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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/606

Metallurgical Examination of 1/4 Inch Thick Rolled Homogeneous Armor Plate

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Research Metallurgist

DATE 8 April 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

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WATERTOWN ARSENAL LABORATORY

Memorandum Report No. WAL 710/50

Partial Report on Problem B-2.2

8 April 1944

Metallurgical Examination of 1/4 Inch Thick Rolled Homogeneous Armor Plate

ABSTRACT

In connection with the development of 1/4 inch armor plate for Specification AXS-710, Revision 2, fourteen 12 inch plates were examined for the purpose of correlating fracture tests for steel soundness and fibre characteristics with armor quality and microstructure. Correlations were made between fracture tests for fibre and microstructure and steel soundness and macrostructure. The steel plates, which were rolled from five heats, were of fair quality. No definite correlations were evident between steel soundness and ballistic tests, probably because the ballistic tests are inordinately severe.

1. This investigation was conducted as part of the program on the fracture test as a measure of steel soundness now in progress at this arsenal. In accordance with a letter from Henry Disston & Sons, Inc. dated 15 December 1943, 12 x 12 x 1/4 inch samples were submitted as listed in Table I.

2. Metallurgical examination consisted of the following tests:

a. Fracture test for steel soundness.

b. Fracture test for fibre.

c. Hardness surveys.

d. Macroscopic examination.

e. Microscopic examination.

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

a. Chemical Analyses.

The chemical analyses, reported by the manufacturer, classified the plates into two groups, namely the medium carbon Mn-Ni-Cr-Mo type and the low carbon high Ni-Mo type, see Table I.

b. Fracture Tests for Steel Quality.

Sections were cut from the plates in the longitudinal and transverse directions, tempered at 1100°F and notched perpendicular to the longitudinal axis and broken slowly under the press. The results of this test indicate that the steel was of fair quality, see Table I. One sample, No. 4776-8-1 from heat No. 4776, showed the presence of a bad lamination in the center and therefore, was rated as a "D" fracture. In a few cases, some variation in steel quality was noted in several fracture samples taken from the plates, see fracture ratings of plates, Nos. 4710-3, 4777-6-1, and 4777-8-2, in Table I.

It was impossible to rate the steel quality of samples, Nos. 4708-2-1 and 4708-9-3 since the fracture of these samples was entirely crystalline.

c. Fracture Test for Fibre.

With the exception of plates, Nos. 4708-2-1, 4708-9-3 and 4710-1, all samples exhibited a fibrous fracture indicating that the plates were heat treated satisfactorily, see Table I. The carbon content of plates, Nos. 4708-2-1 and 4708-9-3 was too low for adequate hardenability and therefore, a crystalline fracture resulted. A small amount of crystallinity was evident in sampleNo. 4710-1.

d. Hardness Surveys.

Brinell hardness surveys were made on the surface of samples of each plate which had been properly surface ground. The results are reported in Table I. The Brinell hardness values determined at Watertown Arsenal were from 10 - 50 points Brinell lower than the hardness values submitted by the manufacturer.

e. Macroscopic Examination.

The results of the macroscopic examination of the plates after etching in hot acid are shown in Figure 1. Centerline segregation was especially evident in sample No. 4776-8-1 and to a lesser degree in samples, Nos. 19296-3, 4708-9-3, 4777-6-1 and 4777-8-2. The balance of the plates was relatively free from laminations as revealed by the macroetch test.

f. Microscopic Examination.

Photomicrographs showing the types of non-metallics and the typical microstructures of the plates are shown in Figures 2 - 5 inclusive. Generally speaking, the samples were free from pronounced segregations of non-metallic inclusions; the types of alumina streaks shown occurred only occasionally either in the center or near the surface of the samples, see Figures 2, 3, and 4.

With the exception of plates, Nos. 4709-7-1 to 4709-9-3, which contained ferrite patches associated with tempered martensite, the balance of the samples which had a fibrous fracture exhibited a satisfactory microstructure, namely either tempered martensite, tempered martensite with possible traces of ferrite or sorbite and possible traces of ferrite, see Figure 5.

4. Ballistic Tests.

The results of the ballistic tests which were made at Aberdeen Proving Ground are given in Table I. The ballistic limits vary from 1 - 117 f/s in excess of the requirements of Specification AXS-48, Revision 2. Generally speaking the plates behaved satisfactorily under the projectile-through-plate test using Cal. .50 AP projectiles with a striking velocity of 1 50 f/s. At a striking velocity of 2400 f/s using the same projectile, nine out of the fourteen plates tested failed to meet the projectile-through-plate test. It is believed that these failures were associated with the high impact velocity and the resultant jacket effect. The majority of the plates with inferior fractures, (crystalline or "D" soundness rating) failed the high velocity PTP test involving jacket penetration. In the same section, none of the plates with pronounced segregated macrostructure passed this test. On the other hand, some of the best plates with respect to fracture quality and microstructure failed to meet the test, reference plates 1929-2-1a, 1929-1.

Eleven of the plates failed to pass the shock test using the 37 M. H.E. projectile. A survey of the ballistic data in the Aberdeen Proving Ground firing records indicated that three of these failed plates, namely Nos. 1929-3, 4710-1 and 4776-8-1 were subjected to a striking velocity of about 90 f/s in excess of the specification requirements for the shock test. On the other hand plate No. 4777-8-2, which passed the shock test, was subjected to a striking velocity of about 0 f/s below the specification requirements. It is apparent, however, that both the high velocity PTP test and the shock test requirements must be modified before even the best armor that can be commercially produced will consistently meet these tests.

5. Metallurgical tests made on the samples submitted indicate that there was a satisfactory correlation between steel soundness and the macrostructure and also between the fibre test and the resultant microstructure. On the other hand, the correlation between steel soundness and the

occurrence of non-metallic inclusions was not evident in these tests. It is believed that the fracture test is more sensitive in revealing steel soundness than a macroscopic or microscopic examination.

The fourteen plates representing five heats were of fair steel quality. Heat No. 19290 was uniformly satisfactory as revealed by the fracture test for steel soundness, while heats Nos. 4710, 4776 and 4777 showed the presence of occasional laminations.

E. L. Reed.
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Research Metallurgist

APPROVED:

N. A. MATTHEWS
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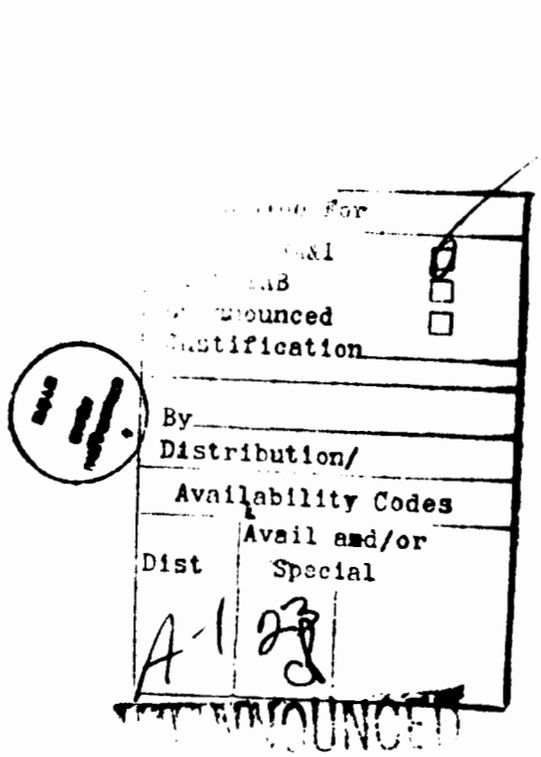
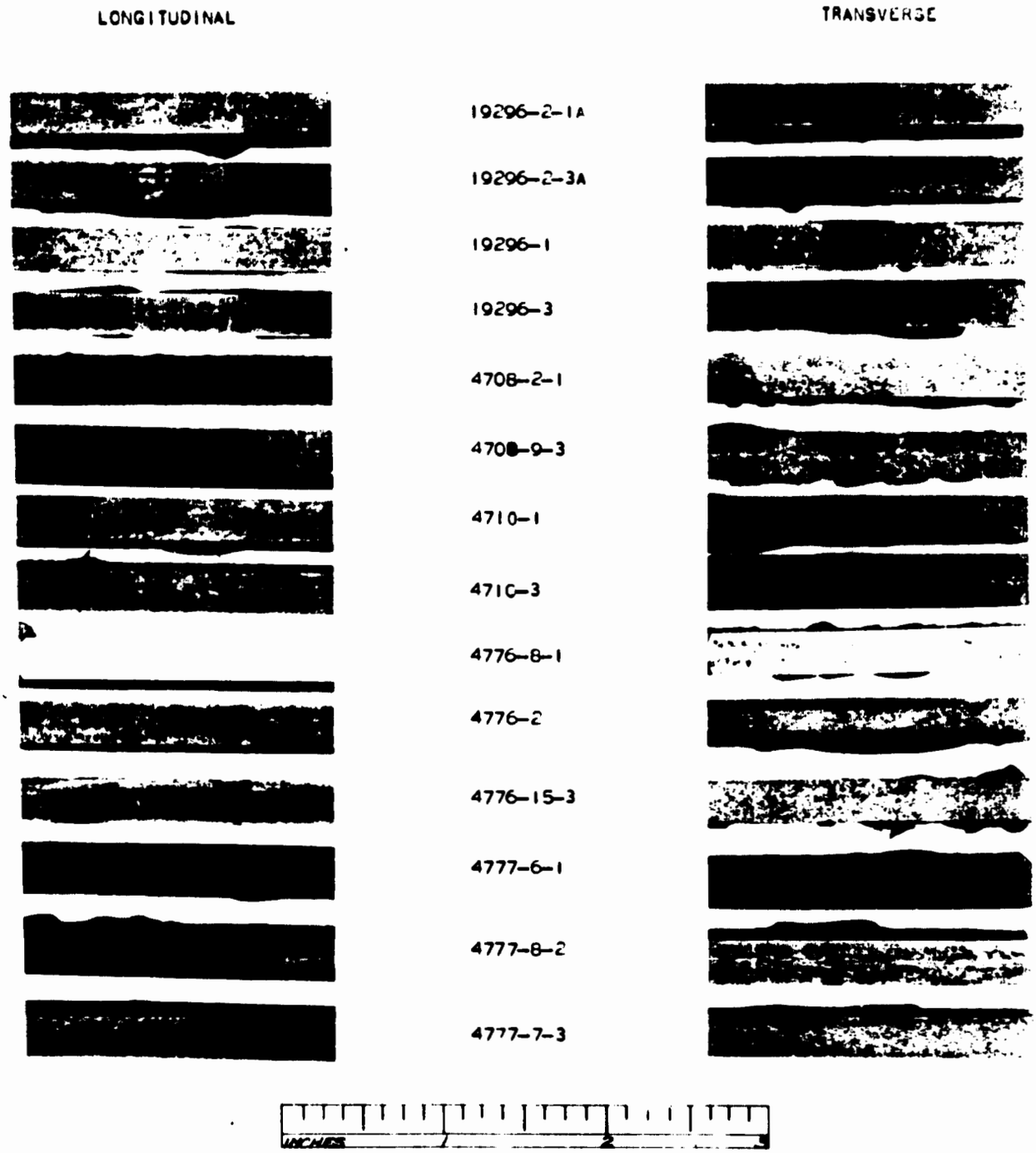
Chief, Armor Section



[illegible]	[illegible]	[illegible]	[illegible]	Sorbite and Possible Traces of Ferrite
[illegible]	[illegible]	[illegible]	[illegible]	Sorbite and Possible Traces of Ferrite
[illegible]	[illegible]	[illegible]	Satisfactory	Tempered Martensite
[illegible]	[illegible]	120 ([illegible])	Satisfactory	Sorbite and Possible Traces of Ferrite
[illegible]	[illegible]	[illegible]	[illegible]	Tempered Martensite
[illegible]tory	[illegible]	121 ([illegible])	Same Centerline [illegible]	Sorbite and Possible Traces of Ferrite
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[redacted]

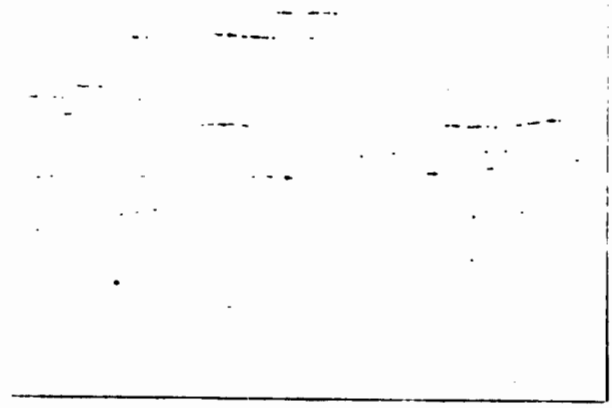


ORDNANCE DEPT U.S.A.
WATERTOWN ARSENAL

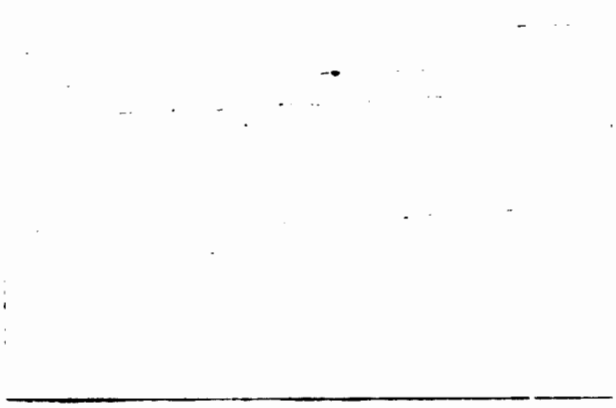
MACROSTRUCTURE OF 1/4" THICK ROLLED PLATES SUBMITTED BY HENRY DISSTON & SONC INC. 2 FEB 1944 WTN.710-2271

Figure 1

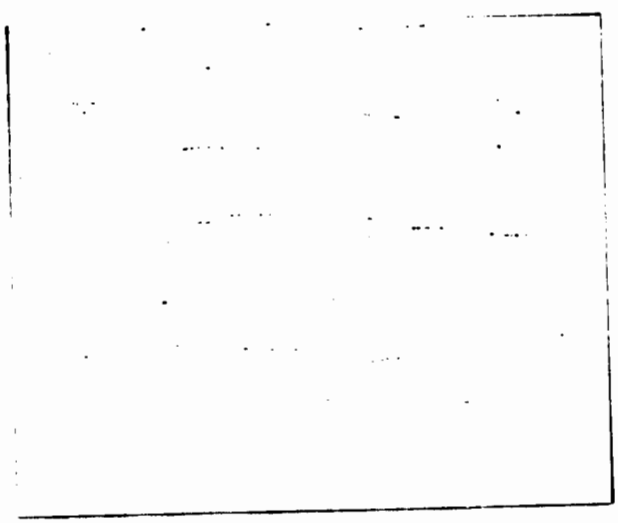
Henry Disston & Sons, 1/4" Homogeneous Armor
Typical Non-Metallic Inclusions
X100 - Unetched



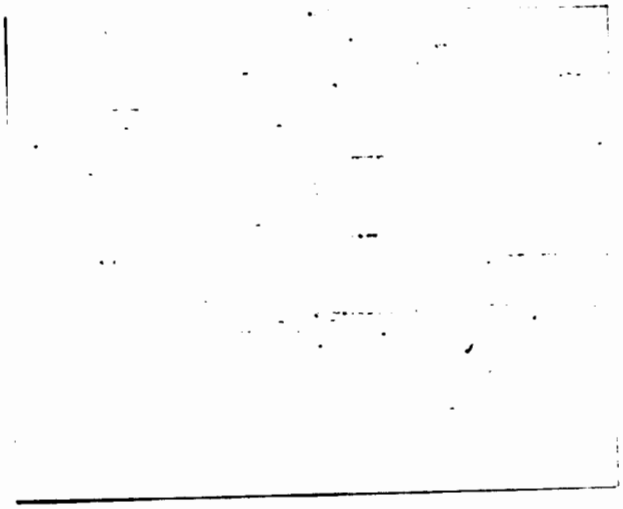
No. 19296-2-1A. Fine oxide-silicate inclusions well distributed.



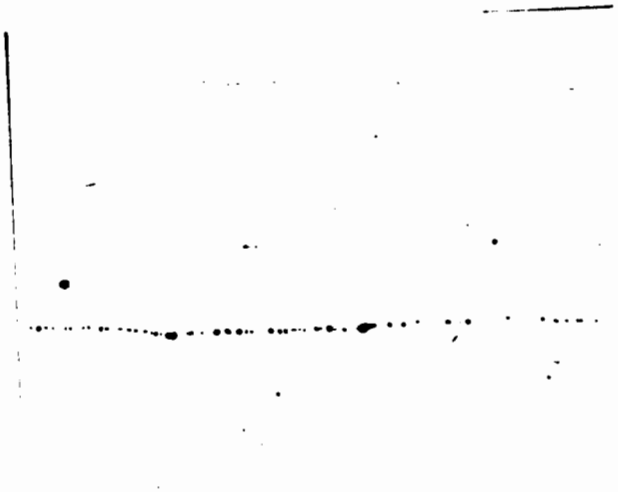
No. 19296-2-3A. Fine oxide-silicate inclusions well distributed.



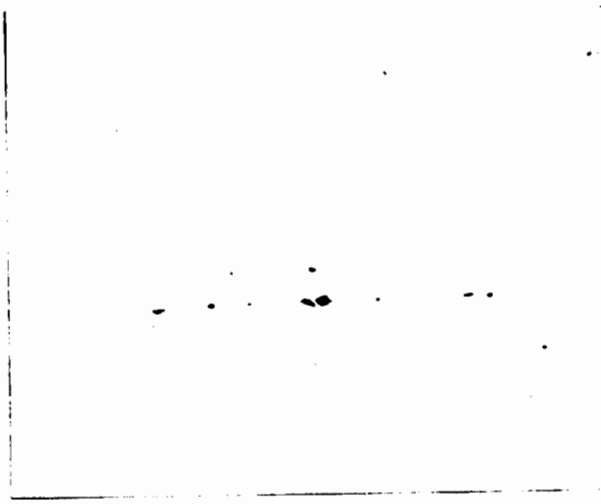
No. 19296-1. Fine oxide-silicate inclusions well distributed.



No. 19296-1. Segregation of oxide-silicate inclusions near plate surface



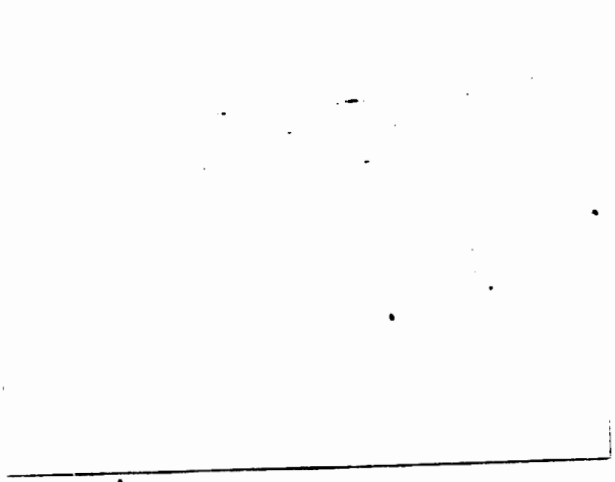
No. 19296-3. Alumina inclusion streaks near surface. Fine oxide-silicate inclusions well distributed.



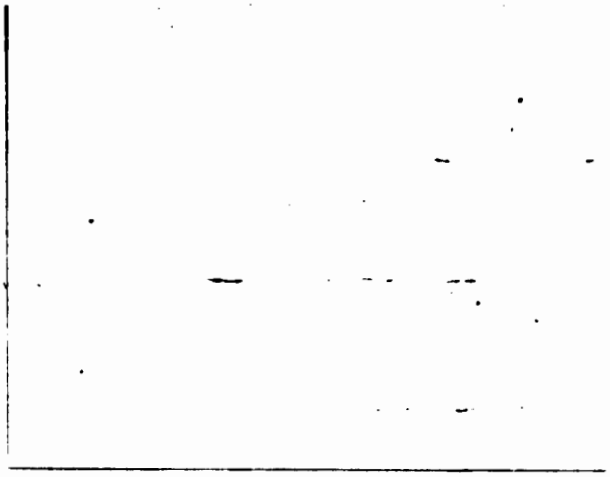
No. 4706-2-1. Small complex oxide inclusions well distributed.

FIGURE 2

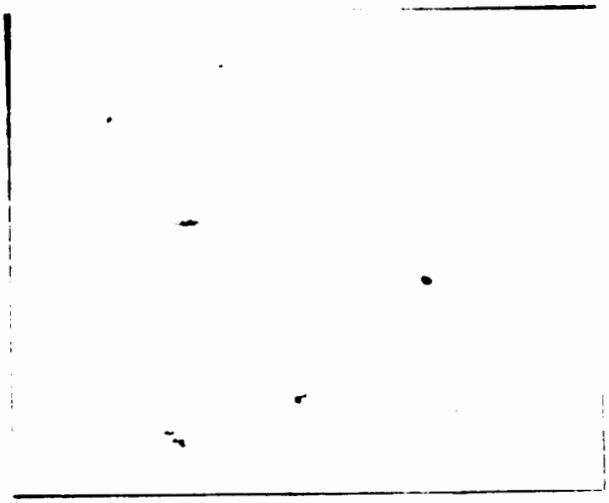
Henry Disston & Sons, 1/4" Homogeneous Armor
Typical Non-Metallic Inclusions
X100 - Unetched



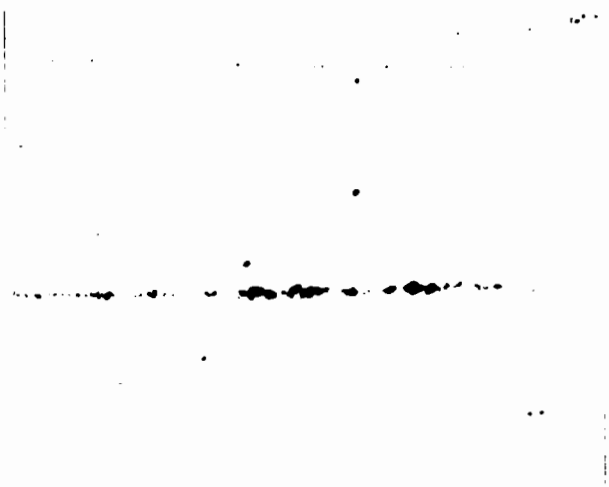
No. 4706-9-3. Fine oxide-silicate inclusions well distributed.



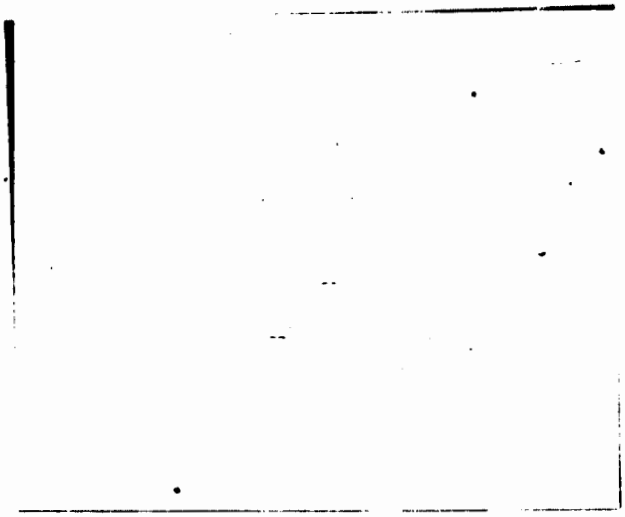
No. 4701-1. Fine oxide-silicate inclusions well distributed.



No. 4710-3. Small oxide sulphide inclusions well distributed.



No. 4776-2. Alumina inclusion streak near surface.

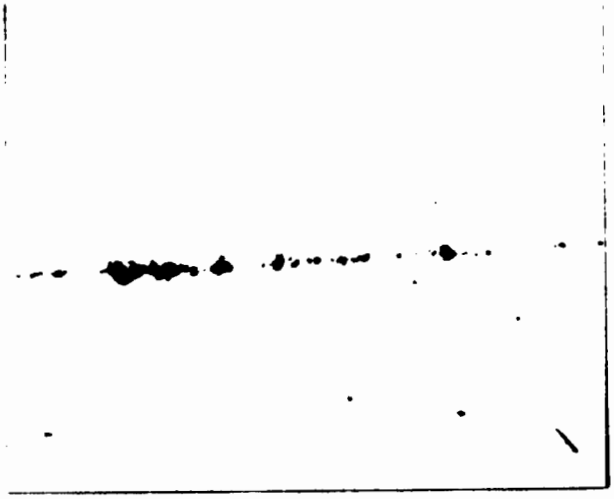


No. 4776-8-1. Fine oxide-silicate inclusions well distributed.

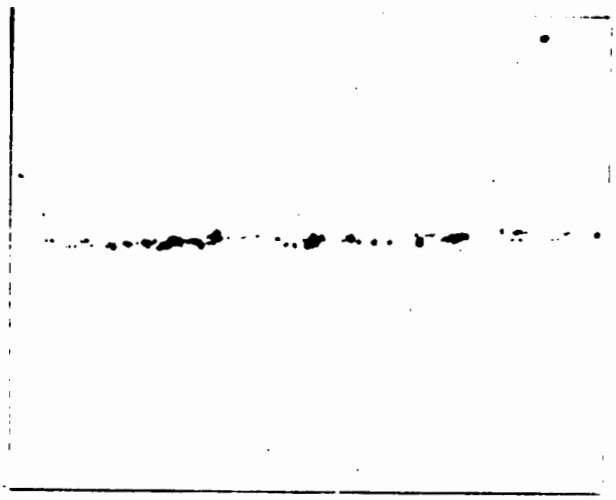
No. 4776-8-1. More pronounced oxide-silicate inclusions near surface.

FIGURE 3

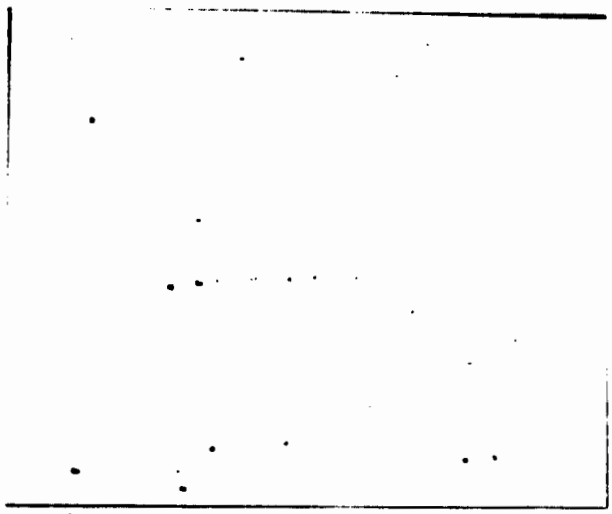
Henry Disston & Sons, 1/4" Homogeneous Armor
Typical Non-Metallic Inclusions
X100 - Unetched



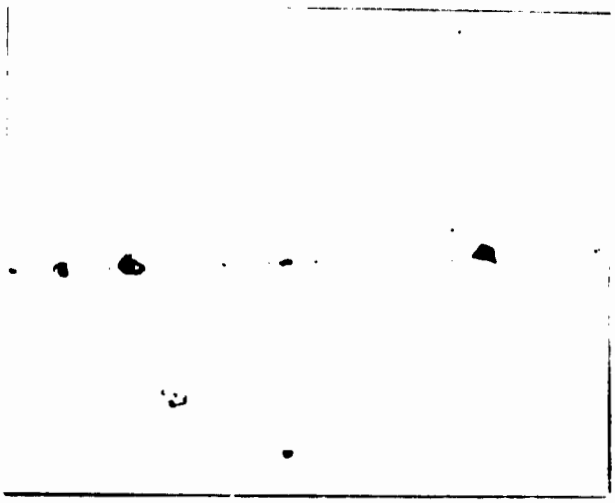
No. 4776-15-3. Alumina inclusion streak near surface.



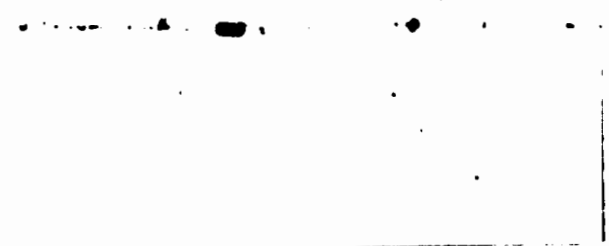
No. 4777-8-2. Alumina inclusions in center of plate.



No. 4777-6-1. Alumina and fine silicate inclusions well distributed.



No. 4777-6-1. Alumina streak associated with angular oxides in center of plate.

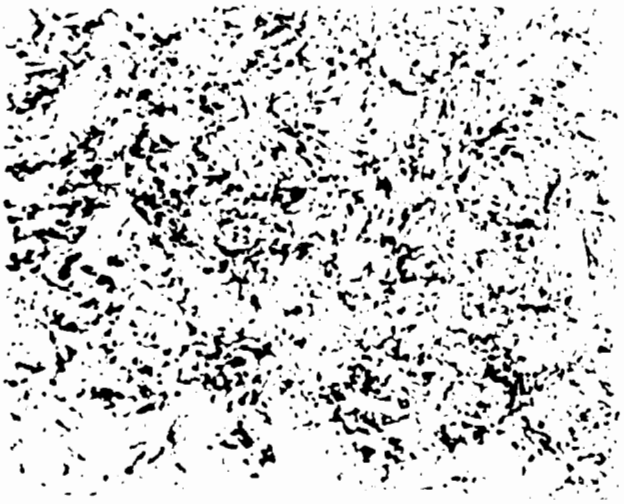


No. 4777-7-3. Alumina

[illegible] transformations, 1/2" [illegible]

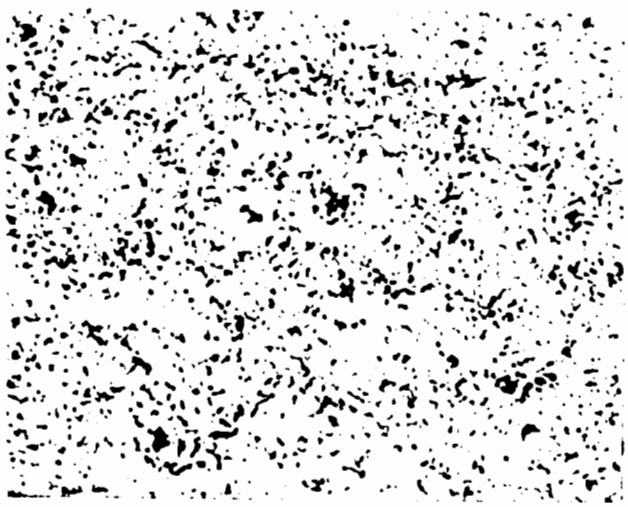
Typical [illegible] structures

X1000 - Picral etch



No. 19296-2-1A. Tempered martensite structure typical of plates 4776-8-2, 4777-15-3, and 4777-2-1.

No. 4709-9-3. Tempered martensite and large patches of ferrite. Typical also of plate 4709-2-1.



No. 4776-8-1. Fairly uniform sorbite and possible traces of ferrite. Typical of plates 4776-15-3, 19296-2-1A, 19296-1, and 19296-3.

No. 4710-1. Tempered martensite and possible traces of ferrite. Typical also of plate 4710-3.

FIGURE 5.