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REPORT

# Test. Lab.

REPORT NO. 310.2/12

LIGHT ARMOR PLATE

SPECIAL STUDY OF SELECTED DISSTON PLATES

BY

D. J. MARTIN

1933



WATERTOWN ARSENAL
WATERTOWN, MASS.

Report No. 310.2/12 October 5, 1933
Watertown Arsenal

## Light Armor Plate

## Special Study of Selected Disston Plates.

### Conclusions

Investigation of specially selected Disston plates made from this arsenal's heats nos. 12-444 and 12-445 indicates that:

1. The most satisfactory plate in the 1/2" group, from the point of view of ballistic efficiency and freedom from cracking and spalling, was plate No. 2-444. This plate was drawn at 900°F and had a case 3.2 mm. deep. It showed a surface hardness of 534-601 Brinell on the front and of 375-444 Brinell on the back. Its ballistic limit was 3076 f.s.
2. Of the 1/4" plates examined, No. 4-444 was the most satisfactory. It was drawn at 1000°F and had a case 0.8 mm. deep. It showed a surface hardness of 514-534 Brinell on the front and of 363-429 Brinell on the back. Its ballistic limit was 1991 f.s.
3. The depths of case obtained were not uniform, and plate No. 3-445 was carburized on both sides.
4. The hardness values of some of the plates showed too much variation over the surface of the plate, particularly on the back surfaces.

## Introduction

The results obtained at the Aberdeen Proving Ground*[1] in the tests of light armor plate submitted by Henry Disston & Sons, Inc., on Watertown Arsenal Purchase Order No. 2376 were, in general, very satisfactory. The Chief of Ordnance has directed[2] that an additional group of plates be made of the same steel composition and heat treatment, except that the draw temperature will be 1000°F for all the plates.

Some of the plates tested under P. O. No. 2376 showed exceptionally good ballistic properties while others, for no apparent reason, were decidedly inferior to the good plates in ballistic efficiency. The object in making the additional lot of plates referred to is to duplicate the results obtained with the better plates of P. O. No. 2376.

## Purpose

The purpose of this investigation was to determine, if possible, the reasons for the high ballistic limits obtained with certain plates and for the poor ballistic limits shown by certain other plates of the same group.

## Experimental Procedure

All of the plates of this lot will eventually be examined at this arsenal as a part of the arsenal's general program for the study of light armor plate. However, in order to enable Henry Disston & Sons, Inc. to proceed

* Numbers refer to references listed at the end of this report.

with the order for additional plate, a few plates were selected for preliminary study. These plates, selected after consultation with Dr. Henry B. Allen, Chief Metallurgist, Henry Disston & Sons, Inc., bore the following serial numbers:

(a) 1/4" plate:-5-445, 4-444, 1-445 and 2-444

(b) 1/2" plate:-3-445, 3-444, 1-445 and 2-444.

Unfortunately, 1/4" plate No. 2-444 has not yet been received at this arsenal and it was, therefore, not possible to include it with this group.

The other plates, as listed above, were examined microscopically to determine:

(a) the general cleanliness of the steel

(b) the depth of case

(c) possible accidental carburization of the back surface of the plate

(d) the structure of the case

(e) the structure of the core

Photomicrographs were taken on longitudinal (in the direction of major reduction in rolling) and transverse specimens at 25 and 1000 diameters and photomacrographs were made at 3 diameters.

The plates were ground on an emery wheel in a number of spots chosen to give a fair representation of the whole surface. Brinell hardness measurements were made in at least six locations on the front and back surface of each plate. The microsections were used to obtain Vickers-Brinell hardness measurements on the cross-section of the

plates.

Experimental Results

All the plates which were examined were made from heats 12-444 and 12-445. The chemical analyses and pertinent data from the foundry records are given in Table I.

Table I

Foundry Data - Armor Plate Ingots

| Heat No. | Date | Charge | Lining | Heat on Lining | Runner Cup | Remarks |
|---|---|---|---|---|---|---|
| 12-444 | 4/20/32 | (Bar Stock (Armco (Iron & (Alloys | MgO Crucible | 9th | 1"sq.hole | Hot pour-Good shrinkage. Slight evolution of gas. |
| 12-445 | 4/20/32 | " | MgO Crucible | 10th | 3/4"sq.hole | Cool pour-Good shrinkage. Quiet. |

Chemical Analyses

| | C | Mn | P | S | Si | Cr | Va | Mo | Ingot Weight |
|---|---|---|---|---|---|---|---|---|---|
| 12-444 | .315 | .53 | .012 | .018 | .13 | 1.33 | .24 | .655 | 500# |
| 12-445 | .32 | .55 | .012 | .018 | .16 | 1.32 | .24 | .68 | 500# |

The plates examined were made from 6 1/2" x 10" rectangular ingots. The ingots were forged to 2" slabs and the slabs were then rolled to the desired thicknesses. The plates were quenched in oil from 1675°F (912°C) and then from 1525°F (829°C). Individual plates were then drawn for two hours at various temperatures, as indicated in Table II. The ballistic limits of the plates, their draw temperatures, the Brinell hardnesses as reported by the Aberdeen Proving Ground[1], and the relative resistance of the plates to spalling are set forth in Table II.

Table II

Summary of Ballistic Data

| Plate No. | Thickness Nominal | Thickness Actual | Brinell Front | Brinell Back | .30 A.P. Ball f.s. Limit | Draw Temperature | Spalling |
|---|---|---|---|---|---|---|---|
| 1-445 | 1/4" | .255 | 600 | 532-555 | 2100 | 600°F | Split into 2 pieces |
| 2-444 | 1/4" | .253 | 600 | 477 | 2290 | - Not available - APG reports that Dr. Allen has this plate. | |
| 5-445 | 1/4" | .257 | 477-495 | 430-444 | 1836 | 1000°F | None |
| 4-444 | 1/4" | .250 | 495 | 387-418 | 1991 | 1000°F | None |
| 2-444 | 1/2" | .503 | 555 | 418 | 3076 | 900°F | None |
| 3-444 | 1/2" | .505 | 495-512 | 321-364 | 2948 | 1000°F | None |
| 1-445 | 1/2" | .510 | 600 | 402 | 3009 | 600°F | Yes |
| 3-445 | 1/2" | .509 | 460-477 | 444-477 | Front - 2817<br>Back - 2837 | 1000°F | # |

# - Plate 3-445 spalled considerably when fired at back surface, and slightly when fired at front surface.

Photomicrographs of the plates are shown in Figures No. 1 to No. 7, inclusive. A summary of the metallographic study, made by Mr. F. G. Carter, Metallographist, is set forth in Table III.

Table III

Armor Plate

Metallographic Study of Slected Disston Plates

| Specimen | Thickness Inches | Non Metallics | Structure of Case | Depth of Case mm (approx.) | Structure of Core |
|---|---|---|---|---|---|
| 2-444 | 1/2 | Very dirty Elongated Sulphides | Cementite embedded in Troostite Troostite changing to Sorbite Very fine grained Banded | 3.2 | Sorbite Fine grained Banded. Small amt. of ferrite in scattered 60° planes Trans.sect. Flattened seg. |
| Figure No. 1 | | | | | |
| 3-444 | 1/2 | Dirty Short elongated sulphides. Crack follows dirt streaks | Ditto Note: No micros but similar to 2-444 | 3.0 | Sorbite Fine grained Banded Small amt. of ferrite in seg.areas 60° planes Trans.Sect. Flattened sect |
| Figure No. 2 | | | | | |
| 1-445 | 1 1/2 | Very dirty Short elongated sulphids Spalled along dirt streak | Ditto Spalled in case | 1.8 | Sorbite Banded High carbon bands very fine grained. Low carbon bands fine grained with considerable ferrite in seg. areas. Trans. Sect. Flattened seg. |
| Figure No. 3 | | | | | |

| Specimen | Thickness Inches | Non Metallics | Structure of Case | Depth of case MM (Approx.) | Structure of Core |
|---|---|---|---|---|---|
| 3-445 | 1/2 | Dirty.short elongated sulphides. Crack and spalling along dirt streak | Ditto,ex-cept cased on both sides. Thickest case on front-spalled at front in case, when fired at from rear | Back 1.8 Front3.0 | Sorbite slightly banded - Fine grained. Considerable scattered ferrite in planes |
| Figure No. 4 | | | | | |
| 1-445 | 1/4 | Very dirty Long chains of elongated sulphide. Crack and split follows dirt chain | Ditto 2-444 | .9 | Sorbite very banded Crack and split follows bands. Fine grained numerous 60 planes. Very little free ferrite Trans Sect. Flattened Seg. |
| Figure No. 5 | | | | | |
| 1-444 | 1/4 | Dirty.Short elongated sulphides | Ditto 2-444 | .8 | Sorbite banded - fine grained.Small amt. of free ferrite in small scattered areas. Trans.Sect. flattened seg. |
| Figure No. 6 | | | | | |
| 5-445 | 1/4 | Very dirty. Elongated sulphide cracks follow dirt streaks | Ditto 2-444 | 1.4 | Sorbite banded - crack follows band - fine grained. Small amt. of free ferrite in small scattered areas |
| Figure No. 7 | | | | | |

Note 1 - All specimens showed considerable cold work at edge of bullet hole.

" 2 - Spalling and longitudinal cracks caused by the bullet impact on the steel weakened by long elongated sulphide inclusions and severely banded structures.

" 3 - Depth of case is approximate as the steel is in a semi-hardened condition.

A summary of the Brinell hardness readings obtained on both surfaces of each plate, showing the lowest and the highest reading for each surface, is given in Table IV. For comparison, the Brinell hardnesses reported by the Aberdeen Proving Ground are also given in this table. As a check on the comparative impressions made with the two Brinell machines, Brinell hardnesses were taken as close as possible to those made at the Proving Ground. The greatest variation between this Arsenal's machine and the Proving Ground machine was .05 mm in the diameter of the impression. This is equivalent, in the range used, to about 14 points on the Brinell hardness scale.

Table IV

Light Armor Plate

Disston Plates Selected for Special Study

Summary of Hardness Survey

| Plate No. | Thickness | Brinell Hardness Front *APG Report | Front W.A. Survey | Back APG Report | Back W.A. Survey |
|---|---|---|---|---|---|
| 2-444 | 1/2" | 555 | 534 - 601 | 418 | 375 - 444 |
| 1-445 | 1/2" | 600 | 601 - 653 | 402 | 293 - 477 |
| 3-444 | 1/2" | 495 - 512 | 514 - 534 | 321-364 | 321 - 401 |
| 3-445 | 1/2" | 460 - 477 | 514 - 534 | 414-477 | 293 - 444 |
| 5-445 | 1/4" | 477 - 495 | 477 - 495 | 430-444 | 415 - 444 |
| 4-444 | 1/4" | 495 | 514 - 534 | 387-418 | 363 - 429 |
| 1-445 | 1/4" | 600 | 578 - 601 | 532-555 | 477 - 514 |

* Figures taken from A.P.G., Partial Reports of Test of Thin Armor, Nos. 63, 65 and 66.

Detailed results of the hardness tests, and Vickers-Brinell hardnesses on the cross-section of the plates, are shown in Figures No. 8 to No. 14, inclusive.

Discussion

The microstructure of all of the plates was very similar. It will be sufficient, therefore, for a general discussion, to refer to Figure No. 1. The appearance of a section of plate No. 2-444, 1/2", in the vicinity of a partial penetration is shown in Figure 1, A, at 3X. The depth of case, and the marked banding of the core are readily apparent. This banding as it appears in a transverse section, (i.e. at right angles to that shown in A) is pictured at 25X in Figure 1, B. The steel contained an objectionable amount of dirt, as shown in longitudinal and transverse sections at 25X in Figures 1, G, and H, respectively. The appearance of the case and core is shown at 25X in Figure 1, F. The light band at the top of the case is caused by an agglomeration of large carbide particles. It extends into the case for a distance of about 0.2 m.m.

This unusual condition might be attributed to "abnormality". It is felt, however, that what is commonly termed an "abnormal" steel would show signs of agglomeration for a greater depth into the case. A possible

reason for the condition noted may be that the steel was exposed to the atmosphere at a rolling heat in the rolling which took place after carburization. Absorption of oxygen from the atmosphere might cause agglomeration in the surface zones thus involved. It should, however, also leave evidence of surface decarburization which was not apparent. Figure 1,C, shows the nature of these carbide particles as seen at 1000X, and the abrupt change from the surface zone to rest of the case is evident. The structure of the rest of the case is shown in Figure 1,D, at 1000X, and that of the core at the same magnification is shown in Figure 1,E.

The depth of case was not particularly uniform, as can be seen from Table II, or from an examination of figure 4, A. Plate No. 3-445 was accidentally carburized on both sides. Apparently the depth of case was but a small factor in determining the quality of the 1/2" plates. 2-444 had a case 3.2 m.m. deep and gave a ballistic limit of 3076 f.s., while plate 1-445, which had a case only 1.8 m.m. deep gave a ballistic limit of 3009 f.s., and plate 3-444, with a 3.0 m.m. case had a ballistic limit of 2948 f.s.. The fourth plate of the group, 3-445, was cased on both sides and cannot be considered. It would seem that plate 1-445 showed high resistance in spite of its thin case chiefly because of its hardness. Although plate 1-445 showed a high ballistic resistance it did spall considerably. It was drawn at 600°F. Plate 2-444, with a 3.2 m.m. case, shown at 900°F, was undoubted-

ly the most satisfactory plate in the group. Its ballistic limit, 3076 f.s., is excellent, especially when it is considered how dirty the steel was.

As to the 1/4" plates examined, the 1.4 m.m. case on 5-445 was apparently too thick. At any rate, it developed a ballistic limit about 160 f.s., lower than 4-444, which had a case only 0.8 m.m. thick. Both of these plates were drawn at 1000°F. Plate 1-445, which was drawn at 600°F showed a high ballistic limit, but it split into two pieces under firing impacts. Plate 2-444, which was not available for study, developed the highest ballistic limit in its group (2290 f.s.). However, it was drawn at 600°F and reports of test show that it spalled considerably under fire. Hence, it would seem that the best results in 1/4" plate would probably be obtained with a case about 0.8 m.m. deep and a draw temperature of 1000°F.

Figure 2,C, and Figure 5,A and C, present striking evidence that cracks in the plate that finally develop into button or petal spalls have their origin in chains of inclusions or "dirt" particles in the steel. A cleaner steel should result in material increase in resistance to spalling, even with lower draw temperature.

Brinell hardness readings are commonly taken at two points on each surface of a face-hardened plate and the readings thus obtained are listed as the hardness figures for the plate. In the present investigation it was deemed necessary to explore the surfaces more care-

fully to determine the uniformity of hardness in any given plate. The results obtained are set forth in Figures No. 8 to No. 14, inclusive. The lack of uniformity is at once apparent, especially on the back surfaces of plates 1-445, and 3-445. Such variations in hardness were not apparent under the standard method of taking hardness readings, as can be seen from a glance at Table IV. The question may well be raised as to whether tentative Specification AXS-54, Rev. 1, May 1, 1933 should be revised to cover the conditions encountered. Granting that this lot of plate was purely experimental in nature, nevertheless, five plates that passed satisfactory ballistic tests might have been rejected without ever coming to test under the present hardness specification. The other two plates examined, neither of which met ballistic requirements, were satisfactory from the point of view of uniformity of hardness.

Vickers-Brinell hardnesses were taken on the cross-section used for metallographic examination. The results are included with the Brinell hardness readings, in Figures No. 8 to No. 14.

Conclusions

1. Criteria of quality in armor plate must include the following factors:

(a) Ability to withstand penetration of specially hardened, armor piercing bullet cores moving at high velocities; known as the ballistic limit, and expressed, for a given bullet, as striking velocity,

in feet per second.

(b) Resistance to cracking and to breaking off of small pieces of plate; sometimes termed spalling.

(c) Comparative facility of fabrication and repair under field conditions.

This paper deals only with the first two of these factors. From the data presented above it is concluded that the most satisfactory plates of the limited number examined in the two thickness groups were:

| Plate No. | Thickness | Brinell Hardness Front | Brinell Hardness Back | Depth of Case | Draw Temp | Ball. Limit f.s. | Spalling |
|---|---|---|---|---|---|---|---|
| 2-444 | .503" | (534) (601) | (375) (444) | 3.2 mm | 900°F | 3076 | None |
| 4-444 | .250" | (514) (534) | (363) (429) | 0.8 mm | 1000°F | 1991 | None |

2. The non-metallic, or "dirt" content of the steel was high. This condition contributed to the spalling noted in some plates. It also presented the original cause of excessive banding and of the non-uniformity of hardness found in some of the plates.

3. The depths of case obtained were not uniform. 1/2" plate 3-445 was accidentally carburied on both sides.

4. Hardness, especially on the back surfaces of the plates, was not uniform. The failure of the solvent, gamma iron, to uniformly and completely hold in solution, just before and during the quenching operation, the solute, carbon or iron carbide, may be attributed to the high non-metallic content of the steel, a condition known to inhibit

uniformity of solution. This tendency was undoubtedly enhanced by the low quenching temperature (1525°F:829°C) used in the quenching operation for the refinement and hardening of the case.

Respectfully submitted,

D. J. Martin

D. J. Martin
1st Lt., Ord. Dept.

References

1. Partial Reports of Test of Thin Armor, Numbers 63, 65, 66, Aberdeen Proving Ground, Maryland, 1933.

2. Letter, Ordnance Office 470.5/1267, dated May 2, 1933 and 2nd Ind., 6/13/33.

3. Report 310.2/9, W.A., 9/12/33.

4. Report 310.2/10, W.A., 9/12/33.

5. Report 310.2/11, W.A., 9/14/33.

6. Watertown Arsenal, Expenditure Order No. 67-A12, 1933.

Figure 1

| Section | W.A. Negative No. | Etchant | Magnification | Remarks |
|---|---|---|---|---|
| A | C116-2 | Nital-1% | 3X | Longitudinal section near indent left by partial penetration. |
| B | C116-8 | " " | 25X | Transverse section of core. |
| C | C116-4 | " " | 1000X | Hyper-eutectoid zone in case. |
| D | C116-5 | " " | 1000X | Eutectoid zone in case. |
| E | C116-6 | " " | 1000X | Core - very little free ferrite. |
| F | C116-3 | " " | 25X | Case and core. |
| G | C116-1 | None | 25X | Non-metallic content - longitudinal. |
| H | C116-7 | " | 25X | Non-metallic content - transverse section. |

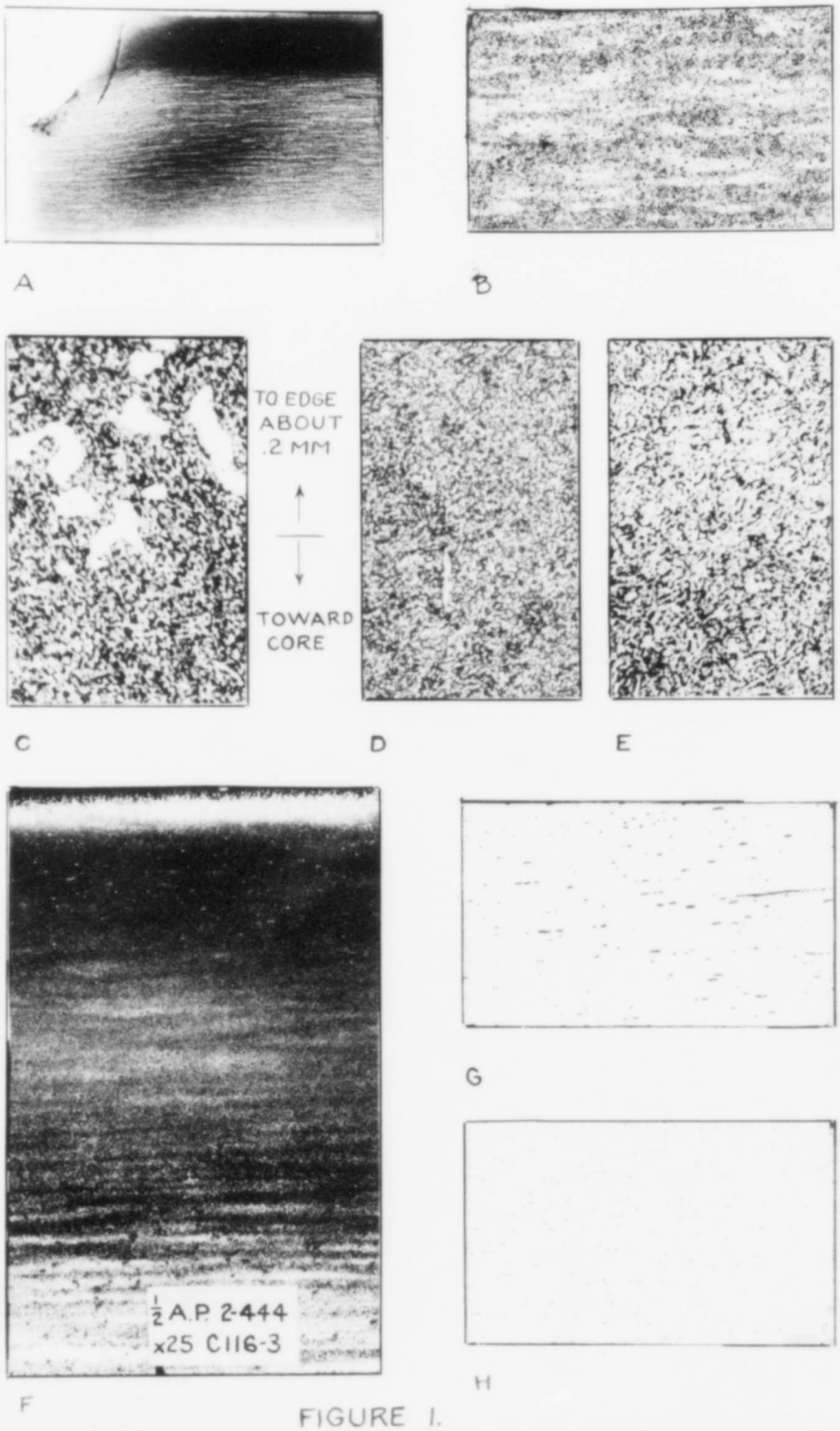
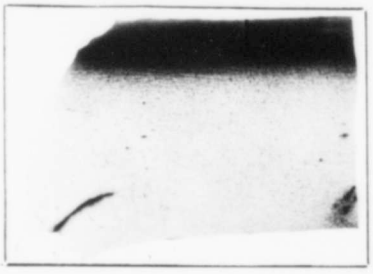



FIGURE 1.

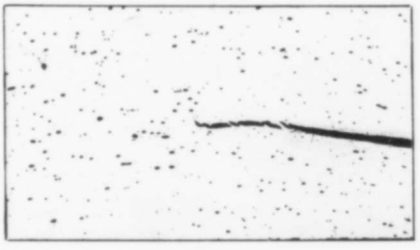
Figure No. 2

| Section | W.A. Negative No. | Etchant | Magnification | Remarks |
|---|---|---|---|---|
| A | C116-10 | Nital-1% | 3X | Longitudinal section near bullet hole- Note cracks. |
| B | C116-11 | " " | 25X | Transverse section of core. |
| C | C116-13 | None | 25X | Non-metallics were cause of crack. Transverse section. |
| D | C116-9 | " | 25X | Non-metallic content - longitudinal section. |
| E | C116-14 | Nital-1% | 25X | Case and core. |
| F | C116-12 | " " | 1000X | Core - a small amount of free ferrite in segregated areas. |



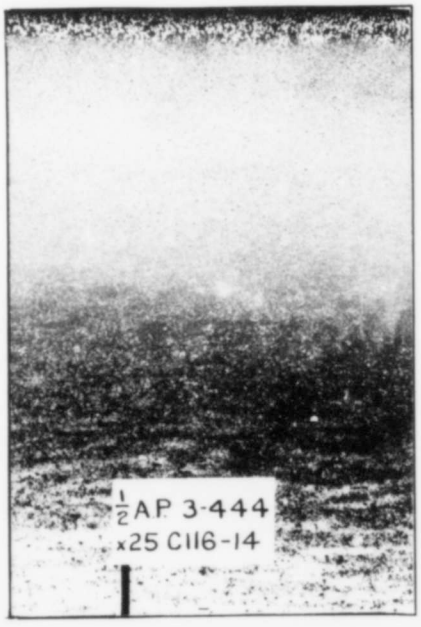
A

B



C

D



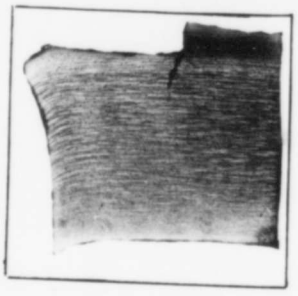

E

F

FIGURE 2

Figure No. 3

| Section | W. A. Negative No. | Etchtant | Magnification | Remarks |
|---|---|---|---|---|
| A | C116-10 | Nital-1% | 3X | Note the thin case on this plate. |
| B | C116-20 | " " | 25X | Transverse section of core. |
| C | C116-15 | None | 25X | Non-metallic content long. |
| D | C116-19 | " | 25X | Non-metallic content transverse. |
| E | C116-17 | Nital-1% | 25X | Case and core. Note pronounced banding in core. |
| F | C116-18 | " " | 1000X | Core showing considerable free ferrite in segregated areas. |



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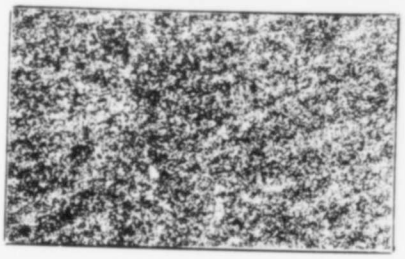

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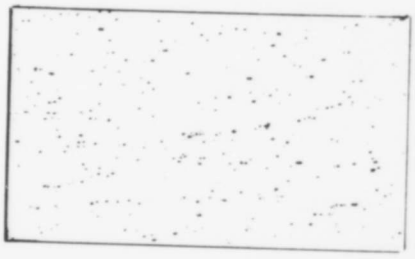
C



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E

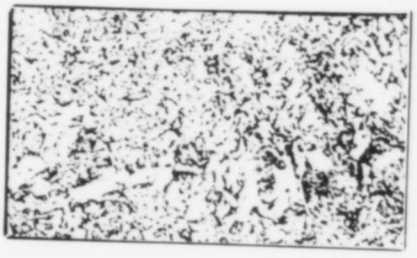

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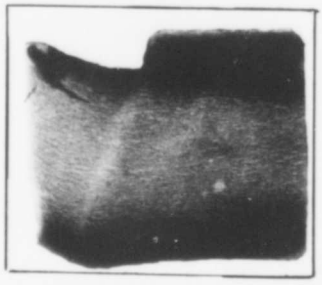
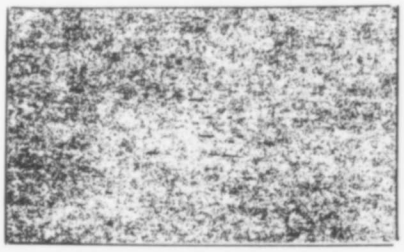
FIGURE 3.

Figure No. 4

| Section | W. A. Negative No. | Etchant | Magnification | Remarks |
|---|---|---|---|---|
| A | C116-22 | Nital-1% | 3X | Note that this plate was cased on both sides. The curvature at the edge was caused by a bullet which penetrated from the rear surface of the plate. |
| B | C116-23 | " " | 25X | Transverse section of core. |
| C | C116-21 | None | 25X | Non-metallic content - longitudinal |
| D | C116-25 | " | 25X | Non-metallic content - transverse |
| E | C116-27 | Nital-1% | 25X | Case and core. |
| F | C116-24 | " " | 1000X | Core - Some free ferrite in segregated areas. |



A



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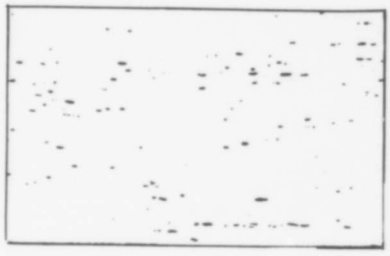

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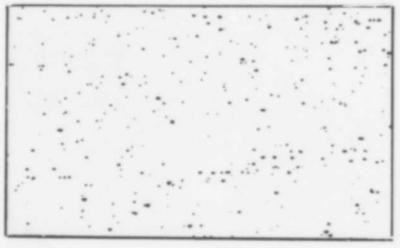

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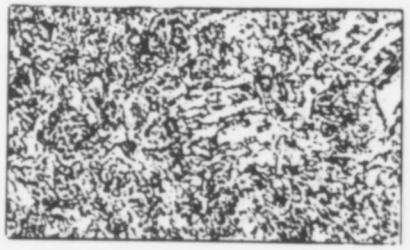

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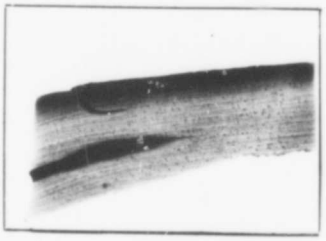
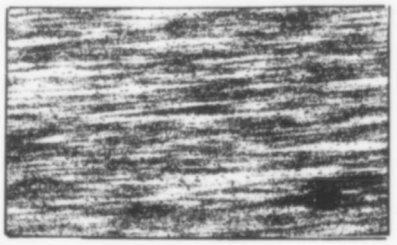
FIGURE 4.

Figure No. 5

| Section | W. A. Negative No. | Etchtant | Magnification | Remarks |
|---|---|---|---|---|
| A | C116-10 | Nital-1% | 3X | Note crack which leads to spalling. |
| B | C116-37 | " " | 25X | Transverse section of core. |
| C | C116-28 | None | 25X | Non-metallic content. Typical cause of cracks shown in A. |
| D | C116-32 | " | 25X | Non-metallic content - transverse. |
| E | C116-30 | Nital-1% | 25X | Case and core. Note pronounced banding and presence of non-metallics in ferrite bands. |
| F | C116-31 | " " | 1000X | Core - Very little free ferrite. |



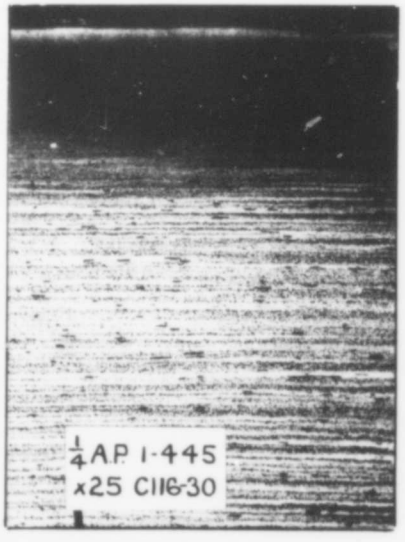
A



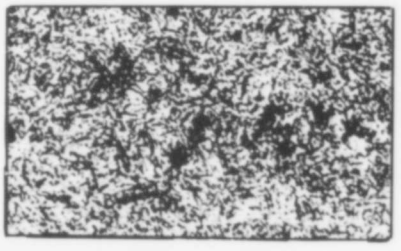
B

C

D




E

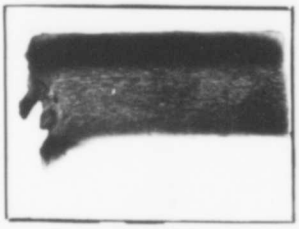


F

FIGURE 5.

Figure No. 6

| Section | U.S.A. Negative No. | Etchtant | Magnification | Remarks |
|---|---|---|---|---|
| A | C116-22 | Nital-1% | 3X | Good ductility indicated by freedom from cracks after penetration. |
| B | C116-36 | " " | 25X | Longitudinal section of core. |
| C | C116-34 | None | 25X | Non-metallic content - longitudinal |
| D | C116-38 | " | 25X | Non-metallic content - transverse. |
| E | C116-39 | Nital-1% | 25X | Case and core Relative freedom from banding. |
| F | C116-37 | " " | 1000X | Core - small amount of free ferrite in scattered areas. |



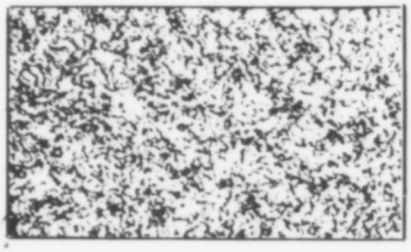
A

B

C

D


E

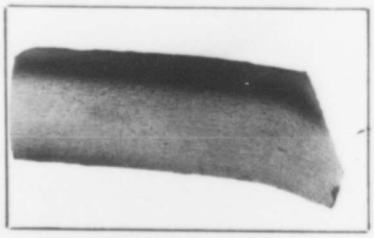


F

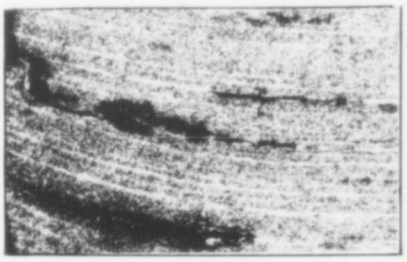
FIGURE 6.

Figure No. 7.

| Section | W.A. Negative No. | Etchtant | Magnification | Remarks |
|---|---|---|---|---|
| A | C116-16 | Nital-1% | 3X | Case and core. |
| B | C116-42 | " " | 25X | Longitudinal section of core. Cracks follow bands. |
| C | C116-40 | None | 25X | Cracks follow non-metallic long. Section. |
| D | C116-44 | " | 25X | Non-metallic content - transverse. |
| E | C116-45 | Nital-1% | 25X | Case and core. |
| F | C116-43 | " " | 1000X | Core. Some free ferrite in segregated areas. |

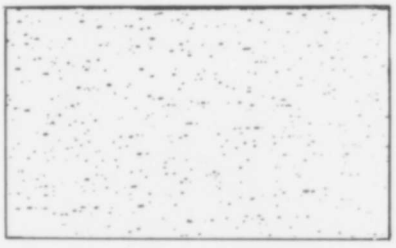


A



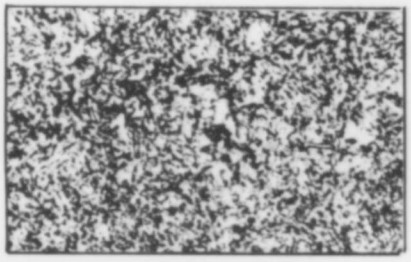
B

C



D


E



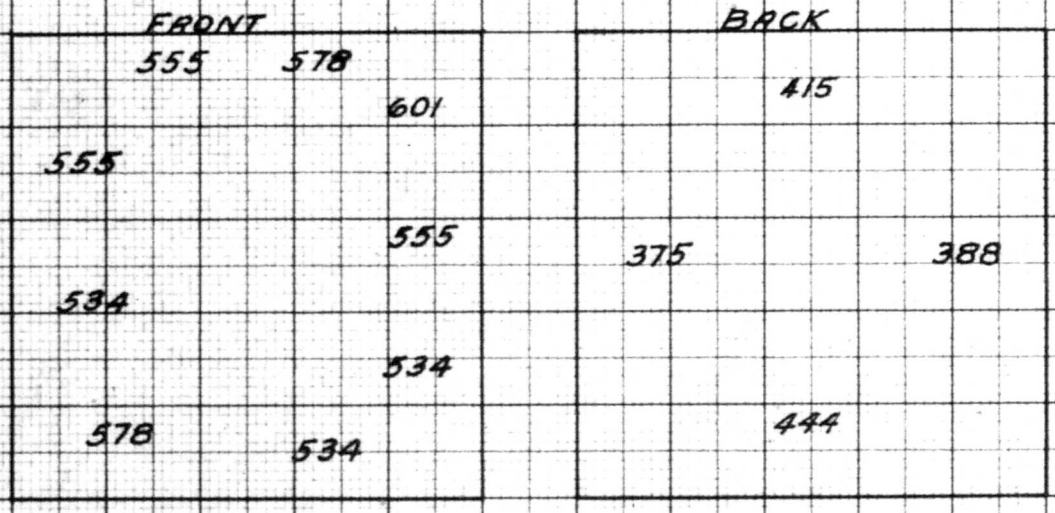
F

FIGURE 7.

# HARDNESS SURVEY

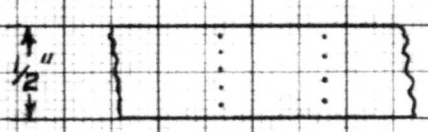
## SPECIAL STUDY – DISSTON ARMOR PLATE
(W. A. EX. O. 67-A-12)

## PLATE NO. 2-444




BRINELL HARDNESS

## CROSS SECTION – VICKERS-BRINELL



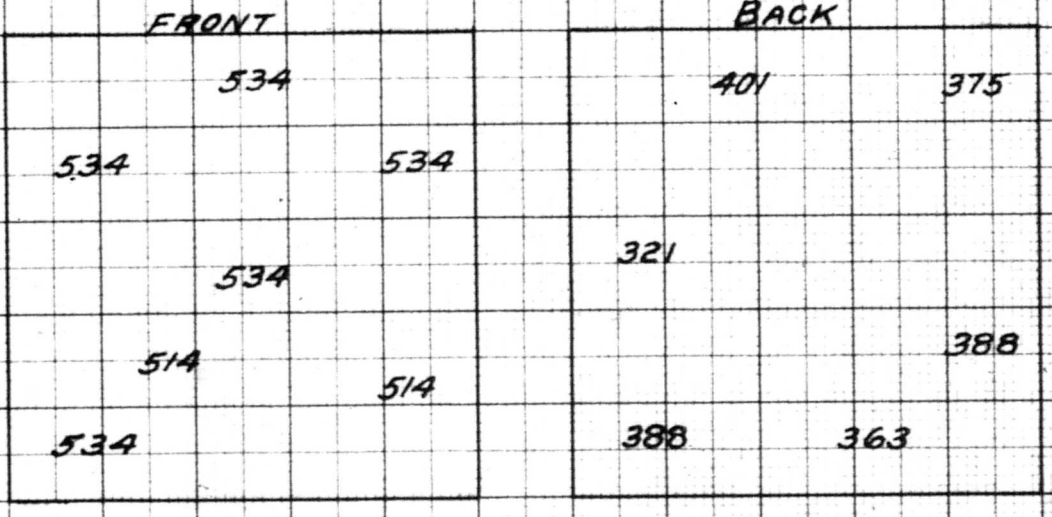

| | | |
|---|---|---|
| FRONT – | 613 | 599 |
| | 613 | 599 |
| | 613 | 599 |
| | 599 | 572 |
| | 536 | 560 |
| | 503 | 473 |
| BACK – | 429 | 421 |

9/14/33 D.J.M.

# HARDNESS SURVEY

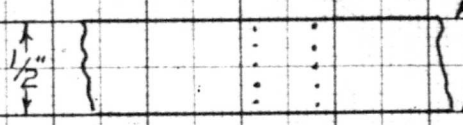
## SPECIAL STUDY - DISSTON ARMOR PLATE
## (W.A. EX.O. 67-A-12)

## PLATE NO. 3-444




BRINELL HARDNESS

CROSS SECTION - VICKERS - BRINELL



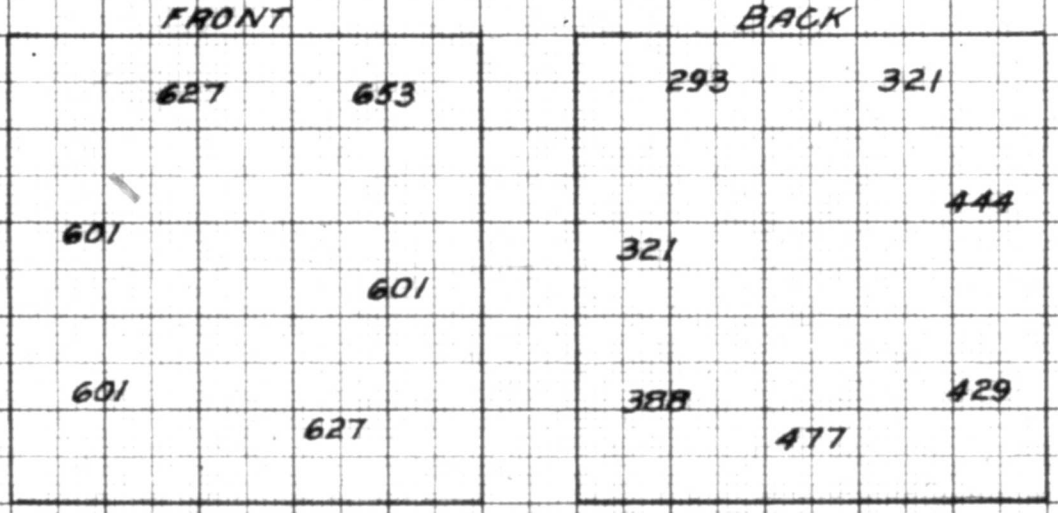

| | | |
|---|---|---|
| FRONT- | 493 | 503 |
| | 493 | 483 |
| | 493 | 483 |
| | 493 | 483 |
| | 493 | 464 |
| | 473 | 421 |
| | 446 | 383 |
| | 390 | 376 |
| BACK- | 369 | |

9/14/33 D.J.M

# HARDNESS SURVEY

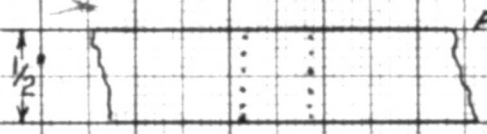
## SPECIAL STUDY - DISSTON ARMOR PLATE
(W. A. EX.O. 67-A-12)

## PLATE NO. 1-445




BRINELL HARDNESS

CROSS - SECTION - VICKERS - BRINELL



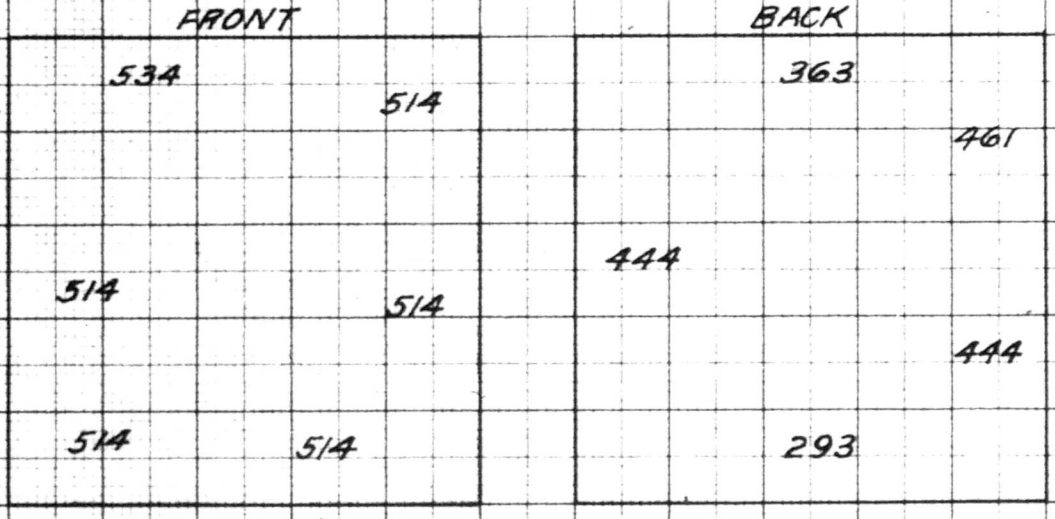

| | | |
|---|---|---|
| FRONT - | 493 | 464 |
| | 493 | 421 |
| | 455 | 390 |
| | 405 | 376 |
| | 369 | 351 |
| | 357 | 351 |
| BACK - | 357 | 351 |

9/14/33 D.J.M.

# HARDNESS SURVEY

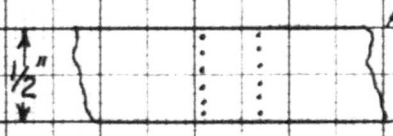
## SPECIAL STUDY - DISSTON ARMOR PLATE
## (W.A. EX. O. 67-A-12)

## PLATE NO. 3-445




BRINELL HARDNESS

### CROSS SECTION - VICKERS - BRINELL




| | | |
|---|---|---|
| FRONT | 464 | 464 |
| | 464 | 464 |
| | 464 | 464 |
| | 464 | 464 |
| | 437 | 446 |
| | 405 | 390 |
| | 363 | 339 |
| | 333 | 322 |
| | 345 | 317 |
| | 333 | 322 |
| | 333 | 327 |
| | 333 | 345 |
| | 345 | 339 |
| | 369 | 357 |
| | 397 | 390 |
| | 413 | 413 |
| | 455 | 437 |
| BACK- | 473 | 455 |

9/14/33 D.J.M.

# HARDNESS SURVEY

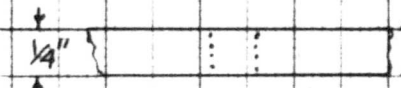
## SPECIAL STUDY - DISSTON ARMOR PLATE
## (W.A. EX. O. 67-A-12)

## PLATE NO. 1-445

| FRONT | | | BACK | | |
|---|---|---|---|---|---|
| 578 | 601 | | 495 | 495 | |
| 601 | | 578 | 477 | | 477 |
| 601 | 601 | 601 | 477 | 514 | 477 |
| 601 | 601 | 578 | 477 | | 495 |
| | | | 514 | 514 | |

BRINELL HARDNESS

CROSS SECTION - VICKERS-BRINELL



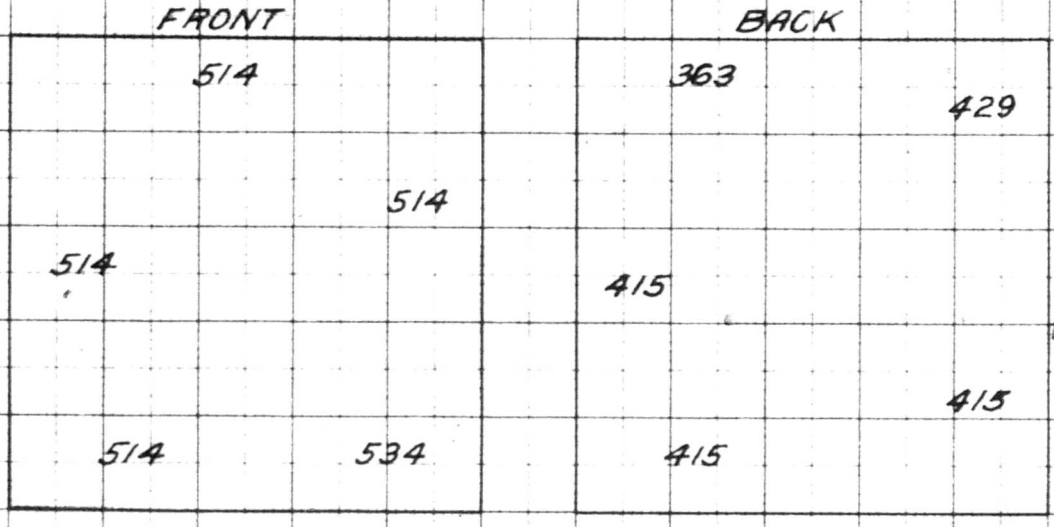

| | | |
|---|---|---|
| FRONT | 525 | 560 |
| | 560 | 572 |
| | 536 | 548 |
| | 514 | 493 |
| | 503 | 464 |
| | 503 | 483 |
| BACK - | 503 | 503 |

9/14/33 D.J.M.

# HARDNESS SURVEY

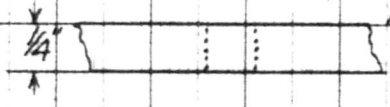
## SPECIAL STUDY - DISSTON ARMOR PLATE
(W.A. EX. O. 67-A-12)

## PLATE NO. 4-444




BRINELL HARDNESS

CROSS SECTION - VICKERS-BRINELL




| | | |
|---|---|---|
| FRONT - | 464 | 464 |
| | 464 | 464 |
| | 464 | 464 |
| | 437 | 446 |
| | 421 | 429 |
| | 405 | 421 |
| | 405 | 421 |
| BACK - | 405 | |

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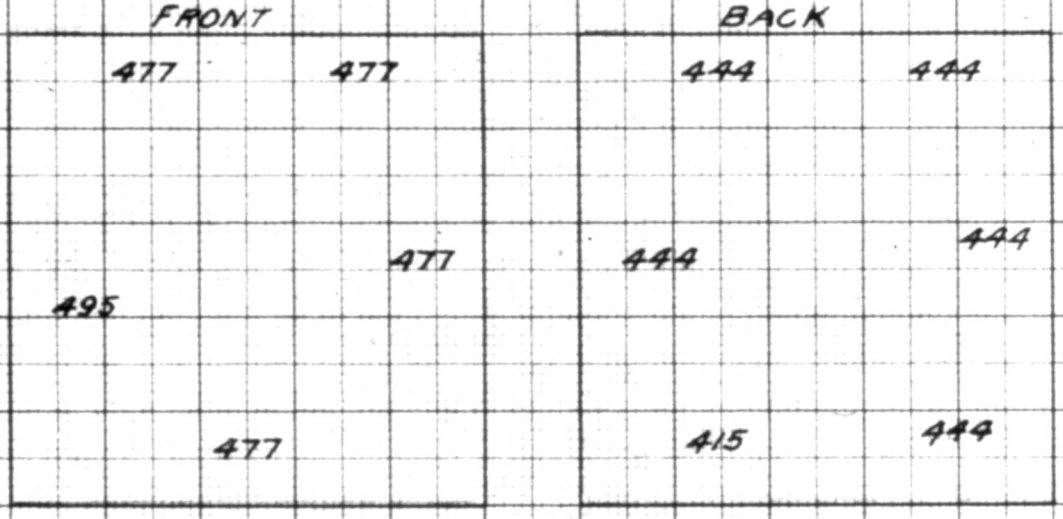
# HARDNESS SURVEY

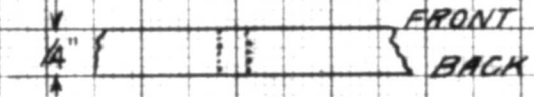
## SPECIAL STUDY - DISSTON ARMOR PLATE
## (W.A. EX. O. 67-A-12)

## PLATE NO. 5-445




BRINELL HARDNESS

CROSS SECTION - VICKERS - BRINELL




| | | |
|---|---|---|
| FRONT - | 473 | 493 |
| | 488 | 493 |
| | 464 | 493 |
| | 437 | 464 |
| | 405 | 429 |
| | 376 | 397 |
| | 397 | 397 |
| | 397 | 397 |

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