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AD-A954 161

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

DTIC
SELECTED
MAY 2 1985
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BY
Anna M. Turkalo
Phy. Sci. Aide

and

S. A. Herres
1st Lt., Ord. Dept.

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DATE 28 August 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

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INTRODUCTION

Specimens approximately 2 x 8 inches were flame cut across the welded section of each of a total of four repair welded 2-inch thick cast armor test plates, after ballistic testing at Aberdeen Proving Ground, and forwarded to this Laboratory. Metallurgical examination of these specimens was carried out in accordance with a request from the Office, Chief of Ordnance-Detroit, SPOME-EE. The basic correspondence is included in Appendix A.

TEST MATERIALS

Samples received for metallurgical examination were taken from two ballistic test plates submitted by American Steel Foundries, and two plates submitted by Continental Roll and Steel Foundries. Complete welding and ballistic data are given in Aberdeen Proving Ground reports Numbers A-12571 and A-12572.

All four plates were welded in the normalized condition with the Harnischfeger AW-2C Mn-Mo ferritic electrode with stainless type coating. The weld recess was 6 x 24 x 1-3/4 inches. A multiple weld bead technique was used and after part or all of the welding had been completed from the front, the back of the plate was chipped out to a minimum depth of 1/2 inch and welded. The heat treatment and ballistic data for each plate may be summarized as follows:

Plate A-814, American Steel Foundries

Actual plate thickness: 2.14 inches
" weld " : 1.90 "
Heat treatment:
Prior to welding - 1650° F., 4 hrs. air
1250° F., 2 hrs. air
After welding - 1650° F., 4 hrs. water
1250° F., 4 hrs. water
Ballistic limit of plate: 1675 f/s
" " " weld: 1423 f/s
Shock test results: 23-1/2 inch crack in weld through impact
of 75 mm. proof projectile T21 at
1325 f/s and previous A.P. impacts.

Plate A-846, American Steel Foundries

Actual plate thickness: 2.00 inches
" weld " : 1.94 "
Heat treatment:
Prior to welding - same as that given to A-814
After welding - 1650° F., 4 hrs. water
1200° F., 4 hrs. water
Ballistic limit of plate: 1582 f/s
" " " weld: 1496 f/s
Shock test results: 25-3/4 inch crack in weld through impact
of 75 mm. proof projectile T21 at
1364 f/s and previous A.P. impacts.

Plate 6292-2, Continental Roll and Steel Foundries

Actual plate thickness: 1.98 inches
" weld " : 2.10 "
Heat treatment:
Prior to welding - 1625° F., 8 hrs. air
After welding - 1575° F., 10 hrs. water
1210° F., 10 hrs. water
Ballistic limit of plate: 1550 f/s
" " " weld: 1534 f/s
Shock test results: 7-inch crack near fusion zone from impact
of 75 mm. proof projectile T21 at 1430 f/s.

Plate 6335-2, Continental Roll and Steel Foundries

Actual plate thickness: 2.08 inches
" weld " : 2.08 "
Heat treatment - Same as that used for 6292-2
Ballistic limit of plate: 1662 f/s
" " " weld: 1498 f/s
Shock test results: 8-1/2 inch and 7-inch cracks in weld
(through A.P. impacts) from impact of
75 mm. proof projectile T21 at 1473 f/s.

TEST PROCEDURE

Figures 1 and 2 are sketches of the samples from the ballistic test plates. Locations of specimens for standard .357 inch diameter tensile bars, Charpy V notch impact tests, and weld metal Jominy bars, as well as sections for macroexamination, hardness surveys and microscopic examination are indicated. After the completion of the Jominy tests, the bars were cut into 3/8 inch thick sections for heat treatments to check austenitizing temperatures. Details of testing are given with the data and discussion of results.

DATA AND DISCUSSION

Chemical Analyses

Chemical analyses of the base and weld metals as given in firing records (Aberdeen Report Numbers A12571 and A12572) were as follows:

<u>Plate No.</u>		<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Ni</u>	<u>Cr</u>	<u>Mo</u>
American	plate	.283	1.60	.54	.023	.017	--	.60	.32
A814	weld			not given					
American	plate	.288	1.54	.48	.025	.016	--	.53	.32
A846	weld			not given					
Continental	plate	.31	1.30	.37	.036	.043	.69	.62	.41
6292-2	weld	.15	1.66	.27	.020	.020	Tr.	.07	.42
Continental	plate	.28	1.24	.36	.042	.040	.62	.63	.45
6335-2	weld	.15	1.66	.27	.020	.020	Tr.	.07	.42

Check analyses made on drillings from broken weld metal Charpy bars gave the following results:

<u>Plate No.</u>		<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Ni</u>	<u>Cr</u>	<u>Mo</u>
American A814	weld	.17	1.97	.24	--	--	N11	.03	.52
American A846	weld	.17	1.89	.27	--	--	N11	.04	.46
Continental 6335-2	weld	.15	1.81	.25	--	--	Tr.	.10	.46

Macroexamination

Figure 3 shows transverse sections through the repair welds in the ballistic test plates, as etched with a saturated solution of ferric chloride. The cracking shown was developed on ballistic testing. The weld metal deposits are relatively sound. A small amount of centerline shrinkage is present in the cast base metals. The postheat treatment has removed all evidence of the weld heat-affected zone.

Hardness Surveys

Rockwell C hardness surveys taken at 1/4 inch intervals through the thickness of the base metal and weld metal deposits gave the following results:

<u>American</u>				<u>Continental</u>			
<u>A814</u>		<u>A846</u>		<u>6292-2</u>		<u>6335-2</u>	
<u>Plate</u>	<u>Weld</u>	<u>Plate</u>	<u>Weld</u>	<u>Plate</u>	<u>Weld</u>	<u>Plate</u>	<u>Weld</u>
18.5	12.5	21.5	14.0	17.0	11.0	19.0	8.0
20.0	11.0	24.5	14.5	20.0	8.5	21.0	8.5
18.5	10.0	22.5	16.0	19.5	9.5	21.5	7.0
17.5	11.0	23.5	16.0	17.5	11.5	20.0	8.0
16.5	12.0	22.5	17.0	19.5	12.5	18.5	6.0
18.0	13.0	11.5	17.0	19.5	13.0	22.0	9.0
19.5	13.0	24.0	18.0	19.5	11.5	21.5	9.5
18.5	13.5	24.0	17.0	19.0	11.5	23.5	11.5

No significant variance in hardness was apparent through the thickness of either the weld or plate metals. The higher hardness levels of weld and base metals in plate A846 than that of A814 is explainable since the former was drawn at a 50° F. lower temperature. The reason for the difference in hardness level between the two Continental plates is not clear since they were reported to have been welded and heat treated in the same manner.

Tensile and Impact Tests

The amount of material in the samples allowed only limited testing. Two all-weld metal tensile bars were taken midwall from plate A846. Values obtained were as follows:

Tensile	97,800 - 99,500 psi.
Yield	80,500 - 84,000 psi. at .1% offset
Elongation	20.7 - 22.9%
Reduction of Area	67.0 - 67.6%

The tensile strength is within the expectancy range for the hardness level shown for this weld metal. A decrease of about 10,000 to 15,000 psi. in yield and tensile strength would be expected for the lower hardness weld metals of the other three plates.

Charpy V notch impact bars were taken midwall from both plate and weld metal of plate A846, and the following test values were obtained:

Temperature of Test	70° F. ft.lbs.	0° F. ft.lbs.	-20° F. ft.lbs.	-40° F. ft.lbs.
Base Metal	44.1 - 51.3	29.5, 51.0	51.0, 51.2	49.1, 52.8
Weld Metal (longitudinal)	79.1 - 96.8	42.7	47.5	45.4

The following impact values were obtained for V notch Charpy test bars taken transverse to the rolling direction from various locations in weld and base metals of plates A814 and 6335-2 and tested at +70° F.:

	Surface ft.lbs.	Midwall ft.lbs.	Center ft.lbs.
<u>Plate No. 814</u>			
Base metal	54.6	51.3	38.7*
Center of weld	108.1	108.1	97.0
Base of notch-weld metal 1/8 in. from fusion line	98.8	103.5	95.2
<u>Plate No. 6335-2</u>			
Base metal	57.1	54.7	61.2
Center of weld	105.8	101.0	93.4
Base of notch-base metal 1/8 in. from fusion line	66.0	56.6	49.2

* Broke through casting defect - shrinkage cavity.

The higher impact values of the weld metal for the last two plates are consistent with the lower hardness observed in these plates than that in plate A846. No deleterious effects on either the base or weld metal properties are observed in the bars taken near the fusion line.

Microexamination

Figures 4 through 7 show the microstructures at 1000X at the center, midwall, and 3/16 inch from the surface in base metal and weld metal of each of the four test plates.

The microstructure of the base metal is largely tempered martensite but there are occasional patches of heterogeneous structure consisting of ferrite and high transformation temperature carbides as seen in the photomicrographs for the midwall of plate 6335-2 (Figure 7), and for the center of plate 6292-2 (Figure 6).

The microstructure of the weld metal consists of heavily tempered carbides in a matrix of ferrite. The distribution of the carbides indicates that the weld metal had insufficient hardenability to completely harden on quenching and that high transformation temperature carbides were present through most of the thickness of the repair welds. The high temperature of the draw treatment has spheroidized most of the carbides, particularly in the two Continental plates (Figures 6 and 7) which were reported to have had a ten-hour hold at the draw temperature, but the heterogeneous carbide distribution is especially evident in plate A846 (Figure 5) which had a shorter hold at a lower draw temperature and which had the highest weld metal hardness.

Hardenability of Weld Metal

Figure 8 gives the results of Jominy hardenability tests of weld metal from plates A846 and 6292-2 end-quenched after 2 hours' hold at 1650° F. The slightly lower hardness of the bar from the latter plate is probably due to the 2-point difference in carbon content. The hardenability indicated by these curves is only sufficient for full hardening of a plate of about 0.7 inch thickness on quenching in water. Published data* indicate that the hardness of this weld metal quenched in water in the form of 2-inch thick plate would be approximately that at 3/4 inch distance from the water-quenched end of the Jominy bar.

To check the effect of austenitizing temperature, the two Jominy bars were cut into 3/8 inch thick discs, quenched from 1600° F. and drawn at 1250° F. for 6 hours to give a prior structure somewhat similar to that obtained in a multiple pass weld; then the individual discs were reheated to various austenitizing temperatures and quenched. After the scale and decarburized metal had been removed, Rockwell C hardness readings were taken. Discs were then tempered for 6 hours at 1250° F. and hardness determined again. The results of these tests were as follows:

<u>Plate No.</u>	<u>Austenitizing Temp. °F.</u>	<u>Rc Hardness Number</u>	
		<u>As Water Quenched</u>	<u>After 1250° F. Draw</u>
A846	1700	40.5	---
6292-2	1700	40.0	9.5
6292-2	1650	40.5	9.5
A846	1600	40.5	---
6292-2	1600	39.5	7.5
6292-2	1550	39.0	8.5
A846	1500	40.5	---
6292-2	1500	40.5	7.0

As-quenched hardness indicates that carbide solution was nearly complete after 1 hour hold at 1500° F. However, the resistance to tempering was somewhat less in specimens which were quenched from temperatures of 1600° F. or lower.

* Hardenability comparisons - Great Lakes Steel Corporation - 1942.

General Considerations

The hardenability determination and the microexamination indicate that the weld metal had insufficient hardenability to develop a homogeneous martensitic microstructure in the repair welds on water quenching in the form of 2-inch thick plates. However, a very severe drop in hardness occurs in this weld metal composition during the draw treatments at temperatures above 1200° F. At this low hardness level, approximately 16.5 to 8.5 Rockwell C, the notched bar impact energy is very satisfactory for testing temperatures as low as -40° F.

Ballistic limits (corrected for actual plate and weld thicknesses) correlate as follows with the hardness determinations:

Plate No.	<u>Base Metal</u>		<u>Weld Metal</u>	
	Av. Hardness Rc	Ballistic Limit ft./sec.	Av. Hardness Rc	Ballistic Limit ft./sec.
A814	19	1563	12	1503
A846	23	1582	16.5	1544
6292-2	19	1566	11.0	1454
6335-2	20.5	1598	8.5	1434

The significance of the ballistic shock test results is questionable because of the large number of prior impacts with A.P. projectiles.

Higher weld metal hardnesses would give higher penetration resistance, but would also mean less spheroidization of the lamellar carbides formed during the quench and this condition would tend to cause a severe decrease in resistance of the weld metal to ballistic shock. However, the best compromise between penetration and shock resistance is believed to be in the direction of a weld metal hardness of at least 15 Rockwell C. Improvement would probably be obtained by an increase in alloy content of the weld metal, particularly in elements that strengthen the ferrite and increase resistance to softening during the draw treatment, as well as increase the hardenability.

It is noted that radiographic examination reveals weld metal cracks in all plates but 6335-2 which was kept at a temperature of not less than 250° F. while it was transferred from welding to the hot heat-treat furnace.

Section for 3 transverse charpy bars (surface, midwall and center) each of plate, weld and fusion zone metal.

Section for specimens for microexamination--cross-hatched areas show exact location.

Section for macroexamination and hardness survey.

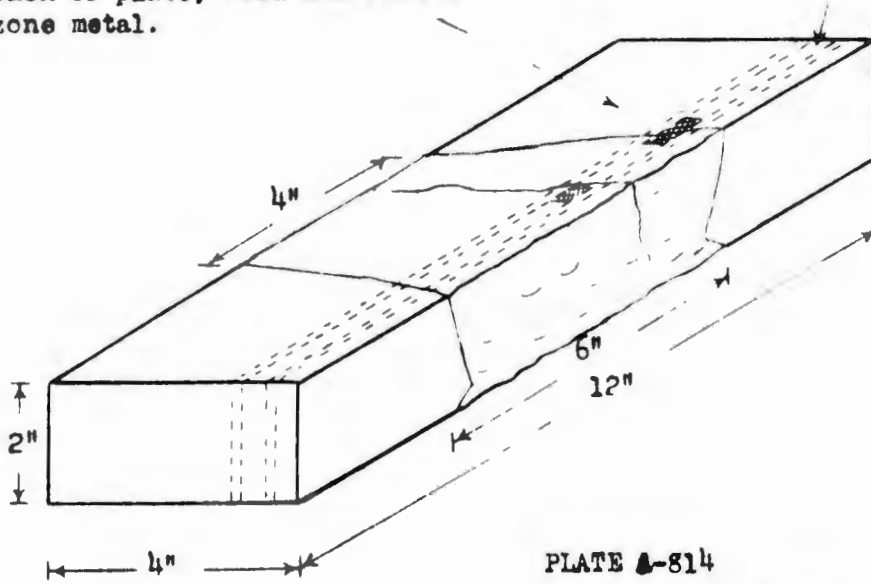
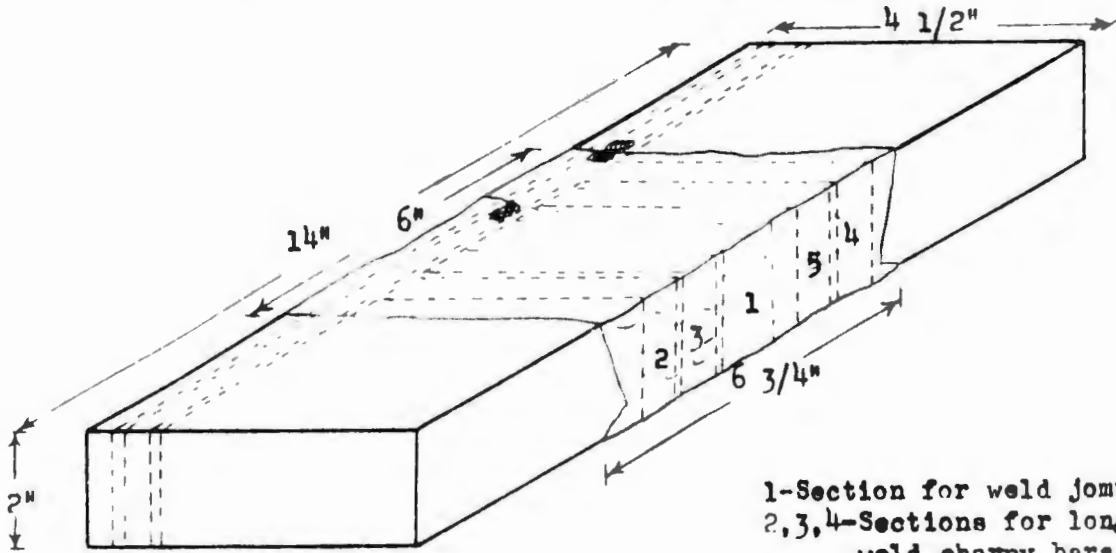


PLATE A-814



Section for specimens for microexamination--cross-hatched areas show exact location.

- 1-Section for weld jominy
- 2,3,4-Sections for longitudinal weld charpy bars (midwall)
- 5-Section for .357" dia. tensile bars (midwall)

Section for macroexamination and hardness survey.

PLATE A-846

FIGURE 1. LOCATION OF TEST SPECIMENS IN REPAIR WELDED AMERICAN CAST ARMOR BALLISTIC TEST PLATES.

Section for macroexamination
and hardness survey

Section for specimens for
microexamination--cross-
hatched areas show exact
location.

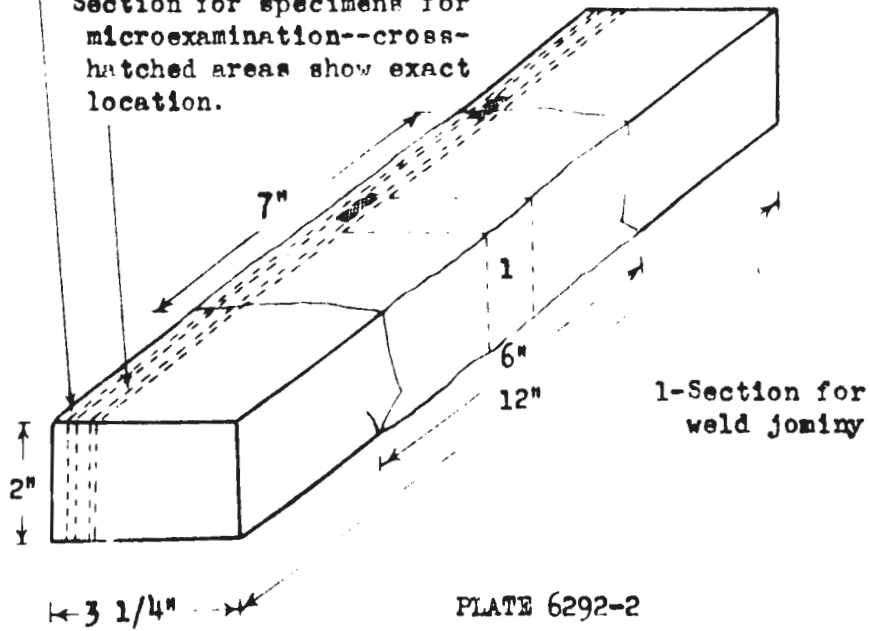


PLATE 6292-2

Section for 3 transverse charpy bars
(surface, midwall, and center) each
of plate, weld, and fusion zone
metal.

Section for macroexamination and
hardness survey

Section for specimens
for microexamination--
cross-hatched areas
show exact
location.

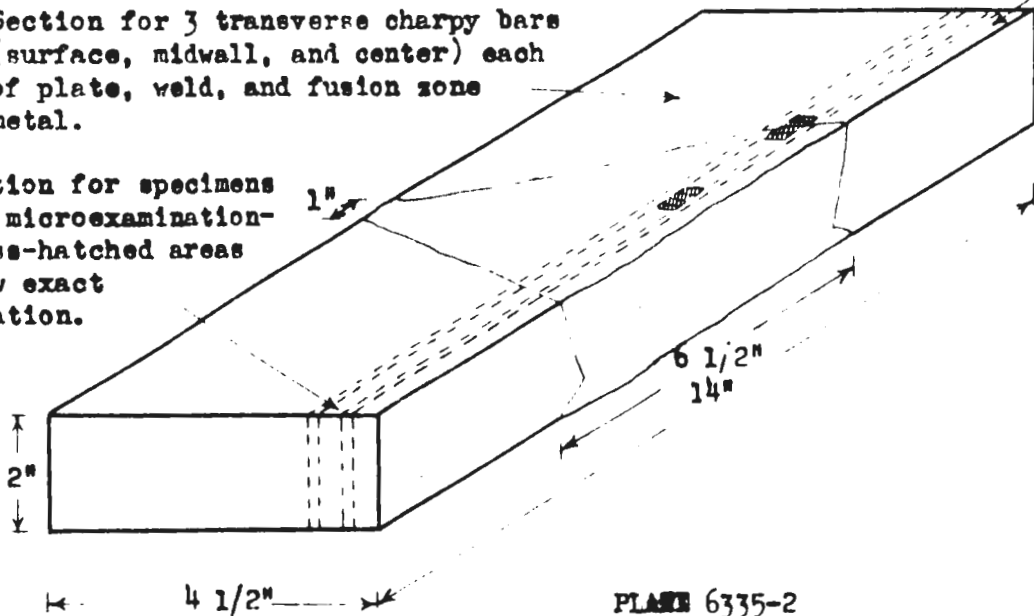


PLATE 6335-2

FIGURE 2. LOCATION OF TEST SPECIMENS IN REPAIR WELDED
CONTINENTAL CAST ARMOR BALLISTIC TEST PLATES.

6C17-639-NLM



American
A-814



American
A-846



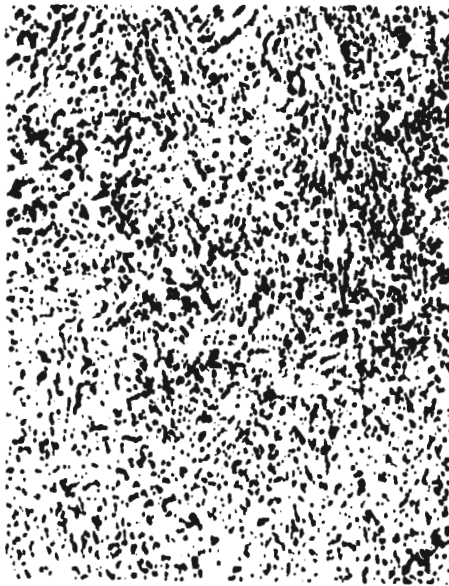
Continental
6292-2



Continental
6335-2

MACROPHOTED SECTIONS THROUGH REPAIR WELDS IN CAST ARMOR BALLISTIC TEST PLATES.

Center



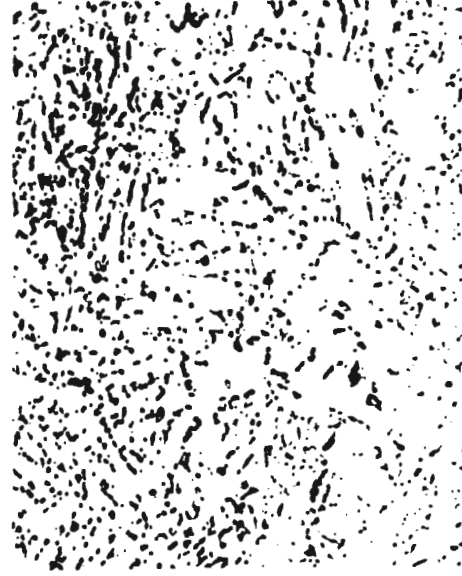
Midwall



3/16 inch from surface



Plate metal microstructure -- X1000 -- Picral etch



Weld metal microstructure -- X1000 -- Picral etch

REPAIR WELDED AMERICAN CAST ARMOR BALLISTIC TEST PLATE A-814.

FIGURE 4

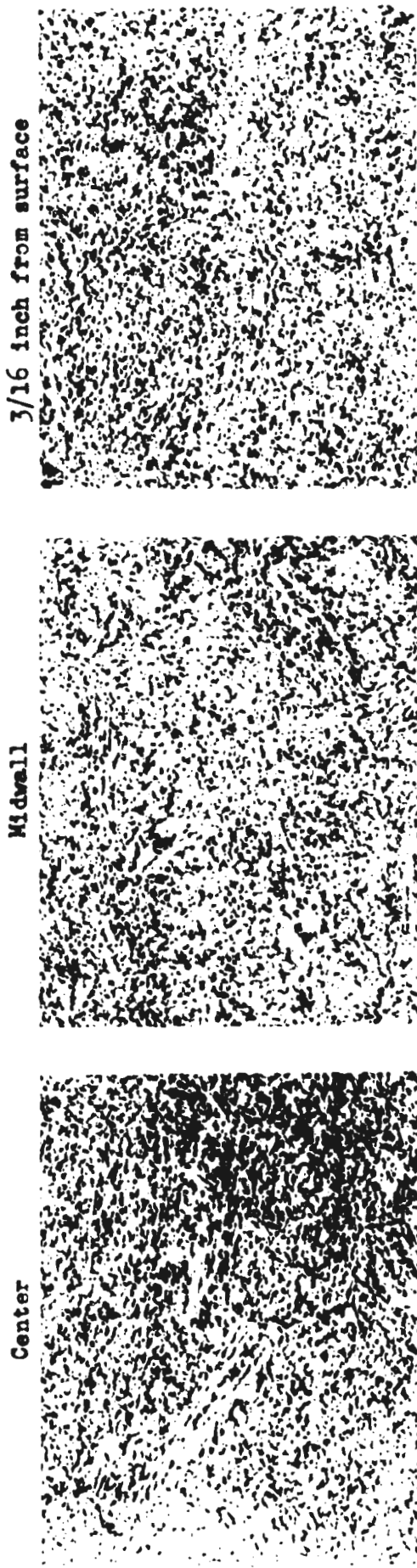


Plate metal microstructure -- X1000 -- Picral etch



Weld metal microstructure -- X1000 -- Picral etch

REPAIR WELDED AMERICAN CAST ARMOR BALLISTIC TEST PLATE A-846.

FIGURE 5

Center



Midwall



3/16 inch from surface

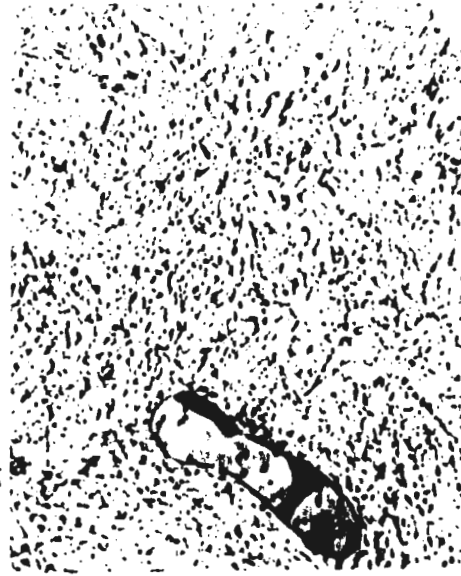
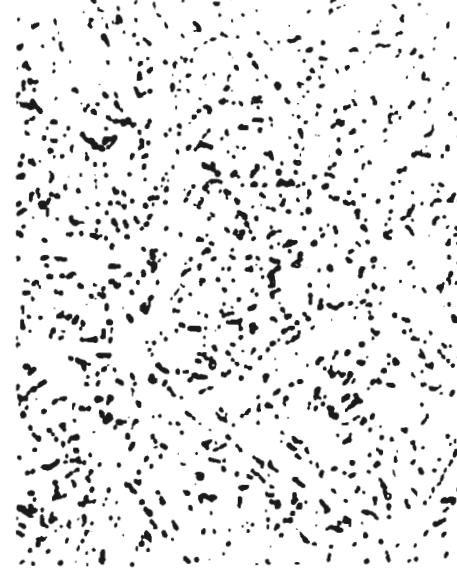
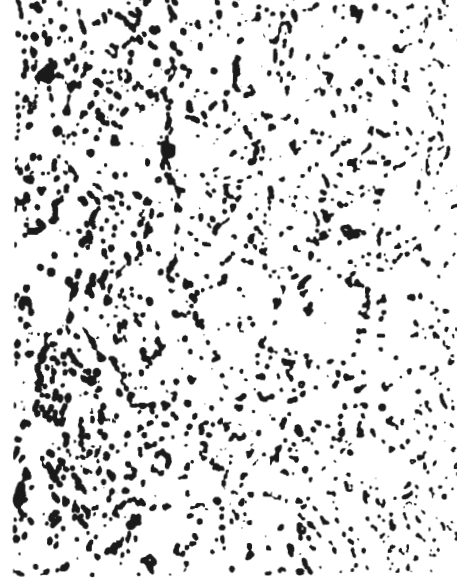


Plate metal microstructure -- X1000 -- Picral etch



Weld metal microstructure -- X1000 -- Picral etch

REPAIR WELDED CONTINENTAL CAST ARMOR BALLISTIC TEST PLATE 6292-2.

FIGURE 6

Center



Midwall



3/16 inch from surface

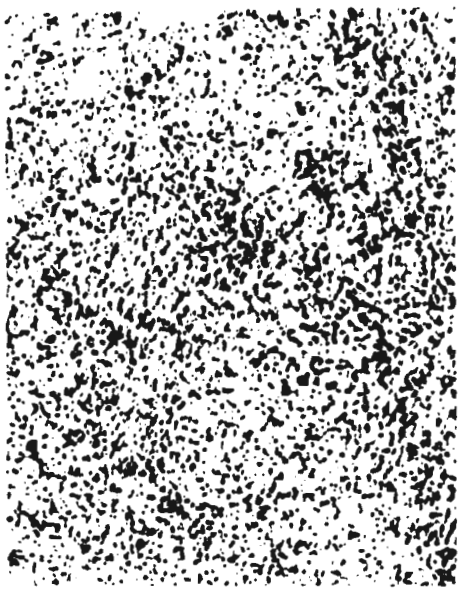
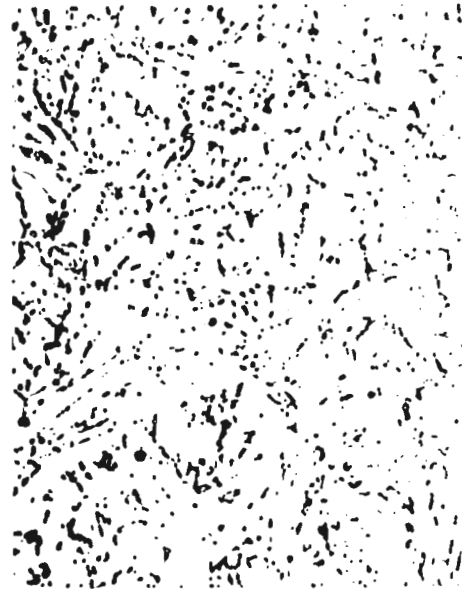


Plate metal microstructure -- X1000 -- Picral etch



Weld metal microstructure -- X1000 -- Picral etch

COOLING RATE, DEG. F PER SECOND AT 1300°F.

500 400 300 200 150 100 90 80 70 60 50 40 30 20 15 10 8 7 6 5 4

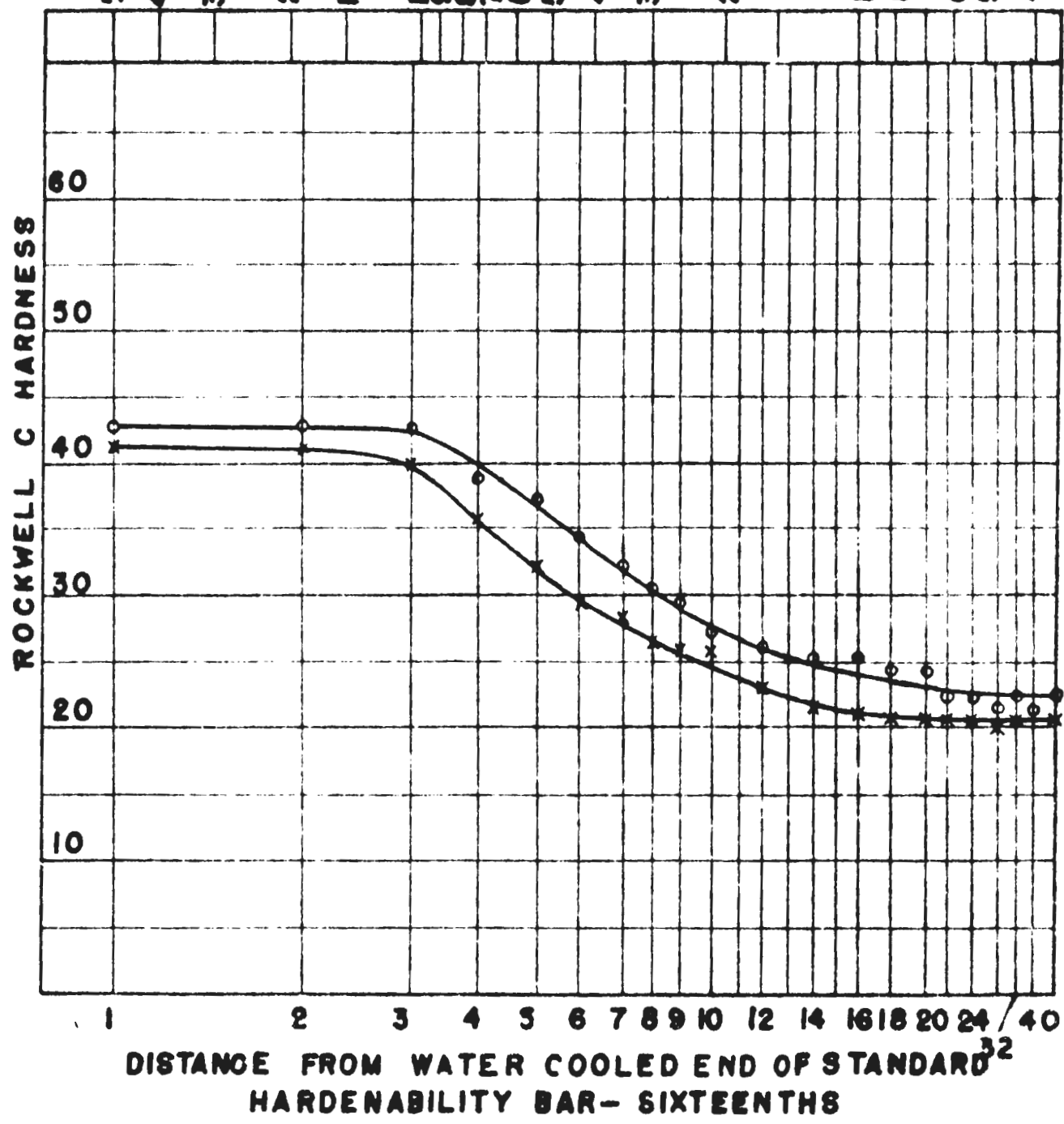


PLATE NO.	HEAT NO.	C	Mn	Si	S	P	Ni	Cr	Mo	QUENCH	
										TEMP	TIME G.S.
A546		.17	1.97	.24	--	--	11	.03	.52	0 -- 0	1650°F 2
6292-2		.15	2.66	.27	--	--	Tr.	.07	.42	X -- X	1650°F 2

Figure 8.

APPENDIX A

Basic Correspondence

RESTRICTED

WAR DEPARTMENT
ABERDEEN PROVING GROUND
MARYLAND

RCN Project 2627
Roth/dlf
4165

APG 470.5/5011
Wtn. 470.5/7981 (r)

11 March 1944

Subject: Samples from repair welded plates

To: Commanding General
Watertown Arsenal
Watertown, Massachusetts

Attention: Laboratory

1. In accordance with Paragraph 4 of the letter from the Office of Chief of Ordnance-Detroit, File No. OOM 400.112/APG 1844 requesting that samples be taken from ballistic test plates submitted for the determination of the resistance to penetration of cast armor repair weld plates and that these samples be sent to Watertown Arsenal, Attention, Mr. W. L. Warner, for metallurgical analysis, subject samples have been taken and are forwarded "Freight Prepaid", B.L. WT5014246.

2. Two plates have been received from American Steel Foundries and samples from these two plates are marked A814 and A846. Two plates also have been received from Continental Roll and Steel Foundries, samples of which are marked 6292-2 and 6335-2. In all cases, samples have been given the same number as was given to the plate.

3. The results of the ballistic test performed upon these plates at this station are contained in Reports No. A-12571 and A-12572, copies of which have been sent to your station.

For the Commanding General:

(s) C. J. Yaeger, Capt. (for)

(t) J. G. Shinkle
Lt. Col., Ord. Dept.
Chief, Armor Branch

RESTRICTED

OOM 470.5/WA (13 Mar.44)
Attn: SPOME-EE
WTN 470.5/9102

1st Ind.

Boucher/fb
Ext.2994 - 24 Fl.

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

Herres/ahk

WAR DEPARTMENT
WATERTOWN ARSENAL
Watertown 72, Mass.

13 March 1944

Wtn. 470.5/9102

Laboratory (SAH)

Subject: Repair of Armor Castings.

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

Attn: SPOME-EE

1. This laboratory would appreciate a directive authorizing and giving pertinent information regarding metallurgical examination of samples from repair welded cast armor ballistic test plates which it is understood are being shipped from Aberdeen Proving Ground.

For the Commanding Officer:

(s/t) H. H. ZORNIG
Colonel, Ordnance Dept.
Assistant