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NAVY DEPARTMENT

Third Partial Report on

N.R.L. Shock-Fracture Test for Welded Joints in  
Connection with Welding Test No. 302

NAVAL RESEARCH LABORATORY  
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WASHINGTON, D. C.

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31 January 1943 and QP/W&C-(4)-(5)  
(692-350) of 9 April 1943

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ABSTRACT

Eight semi-restrained groove double-vee ballistic pendulum test specimens were prepared at the Philadelphia Navy Yard in connection with Welding Test No. 302 and forwarded to the Naval Research Laboratory for testing. The performance in the N.R.L. shock fracture test of the welded S.T.S. armor was considerably better than that of the welded low alloy ballistic steel. Inconclusive results were obtained in comparing Grade IV and Grade V electrodes. The plates welded in the flat position were somewhat better than those welded in the vertical position.

## 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. BuShips Project Order 518/43 (BuShips Welding Test #302).

## OBJECT OF TESTS

2. Results of the N.R.L. Shock Fracture Test on eight restrained groove single-vee ballistic pendulum test pieces prepared by the Philadelphia Navy Yard were reported in the "Second Partial Report on NRL Shock Fracture Test for Welded Joints in Connection with Welding Test #302" (NRL Report M-2163). In continuation of this investigation eight semi-restrained groove double-vee ballistic pendulum specimens prepared by the Philadelphia Navy Yard in accordance with Code 692 Sketch No. 2422-4 dated 2/4/43 (Plate 1) were forwarded to the Naval Research Laboratory for testing.

## PREPARATION OF SPECIMENS

3. It was necessary to shape these weldments down to one inch, the maximum specimen thickness that the present NRL Shock-Fracture Test equipment can accommodate. Since it is desirable to test the tension face of the ballistic specimen in the as welded condition, the excess material was removed from only one face of the weldment. Standard shock fracture specimens (Plate 2) were then prepared from the weldments.

4. The specimens were shock fracture tested with the unmachined face in tension and the limit velocity (the velocity of a .50 caliber bullet required to just break the finger from the specimen) was determined for each of the weldments.

5. Transverse specimens of the weldments were polished for micro and macro examination. The austenitic weld metal was electrolytically etched with a 10 per cent oxalic acid solution and 1 per cent nital was used to reveal the structure of the base metal. Photographs were then taken at 2 diameters and photomicrographs at 200 and 500 diameters. Vickers hardness surveys using a 10 kg. load were made on these specimens to determine the average maximum hardness of the heat affected zone.

## DATA OBTAINED IN TESTS

6. Results of the shock-fracture test of the eight weldments are given in Table I. A summary of these data together with the results of the armor plate performance previously reported in NRL Report M-2163 appear in Table II. Plates 3 to 5 show the appearance of typical specimens after shock fracture testing. Macrostructures of the weld joints are shown in Plate 6 and photomicrographs of the fusion zones are presented in Plate 7. The hardness surveys indicated an average

maximum hardness of 411 to 444 Vickers (10 kg. load) in the heat affected zones of the weldments.

#### DISCUSSION OF RESULTS

7. A detailed discussion of each ballistic test follows:

- 262 Low alloy steel welded in the flat position with 25-20 electrodes. All failures were of the fusion line type (Plate 3).
- 263 Low alloy steel welded in the vertical position with 25-20 electrodes. All failures were of the fusion line type. The fractures clearly showed the bead technique used in welding.
- 264 Low alloy steel welded in the flat position with 19-9 Mn electrodes. Failures were very similar to those of #263 (Plate 6a). The last three values reported for this weldment in Table I give a limit velocity of over 2300 ft./sec. as contrasted to  $2095 \pm 25$  for the other six shots; this indicates a variation in weld quality across the plate.
- 265 Low alloy steel welded in the vertical position with 19-9 Mn electrodes. Failures were similar to those of #263 except that some porosity was present (Plate 4).
- 266 S.T.S. armor welded in the flat position with 25-20 electrodes. Two specimens were improperly machined and therefore could not be tested. No fracture was obtained in the third specimen, but there appeared to be a tendency toward base metal failure.
- 267 S.T.S. armor welded in the vertical position with 25-20 electrodes. Failures started in the heat affected zone and proceeded through the base metal. The fractures were extremely dark, rough and uneven with some evidence of lamination in the base metal (Plates 5 and 6b).
- 268 S.T.S. armor welded in the flat position with 19-9 Mn electrodes. Due to mis-alignment in this weldment, two of the specimens had a base thickness of  $1 \frac{1}{16}$ " and a finger thickness of 1". The third specimen was machined with 1" thick base and  $\frac{15}{16}$ " thick fingers. Results indicated that this variation in thickness was insignificant. Due to the inconsistency in results in the neighborhood of 2700 ft./sec., a limit velocity of  $2700 \pm 100$  ft./sec. was estimated. The only complete fracture was a fusion line failure (Plate 6c). A partial fracture started in the weld metal, followed the fusion line for about  $\frac{3}{8}$ " and then dropped at a sharp angle into the plate for about  $\frac{1}{4}$ " (Plate 6d).

273 S.T.S. armor welded in the vertical position with 19-9 Mn electrodes. All complete fractures were fusion line failures similar to those of #263. A partial fracture started in the fusion line, travelled along it for about  $3/8$ " , and then dropped almost vertically into the base metal for about  $1/2$ " . A tendency toward this type of behavior was evidenced in all of the complete fractures by cracks in the base metal parallel to the face of the specimen.

8. Micro-examination of the weldments showed a white band at the fusion line and a network structure in the base metal similar to those found in the single-vee weldments described in N.R.L. Report No. M-2163. Photomicrographs of specimens 266 and 268 at 200 diameters and specimen 262 at 500 diameters (Plate 7) clearly show the white band structure. The thin black lines in the weld metal are not cracks because they appear only in the etched specimens.

9. The average maximum hardness of the heat affected zones of the weldments does not appear to be sufficiently high to indicate an excessive loss of ductility in this region.

10. On the basis of average limit velocities the performance of the welded S.T.S. armor was considerably better than that of the welded low alloy ballistic steel (2540 ft./sec. compared with 2065 ft./sec.). In previous tests on restrained groove single-vee weldments in these steels (N.R.L. Report M-2163) results for both steels were quite similar to those found for the low alloy ballistic steel in the present investigation. The performance of the steels in the unwelded condition is nearly the same (Table II). Therefore, the superiority of the S.T.S. armor in these tests must be attributable to more satisfactory response to the joint design and to the degree of restraint present in these weldments.

11. Inconclusive results were obtained in comparing Grade IV (25-20) electrodes with Grade V (19-9 Mn) electrodes. In the low alloy steel the two plates welded with 19-9 Mn electrodes averaged 2100 ft./sec. while those welded with 25-20 electrodes averaged 2020 ft./sec. In the S.T.S. armor the two plates welded with 19-9 Mn electrodes averaged 2440 ft./sec. while the one limit obtained for 25-20 electrodes on S.T.S. armor was 2700 ft./sec.

#### SUMMARY OF RESULTS

12. (1) The performance of S.T.S. armor in a semi-restrained groove double-vee weldment is superior to that of low alloy ballistic steel in this type of weldment and to low alloy ballistic steel and S.T.S. armor in a restrained groove single-vee weldment.

(2) Inconclusive results were obtained in comparing Grade IV (25-20) electrodes with Grade V (19-9 Mn) electrodes.

(3) The plates of both steels welded in the flat position were somewhat better than those welded in the vertical position.

TABLE I RESULTS OF SHOCK-FRACTURE TESTS

Specimen No. NRL	BuShips	Velocity ft./sec.	Results	Limit Velocity ft./sec.	
262	K-IV-F	2008	on	2150 ± 50	
		2065	on		
		2110	on		
		2142	off		
		2182	on		
		2195	off		
		2200	off		
		2277	off		
		2308	off		
263	K-IV-V	1722	on	1905 ± 25	
		1795	on		
		1817	on		
		1825	on		
		1885	on		
		1928	off		
		2080	off		
		2090	off		
		2130	off		
264	K-V-F	1987	on	2095 ± 25	
		2000	on		
		2065	on		
		2125	off		
		2210	off		
		2295	Just off		
		2105	on		Over 2320*
		2145	on		
2320	on				
265	K-V-V	1895	on	2105 ± 50	
		2000	on		
		2050	on		
		2055	off		
		2085	on		
		2140	off		
		2150	on		
		2158	off		
		2170	off		
266	L-IV-F	2118	on	Over 2255	
		2255	on		
Third finger mis-machined					

\* See Paragraph 7

Table I (Continued)

Specimen No. NRL	BuShips	Velocity ft./sec.	Results	Limit Velocity ft./sec.
267	L-IV-V	2540	Just on	2700 ± 50
		2592	Just on	
		2638	Just on	
		2710	on	
		2710	off	
		2750	on	
		2760	off	
		2805	off	
		2810	off	
268	L-V-F	*2275	on	2700 ± 100
		2430	on	
		*2430	on	
		2519	on	
		*2534	on	
		*2590	on	
		*2621	on	
		*2680	off	
		2703	on	
273	L-V-V	2002	on	2225 ± 75
		2045	on	
		2092	on	
		2158	on	
		2178	off	
		2212	on	
		2292	off	
		2295	off	
		2492	off	

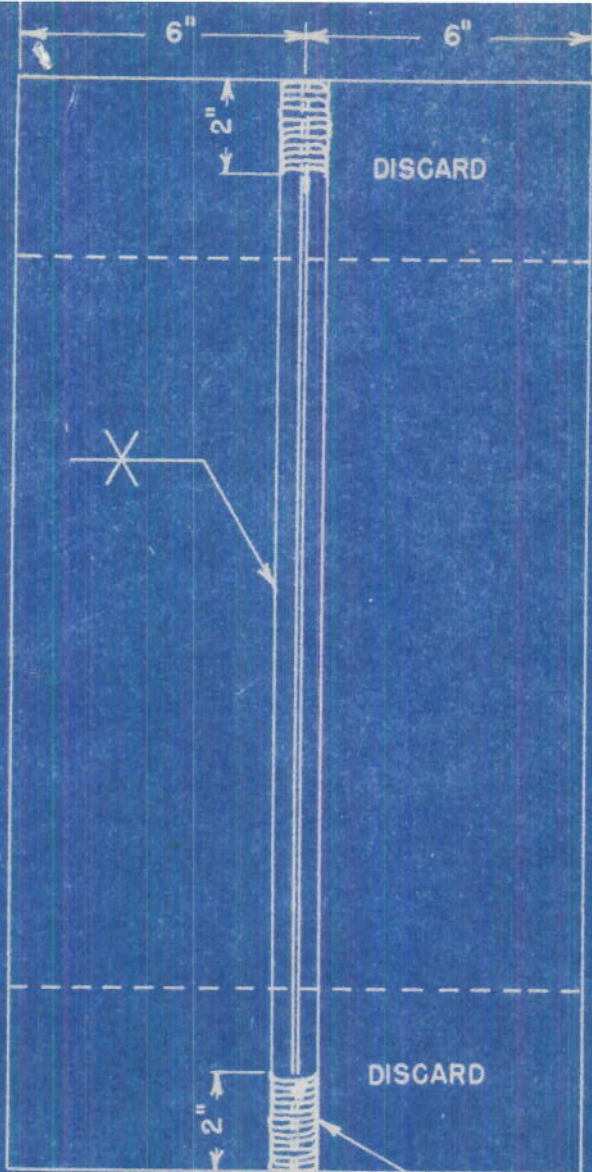
K - 60# low alloy ballistic steel  
 L - 60# special treatment steel  
 IV - Grade IV (25-20) electrodes  
 V - Grade V (19-9 Mn) electrodes  
 F - position of welding flat  
 V - position of welding vertical

\* Specimens had 1 1/16" thick base.  
See Paragraph 7.

TABLE II SUMMARY OF SHOCK-FRACTURE TESTS

Specimen No.		Hardness BHN	Limit Velocity ft./sec.
NRL	BuShips		
<u>Weldments</u>			
262	K-IV-F		2150 ± 50
263	K-IV-V		1905 ± 25
264	K-V-F		2095 ± 25
265	K-V-V		2105 ± 50
266	L-IV-F		Over 2255
267	L-IV-V		2700 ± 50
268	L-V-F		2700 ± 100
273	L-V-V		2225 ± 75
<u>Armor - Data from N.R.L. Report M-2163 (Unwelded plate)</u>			
<u>Low Alloy</u>			
258L	302-M-1	270	2680 ± 25
258T	302-M-1	270	2390 ± 100
<u>Special Treatment Steel</u>			
261L	302-N-1	250	2630 ± 25
261T	302-N-1	250	2290 ± 75

- L - Specimen finger parallel to direction of rolling
- T - Specimen finger transverse to direction of rolling



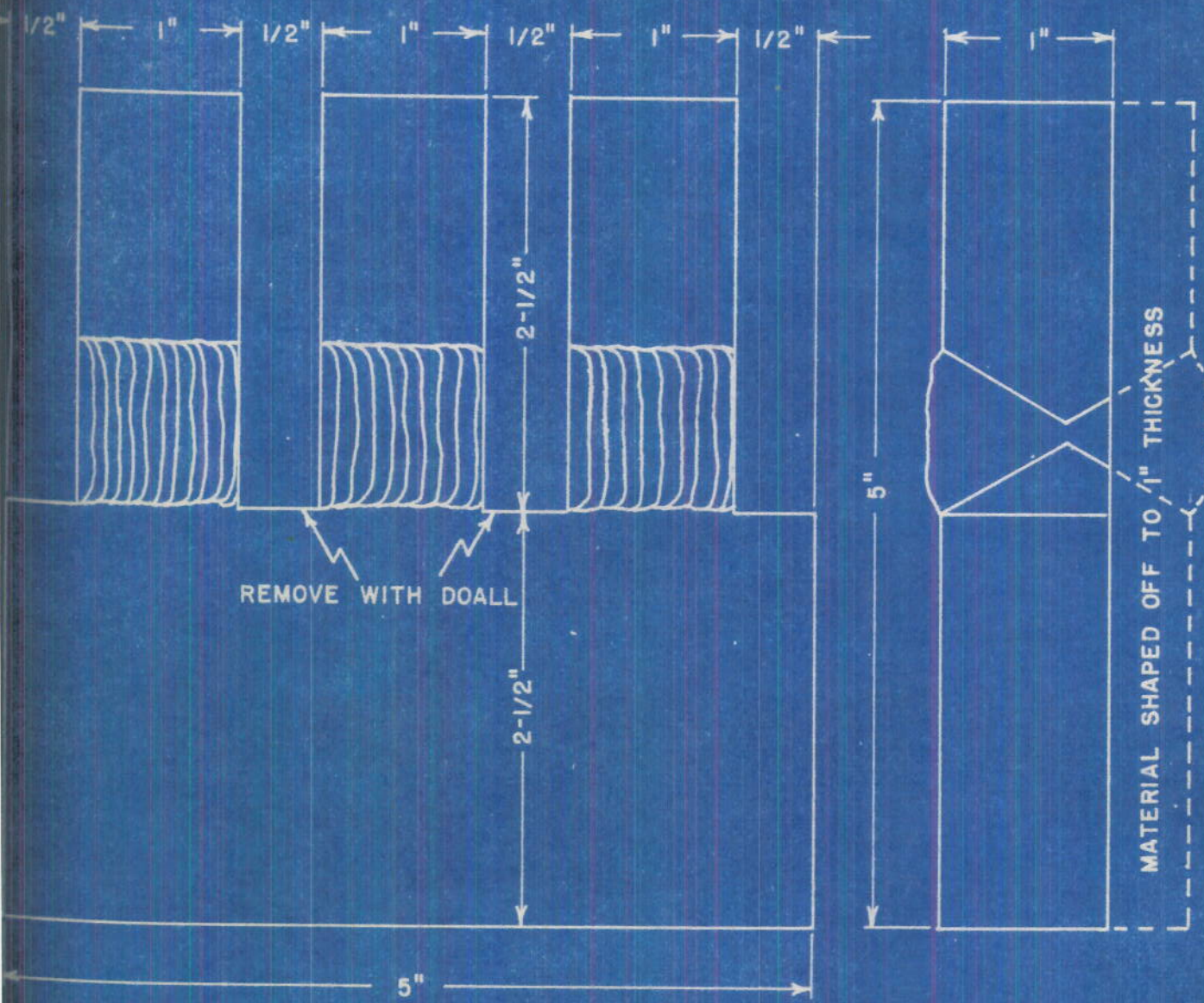
GROOVE TO BE WELDED COMPLETE FOR 2 INCHES EACH END BEFORE MAKING BALANCE OF WELD IN ORDER TO PROVIDE RESTRAINT IN WELD.



SCALE - 1/4 FULL SIZE

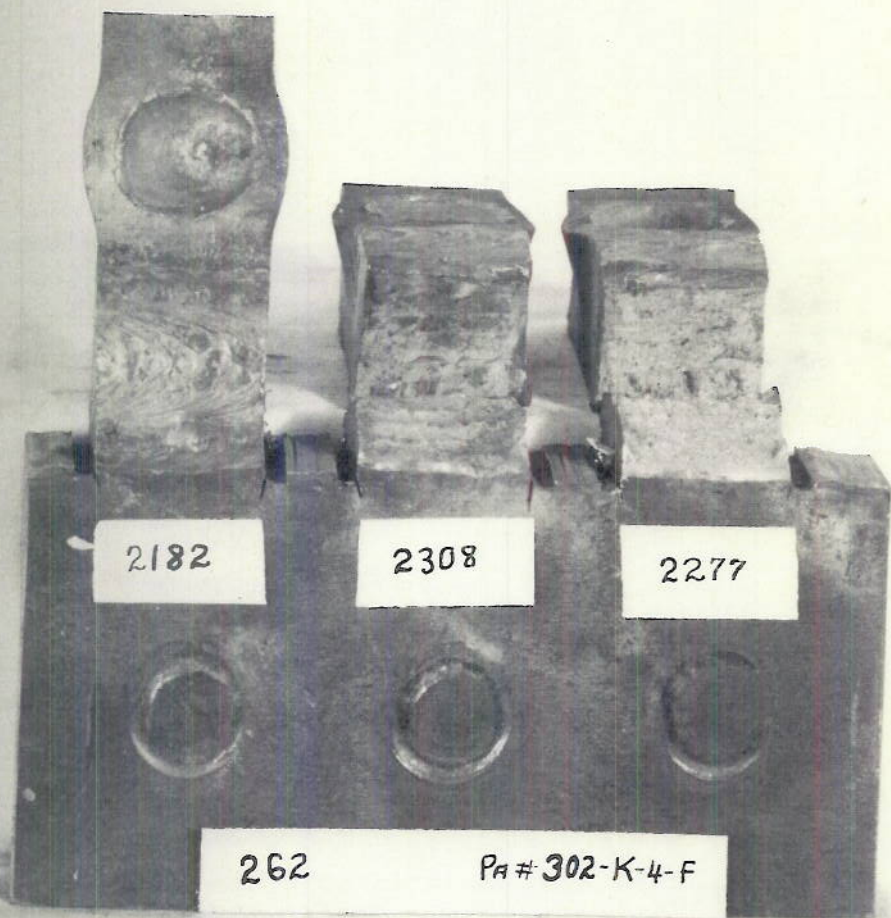
**SEMI-RESTRAINED GROOVE BALLISTIC PENDULUM TEST RESULTS DESIRED:**  
 RESULTS IN LOW ALLOY STEEL SHALL NOT BE LESS THAN THOSE OBTAINED IN REGULAR S.T.S. PLATE.

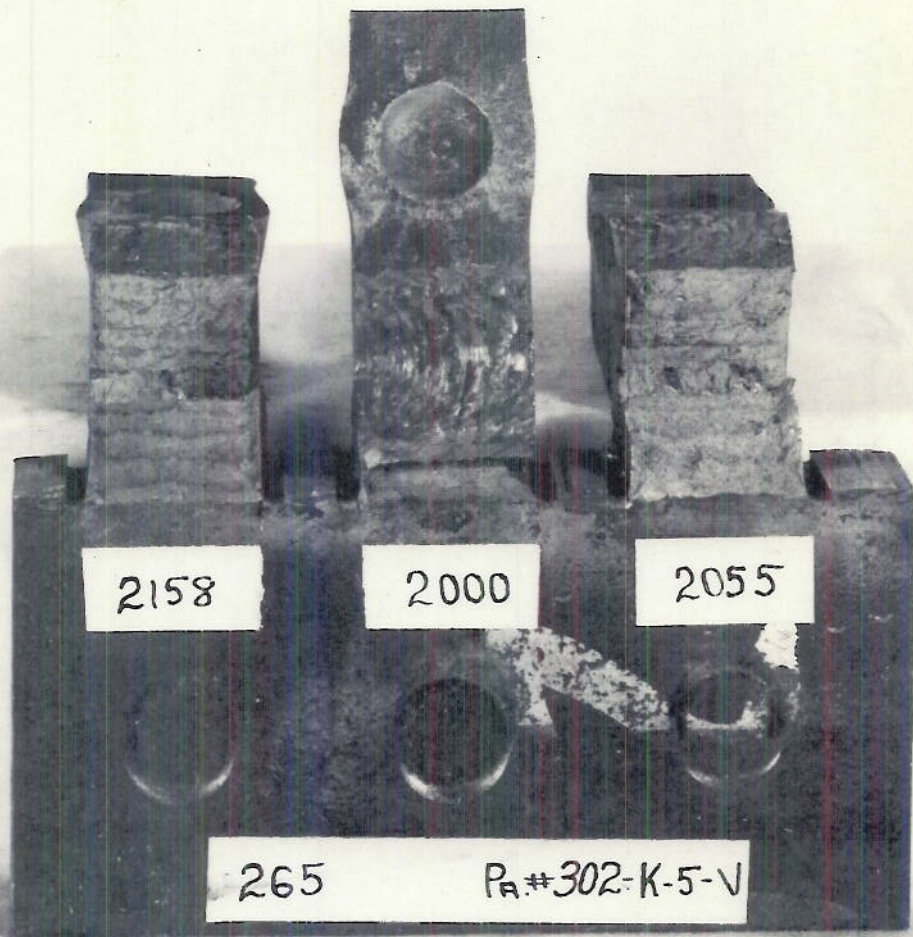
WELDING TEST NO. 302	NAVY DEPARTMENT BUREAU OF SHIPS WASHINGTON, D.C.	CODE 692 SK. NO. 2422-4
	LOW ALLOY BALLISTIC STEEL WELDED WITH 19-9 MN AND 25-20 ELECTRODES	DATED 2/4/43



SPECIMEN PREPARED WITH POWER HACKSAW

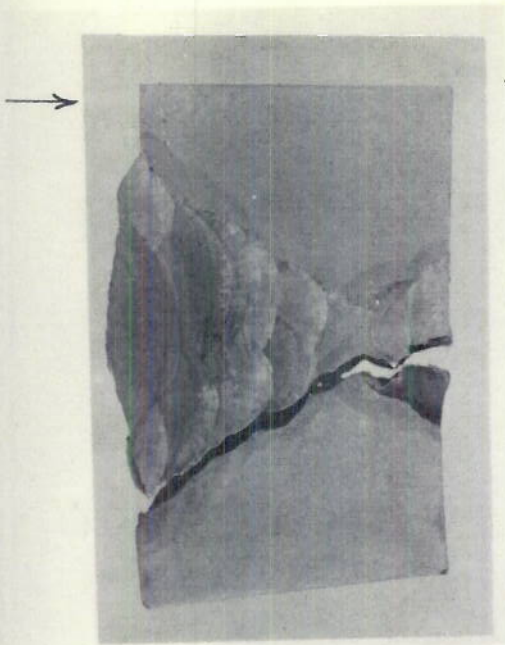
N. R. L. SHOCK FRACTURE TEST SPECIMEN



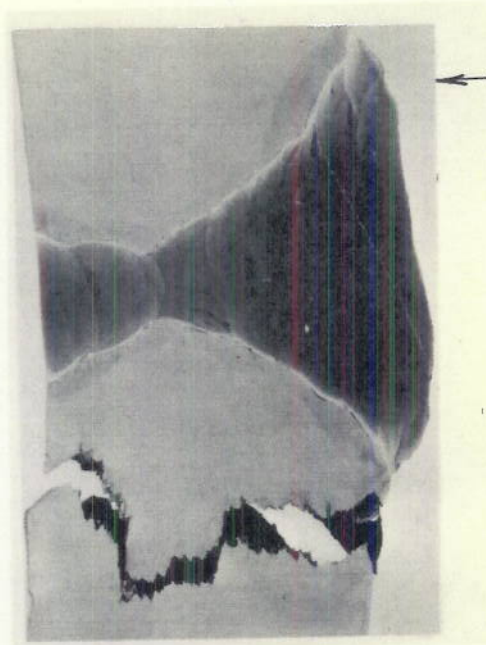




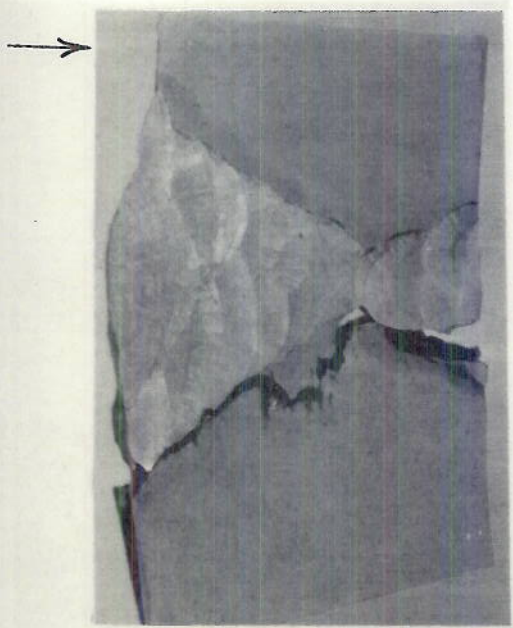
MACROSTRUCTURES OF WELD JOINTS (2X)



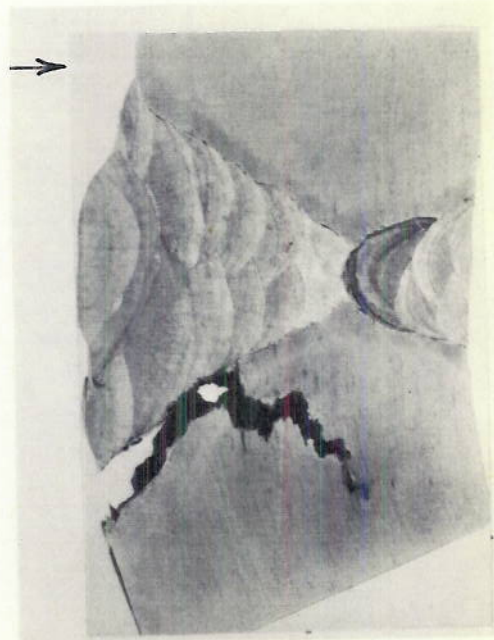
A. 264 - 2210 FT./SEC.



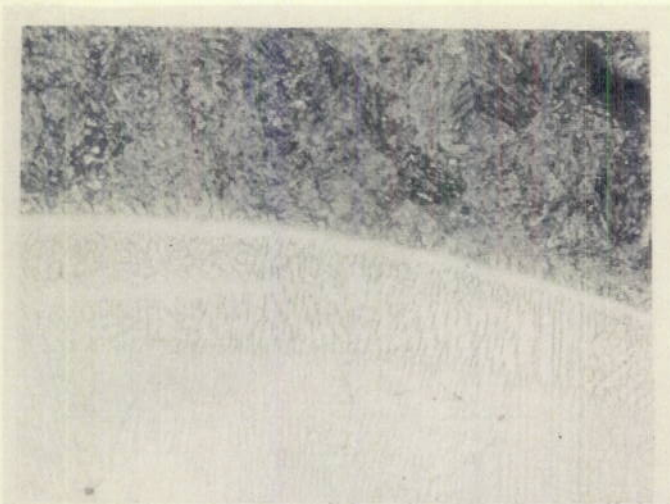
B. 267 - 2540 FT./SEC.



C. 268 - 2680 FT./SEC.



D. 268 - 2534 FT./SEC.



268  
(200X)



266  
(200X)



262  
(500X)

PHOTOMICROGRAPHS OF FUSION LINE STRUCTURES