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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/629

Metallurgical Examination of Twelve

½ Inch Rolled Armor Plates Manufactured

by Republic Steel Corporation

BY

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DATE 9 May 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT WAL 710/629

Final Report on Problem B-4.32

9 May 1944

Metallurgical Examination of Twelve 1/2 Inch Rolled Armor Plates Manufactured by Republic Steel Corporation

Abstract

Metallurgical examination, including Brinell hardness surveys, fracture tests for steel soundness and fibre, macro-etch tests, and microscopic examination, was conducted on each of the twelve plates furnished by Republic Steel Corporation. Chemical analyses were taken of two plates. All plates were satisfactorily heat treated as revealed by the fibre test. However, a trace of crystallinity was evident in the two plates with a hardness of over 360. Plate 4-1, although completely fibrous, exhibited an appreciable amount of ferrite which indicated faulty heat treatment. The improper fibre test indication was undoubtedly because of the abnormally low hardness of this plate.

1. As requested by the Ordnance Research Center, A.P.G. 470.5/4896 - Wtn. 470.5/7955(r), metallurgical examination has been completed on sections from twelve (12) 1/2 inch rolled plates manufactured by the Republic Steel Corporation and tested at Aberdeen as a part of the effect of hardness program. Ballistic results will be reported in Armor Test Report AD-623 of the Ordnance Research Center.

2. Metallurgical examination included the following tests:

a. Brinell hardness surveys

b. Fracture test for steel soundness

c. Fracture test for fibre

d. Macroetch tests

e. Chemical analyses

f. Microscopic examination

3. Results and Discussion. Results of the metallurgical examination are as follows:

a. Brinell hardness surveys.

Brinell hardness readings were taken along a cross section of samples from each plate. The average cross sectional hardness is obtained from three readings taken at equal intervals across the section. Results are listed below in Table I and may be compared with the values reported by the manufacturer.

TABLE I

Plate No.	Cross Sectional Hardness Range	Cross Sectional Hardness Average	Reported Values by Manufacturer
2-2	341	341	340
2-5	311	311	311
3-3	321-331	334	340
3-3A	363	363	364
4-1	285-293	290	321
4-4	363-375	367	388
4-4A	302	302	321
6-3	363	363	388
6-3A	331-341	338	364
7-1	285	285	302
8-1	285	285	302
8-5	302-311	305	311

b. Fracture Test for Steel Soundness.

Sections approximately 5" in length and 2" wide were tempered at 1133°F., notched transversely and broken slowly under a 20 ton hydraulic press. The results are summarized in Table II.

c. Fracture Test for Fibre.

Sections the same size as in the previous fracture test and notched transversely to a depth of 1/2 inch from each side were broken rapidly under a drop weight mechanism. Because of cross sectional rolling it was difficult to distinguish the directional properties. However, the tempered sections were fibrous whereas those in the as-received heat treated condition revealed traces of crystallinity at high hardness. The results are summarized in Table II.

TABLE II

Fracture Test Results

Plate No.	Steel Soundness Tests	Fibre Test	
		Tempered	As-Received
2-2	B	Fibrous	Fibrous
2-5	B	Fibrous	Fibrous
3-3	B	Fibrous	Fibrous
3-3A	B	Fibrous	Fibrous
4-1	B	Fibrous	Fibrous
4-4	B	Fibrous	Fibrous - Trace Crystallinity (High Hardness)
4-4A	B	Fibrous	Fibrous
6-3	B	Fibrous	Fibrous - Trace Crystallinity (High Hardness)
6-3A	B	Fibrous	Fibrous
7-1	B	Fibrous	Fibrous
8-1	B	Fibrous	Fibrous
8-5	B	Fibrous	Fibrous

The specimens, rated in accordance with the fracture standards, were fibrous with the exclusion of two plates. These exceptions revealed a trace of crystallinity which may be attributed to the high hardnesses of over 360 BHN.

e. Macroetch tests.

Macroetch tests were made from sections on each plate and photographic results are shown in Figure 1. The plates are acceptable with respect to segregation.

g. Chemical analyses.

Chemical analyses obtained on two plates were as follows:

Chemical Composition

Plate No.	C	Mn	Si	S	P	Ni	Cr	Mo	V	Cu	Al	B
3-3	.25	1.00	.20	.020	.012	.67	.44	.17	trace	.025	.02	.0016
8-1	.25	1.01	.20	.019	.012	.68	.46	.17	trace	.025	.02	.0015

f. Microscopic examination.

A specimen from each plate was examined for nonmetallic distribution and microstructure.

Typical nonmetallic distribution in the plates is illustrated in Figure 2. Inclusions typical of plate 8-1 are also characteristic of type observed in plates 7-1, 6-3A, 4-4, and 2-2.

The microstructure of plates 2-2, 4-4, 2-5, 4-4A, and 8-1 was tempered martensite with traces of ferrite. The structure of plates 3-3, 6-3, 6-3A, 8-5, 3-3A, and 7-1 was tempered martensite with grain boundary ferrite. The microstructure of plate 4-1 revealed tempered martensite with an appreciable amount of ferrite. Typical photomicrographs are shown in Figure 2.

The surfaces of plates 2-5 and 8-1 showed no evidence of decarburization. Numbers 3-3, 4-1, 8-5 have layers of iron oxide intermittingly dispersed on one surface; the remaining plates have layers on both surfaces ranging from 0.002" to 0.012" in thickness. (See Figure 2-C for illustration.)

4. Steel soundness was satisfactory in all plates. Heat treatment was apparently satisfactory; the varying amounts of ferrite observed in the microstructures are apparently a reflection of the borderline hardenability

of the steel employed. The amounts of high temperature transformation products formed upon quenching were not sufficient to cause unsatisfactory ballistic behavior except in the case of one plate. This plate was of low hardness, however; and, therefore, would probably also be satisfactory under the ballistic attack applied. Plates were of sufficient uniformity so that ballistic results may be considered a function of the respective hardnesses.

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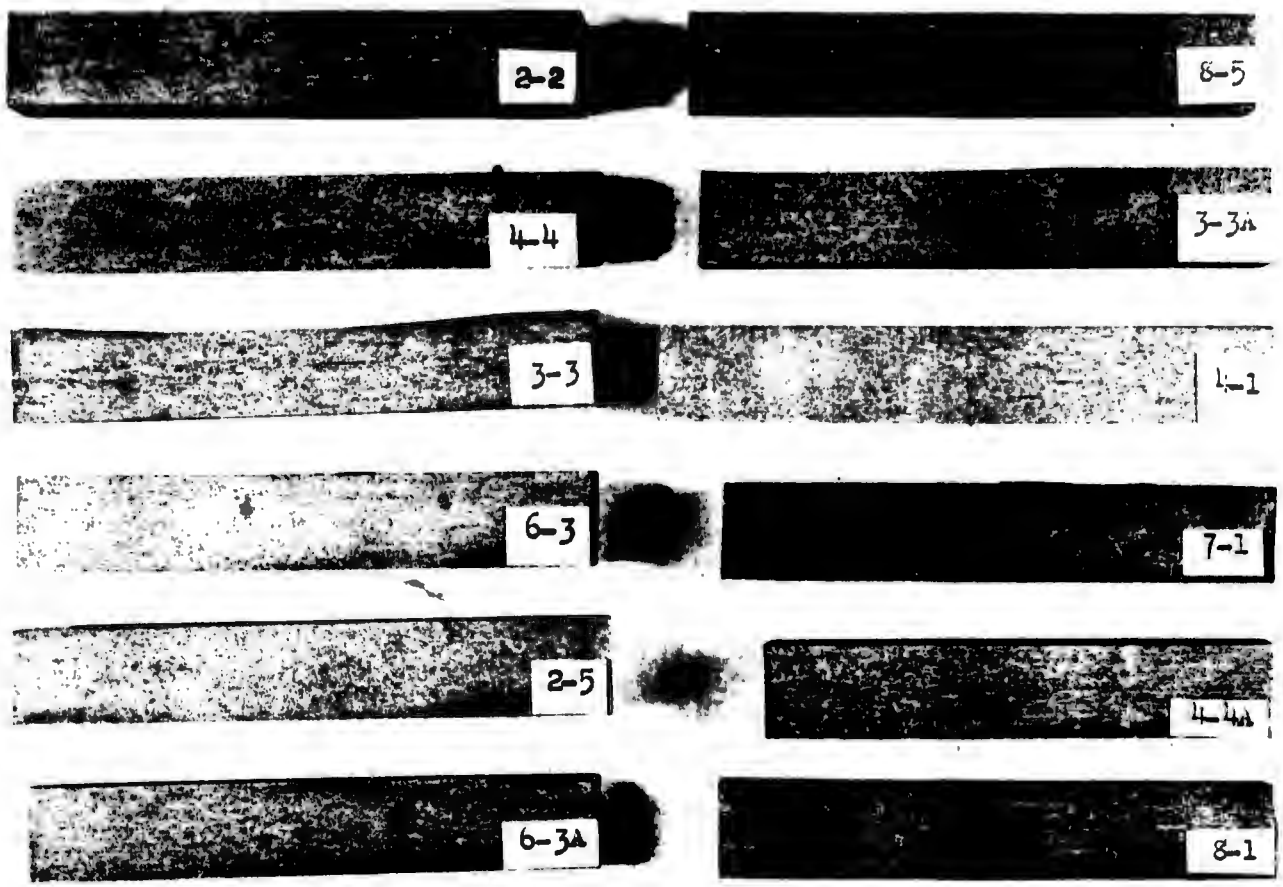

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REPUBLIC STEEL CORPORATION 1/2 INCH ROLLED ARMOR PLATE
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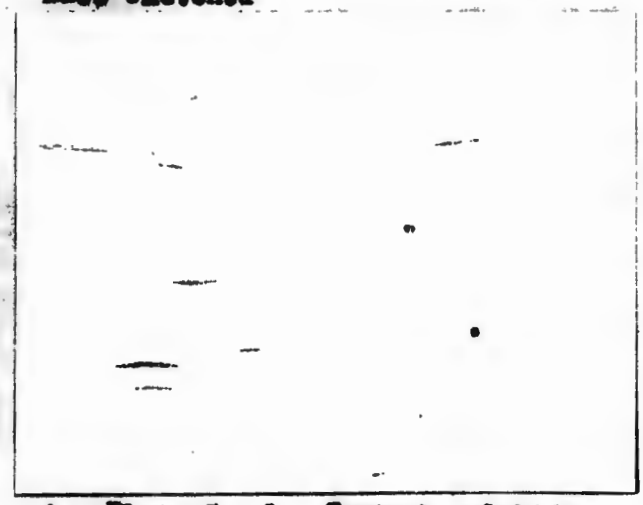
FIGURE 1

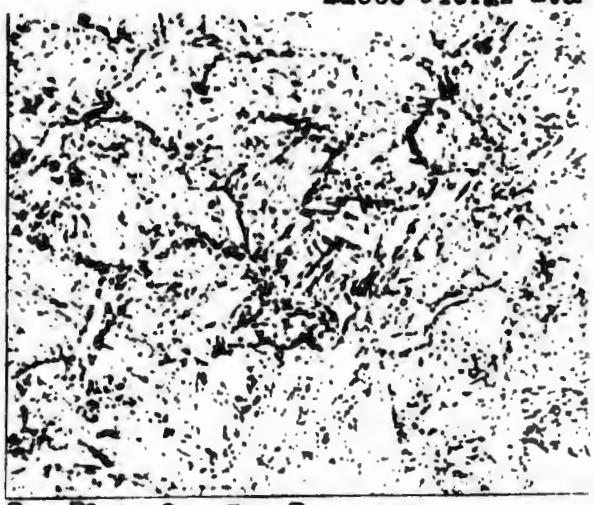
Republic Steel Corporation ½ Inch Rolled Armor Plate
Typical Microstructures

X100 Unetched

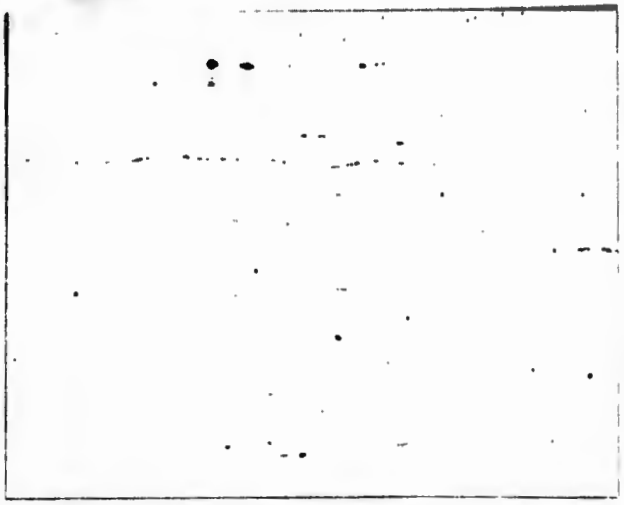


A - Plate 8 - 1. Typical sulphide inclusions.

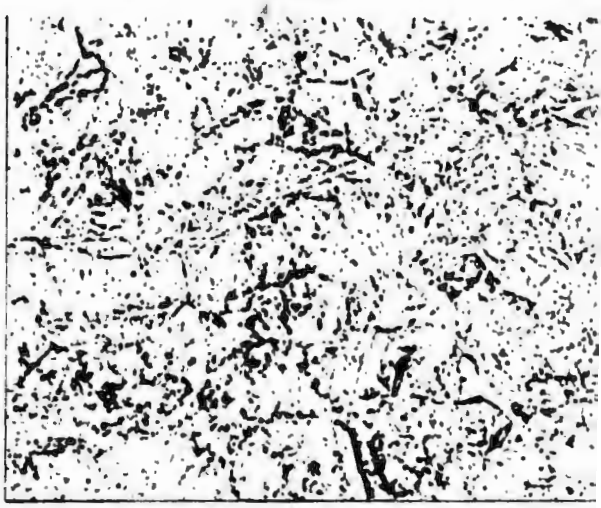
X1000 Picral Etch



D - Plate 2 - 5. Tempered martensite with traces of ferrite.



B - Plate 3 - 3. Typical silicate oxide, some sulphide inclusions.



E - Plate 7 - 1. Tempered martensite and grain boundary ferrite.

C - X100 - Plate 4 - 4. Picral. Area of iron oxide layer also showing depth of decarburization.

F - Plate 4 - 1. Tempered martensite and appreciable amount of ferrite.