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MEMORANDUM REPORT

NO. WAL 710/716

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WAL 710/716

Metallurgical Examination of Twelve 2 $\frac{1}{2}$ " Thick Rolled Homogeneous
and Sixteen 2 $\frac{1}{2}$ " Thick Face Hardened Armor Plates Manufactured
by Carnegie-Illinois Steel Corporation

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Final Report on Problem B-4.54

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19 January 1945

Metallurgical Examination of Twelve $2\frac{1}{2}$ " Thick Rolled Homogeneous
and Sixteen $2\frac{1}{2}$ " Thick Face Hardened Armor Plates Manufactured

by Carnegie-Illinois Steel Corporation



ABSTRACT

A metallurgical examination was conducted on twelve (12) $2\frac{1}{2}$ " thick rolled homogeneous and sixteen (16) $2\frac{1}{2}$ " thick rolled face hardened armor plates manufactured by Carnegie-Illinois Steel Corporation on OCO-D Project 1558. The results of this investigation indicate that, in general, the steel soundness of the face hardened plates was inferior to that of the homogeneous plates. In this connection, the face hardened plates had more pronounced directional properties than the homogeneous plates. The average Brinell hardness of the homogeneous plates was 247-262. The average Brinell hardness of the face hardened series was found to be face, 465-690, and core 208-243. The depth of the effective case at Rockwell C 50 varied from $.26$ "- $.40$ " in from the face of plate (10 plates tested) while in two face hardened plates the case depth was $.09$ "- $.16$ " in from face of plate. In general, the homogeneous and face hardened plates were properly heat treated resulting in fibrous fractures, good V-notch impact properties and a satisfactory microstructure.

1. As requested by the Ordnance Research Center, Aberdeen¹, metallurgical examination has been completed on twelve samples of $2\frac{1}{2}$ " thick rolled homogeneous armor and sixteen samples of $2\frac{1}{2}$ " thick rolled face hardened armor plates manufactured by the Carnegie-Illinois Steel Corporation on OCO-D Project 1558. Due to the fact that the first set of

1. APG 470.5/529 - Wtn 470.5/8399(r) - 24 August 1944

sixteen face hardened sections were cut from the edge of the plates, it was impossible to determine an accurate measurement of depth of case. It was observed that near the edge of the plate the case decreased in thickness to a marked degree. It was, therefore, requested that another set of sixteen face hardened sections be forwarded to this arsenal for accurate case depth measurements and that each section be cut from near the center of the ballistic test plate. In reply to this request only twelve samples were submitted. Sections from plate Nos. 41-3/8, 41-3/4, 41-13/16 and 441 were not available for examination. It was reported that the ballistic properties of the face hardened plates were inferior to those of the homogeneous plates.

2. The purpose of this investigation was to conduct an examination of the samples to determine if there was a metallurgical variation among the homogeneous or the face hardened plates that might affect the ballistic results.

3. The plates under investigation are listed as follows:

| <u>2 1/2" Thick Rolled Homogeneous Plates</u> | <u>2 1/2" Thick Face Hardened Plates</u> |
|---|--|
| 11A | 41 1/16 |
| 21A | 41 1/8 |
| 21B | 41 3/16 |
| 21C | 41 1/4 |
| 21D | 41 5/16 |
| 31A | 41 3/8 |
| 31B | 41 7/16 |
| 41A | 41 1/2 |
| 41B | 41 9/16 |
| 41C | 41 5/8 |
| 41D | 41 11/16 |
| 51B | 41 3/4 |
| | 41 13/16 |
| | 41 7/8 |
| | 41 15/16 |
| | 441 |

4. The results obtained from tests conducted on the twelve homogeneous plates indicated that five plates had a steel soundness rating of "D" while the remainder had "B" and "C" ratings. With the exception of one sample which showed a trace of crystallinity all samples were properly heat treated. Generally speaking, the face hardened plates had more pronounced directional properties than the homogeneous plates as shown by V-notch impact tests and tensile tests. It was noted that the face hardened plates exhibited various degrees of "woodiness" in the fractures made on sections near the edges of the plates. In one case a "D" rating was observed in a center section of a face hardened plate while the remaining center sections had "B" and "C" ratings. The carburized cases exhibited a fine silky fracture. The homogeneous plates

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and the face hardened plates were properly heat treated as shown by the satisfactory V-notch impact properties at -40°F. The homogeneous plates were heat treated to a Brinell hardness range of 247-262. The Brinell hardness of the face hardened plates was as follows, face hardness, 465-690, and core hardness, 208-243. In general the face hardness near the center of the carburized plates was slightly lower than the face hardness near the edge of the plate while the core hardness near the center of these plates was slightly higher than the core hardness near the edge of the plates. In a series of ten face hardened plates the effective case depth to Rockwell C 50 varied from .26" to .20" in from the face of the plate. In two face hardened plates, however, the case depth to Rockwell C 50 was only .09" to .16". Furthermore, the case depth to Rockwell C 40 varied from .58" to .80" in from the face of the plates. The microstructure of the homogeneous plates consisted of tempered martensite. The carburized cases of the face hardened plates were fairly free from pronounced carbide segregations while the cores had a structure similar to that of tempered bainite.

5. The metallurgical examination consisted of the following tests:

- a. Chemical analyses of selected plates.
- b. Fibre fracture test.
- c. Fracture test for steel quality.
- d. Brinell hardness surveys.
- e. Rockwell C hardness surveys.
- f. V-notch Charpy impact tests.
- g. Tensile tests.
- h. Microscopic examination.

6. The results of the metallurgical examinations are as follows:

a. Chemical Analyses. Chemical analyses of representative samples are given in Table I.

b. Fibre Fracture Test. Fibre fracture tests were made on properly notched sections and the steels rated with respect to their heat treated condition, the results of which are given in Tables IV and V. All of the face hardened plates fractured in a fibrous manner and all except one of the rolled homogeneous plates were fibrous. The carburized cases were silky.

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a. Fracture Test for Steel Quality. The results of this test indicated that of the rolled homogeneous plates, five had a steel soundness rating of "D" while the remainder were satisfactory. The samples removed from the edge of the face hardened plates exhibited various degrees of woodiness. The central areas of these face hardened plates did not exhibit this woodiness to such a pronounced degree as noted in the edges. One sample, No. 41-5/16 exhibited a "D" fracture in the central area of the plate. The results of the fracture tests are given in Tables IV and V.

d. Brinell Hardness Surveys. Brinell hardness readings were taken on the surface and cross section of the homogeneous plates. On the face hardened series, Brinell readings were taken on the face and cross sections of the core. All readings were equidistantly spaced throughout the sections tested. The hardness values are listed in Tables II and III. It was noted, in most of the face hardened plates, that in the core hardnesses taken on samples from the edge of the plates the immediate center of the core had a Brinell hardness which was 20-30 points higher than the rest of the section. This may be due to metallic segregation present in the center of the cross section.

a. Rockwell C Hardness Surveys. Rockwell C surveys were made at .05" intervals across the carburized zone, see Figures 1 and 2. The case depth to Rockwell C 40 varied from .58" to .80" in from the face of the plate. The case depth to Rockwell C 50 which may be termed the effective case varied from .26" to .40" in from the face of the plate. In two face hardened plates, however, the case depth to Rockwell C 50 was only .09" to .16".

f. V-Notch Charpy Impact Tests. The results of the V-notch Charpy impact tests made on representative samples taken in longitudinal and transverse directions of the homogeneous and face hardened plates are given in Tables IV and V. The values obtained indicate that the plates were properly heat treated and correlate with the results received in the fibre fracture test. Generally speaking, the face hardened plates had more pronounced directional properties than the homogeneous plates as shown by V-notch impact tests.

g. Tensile Tests. Tensile tests made in the longitudinal and transverse directions on samples are given in Table VI. The results of these tests indicate that the face hardened plates exhibited greater directional properties than the homogeneous plates.

h. Microscopic Examination. The pronounced "woody" condition noted near the edge of some of the face hardened plates was associated with a segregation of alumina streaks. Face hardened plates which only exhibited a trace of woodiness near the edge contained a series of short fine manganese sulphide inclusions. The central areas of the face hardened plates contained occasional sulphide-silicate nonmetallic inclusions. No marked segregation of nonmetallic inclusions was detected in the series of homogeneous plates. Apparently the directional properties noted in the face hardened plates were associated with the elongated nonmetallic inclusions detected in these samples.

The microstructure of the rolled homogeneous plates is typical of tempered martensite. The microstructure of the outer cases of the carburized plates consisted of some excess fine carbides in a martensitic matrix whereas in the inner cases the carbides were of the globular type. This correlates with the silkiness of the carburized cases obtained when fractured. The microstructure of the cores consisted of a uniform distribution of fine carbides in a matrix similar to tempered bainite. Photomicrographs are presented which illustrate typical microstructures of the outer and inner carburized cases and cores of the face hardened plates, see Figures 3 and 4.

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TABLE I

Chemical Analyses

| <u>Plate No.</u> | <u>Type of Armor</u> | <u>Thick- ness</u> | <u>C</u> | <u>Mn</u> | <u>Si</u> | <u>S</u> | <u>P</u> | <u>Ni</u> | <u>Cr</u> | <u>Mo</u> | <u>V</u> | <u>Cu</u> | <u>B</u> | <u>Ti</u> | <u>Zr</u> |
|------------------|----------------------|------------------------|----------|-----------|-----------|----------|----------|-----------|-----------|-----------|----------|-----------|----------|-----------|-----------|
| 11 A | Rolled Homogeneous | 2 $\frac{1}{2}$ " | .29 | 1.29 | .29 | .015 | .017 | .69 | .81 | .33 | Nil | .13 | Tr | Tr | Nil |
| 21 A | " | 2 $\frac{1}{2}$ " | .28 | 1.32 | .27 | .015 | .017 | .69 | .80 | .33 | Nil | .13 | .0009 | Tr | Nil |
| 31 A | " | 2 $\frac{1}{2}$ " | .285 | 1.33 | .29 | .016 | .018 | .71 | .84 | .33 | Nil | .125 | Tr | Tr | Nil |
| 41 C | " | 2 $\frac{1}{2}$ " | .30 | 1.36 | .27 | .021 | .018 | .69 | .84 | .32 | Nil | .12 | Tr | Tr | Nil |
| 41-1/16 | Face Hardened | 2 $\frac{1}{2}$ " | .305 | .23 | .05 | .020 | .013 | 3.70 | 1.75 | Nil | Nil | .055 | Tr | Nil | Nil |
| 41-7/16 | " | 2 $\frac{1}{2}$ " | .355 | .21 | .05 | .023 | .009 | 3.80 | 1.76 | Nil | Nil | .04 | Tr | Nil | Nil |
| 41-9/16 | " | 2 $\frac{1}{2}$ " | .25 | .22 | .06 | .020 | .008 | 3.76 | 1.83 | Nil | Nil | .055 | Tr | Nil | Nil |
| 441 | " | 2 $\frac{1}{2}$ " | .26 | .21 | .06 | .020 | .007 | 3.78 | 1.78 | Nil | Nil | .06 | Tr | Nil | Nil |

TABLE II

Results of Brinell Hardness Survey Conducted on 2 $\frac{1}{2}$ " Thick

Rolled Homogeneous Armor Plates

| <u>Plate No.</u> | <u>Surface Hardness</u> | | <u>Cross Section Hardness</u> | |
|----------------------|-------------------------|----------------|-------------------------------|----------------|
| | <u>Range</u> | <u>Average</u> | <u>Range</u> | <u>Average</u> |
| 11A | 255 | 255 | 248-255 | 253 |
| 21A | 255-262 | 261 | 255-269 | 262 |
| 21B | 262-269 | 263 | 255-262 | 258 |
| 21C | 255-262 | 260 | 255-262 | 258 |
| 21D | 262-269 | 267 | 262-269 | 263 |
| 31A | 255-262 | 258 | 248-255 | 253 |
| 31B | 255-262 | 257 | 248-262 | 255 |
| 41A | 248-255 | 251 | 241-255 | 247 |
| 41B | 248-255 | 251 | 248-255 | 251 |
| 41C | 248-262 | 257 | 241-255 | 250 |
| 41D | 248-255 | 253 | 241-255 | 249 |
| 51B | 255-269 | 264 | 255-269 | 259 |

TABLE III

Results of Brinell Hardness Survey Conducted on 2 $\frac{1}{2}$ " Thick Rolled

Face Hardened Armor Plates

| Plate No. | Face | | | | Cross Section of Core | | | |
|--------------|---------|------|---------|------|-----------------------|------|---------|------|
| | Center | | Edge | | Center | | Edge | |
| | Range | Ave. | Range | Ave. | Range | Ave. | Range | Ave. |
| 41 1/16 | 601-627 | 607 | 653 | 653 | 223-229 | 226 | 207-229 | 212 |
| 41 1/8 | 601 | 601 | 555-601 | 570 | 217-223 | 220 | 217 | 217 |
| 41 3/16 | 601 | 601 | 555-578 | 563 | 223-229 | 225 | 217-223 | 218 |
| 41 1/4 | 627 | 627 | 534-555 | 549 | 241-248 | 243 | 223-229 | 226 |
| 41 5/16 | 495-555 | 518 | 627-653 | 644 | 229-235 | 231 | 217-229 | 223 |
| 41 3/8 | --- | --- | 534-601 | 563 | --- | --- | 217 | 217 |
| 41 7/16 | 601 | 601 | 555-601 | 584 | 223-255 | 233 | 207-212 | 211 |
| 41 1/2 | 653 | 653 | 653 | 653 | 223-235 | 231 | 217-223 | 221 |
| 41 9/16 | 555-578 | 560 | 627-682 | 654 | 212-229 | 219 | 223-229 | 225 |
| 41 5/8 | 578 | 578 | 601-653 | 627 | 212-229 | 216 | 212-217 | 215 |
| 41 11/16 | 444-477 | 465 | 627 | 627 | 241 | 241 | 212-217 | 215 |
| 41 3/4 | --- | --- | 601-627 | 618 | --- | --- | 212-223 | 228 |
| 41 13/16 | --- | --- | 682-712 | 690 | --- | --- | 212-223 | 216 |
| 41 7/8 | 514-534 | 522 | 653-712 | 682 | 229-235 | 233 | 207-212 | 208 |
| 41 15/16 | 601-627 | 617 | 627-653 | 644 | 212-255 | 230 | 207-223 | 211 |
| 441 | --- | --- | 514-601 | 572 | --- | --- | 207-217 | 212 |

TABLE IV

Summary of the Results of Tests Conducted on 2 1/2" Thick Rolled Homogeneous A

| Plate No. | Fracture Tests | | Ave. Cross Sectional BHN | Direction of Rolling | *V-Notch Charpy |
|-----------|-----------------------------|---------------|--------------------------|----------------------------|-----------------|
| | Fibre | Steel Quality | | | Pt./Lbs. |
| 11A | **F | B | 253 | Longitudinal Transverse | 72.8 57.7 |
| 21A | F | B | 262 | Longitudinal Transverse | 71.3 54.1 |
| 21B | F | C | 258 | --- | --- |
| 21C | F | C | 258 | --- | --- |
| 21D | F | D | 263 | --- | --- |
| 31A | F | D | 253 | Longitudinal Transverse | 74.7 61.4 |
| 31B | F | C | 255 | --- | --- |
| 41A | F | D | 247 | --- | --- |
| 41B | F | B | 251 | --- | --- |
| 41C | F | D | 250 | Longitudinal Transverse | 80.6 62.3 |
| 41D | F | D | 249 | --- | --- |
| 51B | F-Tr. of crystallinity C | | 259 | --- | --- |

**F-- Fibrous

* All V-notch Charpy bars were cut from the midwall of the plates.

Midwall indicates a position halfway between the center and surface of the plate.

TABLE IV

Conducted on 2 1/2" Thick Rolled Homogeneous Armor Plates

| | | *V-Notch Charoy Impact Tests | | | |
|-----------|----------------------|------------------------------|--------------------|----------|--------------------|
| | | +70°F | | -40°F | |
| Panel No. | Direction of Rolling | Ft./Lbs. | Fracture | Ft./Lbs. | Fracture |
| | Longitudinal | 72.8 | F | 71.3 | F |
| | Transverse | 57.7 | F | 55.0 | F |
| | Longitudinal | 71.3 | F | 69.8 | F |
| | Transverse | 54.1 | F | 51.9 | F |
| | --- | --- | --- | --- | --- |
| | --- | --- | --- | --- | --- |
| | --- | --- | --- | --- | --- |
| | Longitudinal | 74.7 | F - Tr. woodiness | 71.3 | F |
| | Transverse | 61.4 | F | 56.4 | F |
| | --- | --- | --- | --- | --- |
| | --- | --- | --- | --- | --- |
| | --- | --- | --- | --- | --- |
| | Longitudinal | 80.6 | F - some woodiness | 71.3 | F - some woodiness |
| | Transverse | 62.3 | F | 59.6 | F |
| | --- | --- | --- | --- | --- |
| | --- | --- | --- | --- | --- |

if the plates.
 Inter and surface of the plate.

2

| Sample No. | *Case Depth to | | Fracture Tests | | | | *Hardness Survey | | |
|------------|-------------------|----------|----------------|-------|---------------|---------------------|--------------------------------|--------------------|-----|
| | Rc 40 | Rc 50 | *Fibre | | Steel Quality | | Maximum Rc Hardness of Case | Average Har BHN | |
| | | | Core | Case | Edge | Center | | | |
| 41 1/16 | .74" | .40" | Fibrous | Silky | B | moderate woody | B | 54.5 | 226 |
| 41 1/8 | .70" | .38" | Fibrous | Silky | B | moderate woody | B | 56.5 | 220 |
| 41 3/16 | .58" | .36" | Fibrous | Silky | B | moderate woody | B | 55.0 | 225 |
| 41 1/4 | .60" | .36" | Fibrous | Silky | B | moderate woody | B | 57.5 | 243 |
| 41 5/16 | .58" | .09" | Fibrous | Silky | B | pronounced woody | D | 50.5 | 231 |
| 41 3/8 | -- | -- | -- | -- | B | pronounced woody | - | -- | - |
| 41 7/16 | .68" | .30" | Fibrous | Silky | B | moderate woody | B | 55.5 | 233 |
| 41 1/2 | .80" | .26" | Fibrous | Silky | B | moderate woody | B | 56.5 | 231 |
| 41 9/16 | .58" | .16" | Fibrous | Silky | C | pronounced woody | C | 53.5 | 219 |
| 41 5/8 | .63" | .36" | Fibrous | Silky | B | pronounced woody | B | 54.5 | 216 |
| 41 11/16 | .80" | | Fibrous | Silky | B | pronounced woody | B | 50.0 | 241 |
| 41 3/4 | -- | -- | -- | -- | B | pronounced woody | - | -- | - |
| 41 13/16 | -- | -- | -- | -- | C | pronounced woody | - | -- | - |
| 41 7/8 | .65" | .26" | Fibrous | Silky | B | pronounced woody | B | 51.5 | 233 |
| 41 15/16 | .64" | .40" | Fibrous | Silky | C | pronounced woody | C | 56.0 | 230 |
| 441 | -- | -- | -- | -- | B | moderate woody | - | -- | - |

NOTE: V-notch Charpy bars were taken from midwall section of plates. Midwall in face harden

*Samples taken from central areas of ballistic test plate.
 **Samples taken from areas near edge of ballistic test plate.

Summary of Results of Tests Conducted on 1/2" x 1/2" x 1/2" Plates

| By enter | *Hardness Survey | | | Direction of Rolling | +70°F. Ft/Lbs. | Y-Notch Char Fracture |
|-------------|--------------------------------|----------------|----------------------------------|--|--------------------------------|--|
| | Maximum Rc Hardness of Case | Average BHN | Hardness of Core Rc Converted | | | |
| B | 54.5 | 226 | 19 | | | |
| B | 56.5 | 220 | 18 | | | |
| B | 55.0 | 225 | 19 | | | |
| B | 57.5 | 243 | 23 | | | |
| D | 50.5 | 231 | 21 | | | |
| - | -- | - | -- | | | |
| B | 55.5 | 233 | 21.5 | *Longitudinal *Transverse **Longitudinal **Transverse | 106.2 67.5 103.6 65.6 | Fibrous Fibrous Fibrous Fibrous |
| B | 56.5 | 231 | 21 | | | |
| C | 53.5 | 219 | 17.5 | *Longitudinal *Transverse **Longitudinal **Transverse | 131.3 46.6 98.5 67.0 | Fibrous (wo Fibrous (break of lamina Fibrous (break of lamina Fibrous (wo |
| B | 54.5 | 216 | 17.5 | | | |
| B | 50.0 | 241 | 23 | | | |
| - | -- | - | -- | | | |
| - | -- | - | -- | | | |
| B | 51.5 | 233 | 21.5 | | | |
| C | 56.0 | 230 | 20.5 | **Longitudinal **Transverse | 127.0 74.2 | Fibrous (wo Fibrous (break of lamina |
| Y- | -- | - | -- | **Longitudinal **Transverse | 112.2 | Fibrous (tr of wo Fibrous |

Location of plates. Midwall in face hardened plate refers to a position halfway between the center of test plate.
to test plate.

V-Notch Charpy Impact Tests

| Direction of Rolling | +70°F. | | -40°F. | |
|-------------------------|---------|---|---------|---|
| | Ft/Lbs. | Fracture | Ft/Lbs. | Fracture |
| Longitudinal | 106.2 | Fibrous | 101.6 | Fibrous |
| Transverse | 67.5 | Fibrous | 65.6 | Fibrous |
| Longitudinal | 103.6 | Fibrous | 113.7 | Fibrous |
| Transverse | 65.6 | Fibrous | 67.5 | Fibrous (woody) |
| Longitudinal | 131.3 | Fibrous (woody) | 90.3 | Fibrous (woody) |
| Transverse | 46.6 | Fibrous (broken ends of laminations) | 47.5 | Fibrous (broken ends of laminations) |
| Longitudinal | 98.5 | Fibrous (broken ends of laminations) | 98.5 | Fibrous (broken ends of laminations) |
| Transverse | 67.0 | Fibrous (woody) | 67.5 | Fibrous (woody) |
| Longitudinal | 127.0 | Fibrous (woody) | 99.5 | Fibrous (woody) |
| Transverse | 74.2 | Fibrous (broken ends of laminations) | 65.6 | Fibrous (broken ends of laminations) |
| Longitudinal | 112.2 | Fibrous (tr of woodiness) | 112.2 | Fibrous |
| Transverse | | Fibrous | 77.6 | Fibrous |

to a position halfway between the center and rear face.

3

Table V

TABLE VI

Tensile Tests

Test Bar .357" Diameter

| Plate No. | Type | Location of Test Specimen | Direction | I.S. Lbs./Sq.In. | T.S. Lbs./Sq.In. |
|-----------|---------------|---------------------------|----------------|---------------------|---------------------|
| 11A | Homogeneous | Midwall | Longitudinal | 105,500 | 124,000 |
| 11A | Homogeneous | Midwall | Transverse | 106,500 | 125,500 |
| 21A | Homogeneous | Midwall | Longitudinal | 110,000 | 128,000 |
| 21A | Homogeneous | Midwall | Transverse | 109,500 | 130,500 |
| 31A | Homogeneous | Midwall | Longitudinal | 107,500 | 125,500 |
| 31A | Homogeneous | Midwall | Transverse | 107,500 | 125,000 |
| 41C | Homogeneous | Midwall | Longitudinal | 103,750 | 123,000 |
| 41C | Homogeneous | Midwall | Transverse | 103,120 | 122,500 |
| 41 7/16 | Face Hardened | Midwall | *Longitudinal | 100,000 | 135,000 |
| 41 7/16 | Face Hardened | Midwall | *Transverse | 114,000 | 157,000 |
| 41 7/16 | Face Hardened | Midwall | **Longitudinal | 80,000 | 105,000 |
| 41 7/16 | Face Hardened | Midwall | **Transverse | 82,500 | 106,000 |
| 41 9/16 | Face Hardened | Midwall | *Longitudinal | 93,500 | 131,500 |
| 41 9/16 | Face Hardened | Midwall | *Transverse | 87,500 | 125,000 |
| 41 9/16 | Face Hardened | Midwall | **Longitudinal | 80,000 | 107,900 |
| 41 9/16 | Face Hardened | Midwall | **Transverse | 84,500 | 108,800 |
| 41 15/16 | Face Hardened | Midwall | **Longitudinal | 77,500 | 102,000 |
| 41 15/16 | Face Hardened | Midwall | **Transverse | 80,500 | 100,900 |
| 441 | Face Hardened | Midwall | **Longitudinal | 80,000 | 104,000 |
| 441 | Face Hardened | Midwall | **Transverse | 83,750 | 106,000 |

NOTE: Midwall indicates a position halfway between the center and surface of the plate.
 Midwall in face hardened plate refers to a position halfway between the center and surface of the plate.
 *Samples taken from central areas of ballistic test plate.
 **Samples taken from areas near edge of ballistic test plate.

TABLE VI

Tensile Tests

Test Bar .357" Diameter

| Location of specimen | Direction | Y.S. Lbs./Sq.In. | T.S. Lbs./Sq.In. | Elongation % | Reduction of Area R.A. % | Average Cross-Sectional BHN | |
|----------------------|----------------|---------------------|---------------------|-----------------|-----------------------------|--|----------------------------|
| | | | | | | Near Edge of Plate | Near Central Area of Plate |
| Wall | Longitudinal | 105,500 | 124,000 | 22.1 | 64.4 | 253 | |
| Wall | Transverse | 106,500 | 125,500 | 20.0 | 58.9 | | |
| Wall | Longitudinal | 110,000 | 128,000 | 20.7 | 63.7 | 262 | |
| Wall | Transverse | 109,500 | 130,500 | 20.0 | 38.9 | | |
| Wall | Longitudinal | 107,500 | 125,500 | 20.7 | 62.0 | 258 | |
| Wall | Transverse | 107,500 | 125,000 | 20.0 | 59.6 | | |
| Wall | Longitudinal | 103,750 | 123,000 | 21.4 | 63.7 | 250 | |
| Wall | Transverse | 103,120 | 122,500 | 20.7 | 58.9 | | |
| | | | | | | Average Cross Section of Core - BHN | |
| | | | | | | Near Edge of Plate | Near Central Area of Plate |
| Wall | *Longitudinal | 100,000 | 135,000 | 17.9 | 56.3 | 233 | |
| Wall | *Transverse | 114,000 | 157,000 | 12.9 | 38.9 | | |
| Wall | **Longitudinal | 80,000 | 105,000 | 26.4 | 71.6 | 211 | |
| Wall | **Transverse | 82,500 | 106,000 | 25.0 | 66.0 | | |
| Wall | *Longitudinal | 93,500 | 131,500 | 17.9 | 55.9 | 219 | |
| Wall | *Transverse | 87,500 | 125,000 | 18.6 | 53.3 | | |
| Wall | **Longitudinal | 80,000 | 107,900 | 25.0 | 70.7 | 225 | |
| Wall | **Transverse | 84,500 | 108,800 | 23.6 | 61.3 | | |
| Wall | **Longitudinal | 77,500 | 102,000 | 25.0 | 72.5 | 211 | |
| Wall | **Transverse | 80,500 | 100,900 | 23.6 | 59.9 | | |
| Wall | **Longitudinal | 80,000 | 104,000 | 26.4 | 71.6 | 212 | |
| Wall | **Transverse | 83,750 | 106,000 | 25.0 | 63.4 | | |

Position halfway between the center and surface of the plate.

*Plate refers to a position halfway between the center and rear face.

**Areas of ballistic test plate.

near edge of ballistic test plate.

2

2 1/2" FACE HARDENED ARMOR
 MADE BY CARNEGIE-ILLINOIS STEEL CORPORATION
 ROCKWELL "C" HARDNESS SURVEYS ACROSS THE CARBURIZED CASE

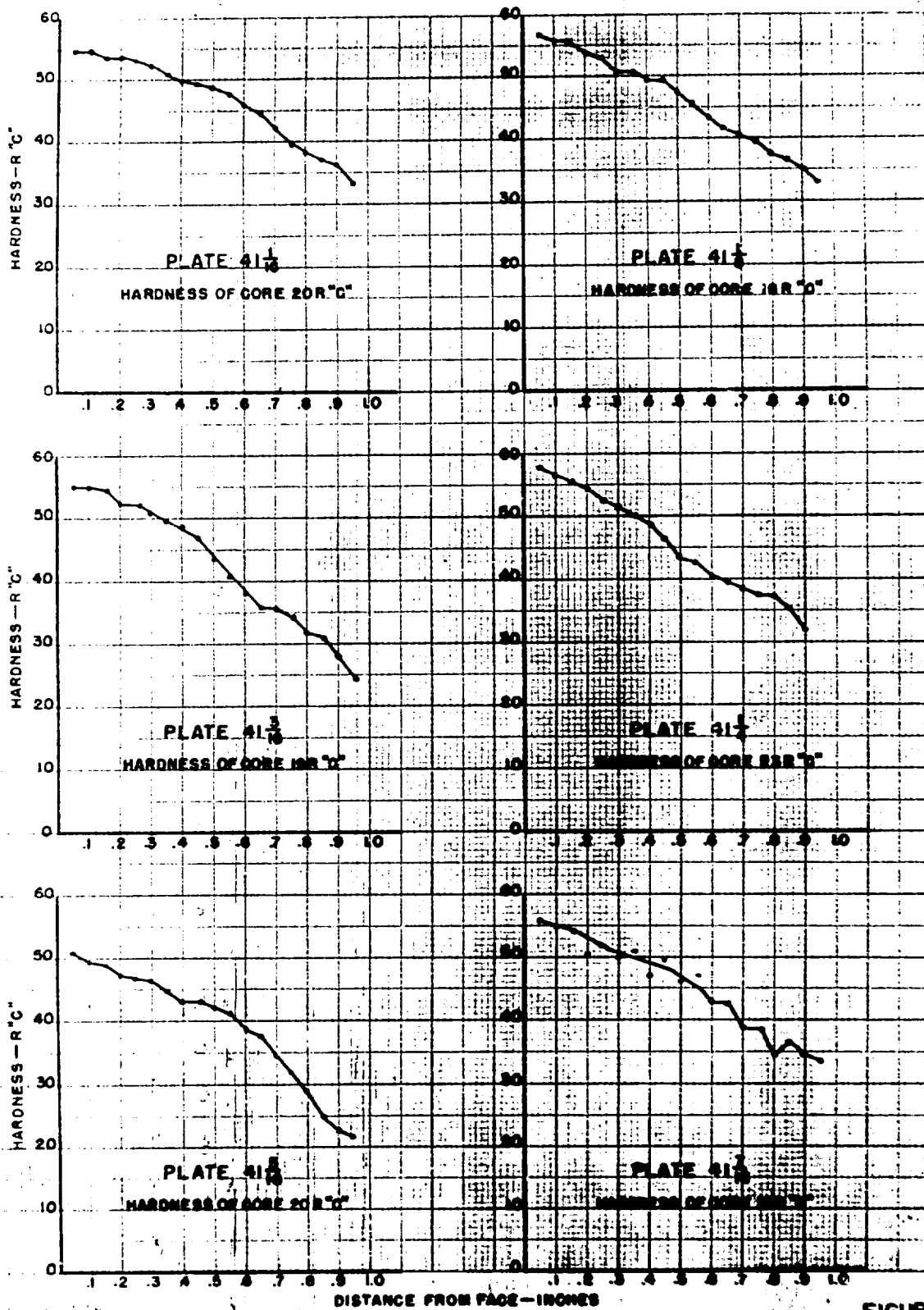


FIGURE 1

2 1/2" FACE HARDENED ARMOR
 MADE BY CARNEGIE-ILLINOIS STEEL CORPORATION
 ROCKWELL "C" HARDNESS SURVEYS ACROSS THE CARBURIZED CASE

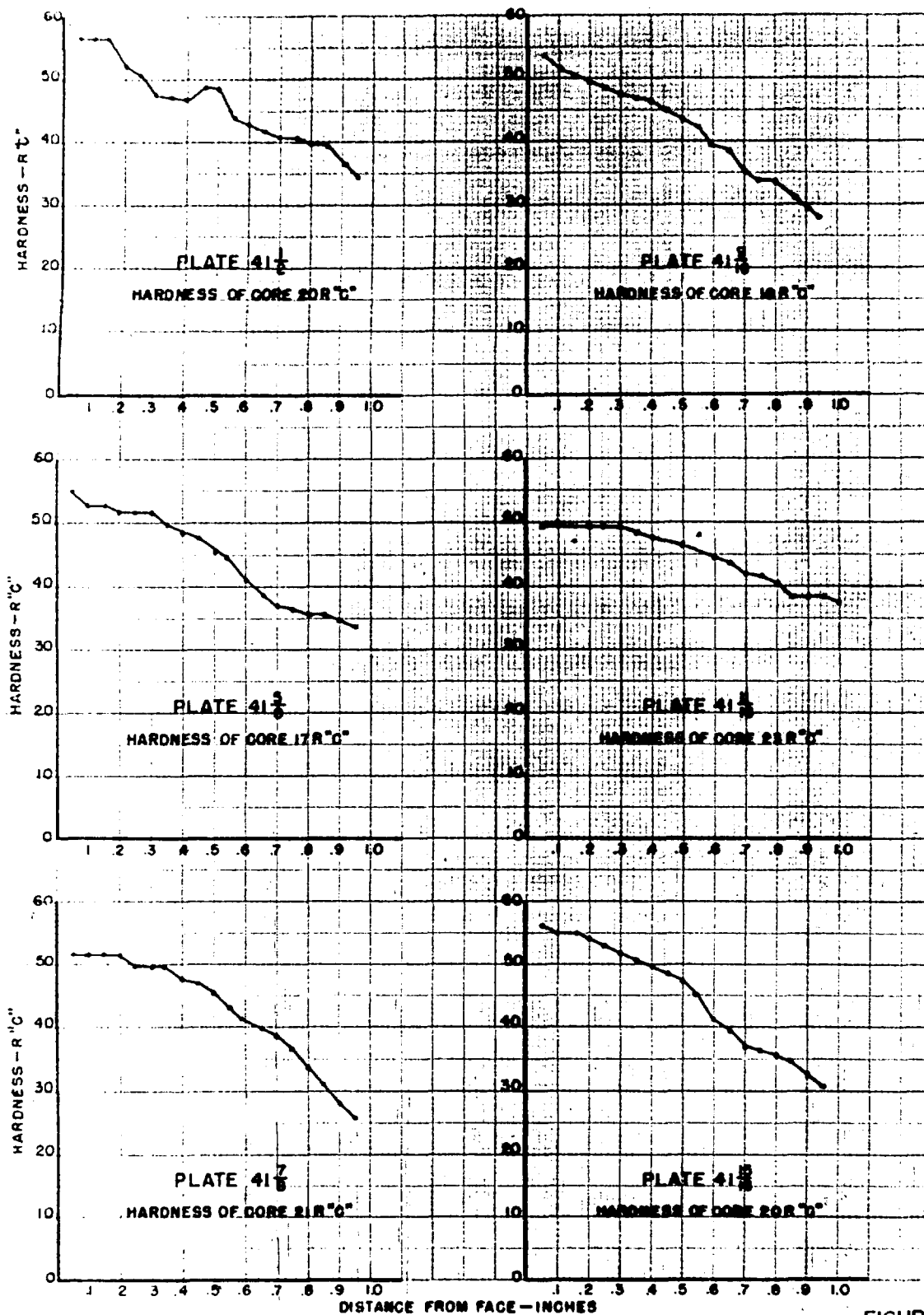
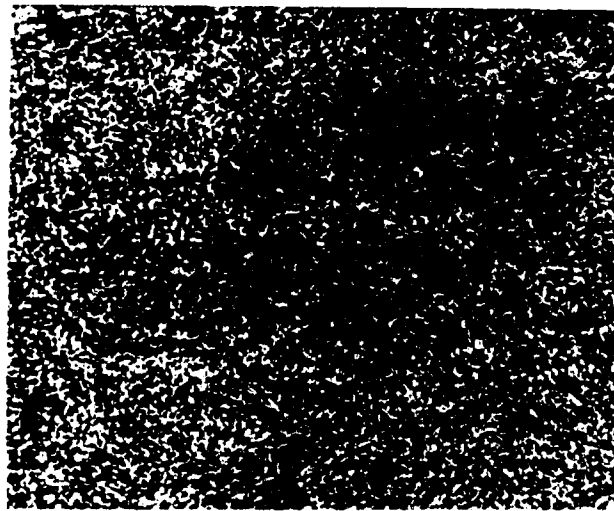


FIGURE 2

Microstructure of 2 $\frac{1}{2}$ " Thick Rolled Homogeneous
Armor Plates



X1000 11A Picral
Tempered martensite.

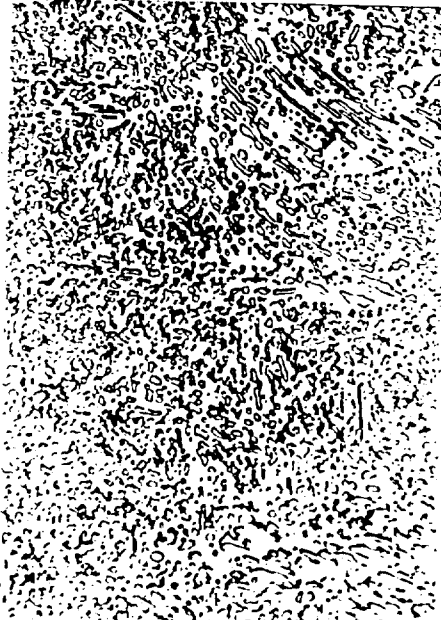


X1000 31A Picral
Tempered martensite.

FIGURE 3

Microstructure of 2 1/2" Thick Rolled Face Hardened Armor Plates

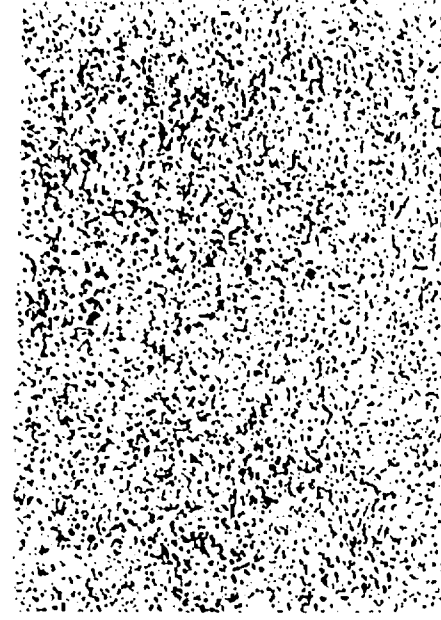
Plate 41 7/16



Outer case - Fine carbide plates in fine martensitic matrix .075" from case face.

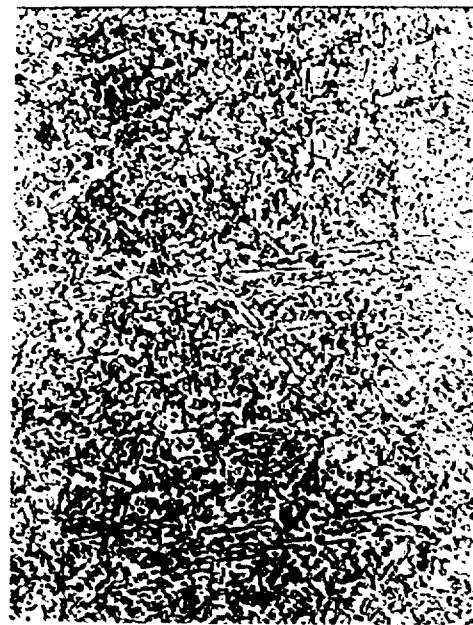


Inner case - Small globular carbides in fine martensitic matrix 0.25" from case face.



Uniform distribution of fine carbides in the core (dark areas similar to tempered bainite).

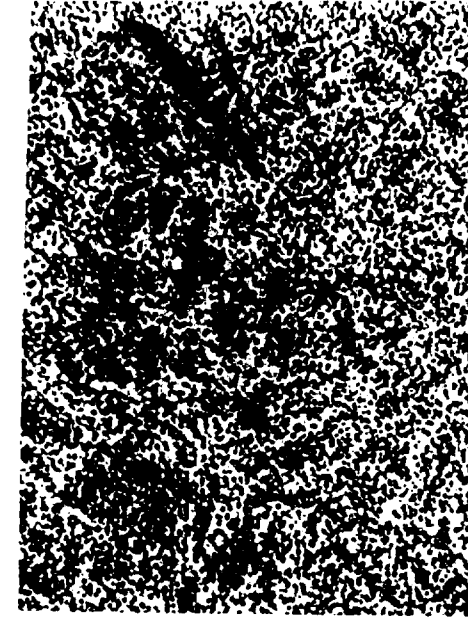
Plate 41 9/16



Outer case - Fine carbide plates (Widmanstatten pattern) in a martensitic matrix .075" from case face.



Inner case - Globular carbides in fine martensitic matrix 0.25" from case face.



Uniform distribution of fine carbides in the core (dark areas similar to tempered bainite).

FIGURE 2

All photomicrographs X1000 - Pical Etch