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WATERTOWN ARSENAL LABORATORY

EXPERIMENTAL REPORT

NO. WAL. 647/8

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REPAIR WELDED CAST ARMOR

Metallurgical Examination of Samples Representing Ninety-six Two Inch Thick Ballistic Test Plates

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DATE: February 1945

WATERTOWN ARSENAL
WATERTOWN, MASS.

Watertown Arsenal Laboratory
Report Number WAL 647/8
Problem Number D-16.2

7 February 1945

REPAIR WELDED CAST ARMOR

Metallurgical Examination of Samples Representing Ninety-six Two Inch Thick Ballistic Test Plates

OBJECT

To carry out metallurgical examination of subject samples.

SUMMARY

1. Metallurgical examination including chemical analyses, macro-examination, hardness surveys, Charpy V-notch impact tests, nick-break fracture tests, Jominy hardenability tests, and microexamination was carried out on selected samples from the 96 two inch thick repair welded cast armor ballistic test plates.

2. The hardness level of weld deposits in the American Steel Foundries plates was generally lower than that of the Continental Steel Foundries deposits, apparently because of a difference in the welding technique. The stress relief treatment reduced the maximum weld metal hardness slightly, and the draw treatment reduced the hardness more markedly. The weld metal hardness of the samples which were quenched and tempered after welding was very low because of low incompletely hardened weld metal. A decrease in resistance to ballistic penetration is apparent for weld deposits with low hardness level.

3. Notched bar impact and nick-break fracture tests indicate that the shock resistance of the weld deposit would be inferior to that of the armor plate under severe ballistic shock, particularly at subnormal temperatures. Notched bar impact tests at -40°F. show a definite decrease in tendency for brittle failure as the weld metal hardness is lowered progressively by stress relief, draw, and quench and draw treatments after welding. This trend was not reflected in ballistic shock tests and all the weld deposits appear equally adequate to withstand the conditions of the ballistic shock tests employed in this program. The Continental cast armor as indicated by Charpy, nick-break fracture and ballistic shock tests was subject to severe temper embrittlement in the samples stress relieved after welding.

4. It is probable that an increase in carbon content or in suitable alloy elements would improve the hardenability and resistance to softening during tempering of this type weld metal resulting in increased hardness and shock resistance and consequent improvement in ballistic properties.

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INTRODUCTION

This report deals with examination of representative samples from a series of 96 repair welded cast armor ballistic test plates. The examination was carried out in accordance with a request from Office, Chief of Ordnance-Detroit (SPOME-EE). A copy of this directive as well as other basic correspondence prescribing details of welding and heat treating procedures, and ballistic testing is included in Appendix A.

A complete account of ballistic testing results is contained in Aberdeen Proving Ground Armor Test Report No. AD-685. Results of a previous examination of samples from four repair welded cast armor ballistic test plates are reported in Watertown Arsenal Laboratory Memorandum Report No. WAL 647/7, 28 August 1944.

TEST MATERIALS

A total of 96 cast armor test plates, 36 x 36 x 2 inches with a 6 x 24 inch repair welded area were procured for ballistic testing, 48 plates from the American Steel Foundries and 48 plates from the Continental Roll and Steel Foundries. All welding was done with Harnischfeger AW 2C Mn-Mo ferritic electrode having a mineral (stainless type) coating. The plates were divided into 16 groups of three to represent various depths of weld repair and post welding heat treatment procedure. The details of heat treatment and ballistic test procedures (which differed in some respects from those originally prescribed) are given in Table I.

Samples approximately 12 inches square including a portion of the repair welded area were flame cut from 94 of the plates after ballistic testing and forwarded to this arsenal. From each group of three similarly welded and heat treated plates, one sample was selected for examination as follows:

Depth of Weld Inches	Post Welding Heat Treatment	American Steel Foundries Plate No.	Continental Steel Foundries Plate No.
2	Quench and Draw	A 1306	6795-4
1-3/4	Quench and Draw	A 1273	6795-12
1-3/8	Quench and Draw	A 1292	1033-3
1	Quench and Draw	A 1276	6842-9
2	Draw	B 52	6815-13
1-3/4	Draw	B 67	6765-4
1-3/8	Draw	B 61	6965-11
1	Draw	B 43	6842-2
2	1100°F Stress Relief	B 114	6795-7
1-3/4	1100°F Stress Relief	B 107	6842-14
1-3/8	1100°F Stress Relief	B 98	397-1
1	1100°F Stress Relief	B 96	6842-7
2	None	B 113	6795-9
1-3/4	None	B 144	6965-6
1-3/8	None	B 143	6965-7
1	None	B 131	6965-8

TEST PROCEDURE

From each of the thirty-two selected samples two sections approximately 1/4 inch thick were cut with an abrasive wheel transversely across the repair welded area. After the surfaces were ground, one section was macroetched in hot acid (1 part H_2SO_4, 3 parts HCE, and 4 parts H_2O) for forty-five minutes, and Rockwell C hardness surveys were made as illustrated in Figure 4 on the other section.

All weld metal standard V-notch Charpy bars were obtained at midwall transverse to the welding direction, from samples with one inch and with two inch depths of weld to represent each of the four conditions of heat treatment. Plate metal Charpy bars were taken midwall opposite to the repair welded area from samples with one inch repair weld depth to represent each of the four conditions of heat treatment. In addition Charpy bars were taken midwall from the unaffected plate metal of the two inch repair weld depth in the as-welded condition. In each case duplicate Charpy bars were broken at both +70°F and -40°F.

Nick-break fracture tests were made on samples with one inch depth of repair weld in each condition of heat treatment. Specimens were notched by flame cutting from each side to leave an unnotched section three inch wide transverse to the direction of welding through the center of the repair welded area. One quarter inch deep notches were then ground across the 3 inch section on both top and bottom to connect the flame cut notches. The specimens were broken in a steam press.

One Jominy bar was taken from the center of plate and one from center of the repair weld in the samples with two inch repair weld depth and no heat treatment after welding. Bars were end quenched after a two hour hold at 1650°F, four flats .030 inch deep were ground, and standard Jominy hardness surveys were made on two flats at 90°.

After hardness surveys had been made, the Jominy bars were used for chemical analyses. In addition, chips were taken for analyses from broken Charpy bars from the samples with one inch depth of weld repair.

Samples for microexamination as described in the section under Data and Discussion were taken from transverse sections used for hardness surveys and macroexamination.

DATA AND DISCUSSION

Chemical Analyses

Chemical composition ranges as summarized from analyses reported by the armor manufacturers were as follows:

Fabricator		C	Mn	Si	P	S	Cr	Ni	Mo
American	plate	.26/ .33	1.40/ 1.63	.38/ .50	.011/ .018	.022/ .033	.44/ .64	--	.28/ .35
	weld metal	.083	1.65	.21	.020	.025	.01	.07	.40
Continental	plate	.28/ .35	1.24/ 1.47	.38/ .45	.029/ .038	.036/ .045	.52/ .71	.52/ .87	.40/ .44
	weld metal	.15	1.66	.27	.020	.020	.07	trace	.42

Check analyses made at this laboratory gave the following results:

Plate No.		C	Mn	Si	P	S	Cr	Ni	Mo
American B 113 2" weld depth	plate	.29	1.68	.50	.015	.025	.53	Trace	.30
	weld	.08	1.74	.24	.023	.021	.03	Trace	.32
American A 1278 1" weld depth	weld	.12	1.78	.23	.023	.020	.06	Trace	.37
Continental 6795-9 2" weld depth	plate	.29	1.52	.42	.043	.030	.67	.77	.41
	weld	.09	1.86	.22	.024	.020	.03	Trace	.38
Continental 6842-9 1" weld depth	weld	.09	1.88	.26	.023	.015	.02	Nil	.36

Macroexamination

Figures 1, 2, and 3 are photographs of typical macroetched sections from the 32 selected samples. The weld metal deposits were sound with the exception of one sample (Plate No. 6842-9, Figure 3). The passes which appear black in this photograph were full of oxide inclusions and small cracks and were etched out very rapidly by the hot acid. It is possible that these passes were made with electrodes from which the coating had spalled.

The heat affected zones in both weld and plate metal of the multiple bead weld deposits are outlined very clearly in the macroetched sections from the as-welded samples, less clearly in sections from the samples which were tempered or stress relieved, and were largely obliterated in the sections from samples quenched and drawn after welding. The metal which has been hardened by the welding thermal cycle etches dark while that which has been retempered either by subsequent welding passes or furnace heat treatment etches fairly uniformly with the unaffected base metals. Considerable irregularity in the extent of the weld hardened zone was observed particularly in the 1-3/4 and 1-3/8 inch depth repairs, but there was no evidence in this or in previous examinations of armor welds made with this type of ferritic electrodes that the extent or character of the weld hardened zone affected ballistic shock performance.

Severe centerline shrinkage, which apparently develops cracks under the influence of ballistic shock, is apparent in several of the cast plates (See Figures 2 and 3). Severe subsurface porosity is also evident in some of the cast plates.

Hardness Surveys

Rockwell C hardness surveys were made on transverse sections from the thirty-two selected samples. Figure 4 shows the pattern for hardness surveys and Table II is a tabulation of the results.

Hardness on the unaffected plate metal in the as-welded samples from Continental Steel Foundries averages 21 to 24 Rockwell C with little variation through the thickness. Slightly lower and more variable hardness readings showing a tendency to decrease at the center of the section were obtained for the plates from American Steel Foundries. Draw or stress relieving treatments subsequent to welding would be expected to have little or no effect on the hardness of the unaffected plate metal because all such treatments involved temperatures and times of holding either identical to or lower than the original tempering treatments. Quench and temper treatments after welding were supposedly identical in practice and effect to those before welding. However, in several plates from both manufacturers the hardness of the unaffected plate metal is unaccountably decreased by the treatments subsequent to welding. There is no consistency in this effect.

The hardness of the weld metal deposits in the as-welded condition shows a considerable variation as would be expected because of the hardening and tempering effects in the multiple pass welds (See pattern developed in Figures 1 and 2). Hardness ranges were approximately 9.5 to 17.5 Rc for the American samples and 11.5-19 Rc for the Continental samples. The lower hardness range for the American samples may be accounted for by the fact that this manufacturer used a weaving technique of bead deposition which resulted in a lower total number of beads and an appreciable higher interpass temperature (350°F max. for American and 290°F for Continental).

The 1100°F stress relief treatment reduced the maximum weld metal hardness slightly. The draw treatment of 1200-1220°F lowered the average hardness range 4 to 6 points Rc; but there were a few relatively high hardness readings in the top layer of weld passes - an indication of resistance to tempering. It is possible that the reheating of the other parts of the weld deposit by subsequent welding passes has decreased its resistance to softening during tempering. A previous investigation[1] indicated that the resistance to tempering may be somewhat dependent upon temperature and rate of cooling from the last austenitizing treatment.

The weld metal hardnesses of the samples subjected to quench and temper after welding are very low (Continental 3.5-12.5 Rc, American 3.15-11.5). The low hardnesses are a result of low hardenability (see discussion of Jominy tests) and low resistance to softening during tempering of the incompletely hardened weld metal.

No attempt was made to determine maximum heat affected zone hardnesses, since these zones were very irregular and there was no indication that the hardened zone influenced ballistic failure. Hardness readings which were obtained in the heat affected areas indicate the same hardening and tempering conditions as those revealed by the macroexamination.

The weld metal passes bordering plate metal are slightly higher in hardness than the remainder of the weld metal as a consequence of carbon and alloy pickup from the base metal.

Notched Bar Impact Tests

Results of Charpy V-notch impact tests at +70°F and -40°F for both weld and plate metals are given in Table III.

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1. Watertown Arsenal Laboratory Memorandum Report No. WAL 647/7, "Repair Welded Cast Armor - Metallurgical Examination of Samples from Four Ballistically Tested 2-Inch Thick Plates", 28 August 1944.

Impact bars taken from plate metal, unaffected by the welding heat, from samples in the as-welded condition gave values as follows:

	+70°F.	-40°F.
American	53 - 55 ft. lbs.	48 - 53 ft. lbs.
Continental	47 - 51 ft. lbs.	33 - 36 ft. lbs.

Specimens taken in plate metal opposite to the 1" deep weld deposit from as-welded samples or samples which were tempered or quenched and tempered after welding show no significant differences from the above values. There is a marked decrease in impact value of plate metal specimens from samples which were stress relieved after welding. The Continental armor suffered the most from this 1100°F heating and furnace cool which undoubtedly induced temper brittleness. Notch bar impact tests obtained at +70°F testing temperature for weld metal specimens obtained from the deposits of 1" and 2" depth were generally on a high level. Scatter in these results is partially a result of hardness gradients in the multiple pass weld, this effect being greatest in specimens from the as-welded specimens and probably eliminated in specimens quenched and tempered after welding. The testing temperature of -40°F is apparently within the range for transition of failure from ductile to brittle for all of the weld metal samples, which fact would account for considerable scatter in values, but there is a definite decrease in tendency for brittle failure as the weld metal hardness is lowered progressively by stress relief, temper, and quench and temper treatments after welding. There are no significant differences in impact energy levels of weld metal samples from the two armor manufacturers or samples representing the 1" and 2" depth of weld deposits.

Fracture Tests

Nick-break fracture tests were made of samples with 1 inch deep repair welds in each condition of heat treatment. Plate metal fractures were fibrous except in the stress relieved samples where, as noted in the discussion of notched bar impact tests, temper brittleness developed. The fracture of the stress relieved Continental armor was dull crystalline dendritic throughout the section; the similarly treated American showed numerous very small spots of crystallinity.

The fracture of the weld heat affected base metals were indistinguishable from the remainder of the plate fractures.

Except for a narrow band at the outer edges, the weld metal fractures were completely crystalline. The brittle failure of the weld metal in this very severe test indicates that the shock performance of the weld deposit would be inferior to that of the armor plate under very severe ballistic shock or when impacted at subnormal temperatures.

Hardenability Tests

Figures 5 and 6 give the results of Jominy end quench tests for weld and plate metals. From published data[2] the hardness of the weld metal, as quenched in water in the form of 2 inch thick plate, would be approximately

2. Hardenability comparisons - Great Lakes Steel Corporation 1942.

that at 3/4 inch from the water quenched end of the Jominy bar or, from the curves of Figures 7 and 8, 12-19 Rockwell C. The American cast armor composition is lower in hardenability than the Continental but either should be capable of fully hardening in two inch thick plate when water quenched.

Microexamination

Figure 7 shows the microstructure of samples from the quenched and tempered base metals at center, midwall and 3/16 inch from the surface of the plate. The microstructure of the Continental cast armor is tempered martensite throughout. The American cast armor, which is lower in hardenability (see Jominy hardenability curves Figure 5 and 6) contains appreciable proportions of free ferrite and intermediate transformation temperature products.

The upper two photomicrographs of Figure 8, at lower magnification, show segregation patterns in the two cast armors. Dendritic segregation is more apparent in the plate with lower hardenability where with the quenching practice employed differences in alloy concentrations influenced the carbide transformation products. The lower four photographs of Figure 8 show the base metal microstructures at midwall in samples which were drawn and stress relieved subsequent to welding. These microstructures are essentially the same as those in the quenched and tempered samples. The presence of slack quenched products in the American cast armor did not affect the notched bar impact values. Microstructures do not indicate the tendency of the base metals toward temper brittleness after the stress relief treatment.

Figures 9 and 10 show the microstructures of the weld metal at midwall of samples in the as-welded, stress relieved, and drawn conditions. A small amount of martensite is present in a matrix of ferrite and spheroidal carbides in the as-welded sample from the Continental plate. Very little martensite is present in the as-welded sample from the American plate (this difference may be explained by the welding techniques - see discussion of hardness surveys). Tempering of martensite patches and growth of spheroidal carbides occurs during stress relieving and to a greater extent during the draw treatment.

Figure 11 shows the microstructures of quenched and drawn weld metal samples to consist of heavily tempered carbides in a matrix of ferrite. The distribution of the carbides indicates that because of the low hardenability of the weld metal high transformation temperature carbides formed through the thickness of the weld metal. The high temperature draw treatment has spheroidized these carbides.

GENERAL CONSIDERATIONS

In general, the resistance to ballistic penetration should correlate with hardness of armor or weld deposits. Resistance to penetration tests made with 37 mm. AP M74 projectile fired at 0° obliquity show the following trends which might be predicted from results of hardness surveys[3]:

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[3] See also Aberdeen Proving Ground Armor Test Report No. AD-685.

The ballistic limit of the weld metal was more than 100 f/s lower than that of the armor for only seven plates: American, heat treated by full quench and draw or draw only, 2" depth of weld, fired on either side of plate; American, full quench and draw, 1-3/4" depth of weld, fired on either side of plate; American, draw only 1-3/4" depth of weld, fired on welded side of plate.

Higher ballistic limits were observed for Continental weld deposits which were found to have a higher hardness than the American weld deposits in the as-welded or stress relieved conditions.

As the depth of weld repair in the plates increased the resistance to penetration was found to decrease.

Higher ballistic limits were obtained when the plates were fired on the unwelded side than when fired on the welded side.

Ballistic shock tests while less conclusive, indicate poor performance of the Continental plates in the stress relieved condition, but no material difference between other plates in the various conditions of heat treatment.

Notched bar impact and nick break fracture tests indicate that the shock resistance of the weld deposits would be inferior to that of the armor plate under very severe ballistic shock and particularly at subnormal temperatures, but all the weld deposits appeared adequate to withstand impact, under the conditions of the ballistic shock tests employed in this program. The stress relief treatment after welding should not be permitted for cast armor compositions subject to temper embrittlement.

As previously noted[4], the hardenability of the type of weld metal deposit is very low, and improvement in both ballistic shock and penetration resistance probably would be obtained by an increase in carbon content or in alloy elements which would increase the hardenability and the resistance to softening during reheating below the critical hardening temperature.

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4. See Footnote 1, Page 5.

TABLE I

Summary of Heat Treatment and Ballistic Data

American Cast Plates

Plate Number	Heat Treatment Hold °F.	Hrs.	Quench	Repair Depth (in.)	Side Impacted	Ballistic Results: Army Ballistic Limit (f/s)[1] Plate	Weld	Shock Results[2] Vel.[3]	Cracking Weld	Plate
B 46	Prior to Welding:			2	front	1580	1455			
	1650	6	Air							
A 1306	1250	2	Air		back			1226[4]	6"	0
	After Welding:							1212[4]	extenied to 17-1/2"	0
	1650	4	H_2O							
B 85	1200-1220	4	H_2O		back	1520	1396			
A 1273				1-3/4	front	1535	1425			
B 110	Same as above.				back			1311	30"	3", 3½"
B 49					back	1562	1455			
A 1290				1-3/8	front	1512	1425			
A 1303	Same as above.				back			1294	0	0
A 1292					back	1606	1530	1305	2"	0
A 1282				1	front	1504	1440			
A 1289	Same as above.				back			1300	0	0
A 1278					back	1640	1617	1308	3"	0
B 55	Prior to Welding:			2	front	1582	1461			
	1650	6	Air							
B 56	1250	2	Air		back			1231[4]	0	0
	1650	4	H_2O					1301	0	0
B 52	1200-1220	4	H_2O		back	1525	1390			
	After Welding:									
	1200-1220	4	H_2O							
B 61				I-3/4	front	1543	1426			
B 145	Same as above.				back			1299	1-1/2"	0
B 57					back	1536	1449	1303	3-3/4"	0

TABLE I (CONT'D)

Plate Number	Heat Treatment Hold °F.	Hrs.	Quench	Repair Depth (in.)	Side Impacted	Ballistic Results: Army Ballistic Limit(f/s)[1] Plate	Weld	Shock Results[2] Vel.[3]	Cracking Weld	Plate
	Prior to Welding:									
B 71	1650	6	Air	1-3/8	front	1538	1466			
	1250	2	Air							
B 65	1650	4	H_2O		back			1305	1/2"	0
	1200-1220	4	H_2O					1317	1/2"	0
B 67	After Welding: 1200-1220	4	H_2O		back	1617	1554			
B 43				1	front	1626	1565			
B 95	Same as above.							1272	10-1/2"	0
								1290	0	0
B 59					back	1573	1571			
	Prior to Welding:									
B 78	1650	6	Air	2	front	1549	1482			
	1250	2	Air							
B 112	1650	4	H_2O		back			1281	0	0
	1200-1220	4	H_2O					1299	5"	2-1/4"
	After Welding:									
B 114	1100 to 600	4	F.C. A.C.		back	1579	1492			
B 83				1-3/4	front	1479	1412			
B 127	Same as above.				back			1308	4-1/2"	2-1/2"
								1310	2"	1"
B 107					back	1538	1495			
B 98				1-3/8	front	1425	1403			
B 103	Same as above.				back			1291	3-1/4"	0
								1296	3-3/4"	3-1/2"
B 91					back	1540	1525			
B 106				1	front	1476	1449			
B 102	Same as above.				back			1263	4-1/4"	0
								1300	1-3/4"	1", 4-3/4"
B 96					back	1544	1559			

TABLE I (CONT'D)

Plate Number	Heat Treatment °F.	Hold Hrs.	Quench	Repair Depth (in.)	Side Impacted	Ballistic Results: Army Ballistic Limit(f/s)[1] Plate	Weld	Shock Results[2] Vel.[3]	Cracking Weld	Plate
	Prior to Welding:									
B 115	1650	6	Air	2	front	1619	1521			
B 139	1250	2	Air		back			1305	2"	2", 2-3/4"
	1650	4	H_2O					1296	1-3/4"	2-1/2"
	1220	4	H_2O							
B 113	After Welding: none				back	1544	1463			
B 116				1-3/4	front	1463	1399			
B 141	Same as above.				back			1298	12-1/2"	3-1/2", 1-1/2"
								1213	1/2"	0
B 144					back	1483	1415			
B 111				1-3/8	front	1487	1405			
B 138	Same as above.				back			1289	5-1/4"	3-1/2", 1-1/2"
								1304	6"	2"
B 143					back	1594	1561			
B 131				1	front	1543	1488			
B 137	Same as above.				back			1275	5-1/4"	3-1/2", 2"
								1295	1"	1"
B 135					back	1586	1551			

1. Obtained with 37 mm. A.P. M74 projectile, 0° obliquity adjusted to weld thickness.
2. Obtained with 90 mm. PPT-9 projectile, 0° obliquity.
3. Corrected to 2.00 inch thickness - correction factor of 5 f/s/.01".
4. Velocity reduced to 1225 f/s for 2.00 inch instead of 1300 f/s - correction factor the same 5 f/s/.01".

TABLE I (CONT'D)

Summary of Heat Treatment and Ballistic Data

Continental Cast Plates

Plate No.	°F.	Heat Treatment Rise Hrs.	Hold Hrs.	Qu.	Repair Depth inches	Side Impacted	Projectile	Obliquity	Ballistic Results: Ballistic Limit(f/s)[5] Plate	Weld	Vel.[6]	Shock Results: Cracking Weld	Plate
6795-2	Prior to Welding:				2	back	105 mm PPT-8	0°			**1167	1"	0
	1625	4-6	8-10-1/2	Air									
	1275	1½-3-1/4	5-5-1/4	F.C.									
6795-11	1575	4-14	8-12-1/2	H_2O		back	3" APC M62	45°	1739+	1614-			
	1190-1210	1-1/4-3	12-14-1/2	H_2O									
6795-4	After Welding: Quench and draw as above					front	37 mm AP M74	0°	1623	1551			
6795-12					1-3/4	back	105 mm PPT-8	0°			*1125	1"	0
6815-3	Same as above.					back	3" APC M62	45°	1818+	1679+			
6795-14						front	37 mm AP M74	0°	1614	1588			
6815-4					1-3/8	back	105 mm PPT-8	0°			*1125	0	0
6923-2	Same as above.					back	3" APC M62	45°	1769+	1695-			
1033-3						back	105 mm PPT-8	0°			1194	4-1/4"	0
6842-9					1"	back	105 mm PPT-8	0°			1200	14-1/8"	0
6842-11	Same as above.					back	3" APC M62	45°	1788+	1698+			
6842-12						back	105 mm PPT-8	0°			1196	0	0
6815-13	Prior to Welding:				2"	back	105 mm PPT-8	0°			1199	6"	0
	1625	3-1/2-6	8-10-1/2	Air									
	1250-1275	2-4	5-7	F.C.									
6815-8	1575	3-1/2-14	8-12	H_2O		back	3" APC M62	45°	1762++	1704-			
	1190-1210	1-1/2-6	12-13-1/2	H_2O									
6740-7	After Welding:					front	37 mm AP M74	0°	1627	1563			
	1200	2-12	10-14-3/4	H_2O									

TABLE I (CONT'D)

Continental Cast Plates

Plate No.	Heat Treatment °F.	Rise Hrs.	Hold Hrs.	Qu.	Repair Depth inches	Side Impacted	Projectile	Obliquity	Ballistic Limit (f/s)[5] Plate	Weld	Vel.[6]	Shock Results Cracking Weld	Plate
	Prior to Welding:												
6765-4	1625	3-1/2-6	6-10-1/2	Air	1-3/4	back	105 mm PPT-8	0°			**1165	0	0
	1250-1275	2-4	5-7	F.C.									
6765-5	1575	3-1/2-14	8-12	H_2O		back	3" APC M62	45°	1749++	1685-			
	1190-1210	1-1/2-6	12-13-1/2	H_2O									
	After Welding:												
6965-13	1200	2-12	10-14-3/4	H_2O		front	37 mm AP M74	0°	1568	1508			
6965-11					1-3/8	back	105 mm PPT-8	0°			Lost(PTP)	0	0
6965-3	Same as above.					back	3" APC M62	45°	1781++	1711++			
6965-5						back	105 mm PPT-8	0°			1167	1-1/2"	0
6842-2					1	back	105 mm PPT-8	0°			*1146	8"	0
6842-3	Same as above					back	3" APC M62	45°	1746++	1731			
6842-4						back	105 mm PPT-8	0°			1195	13-3/4"	0
	Prior to Welding:												
6795-7	1625	3-6-1/2	8-10-1/2	Air	2	back	105 mm PPT-8	0°			1193	6-1/4	0
	1250-1275	1½-3-1/4	5-7	F.C.									
6740-9	1575	3-1/2-14	8-12	H_2O		back	3" APC M62	45°	1808+	1721++			
	1190-1210	1-1/4-6	12-14-1/2	H_2O									
	After Welding:												
6815-7	1100	1-2-1/2	2-2-1/2	F.C or F.C. & Air		front	37 mm AP M74	0°	1590	1551			
6842-14					1-3/4	back	105 mm PPT-8	0°			**1177	1"	0
6965-9	Same as above.					back	3" APC M62	45°	1790+	1683			
6815-10						front	37 mm AP M74	0°	1526	1487			

TABLE I (CONT'D)

Continental Cast Plates

Plate No.	Heat Treatment °F.	Rise Hrs.	Hold Hrs.	Qu.	Repair Depth inches	Side Impacted	Projectile	Obliquity	Ballistic Results: Ballistic Limit(f/s)[5] Plate	Weld	Vel.[6]	Shock Results: Cracking Weld	Plate
	Prior to Welding:												
997-1	1625	3-6-1/2	8-10-1/2	Air	1-3/8	back	105 mm PPT-8	0°			1198	17-1/2"	7-3/4", 14½", 5-3/4"
	1250-1275	1½-3-1/4	5-7	F.C.									
945-2	1575	3-1/2-14	8-12	H_2O		back	3" APC M62	45°	1716++	1765++			
	1190-1210	1-1/4-6	12-14-1/2	H_2O									
	After Welding:												
1033-1	1100	1-2-1/2	2-2-1/2	F.C. or F.C. & Air		back	105 mm PPT-8	0°			1196	broke into 4 pieces	
6842-5					1"	back	105 mm PPT-8	0°			1208	20-1/2"	0
6842-8	Same as above.					back	3" APC M62	45°	1763+	1725			
6842-7						back	105 mm PPT-8	0°			1195	33"	0
	Prior to Welding:												
6795-9	1625	3-3/4-6	8-9½	Air	2"	back	105 mm PPT-8	0°			1195	0	0
	1250-1275	1½-3-1/4	5-7	F.C.							1195	0	0
6795-10	1575	4-3/4-14	8-12	H_2O		back	3" APC M62	45°	1816+	1711+			
	1190-1210	1½-6	12-13	H_2O									
	After Welding:												
6740-13	none					front	37 mm AP M74	0°	1628	1583			
6965-6					1-3/4	back	105 mm PPT-8	0°			1197	5-1/2"	0
6815-14	Same as above.					back	3" APC M62	45°	1754	1710++			
6965-10						front	37 mm AP M74	0°	1553	1515			
6965-7					1-3/8	back	105 mm PPT-8	0°			1191	0	0
6965-4	Same as above.					back	3" APC M62	45°	1750	1717			
6965-14						back	105 mm PPT-8	0°			1195	2-1/2"	0

TABLE I (CONT'D)

Continental Cast Plates

Plate No.	Heat Treatment °F.	Rise Hrs.	Hold Hrs.	Qu.	Repair Depth inches	Side Impacted	Projectile	Obliquity	Ballistic Results: Ballistic Limit(f/s)[5] Plate	Weld	Vel.[6]	Shock Results: Cracking Weld	Plate
	Prior to Welding:												
6965-8	1625	3-3/4-6	8-9-1/2	Air	1	back	105 mm PPT-8	0°			*1137	0	0
	1250-1275	1½-3-1/4	5-7	F.C.									
6923-11	1575	4-3/4-14	8-12	H_2O		back	3" APC M62	45°	1766++	1742			
	1190-1210	1-1/2-6	12-13	H_2O									
6960-1	After Welding: none					back	105 mm PPT-8	0°			1170	broke into 7 pieces	

5. Approximate protection ballistic limit obtained with 3" APC M62 projectile. Plus sign indicates high partial penetration velocity. Minus sign indicates low complete penetration velocity. Two plus signs indicate more than 50 f/s between low complete and high partial penetrations. No sign indicates actual protection ballistic limit. Velocities corrected to 2" (factor: 5 f/s/.01"). Army ballistic limit obtained with 37 mm. AP M74 adjusted to weld thickness.

6. Velocities based on 1200 f/s/2"; velocities corrected to 2" (factor: 5 f/s/.01"); *velocity adjusted to 1125 f/s/2" with same correction factor; ** velocity adjusted to 1175 f/s/2" with same correction factor.

TABLE II

Results of Rc Hardness Surveys

American Cast Plates

Repair Weld Depth	As Welded			Stress Relieved			Drawn			Quenched & Drawn		
	AB	CD	EF	AB	CD	EF	AB	CD	EF	AB	CD	EF
		B 113			B 114			B 52			A 1306	
	15.0	21.0	12.0	9.5	21.5	14.5	13.0	21.5	10.5	3.5	21.0	8.5
	9.5	23.0	11.5	11.5	22.5	13.5	16.5	22.0	14.5	9.5	23.5	8.5
	8.0	21.0	12.5	10.0	19.5	11.0	10.0	19.0	12.5	5.5	21.0	7.5
	14.0	20.5	13.0	10.5	20.5	10.5	9.0	18.5	12.5	3.5	21.5	7.0
2"	9.5	22.0	14.0	11.0	21.5	11.0	10.5	19.0	13.0	6.5	18.0	8.0
	13.5	23.5	13.5	15.5	22.0	10.0	13.5	23.5	10.5	10.0	15.0	9.5
	19.0	22.0	13.5	15.5	23.0	9.0	16.5	22.0	13.5	11.0	23.5	8.5
			13.0			8.0			12.0	11.5	24.0	9.5
			14.5			11.0			13.0			8.0
			14.0			10.0			14.0			5.5
			16.5			10.5			15.5			11.5
						17.0						11.0
		B 144			B 107			B 61			A 1273	
	16.0	21.5	12.5	13.0	20.5	10.5	11.5	21.0	11.5	5.5	17.5	6.5
	13.5	22.0	11.5	12.5	21.5	10.5	7.5	20.0	10.0	5.5	23.5	6.5
	14.5	20.5	13.5	10.5	20.5	11.5	8.5	18.5	10.5	6.5	21.5	5.5
	12.5	17.5	15.5	8.5	19.5	11.0	8.0	15.5	9.0	7.0	21.5	5.5
	11.5	18.5	11.5	11.0	19.5	11.0	7.5	15.5	9.5	5.5	20.5	7.0
1-3/4"	12.5	21.5	13.0	11.5	23.0	11.5	9.5	15.5	10.5	7.5	22.5	6.5
	12.5	21.0	12.5	13.5	22.5	11.5	11.5	21.0	9.5	9.5	23.5	8.0
	11.0		11.5	11.0	20.5	11.5	14.5	20.0	9.5	10.5	22.0	8.0
	15.5		14.5	15.0		12.5	15.5	19.5	11.5	12.5		7.5
	25.5		14.5	20.0		13.0	16.0		13.5	16.5		9.0
			15.5			15.0			15.5			9.5
						18.0						
		B 143			B 98			B 67			A 1292	
	15.0	21.5	15.0	11.0	20.5	12.0	8.5	18.0	7.5	4.5	19.5	6.5
	15.5	20.0	16.0	12.0	19.5	12.5	10.5	18.0	11.5	5.5	19.5	5.5
	15.5	19.5	15.5	11.5	17.5	14.5	6.5	17.5	10.5	5.0	19.0	5.5
	15.5	19.5	15.5	11.0	15.5	14.0	8.5	16.5	9.5	5.0	17.0	4.5
	16.5	19.5	15.0	15.5	21.0	11.5	10.5	15.0	8.5	7.5	16.5	4.0
1-3/8"	23.5	20.5	15.5	16.5	19.0	13.0	17.0	17.0	9.0	19.0	19.5	4.5
	22.5	21.5	12.0	15.5		12.5	13.0	19.5	10.0	21.0	20.5	4.5
			17.5			14.5			8.5	20.5	20.0	4.0
			15.5			13.5			10.0			4.5
			17.0			13.5			11.5			7.0
			15.0			16.5						7.0
												7.0
		B 131			B 96			B 43			A 1278	
	16.0	21.5	13.5	10.0	16.5	8.0	10.0	19.5	9.5	7.5	17.5	5.5
	16.5	23.0	15.0	13.0	19.5	11.0	7.0	21.0	11.0	6.5	17.5	7.5
	15.0	13.0	19.0	12.5	17.0	11.5	12.5	17.5	11.5	8.0	17.5	6.0
	18.0	20.0	17.5	14.5	18.5	11.0	10.5	14.5	9.0	7.5	16.5	6.5
	18.5	19.5	12.5	17.5	18.5	11.0	11.0	18.0	11.0	8.5	16.0	7.5
	22.5	24.0	15.5	19.5	19.0	10.0	13.0	20.0	9.5	12.5	16.5	7.0
1"	26.5	20.0	15.0	17.0	20.0	12.5	20.0	20.5	10.5	13.0	18.5	7.5
	20.5		14.5	18.0		12.5	15.5	18.5	8.0	15.5	17.5	8.5
	22.5		15.0	20.0		13.5	19.5		11.0	17.0		7.5
	22.0		14.5	20.0		14.5	20.0		11.0	20.0		8.0
	21.5		16.5	18.0		16.0	21.5		14.0	21.5		8.0
	20.0		15.0			18.5	20.5		19.5	17.0		7.0

NOTE: Underlined readings taken at 1/8 inch spacing.

TABLE II (CONT'D)

Continental Cast Plates

Repair Weld Depth	As Welded			Stress-Relieved			Drawn			Quenched & Drawn		
	AB	CD	EF	AB	CD	EF	AB	CD	EF	AB	CD	EF
		6795-9			6795-7			6815-13			6795-4	
2"	20.5	22.0	17.5	16.5	16.5	14.5	11.5	19.5	9.5	4.5	22.0	3.5
	17.0	21.5	17.5	17.0	16.0	17.5	11.5	19.0	10.5	4.5	22.5	3.5
	15.5	19.5	16.5	16.5	14.5	16.5	10.5	20.0	11.0	3.5	22.5	4.5
	15.5	23.0	18.0	16.5	16.5	18.5	9.5	17.5	12.5	5.0	20.5	1.5
	16.0	22.5	16.5	19.5	17.0	16.5	6.5	17.5	10.0	4.5	21.5	4.5
	18.5	21.5	18.5	18.0	18.5	14.0	7.0	18.0	11.5	6.0	21.5	3.5
	20.5	23.0	16.0	20.5	19.0	16.0	15.0	18.0	11.5	5.5	20.5	3.5
	20.0	21.0	18.5	20.0	16.5	16.5	9.5		11.5	5.0	22.5	5.0
			19.0						11.5			5.5
			19.0						12.5			4.5
									12.5			3.5
		6965-6			6842-14			6765-4			6795-12	
1-3/4"	15.5	23.0	13.5	15.5	21.5	18.0	11.5	20.5	9.5	10.5	23.5	11.0
	15.5	23.5	13.5	16.5	20.5	16.5	11.5	21.5	12.5	10.5	22.5	9.5
	14.5	22.0	16.5	13.0	20.0	13.5	10.0	20.5	11.5	10.5	21.5	9.5
	12.5	22.5	15.0	15.0	19.5	15.5	9.5	21.5	13.5	9.5	19.0	9.5
	13.5	22.5	14.5	14.5	20.5	13.5	9.5	22.0	12.0	8.5	19.5	9.5
	10.5	23.5	14.5	18.5	20.5	16.5	13.0	21.5	14.0	10.0	20.5	10.5
	13.5	23.0	15.0	19.5	21.5	17.5	12.5	23.5	14.5	11.5	21.5	10.5
	13.0		13.5	24.5	20.5	18.5	16.0	22.5	15.0	12.0	22.0	10.5
	18.5		15.0	20.0		17.5	18.5		14.5	19.5		10.0
	31.0		17.0	19.5		17.5	22.0		16.0	25.5		10.5
	27.5		19.0			17.0	20.5		16.0	22.5		10.0
	26.0		16.5						17.0			6.5
			19.5						18.5			
			20.5									
		6965-7			997-1			6965-11			1033-3	
1-3/8"	20.0	23.5	15.0	17.0	22.5	12.5	20.5	21.5	13.5	4.5	23.5	12.5
	14.5	24.5	16.5	11.5	22.5	12.5	16.5	21.5	8.5	10.5	24.5	12.0
	18.0	22.5	16.5	11.5	22.5	13.5	13.0	20.5	11.5	11.5	21.0	12.5
	14.5	20.0	17.0	12.5	23.0	13.0	10.0	19.5	11.5	10.5	22.0	11.5
	11.5	22.0	17.5	16.5	23.0	9.5	13.5	20.5	10.5	17.0	21.5	10.5
	24.5	20.0	15.5	20.5	24.0	13.5	12.0	20.5	7.5	20.5	22.5	8.0
	24.0	23.5	19.5	26.5	23.5	13.5	20.0	22.5	10.5	23.5	23.0	9.5
	24.5	23.5	19.0	21.5	22.5	13.0	21.0		11.5		22.5	8.5
			19.0			19.0			11.5			9.5
			20.5						11.5			9.0
			20.0						14.5			9.5
												11.5
		6965-8			6842-7*			6842-2			6842-9	
1"	17.0	24.0	14.5	19.5	18.5	17.5	17.5	21.0	12.5	12.0	25.5	8.5
	15.0	23.5	16.5	19.0	18.0	17.5	15.5	20.5	13.0	9.5	24.0	11.0
	14.5	21.5	14.0	19.0	18.5	17.0	12.5	20.5	13.5	9.5	22.5	11.0
	13.5	24.5	14.5	19.0	19.0	18.0	13.5	19.5	12.5	8.5	23.5	11.0
	12.5	24.5	15.5	16.5	19.5	16.5	13.5	19.0	13.5	7.5	24.5	10.5
	14.0	24.5	13.5	20.5	20.5	16.5	13.0	21.5	13.5	9.0	25.0	8.5
	17.5	25.0	15.5	29.5	20.0	17.5	18.0	22.5	12.5	12.5	25.0	9.5
	33.5		14.5	20.0	20.0		20.5	21.5	11.5	21.5	24.0	11.0
	23.0		15.5	21.0			22.5		13.0	23.0		10.5
	21.0		17.0	21.5			22.5		11.5	23.5		10.5
	23.5		17.5	21.5			23.5		12.0	25.0		10.5
	23.5			20.0			23.5		16.0	25.5		11.5
									16.5			

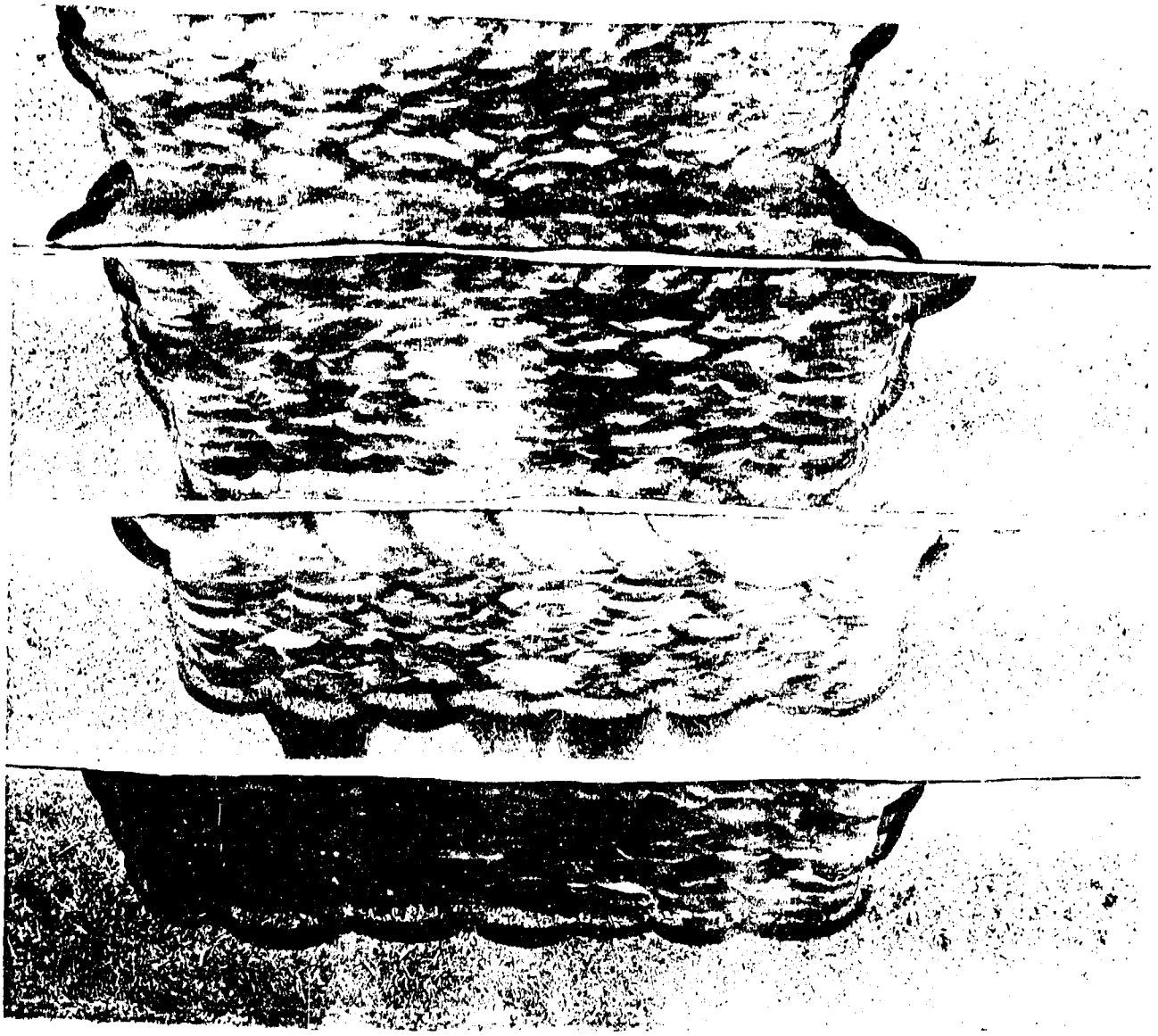
* Inadequate sample - taken near end of weld.

TABLE III

Charpy Impact Results

Depth of Repair	Testing Temp.	Charpy Impact Values - Ft. Lbs. As Welded Weld	As Welded Plate	Stress-Relieved Weld	Stress-Relieved Plate	Drawn Weld	Drawn Plate	Quenched & Drawn Weld	Quenched & Drawn Plate
American Cast Plates									
2"	70°F	103	53	100		111		91	
		113	55	83		93		97	
	-40°F	29	48	29		60		73	
		38	53	39		47		100	
1"	70°F	32	47	108	46	112	56	106	66
		75	46	98	46	119	59	96	67
	-40°F	32	39	37	31	27	53	28	52
		11	36	42	36	52	56	33	49
Continental Cast Plates									
2"	70°F	107	47	74		101		132	
		122	51	56		134		132	
	-40°F	22	36	31		128*		94	
		22	33	25		45		95	
1"	70°F	92	51	95	22	120	46	117	41
		74	47	86	22	114	48	128	48
	-40°F	27	26	37	9	105*	33	81	35
		33	27	44	11	21	27	71	27

*Weld metal defect present - split fracture.

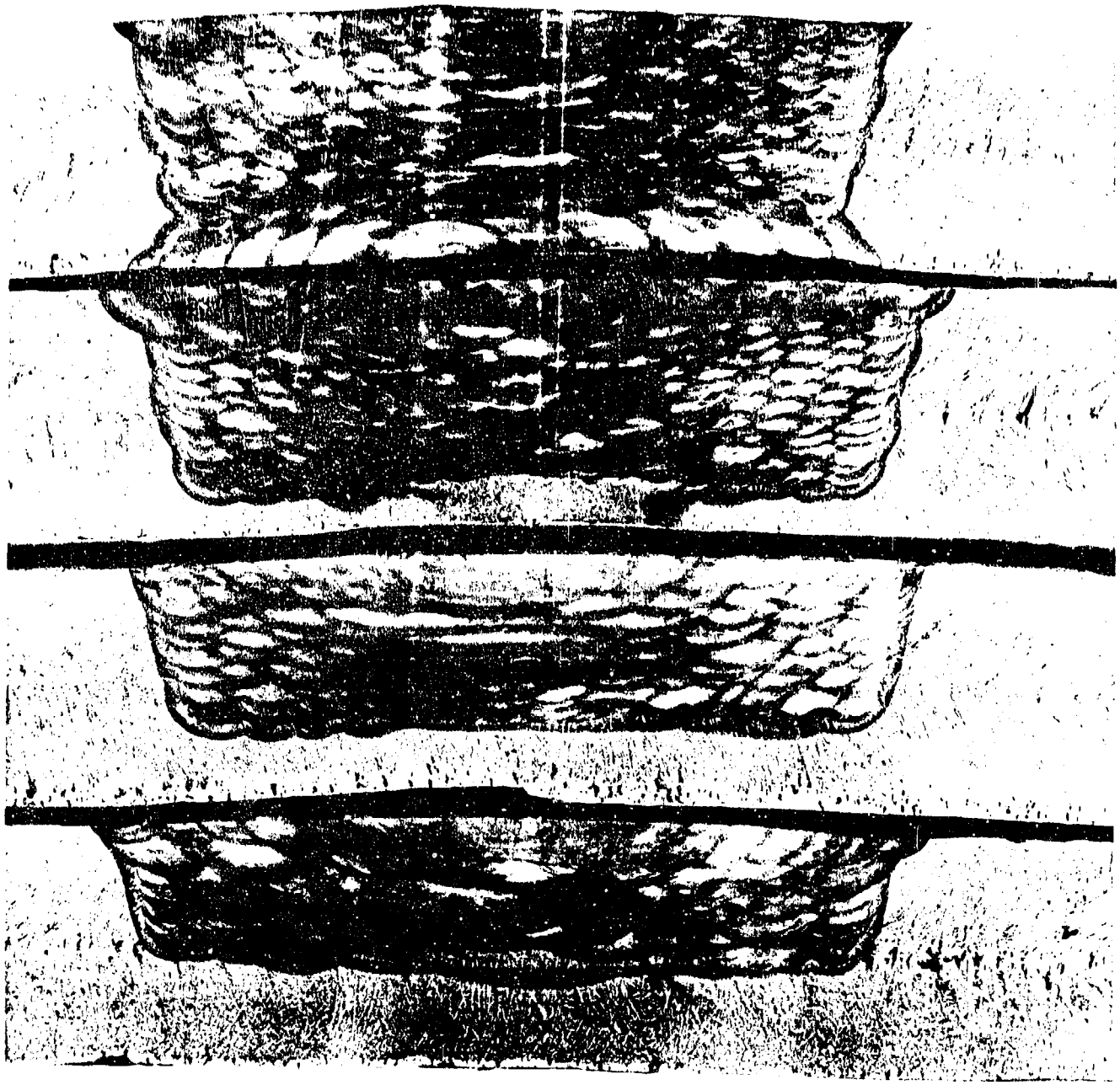


WATERTOWN ARSENAL

MACROETCHED SECTIONS THROUGH REPAIR WELDS IN AMERICAN CAST ARMOR BALLISTIC TEST PLATES AS WELDED. PLATE B113 – DEPTH OF WELD: FULL THICKNESS. PLATE B144 – DEPTH OF WELD : 1 3/4 INCHES. PLATE B143 – DEPTH OF WELD: 1 3/8 INCHES. PLATE B131 – DEPTH OF WELD : 1 INCH. MAG. X 3/4. 11 JAN 1945 WTN.121-606

FIG. 1

REPRODUCED AT GOVERNMENT EXPENSE

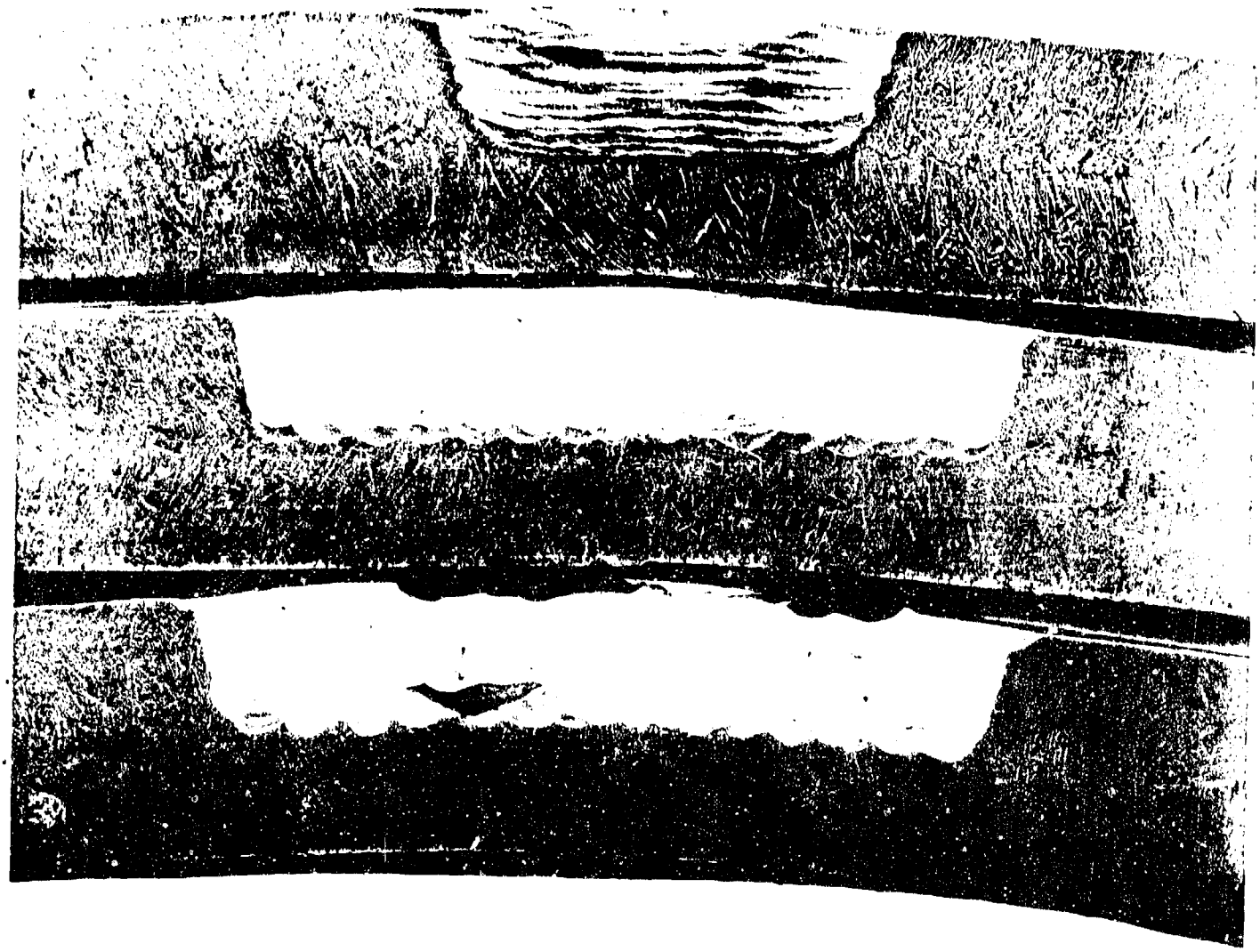


WATERTOWN ARSENAL

MACROETCHED SAMPLES THROUGH REPAIR WELDS IN CONTINENTAL CAST ARMOR BALLISTIC TEST PLATES AS WELDED. PLATE 6795-9 DEPTH OF WELD: FULL THICKNESS. PLATE 6965-6 DEPTH OF WELD : 1 3/4 INCHES. PLATE 6965-7 DEPTH OF WELD: 1 3/8 INCHES. PLATE 6965-8 DEPTH OF WELD : 1 INCH. MAG. X 3/4. 12 JAN 1945 WTN.121-607

FIG. 2

REPRODUCED AT GOVERNMENT EXPENSE

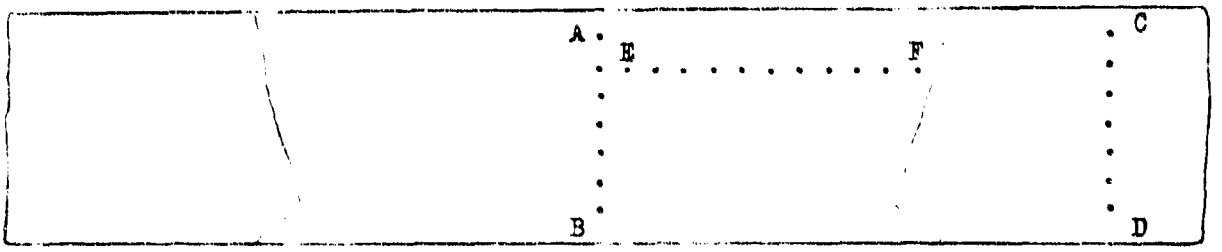


WATERTOWN ARSENAL

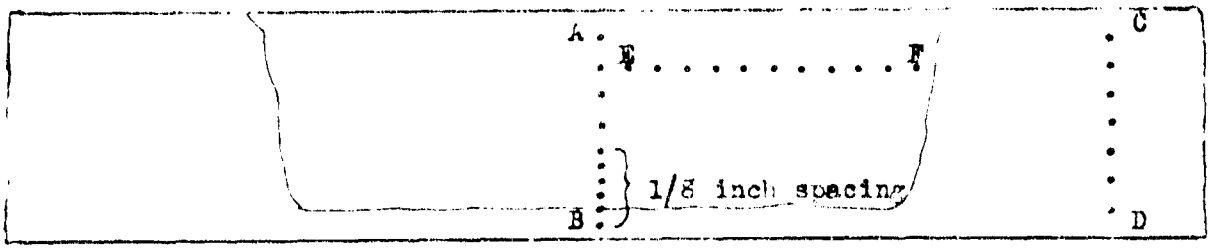
Macroetched Samples through Repair Welds in Continental Cast Armor Ballistic Test Plates - Variously Heat Treated. Plate 6842-7: (Inadequate Sample - Taken Near End of Weld) One Inch Deep Weld-Stress Relieved after Welding; Plate 6842-2: One Inch Deep Weld-Drawn after Welding; Plate 6842-9: One Inch Deep Weld-Quenched and Drawn after Welding. Mag. X 3/4 WTN. 121-615

Figure 3.

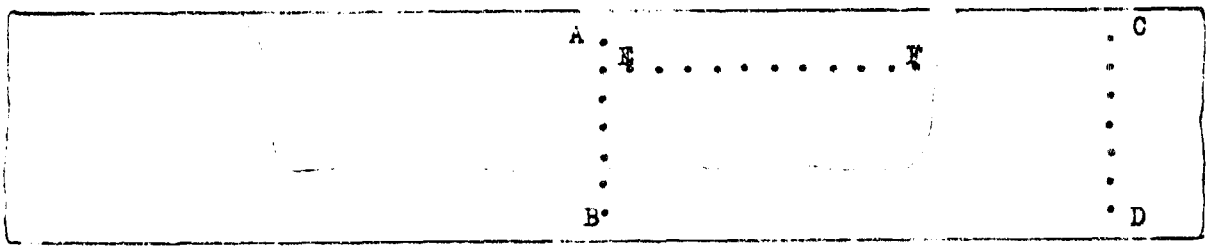
REPRODUCED AT GOVERNMENT EXPENSE



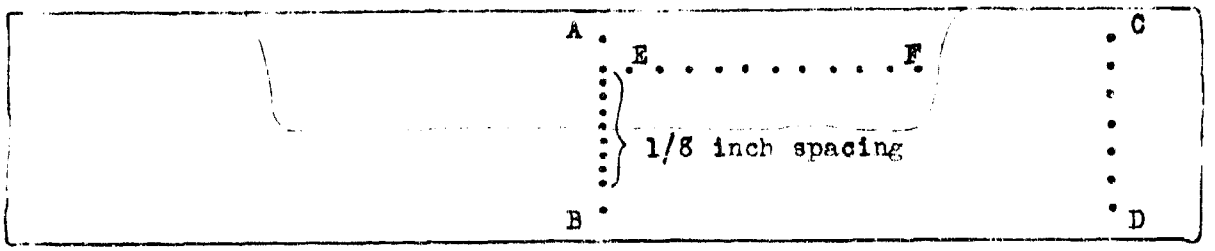
weld depth: 2 inches - 1/4 inch spacing



weld depth: 1-3/4 inches - 1/4 inch spacing except where noted otherwise



weld depth: 1-3/8 inches - 1/4 inch spacing



weld depth: 1 inch - 1/4 inch spacing except where noted otherwise

Figure 4. Method of Making R_c Hardness Surveys.

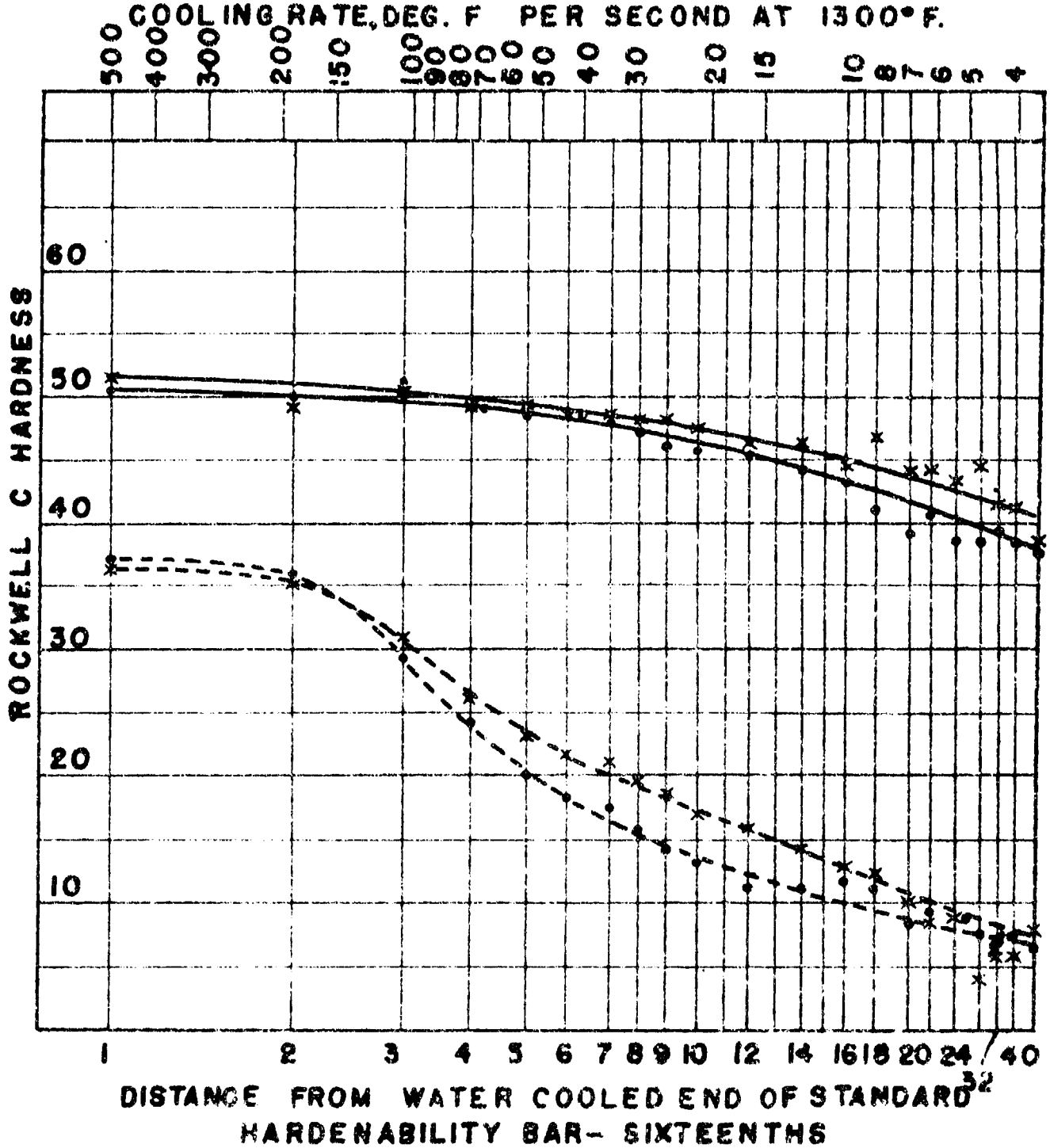


PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO		QUENCH TEMP	TIME	G.S.
B113	plate	.29	1.68	.50	.025	.015	Tr	.53	.30	———	1650°	2 hrs.	
	weld	.08	1.74	.24	.021	.023	Tr	.03	.32	- - - -	1650°	2 hrs.	

Figure 5. Jominy Hardenability Curves for American Plate and Weld Metals.

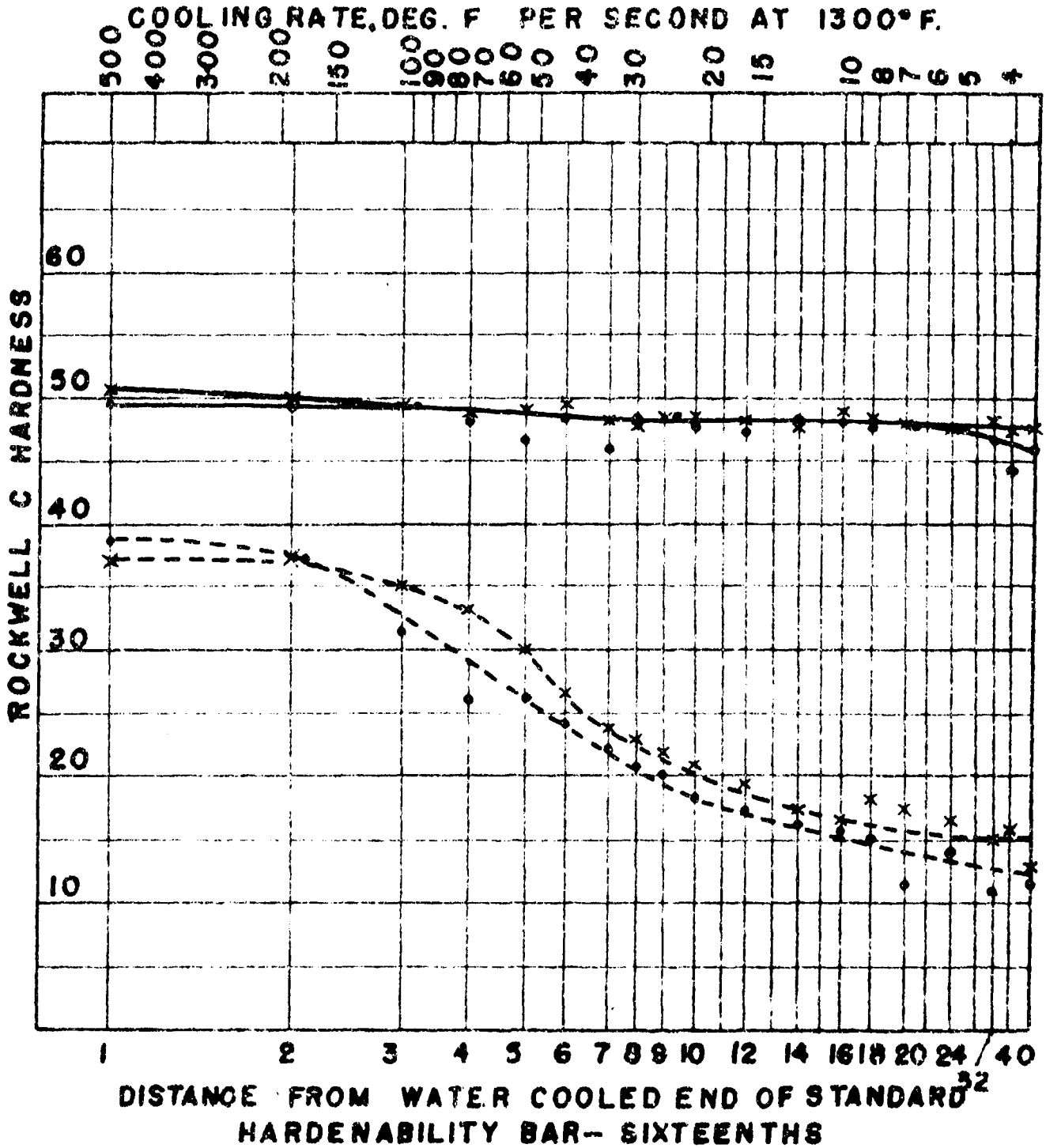
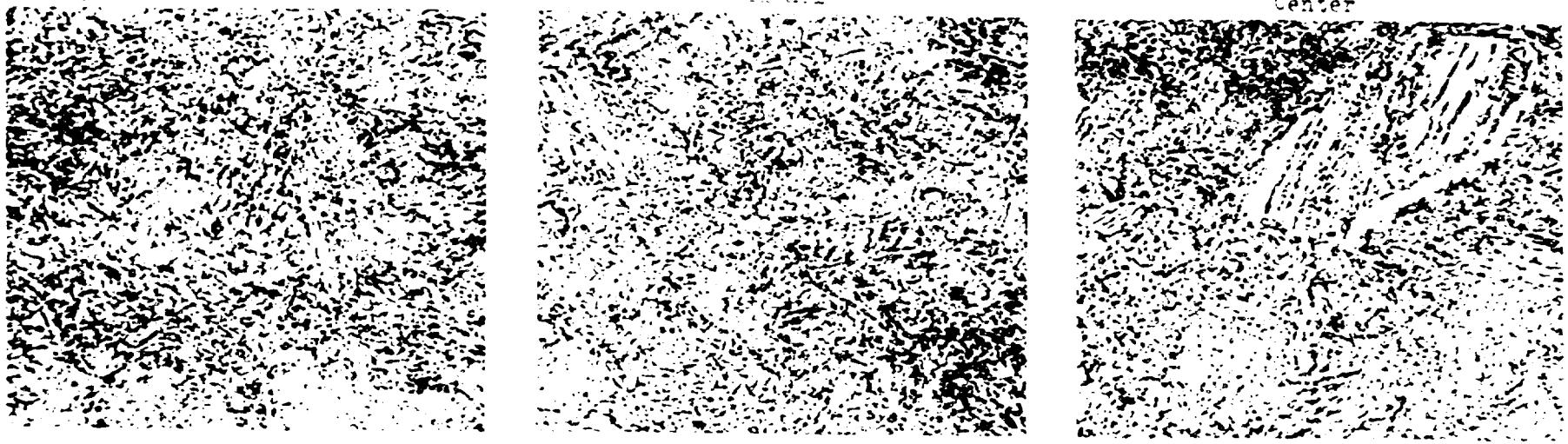


PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO			QUENCH TEMP	TIME	G.S.
6795-9	Plate	.29	1.52	.42	.030	.043	.77	.67	.41		———	1650°F	2 hrs.	
	Weld	.09	1.86	.22	.020	.024	Tr.	.03	.38		- - -	1650°F	2 hrs.	

Figure 6. Jominy Hardenability Curves for Continental Plate and Weld Metals.

REPRODUCED AT GOVERNMENT EXPENSE

3/16 inch from surface | Midwall | Center

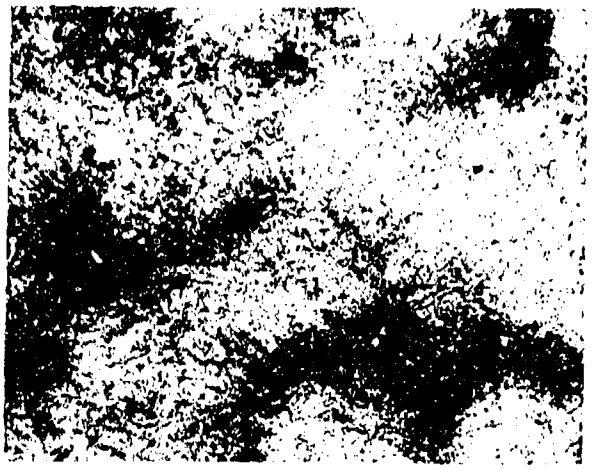


American Plate A1273 -- X1000 -- Picral Etch

Continental Plate 6795-12 -- X1000 -- Picral Etch

Microstructure of Plate Metal Quenched and Drawn after Welding.

Figure 7



X100 Picral

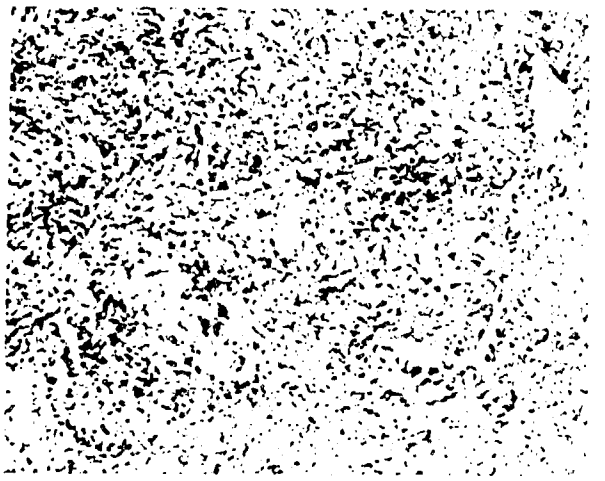
American plate A1273 - Quenched and drawn after welding. (Midwall)

X100 Picral

Continental plate 6795-12 - Quenched and drawn after welding. (Midwall)

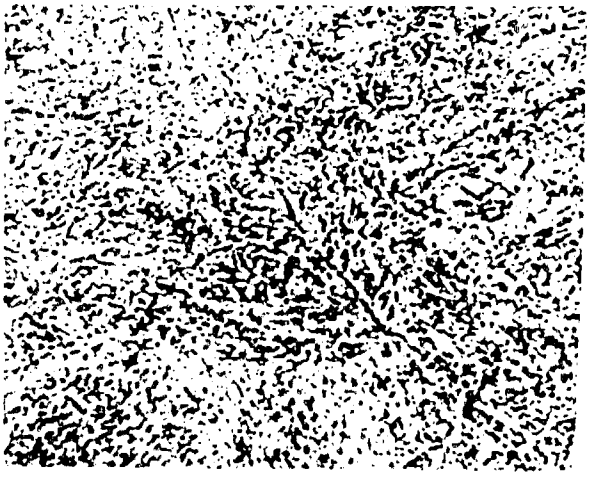
X1000 Picral

American plate B96 - Stress relieved after welding. (Midwall)



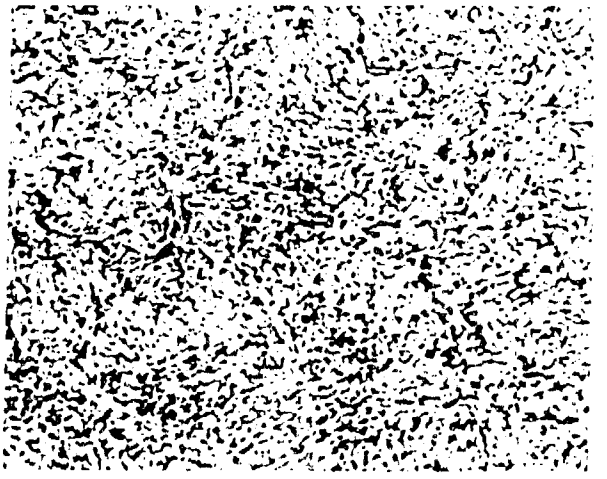
X1000 Picral

American plate B43 - Drawn after welding. (Midwall)



X1000 Picral

Continental plate 6842-7 - Stress relieved after welding. (Midwall)



X1000 Picral

Continental plate 6765-4 - Drawn after welding. (Midwall)

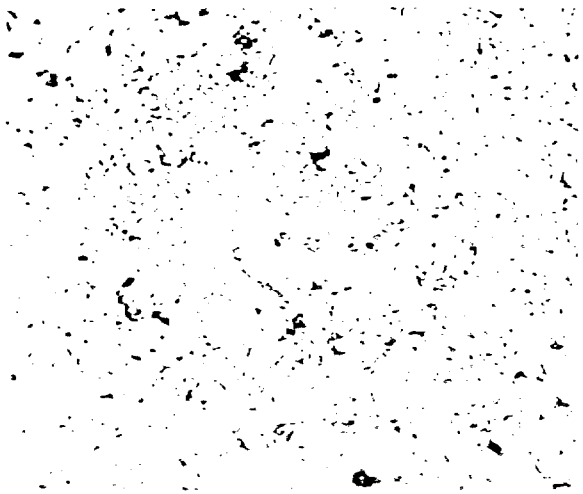
WIN.639-7645

Figure 8

IS PRODUCED AT GOVERNMENT EXPENSE

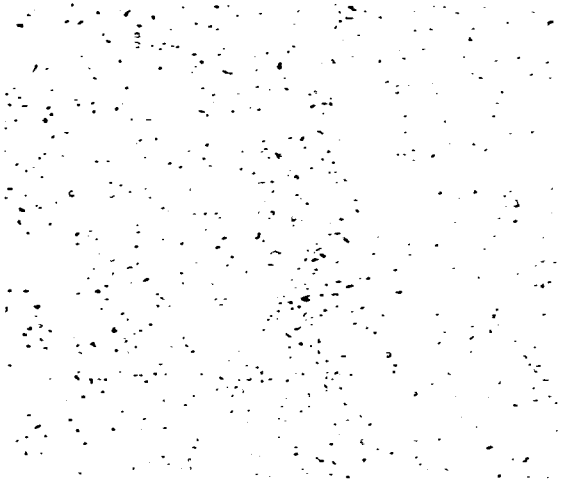
REPRODUCED AT GOVERNMENT EXPENSE

As Welded



Stress Relieved after Welding

Drawn after Welding



Microstructure at X1000 -- Picral etch

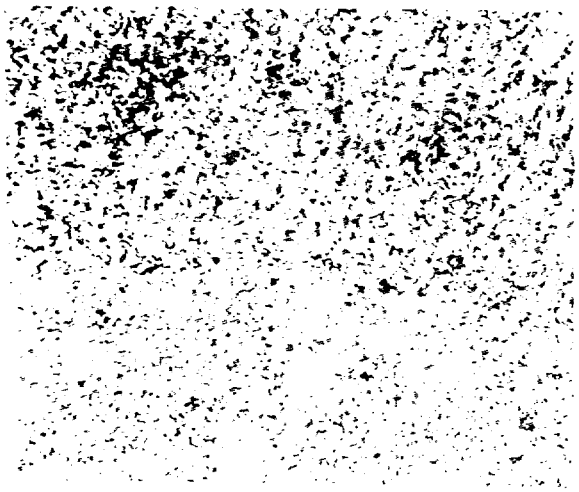


Plate 6795-[illegible]

Microstructure at X1000 -- Picral etch
Plate 6795-7

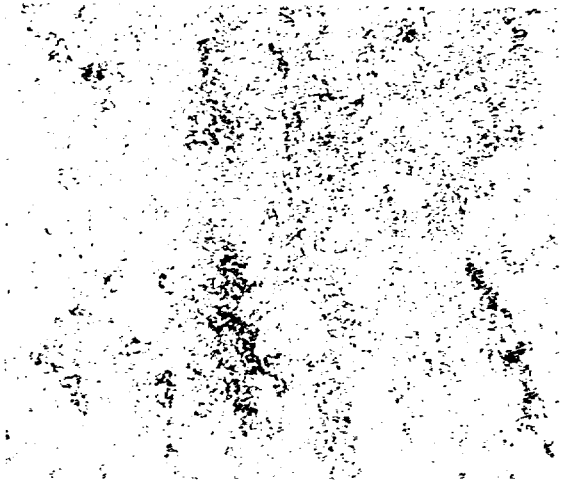
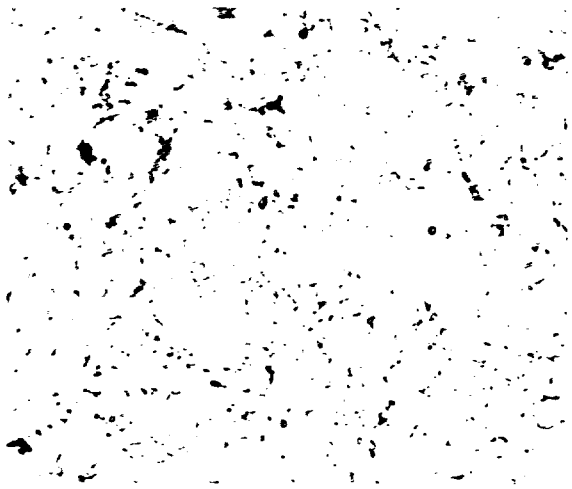


Plate 6815-13

Continental Weld Metal Microstructure.
Figure 9

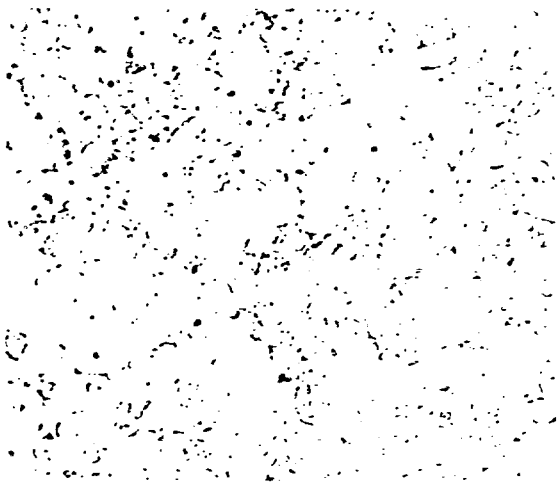
REPRODUCED AT GOVERNMENT EXPENSE

As Welded



Stress Relieved after Welding

Drawn after Welding



Microstructure at X1000 -- Picral etch

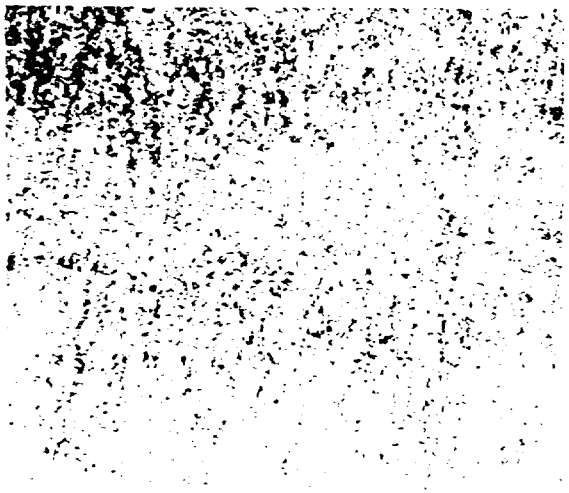
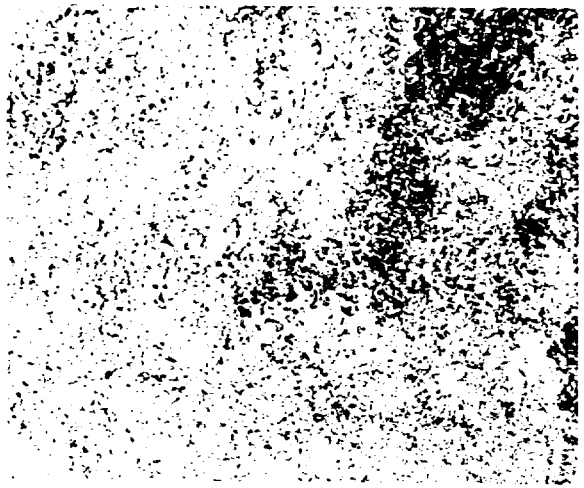


Plate B144



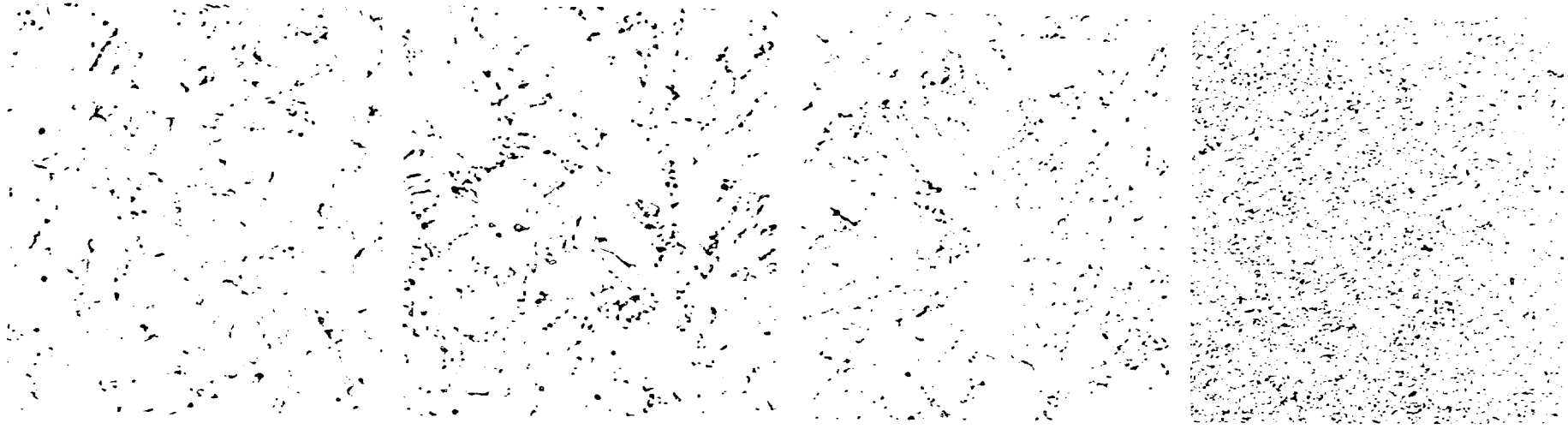
Microstructure at X100 -- Picral etch
Plate B114

Plate B52

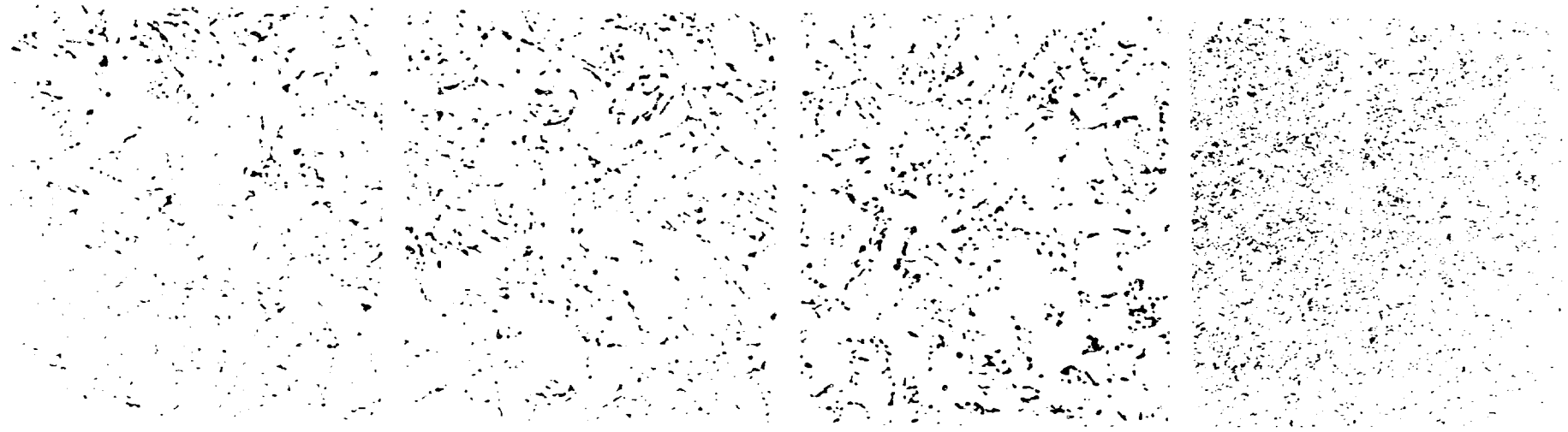
American Weld Metal Microstructure.
Figure 10

REPRODUCED AT GOVERNMENT EXPENSE

3/16" from surface (X1000) Midwall (X1000) Center (X1000) Midwall (X100)



American plate A1273 -- Picral etch



Continental plate 6795-12 -- Picral etch

Microstructure of Quenched and Drawn Weld Metal.
Figure 11

APPENDIX A

Basic Correspondence

COPY

ARMY SERVICE FORCES

OFFICE OF THE CHIEF OF ORDNANCE - DETROIT

DETROIT 32, MICHIGAN

OOM
470.5/Wtn Ars. (4-4-44)

Attention
SPOME-EE

Boucher/fb
Ext. 2994 - 24 Fl.

4 April 1944

Subject: Repair Welded Cast Armor Specimens

To: Commanding Officer
Watertown Arsenal
Watertown 72, Massachusetts

Attn: Laboratory

1. The attached directive is submitted for your information in connection with Project 1103 this office. Also attached is copy of first indorsement, file OOM 470.5/WA (13 Mar. 44), Wtn 470.5/9102, which requested information on four plates previously submitted by Continental Roll & Steel Foundry and American Steel Foundries. It is requested that the same information be obtained on specimens which will be shipped to you by Aberdeen Proving Ground after firing, in accordance with the requirements of this directive.

By order of the Chief of Ordnance:

(s) John F. Randall (for)
Captain, Ord. Dept.

(t) D. C. PIPPEL
Major, Ord. Dept.
Assistant

1 Incl - Copy of letter to APG,
31 Mar. 44, w/incls.

COPY

COPY

Boucher/fb
Ext.2994 - 24 Fl.

SPOME-X

31 March 1944

Subject: Repair Welded Cast Armor Specimens

To: The Director
Ordnance Research Center
Aberdeen Proving Ground, Maryland

Attn: Armor Branch

1. Production Order Nos. T12792 and T12795 have been issued to Continental Roll & Steel Foundry and American Steel Foundries for a total of 96 welded specimens which will be made in accordance with the instructions set forth by this office in the request for quotation. A copy of the request for quotation to American Steel Foundries is attached. The same request was sent to Continental. All plates covered by these production orders will be marked "Project 1103".

2. These specimens are being submitted for the determination of ballistic and shock results of repair welds made with ferritic electrodes under varying conditions, i.e., depth of repair and heat treatment.

3. It is believed advisable to withhold the testing of any specimens until the complete series is received from one source, i.e., Continental or American. If, for example, all specimens are received from American Steel Foundries, testing should be withheld on specimens from Continental until the complete series from American has been tested, as it may be desirable to amend the testing procedure as established herein. This office should be advised as to the progress and the results of this program.

4. The plate shall be tested as follows:

a. One plate representing each depth of repair and each heat treatment condition shall be tested for resistance to shock, using 90-mm. proof projectiles. (If these projectiles are not available or you believe them to be unsuitable, it is recommended that your station indorse this file back to this office and recommend what you would consider to be a satisfactory test).

b. One plate representing each depth of repair and each heat treatment condition shall be tested for the establishment of ballistic limit in the welded area and unaffected plate at 0° obliquity. In this series the front of the plate shall be facing the piece. 37-mm. A.P. M74 projectiles shall be used.

c. One plate representing each depth of repair and each heat treatment condition shall be tested for the establishment of ballistic limit in the welded area and unaffected plate at 0° obliquity. In this series the rear of the plate shall be facing the piece. 37-mm. A.P. M74 projectiles shall be used.

COPY

To: Aberdeen Proving Ground 31 March 1944

d. Any additional testing may be conducted at the discretion of your station.

5. Specimens 4" x 10" shall be taken across the weld, preferably a section which contains no impacts and sent to Watertown Arsenal, attention of Laboratory. These specimens should be marked suitably so that they may be properly identified with the plate from which they were taken. Watertown will then conduct a series of physical and metallurgical tests.

6. The material submitted on these production orders is Government owned, and at the completion of the tests and removal of samples, the material may be disposed of in accordance with Army regulations.

7. Distribution of reports should include one copy to National Research Council, attention of Mr. G. S. Nikhalapov.

By order of the Chief of Ordnance:

E. L. CUMMINGS
Colonel, Ord. Dept.
Assistant

2 Incls.
Incl. 1 - Copy of letter to American Steel Foundries, w/incls., 17 Dec. 43
Incl. 2 - Copy of 1st Ind. to Watertown Arsenal, 17 March 44

cc Col. E. L. Cummings - SPOME-X
cc OCO-Washington, SPOTB
cc Development Branch
cc Watertown Arsenal

COPY

WAR DEPARTMENT

ARMY SERVICE FORCES

OFFICE OF THE CHIEF OF ORDNANCE

TANK-AUTOMOTIVE CENTER

Union Guardian Building

Detroit 26, Michigan

Dalcher/dw
2994/24th Fl.

Attention
SPOME-EE

17 December 1943

American Steel Foundries
410 North Michigan Ave.
Chicago, Illinois

Attention: Mr. A. J. McDonald

Gentlemen:

This office is conducting a series of tests to ascertain the limits which may safely be allowed for cast armor repair, utilizing presently available welding electrodes. Your cooperation in this program is requested, and, accordingly, this office would appreciate receiving your quotation for the specimens described below.

Specimens Required. A total of forty-eight (48) specimens will be required, consisting of cast armor plate 2" x 36" x 36", prepared with a cavity and repaired by welding as shown in Sketch 1 attached. The plates will be welded in various conditions of heat treatment and subjected to various heat treatments after welding as follows:

a. Plates Prepared and Welded in Accordance with Conditions of Series "a" as shown in Sketch 1. (12 Plates)

(1) Three (3) plates welded in the normalized condition and fully heat treated after welding.

(2) Three (3) plates welded in the fully heat treated condition and subjected after welding to the draw temperature and time at temperatures normally used for the armor composition involved.

(3) Three (3) plates welded in the fully heat treated condition and subjected after welding to stress relieving at 1100°F. for one hour per inch of thickness.

(4) Three (3) plates welded in the fully heat treated condition and given no heat treatment after welding.

b. Plates Prepared and Welded in Accordance with Conditions of Series "b" as shown in Sketch 1. (12 Plates)

(1) Three (3) plates welded in the normalized condition and fully heat treated after welding.

(2) Three (3) plates welded in the fully heat treated condition and subjected after welding to the draw temperature and time at temperature normally used for the armor composition involved.

(3) Three (3) plates welded in the fully heat treated condition and subjected after welding to stress relieving at 1100°F. for one hour per inch of thickness.

(4) Three (3) plates welded in the fully heat treated condition and given no heat treatment after welding.

c. Plates Prepared and Welded in Accordance with Conditions of Series "c" as shown in Sketch 1. (12 Plates)

(1) Three (3) plates welded in the normalized condition and fully heat treated after welding.

(2) Three (3) plates welded in the fully heat treated condition and subjected after welding to the drawn temperature and time at temperature normally used for the armor composition involved.

(3) Three (3) plates welded in the fully heat treated condition and subjected after welding to stress relieving at 1100°F. for one hour per inch of thickness.

(4) Three (3) plates welded in the fully heat treated condition and given no heat treatment after welding.

d. Plates Prepared and Welded in Accordance with Conditions of Series "d" as shown in Sketch 1. (12 Plates)

(1) Three (3) plates welded in the normalized condition and fully heat treated after welding.

(2) Three (3) plates welded in the fully heat treated condition and subjected after welding to the draw temperature and time at temperature normally used for the armor composition involved.

(3) Three (3) plates welded in the fully heat treated condition and subjected after welding to stress relieving at 1100°F. for one hour per inch of thickness.

(4) Three (3) plates welded in the fully heat treated condition and given no heat treatment after welding.

Armor Plate Requirements.

a. The armor plates used for these specimens shall be from ballistically approved heats in accordance with Specification AXS-492.

COPY

To: American Steel Foundries 17 December 1943

Revision 3, Amendment 1, The plates need not be from the same heat, but must be in the same composition range.

b. The plate material shall be subject to radiographic examination and shall meet the requirements of Specification AXS-476 and Standard III of Appendix II of that specification. One plate of each twelve plates required under Subparagraphs a, b, c, and d of "Specimens Required" shall be completely radiographed. The film sizes and locations shall be as shown in Sketch 2.

c. Each plate shall be tested for Brinell hardness in not less than four places, two on each side and preferably at opposite corners, and shall be within the declared hardness range for this class of armor.

Weld Requirements

a. Electrodes for welding these specimens will be furnished at no cost by the National Research Council and will carry the designation, "NRC-2A".

b. The plates will be preheated prior to welding to a temperature to be specified by this office. The preheating temperature will not be less than 200°F., but the exact temperature will be determined after examination of data on restrained joint tests now being conducted at your plant.

c. The interpass temperature shall be measured for each specimen at the point indicated on Sketch 1. It shall not be less than the preheat temperature nor more than 150°F. above the preheat temperature.

d. Reenforcement of welds shall be ground flush with the plate surface.

e. The welds shall be subject to radiographic examination and shall meet the requirements of Specification AXS-476 and Standard II of Appendix I of that specification. The welded area of each plate shall be radiographed completely. The size and location of the radiographs shall be as shown in Sketch 2.

Fiber Test Specimens.

Each plate shall have two fracture test blocks attached at the time of heat treatment. One specimen shall be broken and interpreted at your plant; and the others shall be sent to Watertown Arsenal, with the proper composition and heat treatment information, to be broken by Watertown Arsenal so that a comparison may be made of the interpretations of the specimens. The fiber test specimens shall show a completely fibrous structure before the plates will be accepted.

Data to be Furnished.

Complete C.S-2 and WAS-2 forms marked, "Experimental", shall be furnished for each specimen unless the plate material is from the same heat and the weld procedures are similar.

COPY

To: American Steel Foundries 17 December 1943

Please transmit your quotation to the Chicago Ordnance District and, in addition, forward four copies to the Tank-Automotive Center for the attention of the Armor and Welding Group, Engineering Section, Engineering-Manufacturing Branch.

Inasmuch as the experiments mentioned in the first paragraph must be conducted as soon as possible, anything you can do to expedite this quotation will be appreciated. This request is not to be considered as an order.

For the Chief of Ordnance:

Very truly yours,

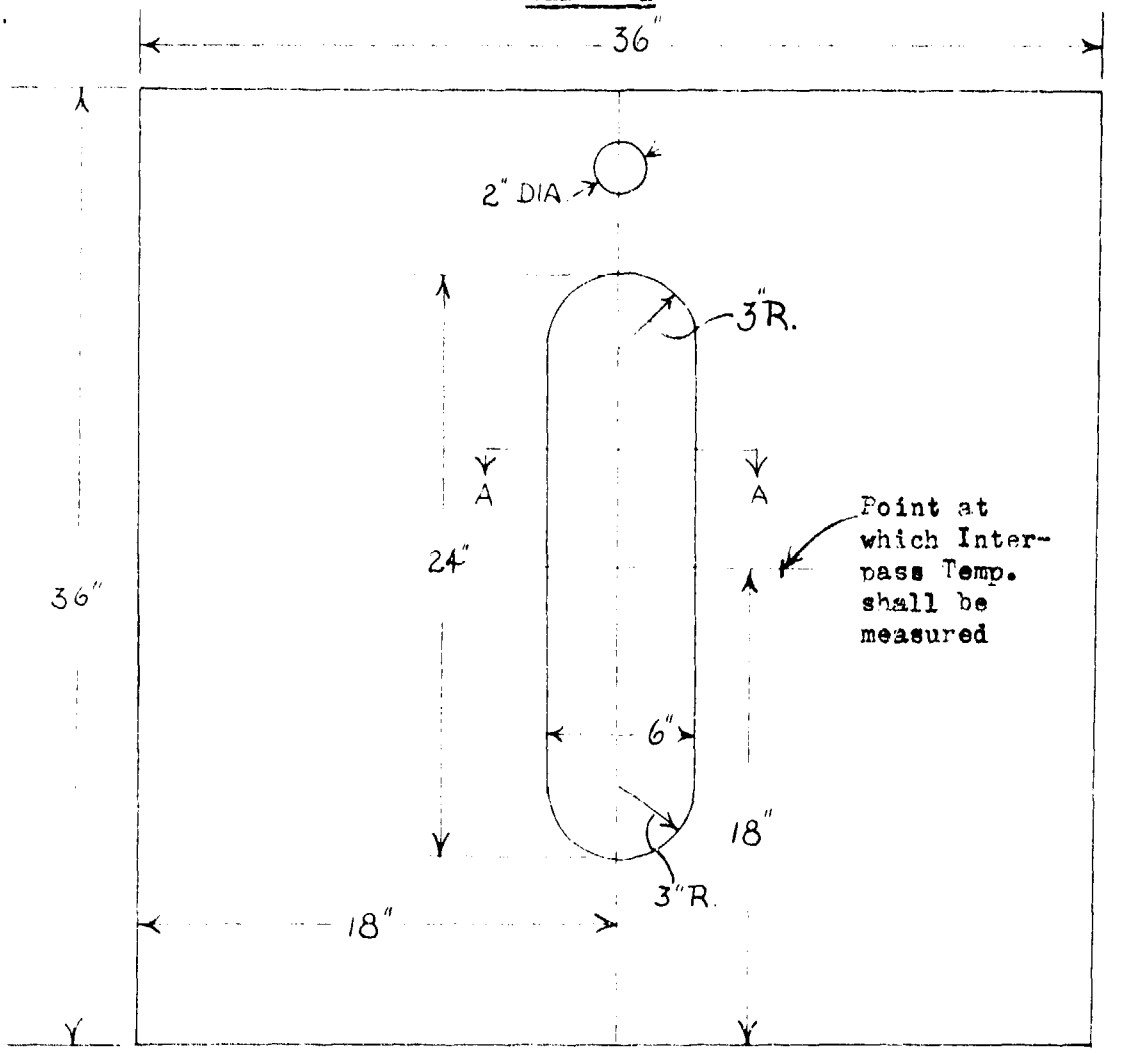
(s/t) D. C. PIPPEL
Major, Ord. Dept.
Assistant

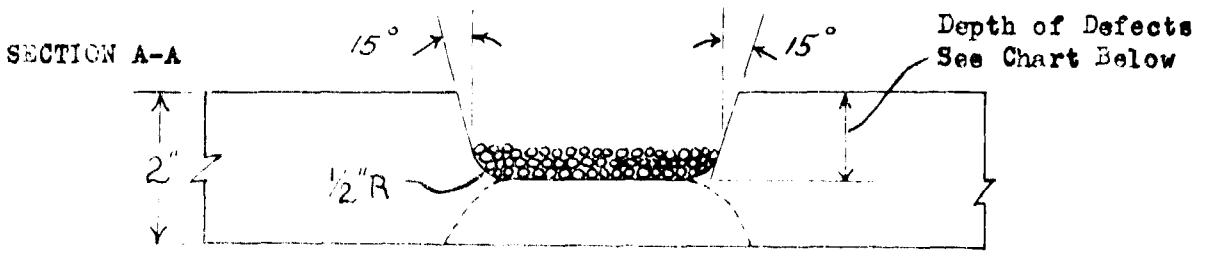
2 Incls:
Incl. 1 - Sketch 1
Incl. 2 - Sketch 2

CC: Chicago Ordnance District

BALLISTIC TEST PLATE
SPECIAL TEST

SKETCH 1



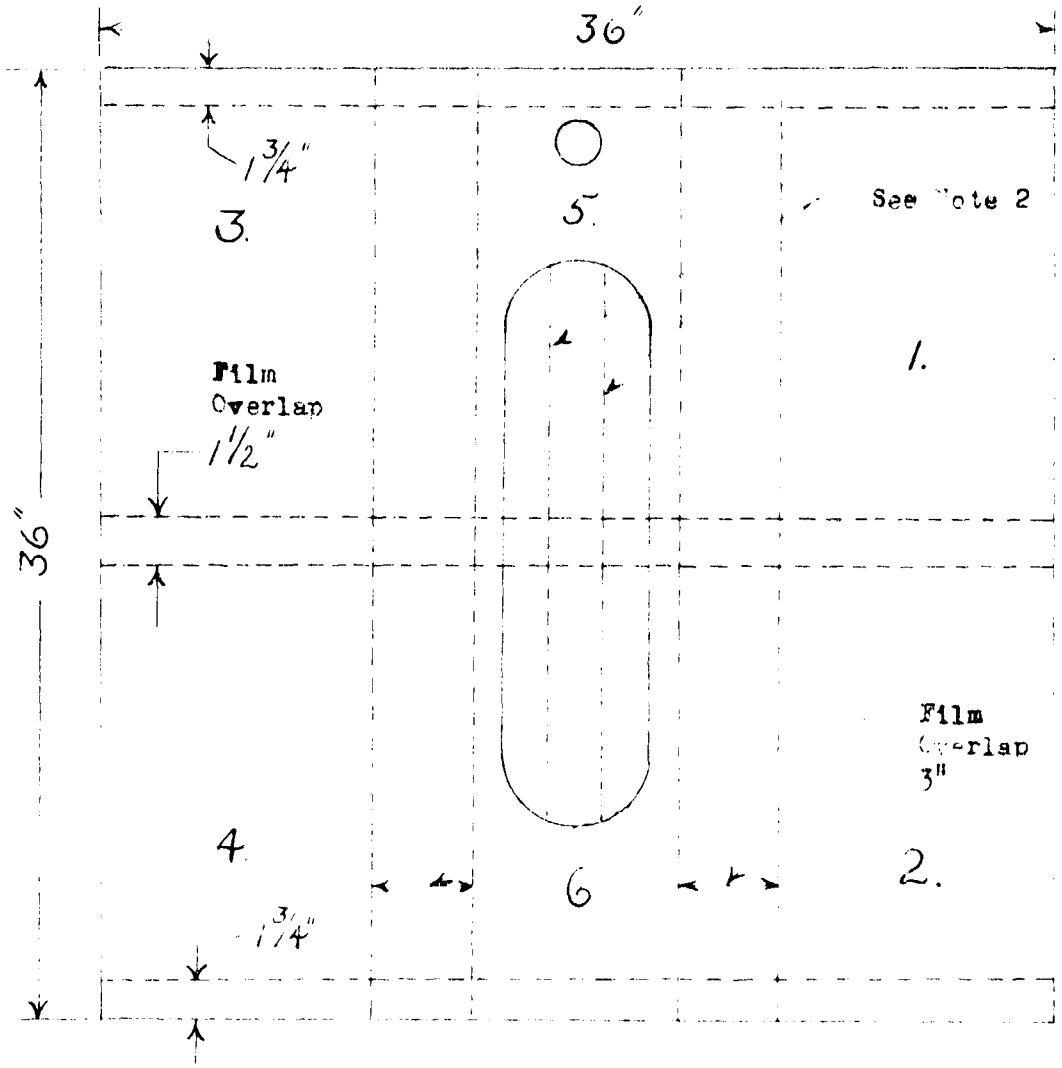


Series	Depth of Defect	Back Chip & Weld
a	1-3/4"	Yes
b	1-7/4"	No
c	1-3/8"	No
d	1"	No

RESTRICTED

BALLISTIC TEST PLATE
RADIOGRAPHIC POSITION CHART

SKETCH 2



Note 1 - Six Films, Size 14" x 17".

Note 2 - For purposes of Evaluation of Weld Defects, the Weld Area shall be considered as Three Welds each 24" long and 2" wide.

COPY

OOM 470.5/WA (13 Mar. 44) 1st Ind. Boucher/fb
Attn: SPOME-EE Ext.2994 - 24 Fl.
WTN 470.5/9102

Army Service Forces, Office, Chief of Ordnance - Detroit, Detroit 32, Michigan, 17 March 1944.

To: Commanding Officer, Watertown Arsenal, Watertown 72, Massachusetts.

1. A total of four plates were submitted by American Steel Foundries and Continental Roll & Steel Foundry Company for the determination of resistance to penetration in an area composed entirely of weld metal. The plates were welded in the normalized condition with NRC-2A electrodes, and after welding were quenched and drawn.

2. The results of the testing, as well as details of the fabrication and heat treatment, are recorded in Aberdeen Report Nos. A12571 and A12572, copies of which are at your station.

3. Specimens 2" wide x 8" long have been taken across the welded section. These specimens have at least 1" of plate material on each end. It is the understanding of this office that Aberdeen has forwarded these specimens to your station. It is requested that the following information be obtained.

a. Photo-micrographs of weld metal and plate material at depths of 3/16", 1/2" and 1" from the surface of the plate.

In the event that the sections are of sufficient size, the following additional information is requested.

a. .505 all weld metal specimens.

b. End quench Jominy data - all weld metal.

4. It is expected that the facilities will make similar studies when the plates are returned. Your cooperation in obtaining this data is appreciated.

By order of the Chief of Ordnance:

(s/t) D. C. PIPPEL
Major, Ord. Dept.
Assistant

Subject: Repair of Armor Castings

COPY

COPY

Wtn 470.5/9122
OOM 470.5/Wtn Ars. (4/4/44)
Attn: SPOME-EE 1st Ind. Herres/ahk

ASF, Watertown Arsenal, Watertown 72, Massachusetts. 6 September 1944.

To: Commanding General, Office, Chief of Ordnance-Detroit, Union Guardian Building, Detroit 32, Michigan. Attn: SPOME-EE

1. Reference 2nd Indorsement transmitting Memorandum Report No. WAL 647/7, entitled "Repair Welded Cast Armor - Metallurgical Examination of Samples from Four Ballistically Tested 2-Inch Thick Plates," which completes the examination of the four plates previously submitted by Continental Roll and Steel Foundries and American Steel Foundries.

2. With regard to examination of the subject 96 repair welded cast armor specimens, the following program of examination is submitted for his concurrence: Representative sample to be selected from each group of three similarly processed plates (same depth of weld, heat treatment, and armor manufacturer) on the basis of results of ballistic tests. The following series of tests to be run on each representative sample: (1) Hardness to be determined by Rockwell C surveys through section of weld heat-affected zone and base metal; (2) Toughness to be determined by Charpy V-notch impact specimens of weld and plate metals tested at +70° 0° and -40° F.; (3) Soundness to be determined by macroetching sections through repair welded areas. In addition, Jominy hardenability determinations and microexamination will be made on one sample representing each heat-treat condition and armor manufacturer; check chemical analyses will be taken on representative base and weld metals; and nick-break fracture test will be attempted and if found practical will be correlated with Charpy impact test data.

3. Sixty-four of the samples have thus far been received from Aberdeen Proving Ground. Examination will begin upon receipt of his comments on the above-outlined program.

For the Commanding Officer:

(s) C. M. SCHWITTER (for)
Major, Ord. Dept.

(t) H. H. ZORNIG
Colonel, Ord. Dept.
Assistant

1 Incl. w/d

OOM 470.5/WA (4 Apr. 44)
Attn: SPOME-EE
WA 470.5/9122 2nd Ind. Boucher/fb
2994 - 24 Fl.

Army Service Forces, Office, Chief of Ordnance-Detroit, Detroit 32, Michigan
12 September 1944.

To: Commanding Officer, Watertown Arsenal, Watertown, Massachusetts.

1. This office concurs in paragraph 2 of the first indorsement.

By order of the Chief of Ordnance:

(s/t) D. C. PIPPEL
Major, Ord. Dept.
Assistant

COPY

WAR DEPARTMENT

ABERDEEN PROVING GROUND

MARYLAND

9 September 1944

Subject: Repair Welded Cast Armor Specimens;
Office, Chief of Ordnance-Detroit
Project No. 1103

To: Commanding Officer
Watertown Arsenal
Watertown, Massachusetts

Attn: Laboratory Section

1. In accordance with Paragraph 5 of the directive from the Office, Chief of Ordnance-Detroit, letter file OOM 470.5/APG (3-31/44), APG 470.5/5439, as amended by teletype, Office, Chief of Ordnance-Detroit 71596 dated 14 April 1944, this station has shipped to Watertown Arsenal thirty (30) samples from the Continental Foundry and Machine Company cast homogeneous repair welded plates approximately 12"x12"x2".

2. Each sample is marked with the serial number of the plate. It will be appreciated if your office will furnish this station complete results of the metallurgical survey.

3. Originally, it was intended to ship your station thirty-two (32) samples from the Continental Foundry and Machine Company plates but two plates were so badly broken that it was impossible to obtain a sample suitable for your requirements.

4. This shipment of thirty (30) samples will make a total of ninety-four (94) samples forwarded your station (forty-eight (48) from American Steel Foundries plates and forty-six (46) from Continental Foundry and Machine Company). This completes the program.

For the Commanding General:

(s) J. Colleran (for)

(t) G. G. EDDY
Colonel, Ord. Dept.
Director,
Ordnance Research & Development Center

Project No. 3891 (337 AM4-154

COPY