WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/565

Metallurgical Examination of Six 1½ Inch Rolled Homogeneous Armor Plates Manufactured by Carnegie-Illinois Steel Corporation

BY
N. A. Matthews
Major, Ord. Dept.

DATE 8 December 1943

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.

UNCLASSIFIED

Watertown Arsenal Laboratory

Memorandum Report WAL 710/565

Final Report on Problem B-4.16

8 December 1943

Metallurgical Examination of Six 1½ Inch Rolled Homogeneous Armor Plates Manufactured by Carnegie-Illinois Steel Corporation

1. The Proving Center, Aberdeen requested (APG 470.5/2190, WTN 470.5/7468r) that metallurgical examination be conducted on six (6) 1½ inch rolled homogeneous armor test plates manufactured by the Carnegie-Illinois Steel Corporation. The six plates were tested at Aberdeen as a part of the large program on the effect of hardness on ballistic properties. The plates, therefore, were from the same heat of steel and were similarly heat treated except for the final draw temperatures which were varied to give the hardnesses desired. Ballistic results on the plates are to be reported in Armor Test Report number AD-586 of The Proving Center. The six plates were assigned the numbers 1 to 6 by Aberdeen.

2. The results of the metallurgical examination indicate that the six plates are of satisfactory quality. The ballistic results, therefore, should be considered representative of acceptable quality armor; and since the plates were fairly uniform except for hardness, the variation in ballistic performance observed among the several plates may be attributed to the differences in hardness.

3. Metallurgical examination consisted of the following tests:

a. Fibre fracture test. Specimens also examined for steel quality.

b. Macroetch tests.

c. Physical tests.

d. Brinell hardness determinations.

e. Jominy hardenability and chemistry on plate 1.

f. Microscopic examination.

UNCLASSIFIED RESTRICTED

4. The detailed results of the metallurgical examinations are as follows:

a. Fracture tests. Samples approximately 3"x6" in size were cut from each sample furnished. The samples were notched transversely to the long dimension to a depth of 1/2" on each side and broken under the impact of a forge hammer. The resulting fractures were then examined for the presence of crystallinity and for steel quality. These results follow:

Sample No.	Fracture Direction	Fracture Condition	Steel Quality
1	Longitudinal	Fibrous	Satisfactory B Fracture
2	Longitudinal	Fibrous	Satisfactory B Fracture Short laminations concentrated in middle third of section.
3	Longitudinal	Fibrous	Satisfactory C Fracture Short laminations concentrated in one plane 1/2" from one face of plate.
4	Longitudinal	Fibrous	Satisfactory C Fracture Short laminations concentrated in middle third of section.
5	Longitudinal	Fibrous	Satisfactory B Fracture
6	Longitudinal	Fibrous	Satisfactory B Fracture

All of the plates were satisfactorily heat treated as indicated by the ductile fibrous fractures. The steel quality was excellent in four (4) of the plates and somewhat inferior in the case of plates 3 and 4. The fractures of plates 3 and 4 were barely inferior to a "B" fracture rating. From the fracture appearances it was difficult to tell whether the fracture was longitudinal or transverse, and it, therefore, is concluded that the armor was well cross rolled and would show little directional characteristics.

b. Macroetch tests. The results of the macroetch tests are shown in Figure 1. All plates, except number 5, show a definite ingot pattern effect which in some cases has been associated with back spalling tendencies in heavier gauge plate produced by this manufacturer. The darker etching bands, symmetrical about the center of the plate, apparently correspond to the zone of the junction between the columnar and equiaxed dendrites in the original ingot and, therefore, undoubtedly reflect metallic segregation together with a zone of reduced density. The streaks shown by the macroetch do not correspond to zones of increased concentrations of non-metallic inclusions. The macroetched sections represented are in the transverse direction.

c. Physical tests. Standard tensile test specimens (.357" diameter) were cut in the transverse direction from each plate at a location corresponding to the midpoint between surface and center of the plate. The results on each plate follow:

Plate No.	Pounds Per Square Inch		% El.	%
	Tensile Strength	Yield Point, .1% Offset	in 1.4"	R.A.
1	135,500	109,400	18.6	54.8
2	153,500	135,600	15.7	50.2
3	135,500	110,000	18.6	55.9
4	162,000	141,300	15.0	47.8
5	146,000	125,000	17.1	52.9
6	134,000	98,000	18.6	55.2

Fractures of all bars showed satisfactory cup and cone characteristics. The reduction of area values are considered excellent for the transverse direction and in consideration of the strength levels of plates 2 and 4.

d. Brinell hardness tests. Brinell hardness determinations, using the tungsten carbide ball, were made on the surface and across the thickness of each plate. Surface readings were made after grinding to a depth of approximately 3/32". Surface values are the average of four readings whereas six determinations, equidistantly spaced, were made across the section. The results are given below.

Plate No.	Surface Brinells		Cross Sectional Brinells	
	Range	Average	Range	Average
1	269-269	269	269-285	271
2	302-311	309	302-321	313
3	262-269	267	262-293	277
4	321-321	321	321-331	326
5	302-302	302	293-311	304
6	277-277	277	269-285	278

Hardnesses were uniform across the section confirming the satisfactoriness of the heat treatment. The Brinell hardnesses obtained correlate well with the tensile test data reported above.

e. Chemistry and Jominy hardenability. The chemical analysis and hardenability of plate number 1 were determined.

Sample No.	C	Mn	Si	S	P	Ni	Cr	Mo	B
1	.28	1.23	.24	.022	.011	.72	.79	.21	.0009

This is the familiar analysis characteristic of that used by Carnegie-Illinois Steel Corporation during the past year. The boron content analyzed is that usually found resulting from additions amounting to approximately .002%.

The Jominy hardenability curve is shown as Figure 2. The steel retains a Rockwell C 43 hardness at approximately 13/16 inches from the quenched end which corresponds to a plate thickness of 2" which will quench out to a Brinell hardness of 400 in a still water quench. The hardenability, therefore, is adequate for the 1½ inch plate thickness involved in this series.

f. Microscopic examination. Microspecimens across the section were examined for decarburization, grain size, types and concentration of nonmetallic inclusions, and heat treated structure. The decarburization on all plates was slight, amounting to .006-.008 inches. The grain size of all plates was a uniform A.S.T.M. 6-7. The detailed results of the microscopic examinations follow:

(1) Plate 1. Clean steel with scattered short sulphide and silicate inclusions and occasional minor streaks of alumina inclusions. Microstructure was a uniform tempered martensitic structure with traces of high temperature transformation products including ferrite. (See Figure 3.)

(2) Plate 2. Clean steel with scattered short sulphide and silicate inclusions. Microstructure tempered martensite with traces of high temperature products including ferrite.

(3) Plate 3. Moderately clean steel with well distributed silicate, sulphide and alumina inclusions. Microstructure tempered martensite with traces of high temperature product.

(4) Plate 4. Moderately clean steel with scattered silicates and sulphides and some streaks of alumina inclusions. Microstructure tempered martensite with traces of high temperature product. (See Figure 3.)

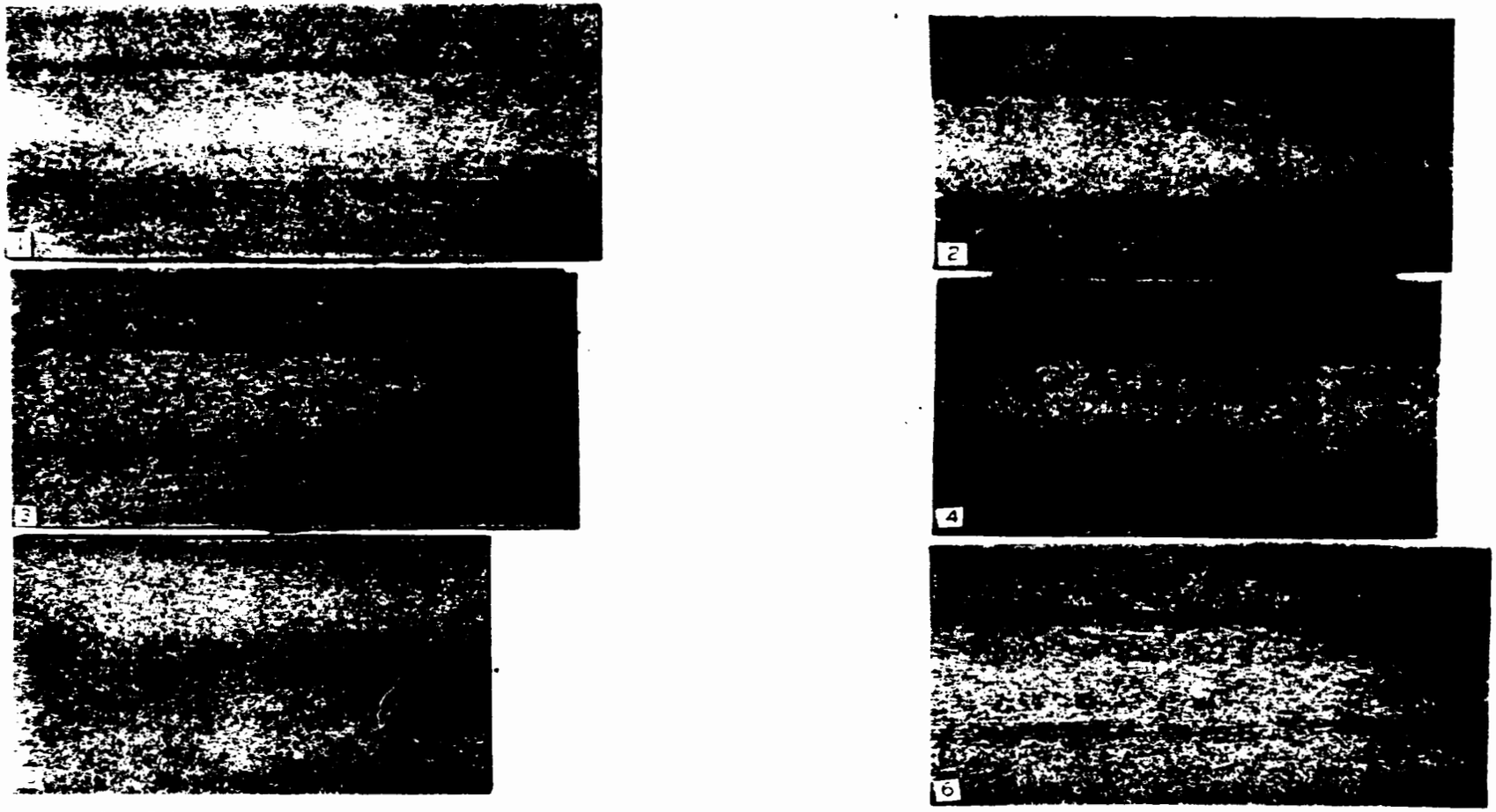
(5) Plate 5. Clean steel with short, well distributed silicate and sulphide inclusions. Tempered martensitic structure with traces of high temperature transformation products.

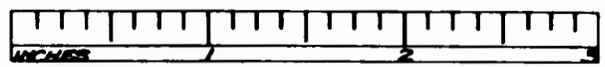
(6) Plate 6. Clean steel with scattered sulphide inclusions. Structure tempered martensite with traces of high temperature transformation product.

The microscopic examination confirmed the fibrous fractures and the satisfactory heat treated condition of these plates. The higher concentrations of nonmetallic inclusions in plates 3 and 4 correspond with the relatively poor fractures of these two plates.

5. The metallurgical tests conducted indicate the six plates involved to be satisfactorily heat treated and of adequate steel quality. Ballistic results, therefore, may be considered representative of satisfactory armor at the respective hardnesses.

N. A. MATTHEWS
Major, Ord. Dept.





ORDNANCE DEPT. U.S.A.
WATERTOWN ARSENAL

CARNEGIE – ILLINOIS STEEL CORP. 1½" HOMOGENEOUS ARMOR

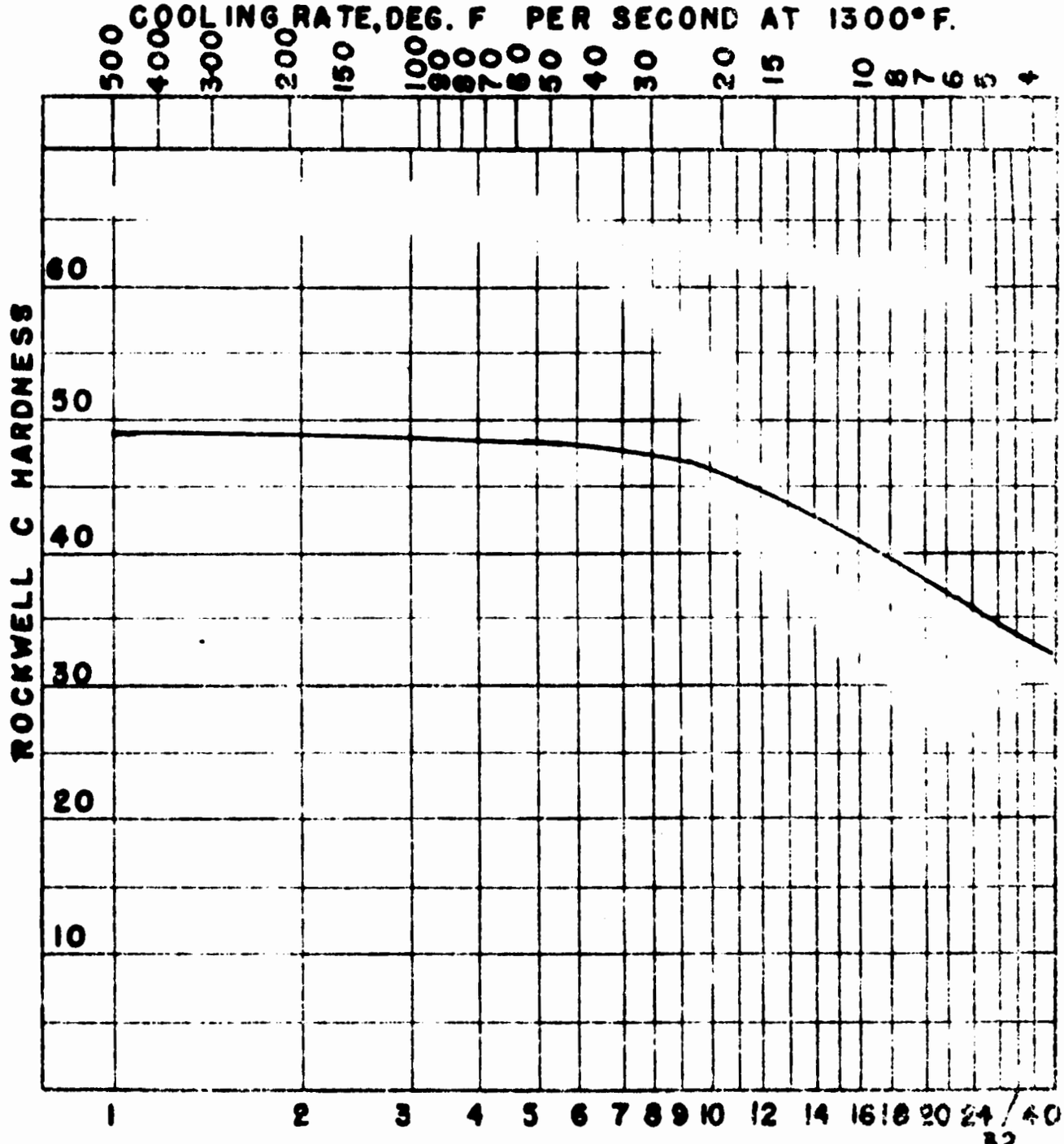
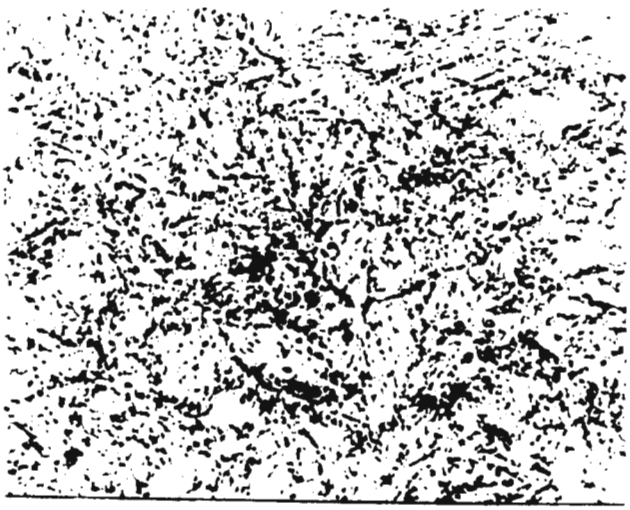


PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	B	QUENCH TEMP	TIME	G.S.
1	C.I.	.28	1.23	.24	.022	.011	.72	.79	.21	.0009	1575°F	2hrs.	6-7

FIGURE 2

Carnegie-Illinois 1½" Homogeneous Armor
Typical Microstructures



X1000 Plate 1 Picral Etch
Tempered martensite with traces of high temperature transformation products including ferrite.

X1000 Plate 4 Picral Etch
Tempered martensite with traces of high temperature transformation products including ferrite.

FIGURE 3