WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/593

Metallurgical Examination of Face Hardened Armor Plate

BY

E. L. REED
Research Metallurgist

DATE 29 February 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

REPRODUCTION QUALITY NOTICE

This document is the best quality available. The copy furnished to DTIC contained pages that may have the following quality problems:

- Pages smaller or larger than normal.
- Pages with background color or light colored printing.
- Pages with small type or poor printing; and or
- Pages with continuous tone material or color photographs.

Due to various output media available these conditions may or may not cause poor legibility in the microfiche or hardcopy output you receive.

☐ If this block is checked, the copy furnished to DTIC contained pages with color printing, that when reproduced in Black and White, may change detail of the original copy.

[redacted]

Watertown Arsenal Laboratory

Memorandum Report No. WAL 710/593

Final Report on Problem B-4.22

29 February 1944

Metallurgical Examination of Face Hardened Armor Plate

ABSTRACT

This investigation indicates that the fibre fracture test applied to face hardened armor will probably enable prediction as to whether or not the plate will resist cracking under projectile impact. Furthermore, the steel soundness may be ascertained and the approximate case depth can be determined. The total depth of the carburized case as revealed by the fracture test coincides fairly well with the depth of the case as determined by macroscopic and microscopic examination and by the analysis of the carbon distribution in the case. The Vickers Brinell hardness survey indicated the depth of the effective case.

The three Disston plates had poor metallurgical properties, namely:- (a) inadequate hardenability of the base steel, resulting in a crystalline fracture when subjected to the fibre test and (b) a shallow case of insufficient hardness with a carbon content in the outer layers varying from 0.84% to 1.07%; (c) variations of fine and coarse tempered martensitic structure of the case and pronounced ferrite segregations and some small carbides in lamellar configuration associated with tempered martensite in the core. The metallurgical properties of the Carnegie-Illinois plate were satisfactory, namely:- (a) adequate hardenability of the base steel, resulting in a fibrous fracture under the fibre test, (b) a deep case of high hardness containing 1.19-1.31% carbon in the outer layers which decreased gradually from the case to core, (c) a fairly uniform distribution of hypereutectoid carbides in a fine martensitic matrix of the case and a fairly uniform structure of the core consisting of tempered martensite, traces of ferrite and some high temperature transformation products in the rear face of the plate.

The steel soundness of the Disston plates was satisfactory as determined by metallurgical tests. Some metallic banding associated with occasional nonmetallic inclusions was present in the Carnegie-Illinois plate but this was not revealed in the fracture test for steel quality.

1. As requested by The Proving Center, Aberdeen,[1] metallurgical examination has been completed on four (4) samples of face hardened plate varying in thickness from 2"-2-1/2" as itemized below: -

a. Sample No. 1 - 2" Thick Face Hardened Disston Plate No. 1 Ht. D-3574 FR-A7764

b. Sample No. 2 - 2½" Thick Face Hardened Disston Plate No. 427 Ht. 3426

c. Sample No. 3 - 2½" Thick Face Hardened Disston Plate No. 3 Ht. 4599 FR-A10721

d. Sample No. 4 - 2½" Thick Face Hardened Carnegie-Illinois Plate No. JJ999

The purpose of this investigation was to obtain comparative metallurgical data on 2½" thick face hardened armor which might be of value in the writing of specifications for the acceptance of face hardened armor plate for the testing of armor piercing projectiles.

2. Metallurgical examination consisted of the following tests:

a. Chemical analysis of the core and determination of the carbon distribution in carburized case.

b. Fibre fracture test.

c. Fracture test for steel quality.

d. Brinell hardness tests on face and back.

e. Vickers Brinell hardness surveys.

f. Macroscopic examination.

g. Microscopic examination.

h. Summary of measurements of depth of case.

i. Jominy hardenability tests.

[1] A.P.G. 470.5/3076 - Wtn 470.5/7384 dated 23 November 1943.

3. The results of the above tests in detail are presented below:

a. Chemical Analyses

(1) Chemical Analyses of Steel Base

Chemical analyses of the steel base of the carburized plates are given in Table I.

TABLE I

Chemical Analyses of Steel Base of Carburized Plates

Sample No.	Chemical Composition C	Mn	Si	S	P	Ni	Cr	Mo	Cu	B	Al	V
1-Disston-2" D-3754 FR-A7764	.21	.50	.23	.021	.020	3.55	.11	.27	.17	.001	.008	nil
2-Disston-2½" 427 3426	.22	.44	.26	.020	.018	3.46	.09	.25	.13	.0007	.009	nil
3-Disston-2½" 4599 FR-A10721	.13	.56	.24	.021	.017	4.92	.16	.31	.15	.0006	.009	nil
4-Carnegie-Illinois 2½" JJ999	.33	.16	.23	.039	.013	3.39	1.62	nil	.04	.0007	.01	trace

(2) Variation in the Carbon Content from the Outer Carburized Case to the Core

The variation in the carbon content from the outer carburized case to the core is presented in Table II and also is plotted in Figure 1.

TABLE II

Variation in Carbon Content from the Outer Carburized Case to Core

Determination of % Carbon in Each Successive Layer - 1/16" Deep

Sample No.	Case				Core											
	1/16"	1/8"	3/16"	1/4"	5/16"	3/8"	7/16"	1/2"	9/16"	5/8"	11/16"	3/4"	13/16"	7/8"	15/16"	1"
1-Disston-2" D-3754 FR-A7764	.84	.59	.38	.26	.21	.21	.20	.20	.20	.20	.20	.20	.21	-	-	-
2-Disston-2½" 427 3426	1.07	.87	.66	.45	.30	.24	.23	.20	.20	.21	-	-	-	-	-	-
3-Disston-2½" 4599 FR-A10721	.86	.76	.53	.35	.21	.15	.13	.12	.12	.13	.13	-	-	-	-	-
	Case											Core				
4-Carnegie-2½" Illinois JJ999	1.19	1.31	1.26	1.16	1.06	.94	.83	.72	.62	.53	.51	.42	.38	.34	.34	.34

Core Continued

1-1/16"	1-1/8"	1-3/16"	1-1/4"	1-5/16"	1-3/8"	1-7/16"	1-1/2"	1-9/16"	1-5/8"	1-11/16"
.34	.34	.36	.35	.33	.32	.34	.33	.33	.33	.33

As noted in Table I, the chemical composition of samples, Nos. 1 and 2 submitted by Disston contain insufficient chromium and carbon for adequate hardenability in the sections involved. An addition of about 0.10% carbon and 1.50% chromium would undoubtedly have given these steels adequate hardenability. The Disston sample, No. 3, contains a too low carbon content for a satisfactory steel base of the thickness in question, although the nickel content was high. The fact that the Disston steels had low hardenability was clearly revealed by an examination of the fibre fracture tests. It was determined that all of these steels were decidedly crystalline. The chemical composition of the Carnegie-Illinois Sample No. 4 is ideal for this type of face hardened armor since it has sufficient hardenability and exhibited a fibrous fracture, indicating a proper response to heat treatment.

It was noted that the sulphur content of the Carnegie-Illinois plate No. 4 was relatively high, namely, .039%.

Since the Disston Sample No. 1 contains .001% boron, and only traces of this element were found in Disston Samples Nos. 2 and 3 and Carnegie Sample No. 4, it appears that plate No. 1 was the only plate of this series intentionally treated with boron.

A survey of the carbon distribution in the carburized cases of the Disston Plates Nos. 1, 2 and 3 indicates that depth of case in these plates varies from 1/4" to 5/16". These carburized cases are too shallow for plates of the thicknesses involved. The carbon content in the outer layers of these cases varied from 0.84-1.07% C.

It is believed that a carburized case with characteristics similar to that of the Carnegie Plate No. 4 would have been more effective than the shallow cases noted on the Disston plates, namely, a good diffusion of carbide in the hypereutectoid, eutectoid, and hypo-eutectoid zones, high hardness of case, and an effective depth of case of about 0.5" which showed evidence of a gradual decrease in hardness and carbon content. The carbon content in the outer layers of the Carnegie-Illinois plate was 1.19-1.31%. Furthermore, the carbon gradient in the heavy case noted in this plate was not as steep as that noted in the shallow cases of the Disston plates. The relatively high carbon content of this case extended into the face of the plate to a depth of about 0.5 of an inch. The total depth of this case was found to be 0.81".

b. Fracture Test for Fibre

Fracture test specimens, approximately 6" long, 2-3"x2½" were cut from plates, Nos. 2, 3, and 4 and nicked perpendicularly to the longitudinal axis and broken by a sharp blow. Sample No. 1 was too small to be given the fibre test. The results of the fibre tests are given in Table III.

TABLE III

Results of Fibre Test

Sample No.	Fibre Test: Case	Area Back of Case	Core	Total Depth of Case Revealed by Fracture Test
1-Disston-2" D-3754 FR-A7764	Fine Crystalline 3/32" Deep	Dark Fibrous Band 7/32" Deep	Coarse Crystalline	5/16"
3-Disston-2½" 4599 FR-A10721	Medium Fine Crystalline	Coarse Crystalline	Coarse Crystalline	9/32"
4-Carnegie-Illinois-2½"	Fine Silky	Fibrous	Fibrous	3/4"

Note:- Sample No. 1 was a small broken fragment from the cracked test plate. The fracture of this sample was finely crystalline and the depth of case was not clearly observed in the fractured sample as received. It was estimated to be about 0.25" deep.

The results of the fibre test indicated that the base compositions of the Disston plates were not thoroughly quenched out resulting in crystalline fractures when given the fibre test. As noted in Table I, the alloy content of these Disston plates was not sufficient to promote adequate hardenability. The alloy content of the Carnegie-Illinois plate was sufficient with the medium percentage of carbon to result in adequate hardenability, thereby exhibiting a fibrous fracture when subjected to the fibre test. The fractures of the carburized cases of the Disston plates were fine and coarsely crystalline. The fracture of the carburized case of the Carnegie-Illinois plate was of a fine silky nature, especially in the outer layers. The total depth of the carburized case was readily revealed in the fibre fracture test, see the fracture of Disston Plate No. 2 in Figure 2. The light layer extending about 0.2" from the surface of the plate into the carburized case is really the effective part of the case, that is, the region containing tempered martensite and some carbides but no ferrite.

c. Fracture Test for Steel Quality

Fracture test specimens approximately 4-6" long and 2-3"x2-2-1/2" were cut from the longitudinal and transverse directions of plates, Nos. 2, 3 and 4 and nicked perpendicularly to the longitudinal axis and broken slowly under a press. Sample No. 1 was too small to be subjected to the fracture test for steel quality.

The results of these tests showed that the Carnegie-Illinois plate No. 4 had a "3" rating according to the standards given in Specification AXS-488 Revision 2, see Figure 2. Because of the fact that a crystalline fracture was obtained on the Disston plates, Nos. 2 and 3, it was impossible to determine the steel quality rating of these samples. The depth of case was readily detected in the fracture test for steel quality, see the fracture of the Carnegie-Illinois plate No. 4, Figure 2.

d. Brinell Hardness Tests - Face and Back of Plates

The Brinell hardness determinations made on the face and back of the plates are given in Table IV.

TABLE IV

Brinell Hardness Determinations

Sample No.	Face	Back
Disston - No. 1 - 2"	477-514	341-352
Disston - No. 2 - 2⅛"	415-415	255-277
Disston - No. 3 - 2⅛"	514-534	341-352
Carnegie - No. 4 - 2⅛"	653-682	207-217

Note:- 1/32" removed from face and 1/8" removed from back before Brinell hardness tests were made.

As noted in Table IV, the hardness values of the carburized cases of the Disston plates are relatively low as compared to the hardness of the case of the Carnegie-Illinois plate. This variation in hardness noted in the plates manufactured by the two companies is due to difference in the carbon content of the cases and also to differences in heat treating cycles. The Brinell hardness values of the cores of the Disston plates, Nos. 1 and 3 are fairly high for plate of this thickness. On the other hand, the hardness of the core of the Disston plate No. 2 and Carnegie plate No. 4 is more desirable.

e. Vickers Brinell Hardness Survey

The results of the Vickers Brinell hardness surveys are shown in Figure 3. Vickers Brinell hardness determinations were made every .01" apart on the carburized cases and every .02" apart on the core. As noted in Table V, the depth of the effective case, namely at 400 Vickers Brinell hardness as recommended by some of the manufacturers of face hardened plate, is recorded.

The three Disston plates have shallow cases as determined by this hardness survey and also by studies of carbon distribution in the case noted in Figure 1. The difference in hardness between the cases of the Disston plates and the Carnegie plate is also clearly indicated. A gradual decrease in hardness from the case to core is evident in the Carnegie plate. Furthermore, the hardness gradient in the core of the Carnegie plate,noted in Figure 1, is undoubtedly due to the method of quenching the face of the plate. The variations noted in the cores of the Disston plates were due to the presence of ferrite banding associated with tempered martensite.

f. Macroscopic Examination

The results of the macroscopic examination of the four plates are shown in Figure 4. The steel quality of the Disston plates is satisfactory. Some metallic banding which occasionally contained non-metallic inclusions was fairly well distributed throughout the cross section of the Carnegie plate. This metallic banding when not associated with long stringers of nonmetallics apparently does not adversely affect the steel quality to any great degree as revealed by the fracture test for steel soundness. The carburized cases are readily revealed by the macroetch and summarized in Table V. The total depth of the case of the Carnegie plate, namely .75", is not clearly revealed in Figure 4. The effective case of about .44" is readily shown for this plate.

g. Microscopic Examination

The results of the microscopic examination are shown in Figures 5 and 6. Photomicrographs are presented which illustrate the microstructures of the outer, middle and rear cases and also the typical structure of the core materials.

The case depths of each plate were determined on samples annealed in "neutra-pack" at 1500°F for 1 hour and slowly cooled in furnace, the results of which are tabulated in Table V.

The microstructure of the case of the Disston plate No. 1 consisted of fine tempered martensite while the core contained areas of massive ferrite and some small carbide in a lamellar configuration associated with tempered martensite.

Since the carbon content of the outer layers of the case were somewhat higher in Disston plate No. 2, some rounded hyper-eutectoid carbides were evident in this portion of the case. Very fine carbides and tempered martensite were present in the center and rear case while pronounced segregations of ferrite and small carbide in a lamellar configuration associated with tempered martensite were present in the core. A coarse tempered martensite was present in the case of Disston plate No. 3. The core consisted of tempered martensite associated with ferrite, small carbides an a lamellar configuration and grain boundary carbides. The outer case of Carnegie plate No. 4 contained a fairly uniform distribution of hyper-eutectoid carbides in a matrix of fine martensite. The center case contained small globular carbides in a fine martensitic matrix while the rear case showed the presence of fine carbides in a medium carbon martensite and also traces of ferrite. The core of this plate contained fine tempered martensite, some ferrite and fine carbide while high temperature transformation products were evident near the rear face of the plate.

A survey of the microstructures of the Disston plates indicates that these plates were given a single quench from above the critical range of the carburized case and subsequently tempered. The steel base of these compositions had insufficient hardenability and therefore when subjected to this heat treatment exhibits a crystalline fracture under the fibre test. These crystalline fractures were associated with a microstructure consisting of ferrite segregations some fine carbides in lamellar configuration and tempered martensite. Crystalline fractures and such poor microstructures are conducive to shock failures. In fact the Disston plates, Nos. 1 and 3 which had crystalline fractures when tested under the fibre test and core structures of ferrite, small carbide of lamellar configuration, and tempered martensite failed by shock, (reference A.P.G. Armor Test Report A7764 dated June 1943 and A.P.G. Test Reports A-10721 dated November 1943 respectively). Ballistic test data on the other plates were not available.

The microstructure of the Carnegie plate No. 4 is typical of a plate quenched from above the critical of the core, reheated to a temperature just above the critical of the case and spray quenched on the face. This would explain the high hardness of the face, the gradient hardness of the case and core and the presence of some high temperature transformation products in the rear face of the core as the result of this section of the plate cooling at slower rates. The presence of small amounts of ferrite in the core is probably due to the reheating of the plate just between the lower and upper critical of the core, while evidence of martensite in the core is the result of quenching from this intercritical temperature. A more uniform distribution of carbide in the core of the Carnegie plate is responsible for a fibrous fracture under the fibre test.

h. Summary of Measurements of Depth of Case

A summary of the measurements of case depths as determined by the various methods described herein is given in Table V.

TABLE V

Summary of Measurements of Case Depths

Sample No.	Fibre Fracture Test Measured to Nearest 1/32"	Carbon Distribution in Case Measured to Nearest 1/16"	Vickers Brinell Hardness Survey	Macroscopic Examination Measured to Nearest 1/32"	Microscopic Examination (Made on Annealed Samples) Hyper-Eutectoid	Eutectoid	Hypo-Eutectoid	Total Depth
Disston No. 1 - 2"*	—	1/4"-.25"	.17" at 400 VBH	3/16"-.19"	–	.12"	.09"	.21"
Disston No. 2 - 2½"	5/16"-.31"	5/16"-.31"	.16" at 400 VBH	5/16"-.31"	.20"	–	.10"	.30"
Disston No. 3 - 2½"	9/32"-.28"	5/16"-.31"	.23" at 400 VBH	9/32"-.28"	–	.20"	.09"	.29"
Carnegie Illinois-No. 4 - 2½"	3/4"-.75"	13/16"-.81"	.44" at 400 VBH	3/4"-.75"	.345"	.165"	.21"	.72"

*Insufficient sample to make fibre test. Depth of fracture noted on broken piece as received approximately .25".

For all practical purposes, the depth of fracture determined by the fracture test is satisfactory. These values agree fairly well with those determined by metallurgical analysis. Due to difficulty in determining the end of the hypo-eutectoid zone by hardness surveys, only the effective case was reported as determined at 400 Vickers Brinell hardness. The effective case which may be also designated as that portion of the case which terminates at the junction of the eutectoid and hypo-eutectoid zones agreed fairly closely in some instances with the effective case determined by the Vickers hardness survey.

3. Jominy Hardenability Tests of Steel Bars

The results of the end quench hardenability tests made on Jominy bars machined from the cores of each plate are given in Figure 7. As mentioned previously, it is believed that the Carnegie-Illinois plate was double quenched, first by heating above the critical of the core and quenched, followed by heating above the critical of the case and differentially quenched. The hardenability of the core of this plate was sufficient to warrant proper quench hardening on the first quench. A survey of the Jominy curves of the three Disston plates shows that these steels contain too low alloy content for adequate quench hardening on the first quench of a similar double heat treatment.

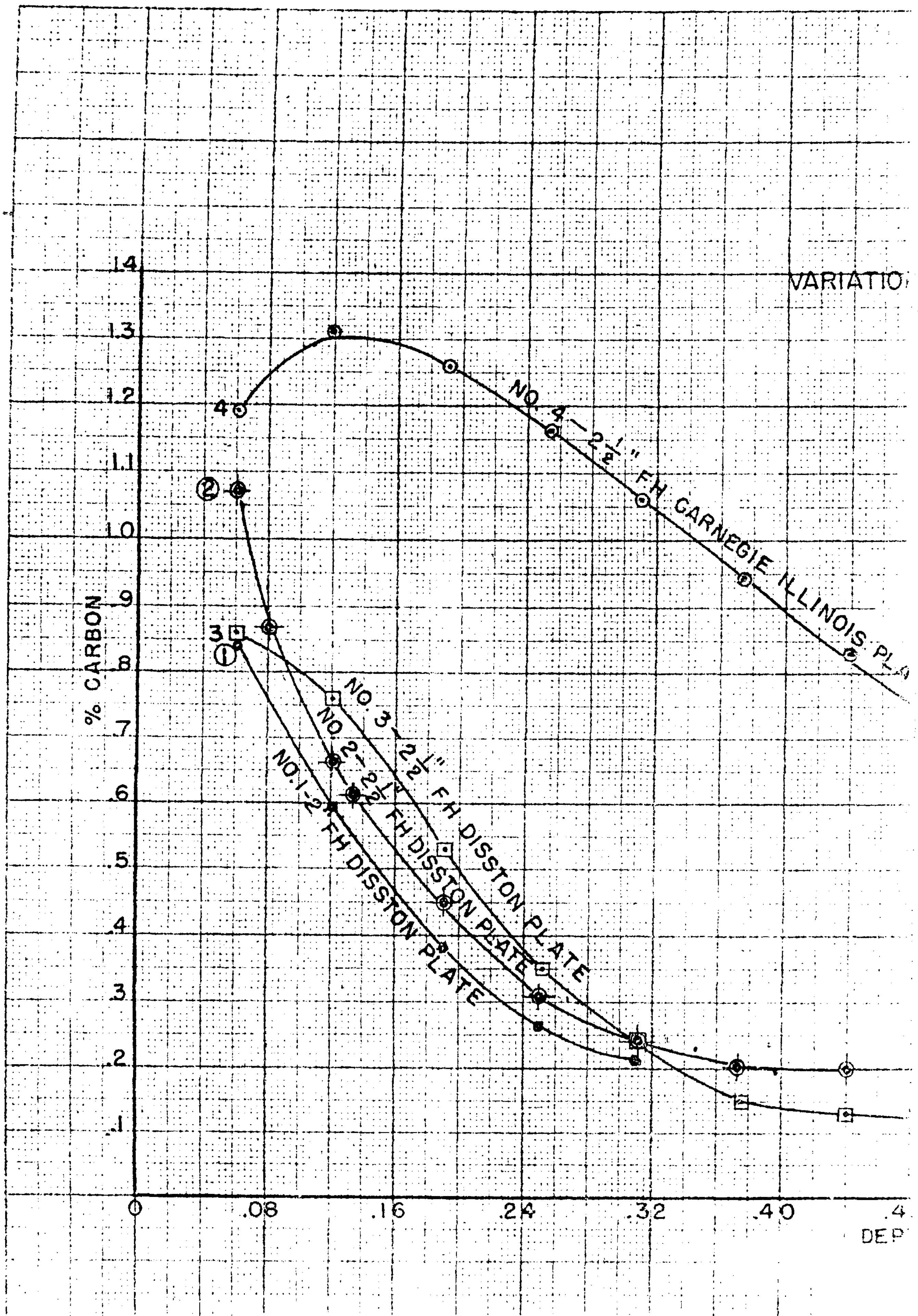
4. Metallurgical tests on the samples submitted indicate that the Disston plates had a shallow carburized case of relatively low hardness with insufficient alloy content in the core to properly quench harden. On the other hand, the carburized plate submitted by Carnegie possessed a deep case of high hardness and a core of adequate hardenability. The fracture test is satisfactory for revealing the case depth, response to heat treatment, and steel soundness of the plate.

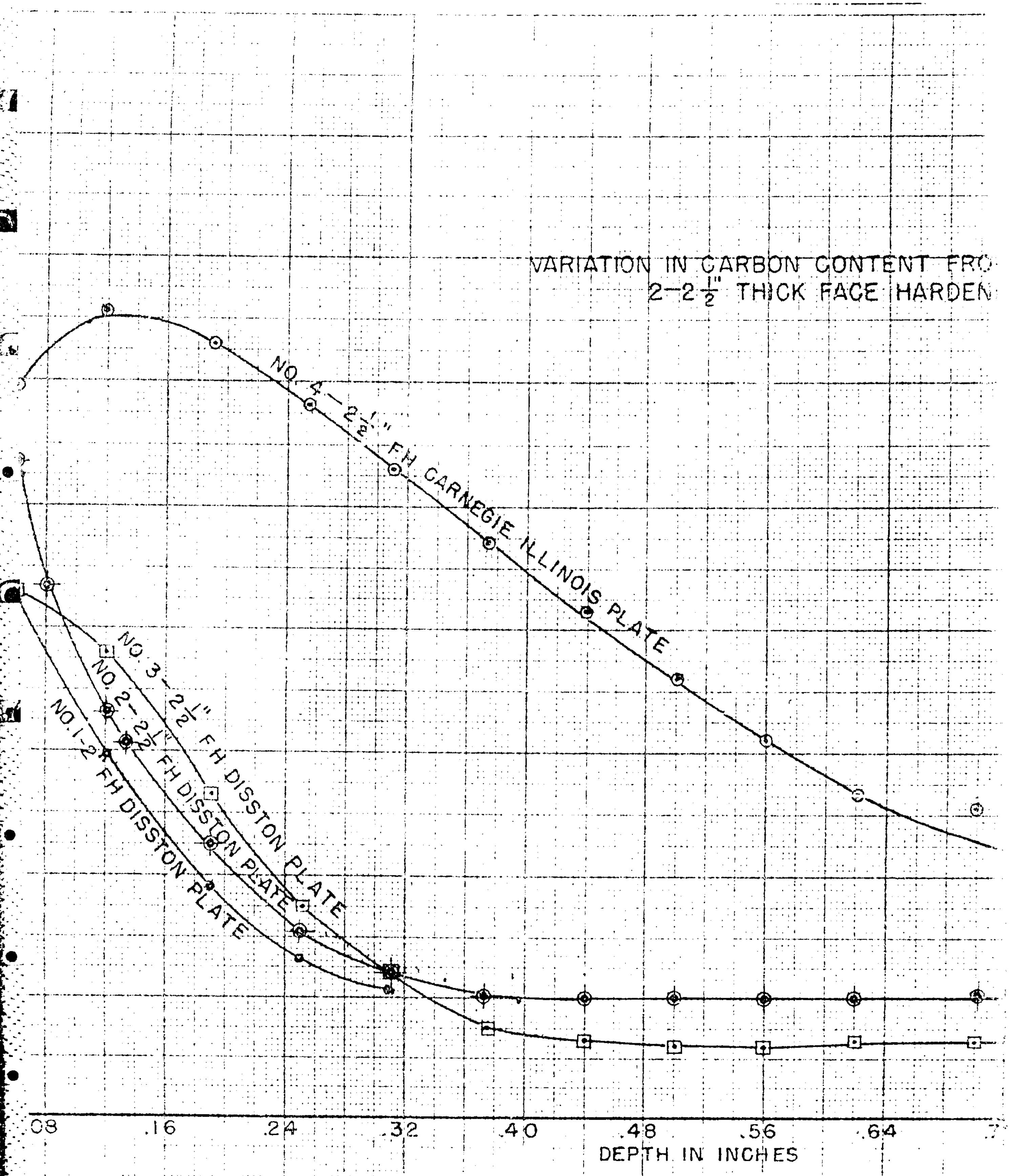
E. L. Reed

E. L. Reed
Research Metallurgist

APPROVED:

H. A. MATTHEWS
Major, Ord. Dept.


VARIATIO
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
% CARBON
0
.08
.16
.24
.32
.40
.4
DEP
4
2
3
1
NO. 4 – 2½" FH CARNEGIE ILLINOIS PLA
NO. 3 – 2½" FH DISSTON PLATE
NO. 2 – 2½ FH DISSTON PLATE
NO. 1 – 2" FH DISSTON PLATE


VARIATION IN CARBON CONTENT FRO
2-2½" THICK FACE HARDEN
NO. 4 - 2½" FH CARNEGIE ILLINOIS PLATE
NO. 3 - 2½" FH DISSTON PLATE
NO. 2 - 2½" FH DISSTON PLATE
NO. 1-2" FH DISSTON PLATE
.08
.16
.24
.32
.40
.48
.56
.64
.7
DEPTH IN INCHES

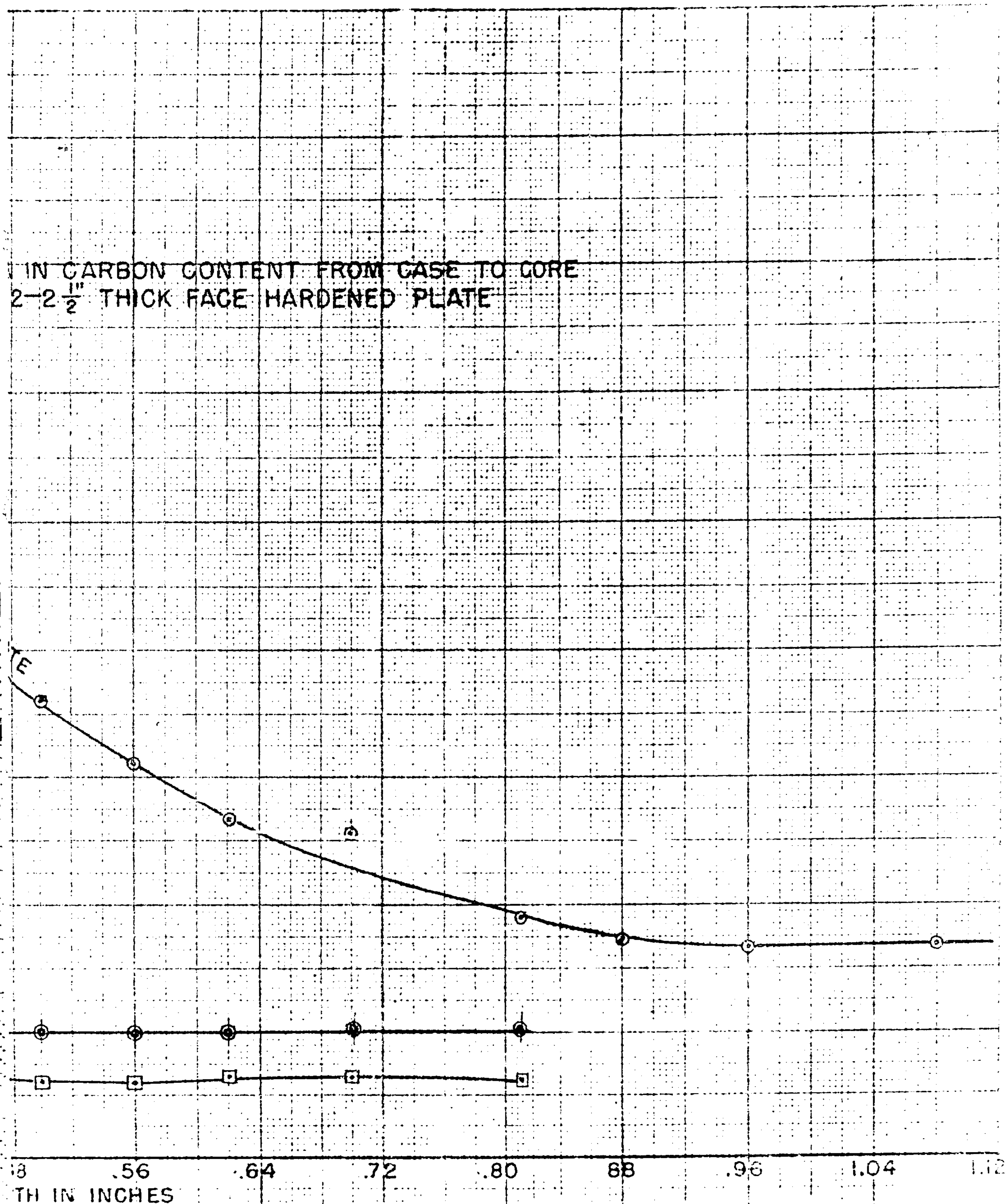
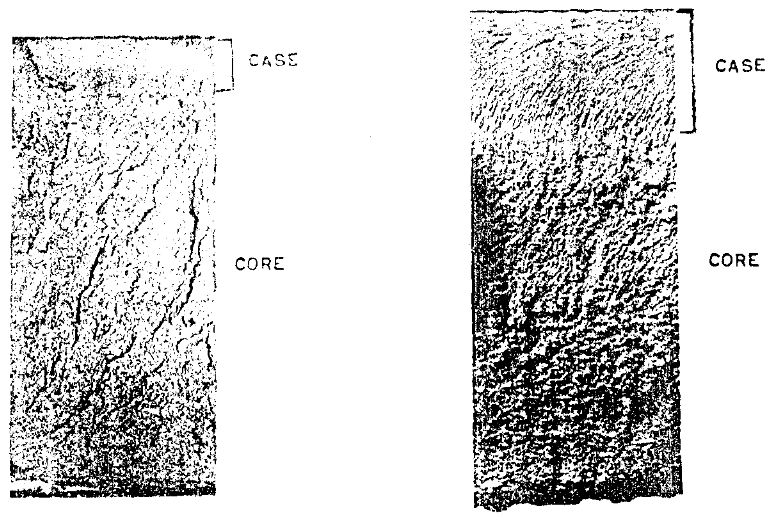

IN CARBON CONTENT FROM CASE TO CORE
2-2 1/2" THICK FACE HARDENED PLATE
E
.56
.64
.72
.80
.88
.96
1.04
TH IN INCHES

FIGURE I



SAMPLE # 2
FIBRE TEST

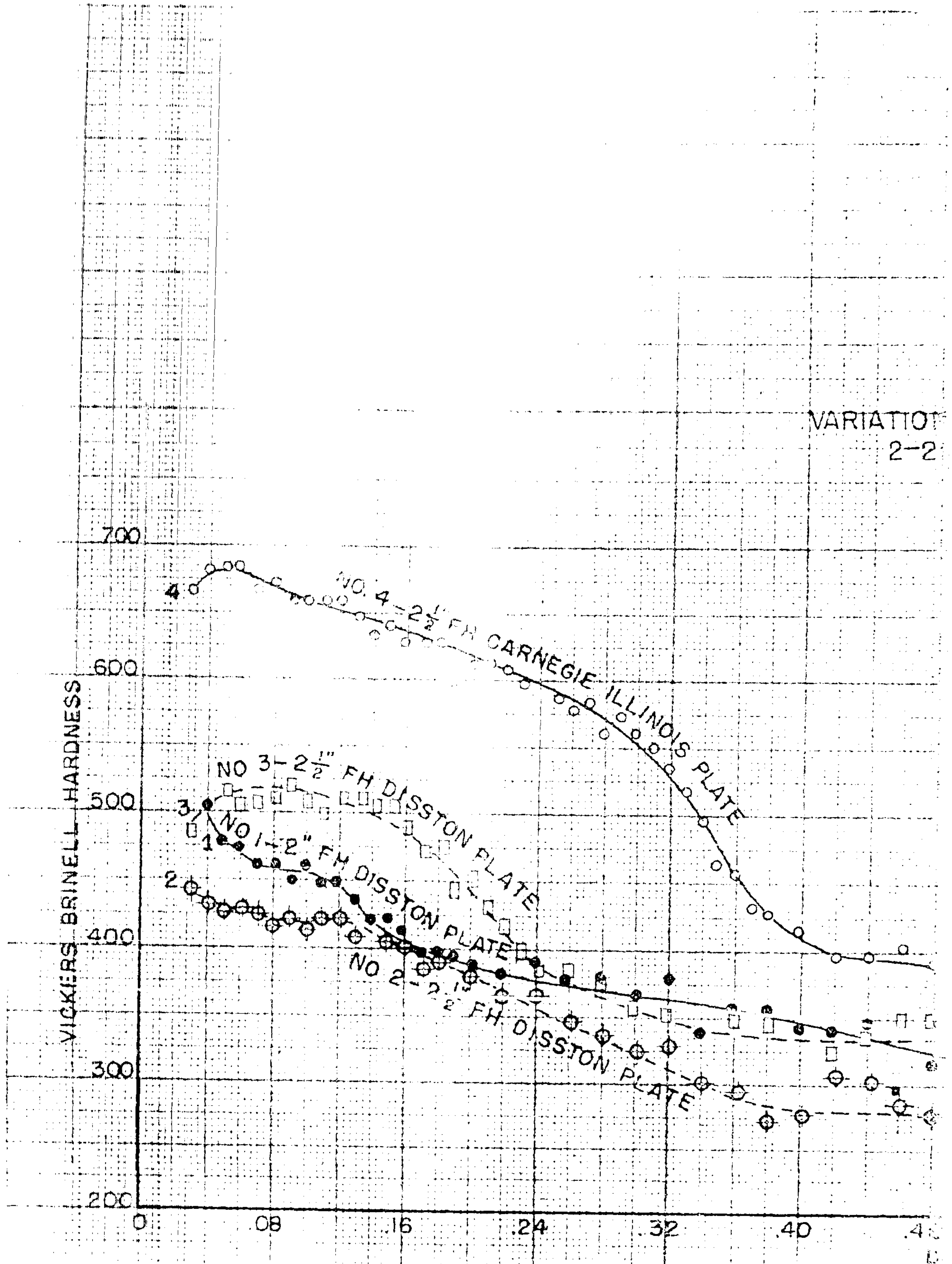
SAMPLE # 4
STEEL QUALITY TEST

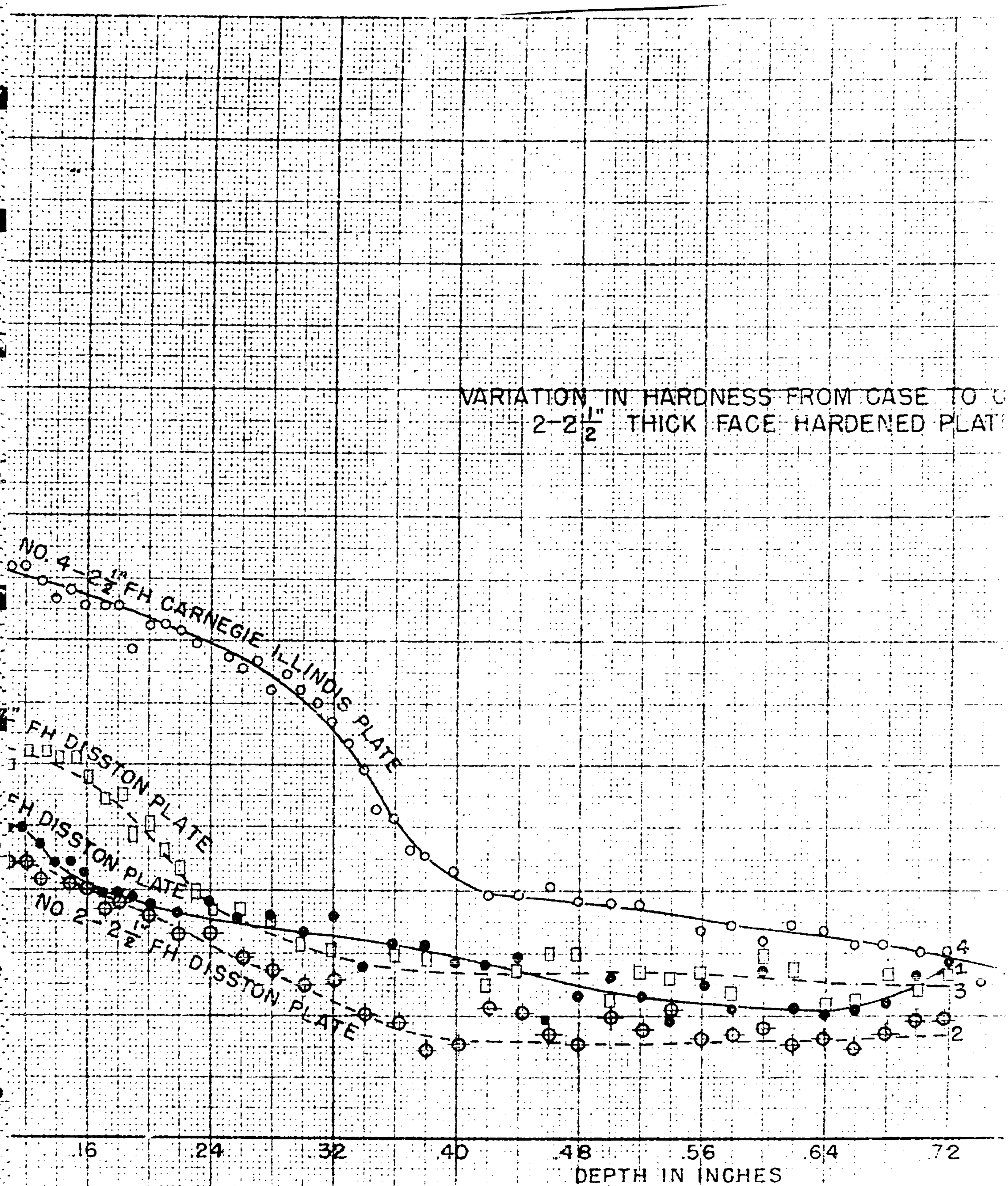
INCHES 1 2 3

ORDNANCE DEPT. U.S.A.
WATERTOWN ARSENAL

FRACTURES OF FACE HARDENED ARMOR
25 JAN 1944 WTN.710-2268

FIGURE 2


VARIATIO
2–2
VICKERS BRINELL HARDNESS
700
600
500
400
300
200
0
.08
.16
.24
.32
.40
NO. 4 – 2½" FH CARNEGIE ILLINOIS PLATE
NO 3 – 2½" FH DISSTON PLATE
NO 1 – 2" FH DISSTON PLATE
NO 2 – 2½" FH DISSTON PLATE
4
3
1
2


VARIATION IN HARDNESS FROM CASE TO C
2-2 1/2" THICK FACE HARDENED PLAT
NO. 4-2 1/2" FH CARNEGIE ILLINOIS PLATE
" FH DISSTON PLATE
FH DISSTON PLATE
NO 2-2 1/2" FH DISSTON PLATE
4
1
3
2
.16
.24
.32
.40
.48
.56
.64
.72
DEPTH IN INCHES

2

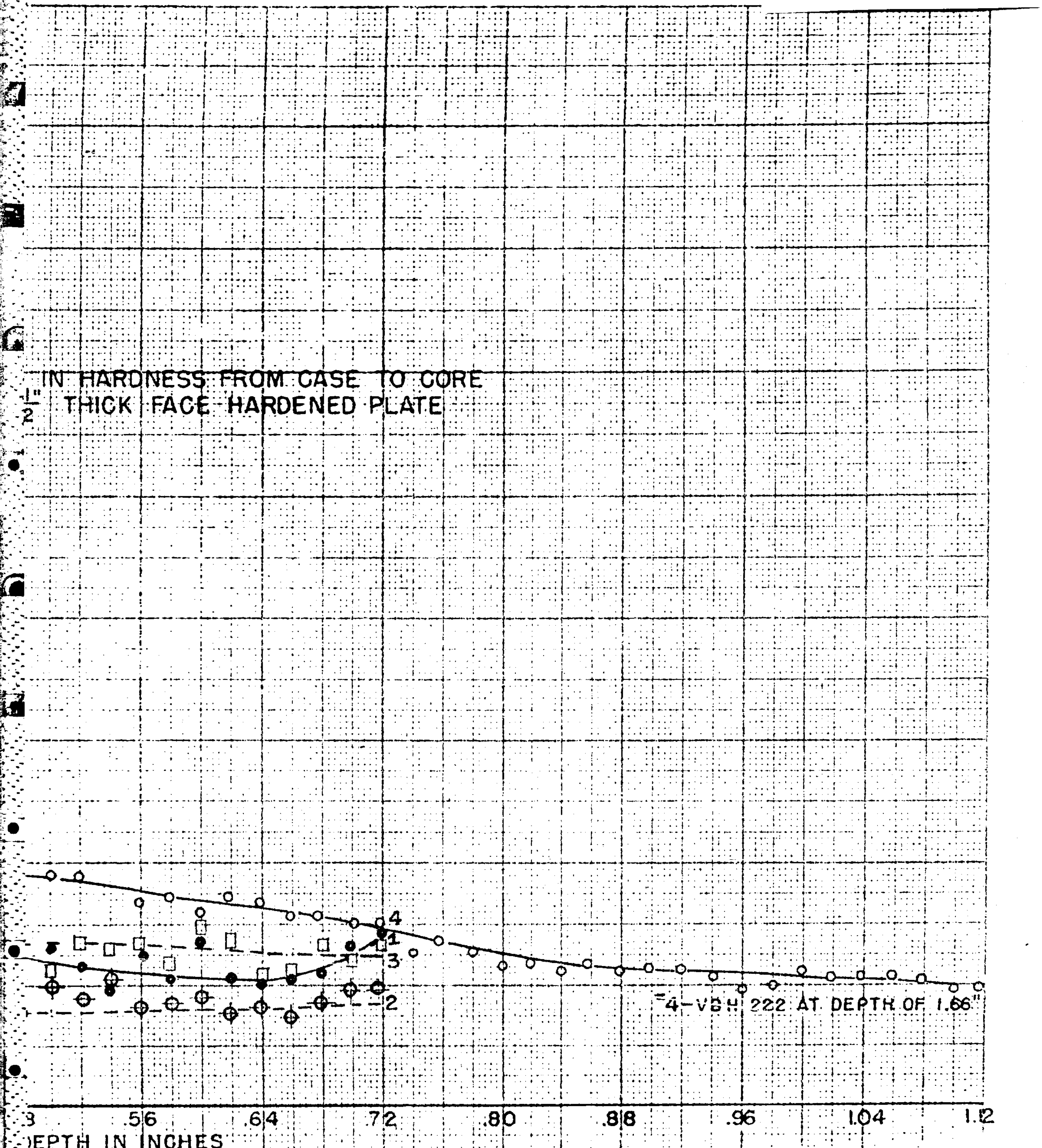
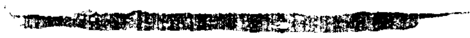

IN HARDNESS FROM CASE TO CORE
1/2" THICK FACE HARDENED PLATE
4
1
3
2
*4 - VBH 222 AT DEPTH OF 1.66"
.56
.64
.72
.80
.88
.96
1.04
1.12
DEPTH IN INCHES

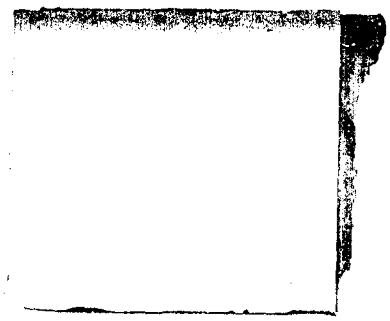
FIGURE 3

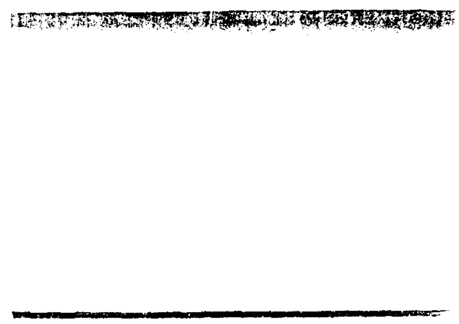
3



NO

2" THICK DISSTON

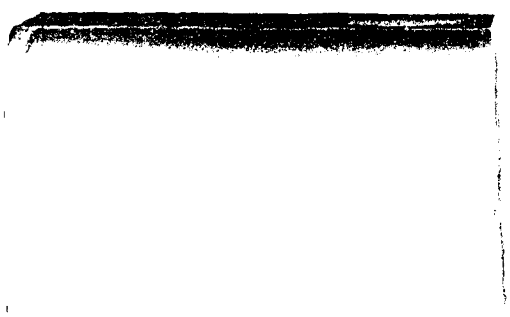


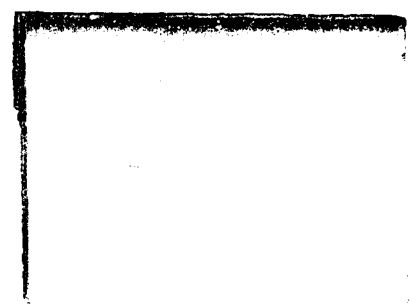


NO 2 LONGITUDINAL

2-1/2" THICK DISSTON

NO 2 TRANSVERSE

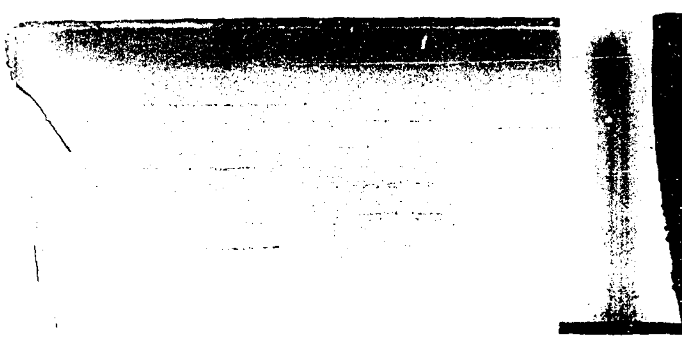


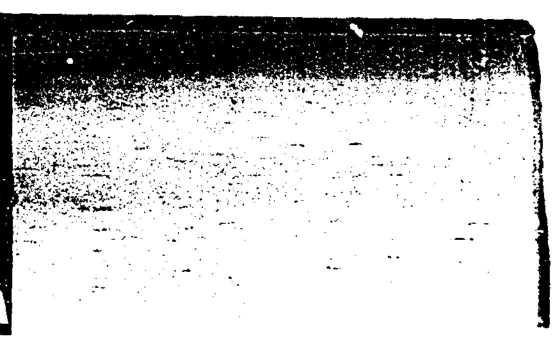


NO 3 LONGITUDINAL

2-1/2" THICK DISSTON

NO 3 TRANSVERSE





NO 4 LONGITUDINAL

2-1/2" THICK CARNEGIE-ILLNOIS

NO 4 TRANSVERSE

INCHES 1 2 3

ORDNANCE DEPT U.S.A

WATERTOWN ARSENAL

MACRO STRUCTURE OF FACE HARDENED PLATE
20 JANUARY 1944 WTN.710-2246

FIGURE 4

Microstructure of Face-Hardened Armor Plate

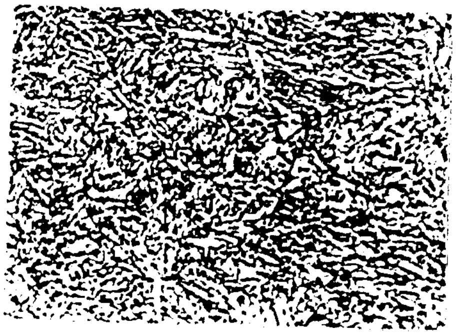
No. 1 — 2" Disston | **No. 2** — 2½" Disston

OUTER CASE

Tempered martensite and trace of fine carbides.
C - 0.80% approx.

Tempered martensite and fine carbides.
C - 1.0% approx.

CENTER CASE

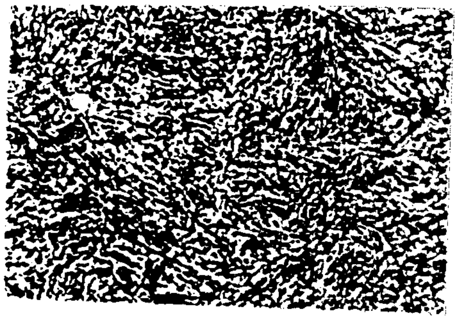


Tempered martensite.

C - 0.60% approx.

Tempered martensite and some fine carbides.
C - 0.60% approx.

REAR CASE

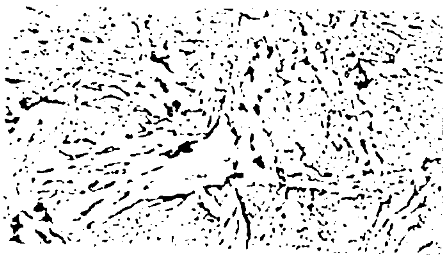


Tempered martensite.

C - 0.40% approx.

Tempered martensite and some fine carbides.
C - 0.40% approx.

CORE



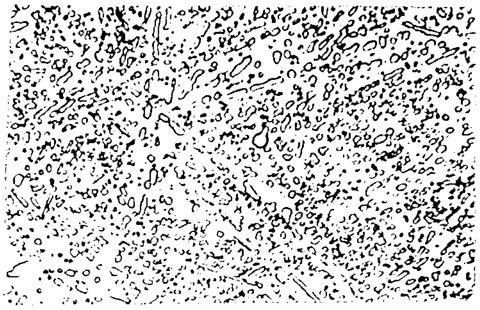
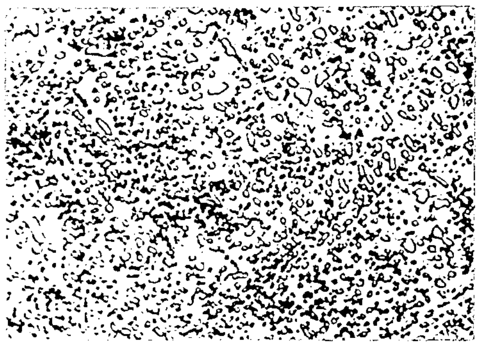
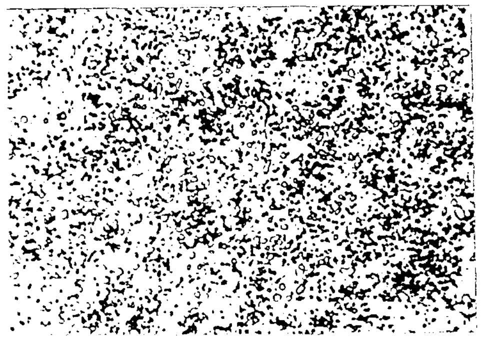
Ferrite and tempered martensite and small carbides in lamellar configuration.
C - 0.20%

Ferrite and tempered martensite and some fine carbides in lamellar configuration.
C - 0.20%

Samples Etched in Picral - Magnification X1000

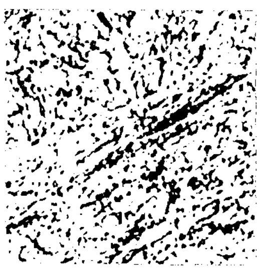
FIGURE 5

Microstructure of Face-Hardened Armor Plate

No. 3 — 2½" Disston		No. 4 — 2½" Carnegie-Illinois
	OUTER CASE	
Coarse tempered martensite. C - 0.85% approx.		Carbides in fine martensitic matrix. C - 1.30% approx.
	CENTER CASE	
Coarse tempered martensite and trace of carbide. C - 0.50% approx.		Small globular carbides in fine martensitic matrix. C - 1.0% approx.
	REAR CASE	
Coarse tempered martensite and trace of fine carbide. C - 0.35% approx.		Fine carbides in medium carbon martensite (gray) and some ferrite (white). C - 0.60% approx.

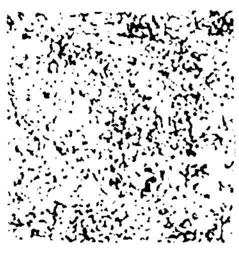
CORE

-A-
Area of ferrite, tempered martensite, carbides in lamellar configuration.

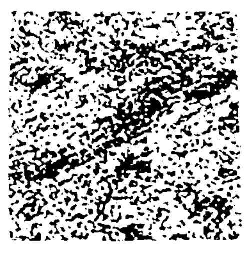


-B-
Area of tempered martensite and fine carbide.

C - .13%



-A-
Medium carbon, martensite (gray) ferrite (white), fine carbide.



-B-
High temperature transformation products (dark) ferrite (white), fine carbide.

C - .33%

Samples Etched in Picral - Magnification X1000

FIGURE 6

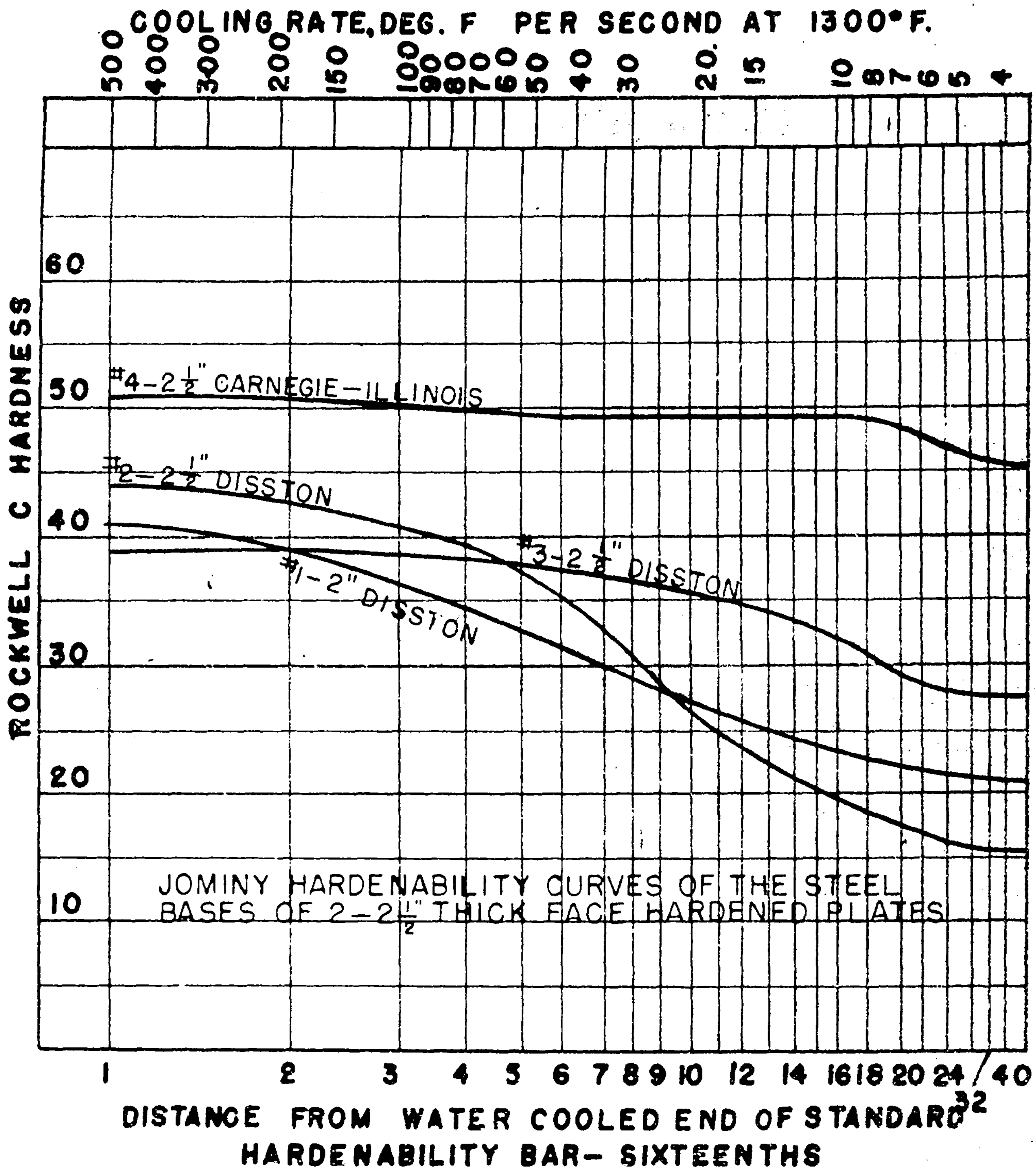


PLATE NO.	HEAT NO.	C	MN	SI	S	P	NI	CR	MO	Cu	B	AL	QUENCH TEMP.	QUENCH TIME	G.S.
1	D-3574 FR-A7764	.20	.50	.23	.021	.020	3.55	.11	.27	.17	.001	.008	1500	1 hr.	
(2) 427	3426	.20	.44	.26	.020	.018	3.46	.09	.25	.13	.0007	.009	1500	1 hr.	
3	4599 FR-A10721	.13	.56	.24	.021	.017	4.92	.16	.31	.15	.0006	.009	1600	1 hr.	
4	JJ999	.33	.16	.23	.039	.013	3.39	1.62	—	.04	.0007	.01	1500	1 hr.	

FIGURE 7