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WATERTOWN ARSENAL
LABORATORY

MEMORANDUM REPORT

NO. WAL 710/257

Metallurgical Examination of Twenty-Five 1/2 Inch

Rolled Homogeneous Armor Plates

Manufactured by Republic Steel Corporation

BY

M. IOFFA
Asst. Phy. Sci. Aide

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DATE 29 August 1944

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WATERTOWN ARSENAL
WATERTOWN, MASS.

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WATER TOWN ARSENAL LABORATORY

Memorandum Report No. WAL 710/257

Final Report on Problem B-4.48

29 August 1944

Metallurgical Examination of Twenty-Five 1½ Inch

Rolled Homogeneous Armor Plates

Manufactured by Republic Steel Corporation

ABSTRACT

Metallurgical examination, including Brinell hardnesses, fracture tests for steel soundness, fracture tests for response to heat treatment and macroetch tests, was conducted on each of the twenty-five plates furnished by Republic Steel Corporation. Microscopic examination, chemical analyses and Jominy hardenability determinations were made of selected plates. All plates were uniformly satisfactory with respect to steel soundness and were properly heat treated as revealed by the fibrous manner in which all except those samples of the maximum hardnesses fractured.

1. As requested by the Ordnance Research Center (APG OCM 470.5/313 - Wtn 470.5/8337(r)), metallurgical examination has been completed on sections from twenty-five (25) 1½ inch rolled homogeneous armor plates manufactured by Republic Steel Corporation and tested at Aberdeen as a part of the effect of hardness program. The ballistic test results will be reported in AD-679.

2. Metallurgical examination included the following tests:

- a. Brinell hardnesses on surface and through section.
- b. Fracture tests for steel soundness and response to heat treatment.
- c. Macroetch tests.
- d. Chemical analyses and Jominy hardenability.
- e. Microscopic examination.

3. The results of the metallurgical examination are as follows:

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a. Brinell Hardness. Brinell hardness results are based upon the average of four surface readings and six equidistantly spaced readings through the section. All readings listed in Table I are reported in the same sequence in each sample.

b. Fracture Tests for Steel Soundness and Response to Heat

Treatment. Fracture tests for steel soundness in both directions and for response to heat treatment (fibre test) in one direction were made on samples from each plate. The plates were satisfactory with respect to steel soundness and were properly heat treated as evidenced by the fibrous fractures. However, although plates R45, R46, R48 and R49 revealed a slight crystallinity in the center of the section it may be considered of not great importance and to be expected at the hardness levels involved. See Table II for results of both fracture tests. The fracture tests were made in accordance with the requirements in Specification AXS-488, Revision 2.

c. Macroetch Tests. Macroetch tests were made on samples from plates R4, R57 and R59. No pronounced laminations or segregations were observed. See Figure 1 for photomacroscopic results.

d. Chemical analyses and Jominy hardenability determinations were conducted on samples from plates R4, R57 and R59. The chemical analyses are as follows:

Chemical Composition

<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>	<u>Cu</u>	<u>V</u>	<u>B</u>
R4	.27	.86	.31	.017	.017	1.75	.88	.33	.085	tr	nil
R57	.28	.87	.30	.015	.016	1.71	.92	.35	.08	tr	nil
R59	.27	.87	.28	.017	.016	1.73	.92	.35	.08	tr	nil

The hardenability is adequate for the section involved. Results of Jominy hardenability data are illustrated in Figure 2.

e. Microscopic Examination. A section from plates R6, R19, R27, R45 and R59 was examined for nonmetallic inclusion distribution and microstructure. The plates were clean with no undesirable nonmetallic inclusions observed. The microstructure of plate R27 was a tempered martensite interspersed with grain boundary ferrite. R19 and R45 were similar to previous plates in the dominant structure with only occasional grain boundaries of ferrite. Whereas, R6 and R59 exhibited a tempered martensite and fine carbide. Photomicrographs of typical microstructures are shown in Figure 3.

4. The plates were uniformly satisfactory with respect to steel soundness and were well heat treated as evidenced by the fibrous fractures at high hardness levels. Thus, the small amounts of ferrite revealed will probably not be sufficient to cause unsatisfactory ballistic behavior.

Therefore, ballistic characteristics will undoubtedly be a function of the respective hardness of each plate.

M. Yoffa

M. YOFFA
Asst. Phy. Sci. Aide

APPROVED:

M. A. Matthews

M. A. MATTHEWS
Major, Ord. Dept.
Chief, Armor Section

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TABLE I

Plate No.	Surface Hardness, BHN					Cross Section Hardness, BHN						
	Reading Numbers				Ave.	Reading Numbers						Ave.
	1	2	3	4		1	2	3	4	5	6	
R2	255	255	241	241	248	248	248	248	248	248	248	248
R3	248	248	248	248	248	241	241	241	248	241	248	243
R4	248	248	255	255	252	248	235	241	241	241	235	240
R6	248	248	248	248	248	255	255	255	255	255	255	255
R9	248	248	255	255	252	255	255	248	255	255	248	253
R10	248	248	255	255	252	255	255	255	255	255	255	255
R15	321	321	331	331	326	352	352	352	352	352	352	352
R18	331	341	341	341	338	341	341	341	341	341	341	341
R19	341	341	341	341	341	341	341	341	341	341	341	341
R25	302	311	302	302	304	285	285	285	277	293	293	286
R26	302	302	302	302	302	302	302	302	302	293	302	300
R27	302	302	302	302	302	302	293	302	293	302	293	298
R30	302	302	302	302	302	302	293	293	302	302	293	298
R35	277	277	277	277	277	277	277	277	277	277	277	277
R45	352	352	352	352	352	363	375	375	375	375	375	373
R46	352	363	363	352	358	375	363	375	363	375	375	371
R47	352	352	363	352	360	363	363	363	363	363	363	363
R48	363	363	352	363	360	341	352	352	352	352	352	350
R49	363	363	363	363	363	363	352	363	352	363	363	359
R52	229	235	235	229	232	229	229	241	241	235	229	234
R53	235	235	235	235	235	229	229	241	241	235	235	235
R55	241	241	235	229	237	229	229	241	241	235	229	234
R56	229	235	235	235	233	235	229	235	229	235	229	232
R57	229	229	229	229	229	229	229	229	229	229	229	229
R59	229	235	241	235	235	235	229	235	235	229	229	232

TABLE II

Plate No.	Fibre Fracture Test	Steel Soundness Test	
		Longitudinal	Transverse
R2	Fibrous	B (woody)	B
R3	"	B (woody)	B
R4	"	B	C
R6	"	B (trace woody)	B
R9	"	B (trace woody)	B
R10	"	B (trace woody)	B
R15	"	B	B
R18	"	B	B
R19	"	B (trace woody)	B
R25	"	B	B
R26	"	B	B
R27	"	B	B
R30	"	B	B
R35	"	B (trace woody)	B
R45	Essentially fibrous, slight crystallinity in center of section	B	B
R46	"	B	B
R47	Fibrous	B	B
R48	Essentially fibrous, slight crystallinity in center of section	B	B
R49	"	B (woody)	B
R52	Fibrous	B (woody)	B
R53	"	B	B
R55	"	B (trace woody)	B
R56	"	B (trace woody)	B
R57	"	B (woody)	B
R59	"	B (trace woody)	B

COOLING RATE, DEG. F PER SECOND AT 1000° F.

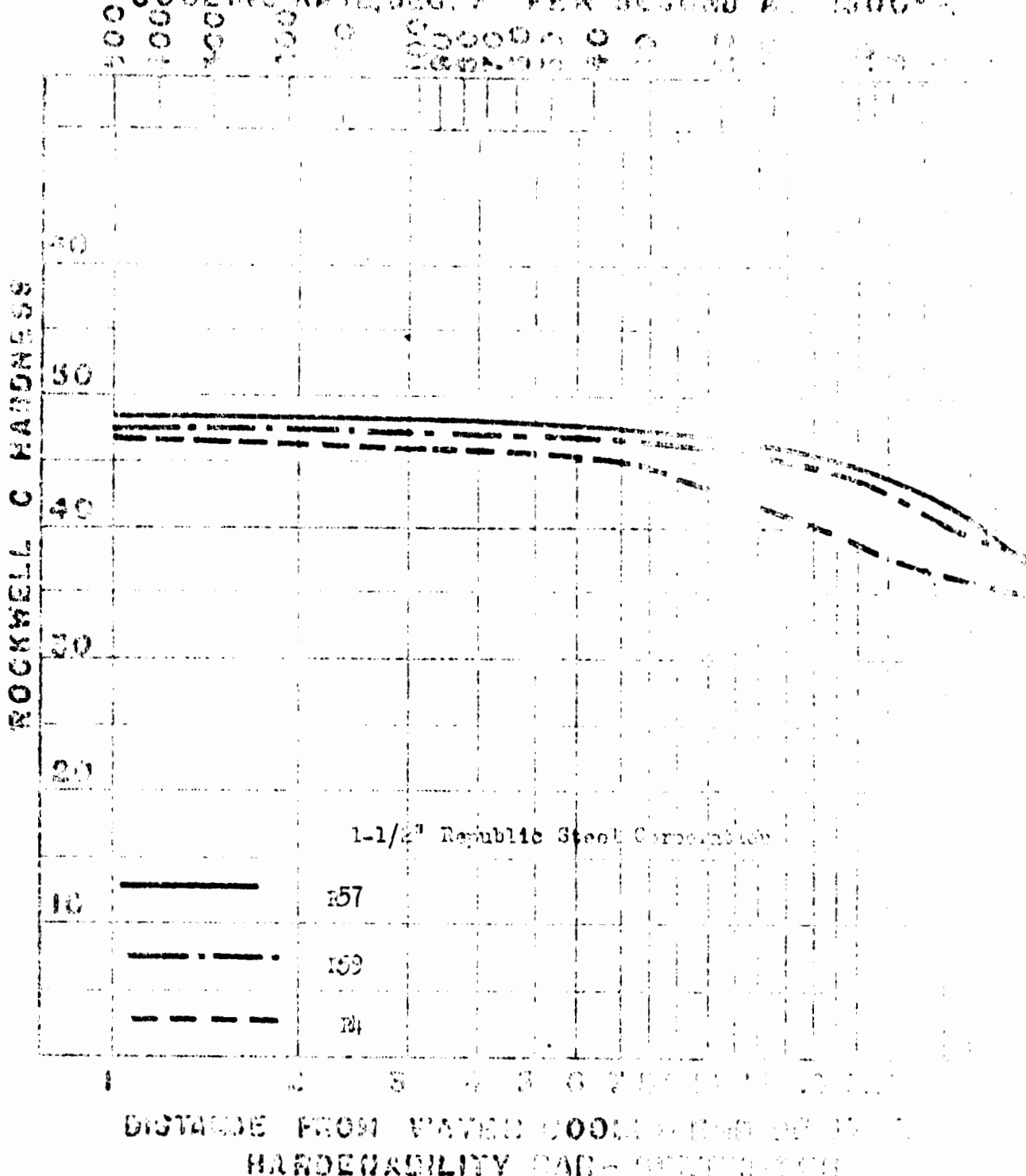
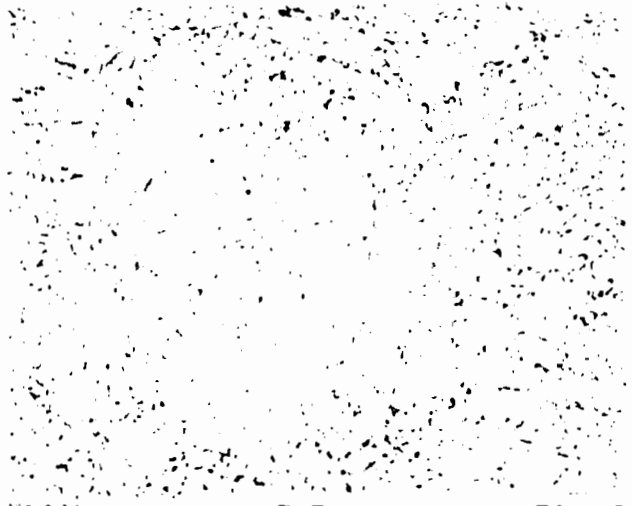


PLATE HEAT NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	CU	VA	REMARKS	COOL. RATE	RISE	DEPTH
R57		.28	.87	.30	.015	.016	1.75	.22	.35	.005	Tr.	N11 1600F	1 1/2 hrs	7 hrs
R59		.27	.87	.28	.017	.016	1.75	.22	.35	.005	Tr.	N11 1600F	1 1/2 hrs	7 hrs
R4		.27	.86	.31	.017	.017	1.75	.23	.33	.005	Tr.	N11 1600F	1 1/2 hrs	7 hrs

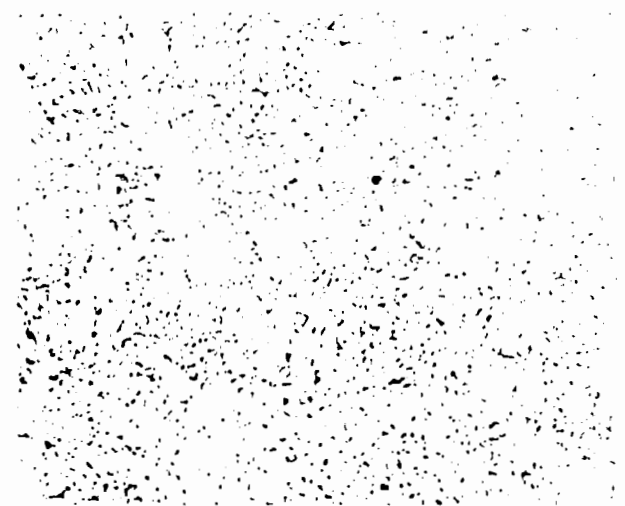
Typical Microstructures



X1000 R27 Picral
Tempered martensite and grain boundary ferrite. BHN 302.



X1000 R45 Picral
Tempered martensite and occasional grain boundary ferrite. BHN 373.



X1000 R59 Picral
Tempered martensite and fine carbides. BHN 235.