WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/627

Metallurgical Examination of Carnegie-Illinois Steel Corporation 1½ Inch Homogeneous Armor

BY

M. A. MATTHEWS
Major, Ord. Dept.

DATE 4 May 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

DISCLAIMER NOTICE

THIS DOCUMENT IS BEST QUALITY PRACTICABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

RESTRICTED

WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT NO. WAL 710/627

Final Report on Problem R-4.30

4 May 1944

Metallurgical Examination of Carnegie-Illinois Steel Corporation 1½ Inch Homogeneous Armor

ABSTRACT

Metallurgical tests, including fracture tests for steel soundness and heat treatment, macroetch tests, Brinell hardness determinations, tensile tests and microscopic examination, were conducted on six plates of varying hardnesses tested at Aberdeen under the effect of hardness program. Heat treatment had been satisfactory in all cases. Steel soundness was satisfactory on all but one plate, this plate showing on the fracture test a continuous lamination ½-inch from one face.

1. As requested by The Ordnance Research Center, Aberdeen (A.P.G. 470.5/4895, Wtn 470.5/7964(r)), metallurgical examination was conducted on samples from six (6) 1½ inch plates produced by Carnegie-Illinois Steel Corporation and tested at Aberdeen as a part of the effect of hardness program. Metallurgical tests had already been conducted on the companion plates which had been shock tested; the plates involved in this report had been fired for resistance to penetration tests. Metallurgical results on the first group of six plates previously examined were reported in Memorandum Report No. WAL 710/565. Ballistic results on all plates are to be found in Report AD-586 of The Ordnance Research Center, Armor Branch.

2. Metallurgical tests consisted of the following:

a. Fracture tests for steel soundness in both rolling directions.

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

c. Macroetch tests.

d. Brinell hardness determinations.

e. Tensile tests.

f. Microscopic examination.

3. The detail results of the examinations are as follows:

a. Fracture tests for steel soundness. Fracture test specimens approximately 3" x 6" were cut in each rolling direction, notched, and broken slowly under a press. The resulting fractures were rated for steel soundness in accordance with the standards of Specification AXS-488, Revision 2. The results are given below under paragraph 3b. Only one plate, Number 6, showed a definite laminated condition which can be considered unsatisfactory. A continuous lamination developed in the transverse fracture of this plate ½ inch from one surface of the plate. None of the other plates showed continuous laminations in any plane. "Woody" fracture characteristic was evident in the longitudinal fractures of each plate. The woody fracture is apparently seen only in armor with some directional characteristics and is caused by fine, elongated non-metallic stringers. The woody condition is inherent in any rolled product which contains inhomogenities. Its effect is not considered to be great except insofar as the directional properties may promote directional cracking and the non-metallic content, as such, may favor the formation of back spalls.

b. Fibre Fracture tests. Specimens approximately 3" wide by 4" in length were notched in to a depth of 3/4" from each side and broken rapidly by the impact of a forge hammer. All samples were completely fibrous indicating that the plates had been satisfactorily heat treated. The detailed results of the fracture tests appear below:

Fracture Test Results

Sample Number	Steel Soundness Test		Fibre Fracture Test	
	Longitudinal*	Transverse	Direction	Result
255-1	B - woody	C	Transverse	Fibrous
293-2	C - woody	C	Longitudinal	"
269-3	B - woody	C - shelving ½" from one face	"	"
302-4	B - woody	C	Transverse	"
277-5	C - woody	B	Longitudinal	"
262-6	B - woody	D - continuous lamination ½" from one face	Transverse	"

*Longitudinal - plans of fracture parallel to direction of major reduction.

c. Macroetch tests. Sections for macroetching were cut from each plate. The results appear as Figure 1. Sections from plates 1, 4 and 6 are longitudinal; the balance of the sections are transverse. An ingot pattern effect is apparent in all sections and is more pronounced in the sections from plates 1, 2, 4, and 6. The ballistic effect of this condition is unknown; however, in some cases wherein the condition is pronounced, it has been associated with laminations in the fractures and a back spalling tendency.

d. Brinell hardness tests. Surface Brinell hardnesses after surface grinding to a depth of 1/8 inch were obtained on each plate. Four impressions were made. Five cross-sectional hardness readings were made at equal spaced intervals.

Sample Number	Brinell Hardness Values			
	Surface		Cross Section	
	Range	Average	Range	Average
255-1	277-285	279	255-277	266
293-2	302-311	309	293-311	304
269-3	269	269	262-269	265
302-4	321-331	326	321-341	331
277-5	302	302	293-311	304
262-6	269	269	262-285	274

Hardness readings tended to be consistently lower at the centers of the plate sections than nearer the plate surfaces indicating that the hardenability of the heat of steel under the quenching conditions employed was borderline for the section thickness.

e. Tensile tests. Standard tensile bars of 0.357" diameter were machined from each plate at a location midway between plate surface and center and in a direction parallel to the macroetch tests. The results are given below:

Sample Number	Direction	Tensile Properties Pounds Per Square Inch Tensile Strength	Yield Point, 0.1% Offset	% El. in 1.4"	% R.A.
255-1	Longitudinal	135,000	95,000	19.3	63.7
293-2	Transverse	153,000	140,000	14.3	47.4
269-3	"	132,500	105,000	17.9	56.7
302-4	Longitudinal	160,000	146,250	15.7	55.9
277-5	Transverse	148,500	134,375	14.3	51.0
262-6	Longitudinal	136,500	106,250	19.3	62.7

The superiority in elongation and reduction of area of the specimens cut in the longitudinal direction is clearly indicated. Tensile properties are satisfactory and the yield and tensile strengths check the relative Brinell hardness values obtained.

f. Microscopic examination. Specimens from each plate were examined for grain size, extent of decarburization, non-metallic inclusions and microstructure. The grain size in all cases was a uniform A.S.T.M. 6-7. Decarburization was negligible. The results of the examinations for non-metallic inclusions and microstructure are presented below for the individual plates:

(1). Plate 255-1. Moderately clean steel showing occasional segregated areas of sulphide and oxide inclusions, see Figure 2A. Microstructure essentially tempered martensite with traces of high temperature products, similar to Figure 2E.

(2). Plate 293-2. Inclusions similar to plate 255-1, see Figure 2A. Microstructure essentially tempered martensite with traces of high temperature transformation products, similar to Figure 2E.

(3). Plate 269-3. Higher non-metallic content than majority of plates consisting of sulphide and silicate inclusions with occasional stringers of alumina inclusions, see Figure 2B. Tempered martensitic structure similar to Figure 2E.

(4). Plate 302-4. Non-metallic inclusions and microstructure similar to plate 255-1, see Figures 2A and 2E.

(5). Plate 277-5. Inclusions similar to plate 255-1, see Figure 2A. Microstructure essentially tempered martensite with traces of higher temperature products, reference Figure 2D.

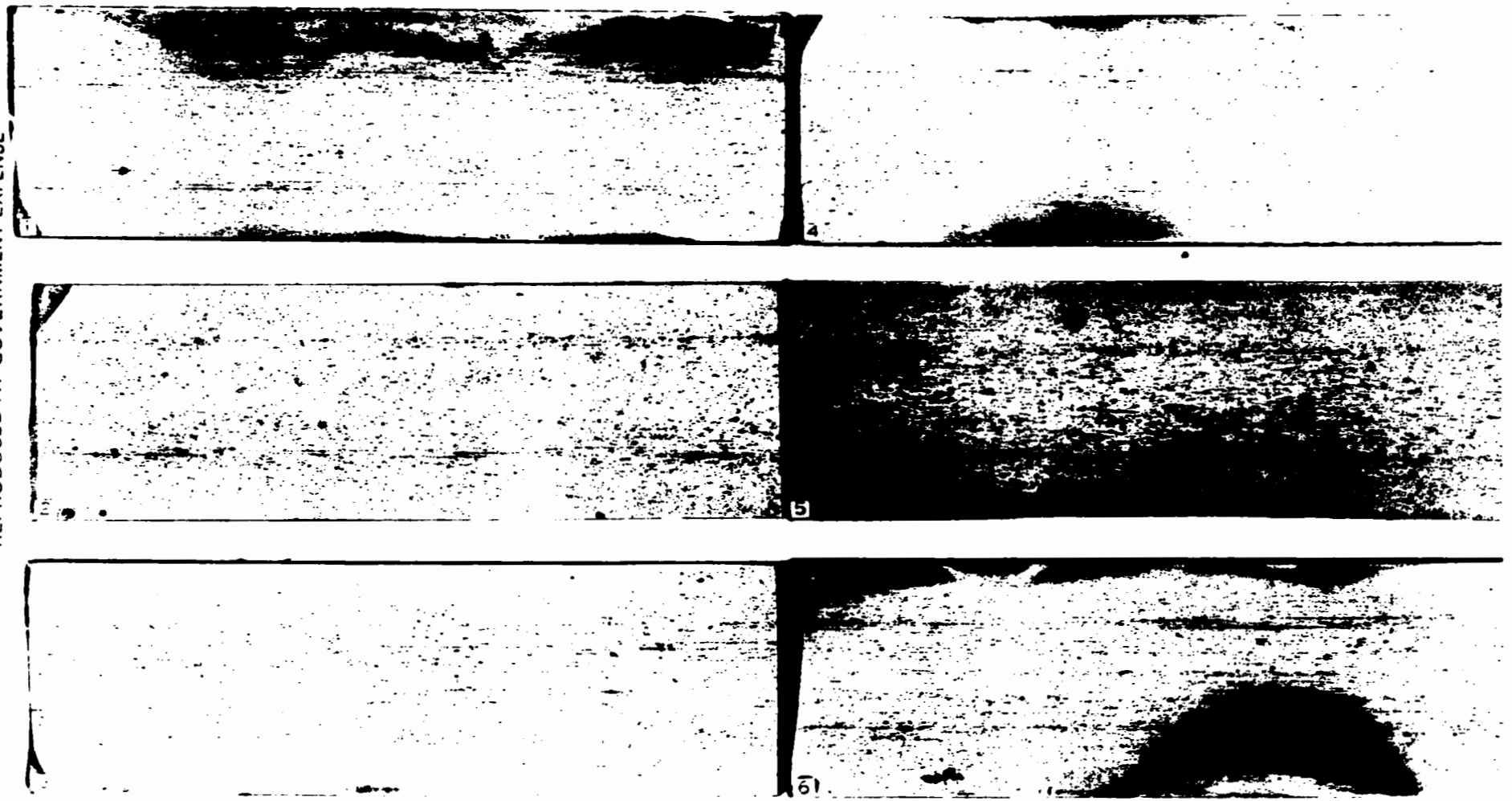
(6). Plate 262-6. Background is clean but there are considerable numbers of elongated oxide-sulphide inclusions, see Figure 2C. Microstructure similar to plate 255-1, see Figure 2E.

NOTE: Metallographic work conducted by M. Yoffa.

4. The plates were, in general, produced from adequately sound steel. However, one plate (262-6) showed a continuous lamination on the fracture test in the transverse direction. Heat treatment was uniformly satisfactory. The plates are considered to be of satisfactory overall quality and of adequate uniformity so that the ballistic results may be considered a reflection of hardness variations.

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

MACROETCH TESTS



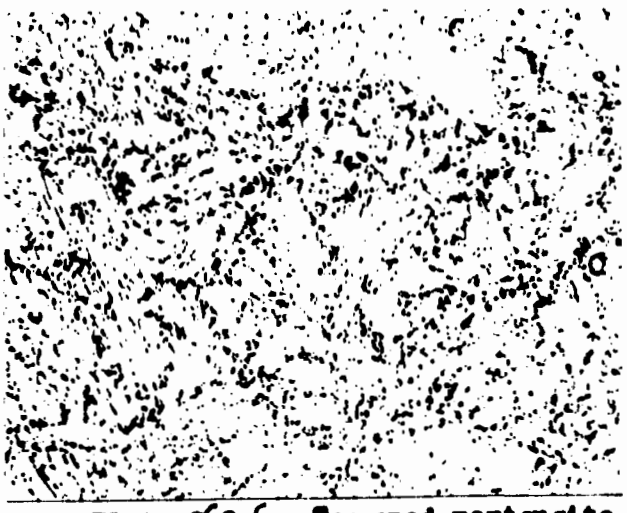
WATERTOWN ARSENAL

CARNEGIE – ILLINOIS STEEL CORPORATION 1½" HOMOGENEOUS ARMOR

Carnegie-Illinois 1½" Homogeneous Armor
Typical Microstructures

Unetched X100

A. Plate 255-1. Sulphide and oxide inclusions.



B. Plate 269-3. Sulphide and silicate inclusions and alumina stringers.

C. Plate 262-6. Complex sulphide-silicate inclusions.

D. Plate 277-5. Essentially tempered martensite.

E. Plate 262-6. Tempered martensite with traces of high temperature transformation products.

Picral Etch - X 1000

FIGURE 2.