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A SUMMARY OF TESTS ON INVAR WELDED WITH 308L AND 8N12 WELDING RODS

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SUMMARY

The cost and difficulty in obtaining Invarod, the recommended welding rod to weld Invar, necessitated the investigation of substituting more readily available rods that would meet the cryogenic design criteria for the National Transonic Facility (NTF). Two weld rods, 308L and 8N12, were chosen as promising candidates. Four welded specimen plates were made; two plates for each type of weld rod. One plate from each of the 308L and 8N12 weldings was thermally cycled 50 times between 366°K (+200° F) and 89°K (-300° F) while the two remaining plates were not thermally cycled. Specimens were machined from all four plates for three types of tests: Tensile, Charpy Impact, and Guided-Bend. The methods in making the specimen plates, conduction of the tests, test results, and conclusions leading to the selection of a weld rod are presented.

INTRODUCTION

Invar is a 36 percent nickel-iron alloy that has a rate of thermal expansion approximately one-tenth that of carbon steel. This physical property makes Invar ideal for applications where dimensional changes due to temperature variation must be minimized. The recommended weld rod for the welding of Invar for cryogenic service is a derivative of the parent material with a small addition of Titanium to minimize weld cracking. This weld rod has become increasingly difficult to obtain in recent years. This paper documents an investigation into the use of two more readily available rods - 308L and 8N12.

Acknowledgement is given to the Advex Corporation, Hampton, Virginia, for their expertise in welding and machining the various test specimens that were used to produce the results shown in this paper.

TESTS

Normal operations of the National Transonic Facility (NTF) will submit many of the internal mechanisms and hardware of the tunnel to temperature ranges from 366°K (+200° F) to 89°K (-300° F). Alignment requirements within the tunnel demand the use of materials that will have small dimensional changes over wide temperature variations. Invar, a 36 percent nickel-iron alloy, has been chosen as one of these materials. Welding of Invar is necessary in order to manufacture some of the larger components within the tunnel. The welding rod recommended is made of Invar which has been extracted from the parent material to be used in manufacture of the component.[1] The high cost of making a special run of welding rod and the long delivery time of approximately 4 to 5 months precludes the use of this type of rod. Two other welding rods, 308L and 8N12, were investigated and used to make four specimen plates from which Tensile Test, Charpy Impact Test, and Guided-Bend Test specimens were machined. All of the test procedures and conclusions are in accordance with the standards set forth in the ASME Boiler and Pressure Vessel Code, Section II, Part A, Specification SA-370 and Section IX, Articles I through IV (ref. 1).

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[1] Technical Data Sheet - Carpenter Invarod, 1970, p. 1.

Mechanical Properties and Compositions

Mechanical properties of Invar[2] and the welding rods, 308L[3] and 8N12,[4] are shown in table I, and the compositions of all three materials are shown in table II.[5,6,7]

Specimen Plate

Each plate was made as shown in figure 1 using the shielded metal arc welding procedure.[8] The weld joint is a double U configuration with a 0.318 cm (0.125 in.) root gap and a 0.159 cm (0.0625 in.) land. Arc amperage of 80 to 120 amps and arc voltage of 24 volts were maintained according to the manufacturer's recommendations.[9] The plates were cleaned with an acetone based degreaser and dryed prior to welding. No attempt was made to control the temperature of the plates during welding. After welding the plates were left to cool in ambient air. One plate for each type of weld rod was subjected to 50 thermal cycles from 366° K (+200° F) to 89° K (-300° F). This cycling represented 2 years of normal operation time of the NTF tunnel. The

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[2]Technical Data Sheet - Carpenter Invar "36," 1970, p. 1.
[3]ARCOS Welding Products, 1978, p. 35.
[4]Ibid., p. 40.
[5]Ibid., p. 33.
[6]Ibid., p. 41.
[7]Technical Data Sheet - Carpenter Invar "36," 1970, p. 1.
[8]ARCOS Welding Products, 1978, pp. 4-9.
[9]Ibid., p. 5.

two remaining plates were left as welded. All of the test specimens were then machined from these plates to form four basic specimen types. Each specimen was identified by the following code:

308	-	1	-	2
WELD ROD	-	PLATE TYPE	-	TEST NUMBER

The plate type identification is:

#1 - cycled 50 times

#2 - non-cycled

Tensile Test

Eight tensile specimens, two from each type of plate, were machined as per figure 2. The specimens were loaded using an INSTRON minimum 222,400 N (50,000 lb) capacity tensile tester at a rate of 26,688 N/min (6,000 lb/min). An extensometer was attached to the specimen, and its readout was recorded on a x-y plotter. The plots from each of these tests are shown in figures 3 through 6. Prior to the specimen breaking, the extensometer was removed and the break point was recorded on the Instron machine gage. The 2 percent offset method was used to find the yield point. The specimens after testing are shown in figures 7 through 10.

Charpy Impact Test

Charpy Impact Tests were run on four specimens from each type of plate. The tests were run on a U-type pendulum impact machine with the specimens at 77° K (-320° F). The specimen configuration is shown in figure 11. Test results are given in the Impact Test Reports, figures 12 and 13. Figures 14 through 17 show the specimens after impact testing.

Guided-Bend Test

Transverse side bend tests were done on four specimens from each plate type using a Guided-Bend jig. The specimen configuration and the jig used is shown in figure 18. Figures 19 through 22 show the specimens after the bend tests were completed.

RESULTS

Three main results were determined from the tensile tests. The ultimate strength, yield strength, and location of separation were determined for each tensile specimen. The strengths are tabulated in table III along with a comparison column for the parent material, Invar. The ultimate strength of the test specimen ranged from 4.45×10^8 N/m^2 (64.6 ksi) to 4.53×10^8 N/m^2 (65.7 ksi). These compare favorably to the ultimate strength for Invar of 4.48×10^8 N/m^2 (65 ksi). The yield strength values of the test specimen were slightly higher than the Invar value of 2.76×10^8 N/m^2 (40 ksi). The test specimen yield strength ranged from 3.07×10^8 N/m^2 (44.5 ksi) to 3.32×10^8 N/m^2 (48.2 ksi). Every tensile specimen separated at a location far removed from the weld material and the weld line, i.e., separation occurred in the parent material.

The results of the Charpy Impact tests are listed in figures 12 and 13. The Impact Value for specimen 8N12-1-3 and 8N12-1-4 are high because the breaks occurred both in the weld metal and the base metal. Specimen 8N12-1-1, 308-1-2, 308-1-3, and 308-1-4 had about 90 percent weld metal breaks. All other specimen had 100 percent weld metal breaks.

The criteria of no open defects exceeding 0.32 cm (1/8 in.) measured in any direction on the convex surface of the specimen was met by all of the Guided-Bend Test specimen as verified by visual inspection.

CONCLUSIONS

Analysis of the data from each of the three tests indicate either the 308L or the 8N12 weld rod is suitable for welding Invar. There is excellent comparison between the ultimate and yield strength values of the test specimen and the Invar properties. The Charpy Impact Values show that the 308L material has less resistance to fracture than the 8N12. However, both materials meet the NTF criteria of a Charpy Impact Value of 27 J (20 ft-lb) or greater. The data do not show any difference in material properties between the thermally cycled and the noncycled test specimen.

In choosing between the two weld rods, the cost and delivery schedule were important considerations. Also, included in the decision was the welder's evaluation of the weldability of the two candidate rods. These became the three deciding factors in choosing the 308L weld rod for use in construction of the National Transonic Facility.

REFERENCES

1. ANON.: ASME Boiler and Pressure Vessel Code, ASME, 1974.

BIBLIOGRAPHY

1. ANON.: ARCOS Welding Products, ARCOS Corporation, 1978.

2. ANON.: Technical Data Sheet - Carpenter Invarod, Carpenter Technology Corporation, 1970.

3. ANON.: Technical Data Sheet - Carpenter Invar "36," Carpenter Technology Corporation, 1970.

TABLE I.- MECHANICAL PROPERTIES

Material	Yield Strength		Ultimate Strength		Elongation, %	Reduction of Area, %
	$N/m^2 \times 10^8$	KSI	$N/m^2 \times 10^8$	KSI		
Invar	2.76	40	4.48	65	35	65
308L	4.14	60	5.86	85	40	60
8N12	3.93	57	6.55	95	40	55

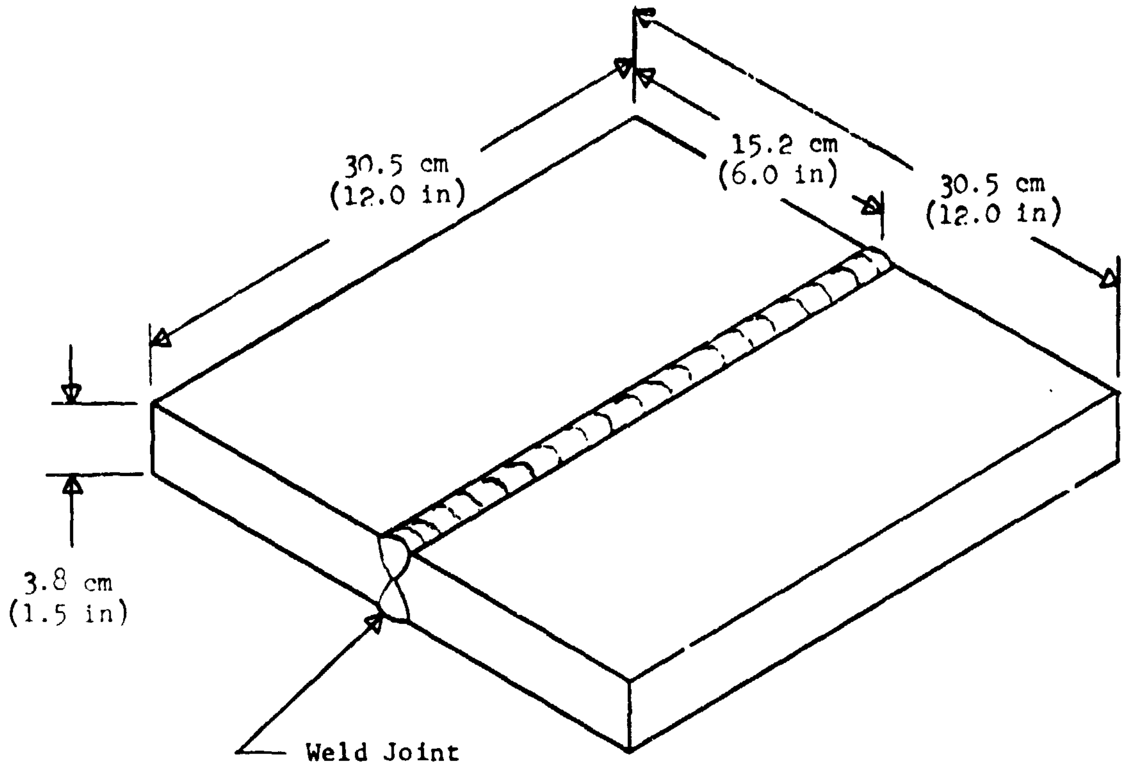
TABLE II.- MATERIAL COMPOSITION

Material	C	Mn	Si	S	P	Cr	Ni	Cb	Fe
Invar	0.12	0.35	0.30				36.00		Balance
308L	0.035	1.70	0.40	0.02	0.02	19.50	10.00		Balance
8N12	0.04	6.5	0.50			15.80	Balance	1.90	5.0

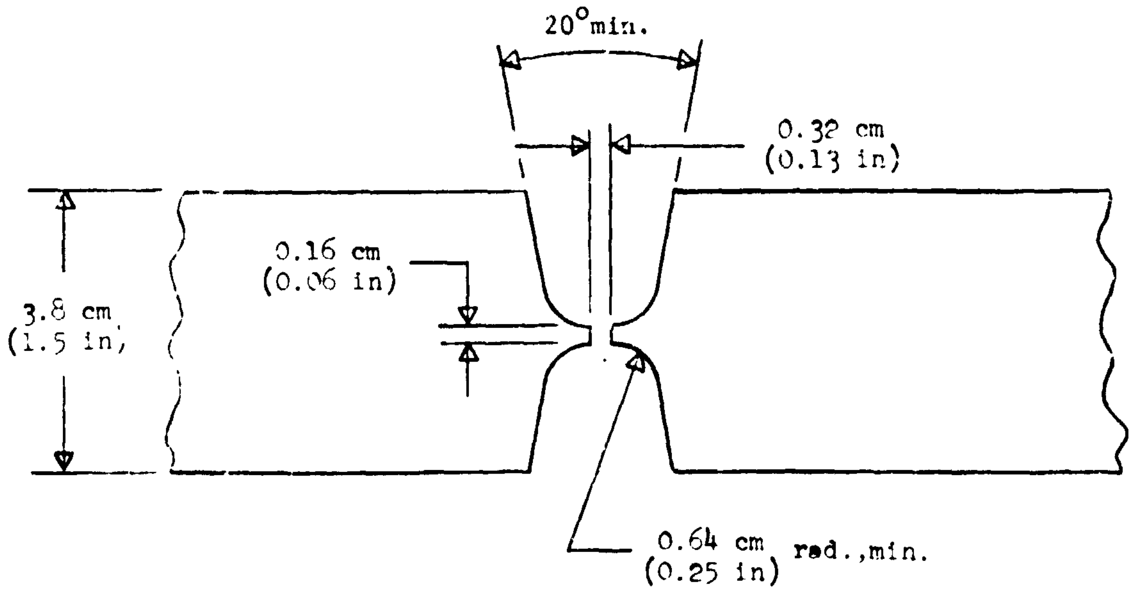
TABLE III.- TENSILE TEST RESULTS

Specimen	Ultimate Strength		Yield Strength	
	$N/m^2 \times 10^8$	KSI	$N/m^2 \times 10^8$	KSI
Invar[a]	4.48	65.0	2.76	40.0
308-1-1	4.51	65.3	3.33	48.2
308-1-2	4.51	65.4	3.24	46.9
308-2-1	4.48	65.0	3.24	47.0
308-2-2	4.48	64.9	3.26	47.3
8N12-1-1	4.46	64.7	3.16	45.8
8N12-1-2	4.46	64.6	3.07	44.5
8N12-2-1	4.53	65.7	3.10	44.9
8N12-2-2	4.53	65.7	3.15	45.7

[a] Technical Data Sheet - Carpenter Invar "36", 1970, p. 1.



SPECIMEN PLATE



DOUBLE U WELD JOINT

Figure 1. - Specimen Plate and Weld Joint Configuration.

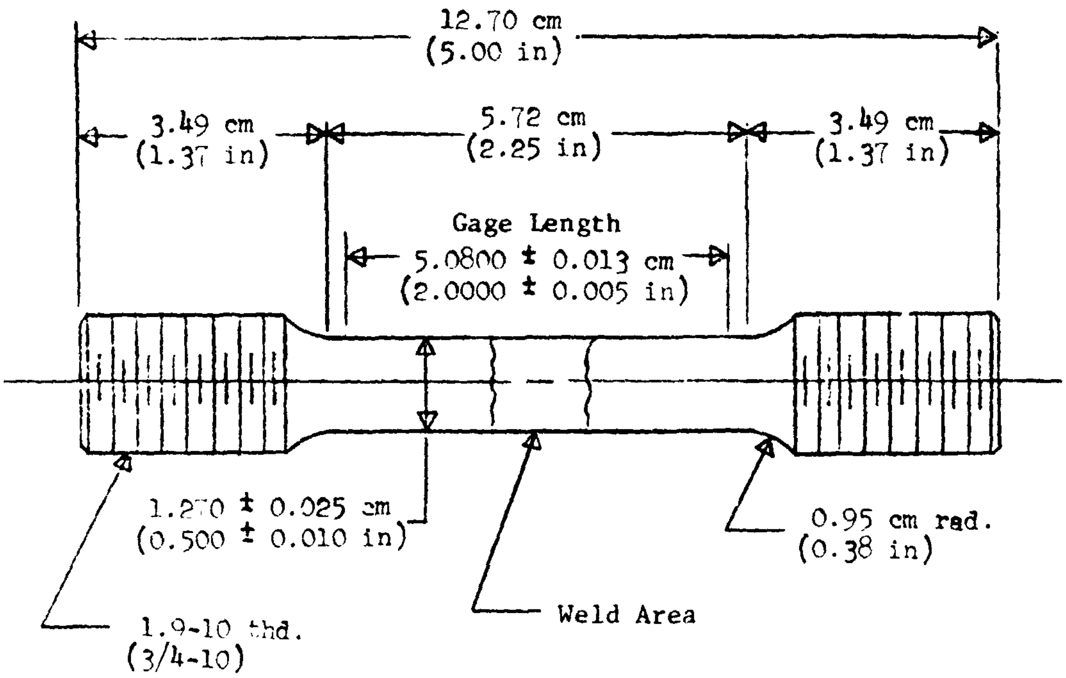


Figure 2. - Tensile Test Specimen Configuration.

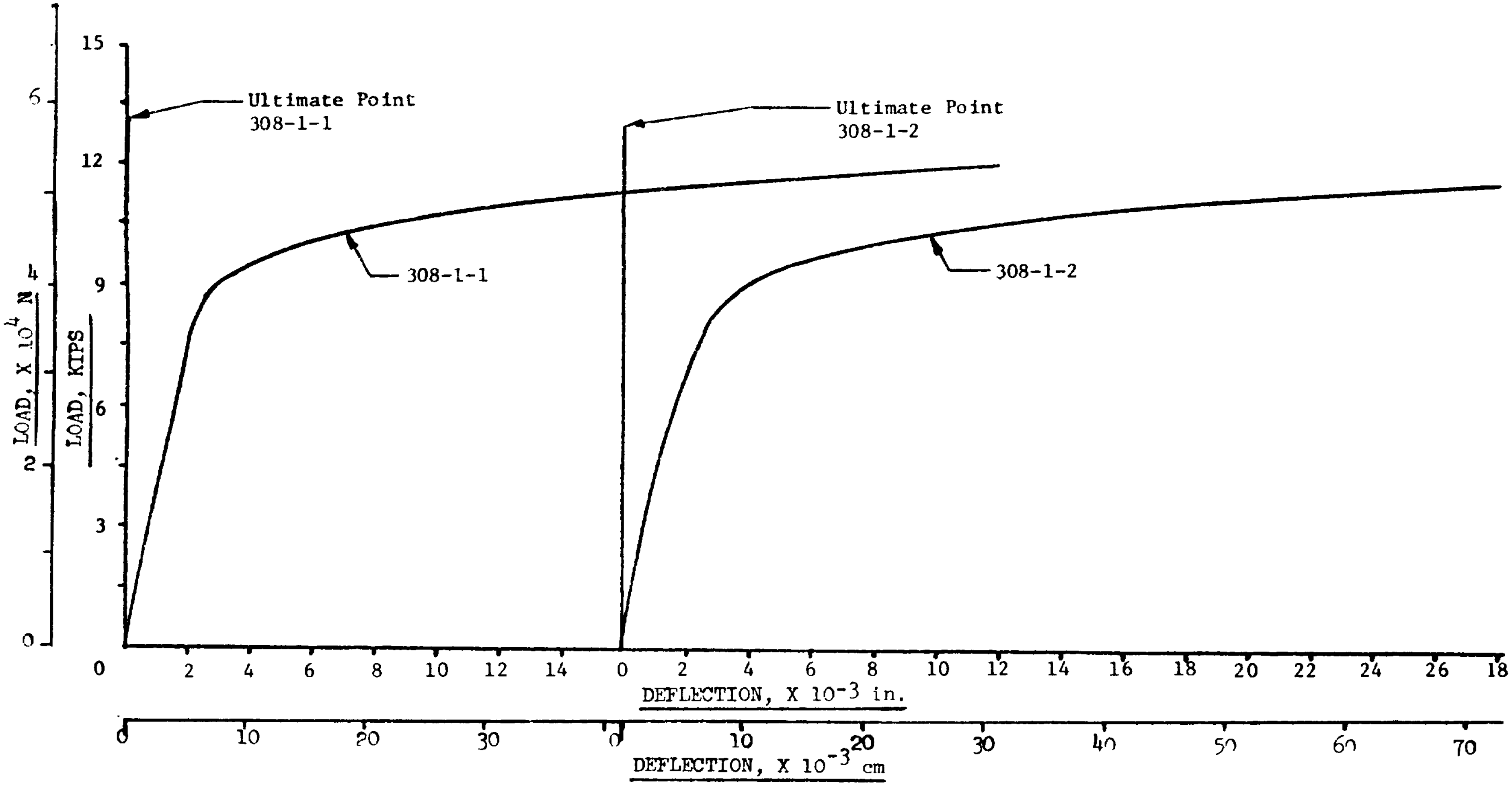


Figure 3. - Graph of Tensile Load vs Deflection for 308-1.

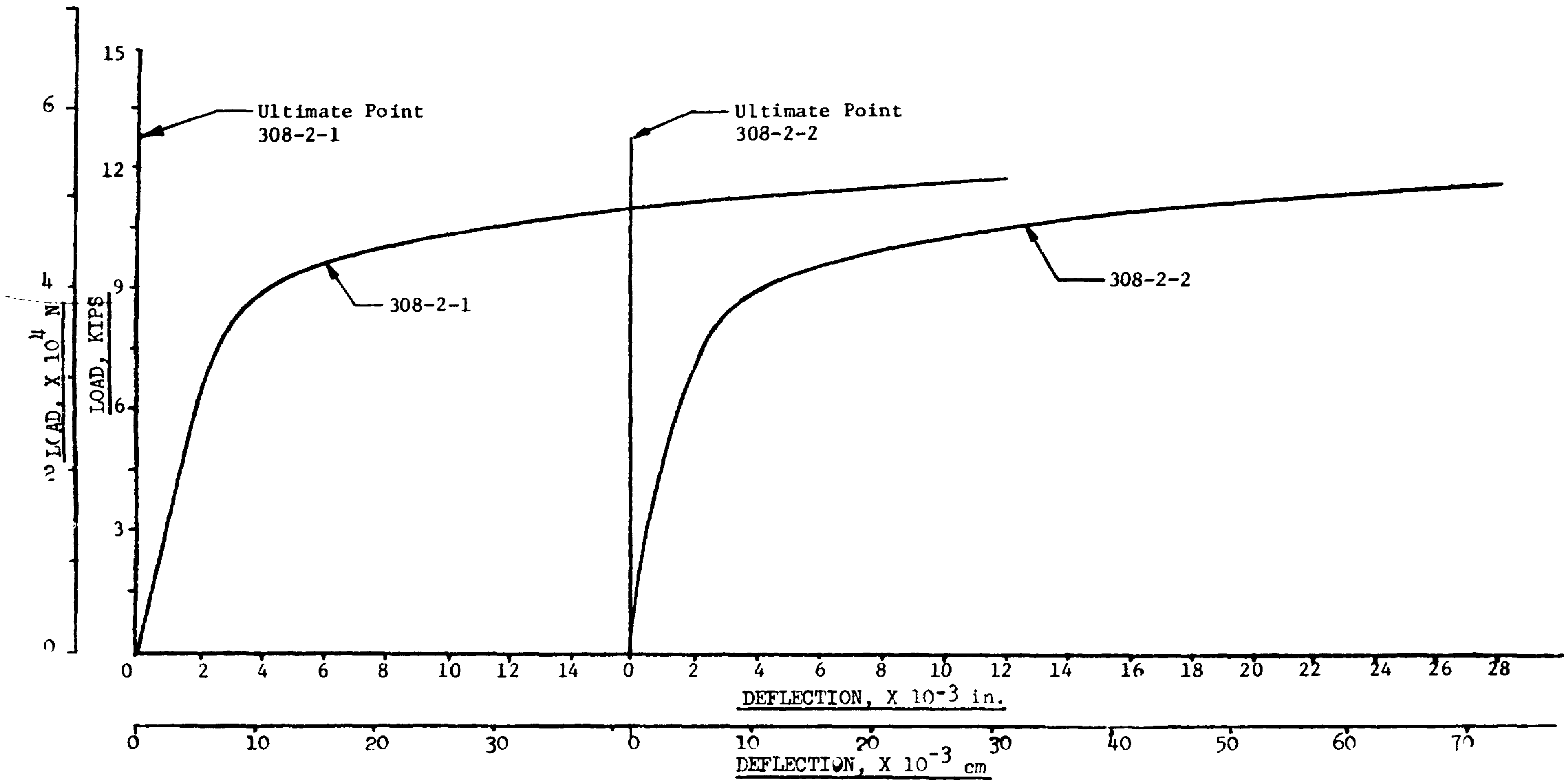


Figure 4. - Graph of Tensile Load vs Deflection for 308-2.

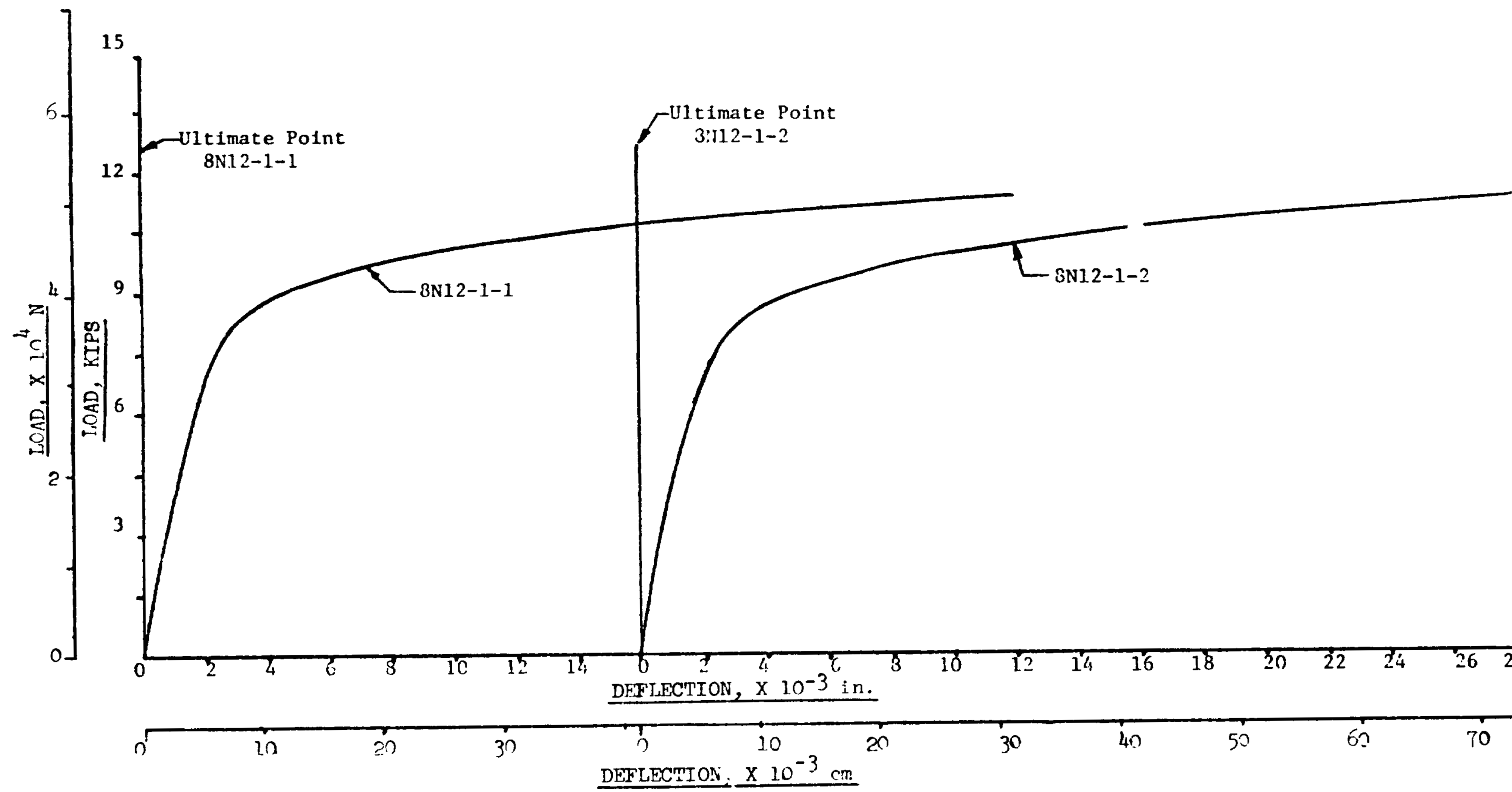


Figure 5. - Graph of Tensile Load vs Deflection for 8N12-1.

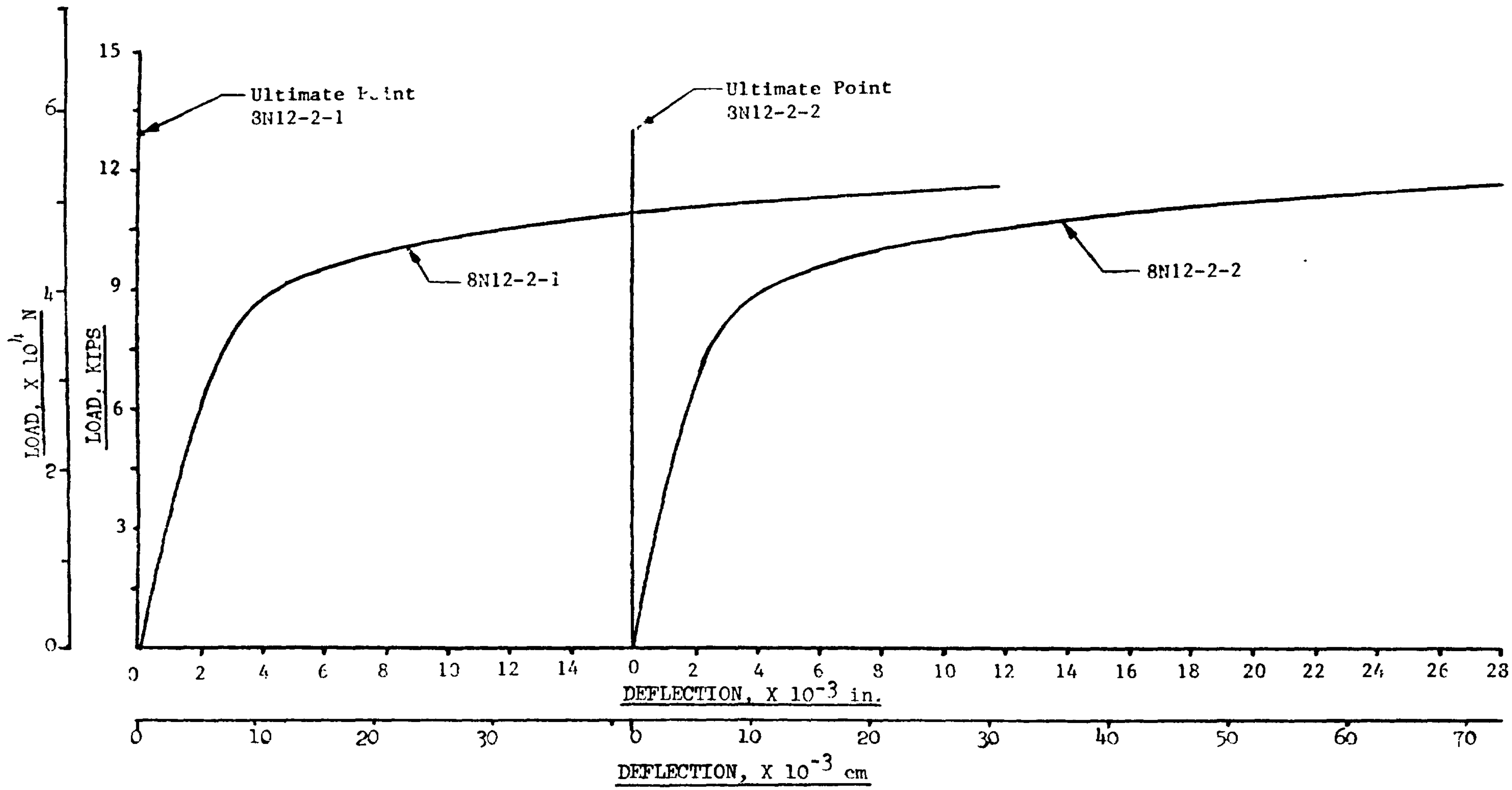


Figure 6. - Graph of Tensile Load vs. Deflection for 8N12-2.

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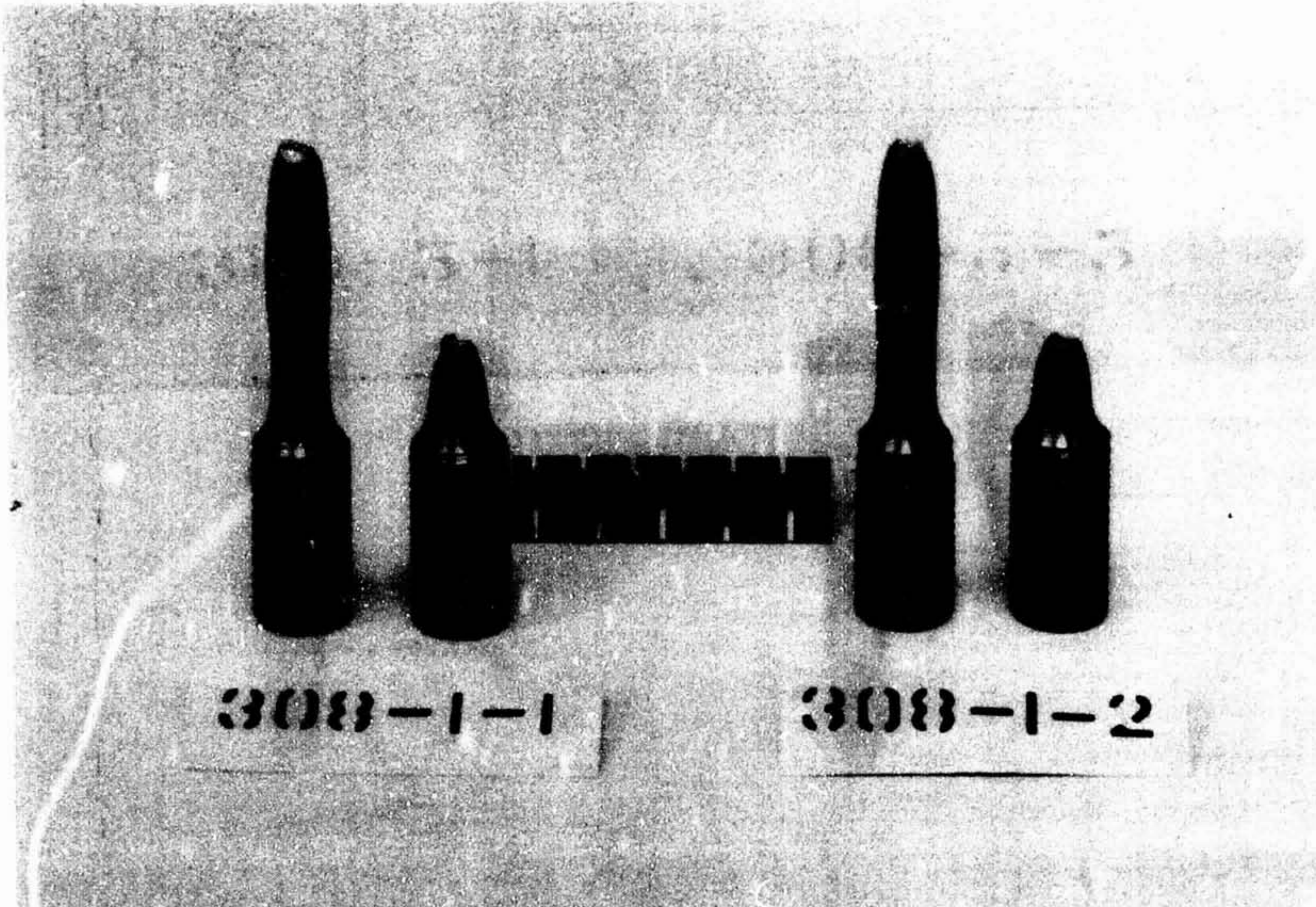

Figure 7.-Tensile Specimen of 308-1

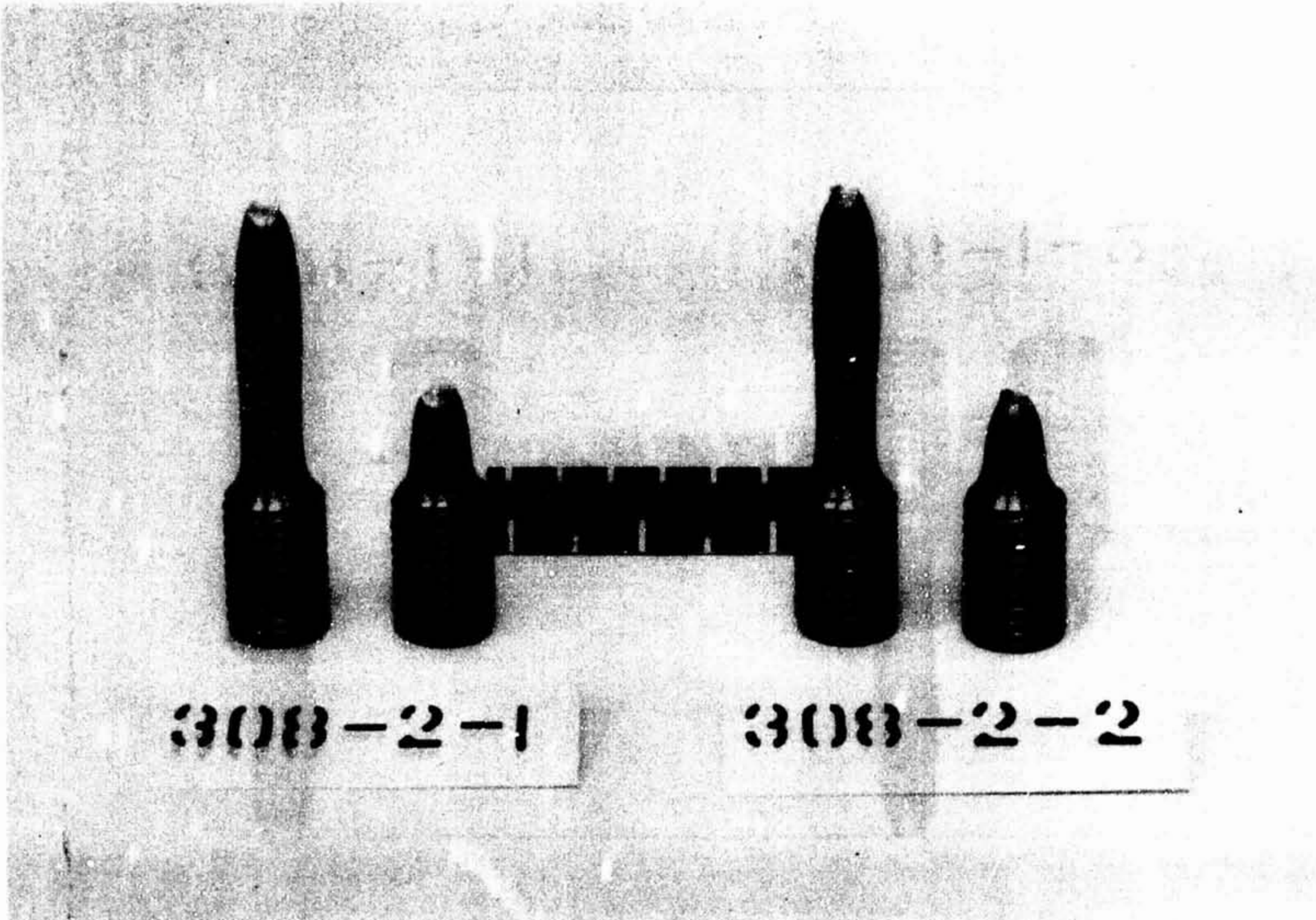

Figure 8.-Tensile Specimen of 308-2

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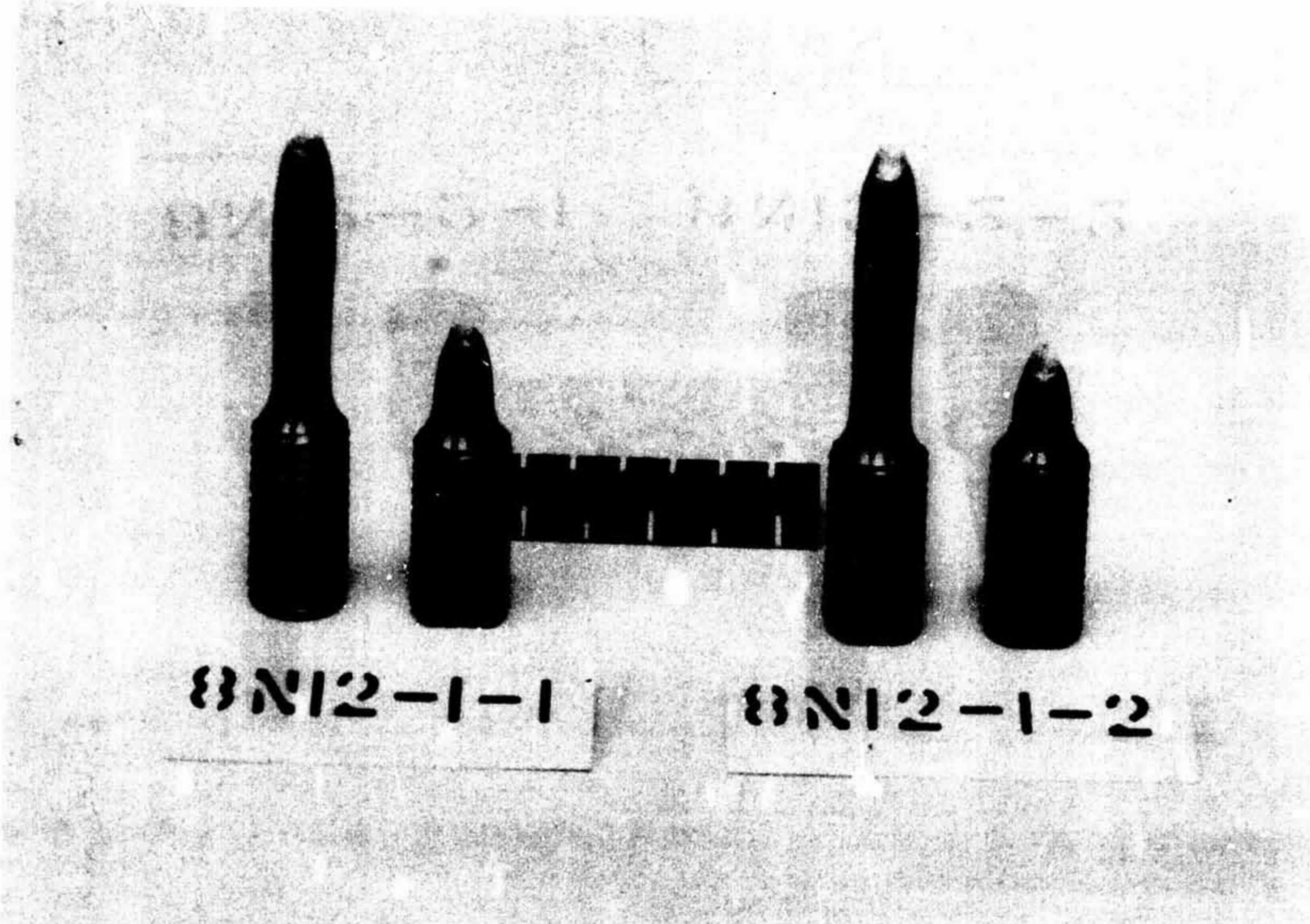

Figure 9.-Tensile Specimen of 8N12-1

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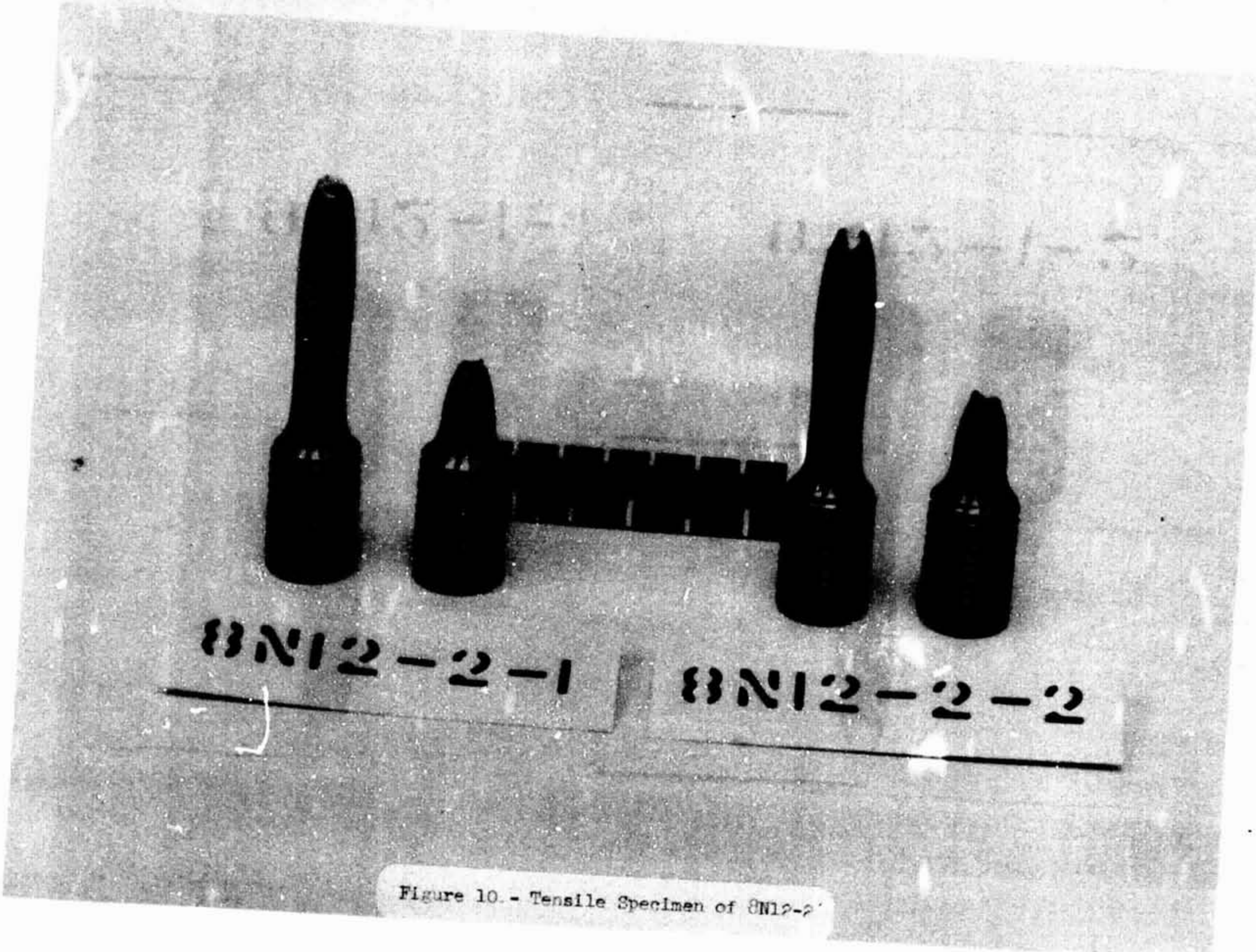

Figure 10. - Tensile Specimen of 8N12-2

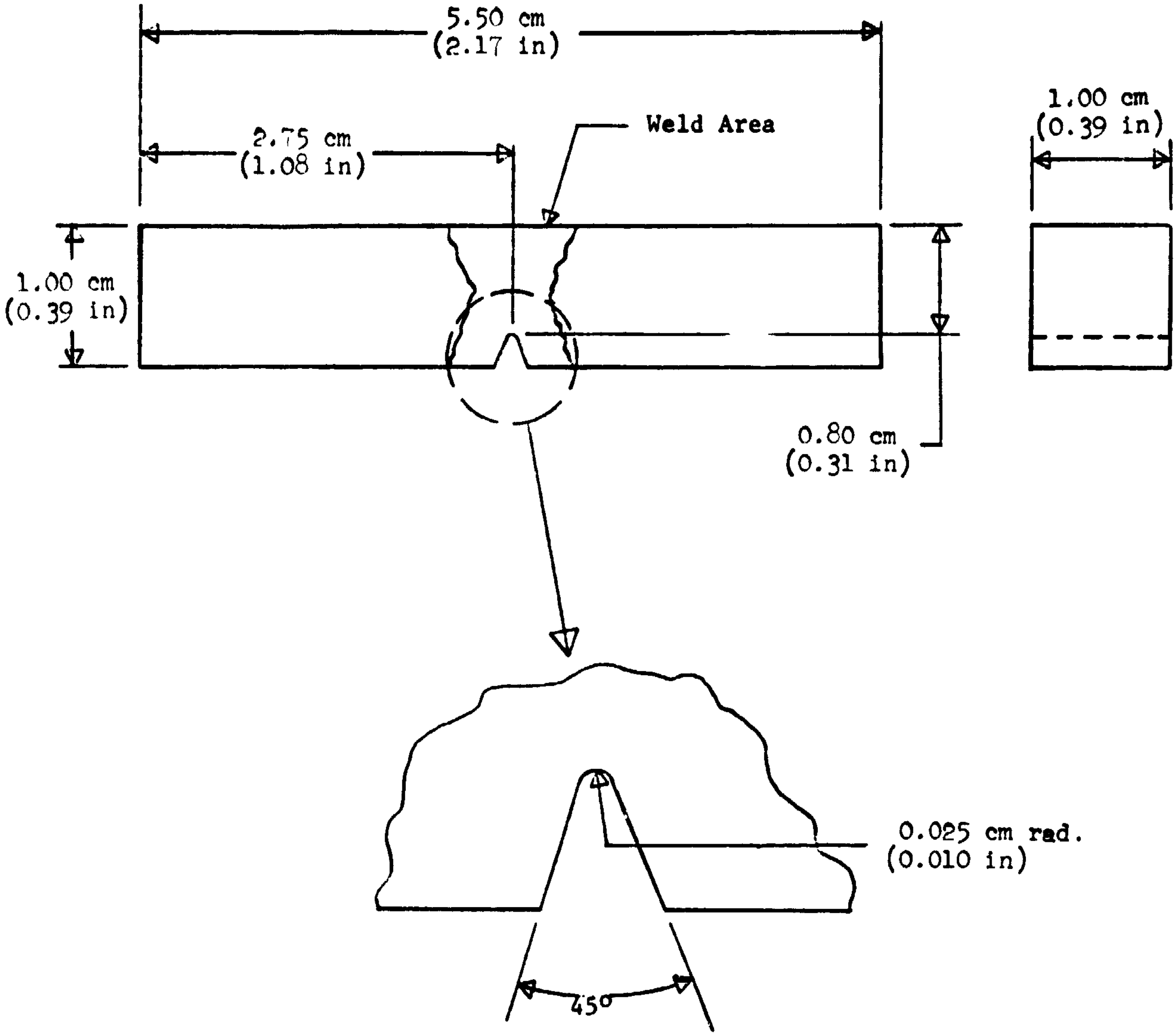

Figure 11. - Charpy Impact Test Specimen Configuration

IMPACT TEST REPORT

DATE: 6-20-80

Machine - Satec SI-1C, Capacity: FT-LBS. 240 *

Tested By: Lawson-Brooks

Impact Velocity, FT/SEC. 17 *

Specimen/Type: CVN   SIZE: STD.   MAT'L: Invar (B.M.) & 308L Transverse Weld

SP. NO.	TEST TEMP. °F *	IMPACT Value Ft-Lbs. *		LATERAL Expansion Mils *		% SHEAR Fracture	SP. Variables	Comments
308-1-1	-320	18.0		14			Cycled	100% Weld Break
308-1-2	-320	24.0	Avg =	18	Avg=		Cycled	95% Weld Break
308-1-3	-320	23.0	24.9	16.5	17.9		Cycled	90% Weld Break
308-1-4	-320	34.5		23			Cycled	90% Weld Break
308-2-1	-320	34.0		23			As Welded	100% Weld Break
308-2-2	-320	29.0	Avg =	27	Avg =		As Welded	100% Weld Break
308-2-3	-320	25.0	29.1	22	22.3		As Welded	100% Weld Break
303-2-4	-320	28.5		19			As Welded	100% Weld Break

* -320 °F = 77.6 °K
1.0 ft-lb = 1.4 J
1.0 Mil = 0.0254 mm
1.0 ft/sec = 0.3 m/sec

Figure 12. - Impact Test Report On 308L.

IMPACT TEST REPORT

Date : 6-20-80

Machine -Satec SI-1C, Capacity: FT-LBS. 240*

Tested By: Lawson-Brooks

Impact Velocity, FT/SEC. 17*

Specimen/Type: CVN SIZE : STD. MAT'L Invar (B.M.) & 8N12 Transverse Weld

SP. NO.	TEST TEMP °F *	IMPACT VALUE FT-LBS *		LATERAL EXPANSION, MIL *		%SHEAR FRACTURE	SP. VARIABLES	COMMENTS
8N12-1-1	-320	62.6		58			Cycled	90% Weld Break
8N12-1-2	-320	60.1	Avg =	50	Avg =		Cycled	100% Weld Break
8N12-1-3	-320	78.0	69.9	62	58.5		Cycled	70% Weld Break
8N12-1-4	-320	78.8		64			Cycled	50% Weld Break
8N12-2-1	-320	67.0		50			As Welded	100% Weld Break
8N12-2-2	-320	75.0	Avg =	58	Avg =		As Welded	100% Weld Break
8N12-2-3	-320	71.5	71.4	54	55.0		As Welded	100% Weld Break
8N12-2-4	-320	72.0		58			As Welded	100% Weld Break

* $-320\ ^{o}F = 77.6\ ^{o}K$

1.0 ft-lb = 1.4 J

1.0 Mil = 0.0254 mm

1.0 ft/sec = 0.3 m/sec

Figure 13. - Impact Test Report On 8N12

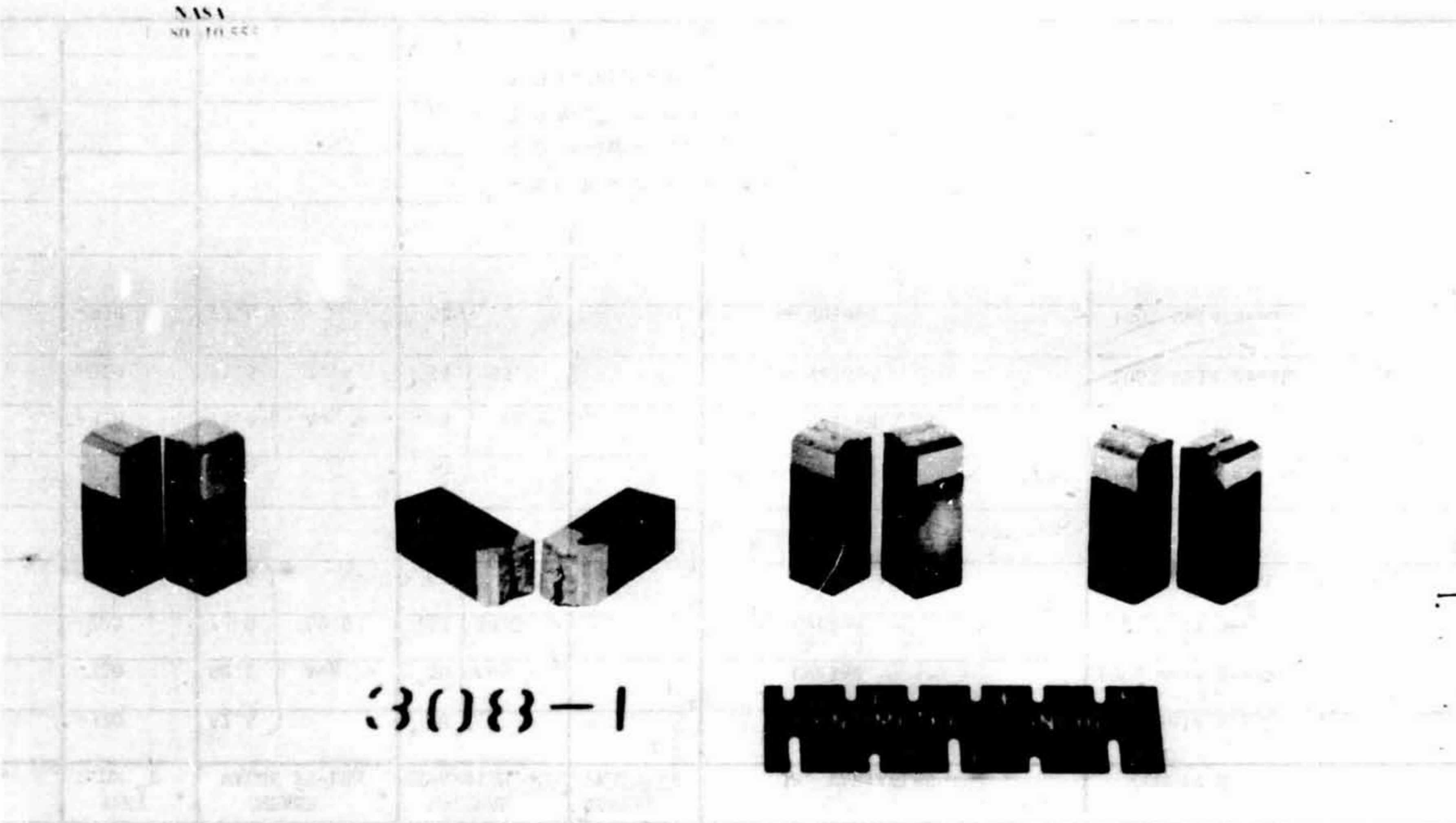

Figure 14.-Charpy Impact Specimen of 308-1

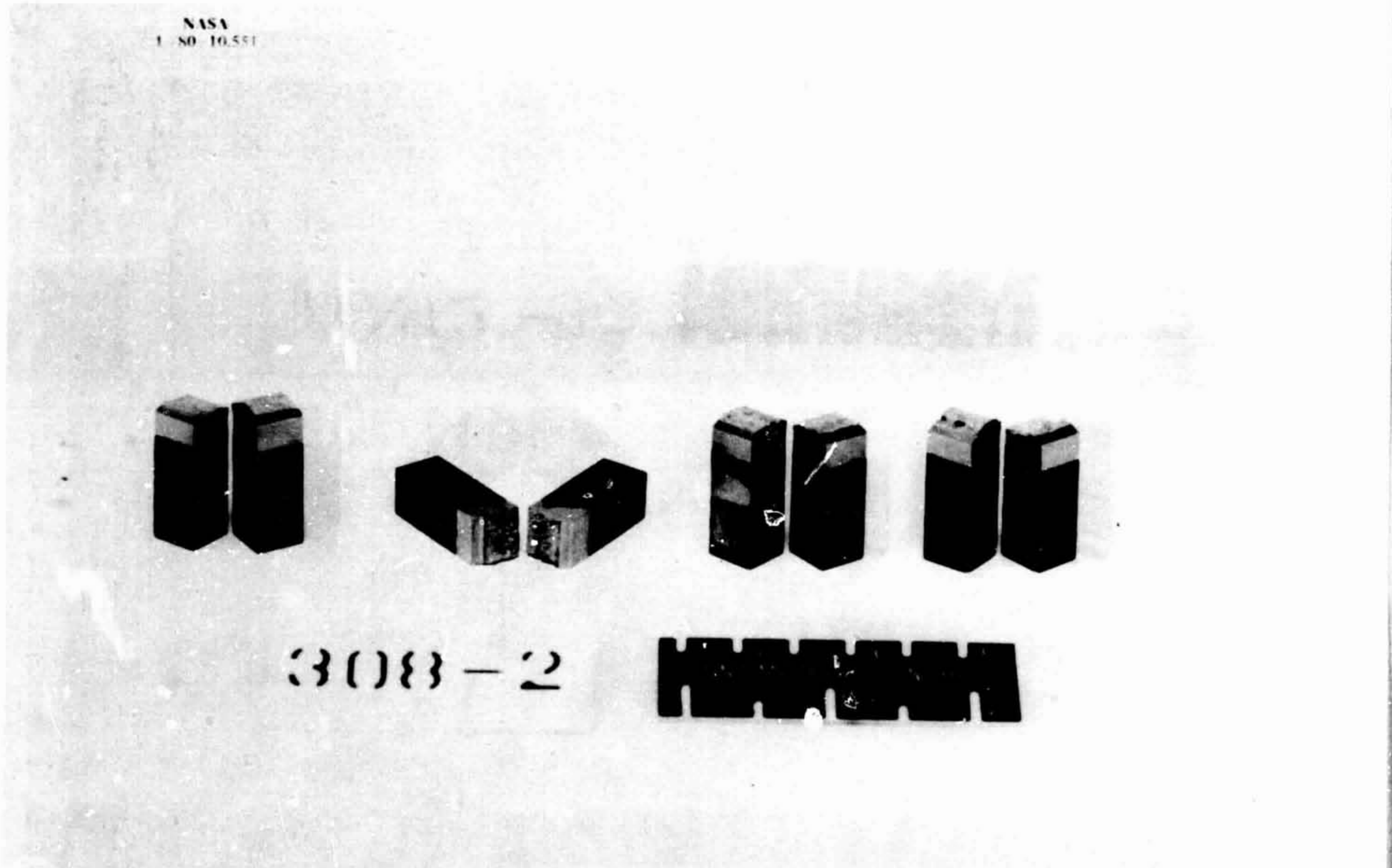

Figure 15 - Charpy Impact Specimen of 308-2

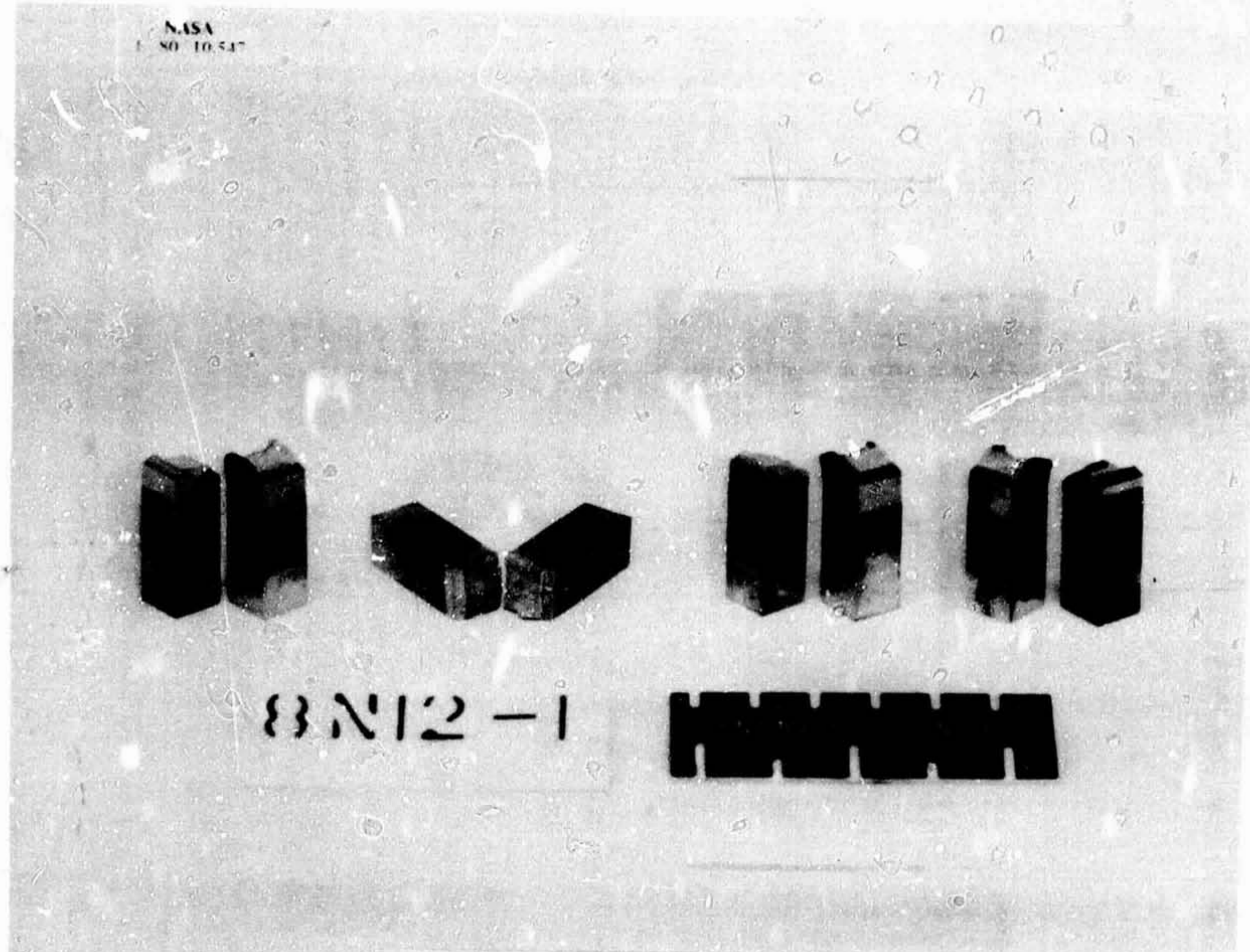

Figure 16.- Charpy Impact Specimen of 8N12-1

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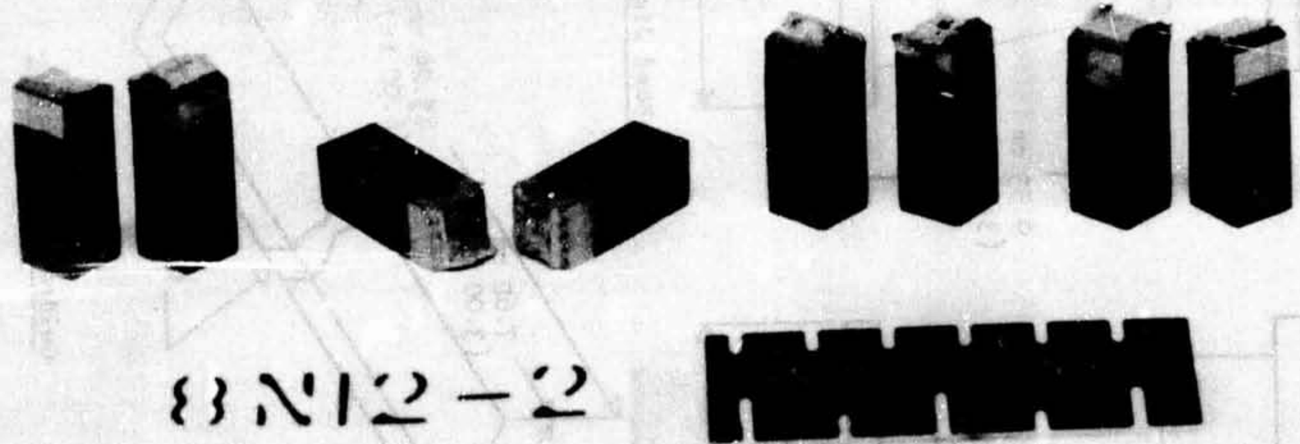

Figure 17.- Charpy Impact Specimen of 8N12-2

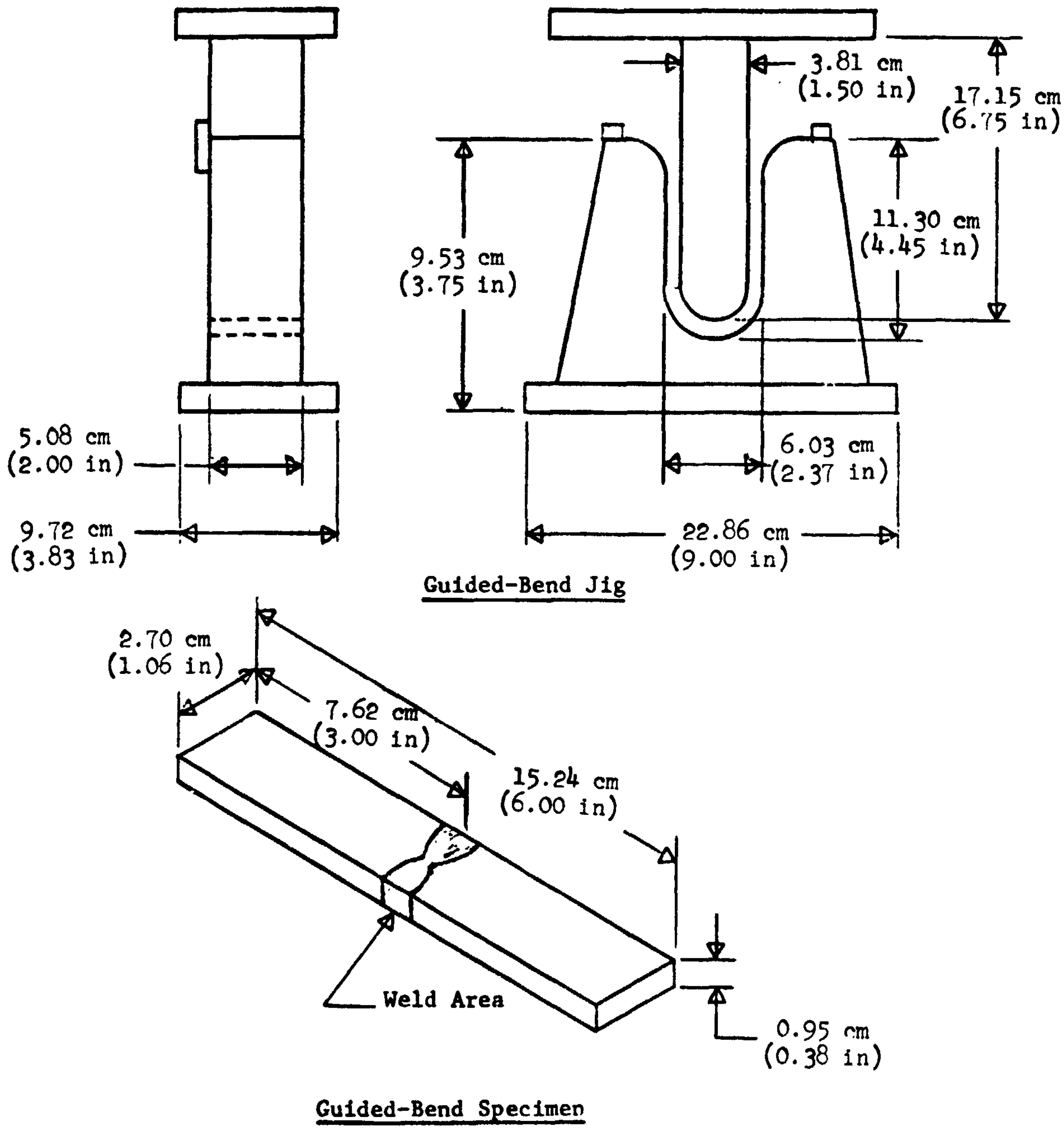

Figure 18. - Guided-Bend Jig and Specimen Configuration

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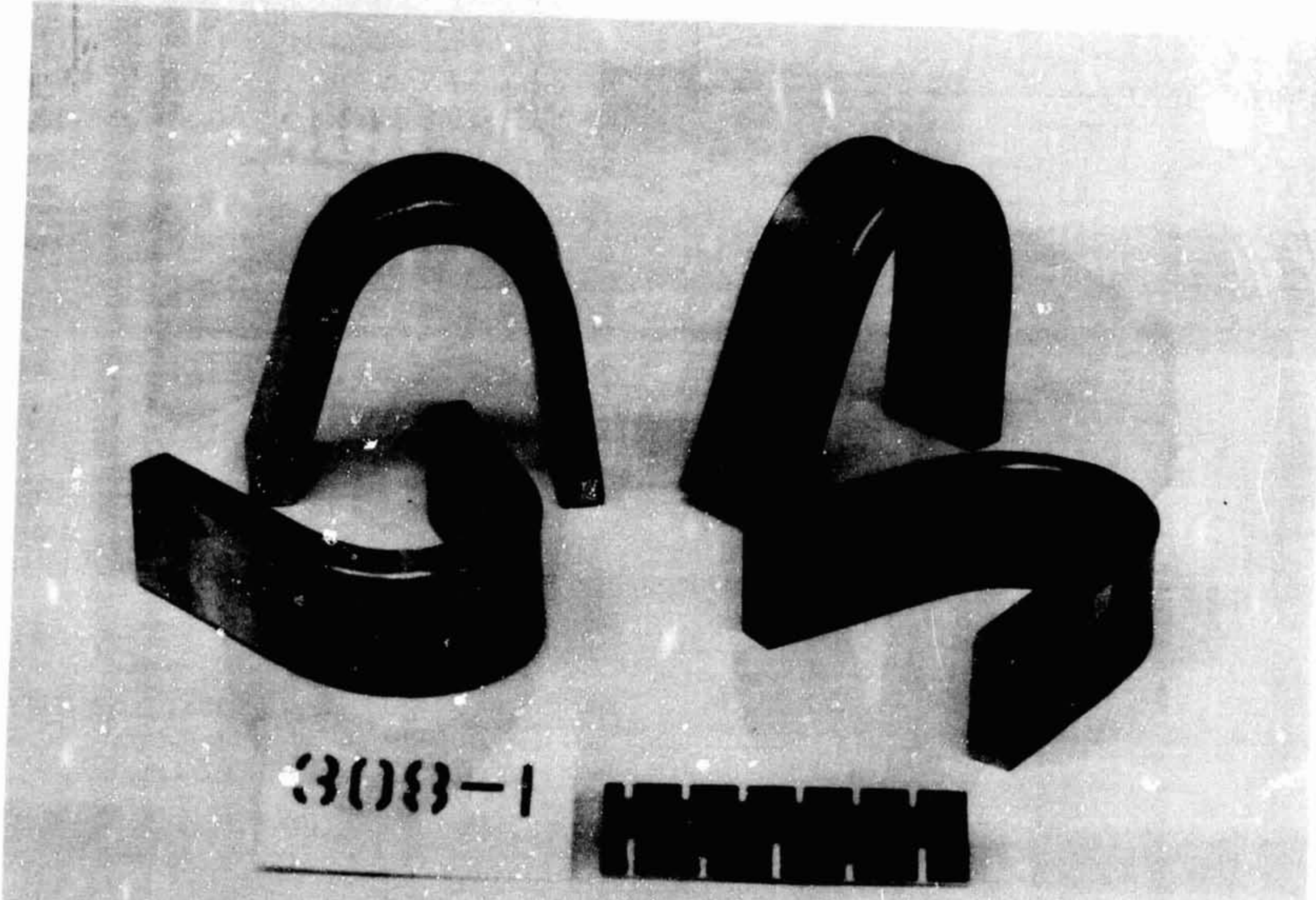

Figure 19.- Guided-Bend Specimen of 308-1

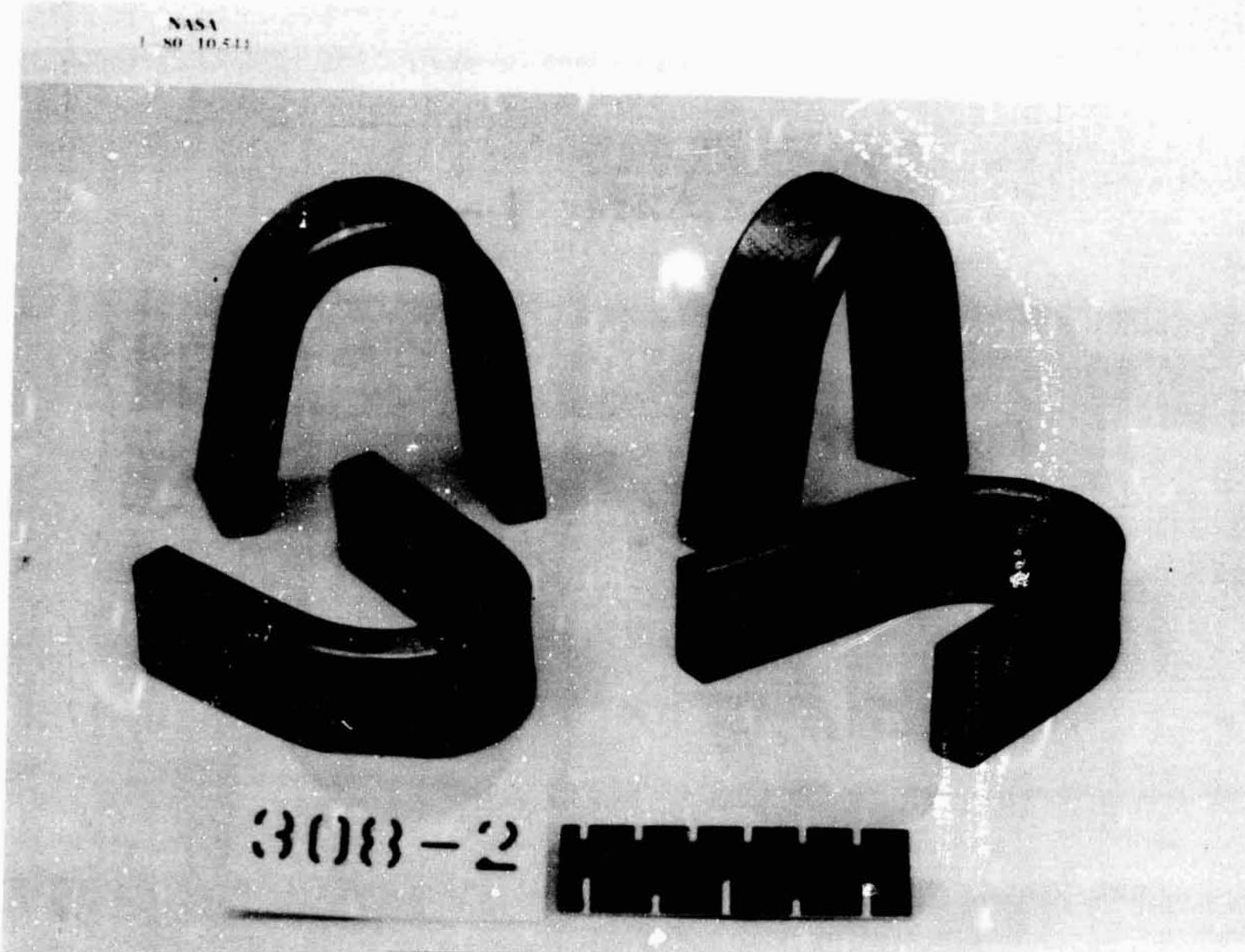

Figure 20. - Guided-Bend Specimen of 308-2

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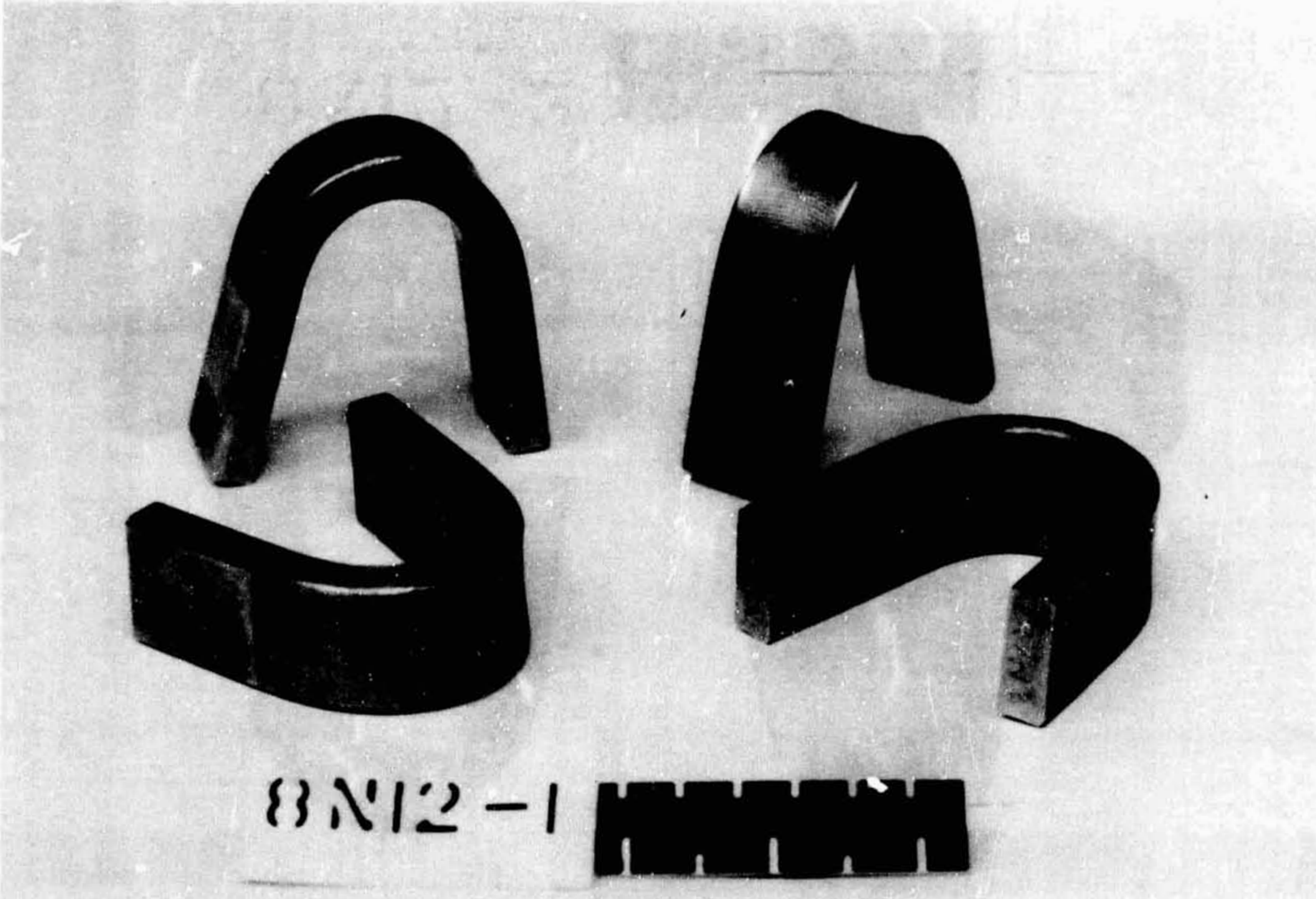

Figure 21.- Guided-Bend Specimen of 8N12-1

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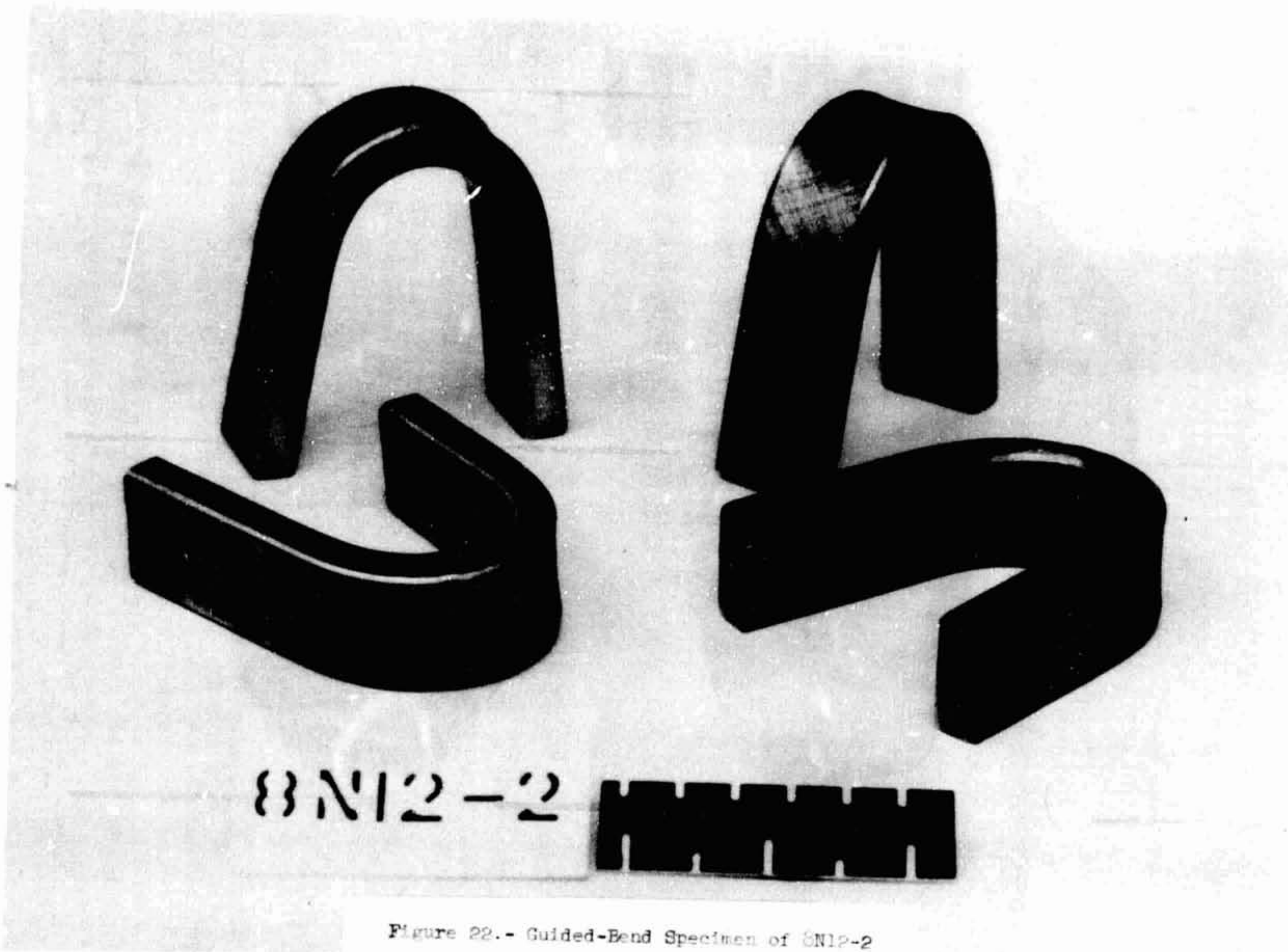

Figure 22.- Guided-Bend Specimen of 8N12-2