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September 1943 NRL Report No. M-2163

NAVY DEPARTMENT

FR-2163

Second Partial Report

on

N.R.L. Shock-Fracture Test for Welded Joints
in Connection with Welding Test #302

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

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TABLE OF CONTENTS

ABSTRACT

Eight weldments prepared by the Philadelphia Navy Yard in connection with welding test No. 302 were forwarded to the Naval Research Laboratory for NRL Shock-fracture Test. The performance of welded and unwelded low alloy ballistic steel (302-M-1) compares favorably with that of special treatment steel (302-N-1) when subjected to the N.R.L. shock-fracture test.

AUTHORIZATION

1. This problem was authorized by Bureau of Ships letters QP/W&C-(4)-(5)(3692) of 31 January 1943 and QP/W&C-(4)-(5)(692-350) of 9 April 1943.

OBJECT OF TESTS

2. Eight restrained groove ballistic pendulum test pieces were prepared by the Philadelphia Navy Yard in connection with Welding Test No. 302 (Low Alloy Ballistic Steel Welded with 19-9 Mn and 25-20 Electrodes - Weldability of) in accordance with Code 692 SK No. 2422-3 dated 1-8-43 (reproduced here as Plate 1). These were forwarded to the Naval Research Laboratory for investigation of their performance in the NRL Shock-Fracture Test, using methods reported in the "First Partial Report on N.R.L. Shock-Fracture Test for Welded Joints in Armor" (N.R.L. Report No. M-2050 of 26 April 1943).

3. In order to evaluate the efficiency of the weld joints a sixty (60) pound 12 inch by 15 inch plate of each composition of armor was also forwarded to the Laboratory for shock-fracture testing. The eight single V-groove weld joints and the two samples of armor were identified as shown in Table I. The composition of the weld metal as determined by chemical analysis from specimens 216 to 223 inclusive is given in Table II.

NARRATIVE OF TESTS AT THE NAVAL RESEARCH LABORATORY

4. Since the present N.R.L. shock fracture test equipment was designed for a maximum specimen thickness of one inch, it was necessary to machine the low alloy and special treatment steel armor plate to this thickness. Specimens were then prepared (Plate 2) with the length of the fingers both along and transverse to the principal direction of rolling. It was desirable to test the root of the weld in the as welded condition, hence, the backing strips of the weldments were removed and the face sides of the welds were shaped off to obtain a thickness of one inch. Standard specimens were then machined (Plate 3) from the weldments.

5. The limit velocity, that is, the velocity required to just break the finger from the specimen, was determined for each of the two grades of armor used in the tests and for each weldment.

6. Transverse sections of the weldments were examined macroscopically and photographed at 2 diameters. Some microscopic examination was made of the weld joints, particular attention being given to the fusion line.

DATA OBTAINED IN THESE TESTS

7. The performance of the armor and weld joint specimens in the shock fracture test is given in Tables III and IV. Since the fingers of all the weld specimens were in the principal direction of rolling of the base metal, the efficiencies of the weld joints were calculated using the limit velocities of the armor specimens with the fingers longitudinal to the direction of rolling. The appearance of typical test specimens after shock-fracture are shown in Plates 4 to 12. A study of the macrostructures of the weld joints is presented in Plates 13 to 17. Several photographs of the microstructures are shown in Plates 18 to 22.

DISCUSSION OF TESTS

8. A detailed discussion of each test follows:

Armor Behavior

Results of shock fracture tests on low alloy ballistic steel #258(302-M-1), special treatment steel #261(302-N-1) and special treatment steel #206 (Data from NRL Report M-2050) are given in Table IV and Plates 4 to 7. For similar hardness values the specimens with the fingers in the direction of rolling had considerably higher limit velocities than those in the transverse direction. The limit velocities for longitudinal specimens of the three materials indicate that they had approximately the same shock-fracture resistance; greater variations in the limit velocities were noted for the transverse specimens.

Low Alloy Ballistic Steel

No. 216: Low alloy steel welded in the flat position with grade IV electrode. All fractures occurred along the fusion line and clearly showed the bead technique of the weld (Plate 8 and 13a). These fractures were typical of many of the failures for the weldments in this test.

No. 217: Low alloy steel welded in vertical position with grade IV electrode. Failure occurred along the fusion line in all cases. The fractures had a porous appearance, the porosity occurring between the beads of the weld. A partial fracture sectioned through the center of the finger showed that failure started along the fusion line on the impact side of the finger and progressed into the weld (Plate 13b).

No. 218: Low alloy steel welded in the flat position with Grade V electrode. Only one finger was completely fractured and this showed a fusion line failure and bead appearance similar to that of #216 (Plate 9, 10 and 14a).

No. 219: Low alloy steel welded in the vertical position with grade V electrode. Failure occurred along the fusion line in all cases, the fracture being similar to that of No. 216, Plates 11 and 14b. In the specimen tested with the root in compression, there appeared an area about 1/8" deep across the entire front of the fracture which was dark and very rough indicating the presence of a previous weld crack. This condition was also noticeable in the specimens tested with root in tension, the dark area again occurring in the same portion of the weld.

Special Treatment Steel

No. 220: S.T.S. armor welded in the flat position with Grade IV electrodes. Three of the fractures followed the fusion line about two thirds of the way from the impact side of the specimen after which the break progressed into the base metal to a depth about 1/8" below the heat affected zone (Plate 15a). The other fracture (Impact No. 843) was a complete fusion line failure similar to those of No. 216.

No. 221: S.T.S. armor welded in the vertical position with Grade IV electrodes. The fracture revealed a great deal of porosity in the weld, the condition being more pronounced in this specimen than in #217. Two of the fractures were essentially fusion line failures although a part of the fracture occurred in the weld metal (Plates 12 and 15b). The third fracture (Impact No. 751) was similar to the first three described above in No. 220. Evidence of a tendency toward this type of failure in the other two fractures was indicated by a crack in the base metal parallel to the face of the plate.

No. 222: S.T.S. armor welded in the flat position with grade V electrodes. Three of the fractures were fusion line failures similar to those of No. 216 (Plate 16 (a)). The other fracture (Impact No. 756) started at the fusion line and progressed into the weld about 1/8" above the fusion line (Plate 16(b)). Some porosity was evident in these fractures. In Table I the results of the shock-fracture test of this weldment show that one ballistic specimen had a limit velocity above 2400 ft./sec. while the other two had a limit velocity of about 2000 ft./sec; this large discrepancy apparently is due to a variation in weld quality across the plate.

No. 223: S.T.S. armor welded in the vertical position with Grade V electrodes. Three of the fractures (Impacts No. 762, 849, and 853) were fusion line failures while one (Impact No. 851) was a partial weld failure and the other (Impact No. 762) was a complete weld failure (Plate 17(a) and (b)). Evidence of much porosity was present in all cases.

ADDITIONAL EXAMINATION MADE ON TEST WELDMENTS

9. Vickers hardness surveys were made on transverse sections of the weldments. The average maximum hardness in the heat affected zone of all specimens ranged between 340-380 Vickers (10 kg. load).

10. Three out of four of the weldments made in the vertical position showed a great deal of porosity while the fourth, No. 219, showed the presence of a root weld crack by the roughened dark area described above.

11. Metallographic specimens of the weldments were taken from Plate Nos. 216, 220 and 223. These specimens were prepared in the usual manner and etched electrolytically with 10 per cent oxalic acid to reveal the cored structure in the austenitic weld metal. A 5 per cent Nital solution was then used to etch the base metal. Examination disclosed a narrow unetched white band (approximately 0.0005" wide) which separated the weld and base metals (Plates 18 to 20). An attempt to etch this band with potassium ferricyanide was unsuccessful (Plate 19(b)). Micro-hardness surveys made with a Tukon hardness tester (.2 kg. load) indicated that the white band was of approximately the same hardness (I.H.N. 250) as the weld metal. All of the specimens exhibited a network of apparently unetched metal similar to the white band which extended into the base metal from the white band. Although most of the fractures would be considered fusion line failures, they followed the fusion line only approximately and did not coincide to any great extent with the white band. This seems to indicate that the white band was not the weakest part of the welded section (Plates 21 and 22)

SUMMARY AND CONCLUSIONS

12. The following indications are noted from these tests:

1. The resistance of the unwelded low alloy ballistic steel to the N.R.L. shock-fracture test compares favorably with the sample of special treatment steel submitted.

2. The joint efficiency for the low alloy ballistic steel based on limit velocity in the N.R.L. shock-fracture test averaged 80 per cent. For the special treatment steel the joint efficiency averaged 84 per cent for the samples tested; this is not a significant difference.

3. A slight improvement in joint efficiency (2 to 4 per cent) was noted for the Grade IV (25-20 Cr-Ni) electrodes compared with the Grade V (19-9 Cr-Ni 4 Mn) electrodes in these tests; this is not a significant difference.

4. Most of the failures occurred in the weld metal at the fusion zone with fracture occurring haphazardly in the weld metal along and in the white band.

5. The lowest joint efficiency (67 per cent) was obtained for the weld made in the vertical position with Grade V (19-9-4 Mn) electrode on low alloy ballistic steel; an indication of cracking in the root pass was noted. The highest joint efficiency (92 per cent) was obtained for the weld made in the flat position with Grade IV (25-20 Cr-Ni) electrode on special treatment steel.

TABLE I MATERIALS AND IDENTIFICATION

BuShips (692) Sk.No.2422-3 Welds	NRL Identification
H-IV-F	216
H-IV-V	217
H-V-F	218
H-V-V	219
I-IV-F	220
I-IV-V	221
I-V-F	222
I-V-V	223
(H) 302-M-1	258
(I) 302-N-1	261

H - 60# low alloy ballistic steel
I - 60# special treatment steel
IV - Grade IV electrode 25-20 Cr-Ni
V - Grade V electrode 19-9 Cr-Ni & Mn
F - Position of Welding - Flat
V - Position of Welding - Vertical

TABLE II WELD METAL COMPOSITION

Weldment No.	Cr	Per Cent Ni	Mn
H-IV-F (216)	25.26	19.74	2.19
H-IV-V (217)	25.79	19.84	2.19
H-V-F (218)	19.07	9.52	3.88
H-V-V (219)	19.35	9.52	3.85
I-IV-F (220)	25.62	20.31	2.23
I-IV-V (221)	25.45	19.30	2.10
I-V-F (222)	19.47	9.70	3.88
I-V-V (223)	19.35	9.79	3.89

TABLE III RESULTS OF SHOCK-FRACTURE TESTS

Specimen No. NRL	BuShips	Impact No.	Velocity ft/sec.	Results	Limit Velocity ft./sec.
258L	302-M-1 low alloy	1101	2610	on	
		1103	2623	on	
		1104	2639	on	
		1099	2649	on	
		1096	2671	on	
		1102	2685	off	2680 ± 25
		1100	2694	off	
		1098	2714	off	
		1097	2719	off	
258T	302-M-1	1107	2198	on	
		276	2248	on	
		1093	2276	on	2390 ± 100
		275	2340	off	
		1106	2462	off	
		1095	2490	on	
		1094	2492	off	
		1105	2518	off	
		274	2533	off	
261L	302-N-1 Special Treatment	1117	2606	on	
		1091	2617	on	
		1092	2630	just on	
		1118	2632	on	2630 ± 25
		1090	2637	off	
		1119	2699	off	
		1089	2715	off	
261T	302-N-1	277	1939	on	
		278	2132	on	
		279	2162	just on	
		1113	2212	on	
		1110	2216	on	
		1112	2283	off	2290 ± 75
		1108	2301	just on	
		1111	2354	off	
		1109	2425	off	
216	H-IV-F	725	1962	on	
		729	2027	on	
		728	2070	on	
		727	2106	off*	
		730	2143	on	
		731	2205	on	
		733	2258	just off	2250 ± 25
		732	2274	off	
		726	2310	off	

*Weld Defective

Table III (Continued)

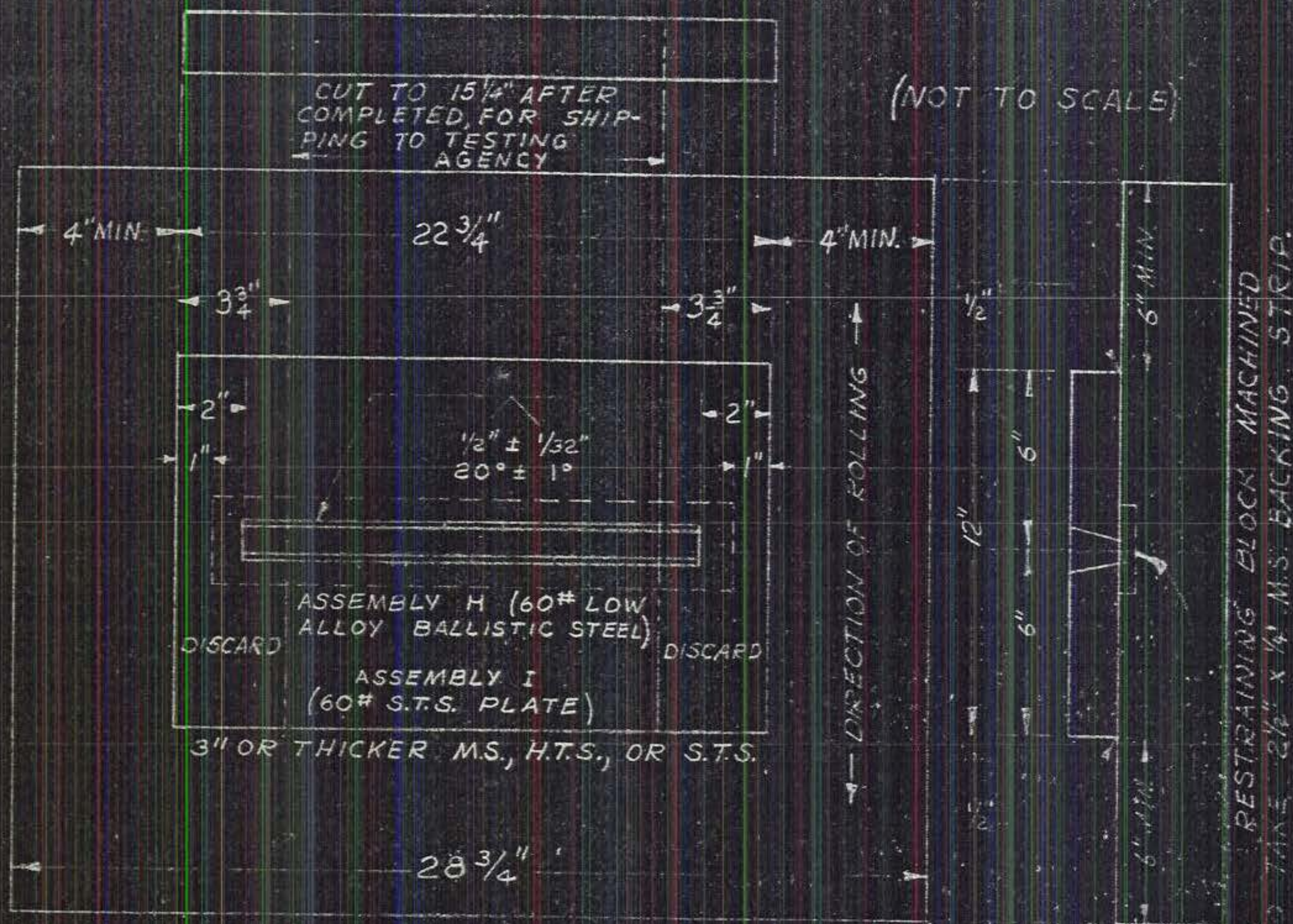
Specimen No. NRL	Specimen No. BuShips	Armor Impact No.	Velocity ft/sec.	Results	Limit Velocity ft./sec.
222	I-V-F	760	1919	on	
		759	2030	off	2000 ± 50
		755	2055	on	
		758	2082	off	
		757	2148	off	
		756	2254	off	
		845	2097	on	
		846	2236	on	
		847	2400	on	Above 2400*
223	I-V-V	761	2123	on	
		763	2277	on	
		848	2297	on	
		762	2300	off	2360 ± 50
		852	2357	on	
		853	2426	off	
		851	2484	off	
		850	2490	off	
		849	2592	off	

* See paragraph 8

TABLE IV SUMMARY OF SHOCK-FRACTURE TESTS

Specimen Number NRL	BuShips	BHN	Limit Velocity ft/sec.	Joint Efficiency Per Cent
Armor				
258L	302-M-1	270	2680 ± 25	100
258T	302-M-1	270	2390 ± 50	
261L	302-N-1(STS)	250	2630 ± 25	100
261T	302-N-1(STS)	250	2290 ± 50	
206L	STS 1"	264	2700 ± 25	(Data from N.R.L.
206T	STS 1"	257	2480 ± 25	Report M-2050)
Weldments				
216	H-IV-F		2250 ± 25	84
217	H-IV-V		2130 ± 50	80
218	H-V-F		2380 ± 25	89
219	H-V-V		1800 ± 25	67
			Average - - - - - - - -	80
220	I-IV-F(STS)		2410 ± 50	92
221	I-IV-V		2404 ± 25	78
222	I-V-F		2000 ± 50	76
223	I-V-V		2360 ± 50	90
			Average - - - - - - - -	84

L - Longitudinal
T - Transverse



RESTRAINED GROOVE BALLISTIC PENDULUM TEST

RESULTS DESIRED:

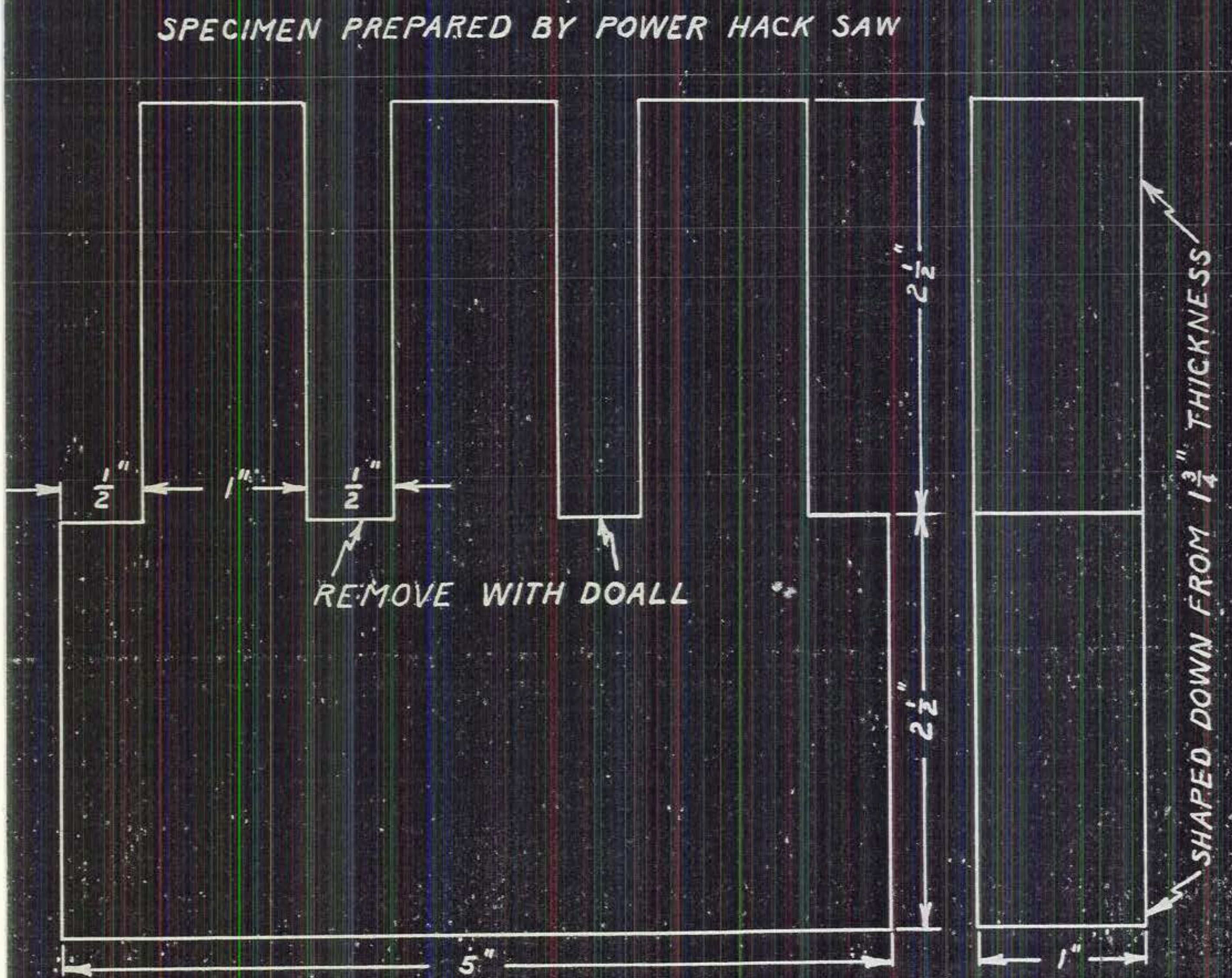
RESULTS IN LOW ALLOY STEEL SHALL NOT BE LESS THAN THOSE OBTAINED IN REGULAR S.T.S. PLATE.

NOTE 1- SEE NOTES FOR ASSEMBLY E.

NOTE 2- SEE FIG. I FOR WELDING TECHNIQUE.

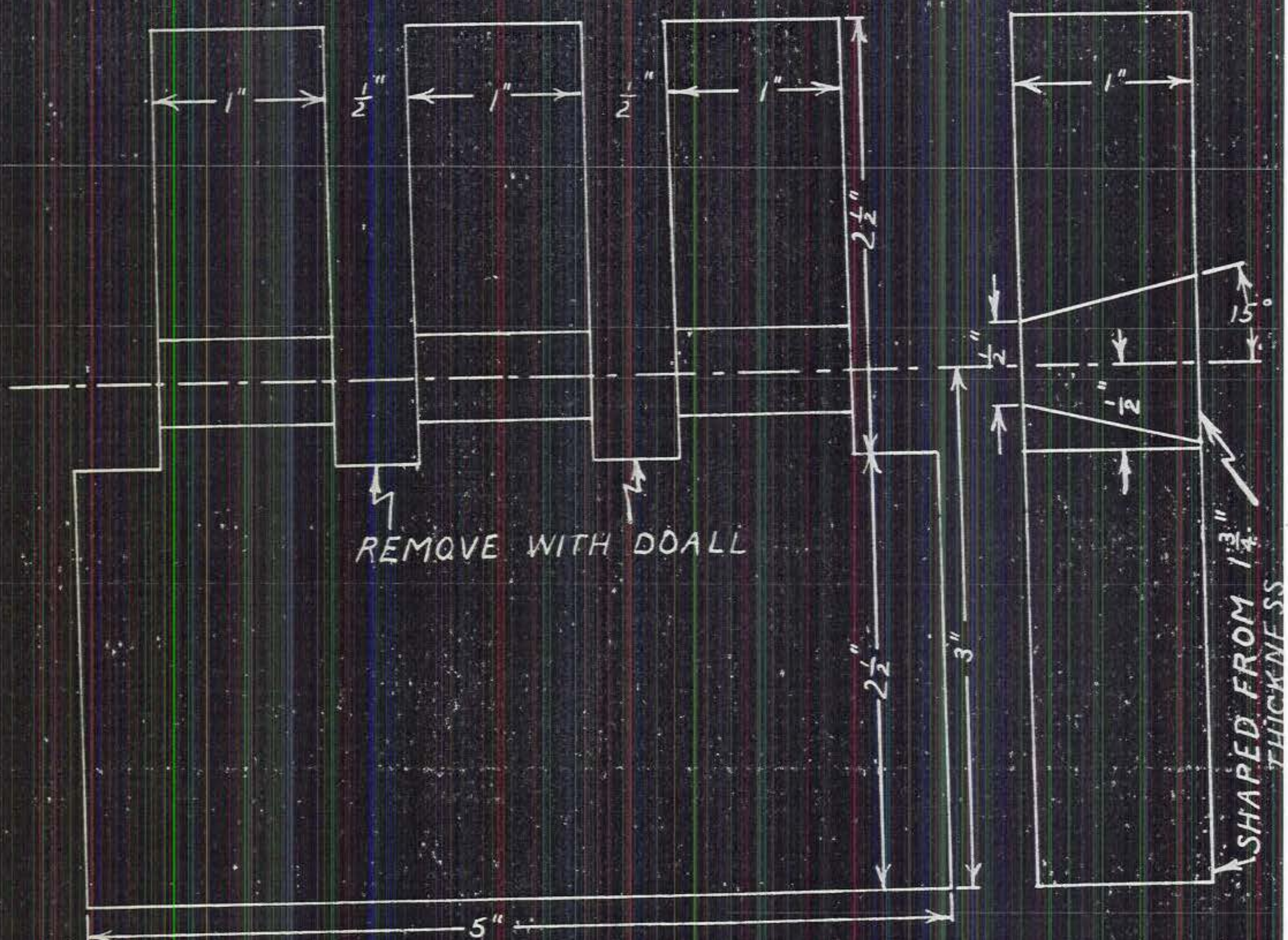
	GRADE ELECTRODE	POSITION OF WELDING	BASE METAL
ASSEMBLY-H-IV-F	IV	FLAT	60# LOW ALLOY BALLISTIC STEEL
ASSEMBLY-H-IV-V	IV	VERTICAL	
ASSEMBLY-H-V-F	V	FLAT	
ASSEMBLY-H-V-V	V	VERTICAL	
ASSEMBLY-I-IV-F	IV	FLAT	60# S.T.S. PLATE
ASSEMBLY-I-IV-V	IV	VERTICAL	
ASSEMBLY-I-V-F	V	FLAT	
ASSEMBLY-I-V-V	V	VERTICAL	

PLATE 1

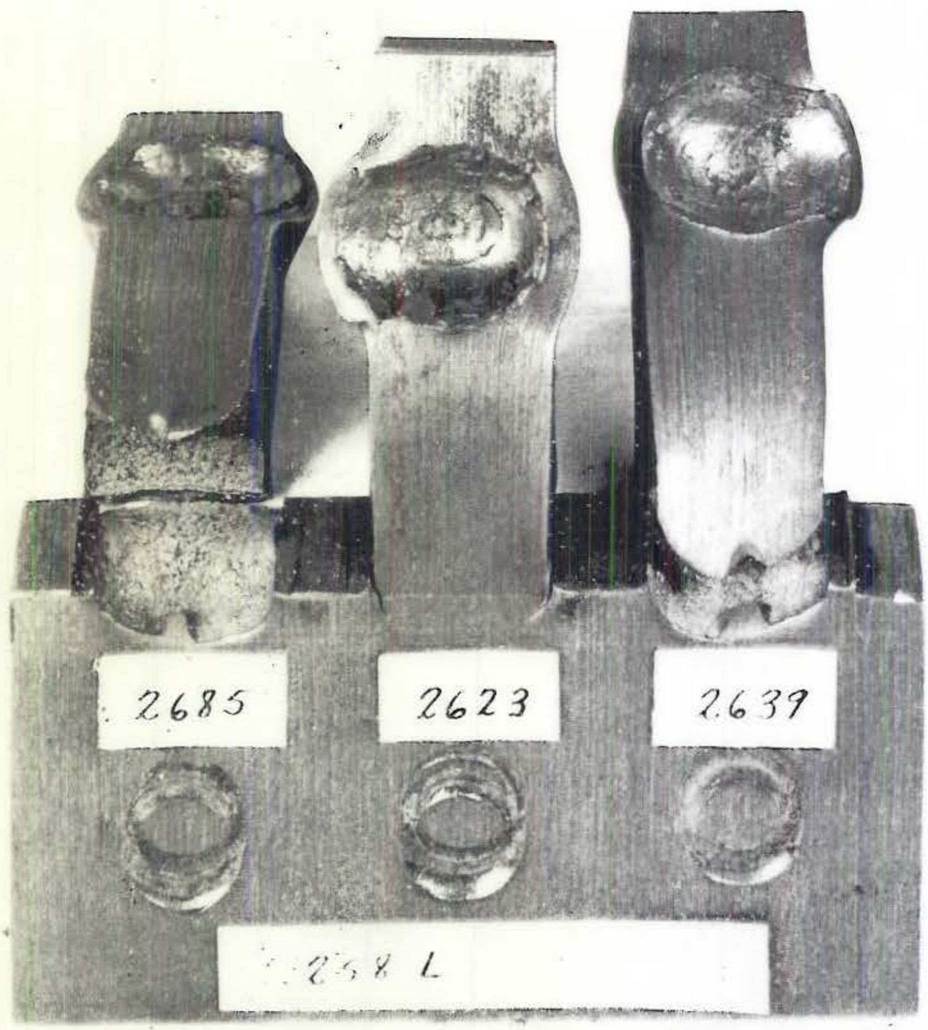


NRL SHOCK FRACTURE TEST SPECIMEN

SPECIMEN PREPARED BY POWER HACK SAW



NRL SHOCK FRACTURE TEST SPECIMEN FOR WELD JOINT



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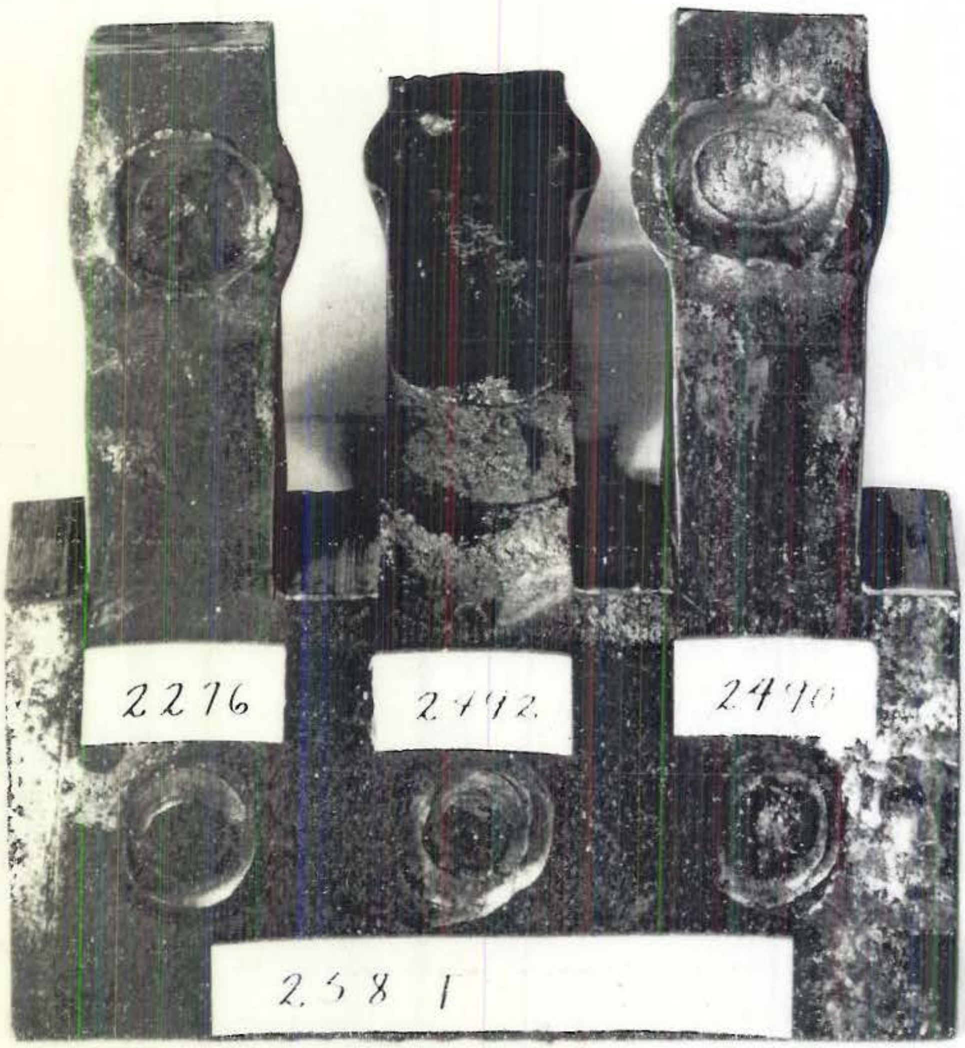

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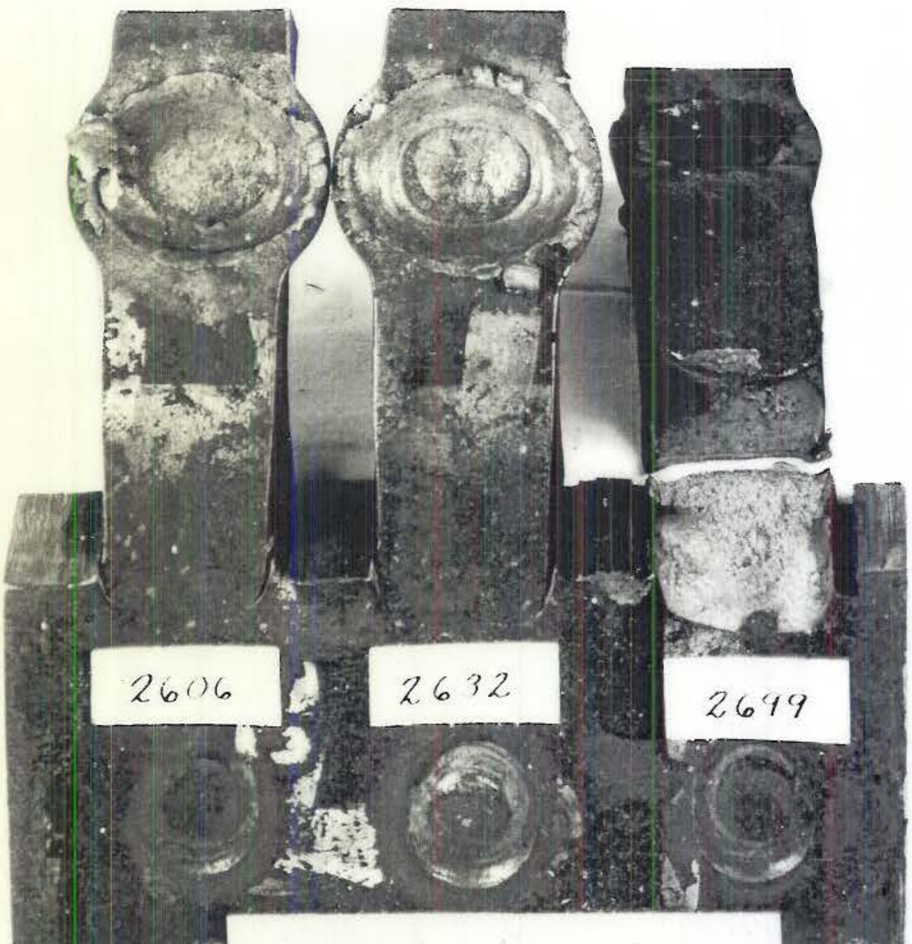
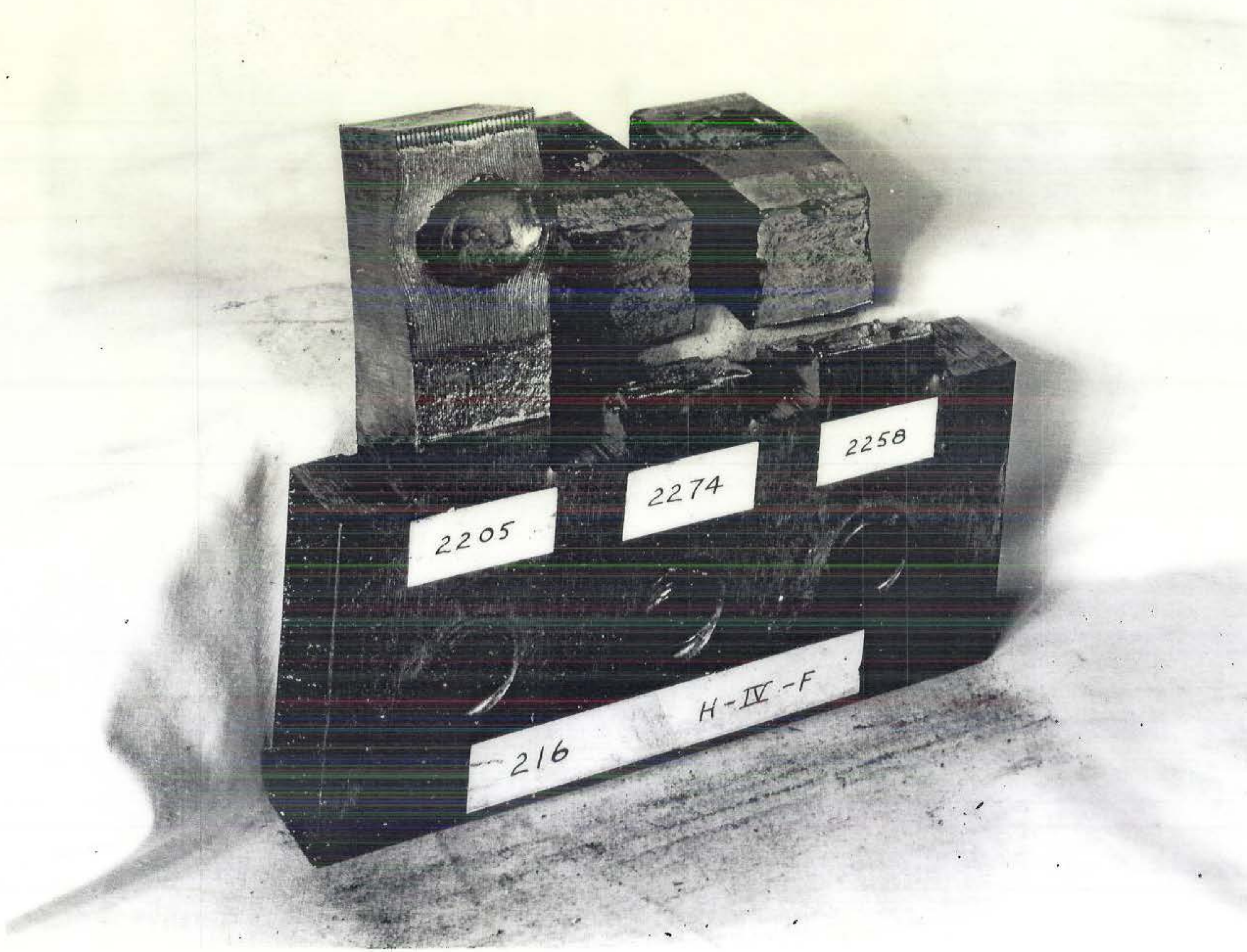


PLATE 6

PLATE 7


2205
2274
2258
216
H-IV-F

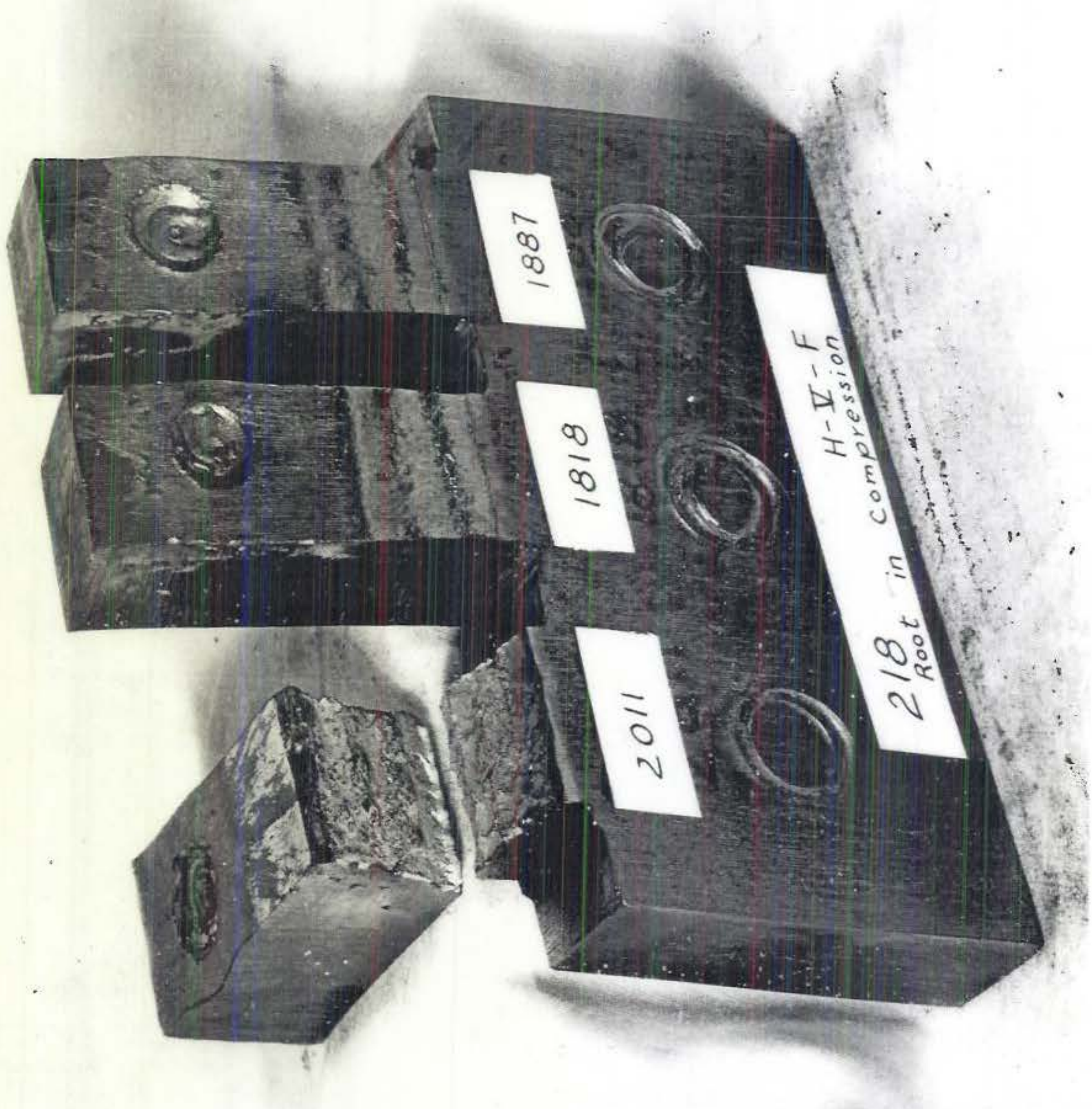
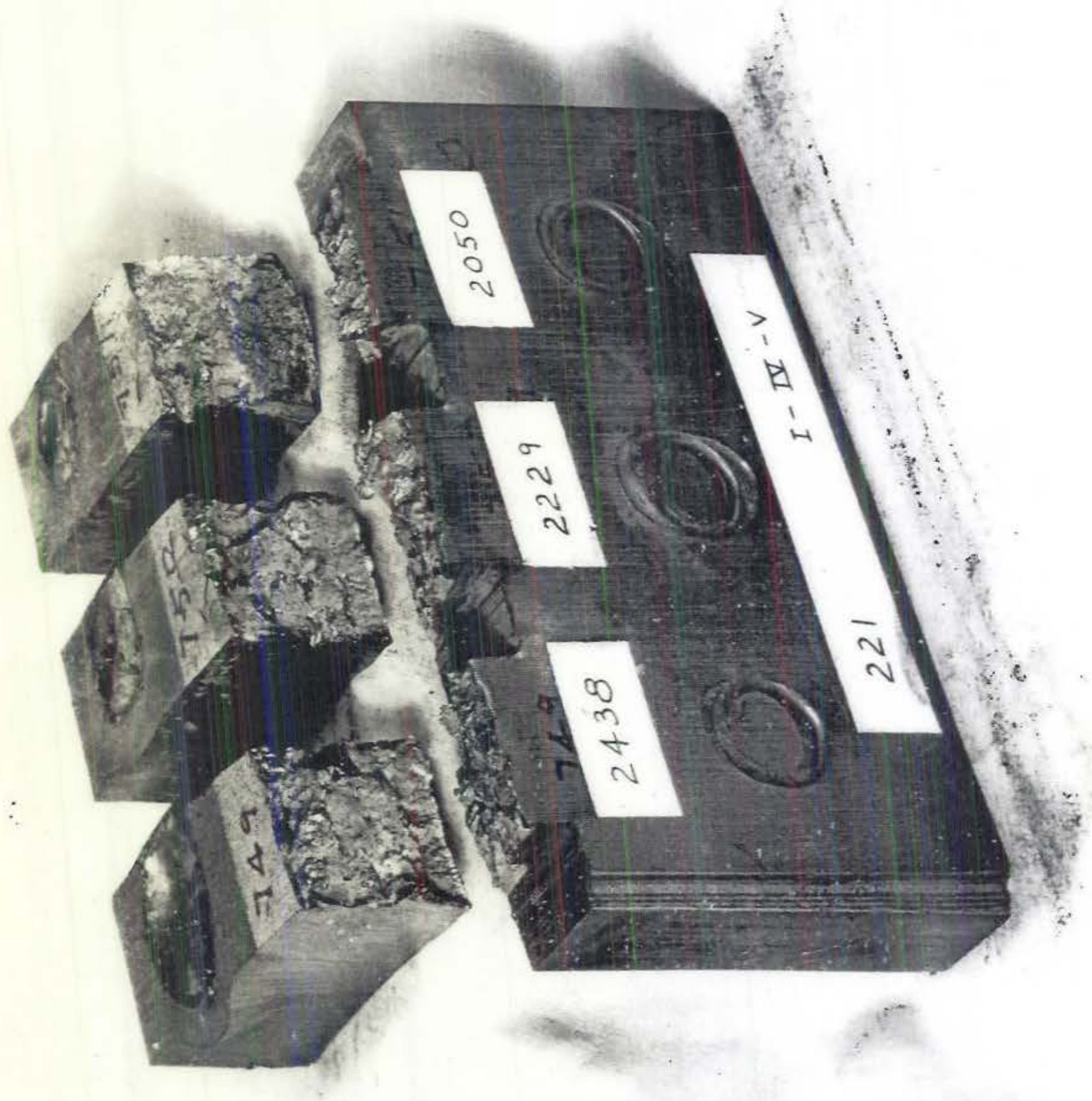


PLATE 9


2000
2243
2395
218
H-V-F

PLATE II



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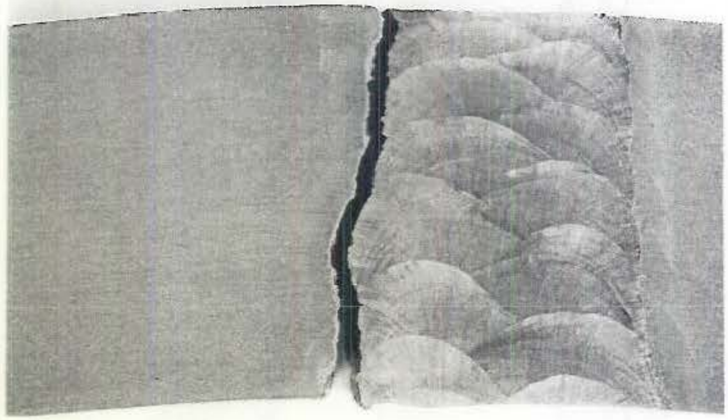
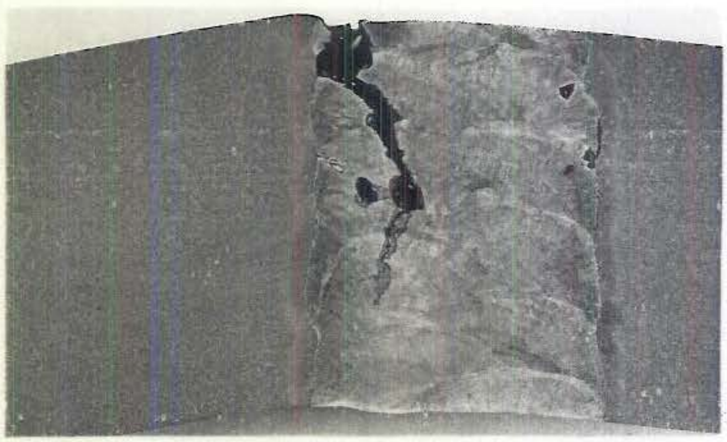
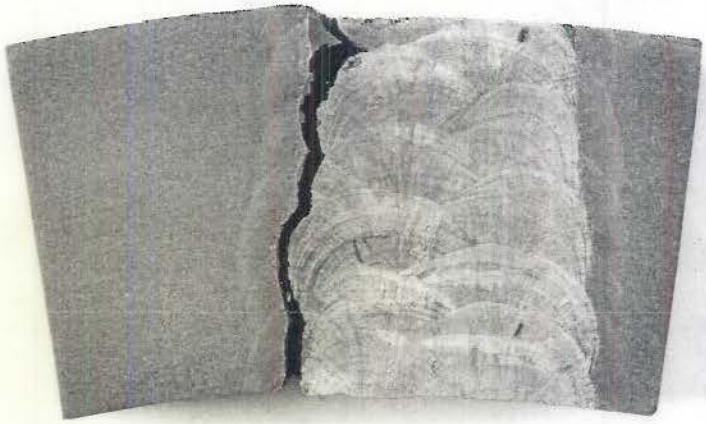


#216
H-IV-F
2106 ft/sec.
Impact 727
(a)

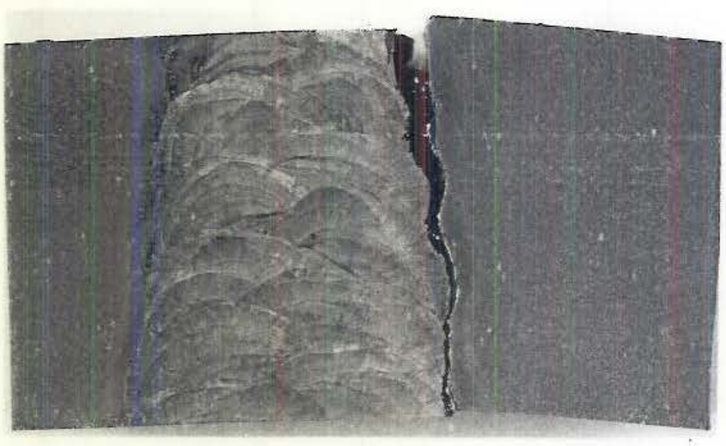


#217
H-IV-V
2045 ft/sec.
Impact 734
(b)

PLATE 13

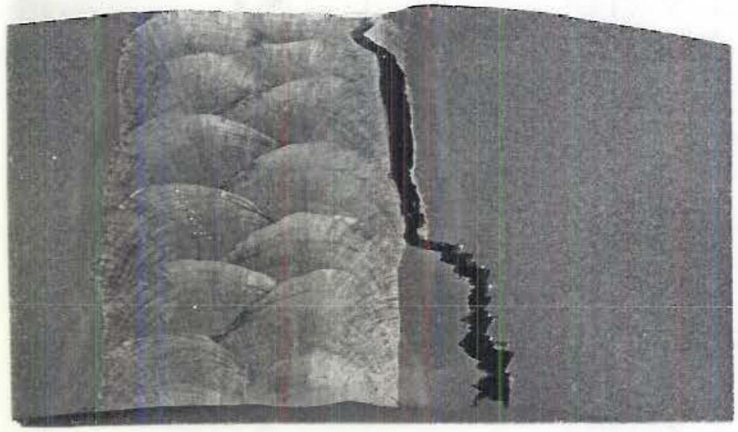


#218
H-V-F
2395 ft/sec.
Impact 739
(a)

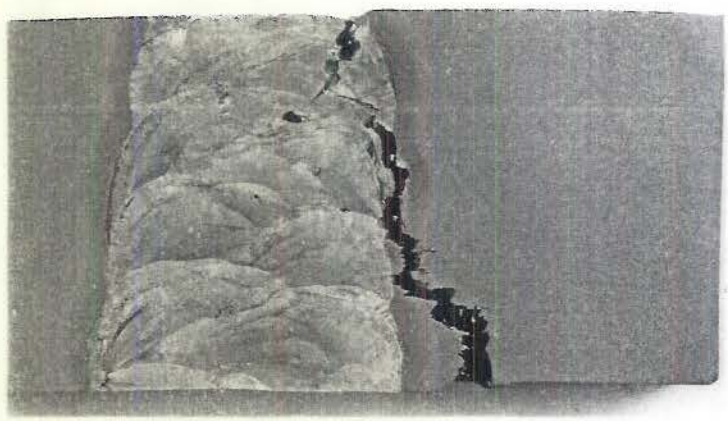


#219
H-V-V
1596 ft/sec.
Impact 832
(b)

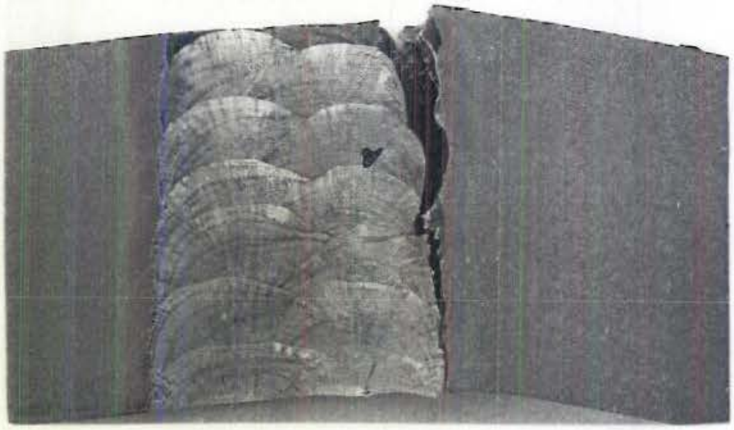
PLATE 14



#220
I-IV-F
2450 ft/sec.
Impact 748
(a)



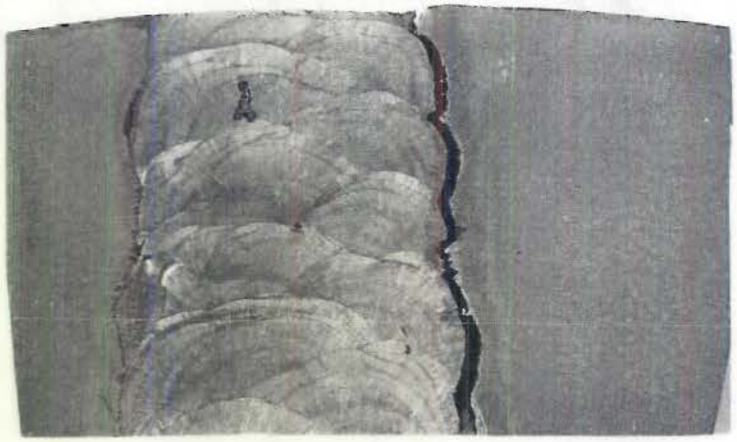
#221
I-IV-V
2050 ft/sec.
Impact 751
(b)



#222
I-V-F
2148 ft/sec.
Impact 757
(a)

#222
I-V-F
2254 ft/sec.
Impact 756
(b)

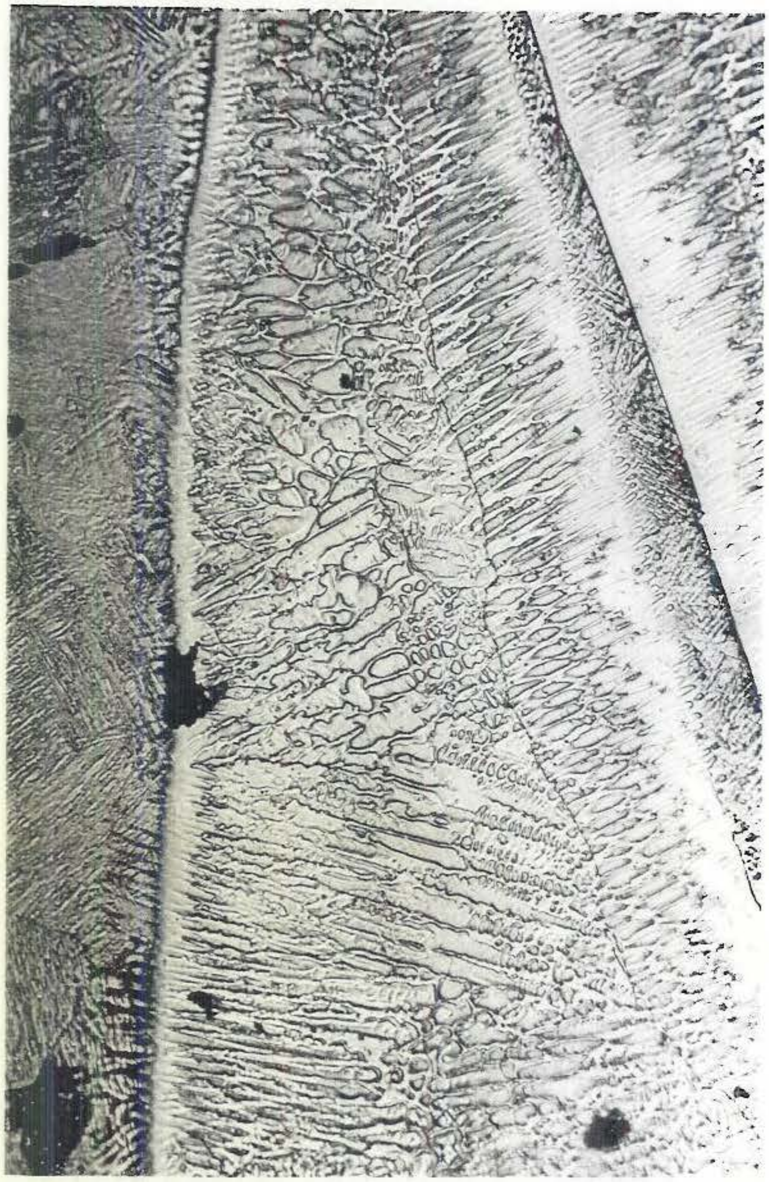
PLATE 16



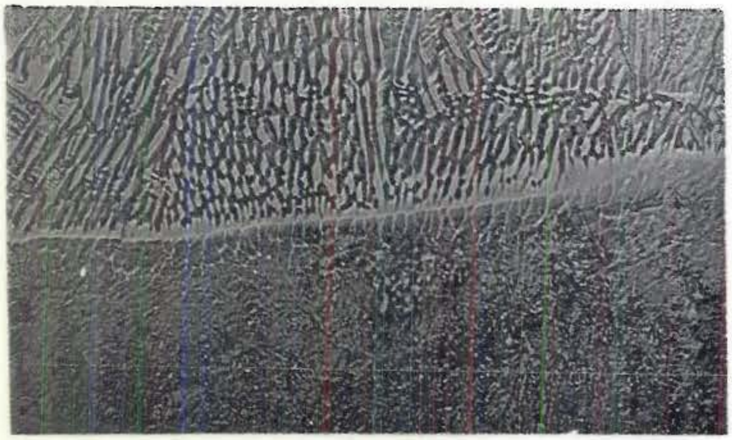
#223
I-V-V
2300 ft/sec.
Impact 762
(a)

#223
I-V-V
2490 ft/sec.
Impact 850
(b)

PLATE 17



#216
H-IV-F
275 X



#220
I-IV-F
Mg. 275x

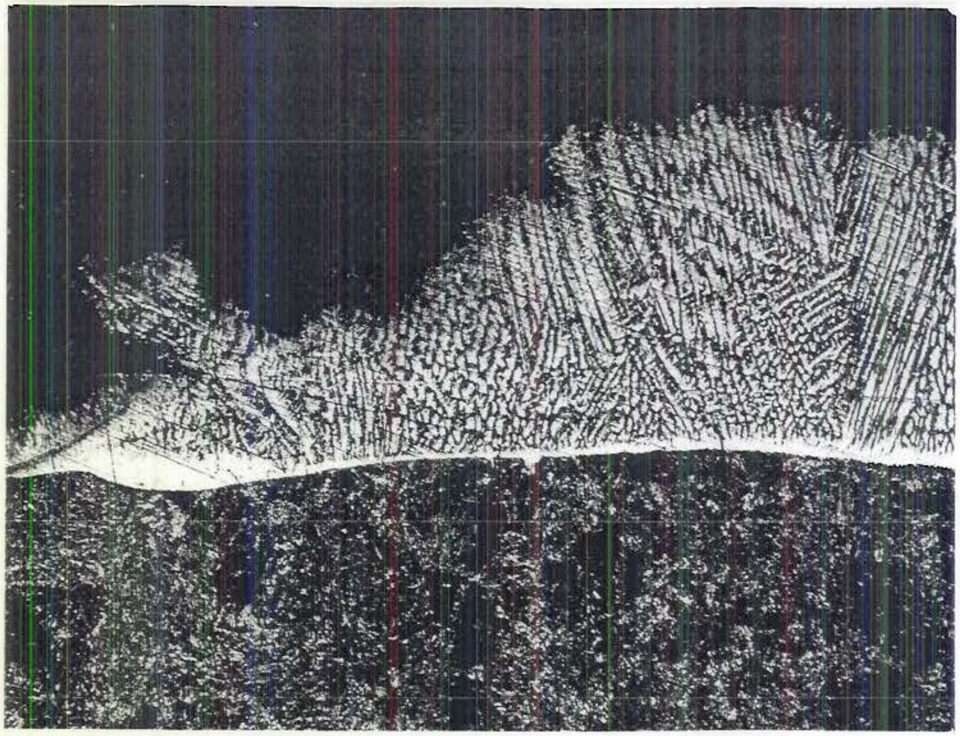
(a)

#220
I-IV-F
Etched Potassium
ferricyanide and
Potassium Hydroxide
(b)

PLATE 19

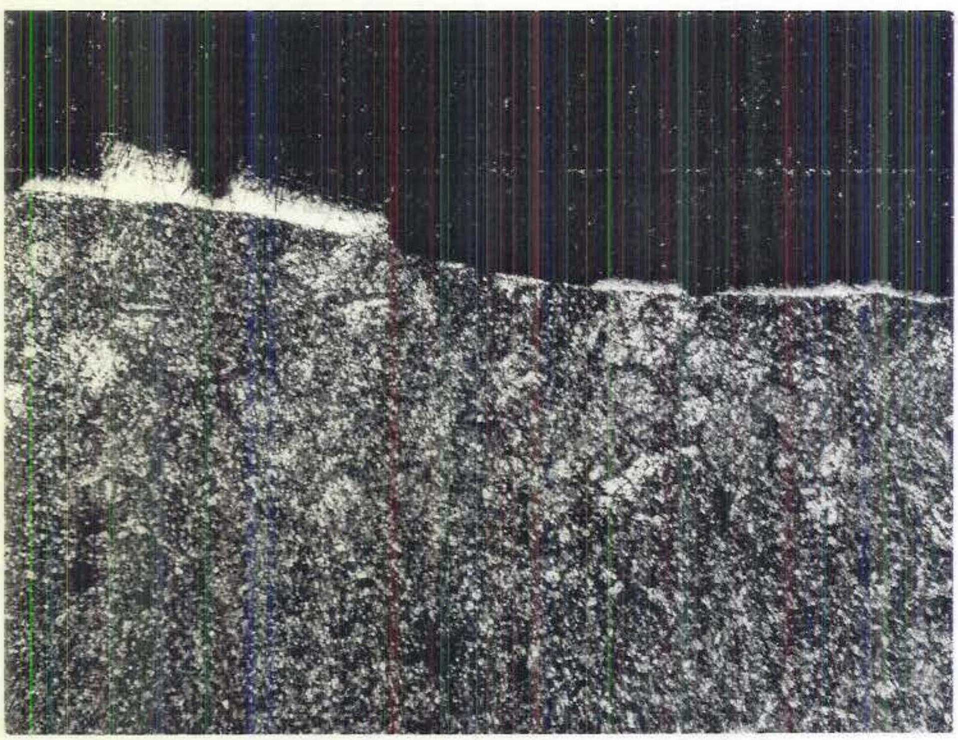
#223
I-V-V

Mg. 275x



#219
Failure in
Weld Metal

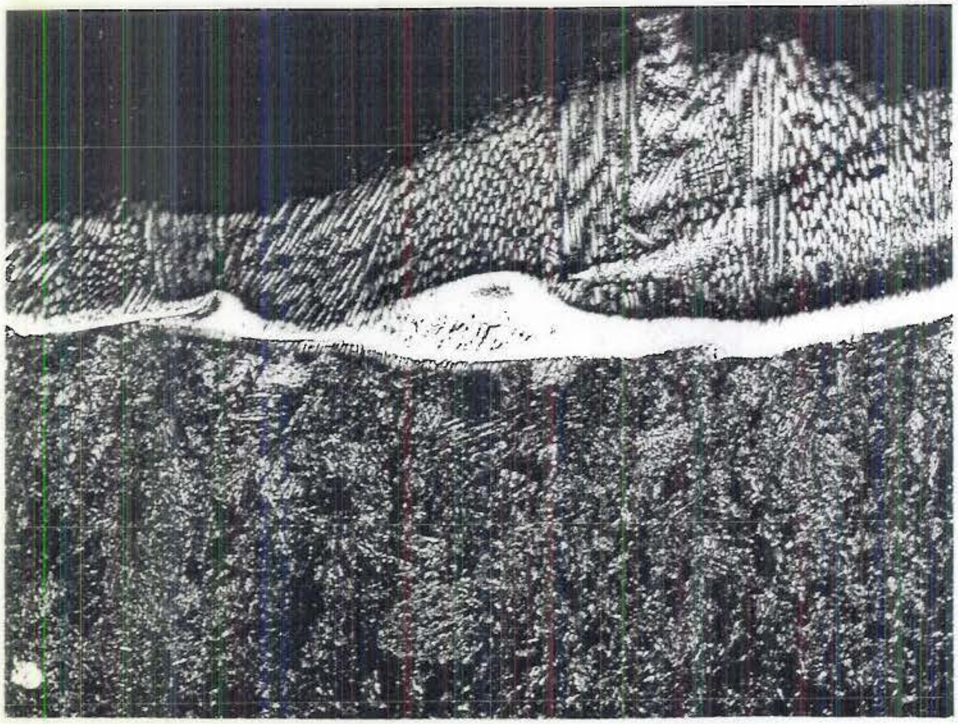
Mg. 100x



#219
Failure in
White Band

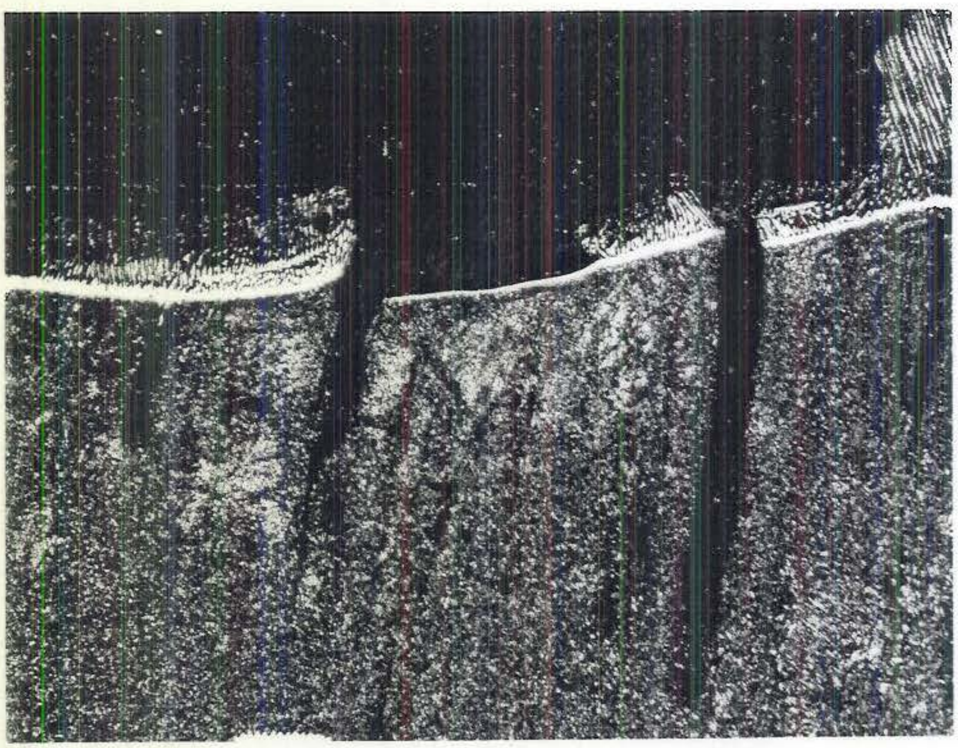
Mg. 100x

PLATE 21



#220
Weld Metal
Failure

Mg. 100x



#220
White Band
Failure

Mg. 100x

PLATE 22