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REPORT NO. 710/407

~~RESTRICTED~~

METALLURGICAL EXAMINATION OF TWO DISSTON 1-1/2" ROLLED HOMOGENEOUS ARMOR PLATES

by

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1st Lt., Ord. Dept.

January 13, 1942
WATERTOWN ARSENAL
WATERTOWN, MASS.

Report No. 710/407
Watertown Arsenal
Restricted

January 13, 1942

Metallurgical Examination of Two Disston 1-1/2" Rolled Homogeneous Armor Plates

OBJECT

To determine the metallurgical characteristics of good and poor quality Disston 1-1/2" rolled homogeneous armor plates, including chemical analyses, macroscopic and microscopic examination, physical tests, and hardness surveys.

REFERENCES

Letter from Henry Disston & Sons, Inc., dated July 18, 1941

The basic correspondence and material pertaining to this report are contained in Appendix A.

CONCLUSIONS

1. The defective plate from Heat 1843 (D3) was heat treated to a too high hardness (311 Brinell);

2. The macrostructure of the poor Heat 1843 (D3) as revealed by the Oberhoffer reagent indicated that the dendritic structure was improperly refined during the hot rolling operation;

3. The satisfactory plate from Heat 1830 (D4) which was correctly heat treated to a hardness of 293 Brinell showed the presence of some center line banding of a relative high carbon

content although it was not associated with a marked segregation of nonmetallic inclusions. This condition, noted previously in other samples of armor, is not related to spalling when the plate is heat treated to the correct hardness.

4. Heats 1830 (D4) and 1843 (D3) are free from pronounced segregated nonmetallic inclusions.

5. For the purpose of revealing grain boundary carbides it has been determined that a 10% chromic acid electrolytic etch has been found superior to the Murakami's reagent or the alkaline sodium picrate.

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APPROVED:

G. L. Cox,
Major, Ordnance Dept.,
Acting Director of Laboratory.

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INTRODUCTION

This investigation was conducted in accordance with the cooperative program with industry now in progress at this Arsenal on the correlation of metallurgical and ballistic properties of rolled armor.

A sample of good quality rolled homogeneous armor plate, 18"x18"x1-1/2", heat 1830 (D4) and a poor sample, 18"x18"x1-1/2", heat 1843 (D3) were submitted by the Henry Disston & Sons, Inc. for metallurgical examination.

TEST PROCEDURE

Metallurgical examination included chemical analyses, macroscopic and microscopic examination, physical tests, and hardness surveys. Ballistic tests were made at Aberdeen Proving Ground.

RESULTS

1. Chemical Analyses

   a. Carbon Distribution from Face to Core of Plate. (See Table I.)

Table I

Chemical Analyses

Heat No.	1st Cut 1/32"	2nd Cut 1/32"	3rd Cut 1/32"	4th Cut 1/32"	5th Cut 1/16"	6th Cut 1/16"	7th Cut 1/16"	8th Cut 1/16"	9th Cut 1/8"	10th Cut 1/8"	11th Cut 1/8"
1830 (D4) Good quality	.22	.24	.22	.24	.26	.27	.26	.23	.23	.23	.23
1843 (D3) Poor quality	.26	.27	.23	.25	.22	.21	.22	.21	.22	.22	.23

b. Analyses of Steel Base. (See Table II.)

Table II

Heat No.	C	Mn	P	S	Si	Ni	Cr	Cu	Mo	Va
1830 (D4) Good quality	.23	.45	.013	.017	.230	4.88	.084	.125	.30	.09
1843 (D3) Poor quality	.23	.45	.016	.018	.240	4.83	.12	.135	.28	.09

2. Macroscopic Examination

Figure 1 illustrates the macrostructure of the heats 1830 and 1843 after deep etching. Generally speaking, these heats are relatively clean.

Figure 2 shows the macrostructure of these heats after etching in the Oberhoffer reagent. The poor quality heat 1843 shows a deformed dendritic structure both in the longitudinal and transverse sections. Apparently this heat was not hot worked as thoroughly as heat 1830.

3. Microscopic Examination

In the central layers of the good quality heat 1830 (D4) a band of fine nonmetallics about 1/8" in width was detected. With the exception of this band of nonmetallic inclusions this heat was quite free from segregated nonmetallics. (See Figures 3a, b, and c.) The poor quality heat 1843 (D3) was relatively free from nonmetallic inclusions. (See Figure 3d.)

The typical microstructure of the good quality heat 1830 (D4) and also the banded area of the midsections are shown in

Figures 4a, 6a, b, and c. The grain boundary carbides as revealed by the Murakami reagent, 10% chromic acid (electrolytic etch) and alkaline sodium picrate are shown in Figures 7a, b, c, d, e, and 8a, and b. Figure 9 illustrates the segregation in the central layers of heat 1830 and the absence of such segregation in heat 1843 as revealed by the alkaline sodium picrate etch. This segregation is not all carbides as shown by the 10% chromic acid electrolytic etch. (See Figures 7d, and e.)

4. Physical Tests

Physical tests made on the plates are given in Table III.

Table III

Physical Tests

Heat No.	Our No.	Y.S.P. Lbs./Sq.In. Divider Method	T.S. Lbs./Sq.In.	% Elong. in 1.4"	% Red. in Area	Impact Ft./Lbs.
1830	D4-1	111,000	134,800	17.1	50.6	54.8) Average
Good quality	D4-2	111,800	136,000	20.0	60.3	65.0) 59.9
1843	D3-1	114,000	139,400	19.3	63.7	58.4) Average
Poor quality	D3-2	112,400	140,000	15.7	49.8	39.5) 49.0

Note: - Test bars D4-2 and D3-2 cut at right angles to test bars D4-1 and D3-1.

5. Ballistic Tests

Ballistic tests as reported in Aberdeen Proving Ground firing record Nos. 24655A983 dated June 12, and 13, 1941, and No. 25115A1064 are reported in Table IV.

Table IV

Ballistic Tests

Heat No.	Our No.	Thick-ness	Angle of Plate	Projec-tile	Lowest Complete Penetra-tion F/S	Highest Partial Penetra-tion F/S	Ballistic Limit F/S	Shock Test	Result
1830 Good Quality	D4	1½"	Normal	37mm. AP M51	1611	1572	1592		Acceptable
			25°	75mm. AP T12		979		O.K.	
1843 Poor Quality	D3	1½"	Normal	37mm. AP M51	1608	1569	1589		Failed 8" back spall on shock.
			25°	75mm. AP T12	942			Failed	

Specified Ballistic Limit - 1500 f/s

6. Hardness Tests

a. Vickers Brinell Hardness Survey

The Vickers Brinell hardness survey made across a section of heats 1830 (D4) and 1843 (D3) is shown in Table V.

Table V

Vickers Brinell Hardness Survey

10 Kg Load - Readings 0.03" Apart

	Good Quality Heat 1830 (D4)	Poor Quality Heat 1843 (D3)
At Surface A	282	302
	287	302
	287	307
	282	302
	292	302
	292	302
	287	312
	278	312
	282	317
	282	317
	287	312
	287	317
	287	317
	282	312
	282	312
	282	317
	282	317
	282	307
	282	312
	287	317
	278	317
	274	317
	282	317
	278	317
	287	307
	282	312
	282	317
	278	317
	274	312
	278	312
	278	312
	287	317
	282	312
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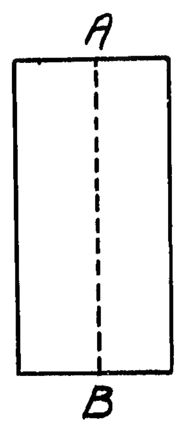
	282	317
	287	312
	292	312
	287	307
	278	312
	282	317
	287	307
	282	307



At Surface A	282	At Surface A	312
	282		312
	282		307
	287		307
	292		312
	287		307
	282		312
At Surface B	282		307
		At Surface B	307
Average	283	Average	312

b. Brinell Hardness Tests

Brinell hardness tests reported by the manufacturer and Watertown Arsenal are given below.

	Manufacturer	Watertown Arsenal
Good Quality Heat 1830 (D4)	293-302	293-293
Poor Quality Heat 1843 (D3)	285-285	311-311

DISCUSSION

The results of this investigation indicated that failure of the heat 1843 (D3) was mainly due to a relatively high Brinell hardness, namely 311 which was determined on the cross section of the plate. A Vickers hardness survey made on this section indicated that the hardness was quite uniform from one surface to the other. The value of 285 Brinell as reported on this plate by the manufacturer was undoubtedly determined on a partially decarburized surface. This heat had a fairly uniform sorbitic structure with some indication of grain boundary carbides present. Such grain boundary carbides with a relatively high hardness are conducive to brittleness under the ballistic test. The average impact value determined on this heat, namely 49.0 foot pounds as compared with the average impact value determined on the good quality heat 1830 (D4) of 59.9 foot pounds indicates a substantial difference in the impact resistance of these two heats, which is undoubtedly a reflection of the difference in hardness. Furthermore, it was observed that the poor quality heat 1843 (D3) showed a more persistent dendritic structure in the longitudinal section as compared to the good quality heat 1830 (D4). Apparently, the poor quality heat 1843 (D3) was not hot worked as thoroughly as the good heat 1830 (D4).

The good quality heat 1830 (D4) showed some banding in the central layers of the plate. These bands were of a higher carbon content than the steel base. Some fine nonmetallic inclusions were present in these bands. The hardness of this heat, which was found to be 293, agreed closely with that reported by the manufacturer, 293-302. Furthermore, a Vickers Brinell hardness survey made across a cross section of this plate showed the material to be uniform in hardness from one surface to the other. It has been observed that banding which is not associated with pronounced segregations of nonmetallic inclusions is not related to spalling tendencies. (Reference, Watertown Arsenal Report No. 710/396.) Furthermore this good quality plate, disregarding the banding present in the central layers had a uniform sorbitic structure and some indication of grain boundary carbides. It is believed that grain boundary carbide associated with a hardness of 293 Brinell is not conducive to brittleness under the ballistic test.

The good quality heat 1830 (D4) had an average grain size of A.S.T.M. No. 8 while the poor quality heat 1843 (D3) had an average grain size of No. 7.

Recent investigations on the use of various reagents for revealing grain boundary carbides indicate that a 10% chromic acid electrolytic etch is superior to the Murakami reagent ,and alkaline sodium picrate. Alkaline sodium picrate attacks other constituents, such as manganese segregations, ferrite rich in silicon, etc. (See "Metallographers' Handbook of Etching" by Berglund, and "Use of Sodium Picrate in Revealing Dendritic Segregation in Iron Alloys" by Sauveur & Krivobok, A.I.M.M.E. Transactions, Vol. LXX, 1924, Pages 239-253.

Figure 7d, e, illustrates the etching of the banded area in heat 1830 (D4) in 10% chromic acid (electrolytic) and also in alkaline sodium picrate. It is to be noticed that alkaline sodium picrate tends to etch or discolor areas in the relatively high carbon band other than carbides.

Figure 1

Macroscopic Examination

Deep Etch

Good Quality Heat 1830 (D4)

Evidence of a segregated band in the central layers of the plate.

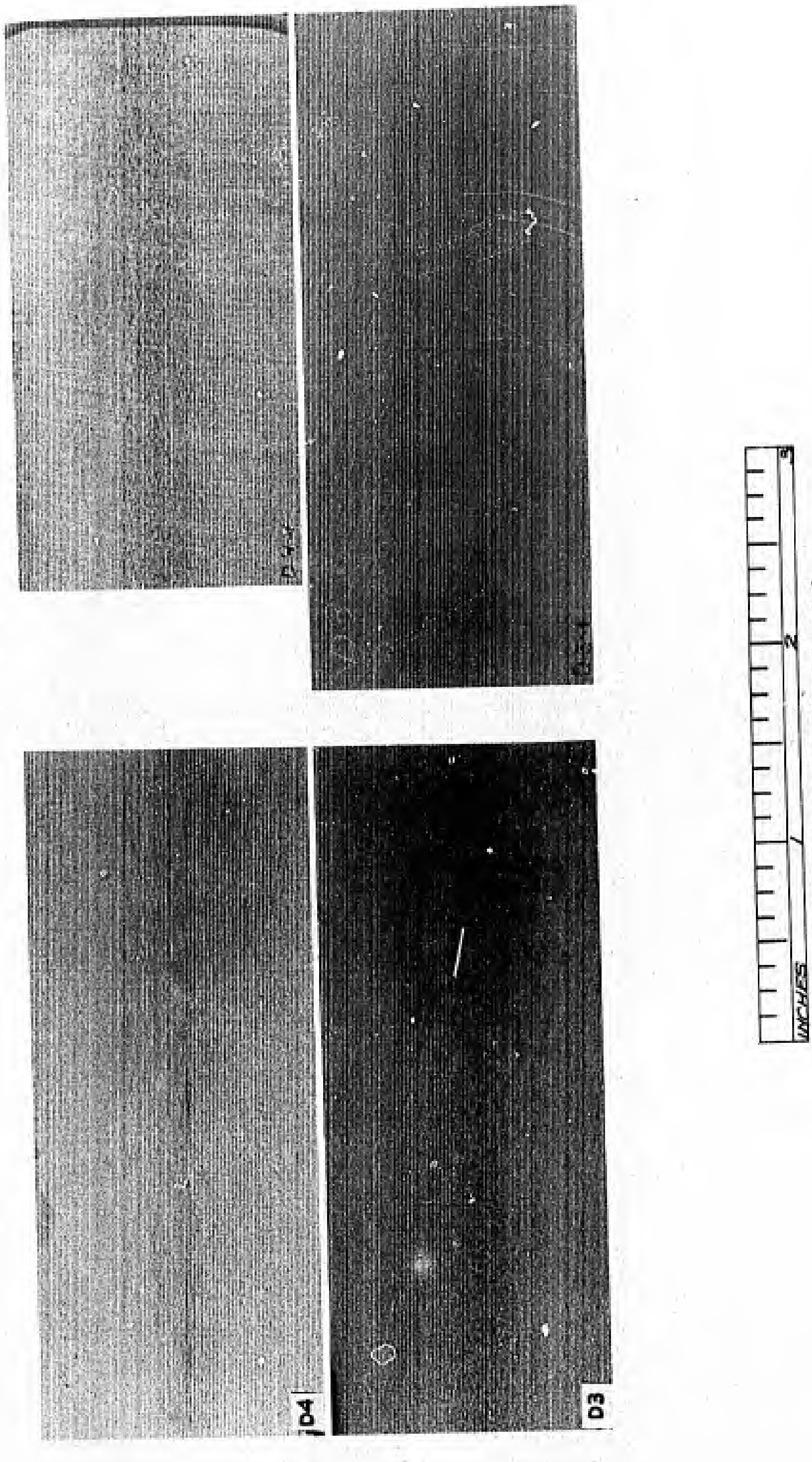
D4-1 section of heat 1830 cut at right angles to D4.

Poor Quality Heat 1843 (D3)

Fairly uniform heat.

D3-1 section of heat 1843 cut at right angles to D3.

FIGURE 1



ORDNANCE DEPT. U.S.A.
WATERTOWN ARSENAL

1 1/2" ROLLED HOMOGENEOUS ARMOR PLATE
AUGUST 30, 1941 W.A.710-1374

Figure 2

Oberhoffer Etch

a. Good Quality Heat 1830 (D4) Longitudinal

Uniform banded structure.

X3 MA-3825

b. Good Quality Heat 1830 (D4) Transverse

Uniform deformed dendritic structure.

X3 MA-3826

c. Poor Quality Heat 1843 (D3) Longitudinal

Uniform deformed dendritic structure. This type of structure indicates that this heat was not hot worked as thoroughly as heat 1830. (See figure 2a.)

X3 MA-3827

d. Poor Quality Heat 1843 (D3) Transverse

Deformed dendritic structure of variable size.

X3 MA-3828

FIGURE 2.

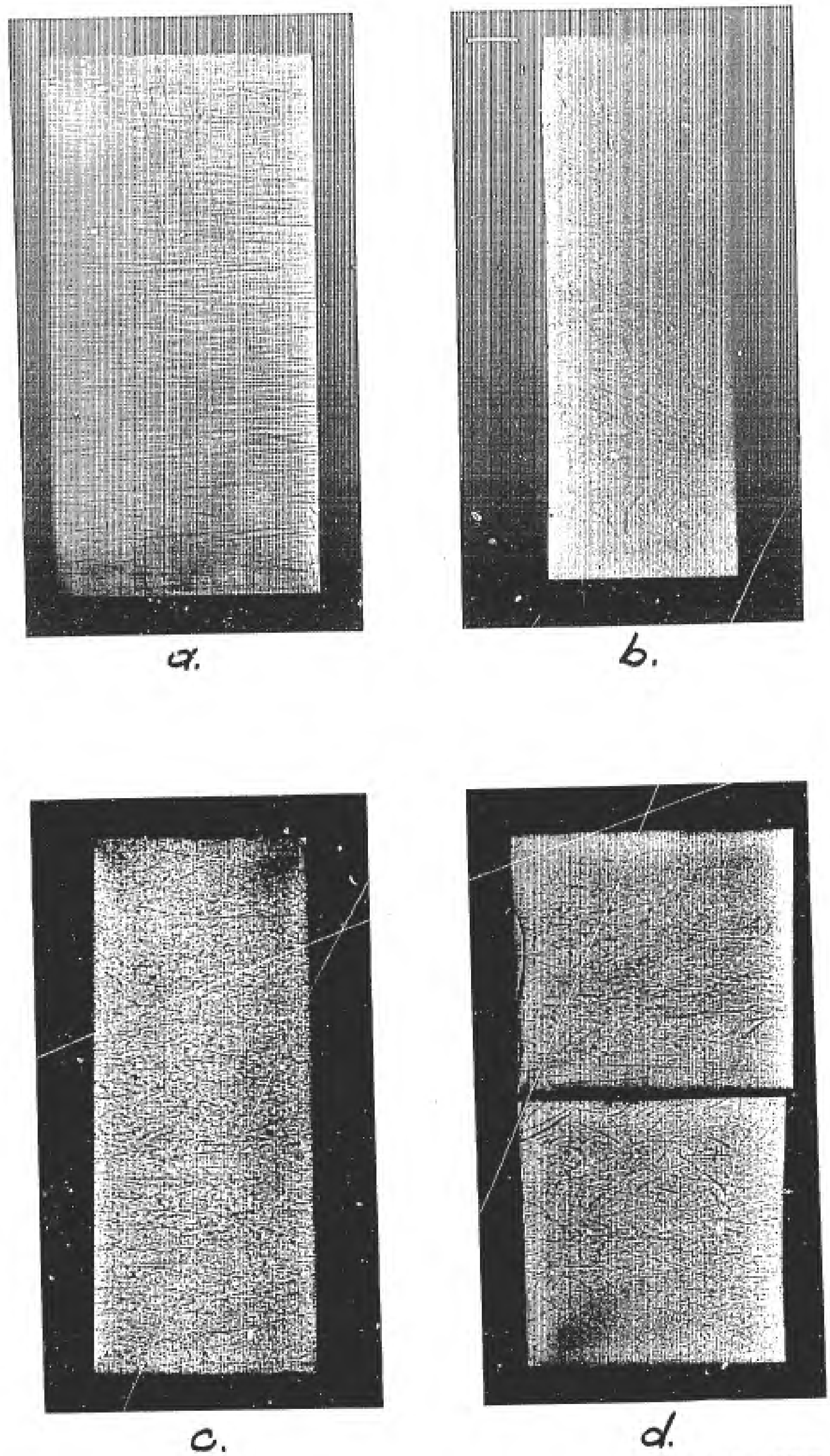


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Figure 3

a. Good Quality Heat 1830 (D4)

Typical nonmetallic inclusions present in plate with exception of segregation of nonmetallics found in the central layers of the plate. (See Figure 3b, c.)

Unetched X25 MA-3761

b. Same as in a showing segregated nonmetallic inclusions in a band about 1/8" in width running through the midsection of the plate.

Unetched X25 MA-3760

c. Same as in b elongated nonmetallic inclusions in central layers located in the midsection of the plate. These bands appear to be of higher carbon content.

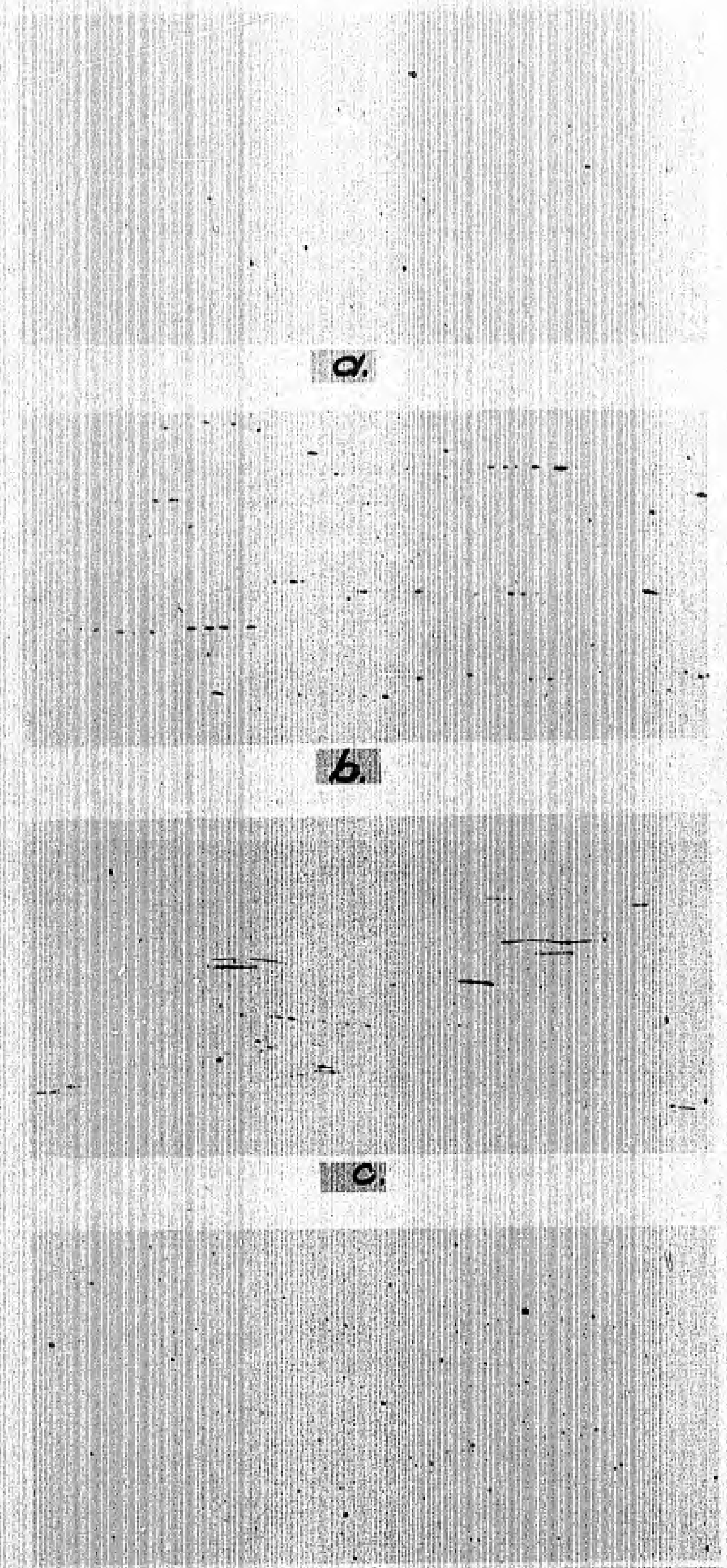
Unetched X100 MA-3820

d. Poor Quality Heat 1843 (D3)

Typical nonmetallic inclusions present. This heat is relatively free from nonmetallic inclusions.

Unetched X25 MA-3762

FIGURE 3.



a. b. c. d.

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Figure 4

Microstructure

a. Good quality Heat 1630 (D4)

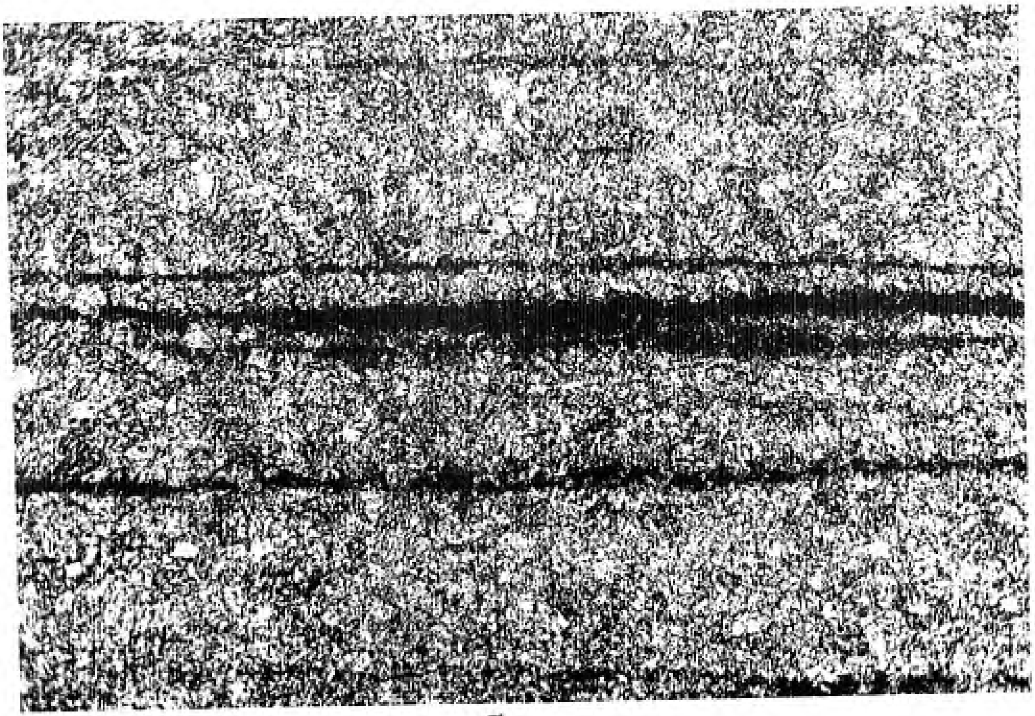
Typical microstructure and also banded central layers of plate. Banded areas are about 1/8" wide in midsection of plate.

Etched in 1% Nital X100 MA-3772

b. Same as a showing banding in central layers of plate.

Etched in 1% Nital. X250 MA-3768

FIGURE 4.



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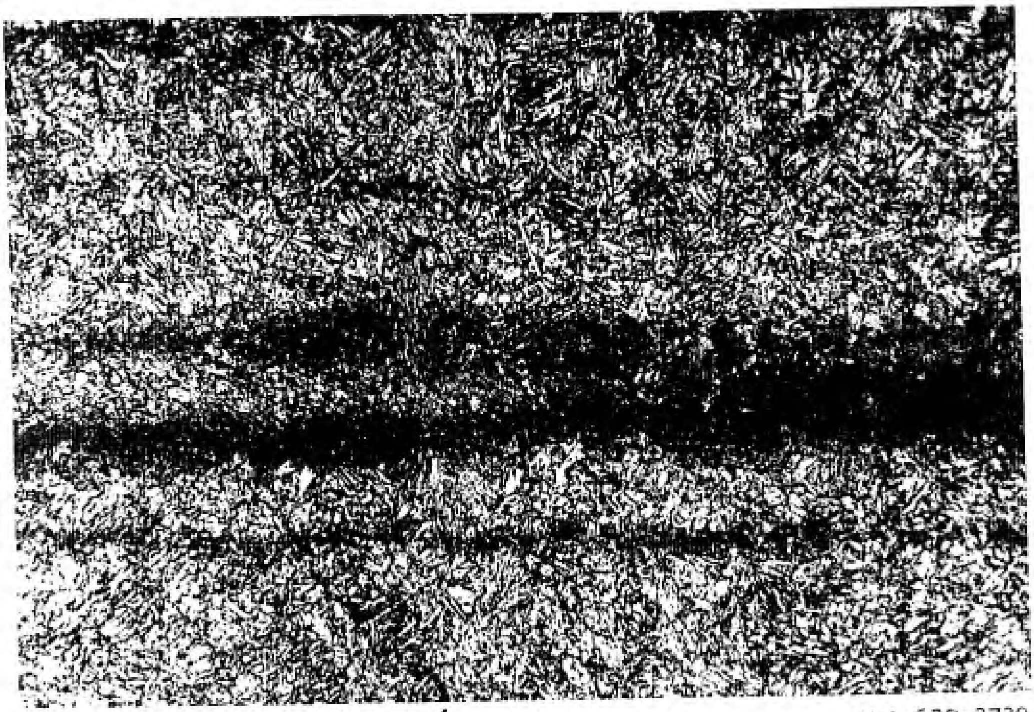

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b.

Figure 5

Microstructure

a. Poor Quality Heat 1843 (D3)

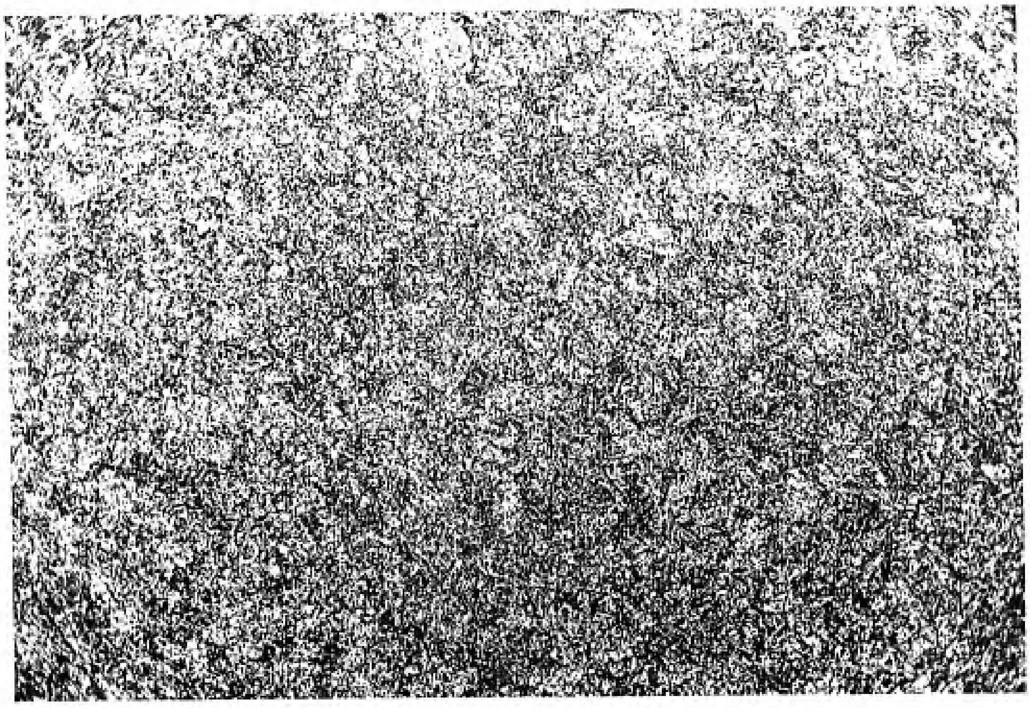
Uniform microstructure.

Etched in 1% Nital X100 MA-3824

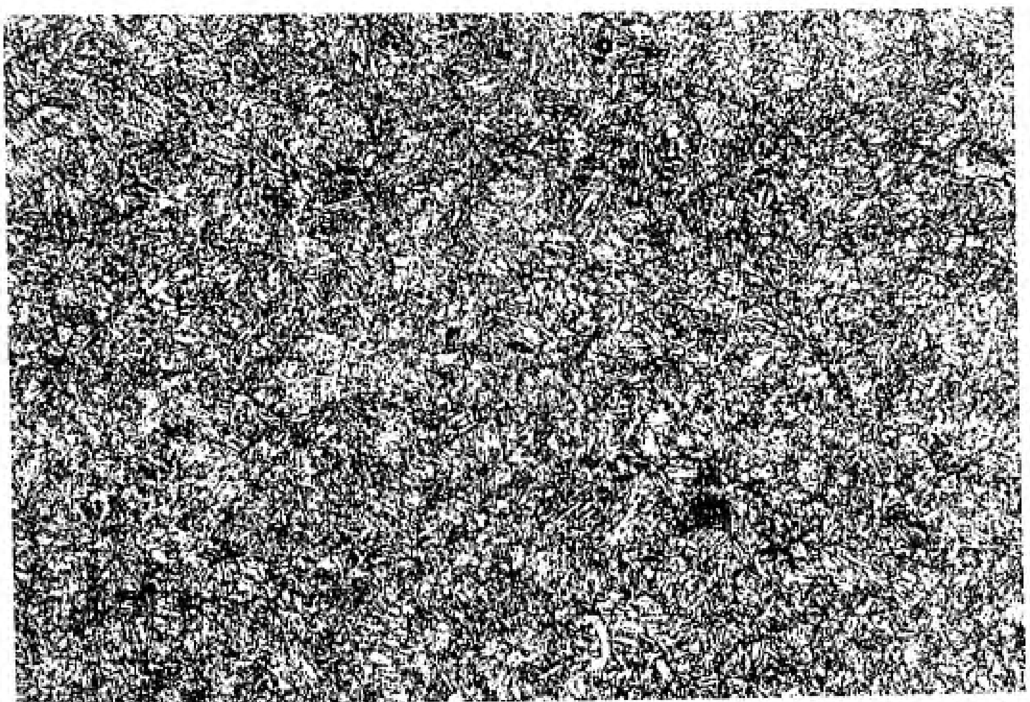
b. Same as a showing uniform microstructure

Etched in 1% Nital X250 MA-3771

FIGURE 5.



a.



b.

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Figure 6

Microstructure

a. Good Quality Plate 1830 (D4)

Typical microstructure of plate, A.S.T.M. grain size No. 8.

Etched in 1% Nital X1000 MA-3764

b. Same as a showing microstructure of band containing relatively high carbon located in the central layers of the plate. The structure of the band is slightly lamellar.

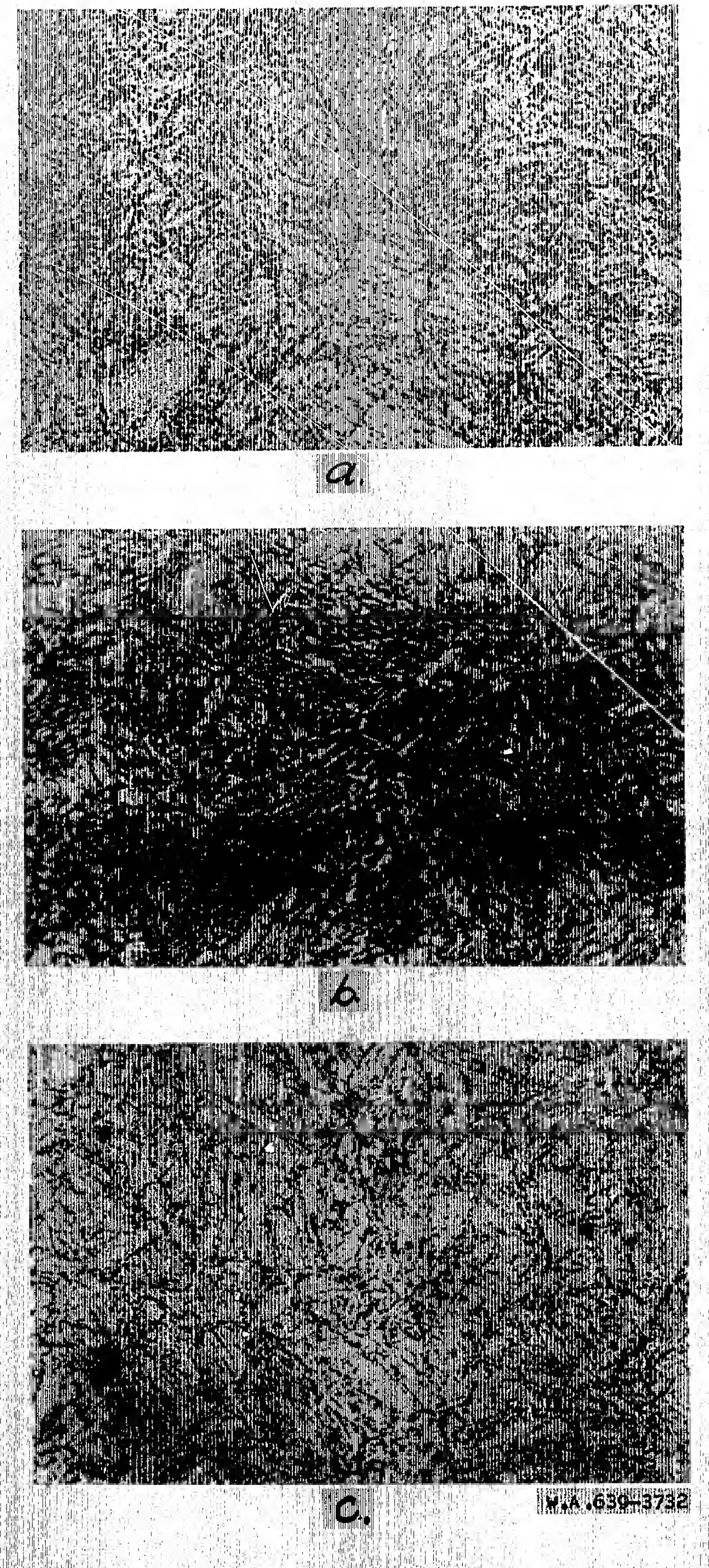
Etched in 1% Nital X1000 MA-3763

c. Poor Quality Plate 1843 (B3)

Typical microstructure of plate. A.S.T.M. grain size No. 7.

Etched in 1% Nital X1000 MA-3765

FIGURE 6.



a.

b

c.

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Figure 7

Carbide Distribution

a. Good Quality Plate 1830 (D4)

Carbide condition as revealed by the Murakami Etch.

X1000 MA-3769

b. Same as a carbide condition as revealed by the 10% chromic acid electrolytic etch.

X1000 MA-3822

c. Same as a carbide condition as revealed by the alkaline sodium picrate etch.

X1000 MA-3803

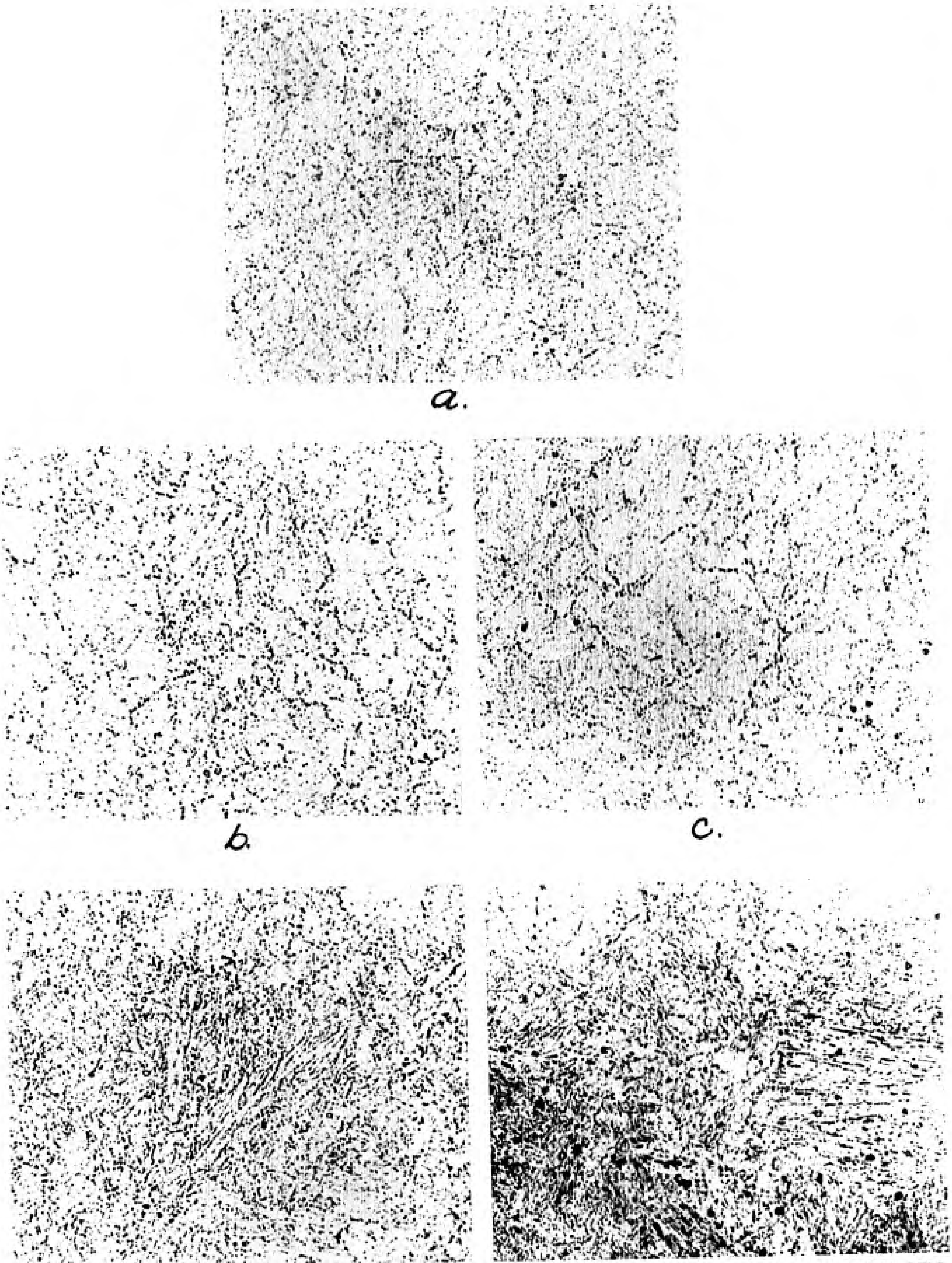
d. Same plate as a showing the high carbon banded area in the central layers of the plate after etching in 10% chromic acid electrolytic etch.

X1000 MA-3821

e. Same high carbon area shown in d after etching in alkaline sodium picrate.

X1000 MA-3802

FIGURE 7.



a. b. c. d. e.

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Figure 8

Carbide Distribution

a. Poor Quality Plate 1843 (D3)

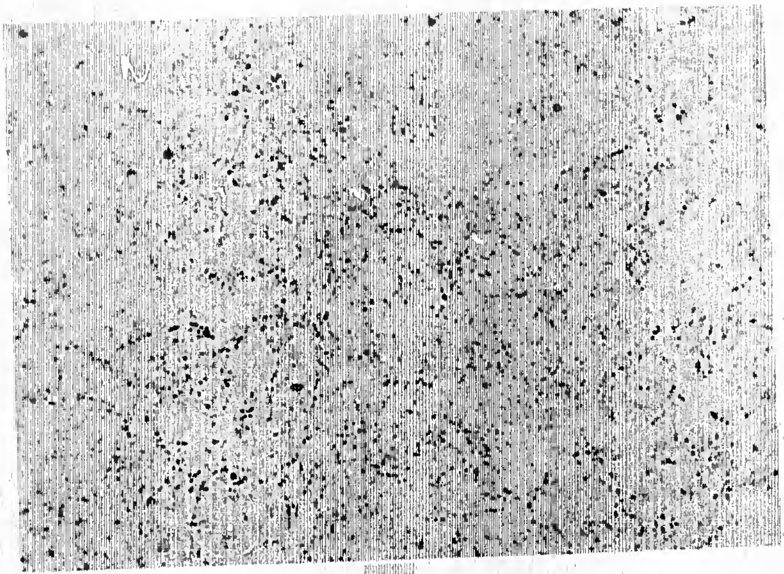
Typical carbide condition in plate.

Etched in Murakami reagent. X1000 MA-3770

b. Same as a after etching in 10% chromic acid electrolytic etch.

X1000 MA-3823

FIGURE 8.



a.

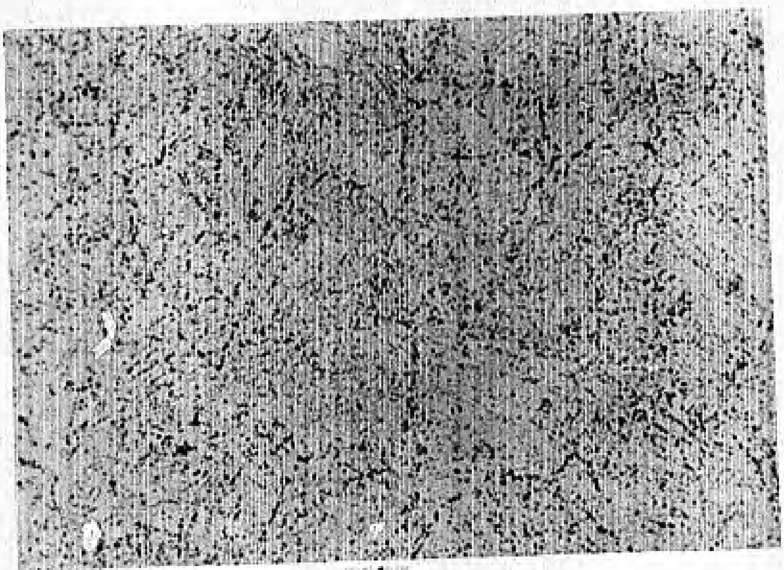


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Figure 9

Segregation

a. Good Quality Plate 1830 (D4)

Banding in central layers of plate revealed by etching in alkaline sodium picrate.

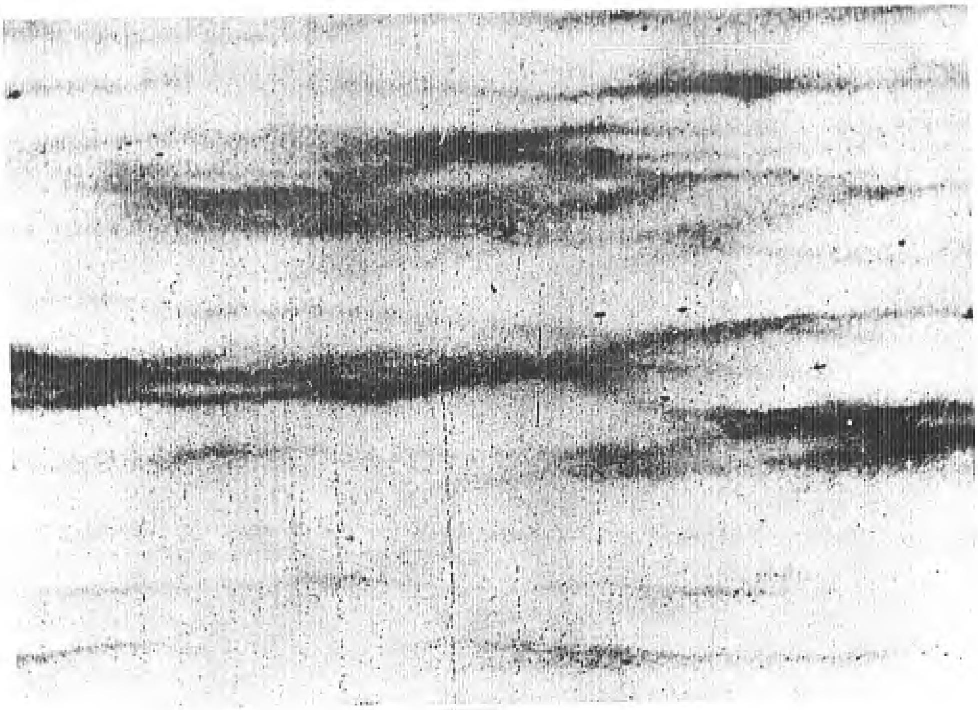
X100 MA-3806

b. Poor Quality Plate 1843 (D3)

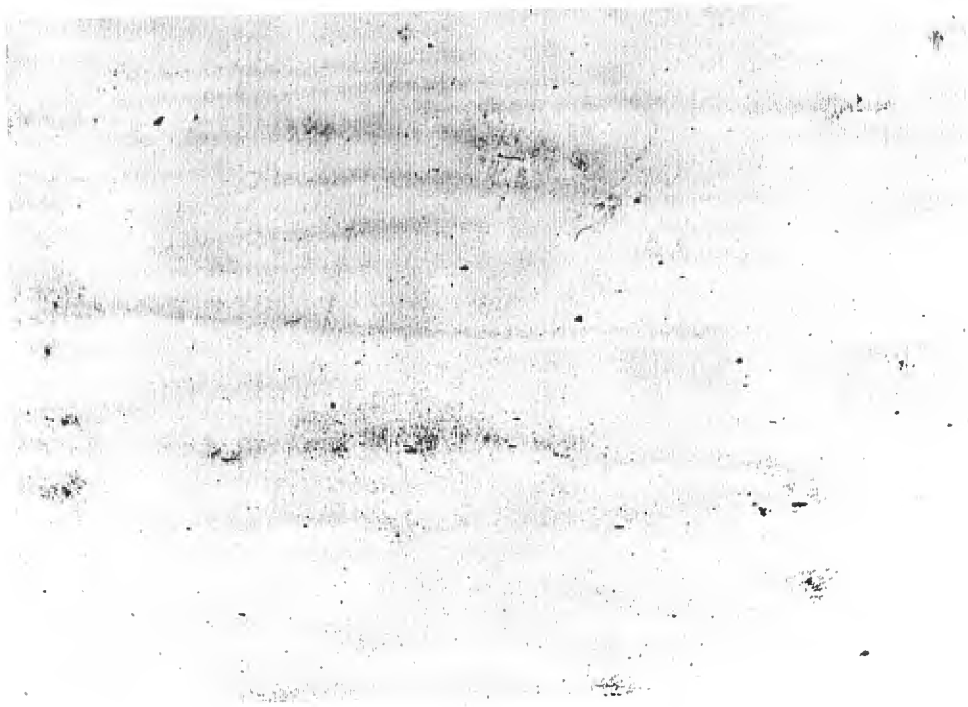
No marked banding evident in plate after sodium picrate etching.

X100 MA-3807

FIGURE 9.



a.



b.

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APPENDIX A

COPY

HENRY DISSTON & SONS, INC.

PHILADELPHIA, U.S.A.

July 18, 1941

Lt. Col. S. B. Ritchie
Watertown Arsenal
Watertown, Massachusetts

Subject: Your letter of July 3

Dear Col. Ritchie:

We are shipping you today by freight two samples 18"x 18"x1-1/2"; one from a good plate and one from a failing plate. These plates were quenched in water from a temperature of 1420° and soaked an hour and a half at temperature. They were drawn at a temperature of 1170° and held two hours at temperature.

The chemical analysis follows:

Heat	C	Mn	P	S	Si	Ni	Va	Mo
1830	.19	.45	.016	.013	.28	4.63	.09	.30
1843	.19	.47	.016	.014	.29	4.98	.09	.29

Ballistic properties:

Heat 1830 Ballistic Limit 1592
Shock Test OK
Heat 1843 Ballistic Limit 1589
Plate failed by spalling

We trust that this information is sufficient for you, and if you require anything further, do not hesitate to call on me.

Very truly yours,

RS:h

Roberts Sibley

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