted as a sliding bearing to avoid tangling the gas lines. Finally, the weldor used a "hand prop" to hold the torch steady along the seam of the joint.

The following factors were evaluated during the investigation:

1) The effect of tack weld oxidation on weld quality

2) The effects of electrode configuration

3) The purge and back-up gas shielding requirements

4) Fixturing and accessibility

5) Weld process variables

The following observations were made: If the inert gas shield is removed from the tack weld before it cools, the tacks will interfere with metal flow, creating a flaw as noted in Figure 7, Specimen No. 3. Also, if any cracks occur in the tacks, they will remain in the final weld.

The configuration of the electrode proved to be critical. A 0.040 in. diameter thoriated tungsten electrode was tapered for a length of 5/16 to 3/8 in. Our observations showed that, when the tip of the electrode was left sharp, a ball of hot molten metal formed on the tip of the electrode, causing the arc to wander along the surface of the ball. When the tip of the electrode was somewhat blunted, this problem was solved. Figure 8 shows the tapered electrode before and after blunting.

An inert gas shield was required for both inside and outside diameters of the tubes. ID shielding was provided by means of the calibrated helium flowmeter at 0.75 CFH. A flow rate of 15 CFH was used for shielding the weld arc.

The fixture was necessary to hold the parts in place and to provide proper fit-up of the joint. Improper fixturing was suspected to be responsible for thin spots in the walls of the parent materials. Improper fit-up caused a portion of the tube wall to be removed in the post-weld reaming operation. Due to lack of sufficient data points, MSFC is unable to recommend an alternative to reaming at this time. Investigation into improved fixturing should be undertaken.

A rubber O-ring was added to the fixture to provide a spring action to maintain fit-up throughout the welding process.

The welding positioner provided needed accessibility by allowing the operator to rotate the assembly at a controlled speed. Figures 9 through 11, respectively, show the fixture, the fixture-tube assembly, and the entire assembly in place on the fixture.

Proper voltage, amperage, and travel speed are necessary to insure any good weld. Our data point observations showed the following set of parameters to be optimal:

Travel Speed: 0.324 IPM (0.275 RPM)
Voltage: 14 to 15 V
Amperage: 3.50 (+0.50 - 0.00) A

These parameters differed from the following, which were used by Wintec.

Travel Speed: 10 RPM
Voltage: Not specified except as Low Range Voltage
Amperage: 3 to 32 A

In addition, the shield and purge gas flow rates differed from our recommendations, as did the configuration of the electrode. Wintec used a shield gas flow rate of 40 CFH and a purge gas flow rate of 7 CFH. The electrode was tapered, but not blunted.

A total of seven test specimens were fabricated at MSFC. Two of the specimens were tested in tension, and failed at an average of 83.9 Ksi. These data compare favorably with the handbook design values of 30 Ksi for yield strength, and 80 Ksi for ultimate strength of 316 stainless. This indicates that there is not a metallurgical problem in the welding of 316 stainless to Haynes 188 when it is welded according to the procedures outlined in this report. The remaining five specimens were evaluated in high-cycle fatigue, with a stress ratio of 0.05 (Stress ratio = Minimum stress/ Maximum stress). Most of the specimens failed at the edge of the weld in the Haynes 188 material. Data for these tests are plotted in Figure 12.

Figure 13 lists X-ray defects and mechanical test results for each specimen. From Figures 12 and 13, it can be seen that radiography is an accurate indicator of most serious weld defects (such as the large lack of penetration seen in Specimen No. 3, Figure 7), but that less evident defects, such as restricted metal flow (see Specimen No. 6, Figure 7), are difficult to determine by radiography. In this limited data sample, there appears to be no good correlation between radiographic results and mechanical test data. Consistent with our experience on other programs, X-ray inspection alone is not adequate to determine overall weld quality.

In addition to the improved parameters developed at MSFC, it is our opinion that the process could be further improved by automation. Both Rocketdyne and Wintec are considering systems that would make the process semi-automatic, with the operator interceding only when it is necessary to change the weld parameters. This system should increase process control and improve the quality of the welds.

A SIMULATION OF WELD 56 IN THE HIGH PRESSURE FUEL TURBO PUMP TURNAROUND DUCT

MSFC also conducted a series of tests to assess the acceptability of weld 56 in the high pressure fuel turbo pump (HPFTP) turnaround duct on two Challenger engines. This study was prompted when post-assembly X-ray of these welds revealed intermittent lack of penetration around the circumference.

The test program included weld specimens configured to the joint dimensions used on the Challenger engines and the anomalous dimensions used on engine 2015 which failed in test. Attempts were made both to fully penetrate the joint and to simulate a condition in which the joint could be "bridged" but not fully penetrated.

The specimen weld beads were ground, etched, penetrant-inspected from the crown side, and X-rayed. Following non-destructive testing, photomacrographs were taken to determine the depth of weld penetration associated with each set of welding conditions.

"Bridging" was easily achieved by feeding in excess filler wire to cool the arc and limit penetration. Visual and surface inspection of the bridged specimens indicated the welds were acceptable, but sections revealed lack of penetration in several cases (Figure 16, Specimens 2a and 3). There was also a lack of penetration noted during sectioning of specimens where weld shrinkage pulled the unfused region of the joint into a very tight crack. Radiography had failed to reveal this problem (Figure 16, Specimens 1a and 2b). An incidental finding was that there appears to be a high potential for residual stress in these joints, as evidenced by the "buckling" of the thinner material in the specimens shown in Figure 16.

Welds simulating the reverse taper of the anomalous 0210R4 joint presented problems. These specimens required a higher welding current (40 to 50 amps) to fully penetrate the joint. Mismatch was also a problem, approaching 100 percent at times. The mismatch was apparently caused when the thinner member slid down the chamfer ahead of the weld.

Figure 14 summarizes the results of all the tests conducted at MSFC. Rocketdyne's "as-welded" allowable ultimate tensile strength is 102 Ksi. Note that the ultimate strength of the specimens was fairly consistent with percent penetration. Fatigue strength is expected to follow the same pattern. Figures 15 through 18 are included for reference.

CONCLUSIONS

Investigation of the welding process used by Wintec on the Challenger engines' heat exchanger coils revealed an unacceptable procedure. Automation of the procedure and use of NDE methods other than radiography are recommended.

Two automatic welding systems are currently being considered for adaptability to the heat exchanger weld process. If automation is not achieved, improved fixturing to reduce the possibility of reamer damage to the parent metal is recommended.

An investigation into new NDE techniques which could be applied to the heat exchanger coils is currently underway at Wintec.

Simulation of the weld 56 joint on the HPFTP revealed a number of constraints on the weldor as well as a procedure that is difficult to follow, resulting in inconsistent welds. In addition, NDE procedures used to date have not been sufficient to detect unfused regions of the joint. In view of these findings, it is recommended that this joint be reviewed by design and manufacturing.

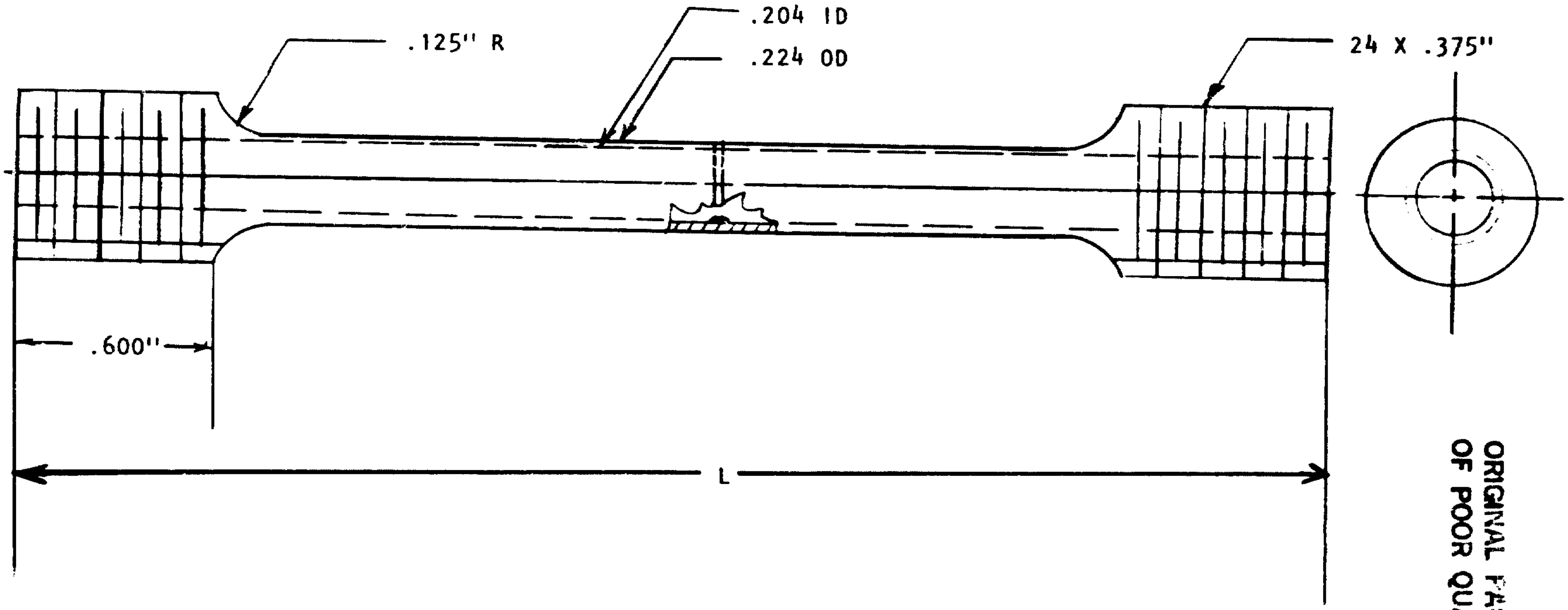
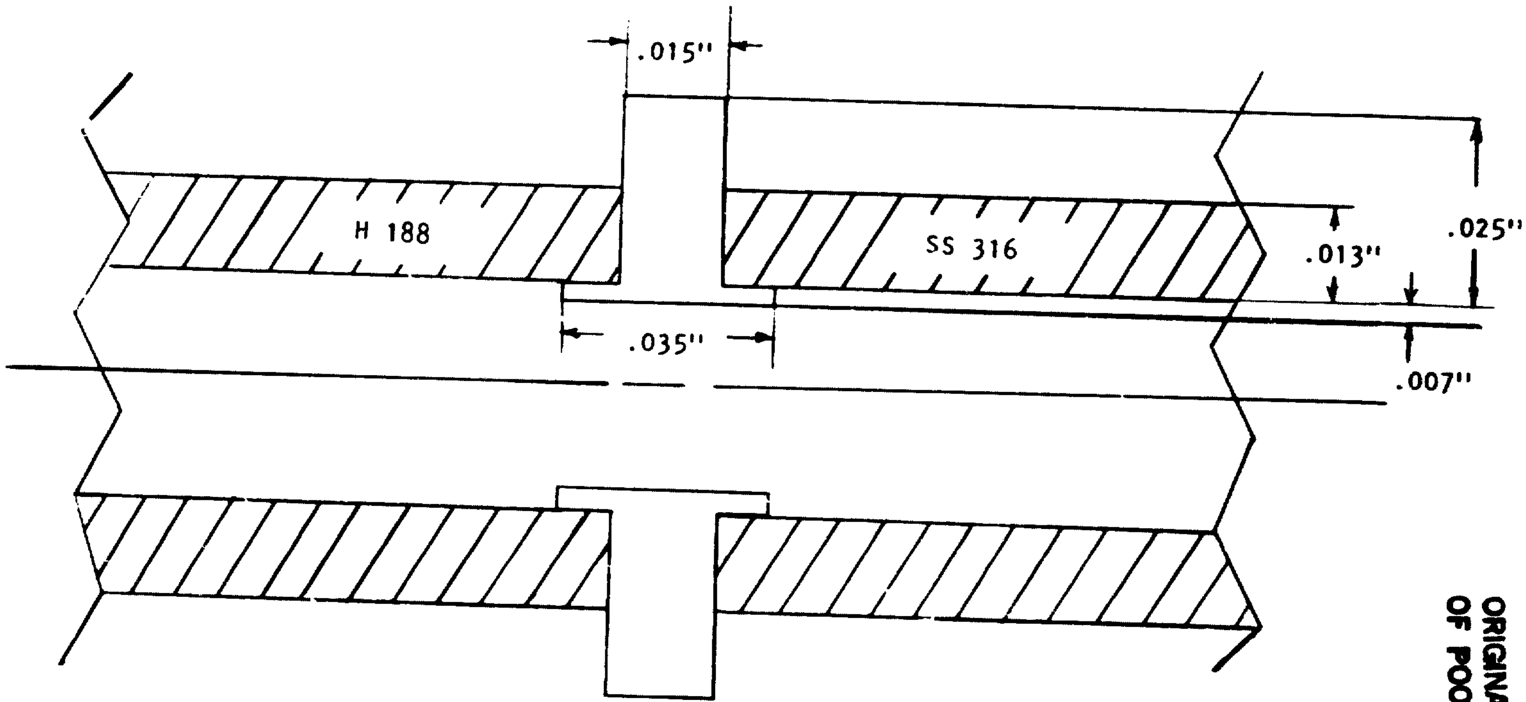


Figure 1. Specimen configuration.



HALF-SECTION

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 2. Weld insert configuration.

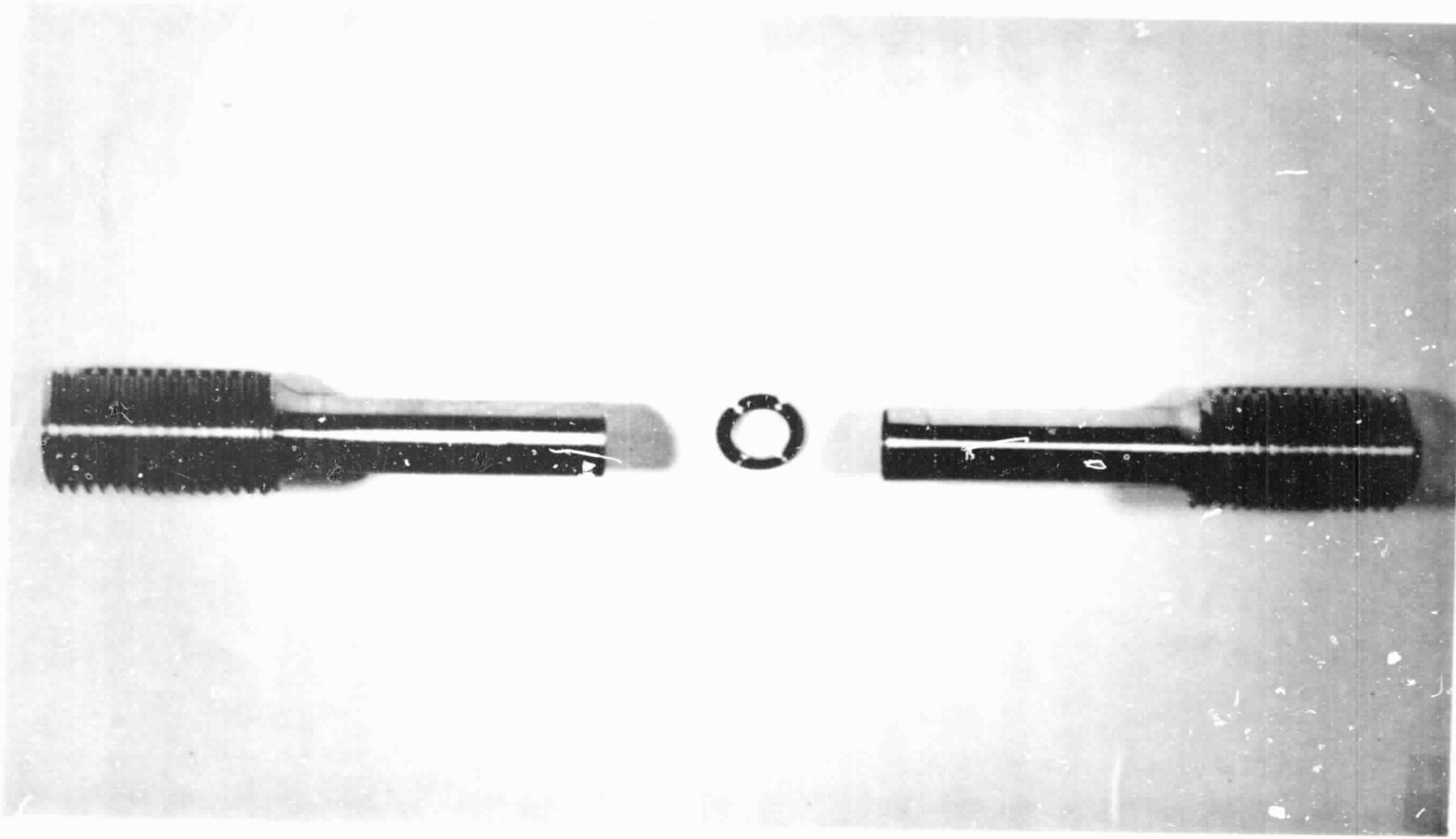


Figure 3. Initial components.

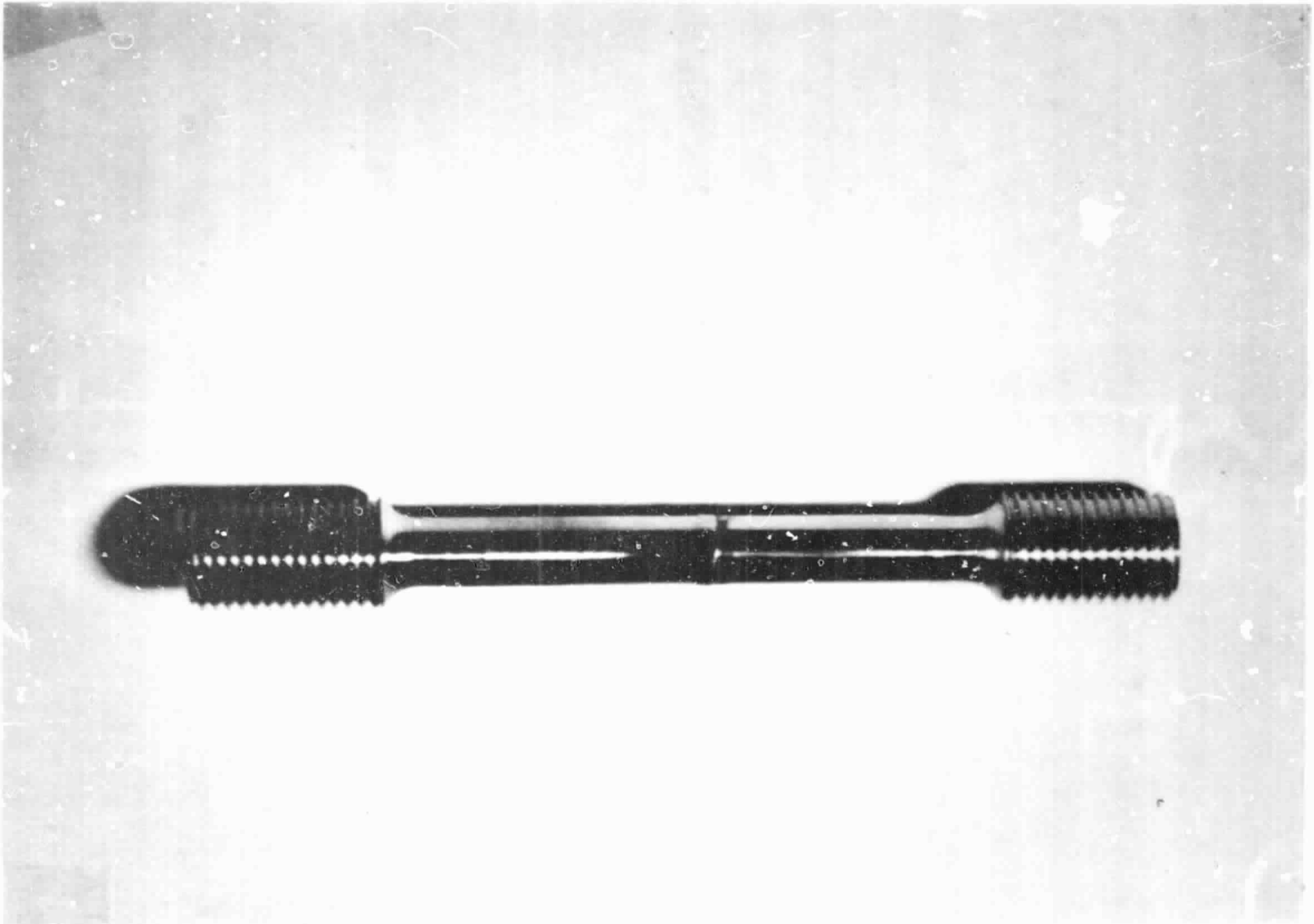


Figure 4. Finished specimen.

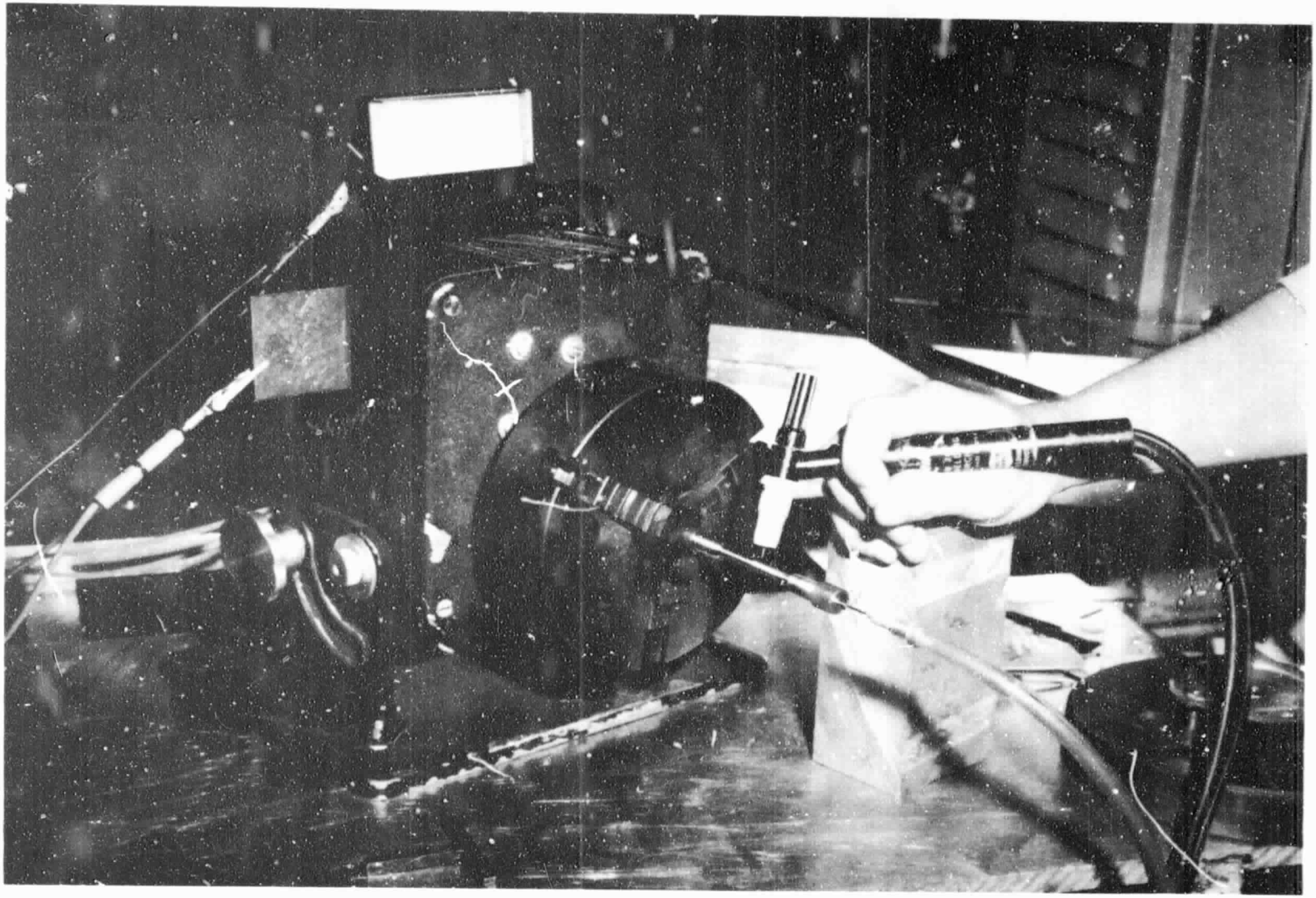


Figure 5. Weld station set-up.

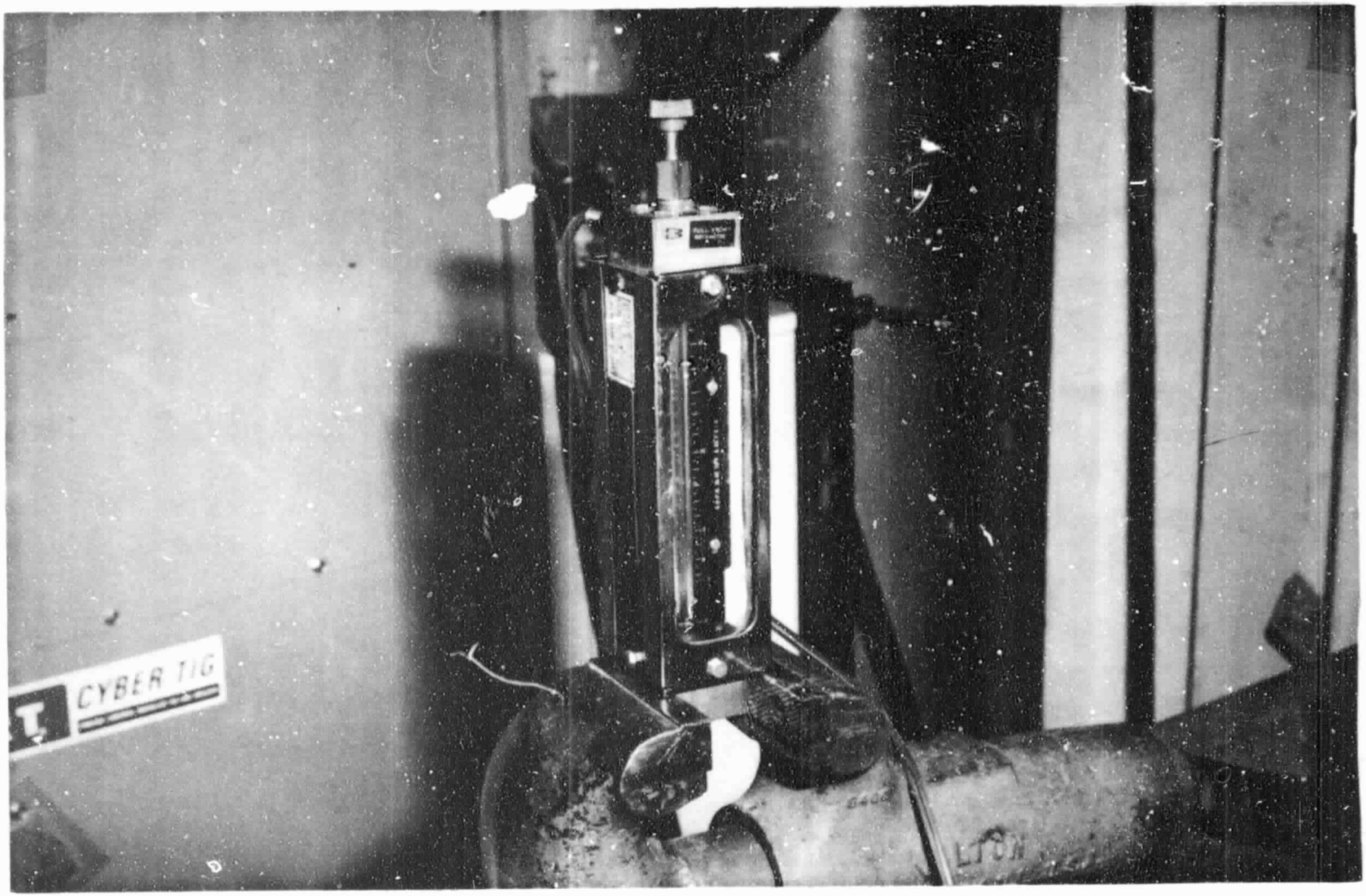


Figure 6. Calibrated flow-meter.

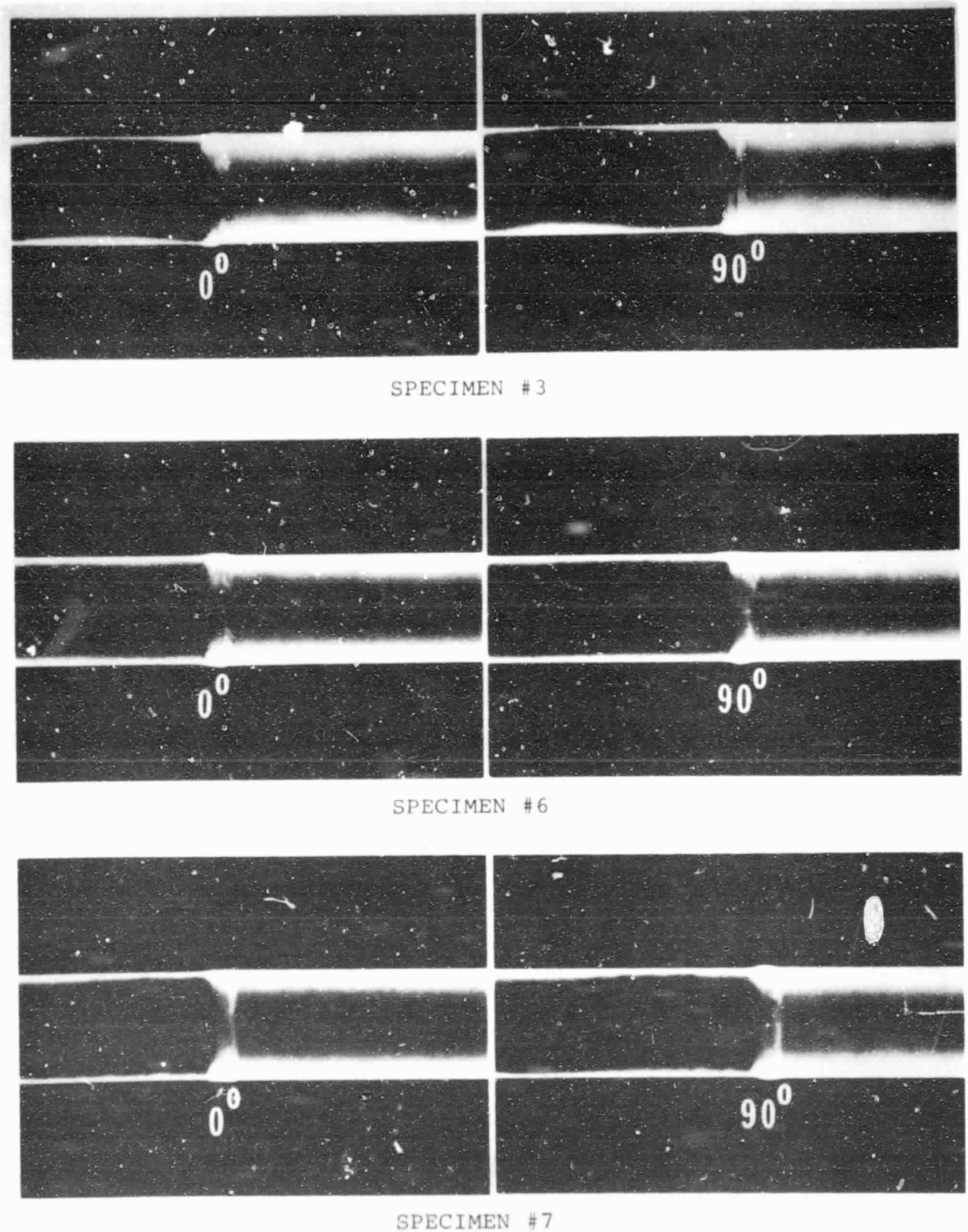


Figure 7. Radiography: HEX coils.

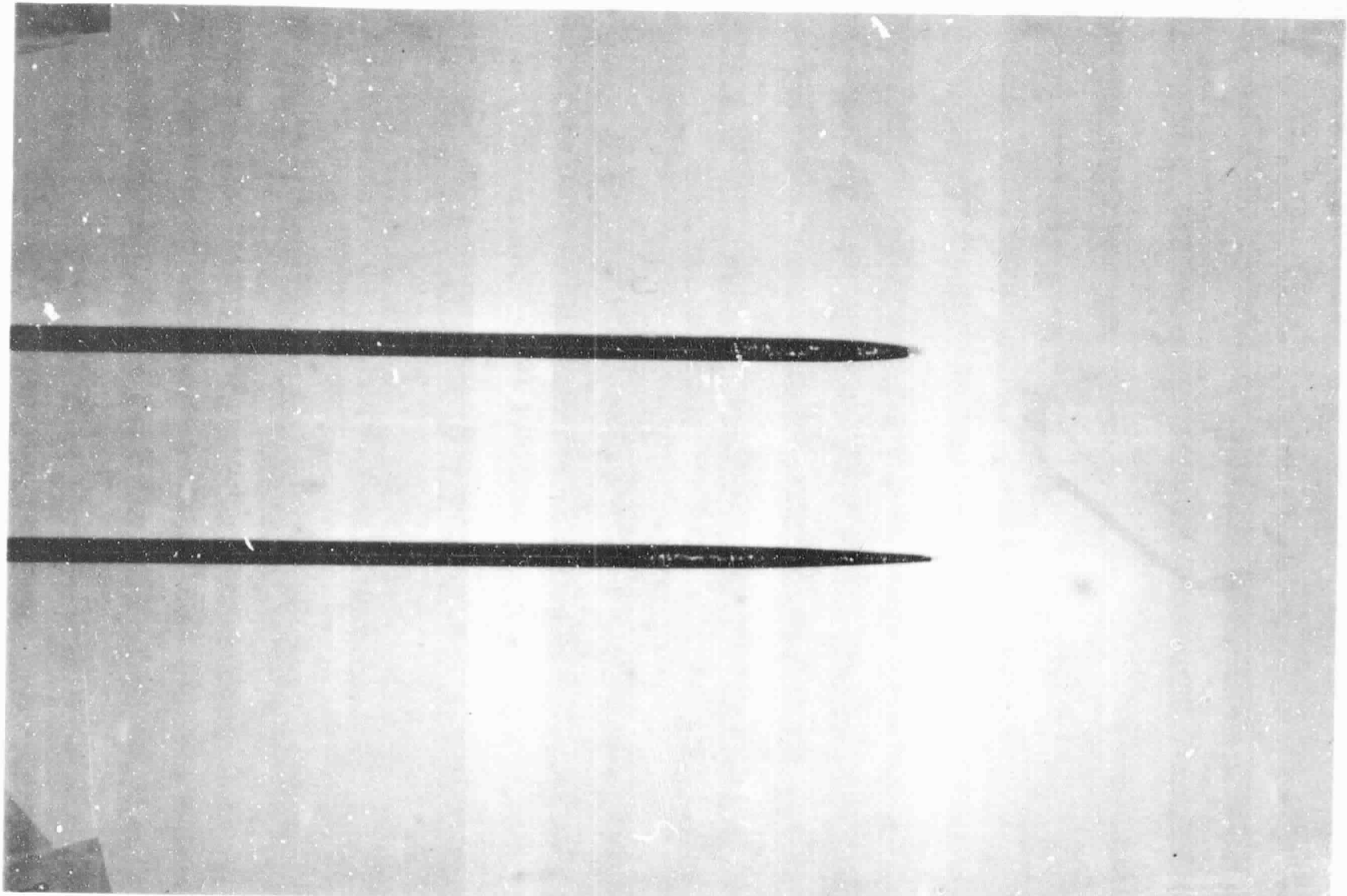


Figure 8. Electrode configuration.

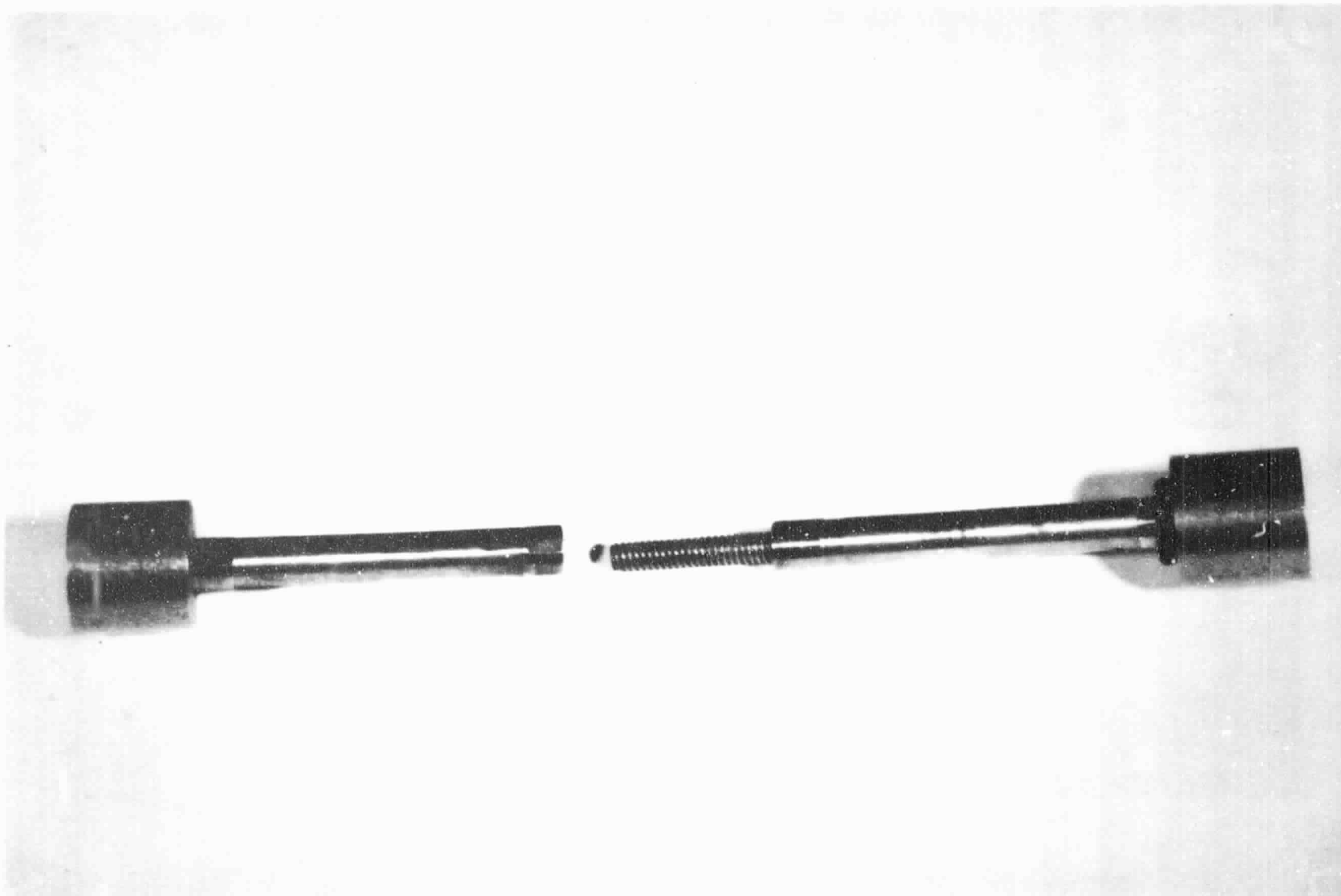


Figure 9. Weld fixture.

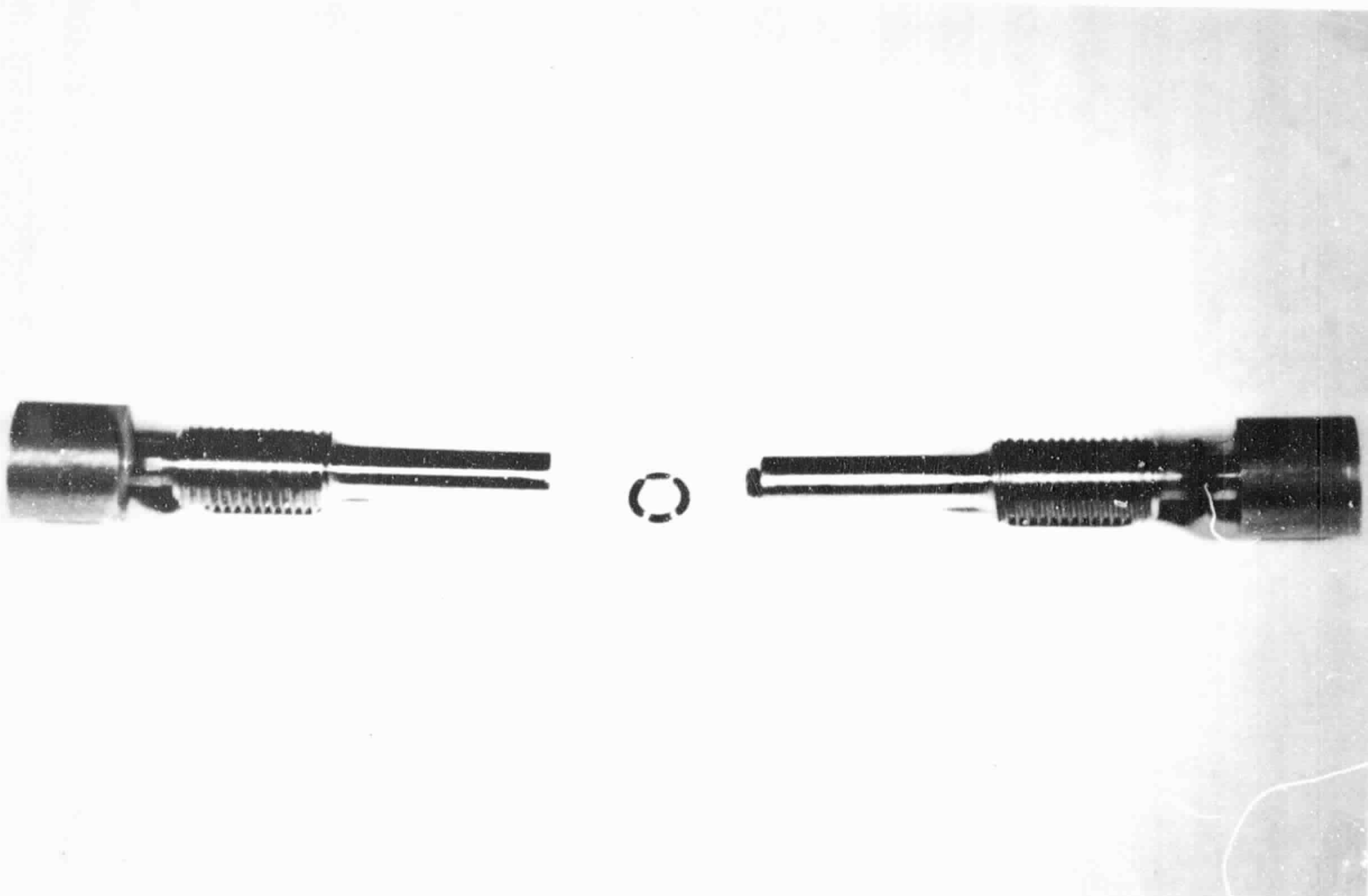


Figure 10. Fixture-tube assembly 1.

Figure 11. Fixture-tube assembly 2.

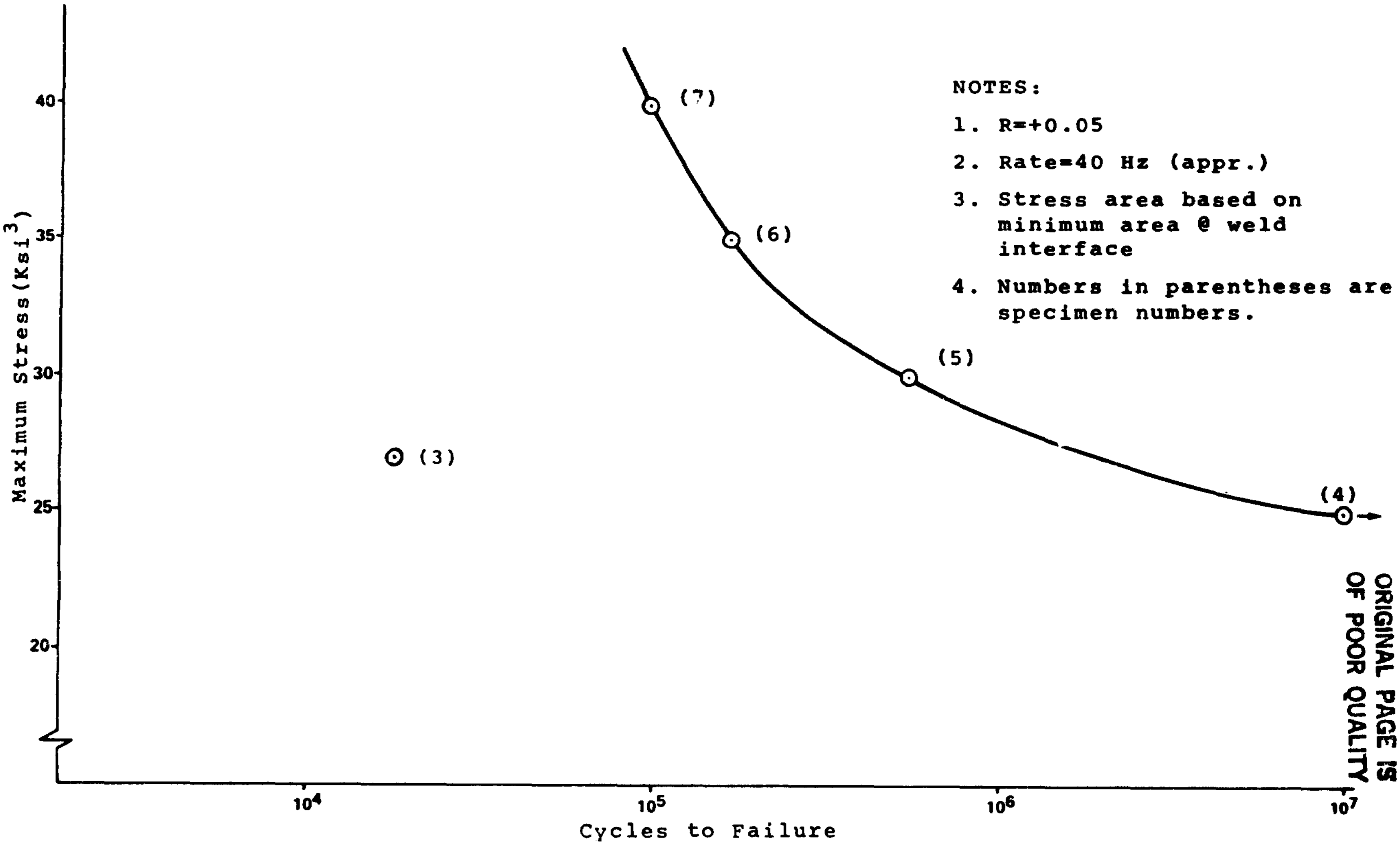


Figure 12. S-N data: HEX specimens.

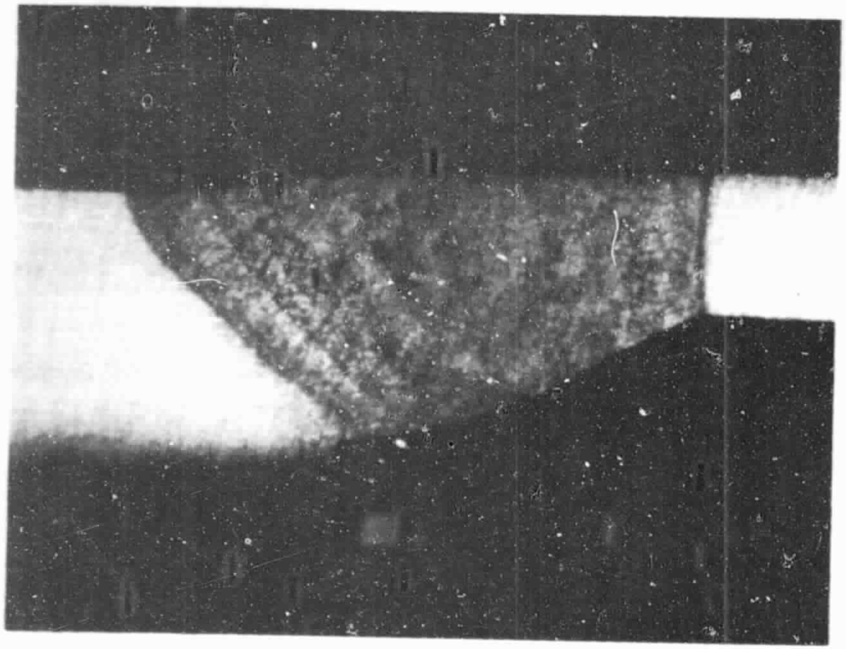
SPECIMEN NUMBER	RADIOGRAPHY DEFECTS	TEST TYPE/ RESULTS
1	Ream damage to both parent materials.	Tensile /83.1 KSI
2	Small lack of penetration, Ream damage to both parent materials.	Tensile/84.8 KSI
3	Large lack of penetration	Fatigue/4.3 x 10^4 cycles @ 27.5 KSI
4	Restricted metal flow	Fatigue/1.0 x 10^7 cycles @ 25 KSI (ran out)
5	Ream damage in both parent materials, Small lack of penetration.	Fatigue/4.4 x 10^5 cycles @ 30 KSI
6	Badly restricted metal flow.	Fatigue/1.6 x 10^5 cycles @ 35 KSI
7	No evident problems	Fatigue/9.5 x 10^4 cycles @ 40 KSI

Figure 13. HEX weld specimen test summary.

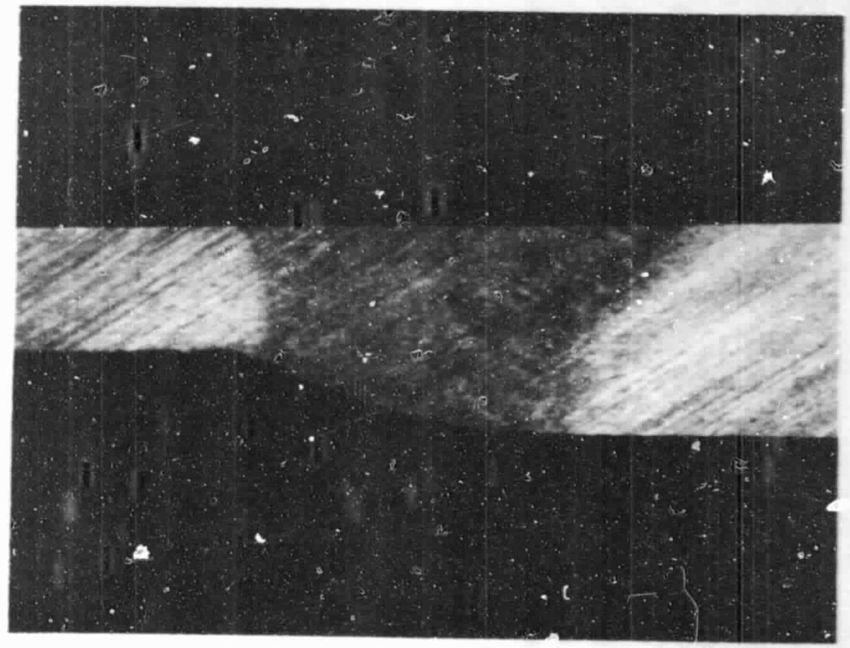
	TESTS			
SPECIMEN NUMBER & CONFIGURATION	RADIOGRAPHY	DYE PENETRANT	MACRO (% PENETRATION)	ULTIMATE STRENGTH
#1A: Bridge Groove	OK	OK	50%	80.5 Ksi
#1B: Good Weld	OK	2 Small Pores	100%	147.3 Ksi
#2A: Penetrate Groove Only	LOP	OK	30%	98.7 Ksi
#2B: Bridge Groove	LOP	OK	40%	92.9 Ksi
#3: Bridge Groove	Porosity, LOP	8 Pores	12% (30%)*	71.9 Ksi
#4: Good Weld	1 Inclusion	OK	100%	147.1 Ksi
#5: Good Weld	Suspect LOP	OK	100%	144.1 Ksi
#6: Penetrate .015"	Porosity, LOP	OK	70%	88.0 Ksi
#7: Bridge Groove	Heavy LOP	1 Pore	40%	76.4 Ksi
#8: Good Weld	OK	OK	100%	137.4 Ksi

* #3: Penetration was 12% on macro, 30% on specimen fracture surface

Figure 14. Summary of weld 56 test data.

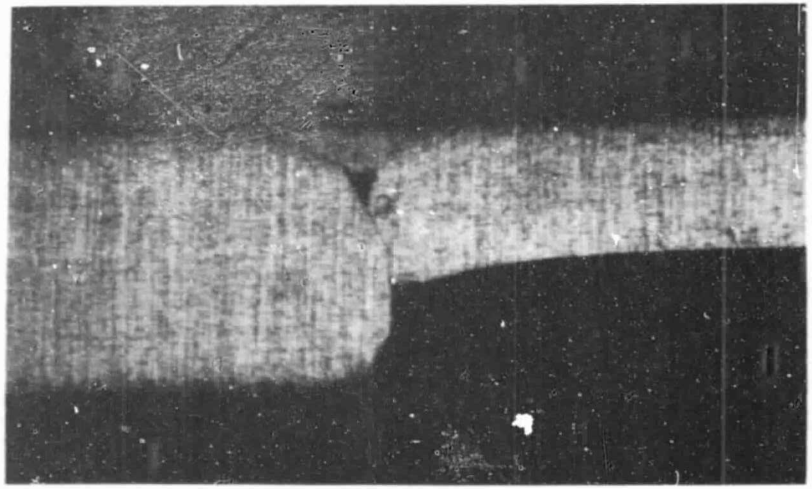


SPECIMEN #1B

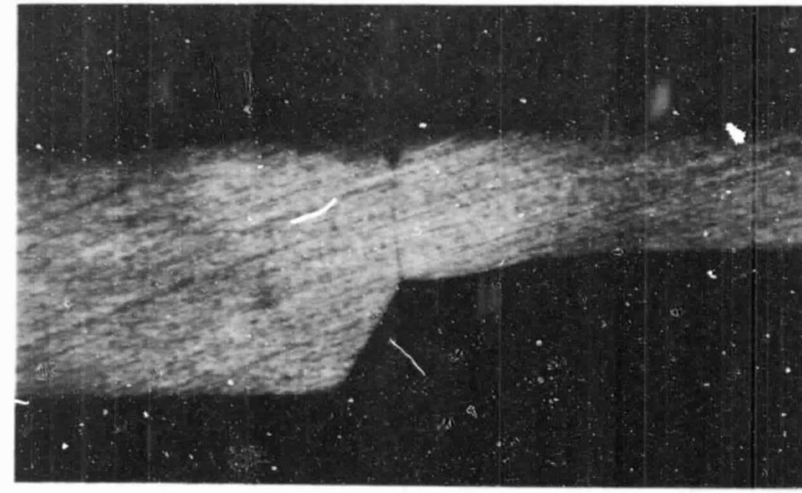


SPECIMEN #4

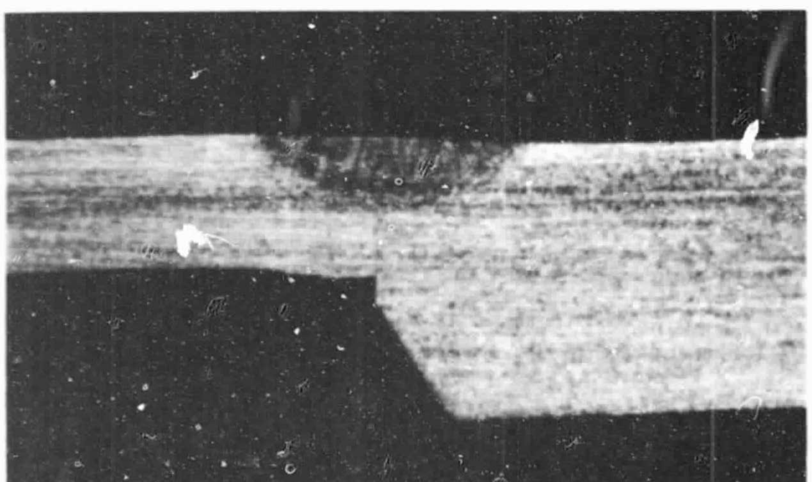
Figure 15. Radiography: weld 56.



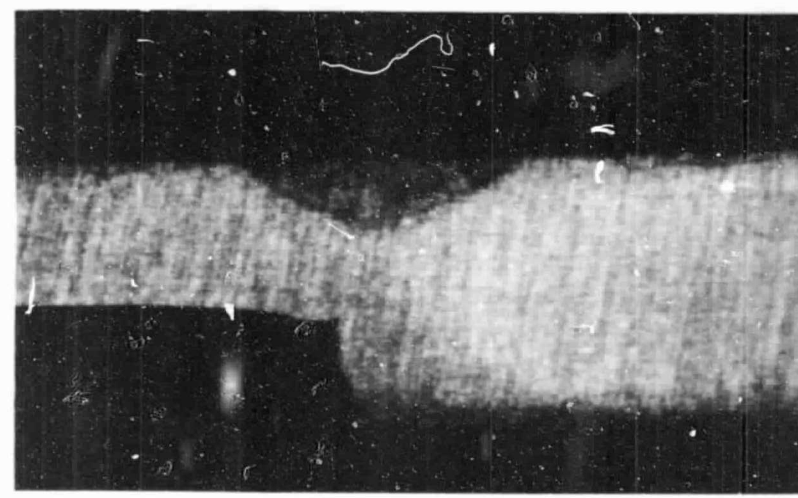
SPECIMEN #2a



SPECIMEN #3

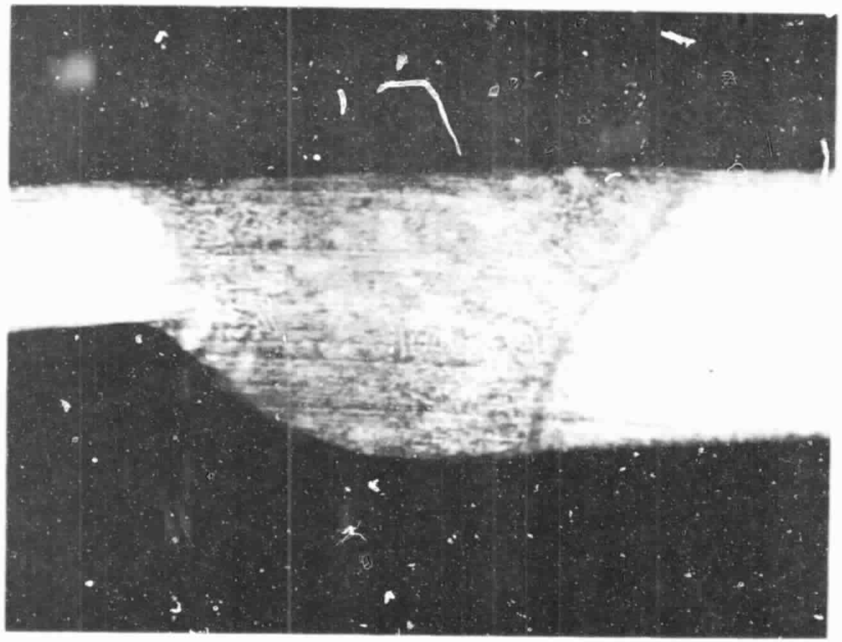


SPECIMEN #1a



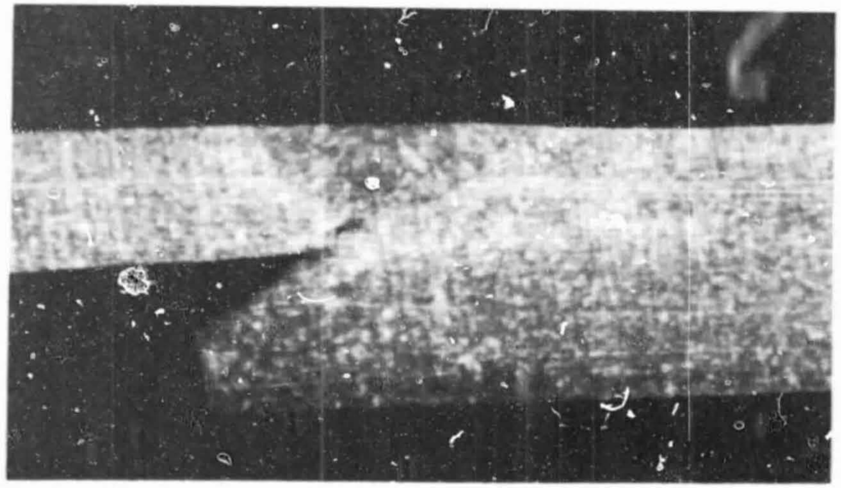
SPECIMEN #2b

Figure 16. Radiography: weld 56.

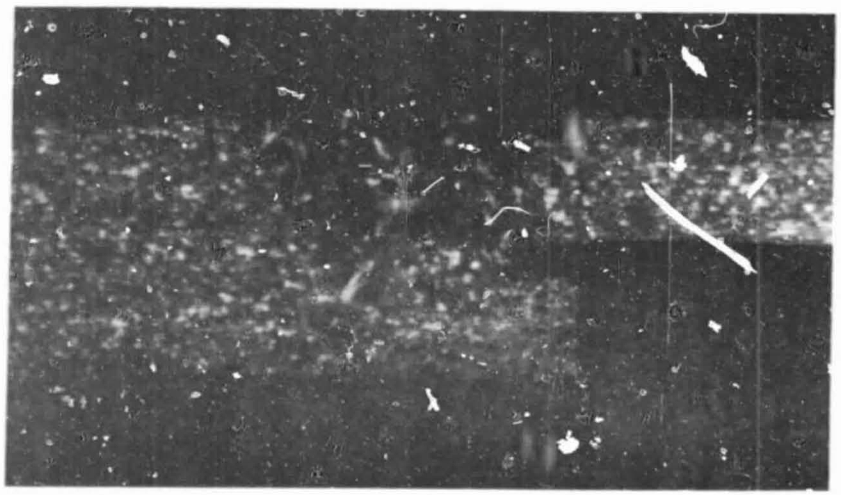


SPECIMEN #10

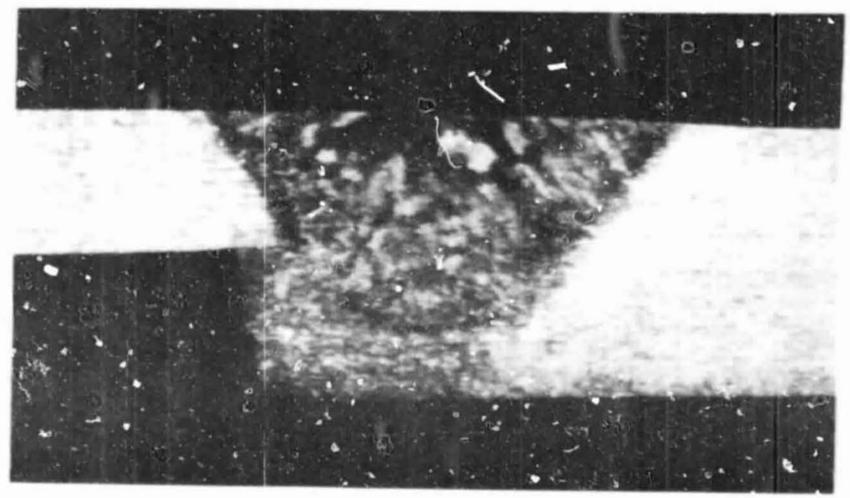
Figure 17. Radiography: weld 56.



SPECIMEN #11



SPECIMEN #12



SPECIMEN #13

Figure 18. Radiography: weld 56.

APPROVAL

IN-HOUSE WELDING STUDIES SUPPORTING THE PRELAUNCH ASSESSMENT OF THE STS-6 MAIN ENGINES

By Lisa L. Hawkins

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

ROBERT J. SCHWINGHAMER
Director, Materials and Processes Laboratory

☆U.S. GOVERNMENT PRINTING OFFICE 1983 –746-070/70