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A 214639

Armed Services Technical Information Agency

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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710-583-1

FC BAC

Metallurgical Examination of 2 1/2" Rolled Homogeneous Armor Plate
Manufactured by H. Disston and Sons, Inc.
Which Backspalled under the PTP Test

BY
A. Harlich
Assoc. Metallurgist

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Watertown Arsenal Laboratory

Memorandum Report No. WAL 710-553-1

Supplementary Report on Problem B-4.26

18 April 1944

Metallurgical Examination of 2 1/2" Rolled Homogeneous Armor Plate

Manufactured by H. Dwyer and Sons, Inc.

Which Backspalled under the PTP Test

ABSTRACT

Backspalling of the subject plate was traced to a locally distributed plane of weakness resulting from a piped condition which was not eliminated when the ingot was cropped. If the fracture test for steel soundness had been applied in accordance with paragraph 3-4b(1) of Specification AXS-458 (Rev. 2) the piped condition would have been discovered and corrected before the plate was submitted for ballistic test. It is believed that when it can be established by retest that a "D" quality fracture represents a plane of weakness, the plate should be considered rejectable.

1. At the request of the Office, Chief of Ordnance, Detroit, Michigan,¹ the entire 60"x48"x2 1/2" rolled homogeneous armor plate manufactured by H. Dwyer and Sons, Inc., heat 4529, plate 1, was forwarded to this arsenal for metallurgical examination. The subject plate backspalled upon impact of a 90 mm. A.P.C. M82 projectile at 40° obliquity, and backspalled on the PTP test with a 90 mm. A.P. M77 at 0° obliquity. The details of the ballistic test are contained in Aberdeen Proving Ground Report No. A-11233, 2-11 December 1943. Additional firing with 90 mm. A.P. M77 projectiles was subsequently performed and is described in

¹ Teletype No. 45881, Appendix A.

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Report No. A-12574, 18 February 1944. Prior metallurgical examination² of a sample cut from a corner of this plate failed to disclose the cause of the backspalling.

2. In paragraphs 2c and 2f of WAI Memorandum Report No. 710/583 it was recommended that the areas of the plate immediately adjacent to the backspalled region be subjected to fracture tests so disclose the existence of possible local variations in steel quality. The backspalled area of round #2 exhibited a peculiar "fish-eye" condition believed associated with some type of embrittlement which might be locally distributed. The examination of the small corner section indicated no brittleness whatsoever; in fact, the material was found to be of superior quality with respect to cleanliness, lack of directional properties, ductility, and tensile and impact strength.

3. Metallurgical examination of sections cut from the plate leads to the following conclusions:

a. Backspalling tendencies displayed by the subject plate are traceable to a locally distributed centerline plane of weakness resulting from the rolling down of an ingot pipe.

b. Insufficient top discard is responsible for the presence of the piped condition in the plate. This may have been the result of an attempt to produce a large plate from a relatively small ingot.

c. It is believed that if the manufacturer had applied the fracture test for steel soundness as described in paragraph F-4b(1) of Specification AAS-468 (Rev. 2) to the slab from which the subject plate was fabricated, the piped condition would have been discovered prior to the submission of the plate for ballistic testing.

d. The portion of the plate away from the piped region has a steel quality rating of B. The piped region has a steel quality rating of D on the basis that the lamination is present on only one plane.

e. The experience with the subject plate lends weight to the contention that a D fracture consisting of one extensive plane of weakness should be considered a basis for rejection.

f. The "fish-eye" condition observed in the backspalled region of round #2 is also evident on the fracture test for steel quality and is believed to represent discontinuous films of oxides present in the piped region.

2. WAI Memorandum Rpt. No. 710/583 - "Metallurgical Examination of 2 1/2" Rolled Homogeneous Armor Plate Manufactured by A. D. Diston and Sons, Inc. Which Backspalled under the PIP Test" - 26 January 1944.

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g. Microscopic examination of the piped regions reveals the existence of discontinuous oxide stringers, high concentrations of complex iron sulfide-manganese sulfide inclusions, oxidized and decarburized areas adjacent to the oxide stringers, and also banded regions apparently high in alloy and carbon content adjacent to other portions of the piped zone.

4. Four 12"x8"x $\frac{1}{2}$ " sections were flame-cut from the plate, see Figure 1, and were notched and fractured in accordance with paragraph F-4b(3) of Specification AISI-433 (Rev. 2). The fractures were rated and photographed, after which the broken sections were cut into specimens for macroetching and microscopic examination.

5. The details of the metallurgical examination follow:

a. Fracture Tests. The layout of the four fracture test blocks is shown in Figure 1. The fractured planes of blocks #1, 2, and 4 lie within six inches of the backspalled area of round #2, while the fractured plane of block #3 is approximately 14 inches away. The appearance of the fractured surfaces of the four blocks is shown in Figure 2.

Blocks #1 and #3 have B quality fractures which resemble that of the originally submitted corner section. Blocks #2 and #4 have D quality fractures, #2 containing one long discontinuous lamination over the entire length of the fracture and #4 showing a similar lamination over 75% of its length. The smear shown on fracture #2, Figure 2, resulted from the contact of this projecting shelf with the lower projecting shelf of the opposing face during fracture. In both fractures #2 and #4, one half of the fractured surface projected approximately one inch above the other half, with the lamination occurring at the boundary. Examination of the backspalled regions on the plate show that the spalls coincide with the laminations revealed on the fractures.

When fracture #2 is turned up 90 degrees, so that one looks down upon the flat plateau between the projecting and depressed portions of the fractured surface, the same "fish-eye" condition is observed that was noted on the backspalled surface of round #2, compare the upper photograph of Figure 3 to the lower one of Figure 1. Thus a definite correlation between the backspall and the lamination is established. The nature of the "fish-eyes" will be considered later.

The lamination is also revealed on the flame-cut edges of some of the fracture blocks, note the lower photograph of Figure 3.

The results obtained from the four fracture tests illustrate the local occurrence of the lamination, which extends over an area approximately 14 inches wide and at least two feet long starting at the right side of the plate, upper photograph of Figure 1, and probably reaching to the vicinity of the impact of round #10. Elsewhere, the steel is of excellent quality and displays good ballistic properties.

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In view of the fact that a D quality fracture which consists of one lamination extending over a major portion or the entire length of the fractured surface can be responsible for excessive backspalling leading to ballistic failure, it is believed that such fractures should be considered rejectable in gages from 1-1/4" to 4" in thickness. According to the present specification requirements, at least three such laminations must exist before the plate is considered rejectable, even though but one plane of weakness is sufficient to cause backspalling.

b. Macroetch Tests. Since macroetching tests made on the original corner section showed that the regions of the plate away from the lamination have excellent macrostructures, sections for macroetching were cut only from blocks #2 and #4 as illustrated in the lower photograph of Figure 1.

The sections were etched in a hot 50% hydrochloric acid solution. Photographs of the etched surfaces are shown in Figure 4. The lamination is revealed as discontinuous cracks confined to a 1/4" wide zone at the middle of the plate. The upper photograph of Figure 4 contains a profile of the fractured surface, illustrating the projecting of one portion of the fracture above the other with a sharp break at the plane of the lamination. The left hand portion of macroetched section #4 coincides with the left hand portion of the fracture shown in Figure 2 and represents the transition from the laminated portion to the region free of laminations.

c. Microscopic Examination. Specimens for microscopic examination were cut from various locations in blocks #2 and #4 and approximately half were polished on faces perpendicular to the polished surfaces of the remaining half.

Disconnected stringers of nonmetallic inclusions were found in the midsection of the plate, see Figure 5A. This type of nonmetallic was identified as iron oxide using the etching procedure outlined on page 748 of the 1939 edition of Metals Handbook. A second type of inclusion was also observed in the midsection of the plate, occurring as high concentrations of short, oval inclusions, Figure 5B. These were identified as iron-manganese sulfides. A typical iron oxide type inclusion is shown in Figure 5C at a higher magnification.

The etched structure in the vicinity of the lamination is shown in Figures 5D and E. Figure 5D shows a region which has been highly oxidized and decarburized. Small globular oxides are visible in the decarburized zone. The arrow points to some iron-manganese sulfide inclusions found in the same region. The "fish-eyes" observed on the plane of the lamination were found to coincide with these highly oxidized and decarburized areas. Figure 5E shows a region at the plane of the lamination which contains segregations higher in alloy and carbon content than the base metal.

It is concluded from the microscopic examination that the lamination represents a piped condition in the ingot which was retained in the subject plate.

6. General Considerations

Paragraph F-4b(1) of Specification AIS-488 (Rev. 2) reads as follows:

Location of fracture test specimens. Specimens for this fracture test shall be taken from plates from the top, middle, and bottom of the first, middle, and last usable ingots of each heat. Each fracture test sample shall be cut from a location in the plate rolled from a slab so that the centerline of the sample falls within the central half of the width (in the case of straightaway-rolled armor) or the length (in the case of cross-rolled armor) of the plate product of the slab. The test sample shall be from the edge corresponding to the top of the slab in the case of top-slab products and from the edge corresponding to the bottom of the slabs in the case of middle and bottom-slab products."

A drawing which shows these locations is attached to the specification.

From the position of the lamination in the plate, it is believed that the right hand side of the plate shown in the upper photograph of Figure 1 corresponds to the top of the ingot. If the fracture test had been applied in accordance with the above paragraph to the slab product from which the subject plate was cut, the existence of the piped condition would have been discovered and proper remedial measures applied. It appears that insufficient top discard was responsible in this case, possibly as a result of an attempt to produce a large plate from an insufficiently large ingot.

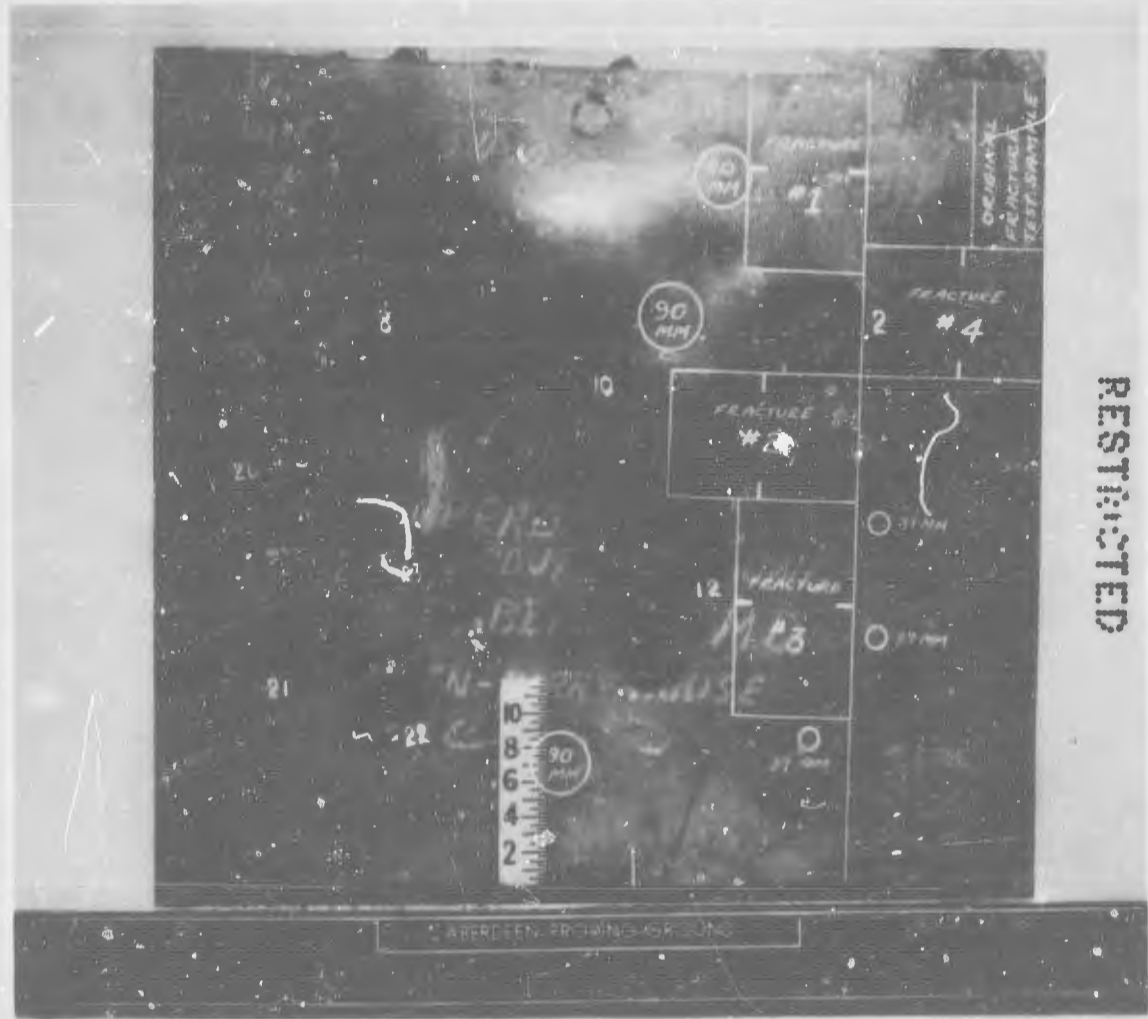
The experience with the subject plate indicates the necessity for a reconsideration of the acceptability of "D" fractures. It is obvious that but one definite plane of weakness is sufficient to promote backspalling. It is believed that if, by retest, it is established that the "D" fracture represents a plane of weakness rather than a single essentially unidimensional inclusion, the plate should be considered rejectable.

A. Hurlich

A. HURLICH
Assoc. Metallurgist

APPROVED:

M. A. MATTHEWS,
Major, Ord. Dept.
Chief, Armor Section

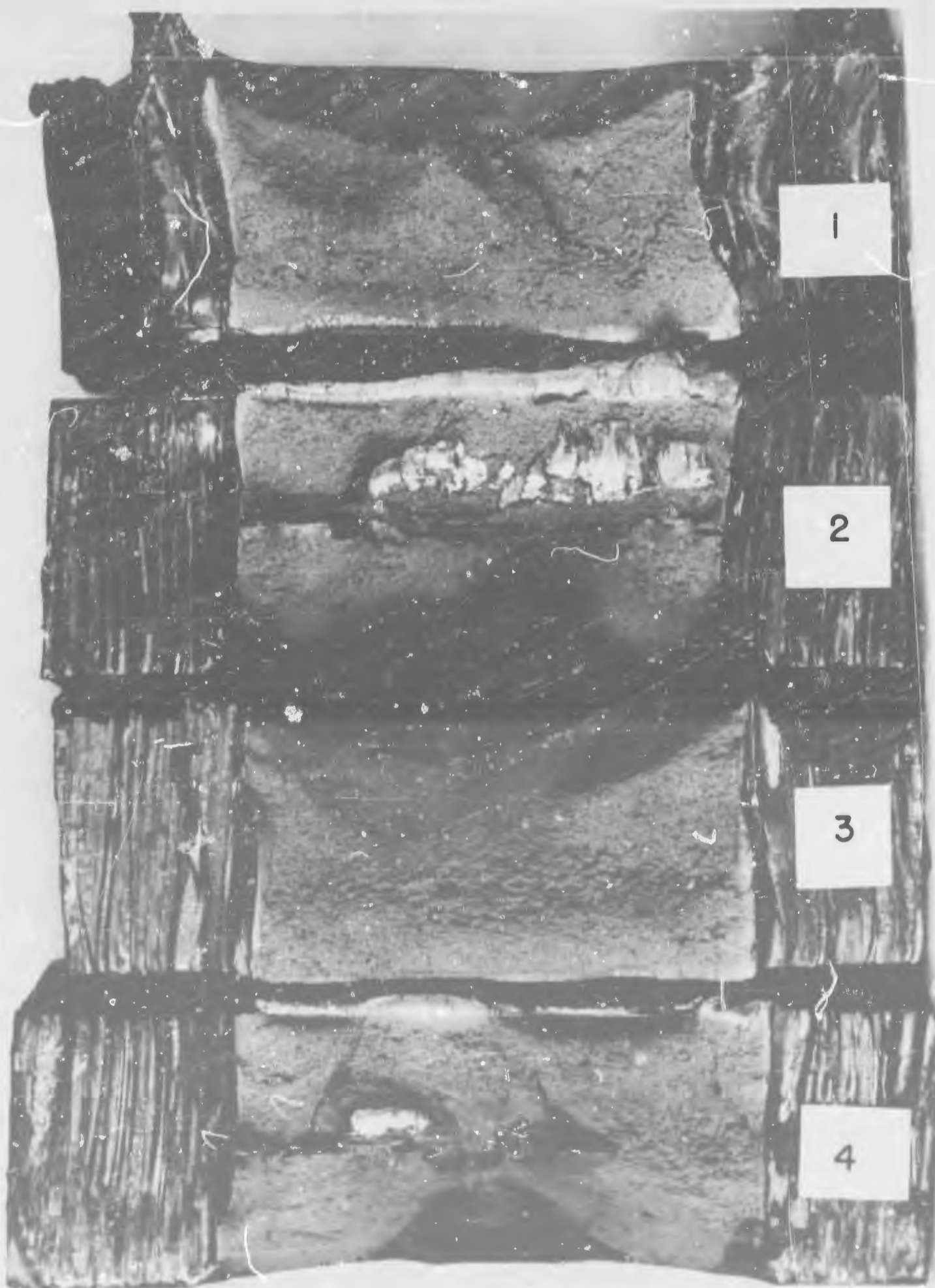


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Layout of Fracture Blocks and Macroetched Sections

FIGURE 1



WATERTOWN ARSENAL
FRACTURES OF DISBYON PLATE #1 - HEAT 4529 WTN.710-2700
24 MARCH 1944

FIGURE 2



"FISH - EYES" ON PLANE OF LAMINATION



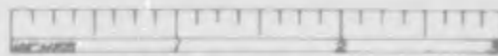
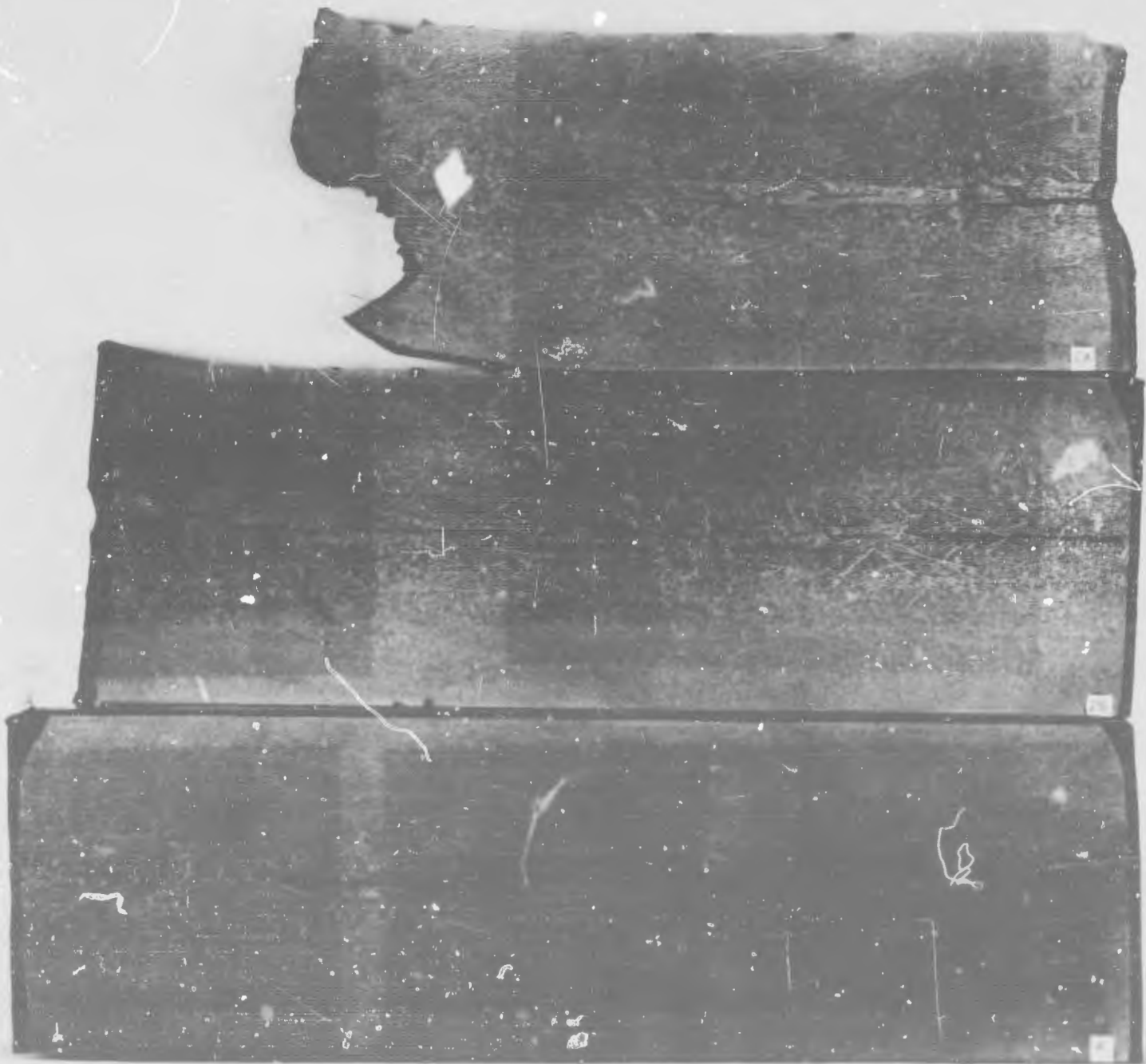
WATERTOWN ARSENAL

LAMINATION REVEALED ON FLAME CUT EDGE - DISSTON 4529-1

WTN, 710-2291

24 MARCH 1944

FIGURE 3



ORDNANCE DEPT U.S.A.
WATERLOO, ARSENAL

MACROETCHED SECTIONS FROM 2 1/2" DIAMETER PLATE #4529-1
6 APRIL 1944 WTN. 710-2293

FIGURE 4

Microstructure of Disston 23rd Plate - #4529-1

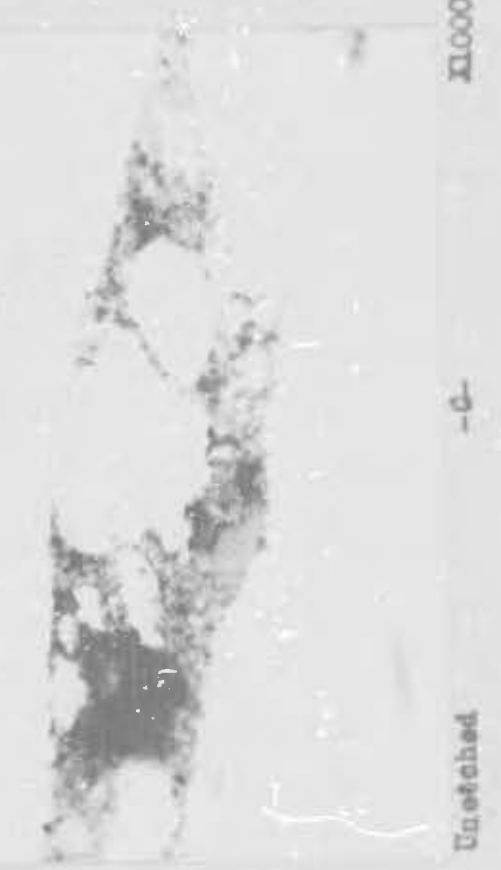
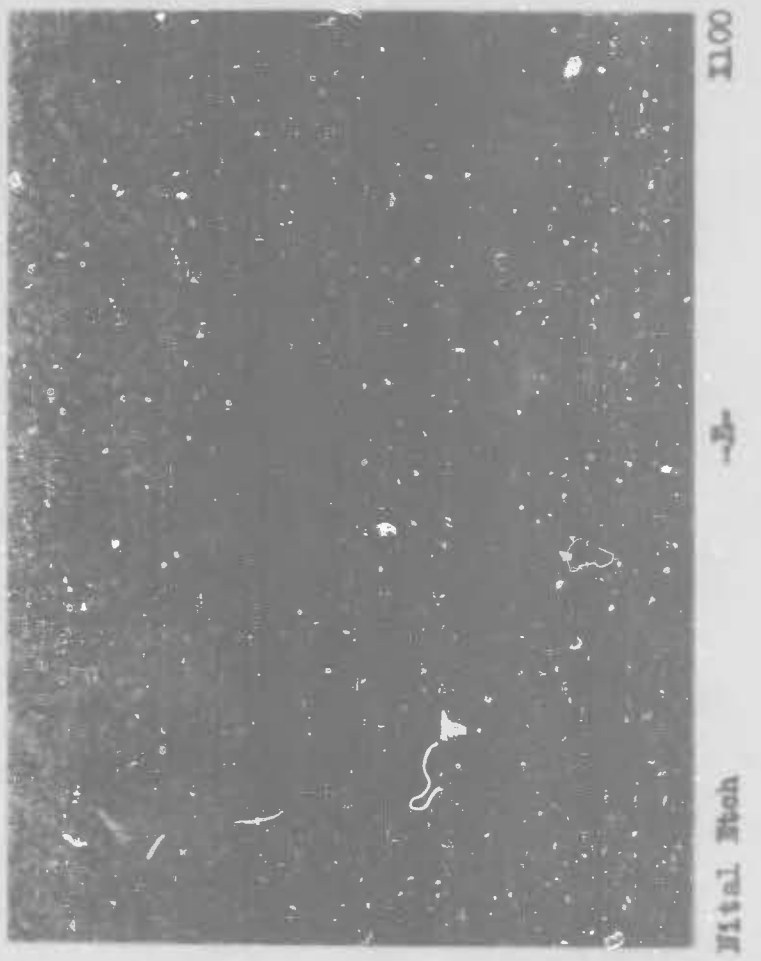
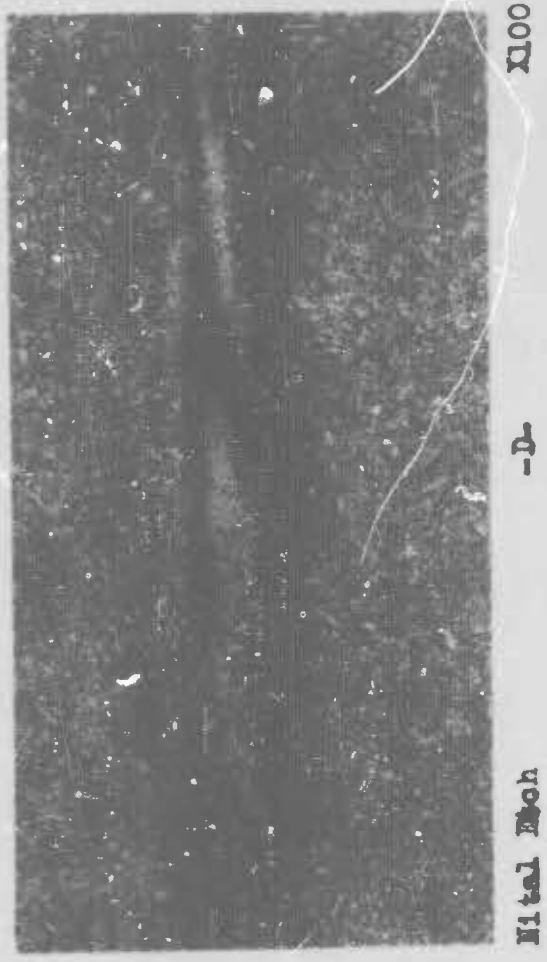


FIGURE 5

APPENDIX A

Correspondence

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TAO V WDT NE139 WD P

FROM CUMMINGS OCO DETROIT WICE 182054Z

TO THE DIRECTOR ORD RESEARCH CENTER ATTN ARMOR BR APG MD

ATTENTION IS CALLED TO WATERTOWN ARSENAL'S REPORT WAL 710/583 26 JAN 44.

2-1/2" ROLLED HOMO. PLATE NO 4529-1 FROM H DISSTON SHOULD BE SENT TO

WATERTOWN ARSENAL FOR COMPLETE METALLURGICAL EXAMINATION AS RECOMMENDED

IN PARAGRAPH 2B. IF THIS PLATE IS STILL AVAILABLE NOTIFY THIS OFFICE

AND SEND ENTIRE REMAINING PLATE TO WATERTOWN. END. CITE SPOME-RE JUDY/MS

TT 45881

2115Z

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Wtn 470.5/7743(r)
APG 470.5/3532

2nd Ind.

Wolff/ebc
5190

Army Service Forces, Ordnance Department, Ordnance Research Center,
Aberdeen Proving Ground, Maryland. 21 February 1944.

To: C.O., Army Service Forces, Ordnance Department, Watertown Arsenal,
Watertown 72, Massachusetts. Attention: Major N. A. Matthews

1. Reference paragraph 2, 1st Indorsement, additional firing as recommended has been conducted on subject plate.

2. It is requested that light "stringer-type" areas shown in the fracture photographs of report No. WAL 710-583 be identified.

3. This station is also interested in learning of any available data where an entire plate may have been cut into a number of fracture tests and such tests rated for different areas.

4. Results of additional rounds fired will be reported in A-12574.

(Note: These rounds were fired through the plate opposite to original firing.)

5. Reference is made to TT 45831 attached. Plate is being forwarded your station as requested by C.O.C.-Detroit.

For the Commanding General:

(S/T) J. G. SHINKLE
Lt. Col., Ord. Dept.
Chief, Armor Branch
Arms & Am'n. Division

4 Incls.
Incls. 1 & 2 - n/c.
Incl. 3 - w/d.
Added 1 Incl.
Incl. 4 - Copy of TT 45831

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