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# WATERTOWN ARSENAL LABORATORY

## MEMORANDUM REPORT

NO. WAL 710/671

Metallurgical Examination of Two 1/4 Inch, Two 3/8 Inch, and Twenty-one 1/2 Inch Rolled Homogeneous Armor Plates Manufactured by Great Lakes Steel Corporation



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DATE 4 July 1944

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WATERTOWN, MASS.

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Final Report on Problem B-4.40

4 July 1944

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## ABSTRACT

Metallurgical examination, including Brinell hardness surveys, fracture test for steel soundness, and macroetch tests was conducted on each of the twenty-five plates furnished by Great Lakes Steel Corporation. Microscopic examination was made on four plates. All plates except 7A were satisfactory with respect to steel soundness.

1. As requested by the Ordnance Research Center, (APG 470.5/6503 - Wtn 470.5/9170), metallurgical examination has been completed on sections from two (2) 1/4 inch, two (2) 3/8 inch, and twenty-one (21) 1/2 inch rolled homogeneous armor plates manufactured by the Great Lakes Steel Corporation and tested at Aberdeen as a part of the effect of hardness program. Ballistic results of the 1/2 inch plates will be reported in Armor Test Report AD-515. The 1/4 inch and 3/8 inch plates are supplemental to those reported in Armor Test Reports AD-505 and AD-514 respectively, of the Ordnance Research Center, Armor Branch.

2. Metallurgical examination included the following tests:

   a. Brinell hardness surveys.

   b. Fracture test for steel soundness.

   c. Macroetch tests.

   d. Microscopic examination.

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

a. Brinell Hardness.

A section from each plate was Blanchard ground to a depth of 1/16 inch to remove any traces of decarburization. Surface Brinell hardness readings were then taken on each section; Brinell readings were also taken in the center of the twenty-one 1/2 inch plates. The average hardness was obtained from four readings taken at equally spaced intervals. Results are summarized below in Table I.

Table I

| Plate No. | Surface Hardnesses Range | Surface Hardnesses Average | Center of Plate Hardnesses Range | Center of Plate Hardnesses Average |
|---|---|---|---|---|
| 1A | 461-477 | 469 | | |
| 1C | 477-495 | 486 | | |
| 2A | 477 | 477 | | |
| 2B | 461-477 | 469 | | |
| 3A | 293 | 293 | 269-285 | 277 |
| 3B | 285-293 | 289 | 277 | 277 |
| 3C | 285-302 | 293 | 285 | 285 |
| 4A | 341 | 341 | 331 | 331 |
| 4B | 321-331 | 326 | 311 | 311 |
| 4C | 341 | 341 | 331 | 331 |
| 5A | 341 | 341 | 321-331 | 326 |
| 5B | 321-341 | 334 | 331-341 | 336 |
| 5C | 331 | 331 | 321-331 | 326 |
| 6A | 341 | 341 | 352 | 352 |
| 6B | 352-363 | 357 | 341-352 | 347 |
| 6C | 352 | 352 | 341 | 341 |
| 7A | 415 | 415 | 415 | 415 |
| 7B | 352-401 | 373 | 415 | 415 |
| 7C | 401-415 | 408 | 415 | 415 |
| 8A | 444 | 444 | 415-429 | 422 |
| 8B | 444 | 444 | 429 | 429 |
| 8C | 444 | 444 | 429 | 429 |
| 9A | 461-477 | 469 | 461 | 461 |
| 9B | 477 | 477 | 444-477 | 465 |
| 9C | 477 | 477 | 461-477 | 469 |

b. Fracture test for steel soundness.

Sections, approximately 6-1/2" in length and 3" wide were cut from each sample in both directions, notched transversely, tempered at 1050°F to reduce the hardness uniformly to approximately 300 Brinell, and then broken slowly under a Baldwin Southwork hydraulic testing machine. Twenty-four of the plates were acceptable with respect to steel soundness. Plates 7A and 9B rated D and C respectively, revealed pronounced laminations near the surface. See Table II for fracture test results.

Table II

Fracture Test for Steel Soundness

| Plate No. | Longitudinal | Transverse |
|---|---|---|
| 1A | B | B |
| 1C | C | B |
| 2A | B | B |
| 2B | B | B |
| 3A | B | B |
| 3B | B | B |
| 3C | B | B |
| 4A | B | B |
| 4B | B | B |
| 4C | B | B |
| 5A | B | B |
| 5B | B | B |
| 5C | B | B |
| 6A | B | B |
| 6B | C | B |
| 6C | B | B |
| 7A | D | B |
| 7B | B | B |
| 7C | B | B |
| 8A | B | B |
| 8B | B | B |
| 8C | B | B |
| 9A | B | B |
| 9B | C | B |
| 9C | B | B |

c. Macroetch tests.

Macroetching of a section from each plate revealed that all plates except three were satisfactory with respect to segregation. Plates 1A, 1C, and 2A exhibited pronounced centerline segregation.

d. Microscopic examination.

Sections were cut from four plates and examined for nonmetallic inclusions and microstructure. Plates 3A, 5B, and 9B were comparatively clean steels. However, in 9B there was evident near the surface an aluminum oxide stringer which showed up as a lamination in the fracture test. Plate 7A contained a fairly high nonmetallic inclusion content distributed uniformly throughout the specimen. The microstructure of Plate 3A was an acicular tempered martensite and 5B a tempered martensite with occasional grain boundary ferrite. Plates 7A and 9B had a tempered martensitic structure, 7A with scattered ferrite patches. Photomicrographs of typical microstructures are shown in Figure 1.

4. Steel soundness was satisfactory in all plates. The microstructure of the specimens implied that the plates were apparently properly heat treated. Thus the small amounts of ferrite revealed will probably not be sufficient to cause unsatisfactory ballistic behavior. The ballistic results may be considered attributable to the respective hardnesses of each plate.

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APPROVED:

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## Great Lakes Steel Corporation 1/2 Inch Rolled Armor Plate

## Typical Microstructures

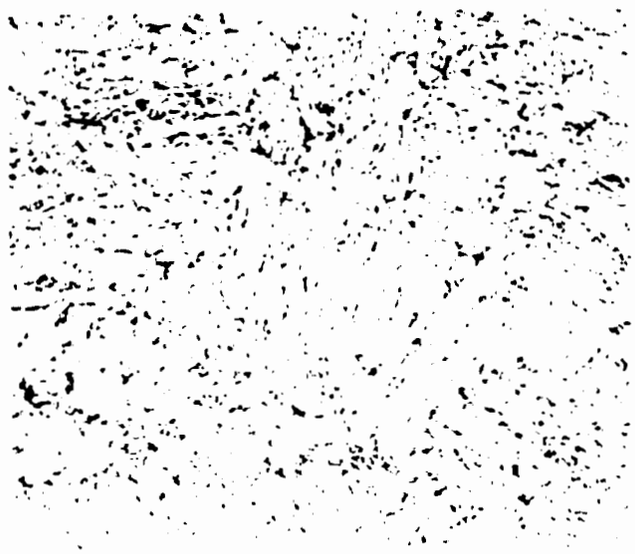

Plate 3A. Acicular tempered martensite. BHN - 277.

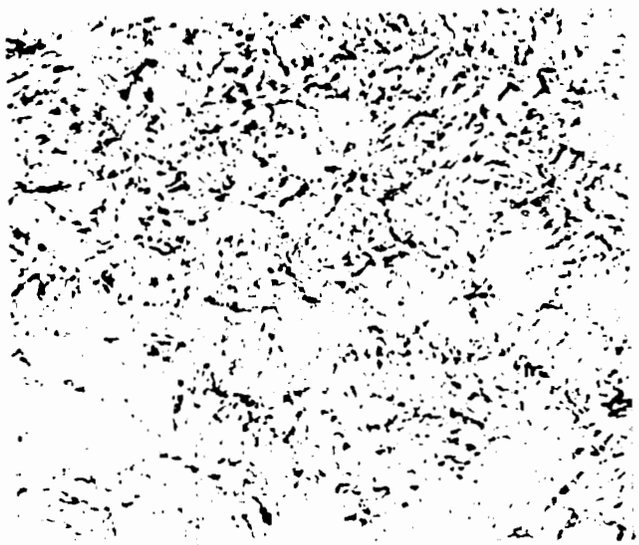

Plate 5B. Tempered martensite with grain boundary ferrite. BHN - 336.

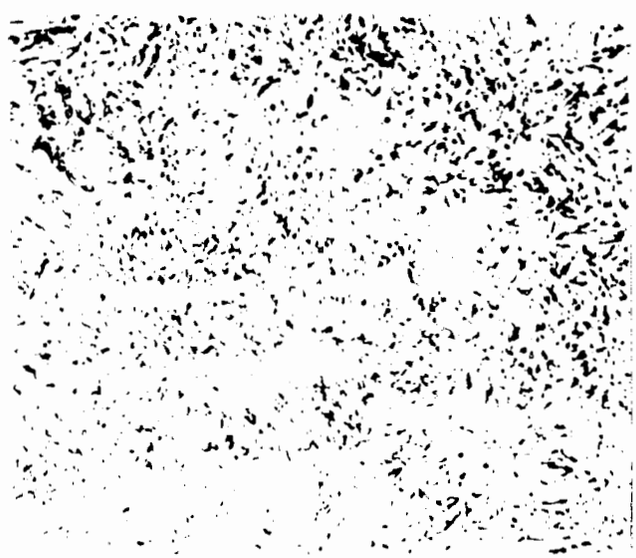

Plate 7A. Tempered martensite with occasional patches of ferrite. BHN - 415.

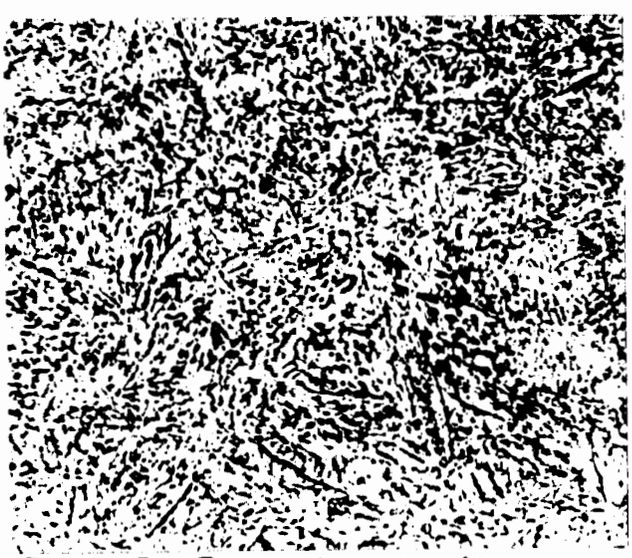

Plate 9B. Tempered martensite. BHN - 465.

All Photomicrographs taken at a Magnification of 1000 Diameters and Etched in Picral.

FIGURE 1.