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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/558

Metallurgical Examination of Six 1" Rolled Homogeneous Armor Plates Manufactured by Great Lakes Steel Corporation

BY

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WATERTOWN ARSENAL
WATERTOWN, MASS.

Watertown Arsenal Laboratory

Memorandum Report WAL 710/558

Final Report on Problem B-4.7

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1. As requested by The Proving Center, Aberdeen (APG 470.5/1325, Wtn 470.5/6906(r)), an investigation has been completed on six (6) samples of 1" rolled homogeneous armor manufactured by the Great Lakes Steel Corporation.

2. The plates from which these samples were selected were reported to have exhibited exceptionally good shock resistance when tested with the 75 mm. T21 proof projectile. The ballistic tests were conducted under the program correlating the effect of hardness on the ballistic properties of armor.

3. The metallurgical tests (fracture test and microscopic examination) indicate that the steel was properly heat treated and would exhibit impact properties commensurate with its hardness. The steel quality was sufficiently poor in four (4) of the six (6) plates examined to be rejectable although it may not have influenced the results of the test applied, since in cross rolled steel laminations do not influence the cracking tendency appreciably unless the test is exceptionally severe or the quality is extremely poor.

4. The metallurgical tests conducted on the samples consisted of the following:

a. Chemical analysis of plates GLS72, GLS84 and GLS166.

b. Hardenability of plates GLS72, GLS84, and GLS166.

c. Fibre fracture test.

d. Fracture test for steel quality.

e. Cross-sectional Brinell hardness surveys.

f. Macroetching.

g. Microscopic examination.

5. Results of the metallurgical examination are as follows:

a. Chemical analyses

The analyses of three of the samples were obtained and are shown in Table 1.

TABLE I

Chemical Analyses of Three Samples of

Great Lakes Steel Corp. Armor

Sample No.	C	Mn	Si	S	P	Ni	Cr	Mo	B	Al
GLS72	.32	1.49	.36	.026	.025	Trace	.53	.25	.0025	.05
GLS84	.31	1.47	.38	.036	.025	.07	.53	.25	.0018	.06
GLS166	.29	1.45	.36	.024	.024	Trace	.53	.22	.0025	.05

The samples examined consisted of a manganese-chromium-molybdenum type steel with boron added. The analyses were similar, and the plates are probably from the same heat of steel.

b. Hardenability

The same three plates analyzed were also selected for hardenability tests and the results are shown in Figure 1. The Jominy end quench test was employed using a nominal heating cycle of 2 hours at 1600°F prior to quenching in the fixture. The results show that the three samples contain hardenability sufficient to harden plates at least 4" thick when quenched in mildly agitated water.* Obviously the steel contains excessive alloy and hardenability for the section size, but this condition may be due to the manufacturer's desire to be on the safe side as well as the necessity of making heavier gauge armor from the same type analysis.

c. Fracture Tests

Sections T x 3" x 6" notched at the sides and broken under the forge hammer were used for both the fracture for steel quality and the fibre fracture test. A slow press break is generally applied for the steel quality fracture test, but the difference between the fast and slow break for steel quality is considered to be rather slight so its use was not warranted in view of the relatively small sample available.

The examination of the fractures for response to heat treatment revealed that the specimens broke in a fibrous manner and would be

*According to J. L. Lamont "How to Estimate Hardening Depth in Bars", Iron Age, 14 October 1943, P. 64.

expected to exhibit satisfactory properties under the room temperature shock test commensurate with their respective hardnesses.

The steel quality of four of the six are unsatisfactory (D fractures) according to the present fracture standards. The results of this test are shown in Table II.

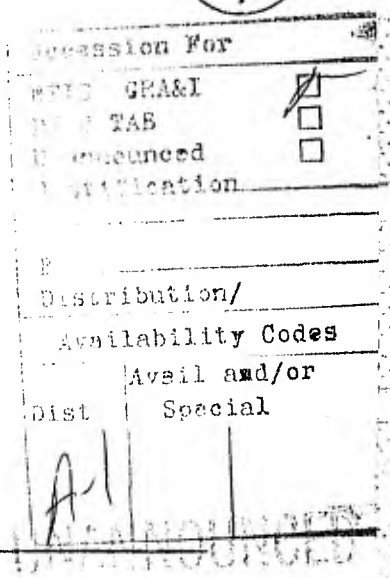

TABLE II

Results of Fracture Test for Steel Quality

Sample No.	Longitudinal* Direction	Transverse Direction
GLS72	C	D
GLS73	B	B
GLS76	B	B
GLS83	D	D
GLS84	D	D
GLS166	C	D

*Refers to direction of the plane of the fractured surface.

The relatively poor steel quality observed in this group of plates probably would not influence its shock properties under the partial penetration of the slug projectile for the laminations are fairly well cross rolled.

The armor would undoubtedly exhibit inferior ballistic properties under the PTP type of test with an overmatching projectile which would introduce shear stresses across the laminations and cause spalling.

d. Hardness Surveys

Brinell hardness tests were conducted along the cross section of the samples as well as on both faces. The results are shown in Table III.

TABLE III

Brinell Hardness Tests

Sample No.	Face 1	Face 2	Cross Section
GLS72	363	363	375/375
GLS73	375	375	375/375
GLS76	352	352	352/352
GLS83	331	331	331/321
GLS84	311	311	311/311
GLS166	352	352	352/352

The face hardness tests were taken relatively close to the surface, yet the values were practically the same as those observed along the cross section indicating the absence of an appreciable amount of decarburization. The values observed along the cross section indicated a uniform hardness from face to center of the plates.

e. Macroetching

The hot acid etch revealed the presence of cross rolled non-metallic segregations in several of the samples as shown in Figure 2. The uniformity of etching in the two rolling directions indicates a satisfactory degree of cross rolling.

f. Microscopic Examination

The samples contained friable oxide non-metallic segregations as well as short elongated stringers which also formed in segregated planes. (See Figure 3A)

The samples possessed a tempered martensitic structure which varied slightly as a function of the tempering temperature. The precipitated carbides were more numerous and the acicularity was somewhat diffused in the steel tempered to a lower hardness. (See Figures 3B, C, and D for typical structures at the various hardness levels of the samples.) The microscopic examination confirms the results of the fibre fracture test and hardenability tests which indicated proper heat treatment of the six samples, for no high temperature transformation constituents were observed in any of the samples examined.

6. The superior shock resistance of these plates is associated with an excellent heat treatment and satisfactory processing in rolling resulting in uniform properties in the two directions of rolling. The non-metallic content of the majority of the plates was high which

correlated with the poor fracture ratings. This condition would be expected to influence spalling conditions under severe ballistic attack at obliquities.

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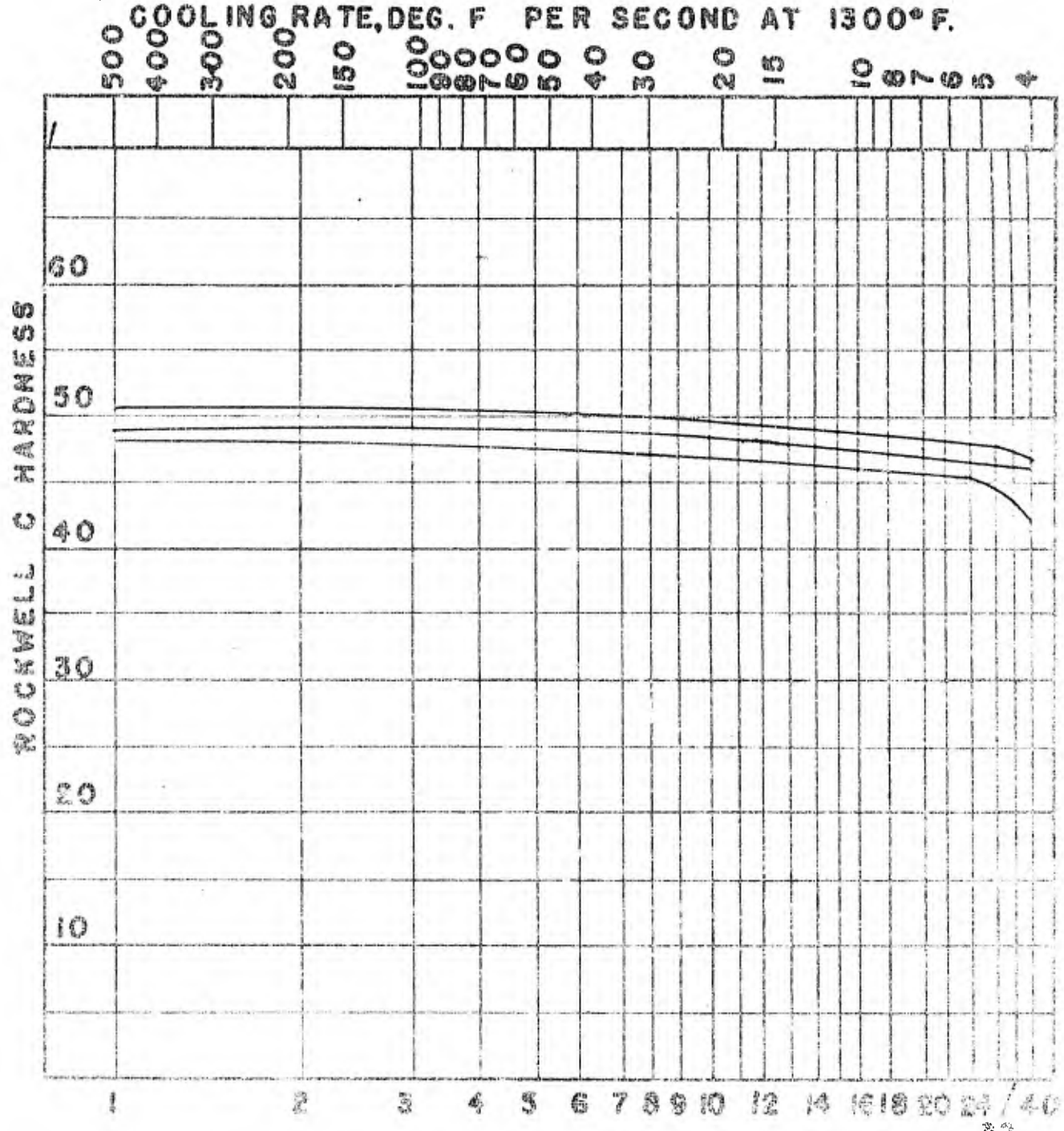

PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	B	Al	QUENCH TEMP	QUENCH TIME	U.S.
72		.32	1.49	.36	.026	.025	Trace	.53	.25	.0025	.05	1600	2 hrs.	
84		.31	1.47	.38	.036	.025	.07	.53	.25	.0018	.06			
166		.29	1.45	.36	.024	.024	Trace	.53	.22	.0025	.05			

FIGURE I

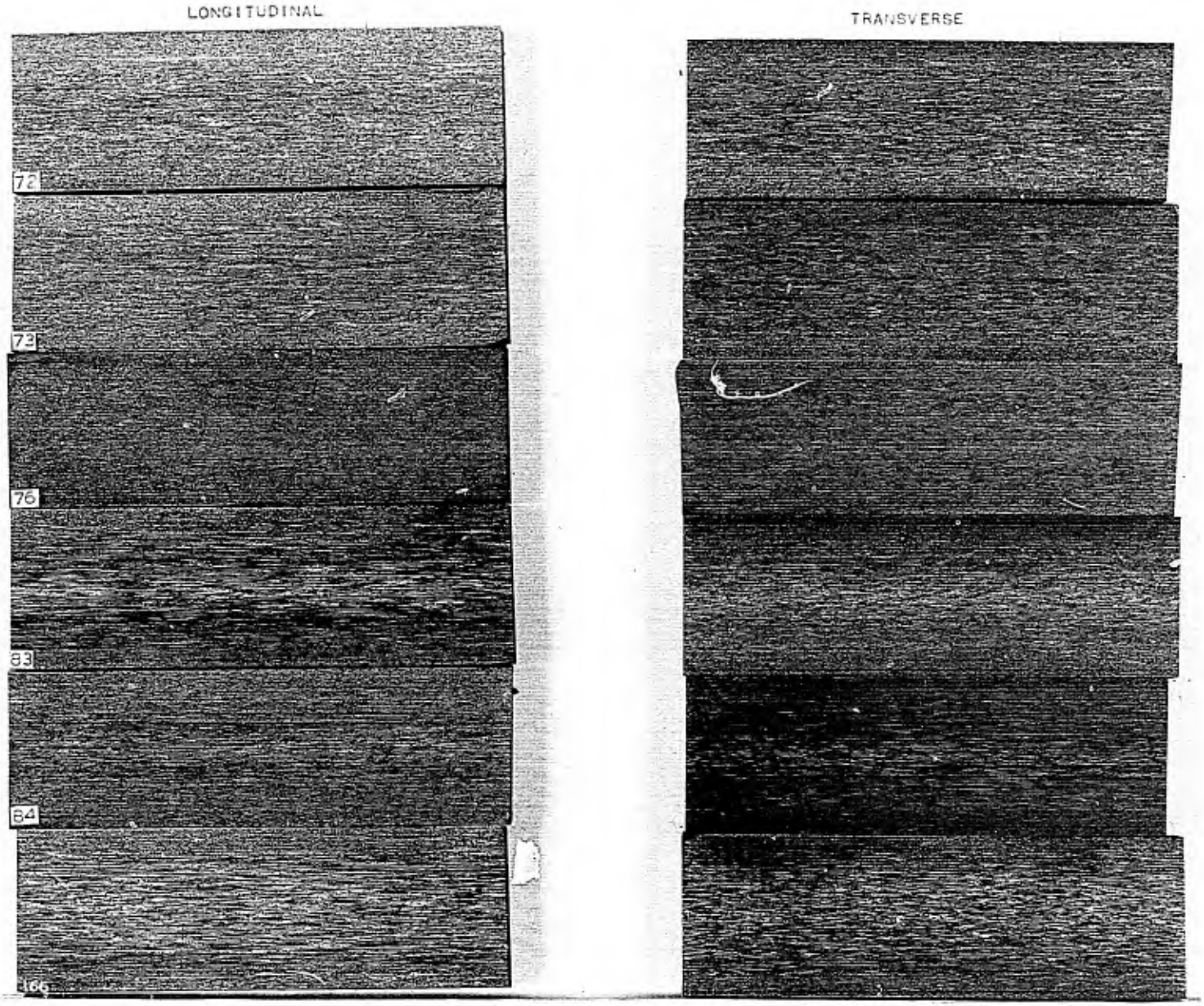

FIGURE 2

MACROETCHED SECTIONS OF 1" ROLLED ARMOR OF VARYING HARDNESSES MADE BY GREAT LAKES STEEL CORP. MAG.XI
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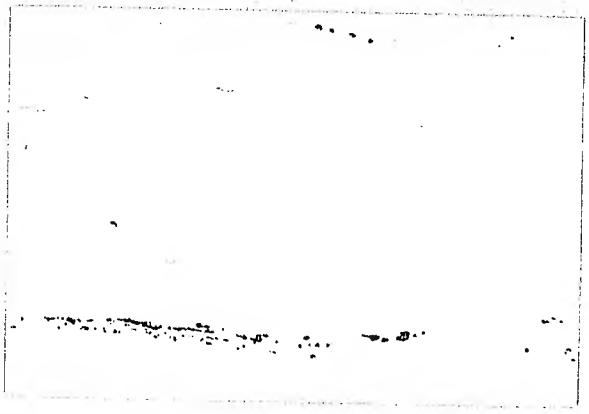
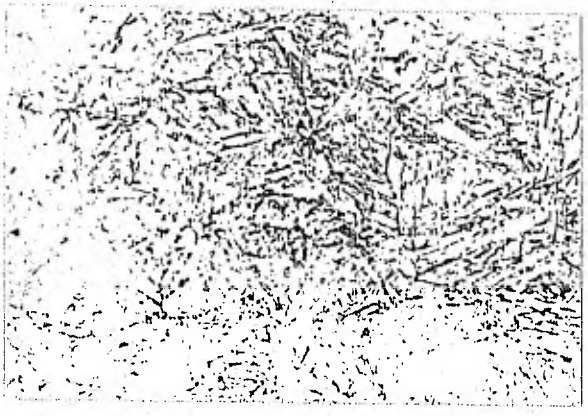
Microstructure of Samples of
Armor Made by Great Lakes Steel Corporation



X100 A Unetched
Sample GLS 166 - Types of nonmetallics observed in the six samples. Short elongated stringers and friable oxide type nonmetallic segregations were observed.



X1000 B Picral Etch
Sample GLS 73 - Tempered martensitic structure observed in samples having a hardness of 375 Brinell.

X1000 C Picral Etch
Sample GLS 83 - Tempered martensitic structure at a hardness of 331 Brinell.

X1000 D Picral Etch
Sample GLS 84 - Tempered martensitic structure at a hardness of 311 Brinell.

FIGURE 3