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Part 14

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IRON - ALUMINUM ALLOY SYSTEMS

PART 14 WELDING OF IRON–ALUMINUM ALLOYS

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FOREWORD

This report was prepared by the Welding Development Department, Manufacturing Research Office, Ford Motor Company, Dearborn, Michigan, under U.S.A.F. Contract Number AF-33(600)-32448, which was initiated under AMC Project Number 7-564, "Ford R and D Program," and WADC Project Number 7351 "Metallic Materials," Task Number 73512, "High Temperature Alloys." This contract was administered jointly by the Manufacturing Methods Branch (MCPBM), Industrial Resource Division, Air Materiel Command, with Mr. A. H. Langenheim acting as Project Monitor, and by the Materials Laboratory, Directorate of Laboratories, Wright Air Development Center, with Mr. Charles B. Hartley acting as project engineer.

This final report covers work performed from October 1958 through January 1959, and is a portion of the work scheduled by the contract under Item 4, Iron-Aluminum Alloy Systems. Summaries of previous progress reports are also contained herein.

ABSTRACT

During the period from October 1, 1958 to January 31, 1959, investigations were continued to develop fusion welding procedures for iron-aluminum alloys. Fabrication of a furnace hearth and a heat-treatment box made from iron-aluminum alloys was completed and they were submitted for service. The manufacturing and fusion welding processes used for these applications are described herein.

A J-57 Turbine Exhaust Cone of iron-aluminum alloy that was submitted for testing was returned to the Welding Development Department. This cone was damaged during endurance testing. Metallographic examination and mechanical testing were conducted on material from the damaged cone.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Richard R Kennedy

RICHARD R. KENNEDY
Chief, Metals Branch
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I. INTRODUCTION

Investigations covered during this report period included fabrication of two iron-aluminum assemblies and evaluation of a damaged J-57 Turbine Exhaust Cone. Research was directed toward expanding data for the fusion welding process.

Fusion welds were made by the manual shielded metal arc and tungsten electrode gas shielded arc welding processes on Heats A-13361 and KA-1053. Radiographic studies of weld samples from Heat A-13361 indicated that crack-free welds were made on small unrestrained samples without preheat or postheat treatment.

The J-57 Turbine Exhaust Cone was returned from the Ford Aircraft Engine Division at Chicago where it had been on endurance tests in a J-57 engine. An accumulation of 137 hours and 17 minutes of operation were completed before it was damaged. An engine component part became loose and hit the cone.

A summary of previous welding investigations on iron-aluminum alloys is contained within this report.

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II. FUSION WELDING

A. Equipment

A Harnischefeger AC-DC power source provided the current for both the manual shielded metal arc and tungsten electrode gas shielded arc welding. A manual tungsten electrode gas shielded arc welding torch was used. The arc shielding gas was argon. A copper-backed hold-down fixture was necessary to insure against warpage of the weld specimen. Current readings were made by means of a clamp-on ammeter.

B. Material

Fusion welding investigations were conducted on iron-aluminum alloys from heats A-13361 and KA-1053. Filler wire of .060" diameter from heat A-13361 was used with the tungsten electrode gas shielded arc process. Coated electrodes of 99.7% nickel and types E308, E309 and E310 stainless steels were used with the manual shielded metal arc welding process.

The iron-aluminum alloys for the entire welding investigation since April 1956 were procured from Universal Cyclops Steel Corporation. All heats were vacuum melted except E-1005, E-1006, and A-13361 which were air melted. The iron-aluminum materials had the following identifications and analyses:

HEAT NUMBER	ANALYSES							
	Al	C	Ti	Si	Mn	Cr	Ni	Fe
UC-1	10.4	.01	---	---	---	---	---	Balance
UC-2	10.5	.06	.45	---	---	---	---	Balance
UC-3	7.6	.04	1.12	---	---	---	---	Balance
KA-567*	7.6	.04	1.12	---	---	---	---	Balance
KA-568*	10.5	.06	.45	---	---	---	---	Balance
KA-569*	7.43	.04	.83	---	Trace	---	---	Balance
KA-570*	8.69	.035	.86	---	Trace	---	---	Balance
KA-571	10.52	.038	.81	---	---	---	---	Balance
KA-1053*	10.66	.03	.53	---	---	---	---	Balance
KA-1054*	10.66	.025	.52	---	---	---	---	Balance
KA-1085*	10.25	.015	.50	.05	---	---	---	Balance
E-1005*	6.93	.045	.70	.66	.50	---	---	Balance
E-1006*	6.08	.06	.82	.40	.54	3.0	.12	Balance
A-13361*	5.45	.05	.46	.23	.50	.06	.04	Balance

* Analyses from Ford Laboratories

C. Cleaning

There were no further attempts made to study the effects of cleaning for fusion welding. Iron-aluminum air-melted heat A-13361 was received with a very light surface oxide and did not necessitate cleaning prior to fusion welding. Cleaning of KA-1053 heat was accomplished by light grinding of the weld joint area.

D. Welding

A limited amount of work indicated that the cracking difficulties encountered during previous investigations on welding of iron-aluminum alloys were considerably lessened by the greater ductility of the A-13361 material. This heat of alloy contained only 5.4% aluminum as compared to the previous heats which ranged up to 10.66% aluminum.

The manual tungsten electrode gas-shielded arc welding process was employed for welding small samples with square butt joints on .093" and .031" thick A-13361 base metal using the following conditions:

Filler Wire - 1/16" diameter from Heat A-13361
Electrode - 3/32" diameter 1% thoriated tungsten
Shielding Gas - 8 cfh Argon
Backing - Copper
Preheat - None
Postheat - None
Current - 45 amperes DC sp for .093" stock
- 35 amperes DC sp for .031" stock

Figure 1 shows radiographs of three crack-free welds in the .093" stock and Figure 2 shows two similar welds on .031" material.

The manual shielded metal arc welding process was used for the welding of .125" and thicker materials. Combinations of .125" stock from heats KA-1053 (10.66% aluminum) and A-13361 were welded with coated electrodes of 99.7% nickel and types E308, E309 and E310 stainless steels. In all cases cracks opened in the KA-1053 material which extended into the weld bead but did not crack the A-13361 material.

With the same coated electrodes listed, crack free welds were made on 6" long test samples containing double "V" joints in .375", .500" and .625" thick A-13361 material. These were accomplished without preheat or postheat. The most ductile appearing joints were obtained in the samples welded with the nickel electrode. For this reason, the nickel electrode was used in the construction of the Furnace Hearth and Heat-Treat Box which are described in the "Applications of Iron-Aluminum Alloys" section of this report.

E. Testing

Most of the test data obtained during this reporting period was obtained in conjunction with the investigation on the turbine exhaust cone which was damaged during engine test. It is contained in the Applications Section of this report.

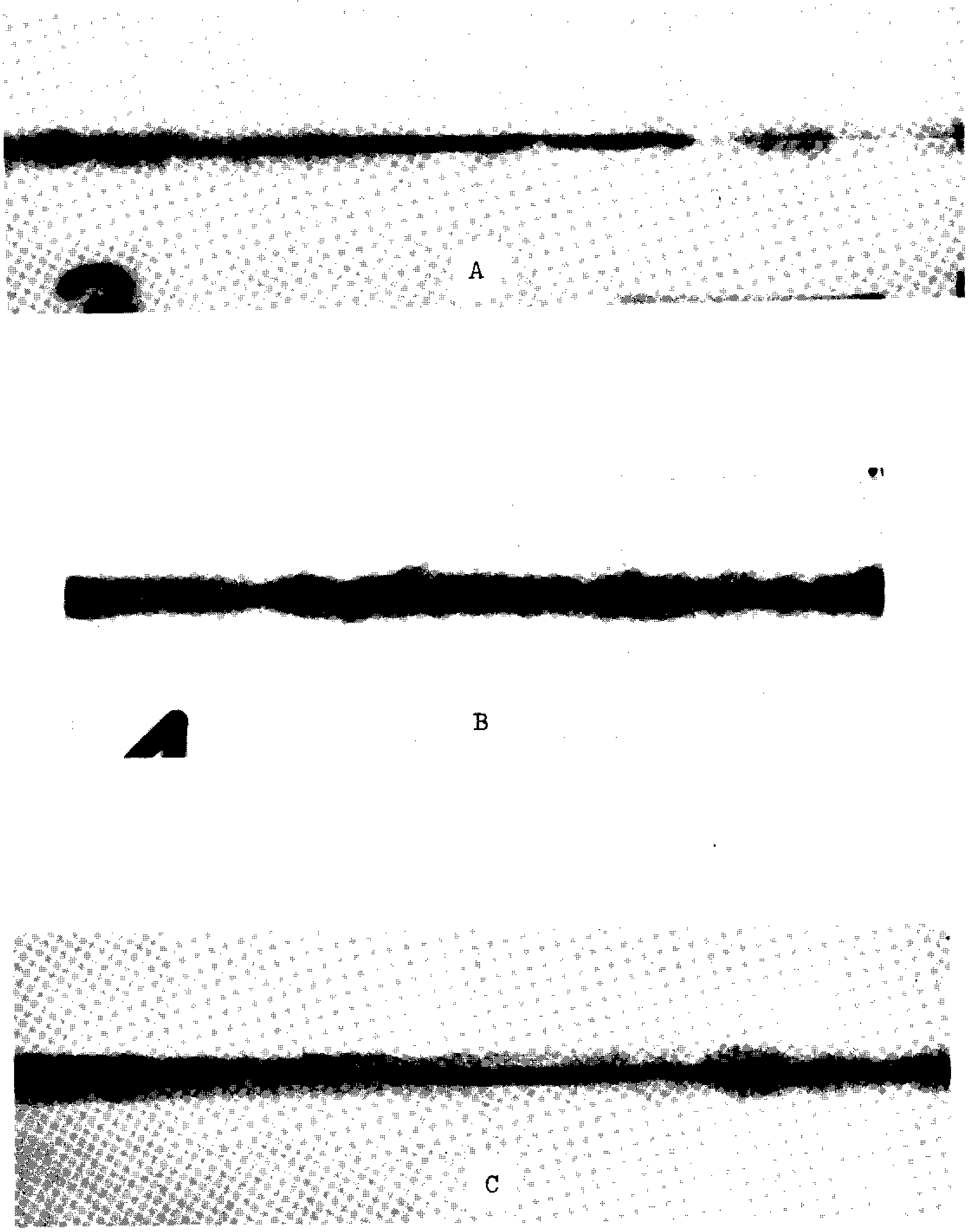

Figure 1 - Radiographs of Manual Tungsten Arc Welds on Iron-Aluminum Heat A-13361, .093" Thick.

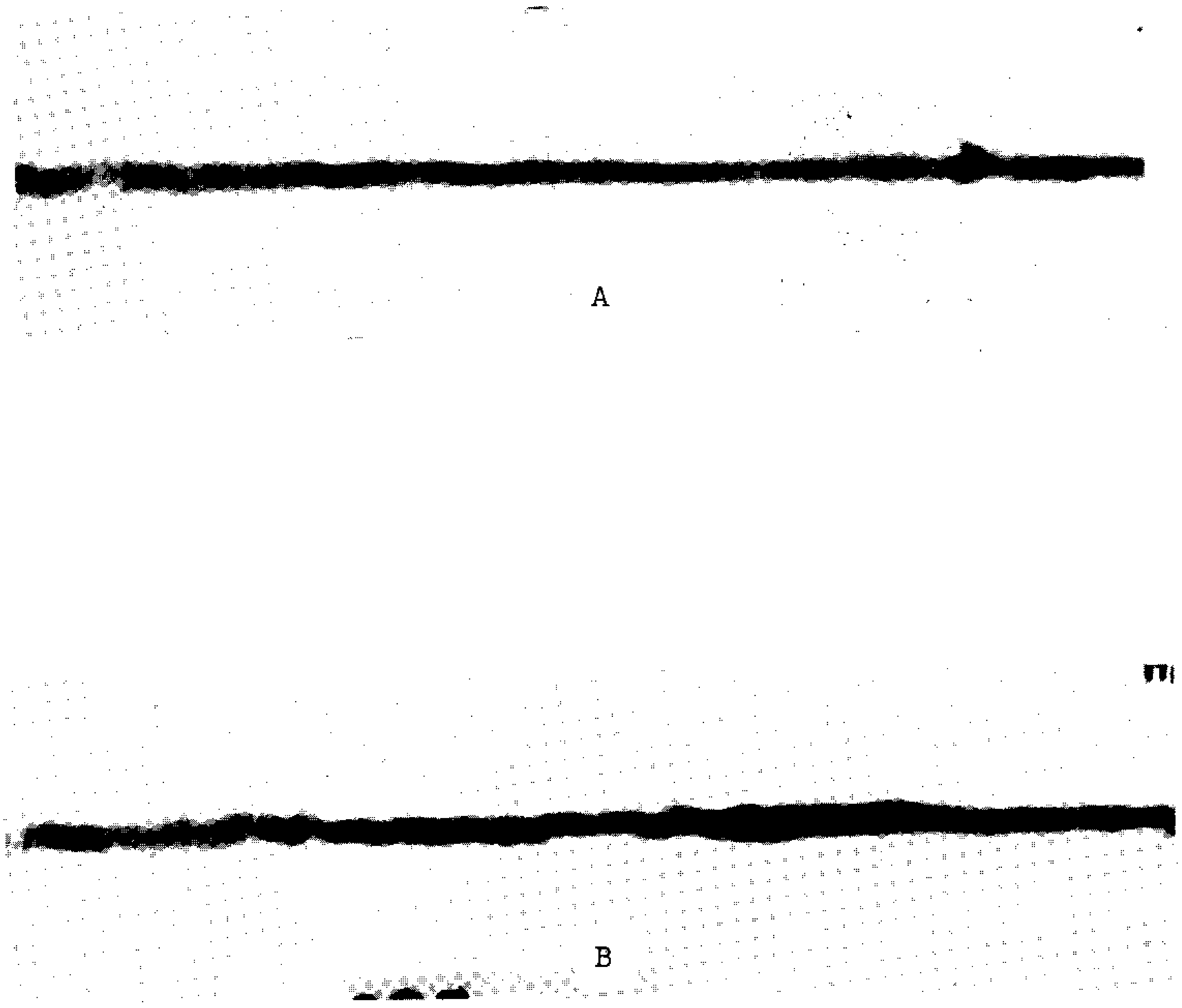

Figure 2 - Radiographs of Manual Tungsten Arc Welds on Iron-Aluminum Heat A-13361, .031" Thick.

The following room temperature tensile data was obtained from reduced section tensile samples machined from .125" thick A-13361 iron-aluminum material and tested in the "as received" condition.

Sample	Ultimate Tensile Strength, psi	Yield Strength, psi	Elongation %
1	79,300	61,100	25
2	77,700	57,600	25
3	78,300	59,600	28
4	78,500	59,400	26

F. Summary and Conclusions

Iron-aluminum from air melted Heat A-13361, supplied by the Universal Cyclops Steel Corporation, contained 5.4% aluminum. It was covered with a very light surface oxide and did not require cleaning prior to fusion welding.

Crack-free welds were produced by both the manual tungsten electrode gas shielded arc welding and the manual shielded metal arc welding processes without use of preheat or postheat.

Tensile data obtained for Heat A-13361 in the "as received" condition showed more ductility and elongation than material from previous heats.

III. APPLICATION OF IRON-ALUMINUM ALLOYS

A. Furnace Hearth

A furnace hearth employing iron-aluminum alloy material from Heat A-13361 was made and placed into service at the Tool and Die Heat-Treat Department. The assembled furnace hearth shown in Figure 3 was fabricated from .625" thick stock. Its dimensions were 2" deep x 19" wide x 38-3/4" long. The end and two side detail parts were attached to the bottom plate and to each other by welding. It was placed into service November 10, 1958 in an electric furnace operating at a maximum temperature of 1700°F.

The welding was done by the manual shielded metal arc welding process using 5/32" diameter 99.7% nickel electrodes. A current of 140 amperes was used and although no preheat nor postheat was required for crack-free welding of simulated test samples both were specified in this application. Due to the size of the furnace hearth and the required clamping pressure necessary to obtain good joint alignment, a preheat of 450°F was applied prior to welding. A postheat operation of 1200°F for 30 minutes followed by air cooling was employed to relieve internal stresses caused by clamping and welding. Radiographic examination of the furnace hearth, prior to entering service, did not reveal any cracks. No visible deterioration was observed after three months operation.

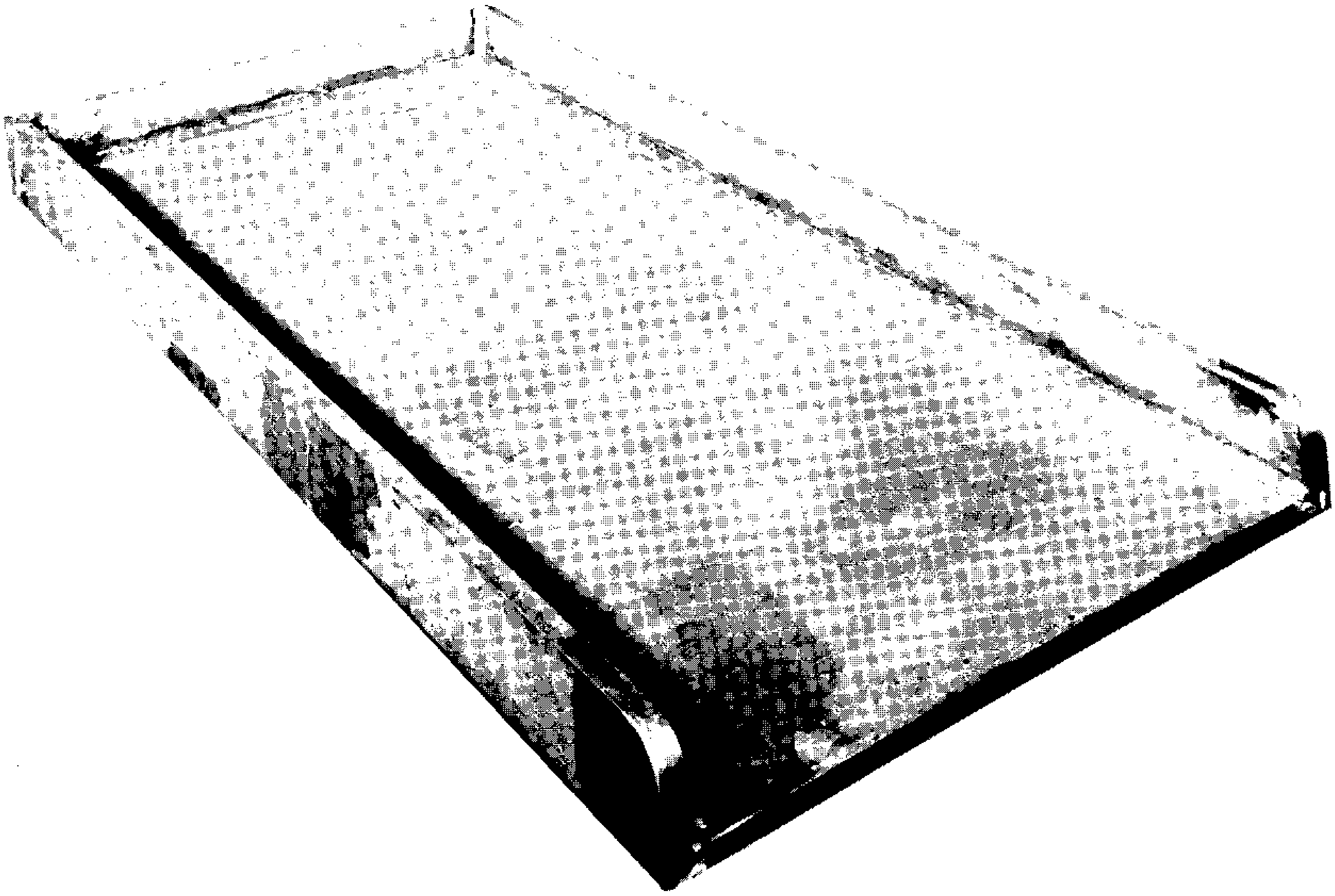

Figure 3 - Welded Furnace Hearth Fabricated from Iron-Aluminum, Heat A-13361, .625" Thick

B. Heat-Treat Box

A heat-treat box and cover made from .25" thick iron-aluminum alloy heat A-13361 was also placed in service at the Tool and Die Heat-Treat Department. Figure 4 shows a photograph of the assembled box which was 10" deep x 12" wide and 34" long. At the time of this report it had been in service for only 22 hours at temperatures from 1650 to 1700°F. Additional service time must be accumulated for complete evaluation. The same nickel electrode and welding procedures which were used for the furnace hearth were employed in the welding of the heat-treat box.

C. Turbine Exhaust Cone for J-57 Engine

The fabrication method used for the J-57 Turbine Exhaust Cone Assembly, which was tested at the Ford Aircraft Engine Division in Chicago, was described in WADC Technical Report 57-298, Part 10. Figure 5 shows the cone assembly before testing.

This cone was damaged during endurance testing. The flight nozzle, which is used in engine testing to simulate flight conditions, became loose and put a large dent in the cone assembly. Visual examination of the cone before disassembly did not reveal any cracks or breaks in the metal. However, it can be assumed that internal stresses were set up when the nozzle hit the cone because, while removing the assembly from the engine, the cone shattered. Figures 6, 7 and 8 show various views of the damaged cone after an accumulation of 137 hours and 17 minutes test time.

As described in WADC Technical Report 57-298, Part 10, iron-aluminum Heat E-1005 of .055" thickness was used for the stiffner detail part while materials from Heat E-1006 of .035" and .085" thickness were used for the cone body and flange detail parts respectively. Successful spinning of all the component parts was done at 925°F. A 1200°F postheat treatment after final spinning was used for relieving internal stresses caused by localized heating and working of the cone material.

Although damage to the J-57 turbine exhaust cone was not caused by defective material, both mechanical and metallographic studies were conducted. This was done in an attempt to evaluate the effect of operating temperatures (approximately 1000°F) on iron-aluminum Heat E-1006 and to determine what had caused the extreme brittleness in the material from the cone assembly which had been subjected to engine test.

Bend test specimens, tensile test specimens, and micro-examination samples were made from .035" thick heat E-1006 iron-aluminum material which had been retained from various stages of cone fabrication and from the damaged cone which had been endurance tested. Guided bend tests were made using the fixture shown in Figure 16 of WADC Technical Report 57-298, Part 3. Conventional reduced section tensile test samples were employed.

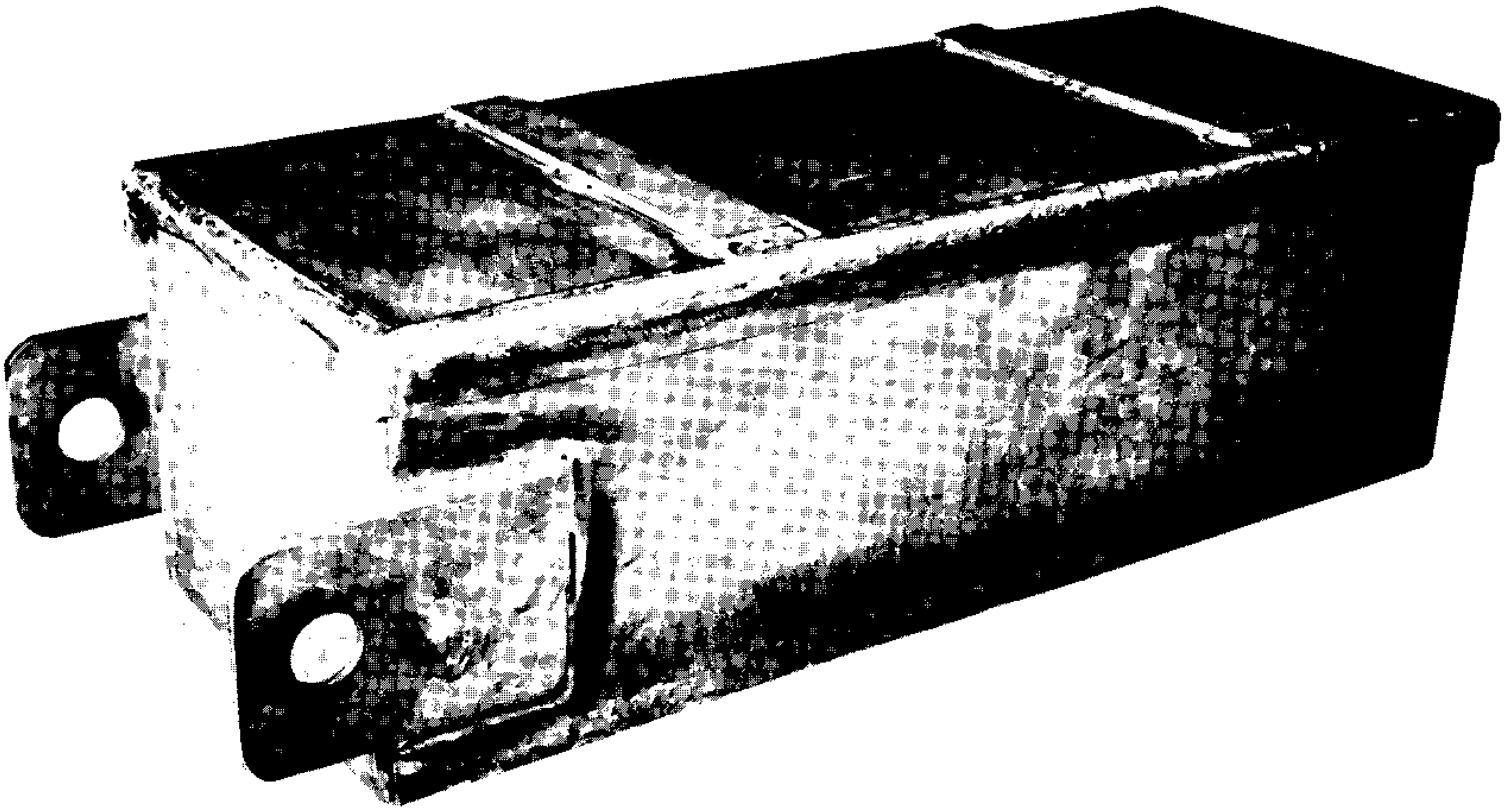

Figure 4 - Heat-Treatment - Box and Cover Fabricated from Iron-Aluminum, Heat A-13361, .250" Thick

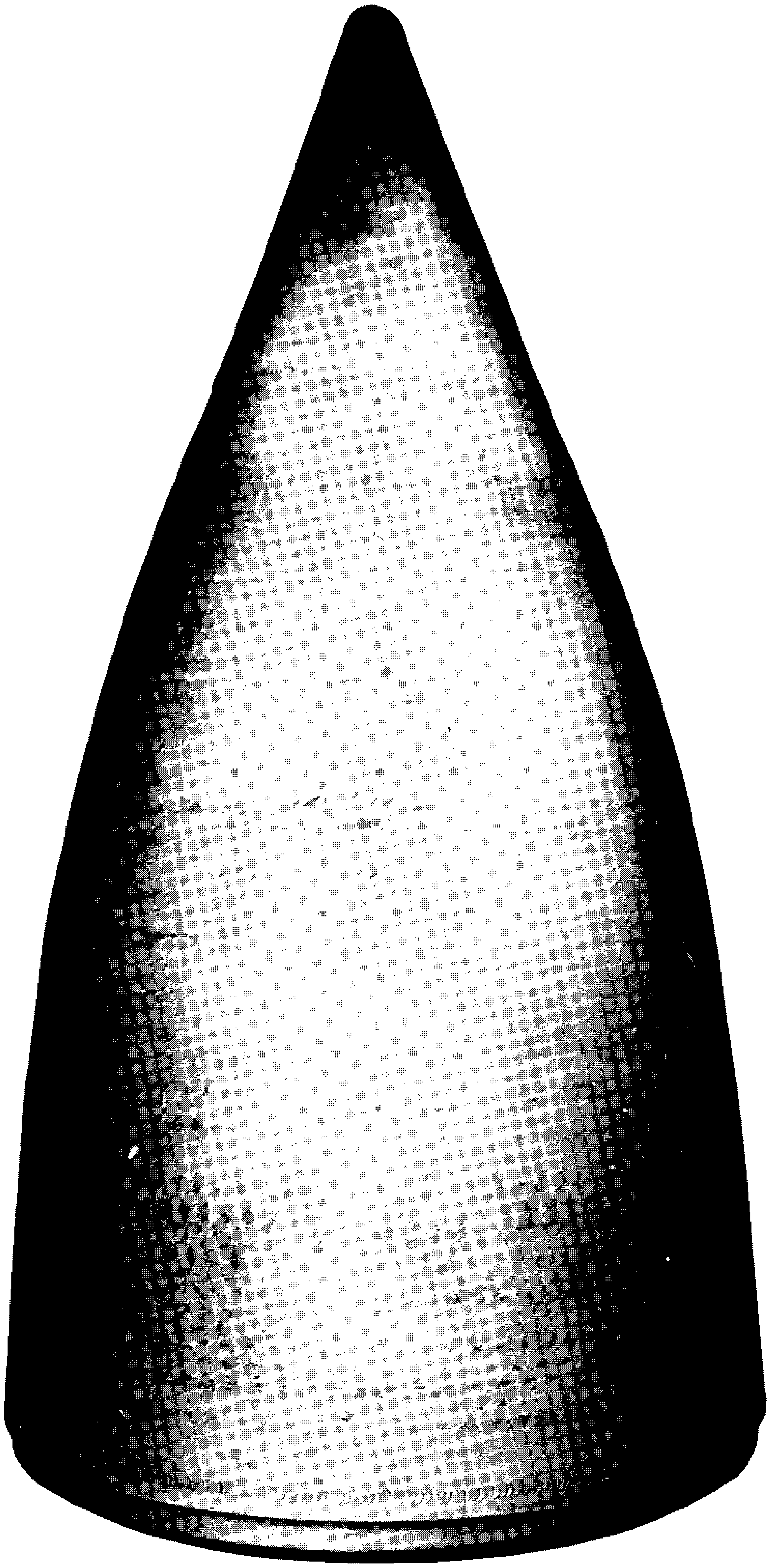

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Figure 5 - J-57 Turbine Exhaust Cone Assembly - Iron-Aluminum, Heats E-1005 and E-1006 - View Before Endurance Test

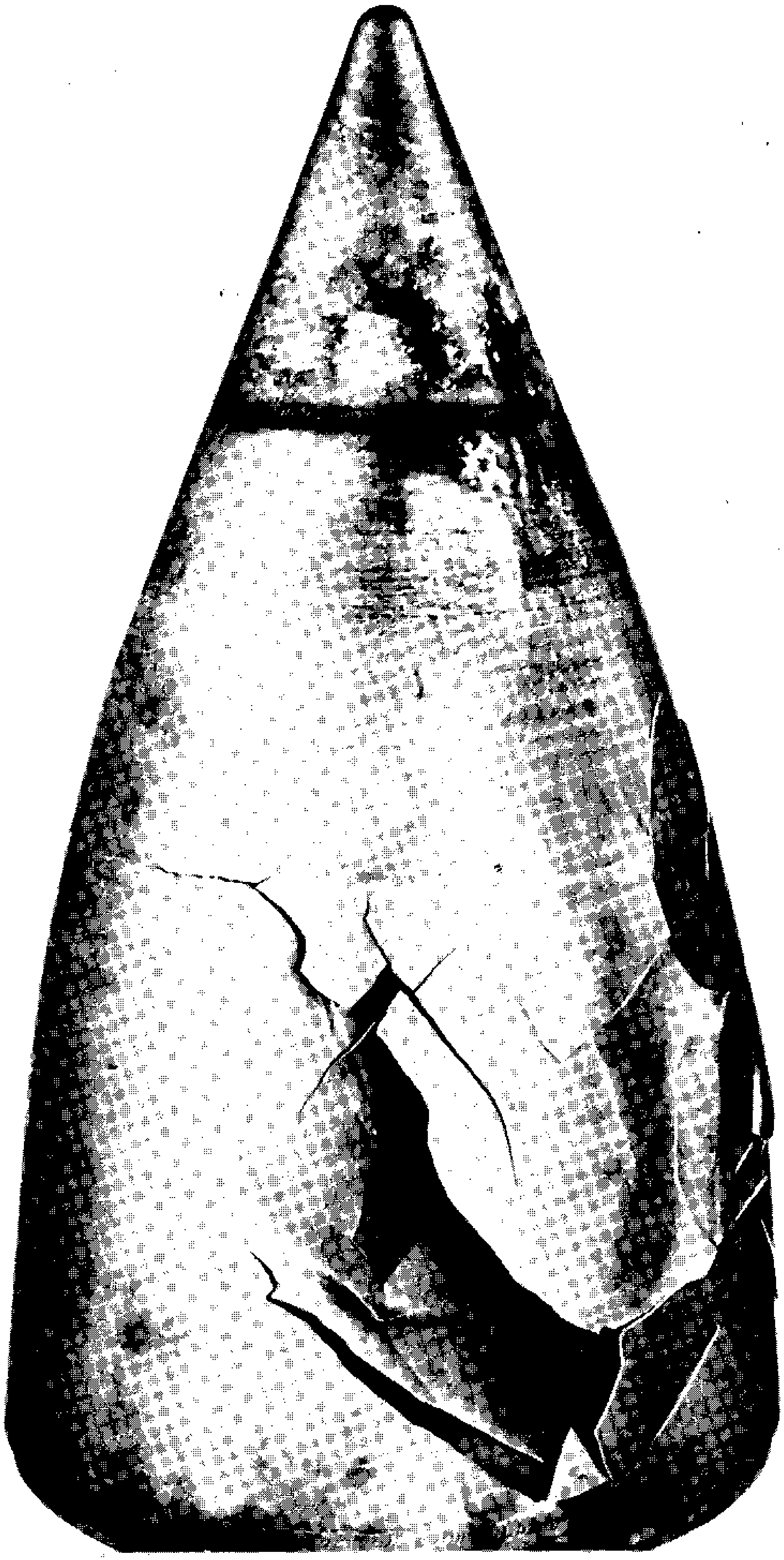

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Figure 6 - Turbine Exhaust Cone - Broken Pieces Assembled to Show Impact Area

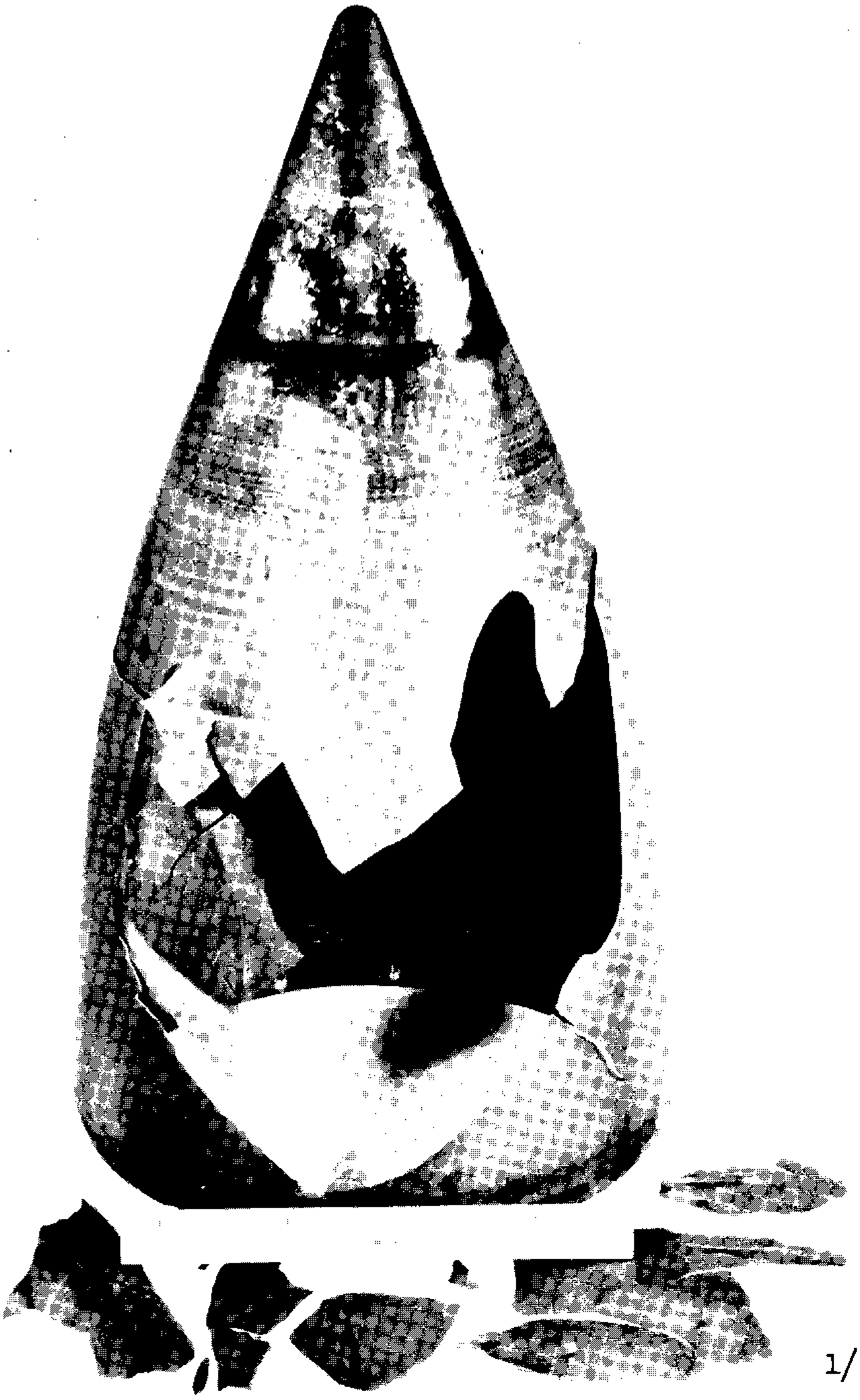

Figure 7 - Turbine Exhaust Cone -
Failure After Being Removed from Engine

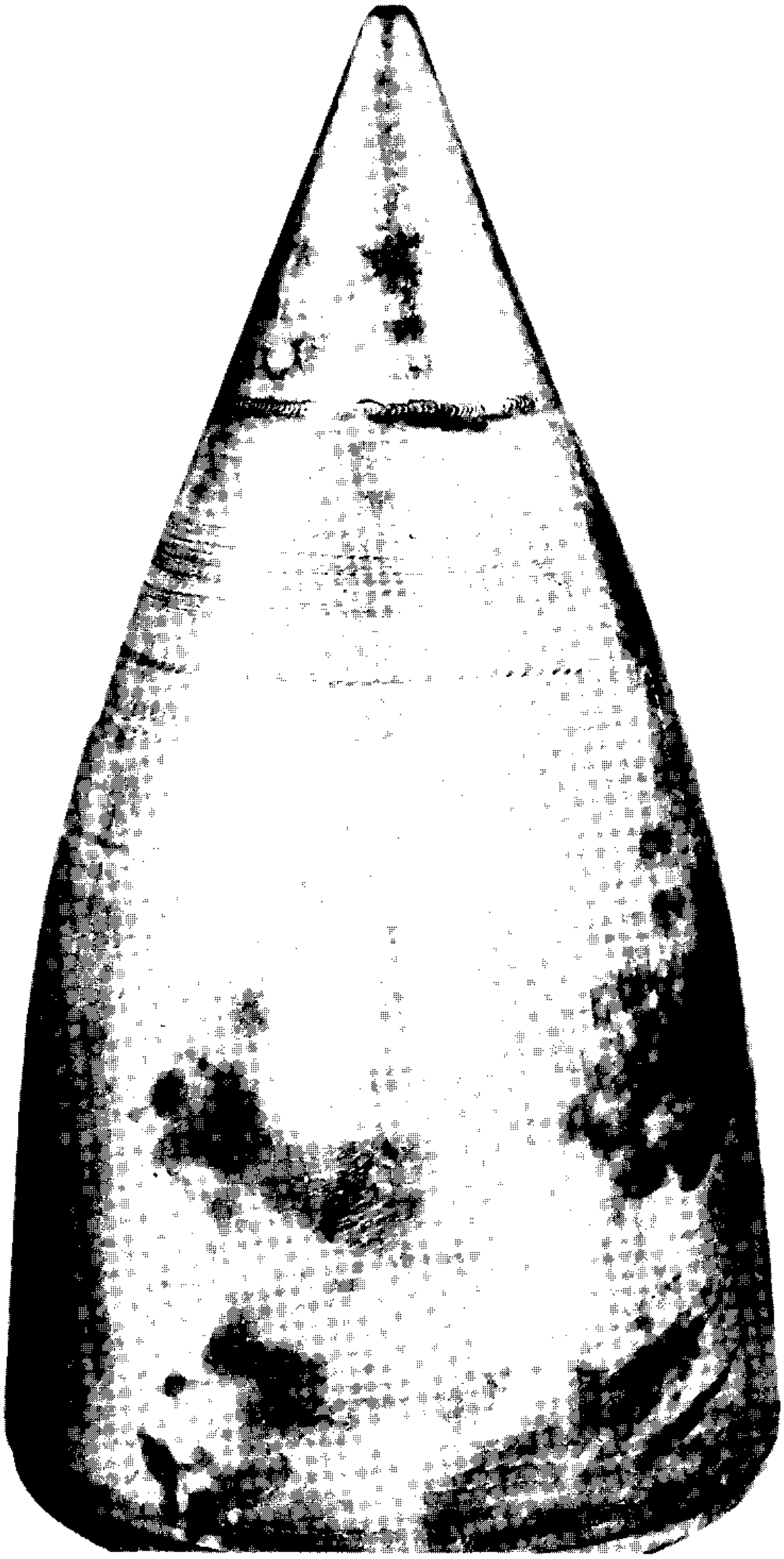

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Figure 8 - Turbine Exhaust Cone Turned 180° in Reference to Damaged Area

Photomicrographs shown in Figures 9 through 14 were prepared by the Process Development Department. Etching of all the samples was done with a mixed acid consisting of 40% glycerin, 40% hydrochloric acid and 20% nitric acid.

Figure 9 photomicrograph was taken from E-1006 "as received" material. This material formed 180° arcs at room temperature in the guided bend fixture without failure. Tensile tests at room temperature gave the following data:

Sample	Ultimate Tensile Strength, psi	Yield Strength, psi	Elongation %
1	92,600	75,300	12
2	92,800	76,100	11
3	89,500	72,100	13
4	90,100	76,500	12

Figure 10 photomicrograph was taken from E-1006 material which had been partially formed by spinning and had cracked to terminate the spinning operation. Two out of three guided bend specimens from this material formed 180° arcs. The other fractured after forming only a 27° bend.

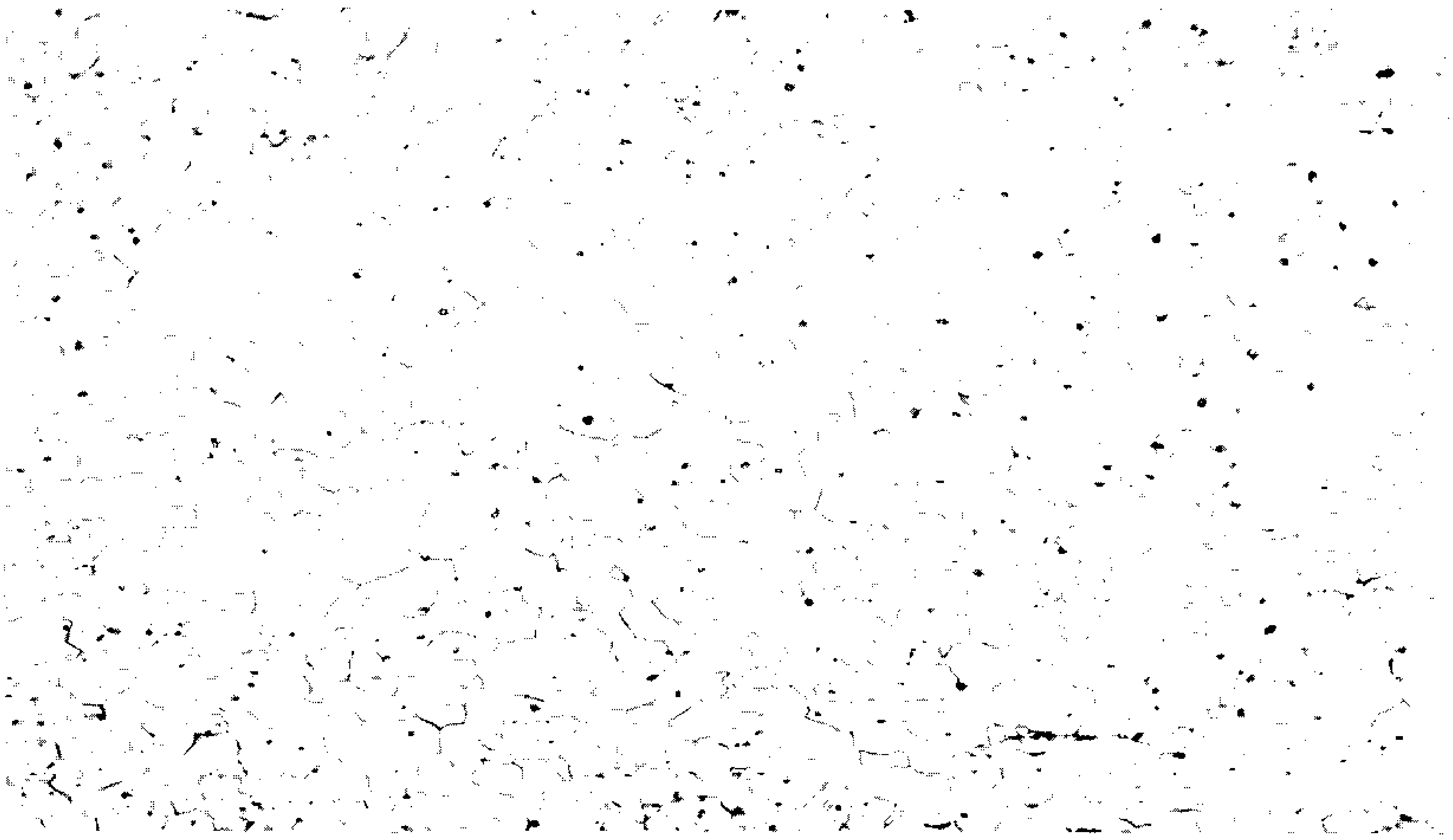
Figure 11 photomicrograph was taken from E-1006 material which had been completely formed by spinning but had not been used because of a slight dimensional discrepancy. This material formed 180° arcs without failure on the guided bend test.

Figure 12 photomicrograph was taken directly from the upper cone body of the damaged cone. This material broke under slight fixture pressure at room temperature with practically no bend on guided bend tests. However, when heated and tested at 175°F, sufficient ductility was attained to form a 180° arc.

Tensile strength test data were not obtained on samples shown in Figures 10, 11 and 12 because there was not sufficient straight materials from which to obtain suitable specimens.

Figure 13 photomicrograph was taken from the lower cone body of the damaged cone. Guided bend tests on this material produced the same results as those from the upper cone section, with zero bending at room temperature and complete 180° bends when heated to 175°F. Tensile tests at room temperature gave the following information:

Sample	Ultimate Tensile Strength, psi	Elongation %
1	145,000	0
2	66,500	0
3	110,400	0
4	49,200	0



100X

Mixed Acid Etch

Figure 9 - Photomicrograph of "As Received" Iron-Aluminum, Heat E-1006

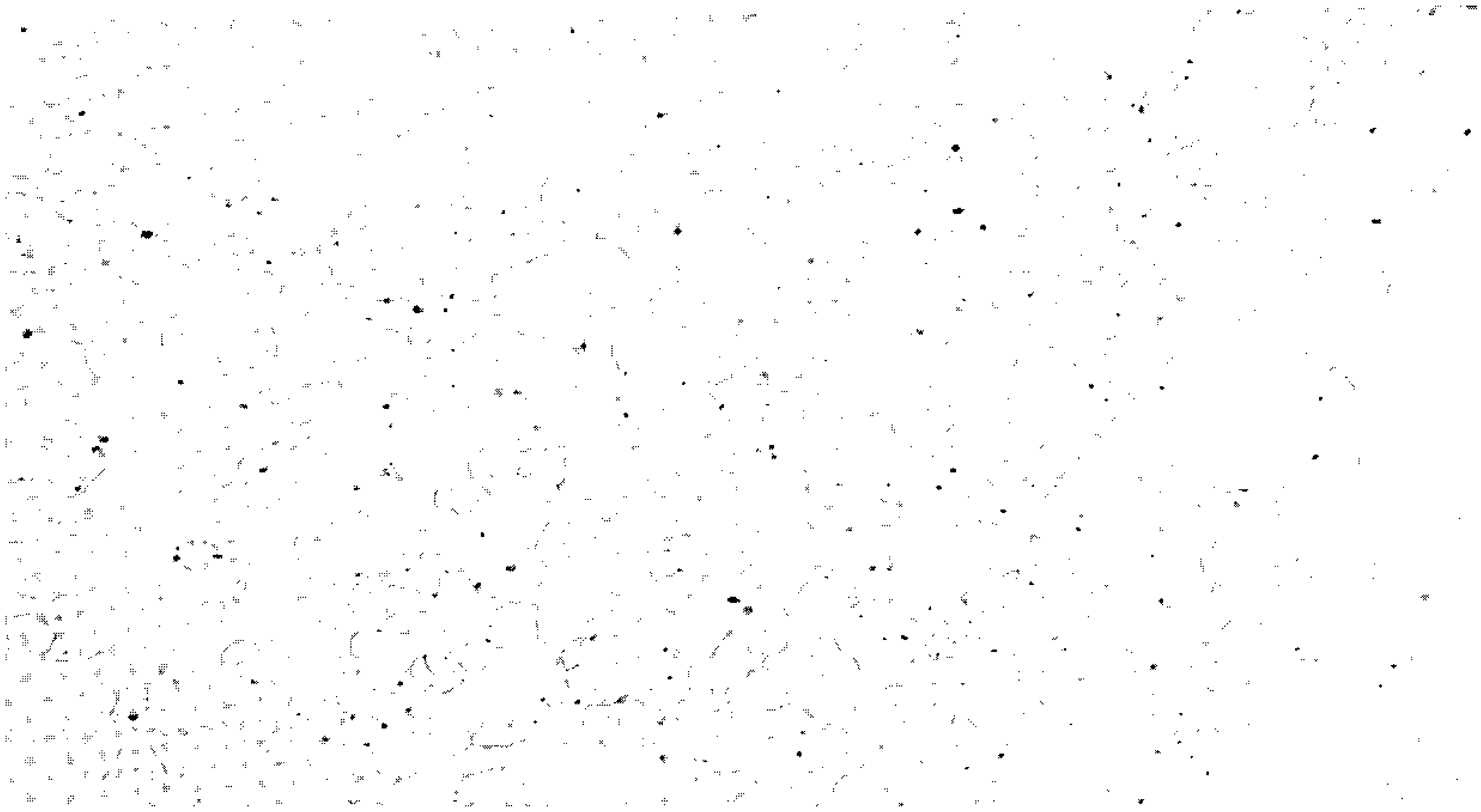


Figure 10 - Photomicrograph of Partially Formed Iron-Aluminum, Heat E-1006

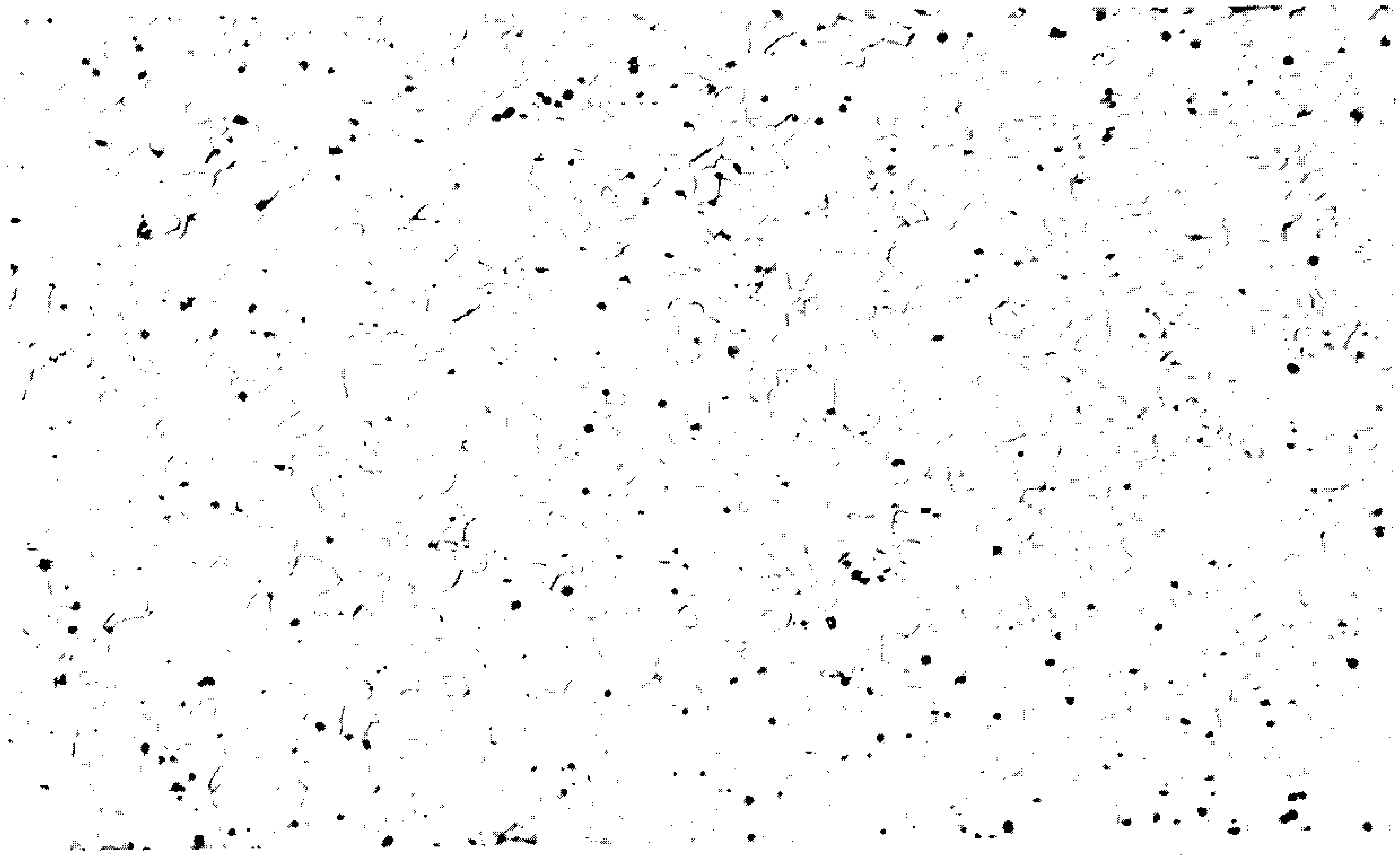


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Figure 11 - Photomicrograph of Formed Iron-Aluminum, Heat E-1006

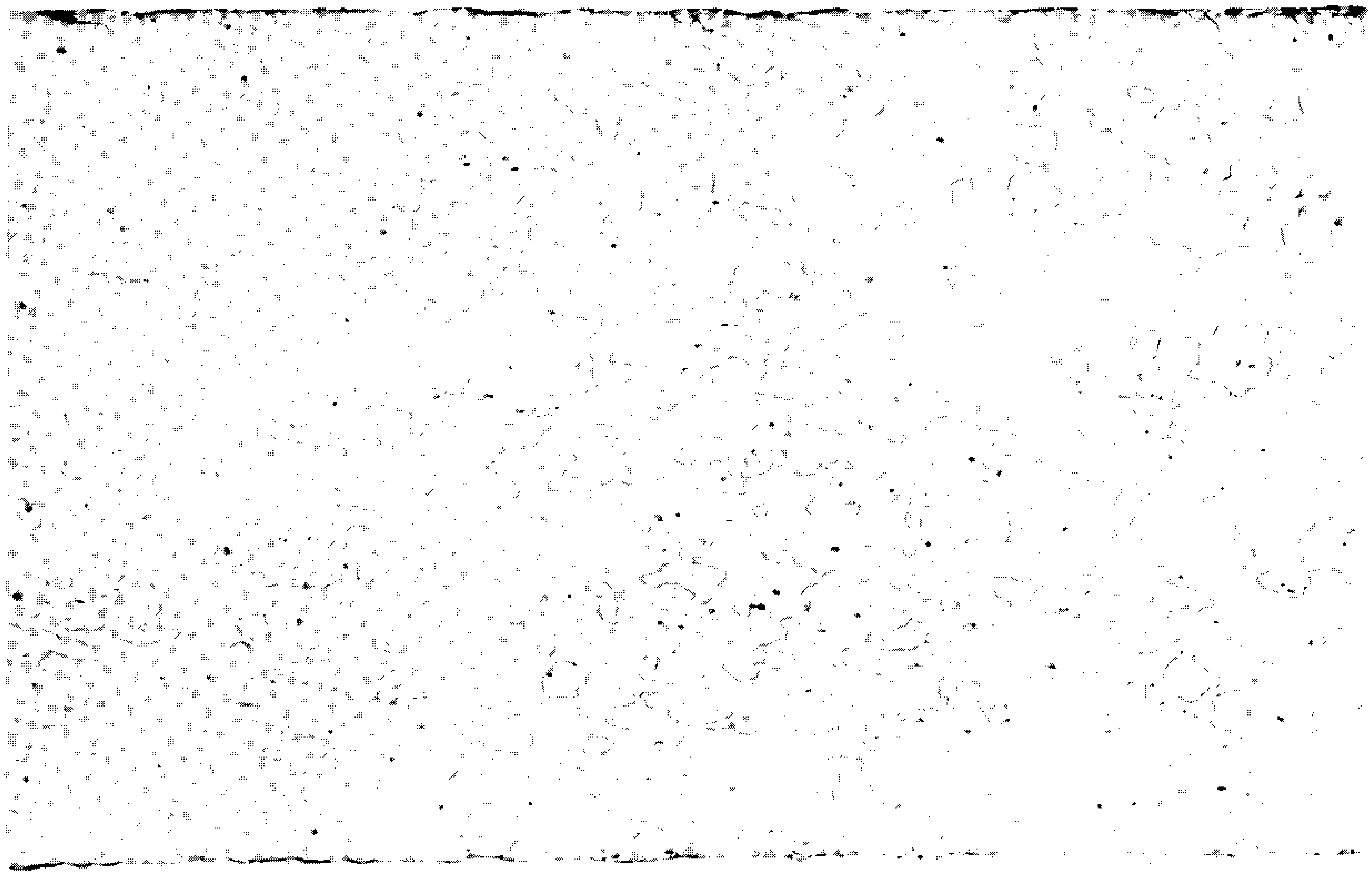

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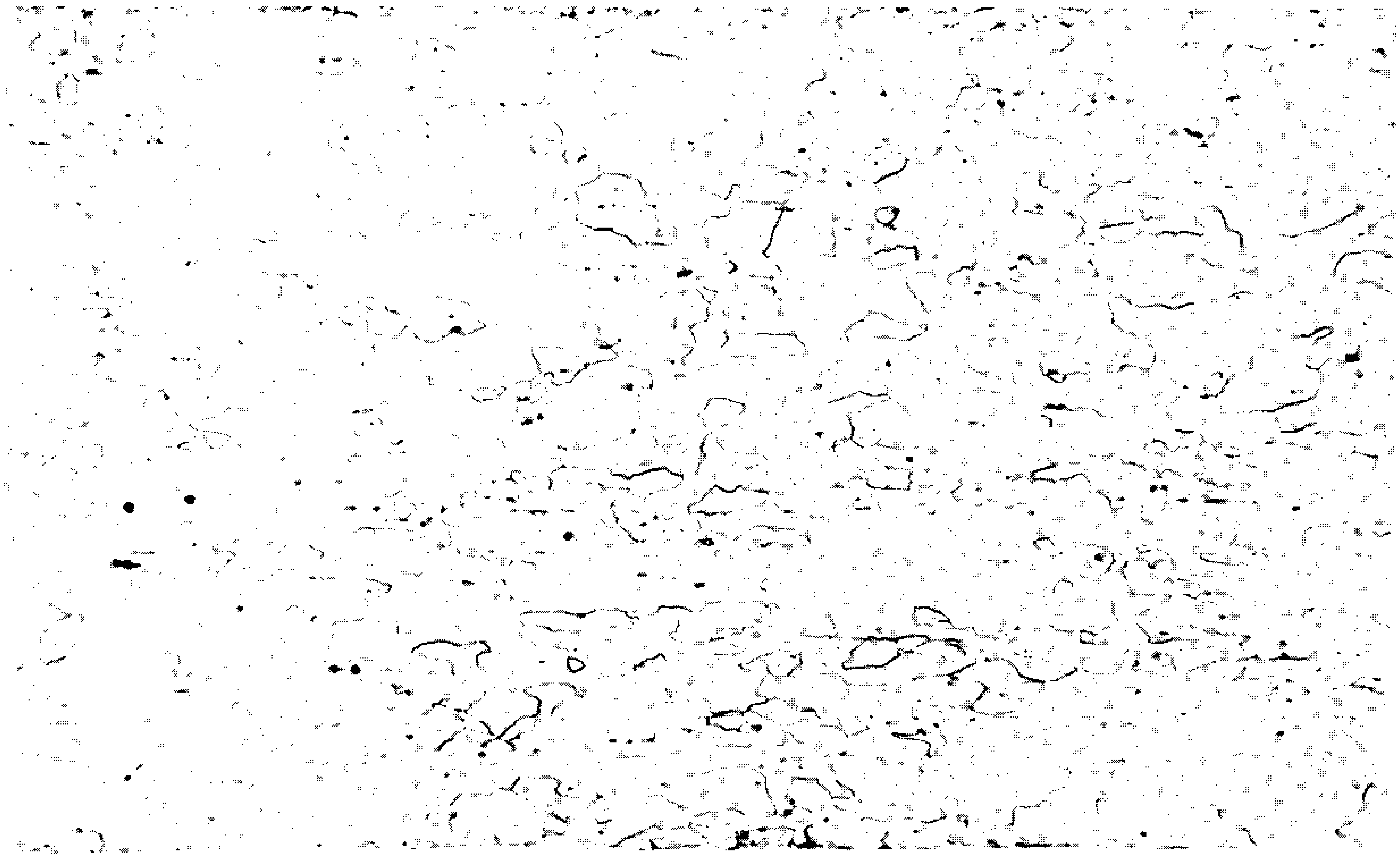
Figure 12 - Photomicrograph of Iron-Aluminum, Heat E-1006 Material Removed from Upper Cone Body of Turbine Exhaust Cone damaged in test.



100X

Mixed Acid Etch

Figure 13 - Photomicrograph of Iron-Aluminum, Heat E-1006 Material Removed from Lower Cone Body of Turbine Exhaust Cone damaged in test.

No measurable value of yield strength could be obtained. The variations in the tensile data may have been caused by partial cracking of the specimens before testing. Two additional samples were completely broken during machining. The results do show that the material was very brittle and the first sample indicates that the material was considerably stronger than in the "as received" condition.

Figure 14 photomicrograph shows the weld deposit in the circumferential fusion weld near the break area on the damaged cone. The welds withstood the impact quite well as compared to the cone in general.

The embrittlement of the E-1006 iron-aluminum material appeared to be partially due to the fabrication of the cone but mostly seems to be associated with the 137 hours and 17 minutes of endurance testing at approximately 1000°F. The metallurgists from the Universal Cyclops Steel Corporation claim that the order-disorder transformation temperature for Heat E-1006 material is 1450°F. In view of this, it would have undoubtedly been beneficial to have heat treated the entire assembly at 1450°F after completing the fabrication.

IV. REVIEW AND SUMMARY OF WELDING IRON-ALUMINUM ALLOYS

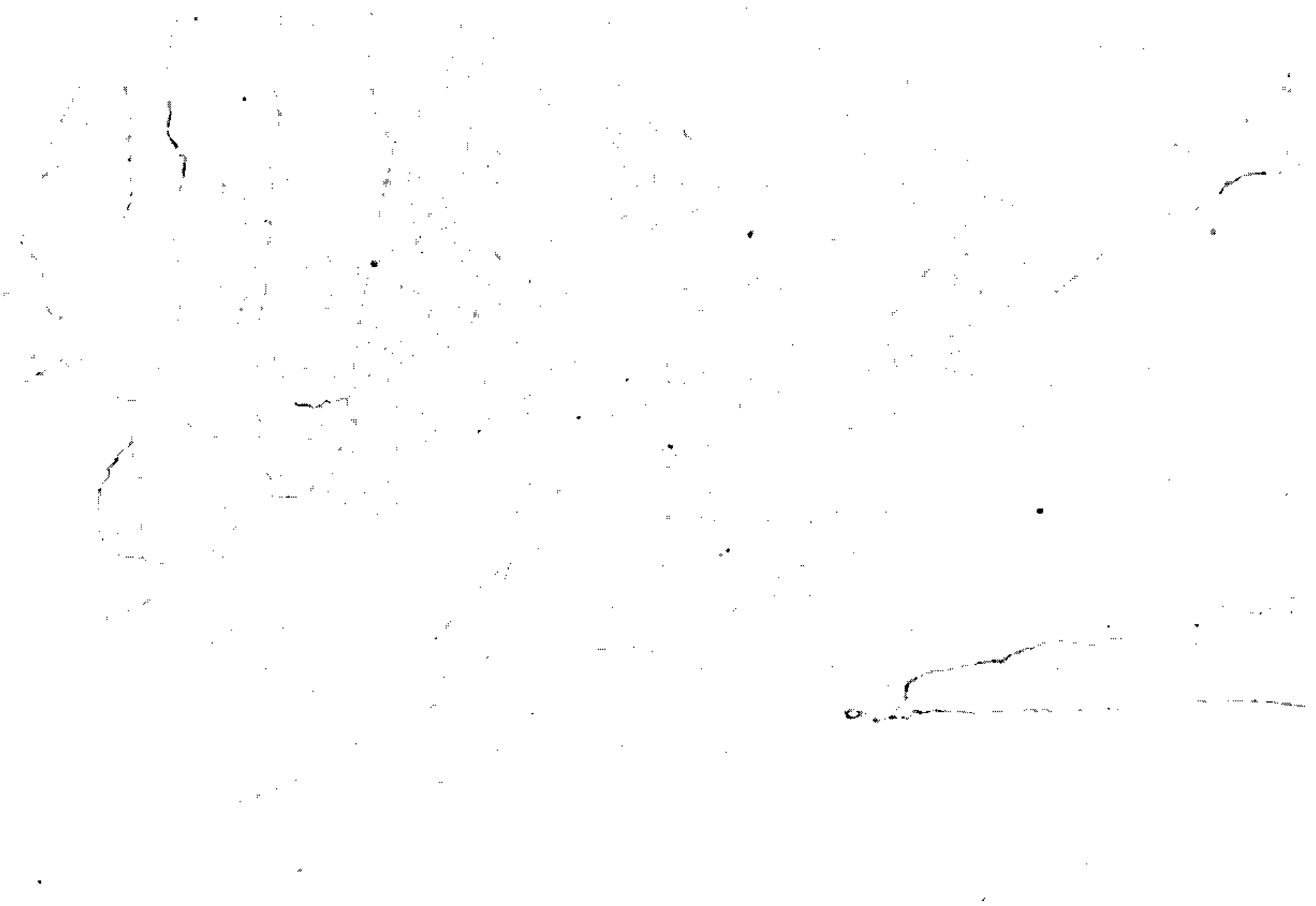
Research and development work on the welding of iron-aluminum alloys has been performed by the Ford Motor Company for the Air Force since April 1956. This work was selected on the basis of mutual interest and value to both the Air Force and Ford. Because of the promising high temperature oxidation resistance which these alloys indicated, it was deemed desirable to develop welding and fabrication methods which would permit their use and application evaluation. Iron-aluminum alloys used during the entire welding investigation were procurred from the Universal Cyclops Steel Corporation.

The following summaries, broken down into each of the reporting periods, outline the work which was done on Item 4, Part C, Welding of Iron-Aluminum Alloys under USAF Contract Number AF-33(600)-32448.

A. April 1956 through March 1957

The work on welding covered during this period was reported in WADC Technical Report 57-298, Part 3. Fusion and resistance welding were performed on three heats of iron-aluminum alloys: UC-1, UC-2 and UC-3. The tungsten electrode gas shielded arc welding process and the resistance spot welding processes were investigated.

A considerable amount of difficulty was encountered, especially with the UC-1 material, in cracking of both the weld and the base metal adjacent to the weld. However, sound fusion welds were made in this material by the tungsten arc process using DC straight polarity current, helium gas shielding, 150°F preheat and immediate 1200°F postheat treatment followed by either air cooling or oil quenching. In the absence of the postheat treatment, cracking occurred after the weld cooled below approximately 125°F.



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Mixed Acid Etch

Figure 14 - Photomicrograph of Weld Deposit Taken from Circumferential Fusion Weld Near Break Area on Turbine Exhaust Cone damaged in test.

Cross sections of weld deposits exhibited a grain size considerably larger than anything defined by ASTM grain size charts. In attempts to reduce this large grain formation, various alloy additions were introduced into the joint. Of several materials investigated, only columbium produced an indication of grain size refinement.

Bend and tensile test data were obtained at room and elevated temperatures on welded and unwelded UC-1 material. The mechanical properties of the welded samples were only slightly less than the unwelded base metal at the lower temperatures. At approximately 1000°F they became equal but at this temperature the tensile strength was only about half that of unwelded material at room temperature.

One of the problems associated with the resistance welding of the materials from the three heats of iron-aluminum materials available was the removal of the reddish-brown oxide film from the surface of the sheets. Several cleaning methods and solutions were tried. Good results were obtained by vapor blasting (an air blast containing water and pulverized quartz) plus immersion in either 10% nitric acid or ammonium persulphate solution. Cracks in the weld nugget also presented a problem.

Three fabrications were made using the fusion welding process in order to evaluate weld and material performance under service condition. These were a carburizing and annealing box, a combustor flame tube assembly and a brazing retort.

B. April 1957 Through September 1957

Results of work during this reporting period were recorded in WADC Technical Report 57-298, Part 6. Additional investigations were made with the tungsten electrode gas shielded arc welding process on Heats UC-1, UC-2 and UC-3 sheet materials with filler wires from Heats UC-1, KA-569 and KA-570. Bend and tensile data were obtained on welded and unwelded samples at ambient and elevated temperatures.

An exploratory investigation was made with the same iron-aluminum materials listed above, using the consumable electrode gas shielded arc welding process. The thickest iron-aluminum material available was 1/8" stock. This process did not show favorable results on such thin base metal.

Resistance spot welds on several hundred specimens were made in UC-2 and UC-3 alloys. Considerable internal cracking was indicated in welds on UC-2 material, while Heat UC-3 produced the most favorable results to date.

C. October 1957 Through March 1958

The continuing investigations on the welding of iron-aluminum alloys for this reporting period were detailed in WADC Technical Report 57-298, Part 10. The use of the tungsten electrode gas shielded arc welding process with alternating current supplemented by high frequency was tried without success. The appearance and penetration of the weld and the life of the tungsten electrode were inferior to results obtained with direct current straight polarity welding power. Materials from iron-aluminum Heats KA-1053 and KA-1054 were received and tried but proved of little value because they contained internal defects. Considerable effort was extended to weld these materials but consistent results could not be obtained.

An investigation was initiated to develop coated manual arc welding electrodes to deposit metal comparable to the iron-aluminum alloys being investigated. Dip coated electrodes were made which deposited up to 10% aluminum content in the weld.

Resistance spot and stitch welding investigations were directed toward the development of procedures and schedules for joining components to be used in a J-57 jet engine cone assembly. The thickness combinations involved were approximately .085" to .031" and .055" to .031". This was the first actual trial application for a resistance welded assembly during these investigations.

The fabrication of a J-57 engine turbine exhaust cone was selected as a suitable aircraft engine component with which to gain further iron-aluminum forming and welding information and to obtain service life data. Metal spinning for forming the details was selected on the basis of previous successful experience with low ductility materials and because the tooling cost was very favorable as compared to other sheet metal forming processes. The metal spinning operations were performed at 1000°F. Cracking was experienced in both the base metal and welded joints made by the tungsten electrode gas shielded arc welding process when attempts were made to spin the cone body from blanks made of Heats KA-1054, KA-567 and UC-3 iron-aluminum alloy materials.

The fabrication of a carburizing box from 1/4" thick UC-2 material welded with Type E330 stainless steel coated electrodes was attempted without preheat. Cracking occurred in a number of locations. Repairing was only partially successful.

D. April 1958 Through September 1958

Technical Report 57-298, Part 12 contained results of the work during this six-month period. Resistance spot and stitch schedules were developed for welding heats E-1005 and E-1006 materials in the thickness combinations used in the previously mentioned cone construction. Materials from these heats of iron-aluminum alloys were successfully fabricated into a J-57 engine turbine exhaust cone with the cone and flange, respectively, being made from .035" and .085" thickness of E-1006 material and the stiffener from .055" thick E-1005 stock. The completed cone assembly, with the flange nuts hot riveted in place, was installed for endurance testing in a J-57 engine at the Ford Aircraft Engine Division in Chicago.

Investigations were continued toward the development of coated iron-aluminum electrodes for manual arc welding. It was found that in order to deposit an appreciable amount of aluminum, it was necessary to have considerable aluminum in both the core wire and the flux coating.

A limited investigation of the brazing properties of iron-aluminum alloys showed that they could be braze welded with the low melting (1125°F-1200°F) silver solder type alloys. However, elevated temperature studies indicated that excessive grain growth might prove to be a problem even though a suitable high temperature brazing alloy and flux could be located or developed.

E. October 1958 Through January 1959

The results of the work for this last period are contained in the first three sections of this report. With the more ductile material from Heat A-13361 iron-aluminum alloy, which contained only 5.4% aluminum, welding without cracking appeared to be considerably simpler.

Two fabrications, a furnace hearth and a heat-treatment box, were welded and placed in service in the Tool and Die Heat Treat Department.

The J-57 engine turbine exhaust cone, made from iron aluminum alloys E-1005 and E-1006, was returned from endurance testing at the Ford Aircraft Engine Division in Chicago. The cone was damaged during operation when the flight nozzle became loose and dented the core assembly after 137 hours and 17 minutes of endurance testing at approximately 1000°F.

Mechanical tests and metallographic examination of materials at various stages of fabrication indicate that the extreme brittleness of the damaged cone material was caused by the test conditions.