NASA Technical Memorandum 78738

(NASA-TM-78738) NINE PERCENT NICKEL STEEL HEAVY FORGING WELD REPAIR STUDY (NASA) 34 p HC A03/MF A01 CSCL 13H

N78-28456

Unclas
G3/37 25900

NINE PERCENT NICKEL STEEL HEAVY FORGING WELD REPAIR STUDY

Clarence P. Young, Jr., A. Harper Gerringer,
Troy G. Brooks, and Robert F. Berry, Jr.

July 1978

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

NINE PERCENT NICKEL STEEL

HEAVY FORGING WELD REPAIR

STUDY

BY

Clarence P. Young, Jr., A. Harper Gerringer,

Troy G. Brooks, and Robert F. Berry, Jr.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

SUMMARY

This report summarizes the results of a study performed to evaluate the feasibility of making weld repairs on heavy section 9% Nickel Steel Forgings such as those being manufactured for the National Transonic Facility (NTF) Fan Disk and Fan Drive Shaft components. Results of the study are provided which indicate that 9% Nickel Steel in heavy forgings has very good weldability characteristics for the particular weld rod and weld procedures used. In addition a comparison of data for known similar work is presented.

INTRODUCTION

The NTF is a closed loop cryogenic wind tunnel being constructed at the NASA Langley Research Center (LaRC). Because of high strength and high toughness properties requirements over the extreme operating temperature range (-320°F to +175°F), as well as manufacturability, 9% Nickel steel was chosen as the material for fabricating the fan disk and fan shaft (see figure 1). Both the fan disk and fan shaft are being manufactured as one piece forgings (which is beyond the current state of the art in this material i.e. no manufacturing specifications exist). Because of the criticality of safe operation of these parts (particularly the fan disk) and the stringent acceptance requirements on maximum flaw size it was decided that a study was needed to evaluate the weldability and feasibility of making acceptable weld repairs in such a large rotating part.

WELD REPAIR EXPERIMENT

Test Procedure

The approach, material selection, weld repair procedure, inspection, and test requirements are given in this section.

Weld Repair Geometry. - The approach was to utilize existing forging material in 9% Nickel that would have the same chemical composition and heat treatment as the actual Fan Disk part. The test part was a 3 inch thick by 10 inch diameter 9% Nickel forging (disk shape) provided by the Fan Disk supplier (see figure 2). A weld repair geometry was selected for simulating the repair of a penny shape flaw 1" long by 0.5" deep flaw embedded near the mid thickness of the NTF Fan Disk Forging, (see figure 3 for photograph of the weld cavity placed in the forged part).

Chemical Composition and Heat Treatment of Forged Part Used for the Weld Repair Test. - It should be noted that the 9% Nickel forging of the size required for the fan disk exceeded that for which any specification has been written. The baseline specification for the fan disk procurement was ASTM A 522-75 which covers forgings up to 5" thickness. As a result of research studies performed by the forging supplier, the chemical composition, heat treatment, and stress relief for the fan disk forging departs from those specified in ASTM A 522-75. The nominal chemical composition of the test forging as determined at LaRC is given in table I-A.

Welding Electrode. - The Inconel 112 Welding Electrode (Arco's Chromend 625) 5/32" diameter rod (for nominal chemical composition see table I-B) was selected for the repair based on favorable results of earlier welding studies performed at LaRC (ref. 1) and by the forging manufacturer (ref. 2).

Weld Repair Procedure. - Once the weld cavity was machined into the forging billet as shown in figure 3 the effective forging mass was increased by sandwiching the part with 1 1/4" plates welded to the part as illustrated in figure 4. This was done to simulate (at least to a degree) the mass effect of making such a repair in the large forging. The dimensions of the weld cavity are shown in the sketch of figure 5. The stepwise procedures used for filling the cavity with the weld material is given as follows:

1. Clean weld area with acetone.
2. Preheat 200°F; Oven soak - 2 hours minimum.
3. Use Shielded Metal Arc Welding (SMAW) process and Inco 112 (Arco's Chromend 625), 5/32" diameter electrode.
    - 3a. Oven temperature for electrode storage; 225°F ± 50°.
4. Weld using direct current, reverse polarity and 155 amps.
5. Interpass Temperature; 300°F maximum.
6. Completely remove slag and spatter after each pass.
    - 6a. "Needle Scaler" may be used.
7. Grind weld surface smooth for radiography.
8. Measure forging thickness to determine weld shrinkage.

Post Weld Heat Treatment. - Post weld heat treatment (PWHT) was not performed for this study since the results reported in reference 2 did not indicate that significant benefits in terms of improved strength or toughness for the type of weld could be realized. In fact lower toughness (impact energy values) were usually obtained from the PWHT specimens. Also time and resources did not permit the same scope of testing for both the as-welded and post-weld heat treatment studies. All data are given for the as-welded condition.

Inspection. - The non-destructive examination consisted of an ultrasonic inspection of the forged billet as received. Upon completion of machining and weld repair of the cavity both ultrasonic and radiographic examinations were made prior to machining specimens out of the billet. In addition, after the test specimens were machined, additional visual and radiographic inspections were carried out for resolution, correlation, and sensitivity evaluation. A complete discussion of the inspection procedures and results is provided in appendix A.

Mechanical Testing. - A comprehensive testing program was carried out to evaluate the tensile strength and toughness properties in the parent material, heat affected zone and weld material. The specimen sizes and test procedures were carried out in conformance with ASTM A370. A total of 32 charpy V-notch and tension specimens were taken from the forging billet shown in figure 5 after weld implacement.

See figure 6 for test specimen location and designation. As can be seen in figure 6 specimens were taken in both the transverse (axial) and longitudinal directions through the weld material with radial, tangential, and axial specimens being taken in the parent material. Note that the transverse (axial) weld tension specimens are "all weld metal" in the reduced section. Also, longitudinal weld specimens are predominately weld metal. It should be noted that the "longitudinal" direction in the weld material is synonymous with the "tangential" direction in the parent material. Similarily, as previously indicated "transverse" in the weld material is synonymous with "axial" in the parent material.

The specimens shown in figure 6 are identified by the following numbering order.

Material Area and Direction

Specimen Number

Specimen Type

For Example

C 11 W T

Weld Material, Transverse Direction

Specimen Number 11

Charpy Specimen

RESULTS AND DISCUSSIONS

The significant results are presented and discussed in this section.

Mechanical Properties

The results of the tensile and fracture toughness testing are tabulated in tables II and III. In order to establish a meanful baseline by which the results may be evaluated the following is a summary of the mechanical properties acceptance requirements for the fan disk forging.

Property	Direction: Tangential	Direction: Radial
Tensile Strength, Min., Ksi	100	100
0.2% Yield Strength, Min., Ksi	75	75
Elongation, % Min.	22	18
Reduction of Area, % Min.	48	40
Impact Energy (-320°F), ft-lbs.	25	25
Lateral Expansion Opposite Notch	> .015 in.	> .015 in.

Parent Material. - From table II it can be seen that all parent material specimens (Nos. 1 through 6) exceeded (by a substantial margin) the minimum values on tensile strength and ductility requirements. The same thing is true of the parent material charpy specimens (Nos. 1 through 8) in table III. Note that the fracture toughness values are exceptionally high in all three directions when compared to the minimum requirements.

Weld Material. - Weld specimens were taken both axial (minimum dimension direction) and longitudinal (maximum dimension direction) in the weld material. The tensile specimens are numbered 7 through 11 in table II. Principal observations for tensile properties in the weld were quite gratifying. As expected some reduction in the yield values were observed and (based on averages) in this case by about 27% in the axial direction and about 27% in the longitudinal direction. This reduction was expected and appears typical see references 1 and 2. However note that the yield values in the longitudinal direction averaged 71.6 ksi while the axial specimens averaged 69.7 ksi, not far below the specified 75 ksi minimum.

The % elongation in the weld material remained high, all exceeding the minimum requirement. However, the reduction in area dropped considerably, as one might expect since all specimens failed in weld metal as dictated by weldment and specimen geometries.

The measured impact values and lateral expansion measurements (table III) exceeded by a substantial margin the minimum requirements for the fan disk forging material.

Heat Affected Zone. - The impact values were measured at or near the heat affected zone and were found acceptable (specimens numbers 16 and 17 in table III). In addition, hardness profiles were taken and are displayed in figure 7. The profile appeared typical with peak values of 315 DPH near the fusion line with values in the weld material remaining fairly constant and very close to the parent material.

Contraction of Test Billet. - The maximum weld and forging contraction, due to transverse weld shrinkage, was .054" measured at a point 1/8" below the rim surface, and .021" at a point 1-1/4" below the rim surface. Relative diminishing contraction then extended outward along the aforementioned radii to points approximately 1/2" beyond the fusion line. The 1-1/4" thick sandwich disks (see figure 4) were not tack welded to the forging in the 3" long weld span, therefore, did not contribute to shrinkage restraint. Intermediate size stringer beads were used for this weld. An evaluation of small versus large stringer beads for this type weldment would be informative since each approach has it's own, sometimes controversial, merits.

Test Results Reported for Other 9% Nickel Weldments. - It is of interest to compare the mechanical properties obtained from the large weld cavity repair to earlier work done at LaRC and by the supplier (Japan Steel Works, Muroran, Japan). The work done at LaRC on 5/8" and 2" 9% Nickel plate material is unpublished and was carried out at the time when 9% Nickel steel was a candidate material for the tunnel shell and reinforcing rings. The work carried out by JSW (references 2 and 3) was done in connection with the manufacturing research on the fan disk forging. A summary of mechanical properties obtained from the aforementioned weldment tests is given in table III.

A direct comparison cannot be made of course because of the difference in weld section geometries, material chemistry, heat treatment, and procedures; however, the one commonality is the use of the Inco 112 weld electrode.

A general observation from the data in table III (when comparing weld material with parent material) shows in general a reduction in yield strength ranging from 12 to 27%. Also, it is seen that only small reductions are found when comparing ultimate strengths. In addition it is seen that fracture toughness remains within the specified minimums.

Application of Test Results to A Field Repair. - It is believed that the results of this weld repair study supports the feasibility of making an acceptable field repair in the Fan Disk forging if it should become necessary. The case for the use of the Inco 112 electrode is proven but the weld repair procedure and quality will be critical to assure a high quality weldment. The study had the additional side benefit of being able to determine the non-destructive examination requirements for weldment in such a large forging. These results are discussed and specifications given in appendix "A".

It is recognized that choices of weld repair cavity geometry and procedure can be influenced by the location of flaw and nature of the repair requirements. In view of this the following recommendations are offered:

1. Although weldment properties and weld quality were relatively good, as shown by radiographic and mechanical properties tests, some modifications in both design and adherence to procedure deserves consideration. A reduction in the number and size of slag inclusions can be readily achieved by minor design changes and more critical attention to flux removal after each weld pass.
2. The included angle of 16.2 degrees for the cavity sides (see figure 5) was made to this extreme for two reasons: (1) To obtain greater cavity depth in the available material and (2) to evaluate the ability to produce sound welds under these restrictions. This minimized angle is partially responsible for the trapped slag found at the base metal/weld interface. For a cavity of this depth an included angle of 20 degrees or greater should be considered. An additional increase in angle and/or radius in the bottom portion of this type cavity would provide even better accessability for slag removal tools and a more favorable electrode angle.

CONCLUSIONS

A weld repair study for evaluating the feasibility of weld repair in heavy 9% Nickel Steel Forgings has been completed.

The results of the study indicate that (if necessary) an acceptable weld repair of substantial size could be made on the NTF Fan Disk Forging or NTF Shaft Forging.

If a weld repair is determined to be necessary the weld rod selection and weld procedures and non-destructive inspection requirements presented in this report should be extremely useful and given high priority as an approach to be considered by the manufacturer.

Another potential benefit from this study could very well be realized if 9% Nickel Steel components installed in the Wind Tunnel should require repair in future years of operation.

APPENDIX A

Weld Repair
Non-Destructive Examination

by

Robert F. Berry, Jr.

Non-Destructive Evaluation (NDE) conducted during the course of this experiment demonstrates that a high quality inspection of weld repaired 9% Ni. steel is feasible.

The initial NDE assignment on this experiment entailed the baseline Ultrasonic (UT) examination of a 9% Ni. forged steel billet, 10 inches in diameter and 3 inches thick. This inspection was performed by utilizing a straight beam technique in the axial and radial modes. The referencing system employed was the 50% signal from a 3/32" flat bottom hole (FBH) at a penetration distance at 2.5 inches. No discontinuities were noted in this billet.

Upon completion of machining and rewelding of a deep cavity in the billet, a second ultrasonic inspection was attempted. To assist in this ultrasonic evaluation a 1/8 inch diameter by 1/2 inch deep FBH was machined in the billet. The location of this FBH was selected so as not to interfere with the Charpy and tension specimens. A series of axial and radial UT examinations were performed. Many extraneous signals were detected. This phenomenon cannot be related to defects in the base or weld material but is caused by interface reflection of the heat affected zone and weld metal grain structure. A series of immersion UT - "C-scan" examinations were also performed at this time. These tests were inconclusive.

A High Energy Radiographic examination was performed on the welded billet configuration at the U.S. Naval Weapons Station, Yorktown, Virginia. This examination consisted of 8 million electron volt (MEV) radial, 5.5 MEV axial and Co60 axial exposures.

Penetrameters were employed to insure a minimum 2% - 2T sensitivity. Upon reviewing the film from this examination the 5.5 MEV axial exposure was found to present the most useful information relative to the weld condition. (This film was graded to have a sensitivity of approximately 1%). Careful evaluation of this film revealed several small low density inclusions along the weld boundary interface. Vague nonhomogenous areas were also noted within the weld nugget. However, these areas were less pronounced than the interface discontinuities. A transparent overlay was made of this radiograph to aid in flaw location and sizing operations.

Utilizing the film image from the 1/8 inch diameter FBH as a landmark, the film overlay was superimposed on the Charpy and tension specimen location drawing. The largest film indication was tentatively identified as lying within Charpy specimen C-13 or C-14. (See figure 6).

After finish machining, the Charpy and tension specimens were subjected to a detailed visual and dye penetrant inspection. The visual inspection was performed by utilizing a 2.5X watchmaker's loupe. This examination revealed small point porosity and slag inclusion indications in five of the Charpy specimens. A high resolution florescent dye penetrant examination was subsequently conducted. The penetrant examination confirmed the previously noted discontinuities and revealed minor surface flaws in two additional Charpy specimens.

The Charpy and tension specimens were subjected to a two axis 140 KV radiographic examination. Film from this examination was found to depict several slag inclusion and porosity discontinuities within the weld material specimens. The largest slag inclusion indication was identified in Charpy specimen No. C-13. This slag inclusion was measured on the film, utilizing a magnifying optical comparator, and sized at approximately 0.080 inches by 0.080 inches by 0.015 inches thick. An exact sizing is not possible due to the irregular nature of the inclusion. After completion of the Charpy test on this specimen, hand machining was performed to expose the slag inclusion. A second sizing was made on the specimen and the surface profile was verified to be approximately 0.080 inches by 0.080 inches. After careful reexamination of the 5.5 MEV radiograph, the film overlay and the specimen drawing, identified the C-13 specimen flaw as the same flaw visible in the 5.5 MEV radiograph.

The flaw represents a film sensitivity of 2.7% which approaches the 2% minimum sensitivity requirement. It should be emphasized that smaller discontinuities were visible on the high energy exposure; however, the flaw located in specimen No. C-13 was the only flaw that could be directly correlated between the high low energy radiographic exposures and the actual specimens.

In the event of field weld repair on the NTF 9% Ni. steel fan disk forging, ultrasonic inspection techniques should not be relied upon as the sole quality determinant. A carefully devised and controlled high energy radiographic examination scheme will be required. The following minimum requirements should be imposed. To insure a satisfactory examination, the exposure energy must be a minimum at 5 MEV is preferable. Film type, target-to-film distance, and screen-film combinations must be controlled to insure a minimum 2% sensitivity. With optimum technique application a 1% sensitivity is achievable; this would display a flaw of 0.108 inch for the full size forging.

REFERENCES

1. NASA Langley Research Center Unpublished Data on Welding 5/8 in. and 2.0 in. 9% Nickel Plate.

2. Japan Steel Works, Fifth Report of the Study for 230 mm Thick 9% Ni Steel Forged Ring - Weldability and Mechanical Properties of SMAW Butt Welds.

3. Japan Steel Works, Fourth Report of The Study for 230 mm Thick 9% Ni Steel Forged Ring - Fracture Toughness Test at Low Temperatures.

4. Japan Steel Works Research Report PL 76-12-236 "Interim Report of the Study of 230 mm Thick 9% Ni Steel Forged Ring," December 3, 1976.

TABLE I-A. - Chemistry Analysis of Weld Repair Test Forging (Performed at LaRC).

M_n	-	.491%
N_i	-	9.32%
C_r	-	.105%
M_o	-	.108%
C_u	-	.132%
C	-	.096%
S	-	.0037%

TABLE I-B. - Nominal Chemical Composition of Inconel Welding Electrode 112.

N_i	-	61%
C_r	-	21.5%
M_o	-	9.0%
M_n	-	0.3%
F_e	-	4.0%
C	-	.05%
N_b	-	3.6%

TABLE II. - Tensile Property Data.

Specimen No.	Condition	Yield, psi	Ultimate, psi	% Elongation	% Reduction in Area
1	Radial specimen of parent material	95470	108610	30.4	74.65
2	Radial specimen of parent material	96930	109850	32.1	75.54
3	Tangential specimen of parent material	97290	110100	30.7	74.6
4	Tangential specimen of parent material	98150	109730	30.4	74.7
5	Axial specimen of parent material	96480	110800	28.5	68.5
6	Axial specimen of parent material	96490	110360	28.0	69.1
7	Longitudinal specimen through the weld	72100	109670	28.6	27.6
8	Longitudinal specimen through the weld	71120	109010	36.4	32.3
9	Longitudinal specimen through the weld	71630	108820	37.9	35.2
10	Axial specimen through weld	70820	102500	23.0	23.8
11	Axial specimen through weld	68640	107280	34.0	36.4

NOTE: All tests performed at room temperature (70°F).

TABLE III. - Impact Test Data (Charpy V-Notch).

Specimen No.	Test Temp. °F	Impact Value ft-lbs.	Average	Lateral Expansion in.	Average	% Shear Fracture	Comments
1 R	-320	85		.054		60 Avg.	
2 R		81	83.7	.050	.051	60 63	Base metal
3 R		85		.050		70	
4 A		63		.038		70	
5 A		[illegible]	60.7	.040	.038	50 57	Base metal
6 A		[illegible]		.037		50	
7 T		[illegible]	78.5	.047	.049	70 70	Base metal
8 T		79		.050		70	
10 WT		35		.030			Weld root specimens.
11 WT		42	39.7	.035	.035	*	# 10 had weld defects
12 WT		42		.041			in fracture zone.
13 WL		38		.035			Weld metal specimens
14 WL		40	39.	.035	.037	*	(Longitudinal)
15 WL		40		.042			
16 HAZ		87	—	.049	—	60	Notched 3.5 mm from fusion line.
17 HAZ		57	—	.040	—	*	Notched 1 mm from fusion line.
18 WT	-320	48	—	.042	—	*	Weld face SP.

* Difficult to Define with any Degree of Accuracy.

TABLE IV.

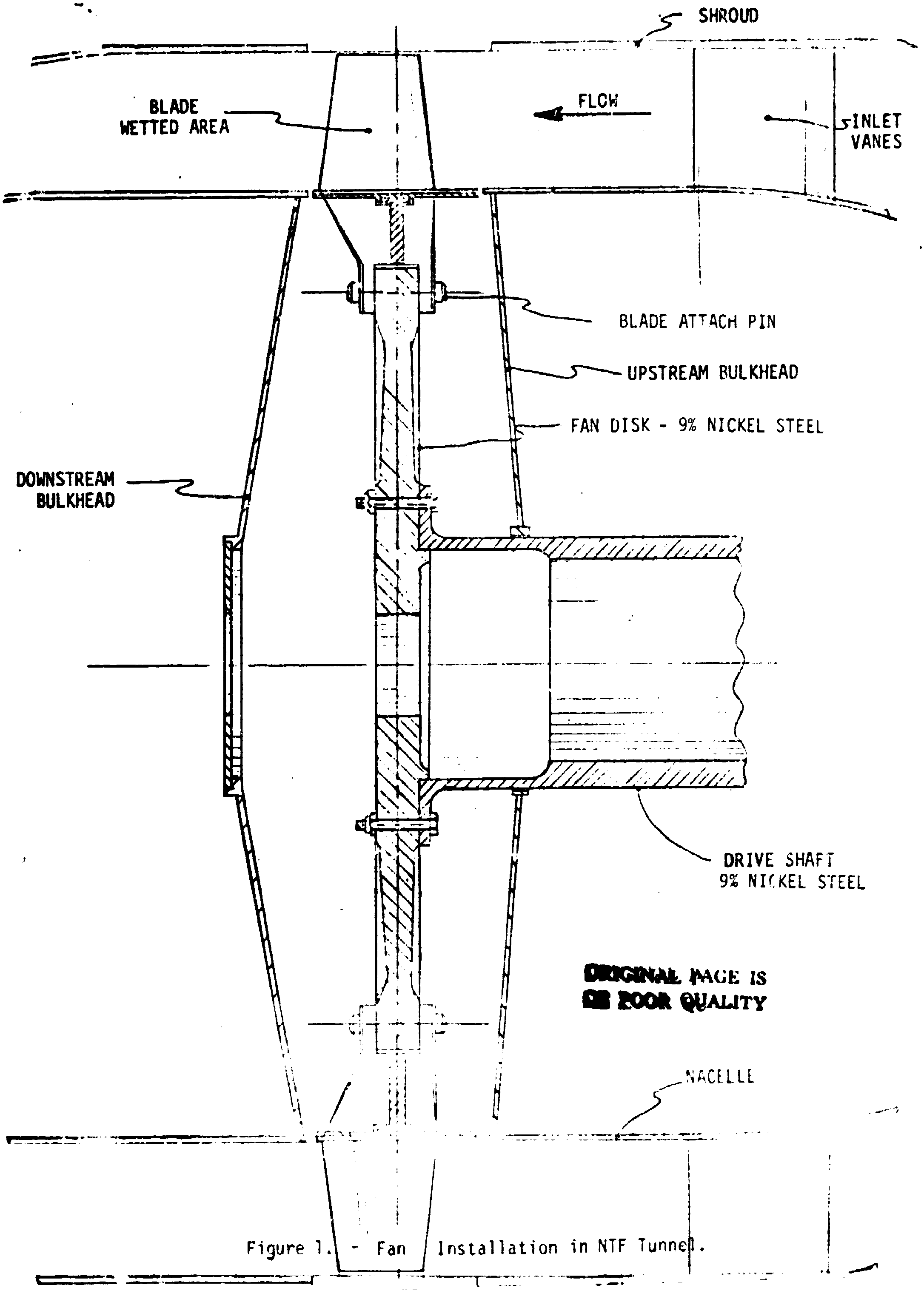
MECHANICAL PROPERTIES OF 9% NICKEL STEELS

RESULTS COMPARISONS OF SEVERAL TESTS.

MATERIAL	SPECIMEN ORIENTATION	YIELD F_{Ty} (KSI) .2% OFFSET	ULTIMATE F_{Tu} (KSI)	ELONG. (%)	REDUCTION OF AREA (%)	IMPACT - CVN (-320°F) ENERGY (FT/LBS)	IMPACT - CVN (-320°F) LAT. EXP. (IN.)	COMMENTS
Test Forging (Base Metal)	Radial	96	109	31	75	84	.051	See figure 6 and Table II.
	Axial	96	110	28	69	61	.038	
	Tan.	97	110	30	74	78	.048	
Test Forging (INCO 112 Weld)	Trans. Weld	69.7	104.9	28.5	*30	41.7	.037	*Tension Sp. Design Produced Failures in Weld Metal.
	Long. Weld	71.6	109	34	*31.7	39.3	.037	
5/8" Plate (Base Metal)	Longitudinal	102	110.7	26	74	69.6	.041	100°F Test Temp. (Ref. 1)
5/8" Plate (INCO 112 Weld)	Trans. Weld	89	110.8	*18 (24,23,7)	74,74,26	32.8	.029	*2 of 3 Tension Specimens Failed in Base Metal
2" Plate (Base Metal)	Longitudinal	99	107	24	76	80	.049	100°F Test Temp. (Ref. 1)
Japan Steel Works 5th Report	Trans. Weld	73.5	104.56	30.6	*70.6	(1/4 T)32.5 (3/4 T)40.5	.025 .030	Avg. of 3 Tests *Base Metal Failures (Ref. 2)
		(Welds in 30 mm Thick Plate Taken from 230 mm Forged Ring)						

NOTES: 1. Properties shown are averaged results unless otherwise indicated.

2. All tests at room temperature unless noted.



ORIGINAL PAGE IS
OF POOR QUALITY

Figure 1. - Fan Installation in NTF Tunnel.

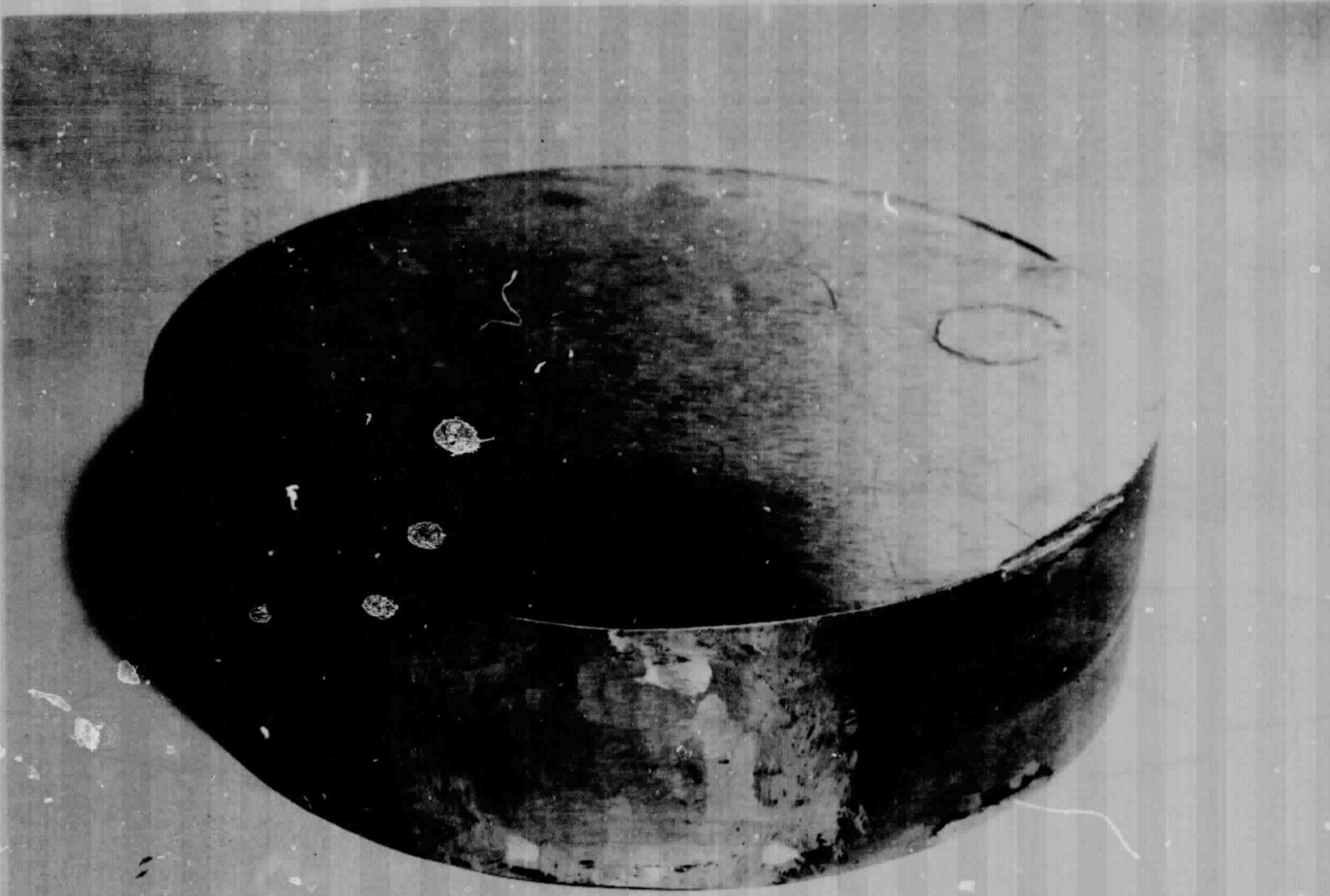


Figure 2. - Forged Test Billet of 9% Ni Steel.

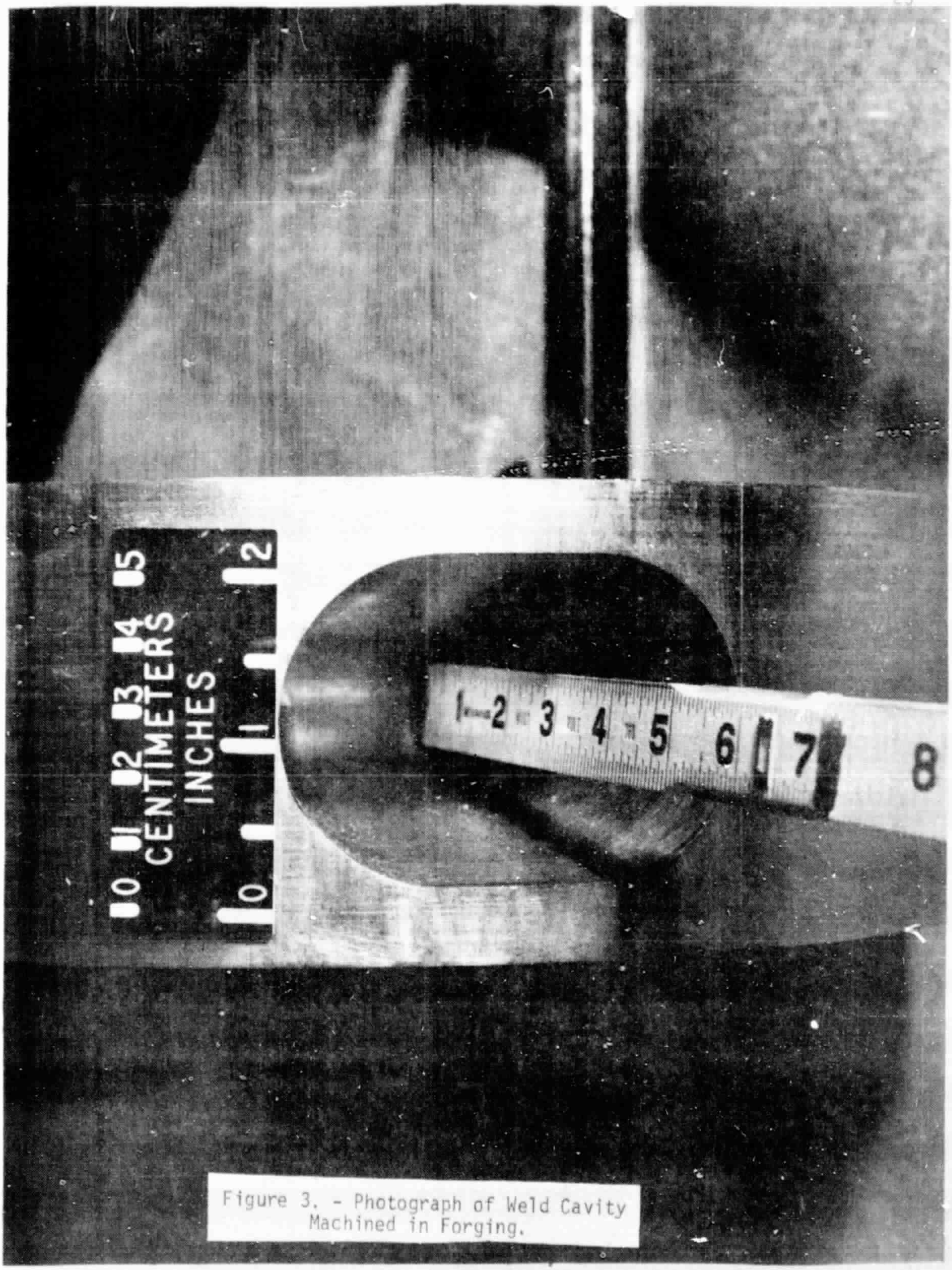


Figure 3. - Photograph of Weld Cavity Machined in Forging.

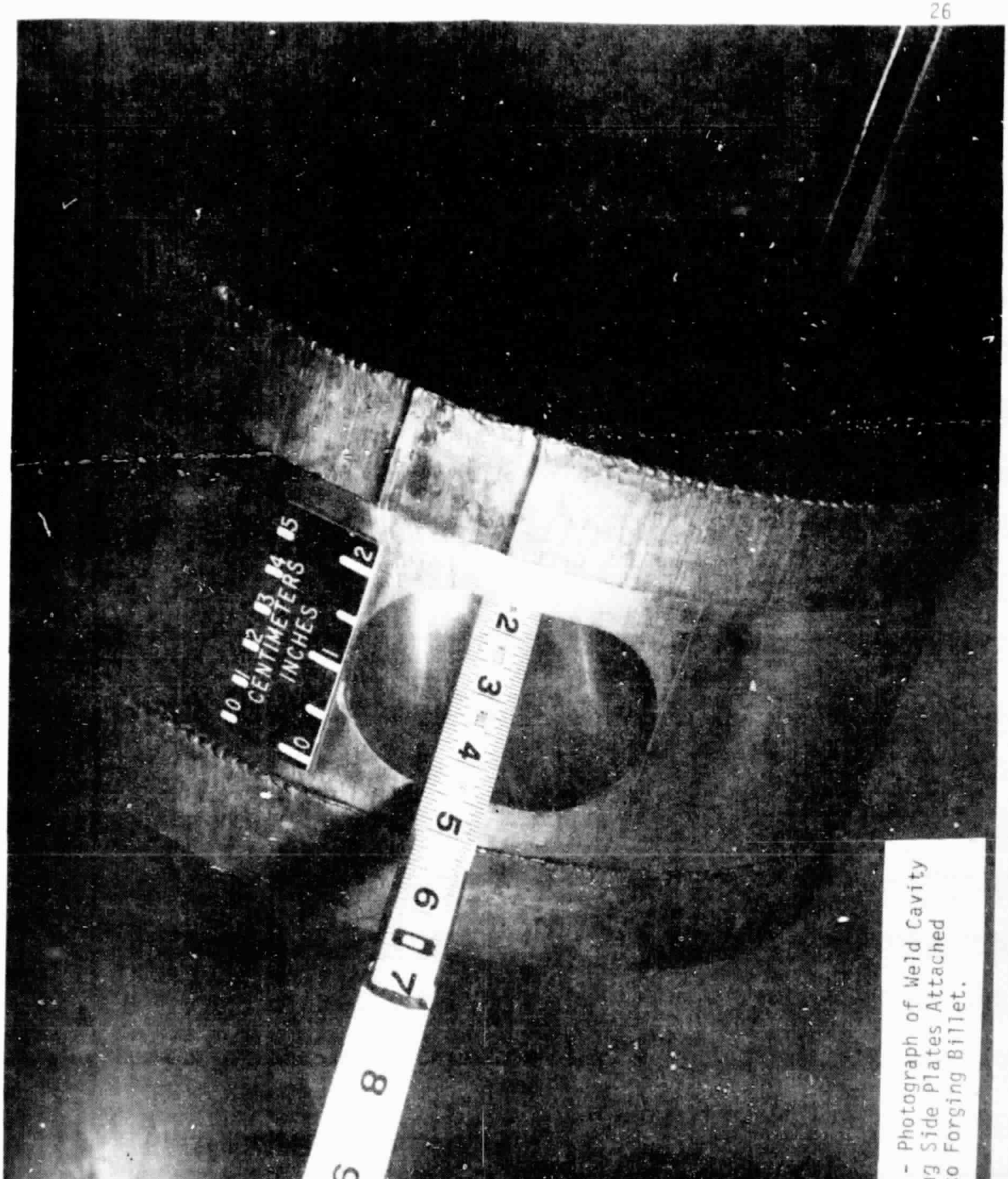
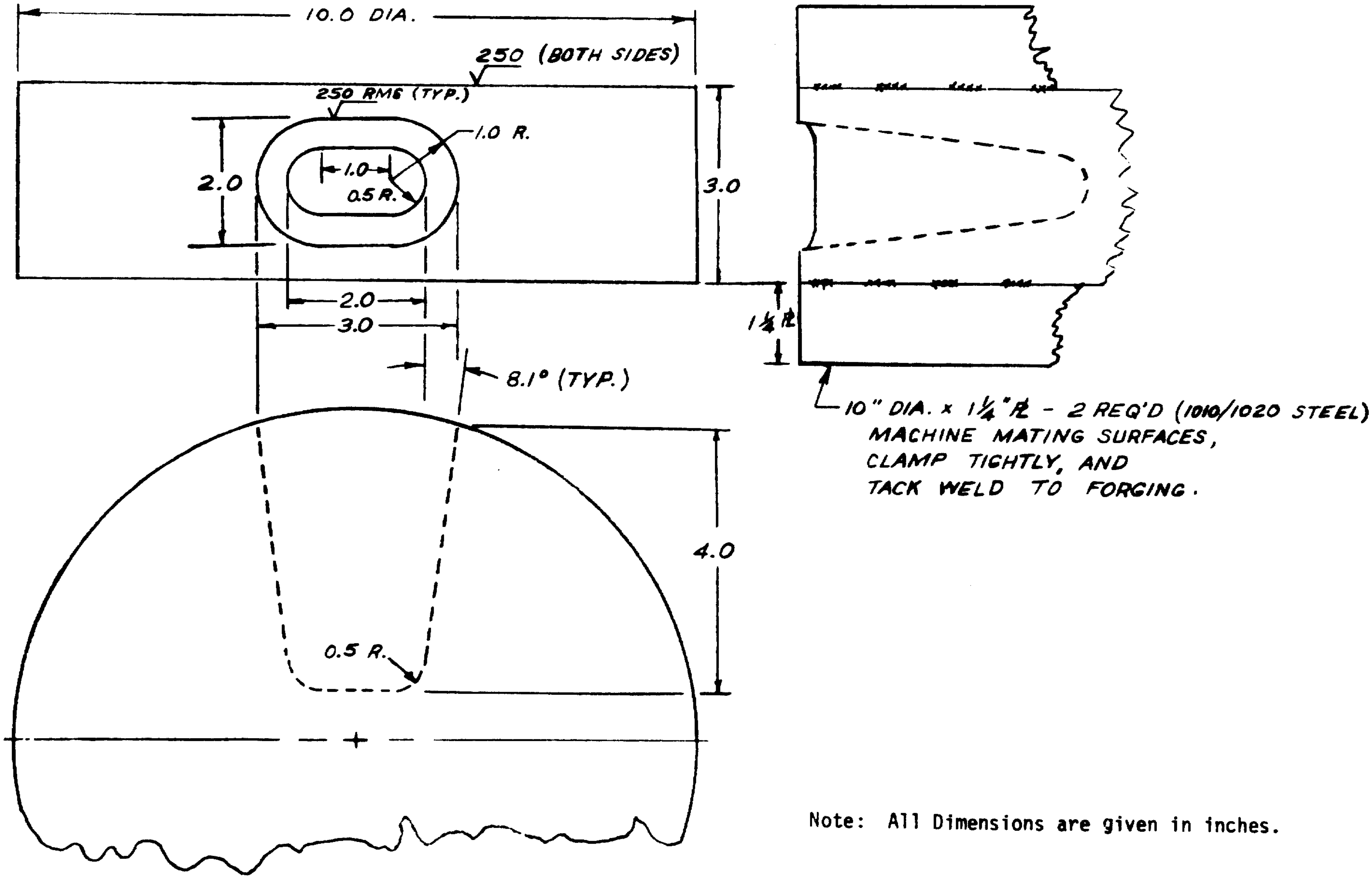


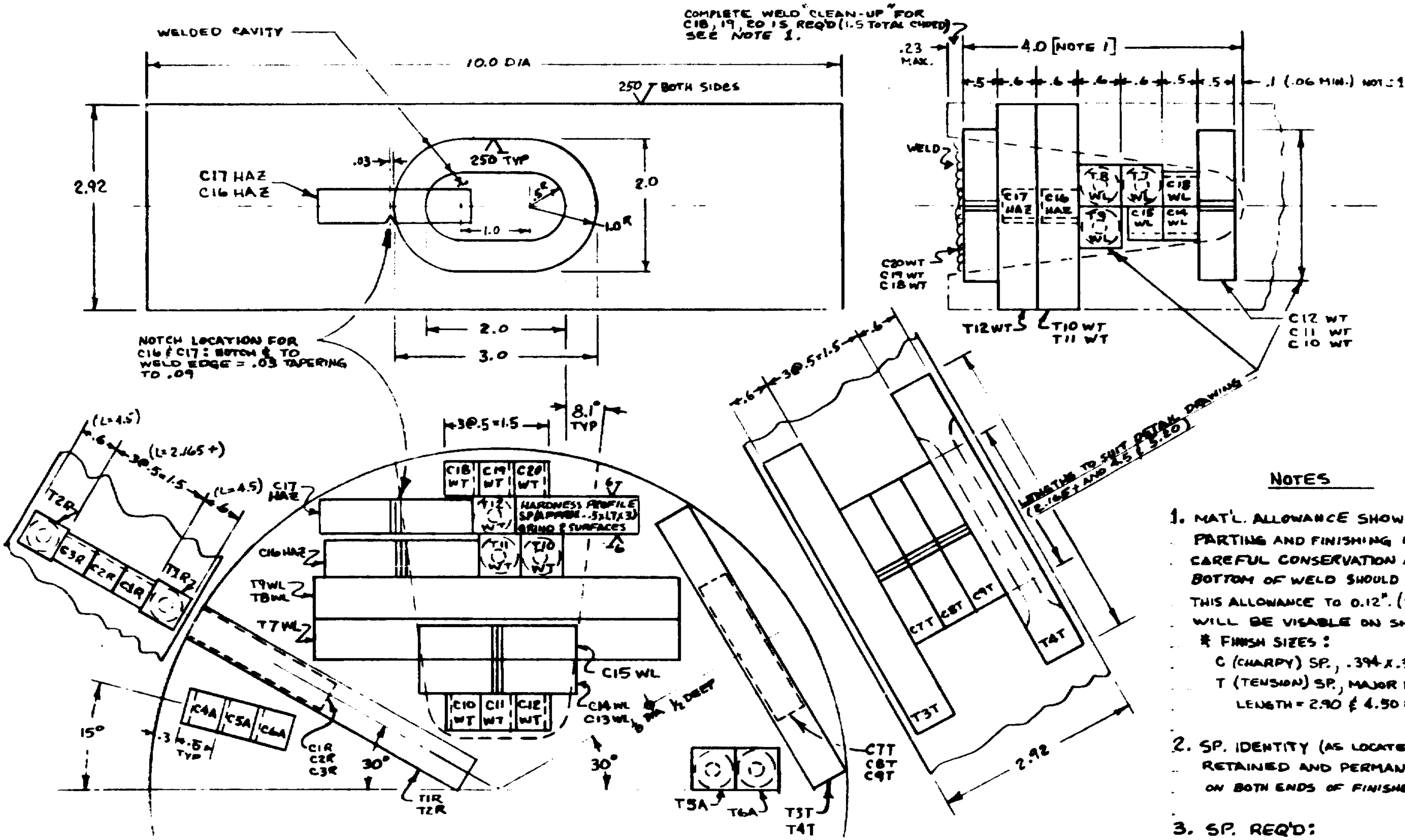
Figure 4. - Photograph of Weld Cavity Showing Side Plates Attached to Forging Billet.

ORIGINAL PAGE IS
OF POOR QUALITY



Note: All Dimensions are given in inches.

Figure 5. - Sketch Showing Dimensions of Weld Repair Cavity.



NOTES

1. MAT'L. ALLOWANCE SHOWN FOR PARTING AND FINISHING IS 0.10". CAREFUL CONSERVATION AT TOP & BOTTOM OF WELD SHOULD INCREASE THIS ALLOWANCE TO 0.12". (WELD OUTLINE WILL BE VISABLE ON SMOOTH FINISH.)
   * FINISH SIZES:
     C (CHARPY) SP., .394 x .394 x 2.165
     T (TENSION) SP., MAJOR DIA. = .50"
     LENGTH = 2.90 & 4.50 & 5.20

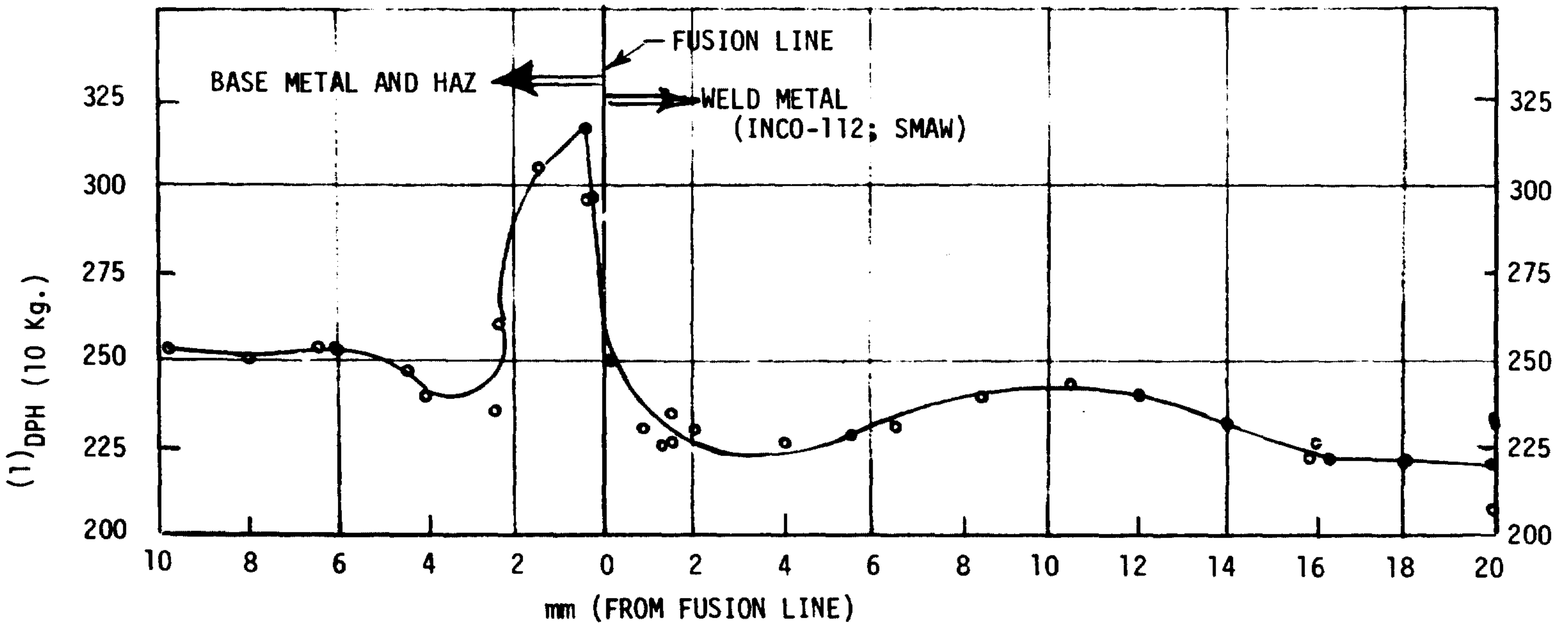
2. SP. IDENTITY (AS LOCATED) SHALL BE RETAINED AND PERMANENTLY MARKED ON BOTH ENDS OF FINISHED SP.

3. SP. REQ'D:

	BASE METAL			WELD		HAZ	TOTAL
	AXIAL	TAN.	RAD.	LONG.	TRANS.		
(C) CHARPY	3	3	3	3	6	2	20
(T) TENSION	2	2	2	3	3	X	12

* ALSO, ONE HARDNESS PROFILE SP.

Figure 6. - Test Specimen Locations in Weld Repair Part.



(1) DIAMOND PYRAMID HARDNESS CONVERTED FROM Rb AND Rc; TAKEN FROM SECTION APPROXIMATELY ONE INCH BELOW SURFACE.

(2) FORGING BY JAPAN STEEL WORKS, 10" DIA. x 3" THICK.

(3) WELD, INCO 112 (SMAW), 4-1/4" DEEP; BY LaRC.

FIGURE 7. - HARDNESS PROFILE 9% NICKEL STEEL FORGING[2] AND WELD[3].