Copy No. 2

710/604

EXTRA COPY

WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/604

X4816

Metallurgical Examination of Fourteen 3/8" Rolled Homogeneous Armor Plates

N. A. MATTHEWS
Major, Ordnance Dept.

DATE 5 April 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

Watertown Arsenal Laboratory

Memorandum Report Number WAL 710/604

Final Report on Problem B-4.27

5 April 1944

Metallurgical Examination of Fourteen 3/8" Rolled Homogeneous Armor Plates

Abstract

Metallurgical examination, including Brinell hardness determinations, macroetch tests, fracture tests for steel soundness and response to heat treatment, and microscopic examination, was conducted on each of fourteen (14) 3/8" homogeneous armor plates furnished by Great Lakes Steel Corporation and tested at The Ordnance Research Center as a part of the effect of hardness program. Steel soundness, with respect to freedom from laminations, was satisfactory in all plates except one (Number 155). All plates had been satisfactorily heat treated as indicated by the fibre test and microscopic examination.

1. As requested by The Ordnance Research Center, Aberdeen Proving Ground, A.P.G. 470.5/4170 - Wtn 470.5/9053, metallurgical examination has been completed on samples from fourteen (14) 3/8 inch homogeneous armor plates of various hardnesses furnished by 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, a high hardenability manganese-chromium-molybdenum analysis treated with a boron addition. Ballistic results will be reported in Report AD-514 of The Ordnance Research Center.

2. Metallurgical examination included the following tests:

a. Brinell hardness determinations.

b. Macroetch tests.

c. Fracture tests for steel soundness in the two rolling directions.

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

e. Microscopic examination.

3. The details of the metallurgical examinations are as follows:

a. Brinell hardness. Brinell hardness determinations were made on one face of each plate after careful grinding to a depth of 1/16 inch to remove all decarburization. Impressions were made with a standard Brinell machine using a 3000 kilogram load and a 10 MM tungsten carbide ball. The values reported below are based upon four impressions on each plate.

Brinell Hardness Results

Plate No.	Range BHN	Average BHN	Plate No.	Range BHN	Average BHN
29	401	401	42	363	363
31	388-401	391	153	444	444
33	363-388	382	154	429-444	440
35	388	388	155	429	429
38	341-363	352	156	321-331	323
39	341	341	157	311-321	316
41	388	388	158	293-302	300

Hardness values were sufficiently uniform on each plate to indicate complete quench hardening followed by an adequate tempering cycle to give uniform hardness throughout the plates.

b. Macroetch tests. The results of the macroetch tests are shown as Figure 1. Segregation is apparent in the majority of the plates but not to a harmful degree. Specimens from plates 154, 156, 157, and 158 are longitudinal; the balance are transverse specimens. In photographing the sections, the figure 1 was mistakenly prefaced to the plate numbers of plates in the first group, numbers 29 - 42.

c. Fracture tests for steel soundness and response to heat treatment (Fibre Test). Fracture tests for steel soundness were made on specimens from each plate in both directions of rolling after the samples had been tempered at 1050°F to yield a hardness of approximately 300-330 Brinell. The tempered samples were broken slowly in an arbor press. The fibre test samples were fractured in the as-received heat treated condition. Samples approximately 2" wide were notched in equidistantly from each side leaving a ½" length of fracture and broken uniformly rapidly by a blow from a steam forge hammer. The results of the two tests are shown below:

Fracture Test Results

Plate No.	Steel Soundness Tests *Longitudinal	Transverse	Fibre Test Direction	Rating
29	B	B	Transverse	Mixed (high hardness)
31	B	B	Transverse	Mixed (high hardness)
33	B	B	Transverse	Fibrous
35	B	B	Transverse	Fibrous
38	B	B	Transverse	Fibrous
39	B	B	Transverse	Fibrous
41	B	C	Transverse	Fibrous
42	B	C	Transverse	Fibrous
153	B	B	Transverse	Mixed (high hardness)
154	B	B	Longitudinal	Mixed (high hardness)
155	D	D	Transverse	Mixed (high hardness)
156	B	C	Longitudinal	Fibrous
157	C	B	Longitudinal	Fibrous
158	B	B	Longitudinal	Fibrous

*Longitudinal - plane of fracture parallel to major rolling direction.

Specimens for steel soundness were rated in accordance with the standards of specification AXS-488, Revision 2. The fracture tests did not show the "woody" type fracture to an appreciable degree. The fibre test fractures of plates in excess of 388 Brinell in hardness showed a small amount of crystallinity which is a function of the steel analysis and the hardness and does not reflect poor heat treatment or incomplete quench hardening.

d. Microscopic examination. Specimens from each plate were examined for quantity and type of nonmetallic inclusions, grain size, decarburization, and metallographic structure. The grain size, determined by microscopic means on several plates, was a uniform 6 - 7 A.S.T.M. Decarburization was negligible. The results of the microscopic examination on each plate are reported below.

(1). Plate 29, BHN 401. Stringers of alumina type inclusions well dispersed throughout section. Tempered martensitic structure.

(2). Plate 31, BHN 391. Clean steel, containing scattered sulphide and silicate inclusions. Tempered martensitic structure.

(3). Plate 33, BHN 382. Clean steel, containing scattered sulphide and silicate inclusions. Tempered martensitic structure.

(4). Plate 35, BHN 388. Stringers of alumina type inclusions well dispersed throughout section. Tempered martensitic structure.

(5). Plate 38, BHN 352. Fairly clean steel with silicate inclusions well distributed. Tempered martensitic structure prominent carbides.

(6). Plate 39, BHN 341. Fairly high concentration of silicate inclusions at center of section, similar to plate 155, see Figure 2B. Tempered martensitic structure.

(7). Plate 41, BHN 388. Fairly high concentration of alumina type inclusions well distributed throughout the section, see Figure 2A. Tempered martensitic structure.

(8). Plate 42, BHN 363. Fairly clean steel with uniformly distributed silicate inclusions. Tempered martensitic structure, see Figure 2D.

(9). Plate 153, BHN 444. Fairly clean steel with uniformly distributed silicate inclusions. Tempered martensitic structure.

(10). Plate 154, BHN 440. Fairly clean steel with uniformly distributed silicate inclusions. Tempered martensitic structure, see Figure 2E.

(11). Plate 155, BHN 429. Fairly high concentration of silicate inclusions, especially at center of section, see Figure 2B. Tempered martensitic structure.

(12). Plate 156, BHN 323. Fairly high concentration of silicate inclusions, especially at center of section. Tempered martensitic structure.

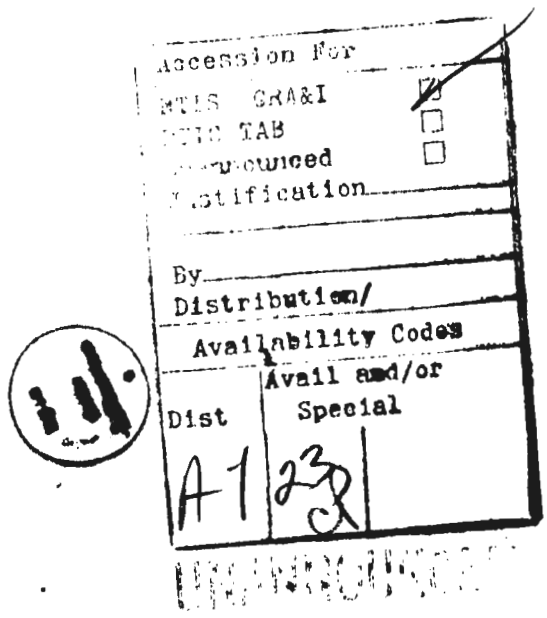
(13). Plate 157, BHN 316. Transverse microspecimen. Fairly clean steel with silicate inclusions well distributed, see Figure 2C. Tempered martensitic structure, see Figure 2F.

(14). Plate 158, BHN 300. Fairly high concentration of silicate inclusions well distributed. Tempered martensitic structure.

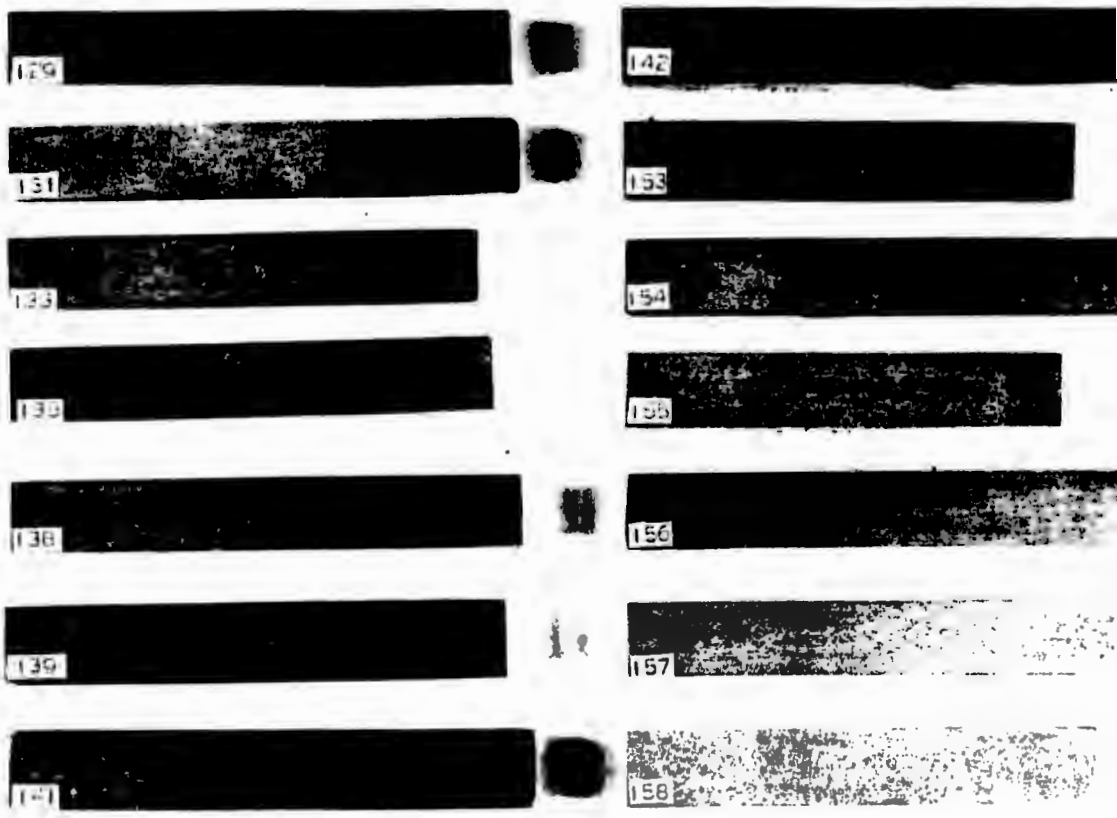
Steel cleanliness is believed to be satisfactory. Although the nonmetallic content was fairly high in some cases, the inclusions were well distributed in the majority of the plates. Heat treatment was uniformly satisfactory in all cases as evidenced by the uniform tempered martensitic structures.

4. All plates but one (number 155) are considered to be satisfactory with respect to freedom from laminations. Heat treatment was properly carried out on a steel of adequate hardenability to produce uniform tempered martensitic microstructures.

N. A. MATTHEWS
Major, Ordnance Dept.



MACROETCH TESTS



ORDNANCE DEPT. U.S.A.
WATERTOWN ARSENAL

GREAT LAKES STEEL CORP. 3/8" HOMOGENEOUS ARMOR
3 MAR 1944 WTN. 710-2283

FIG

GREAT LAKES STEEL CORPORATION

3/8" Homogeneous Armor

Typical Nonmetallic Inclusions and Microstructures

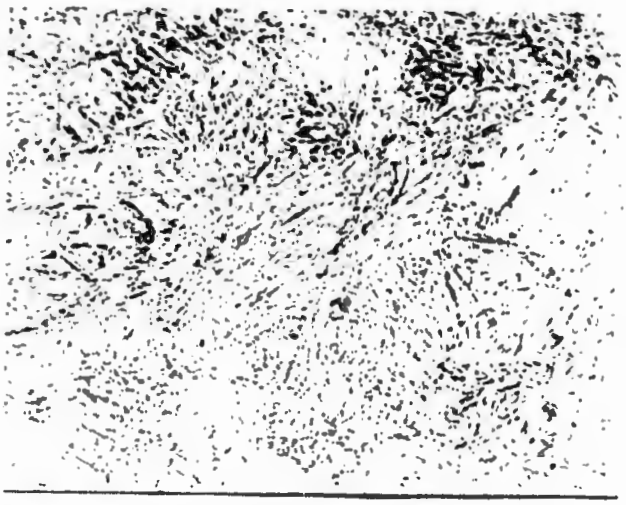
X100 - Unetched

X1000 - Picral Etch

A. Plate 61. Stringers of alumina type inclusions well distributed.

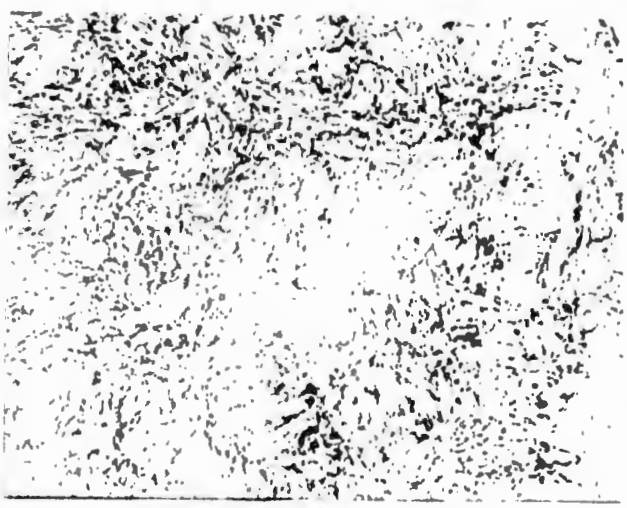
D. Plate 42, 363 BHN. Tempered martensitic structure.

B. Plate 55. High concentrations of silicate inclusions at center of plate.



E. Plate 54, 400 BHN. Tempered martensitic structure.

C. Plate 57. Transverse specimen. Silicate inclusions well distributed.



F. Plate 57, 316 BHN. Tempered martensitic structure.