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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/655

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

BY

N. A. MATTHEWS
Major, Ordnance Dept.

DATE 7 June 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

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Final Report on Problem B-4.31

7 June 1944

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This 1944 report discusses a

ABSTRACT

Metallurgical examination, including fracture tests for steel soundness and response to heat treatment, Brinell hardness tests, which Maccretch tests and microscopic examination, was conducted on sections from six 1 inch thick homogeneous plates. Steel soundness was satisfactory on all but one plate. Poor shock properties, as denoted by crystalline fractures, were observed on all plates at hardnesses above 340 Brinell. In the case of these plates, temper brittleness is assigned as the probable cause.

1. As requested by the Ordnance Research Center, Aberdeen Proving Ground, (A.P.G. 470.5/4906, Wtn 470.5/7970(r)), metallurgical examination has been completed on sections from six (6) 1 inch thick rolled homogeneous armor plates of various hardnesses furnished by the Great Lakes Steel Corporation and tested at the Ordnance Research Center as a part of the effect of hardness program. All plates were rolled from the same heat of steel and were heat treated identically except for the final tempering temperature which was varied to yield the desired hardnesses. Six companion plates have been previously examined and the results reported in Memorandum Report WAL 710/558. Ballistic results on all the plates in the series are to be reported in Armor Test Report AD-558 of the Ordnance Research Center.

2. Metallurgical examination included the following tests:

a. Brinell hardness determinations.

b. Macroetch tests.

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2. Metallurgical examination included the following tests:

a. Brinell hardness determinations.

b. Macroetch tests.

c. Fracture test for steel soundness in both rolling directions.

d. Fracture test for response to heat treatment. (Fibre test)

e. Microscopic examination.

Chemical analyses and Jominy hardenability had been previously determined on plates from this heat of steel, reference report WAL 710/558.

3. The detail results of the metallurgical tests are as follows:

a. Brinell hardness. Surface Brinell hardness tests were made after careful surface grinding to a depth of 1/8 inch, and cross sectional hardness surveys were made on a surface ground section. Four surface impressions were made, whereas five impressions, equidistantly spaced, were made on the cross sections. The results appear below:

Brinell Hardness Test Results

	Surface Brinell		Cross Sectional Brinell	
Plate No.	Range	Average	Range	Average
71	375	375	388	388
75	352-363	355	352-363	358
79	331-341	334	331-341	339
80	331-341	334	321-341	329
81	311-321	314	302-311	306
165	363	363	352-375	363

Hardness results were sufficiently uniform through the sections to indicate complete quench hardening and an adequate tempering cycle to produce a uniform tempered hardness through the section.

b. Macroetch tests. A section from each plate sample was macroetched to reveal segregation tendencies. Sections from plates 71, 80, 79, and 165 showed negligible segregation and no large inclusion voids. Sample 75 showed considerable segregation in the central third of the section with long inclusion voids in a plane 1/4 inch from one face. Sample 81 showed some segregation with scattered inclusion voids of lengths up to 1/2 inch.

c. Fracture tests for steel soundness. Fracture tests for steel soundness were performed on sections cut from each plate in both rolling directions. The results appear below under section d. Only plate 81 showed an unsatisfactory condition. The central third of the section was filled with shelving which constituted a "D" fracture. The soundness of plate 71 could not be determined because of the completely crystalline, brittle fracture. Similarity of fractures in the two directions indicates efficient cross rolling.

d. Fibre fracture tests. Samples from each plate were deeply notched and broken by the blow of a forge hammer. The results are given below:

Fracture Test Results

Sample Number	Fibre		Steel Soundness	
	Direction	Result	Longitudinal	Transverse
71	Longitudinal	Crystalline	Indeterminate	crystalline fracture
75	Transverse	Mixed, mainly fibrous	C	C
79	Longitudinal	Mixed, slight crystallinity	B	B
80	Transverse	Fibrous	C	C
81	Transverse	Fibrous	D	D
165	Transverse	Crystalline	C	C

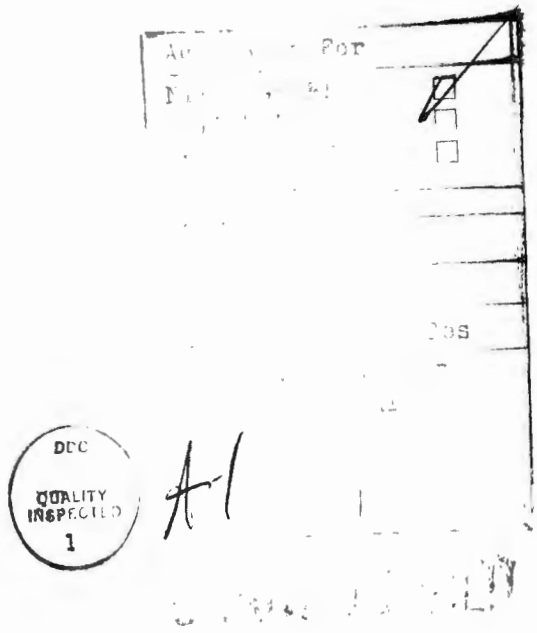
It will be noted that at hardnesses of 339 Brinell and above crystallinity appears in the fractures of this steel. At 363 Brinell and higher, the fractures are completely crystalline. It is probable that the reason for these poor shock properties at higher hardnesses is temper embrittlement. Work performed at Battelle Memorial Institute and investigations now in progress at this arsenal show that embrittlement may occur upon tempering within a tempering range of 800 to 1050°F. This embrittlement cannot be altered by rapid cooling from the tempering temperature. The subject steel is of high hardenability and of comparatively low molybdenum content (0.25%), both factors favoring embrittlement upon tempering.

e. Microscopic examination. Specimens from three plates were examined for grain size, extent of decarburization, non-metallic inclusions, and microstructure. Grain size was a uniform A.S.T.M. 6-7. Decarburization was negligible. With respect to non-metallic inclusions, all three plates showed high sulphide inclusion contents. Elongated silicate inclusions were present but not to a great extent. Occasional long stringers of alumina inclusions were present. In the case of plate 81, the alumina inclusion content was rather high and it is probable that these inclusion stringers were responsible for the poor steel soundness condition observed on the fracture test. Microstructures were uniform tempered martensite indicating satisfactory quench hardening. Typical non-metallic inclusions of plate 81 are shown in Figure 1 as well as the microstructures of plates 71 and 81.

NOTE: Metallographic work performed by Miss Barbara Phelps.

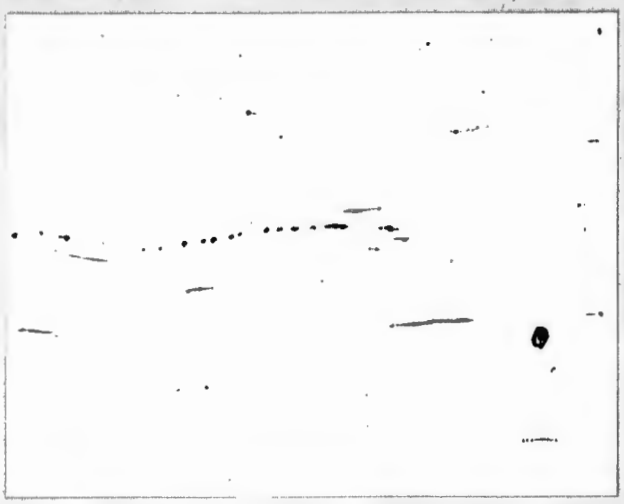
4. Steel soundness characteristics were satisfactory in all plates except one (number 81). Poor shock properties (as indicated by partially and completely crystalline fractures) characterized this steel at hardnesses above 340 Brinell. This condition is attributed to temper embrittlement. Since these plates were employed for penetration tests, however, it is considered that they are adequately similar so that differences in ballistic characteristics (except possibly in the case of plate 81) may be considered a function of the respective hardnesses.

N. A. MATTHEWS
Major, Ordnance Dept.
Chief, Armor Section

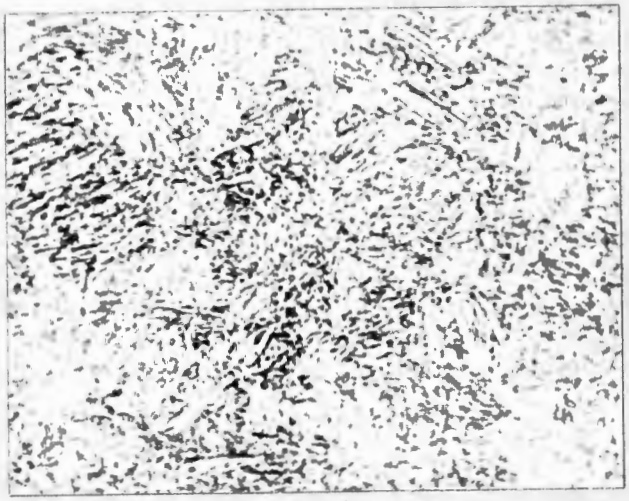


GREAT LAKES STEEL CORPORATION

1" Homogeneous Armor



X100 Unetched
Plate 81. Typical sulphide, silicate and alumina inclusions. Fairly high non-metallic content.



X1000 Picral Etch
Plate 71. Tempered martensitic structure at 388 Brinell hardness.

X1000 Picral Etch
Plate 81. Tempered martensitic structure at 306 Brinell hardness.

FIGURE 1.