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METALLURGICAL EXAMINATION OF EXPERIMENTAL 2" ROLLED DISSTON ARMOR PLATES (CARBURIZED AND HOMOGENEOUS)

BY

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WATERTOWN ARSENAL
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Metallurgical Examination of Experimental 2" Rolled Disston Armor Plates (Carburized and Homogeneous)

Purpose

The purpose of this investigation was to make a metallurgical examination of these plates similarly quenched in order to determine the cause of discrepancy in hardness on the rear face of the carburized plate and the same heat of steel in the homogeneous condition.

Introduction

With reference to letters dated Oct. 17, Oct. 24, Nov. 29, and Dec. 2, 1940, from the Henry Disston & Sons, Inc., it was reported that when the Brinell hardness, developed on the back of a piece of carburized armor plate on quenching, falls within the range of 341 to 415, the same heat quenched as homogeneous plate of the same thickness will invariably exhibit a Brinell of 514.

Samples of two inch heat treated carburized and homogeneous plates from Heat 18340 and samples of two inch homogeneous plate, as quenched, from Heat 963 were submitted for test.

Conclusions

The results of this investigation indicate that:

1. The hardness differential on the face hardened plate is due to pronounced decarburization on the back of the plate.

2. The rear face of the face hardened plate was decarburized to a depth of about 1/4 inch while the homogeneous plate was decarburized to a depth of only 1/32" - 1/16".

3. The grain size of the face hardened plate and the homogeneous plate was practically the same and, therefore, not responsible for the hardness differential reported.

4. This investigation demonstrates the applicability of metallographic methods in conjunction with hardness surveys to the determination of the quality of armor plate. It also shows clearly that a careful technique must be employed at the mills in determining the hardness of the materials. The carburized plate in this case probably would not have been submitted for ballistic test if the excessively high hardness had been discovered.

Test Procedure and Materials

One sample of carburized and two samples of homogeneous plates, 18x18x2", rolled from Heat 18340 and also two pieces, 10x2x2", from Heat 963 were submitted for metallurgical examination by the Henry Disston & Sons, Inc. Samples from Heat 18340 were given the complete ballistic heat treatment whereas samples from Heat 963 were merely quenched in order to study the grain size in the quenched condition.

Metallurgical study on samples from Heat 18340 included a study of carbon distribution in the carburized case, a study of the extent of decarburization on the rear faces of the face hardened and homogeneous plates, macro and microstructure and hardness surveys.

A microscopic examination of a homogeneous plate from Heat 963 was made in order to determine the presence of nonmetallic inclusions and grain size in this particular heat.

Results

1. Carbon Distribution on the Rear Face of Face Hardened and Homogeneous Plates Rolled from Heat 18340

a. Carbon distribution from the rear face into the core of the carburized plate shows excessive decarburization on the rear face as noted below in Table I.

Table I

Heat 18340-1 - Carburized

Back Face						Core				
1st Cut	2nd Cut	3rd Cut	4th Cut	5th Cut	6th Cut	7th Cut	8th Cut	9th Cut	10th Cut	11th Cut
1/32"	1/32"	1/32"	1/32"	1/16"	1/16"	1/16"	1/16"	1/8"	1/8"	1/8"
.07	.09	.13	.19	.225	.245	.27	.285	.29	.295	.30

b. Carbon distribution from the rear face into the core of the homogeneous plates shows practically no decarburization on the rear face as noted in Table II.

Table II

Heat 18340-2 - Homogeneous

Back Face						Core				
1st Cut	2nd Cut	3rd Cut	4th Cut	5th Cut	6th Cut	7th Cut	8th Cut	9th Cut	10th Cut	11th Cut
.23	.275	.295	.305	.305	.305	.30	.315	.28	.28	.28

Heat 18340-3 - Homogeneous

.20	.275	.29	.285	.275	.275	.28	.285	.26	.265	.235

2. Chemical Analyses of Plates Submitted

Chemical analyses of the plates are given below in Table III.

Table III

Chemical Analyses

Plate No.	Type	C	Mn	P	S	Si	Ni	Cr	Mo	V
18340-1	Face Hardened	.30	.48	.011	.018	.24	4.86	.08	.81	.13
18340-2	Homogeneous	.27	.50	.010	.017	.275	4.75	.069	.71	.07
18340-3	Homogeneous	.25	.48	.009	.016	.275	4.75	.069	.71	.07
963	Homogeneous	.30	.41	.013	.016	.27	4.62	.065	.68	.135

Note: The samples as received were marked 18340. In order to differentiate between the face hardened and homogeneous plates, the face hardened plate was marked 18340-1 and the homogeneous plates were marked 18340-2 and 18340-3.

3. Hardness Surveys

a. Vickers Brinell Hardness Survey

Figures 1 and 2 show hardness surveys made on the cross section of the 2" carburized and homogeneous plates. These hardness surveys, in addition to the chemical analyses noted above, indicate a more pronounced decarburization on the rear face of the carburized plate.

b. Brinell Hardness

Brinell hardness determinations as reported and determined at Watertown Arsenal are given in Table IV.

Table IV

Plate No.	Type	Brinell Hardness As Reported	Brinell Hardness Watertown Arsenal Determination
18340	Face Hardened	512/532 Face* 375/364 Back	1/477
18340	Homogeneous	341/352*	0/364
18340	Homogeneous	341/352*	.1/302
963	Homogeneous	477/514** 341/321***	477
963	Homogeneous	444/495** 331/321***	17/512

*Hardness of plates reported in Aberdeen Proving Ground 213th Partial Report.

**Hardness of plates in the "as quenched" condition.

***Hardness of plates reported in Aberdeen Proving Ground Firing Record No. 19026-A26.

4. Microstructure

Figures 1 - 13 inclusive illustrate the microscopic work conducted on the samples.

The carburized plate 18340-1 showed considerable decarburization while the homogeneous plates 18340-2 and 18340-3, see Figures 7 and 8, showed comparatively little.

Homogeneous plates rolled from Heat 18340 contained the highest percentage of nonmetallic inclusions, see Figures 1-6 inclusive.

Figures 9 - 13 inclusive show the microstructure of the carburized case of plate 18340-1 and the microstructure of the steel bases of this carburized plate and also of the homogeneous plates 18340-2, 18340-3, 963-D1, and 963-D2. The relation of grain boundary carbide in the carburized case of plate 18340-1 to crack formations is shown in Figure 13.

5. Grain Size

The ASTM grain size of the plates submitted is given below in Table V.

Table V

Plate	ASTM Grain Size Index
18340-1 Carburized	6 (core grain size)
18340-2 Homogeneous	7
18340-3 Homogeneous	7
963D-1 Homogeneous	8
963D-2 Homogeneous	8

6. Ballistic Tests

As a matter of interest the results of the ballistic tests made at Aberdeen and reported in A.P.G. 213th Partial Report, July 5, 1940 and A.P.G. Firing Record No. 19026-A26 on the heat treated plates from Heats 18340 and 963 are reported in Table VI.

Table VI

Ballistic Tests

Plate	Ballistic Limit F/S 37 mm. M51 Shot	Remarks
18340-1 Face Hardened	1866 normal impact 2619 20° from normal impact	Unsatisfactory due to spalli Back spalls and face spalls 5-1/8x4-5/16" largest back 4x3-1/4" largest face spall
18340-2 Face Hardened	1939 normal impact 2604 20° from normal impact	Unsatisfactory due to spalli 7-1/8x6-1/8" largest back s 3-5/8"x1-3/8" largest face s
18340-1 Homogeneous	2007 normal impact 2158 20° from normal impact	Satisfactory insofar as tes not subjected to shock.
18340-2 Homogeneous	2046 normal impact 2291 20° from normal impact	Satisfactory insofar as tes not subjected to shock.
963-1 Homogeneous	1967 normal impact 2206 20° from normal impact	Satisfactory insofar as tes not subjected to shock.
963-2 Homogeneous	2027 normal impact 2208 20° from normal impact	Unsatisfactory, excessive b spall.

7. Macrostructure

The plate stamped 18340-1 shows a rather prominent interdendritic structure throughout and the nonmetallics present are well distributed.

The specimens stamped 18340-2 and 18340-3 show near the top and bottom surfaces remnants of a well-broken dendritic structure and within this location some elongated streaks of impurities which might be termed "fine laminations" are found.

Discussion

It is believed that the low hardness reported on the rear face of the carburized plate, as quenched, was due to pronounced decarburization while the relatively high hardness reported on the quenched homogeneous plates was due to the absence of decarburization. This is confirmed by the fact that pronounced decarburization was found on the rear face of a quenched and drawn carburized plate, 18340-1, of the same analysis while there was only a slight amount of decarburization on quenched and drawn homogeneous plates 18340-2 and 18340-3 of the same heat. (See Tables I and II for carbon distribution on the rear surfaces of these compositions and hardness surveys made on samples from the plates.)

Furthermore, it should be noted that the Brinell hardness reported on the rear face of the quenched and drawn carburized plate 18340 was 375/364, (see A.P.G. 213th Partial Report). Apparently Brinell tests were made on the decarburized layer since tests made at Watertown Arsenal showed a Brinell hardness of 477, see Table IV.

Microscopic examination showed the presence of mill scale and decarburization to an extent of 0.08" on the rear face of the carburized quenched and drawn plate 18340-1, see Figures 7a, 7b, 7c. Figures 8a and 8b show typical decarburization on the rear face of the quenched and drawn homogeneous plates 18340-2 and 18340-3. The pronounced extent of decarburization as shown by chemical analysis and hardness surveys on the rear face of the carburized plate was not detected by the microscopic examination. It is possible that the microstructure of the rear face of this sample examined was not representative of the back surface of the plate.

The matter of grain size in these plates was considered since it has been shown that a large grain size promotes deep hardening. As the grain size of the homogeneous plate was found to be ASTM No. 7 and the steel base of the carburized plate was found to be ASTM No. 6, the relatively high hardness reported on the quenched homogeneous plate could not be attributed to this factor since the grain size of the two plates was practically the same.

The grain size of two 2" homogeneous plates, as quenched, Nos. 963D-1 and 963D-2 of the same chemistry as Heat 18340, see Table III, was found to be No. 8 and, therefore, it was concluded that the effect of grain size had no bearing on the problem, see Table V for grain size counts in the various plates examined.

As a matter of interest, the homogeneous plate 18340-3 contained the greatest amount of segregated nonmetallic inclusions (figures 1 - 6 inclusive) and this plate showed the most pronounced banded structure (Figure 12). It is possible that this plate was rolled from the upper portion of the ingot. Furthermore, large angular nonmetallic inclusions were found near the rear surface of the plate (Figures 4d and 12b). These nonmetallics probably came from the furnace refractory rather than as a result of the melting practice.

The microstructure of the case and core of the carburized plate 18340-1 was found to be typical of carburized plate of this thickness (Figures 9 and 10). It was noted that a crack system in the carburized case of this plate followed grain boundary carbides in this area (Figure 13).

Figures 11 and 12 illustrate the microstructure of the homogeneous plates 18340-2 and 18340-3.

The macrostructure of the face hardened and homogeneous plates is shown in Figure 14.

The ballistic properties of the heat treated plates from the heats 18340 and 963 are shown in Table VI. Undoubtedly the carburized plates, 18340, failed due to a too high rear face hardness which was not actually determined due to the failure of removing the entire decarburized layer on the back face. Although the homogeneous plates of heat 18340 were satisfactory insofar as tested, it is possible that the segregations of nonmetallic inclusions might have caused failure if subjected to shock tests.

Mr. A. Hurlich made the microscopic examination covered by this report.

Respectfully submitted,

E. L. Reed.

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APPROVED:

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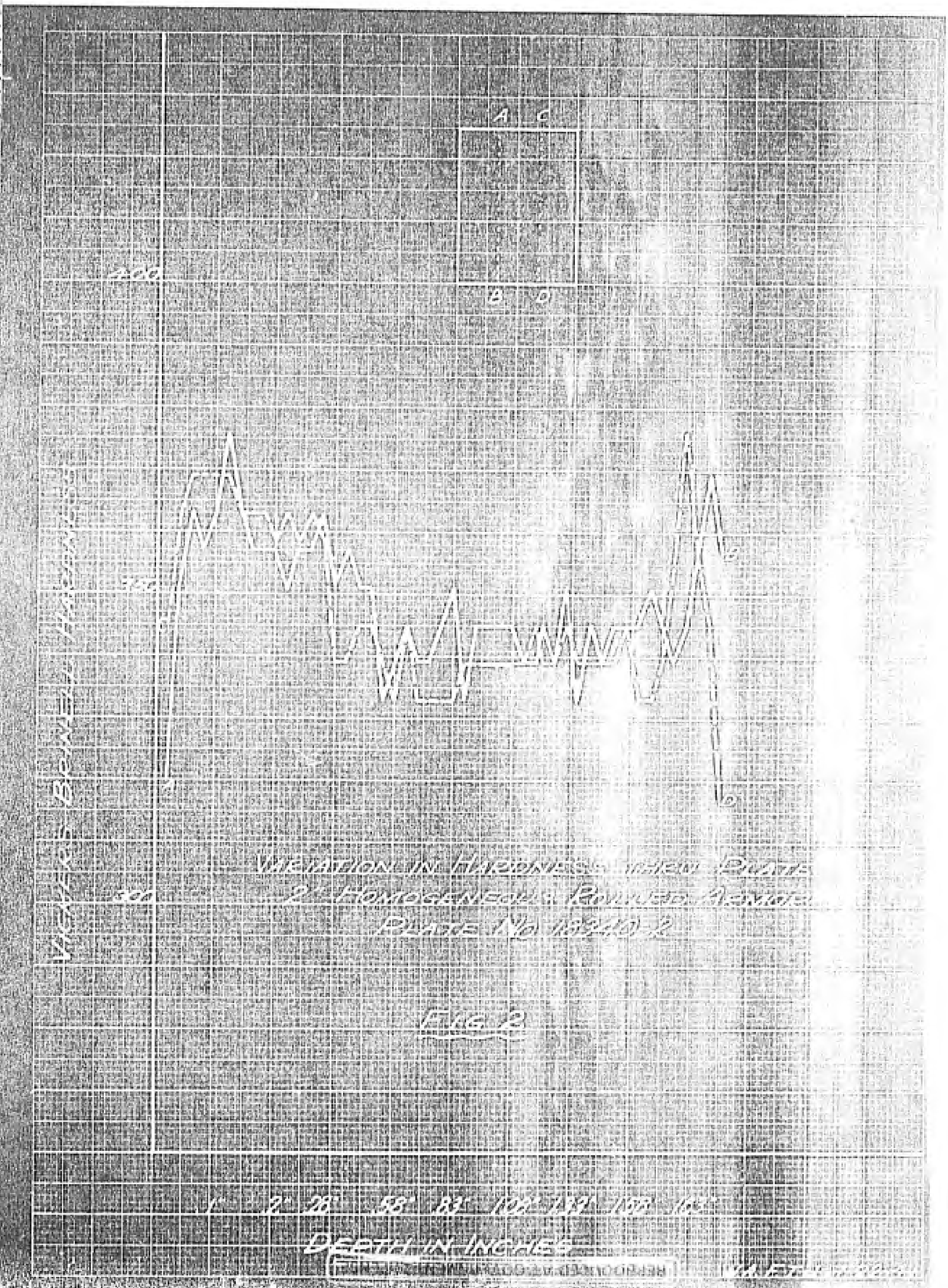


A C
B D
400
350
300
VARIATION IN HARDNESS THRU PLATE
2" HOMOGENEOUS ROLLED ARMOR
PLATE No
1" 2"
DEPTH IN INCHES

FIG 2

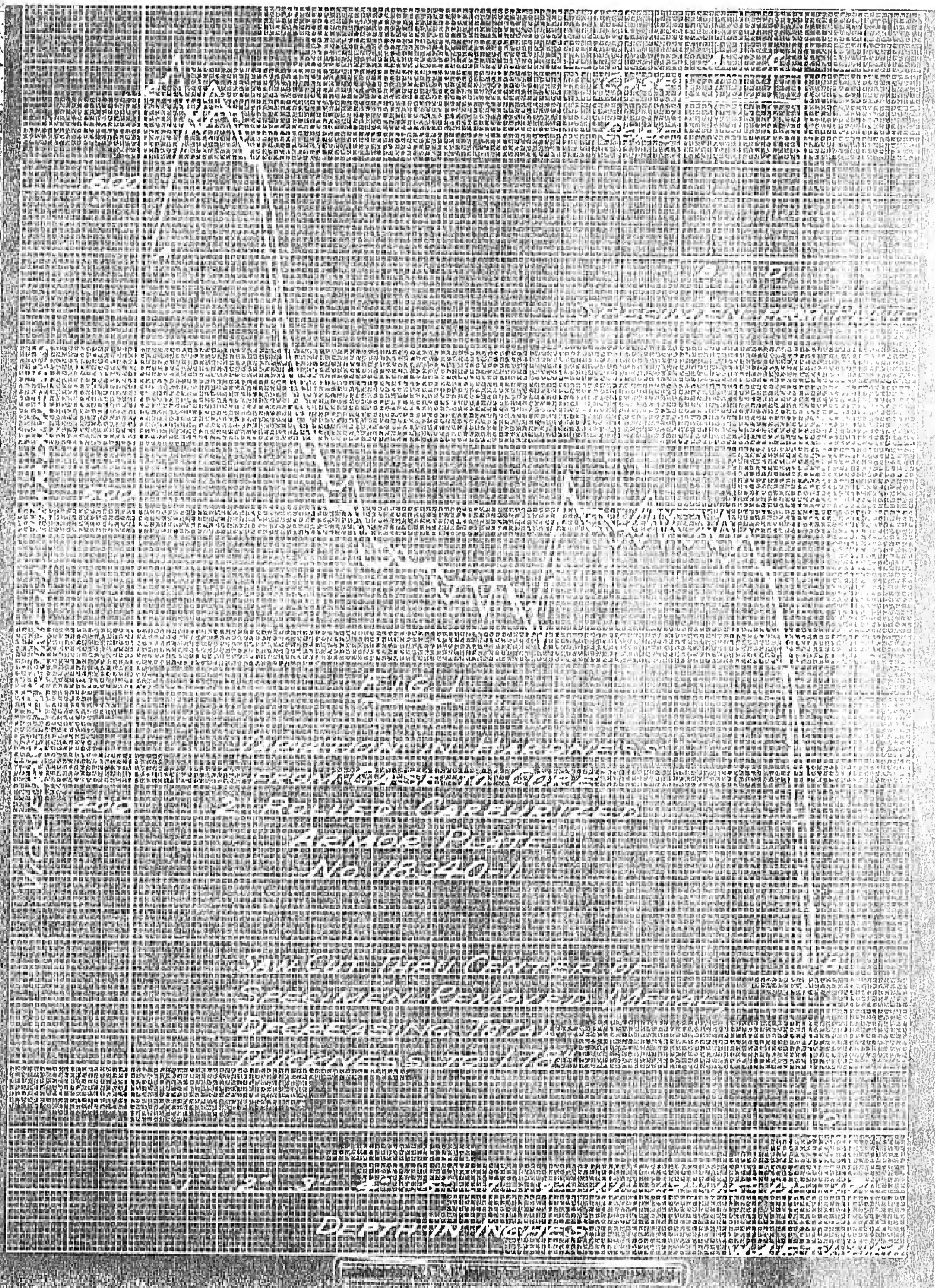

600
500
400
FIG. 1
VARIATION IN HARDNESS
FROM CASE TO CORE
2" ROLLED CARBURIZED
ARMOR PLATE
NO. 18340-1
SAW CUT THRU CENTER OF
SPECIMEN REMOVED METAL
DECREASING TOTAL
THICKNESS TO 1.76"
DEPTH IN INCHES

Figure 3

Distribution of Nonmetallic Inclusions

(a) Carburized plate No. 18340-1 - Numerous fine nonmetallic inclusions fairly well distributed.

X25 MA-2974

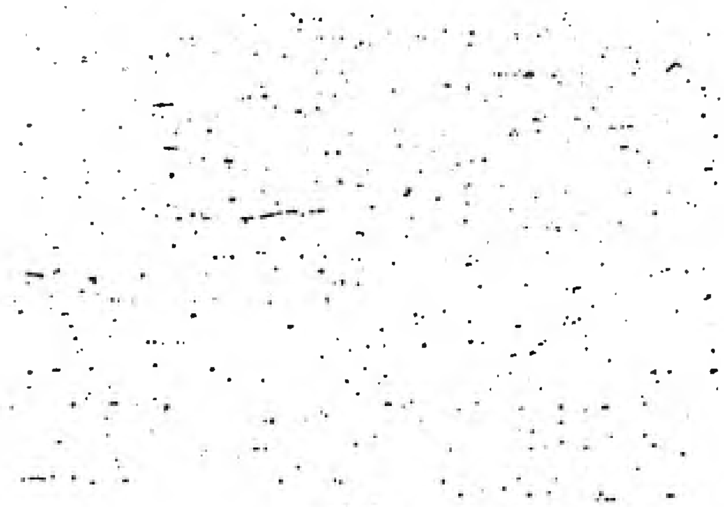
(b) Same as (a). Showing graphite (temper carbon) near carburized surface.

X25 MA-2976

(c) Homogeneous plate No. 18340-2. Fairly clean steel.

X25 MA-2977

Figure 3



(a)

(b)

(c) W.A.639-3387

Figure 4

Distribution of Nonmetallic Inclusions

(a) Homogeneous plate No. 18340-3 - Numerous slag stringers fairly close together. The nonmetallics were concentrated at a distance of about 1/4" in from the back face of the plate.

X25 MA-2978

(b) Same as in (a). Another type of stringer found in the plate.

X25 MA-2980

(c) Same as in (a). Irregular hard nonmetallic occasionally found in the heat.

X25 MA-2981

(d) Same nonmetallic inclusion as shown in (c). This type of a nonmetallic inclusion is probably caused from the furnace refractory, rather than the melting practice.

X100 MA-2988

All specimens unetched.

Figure 4

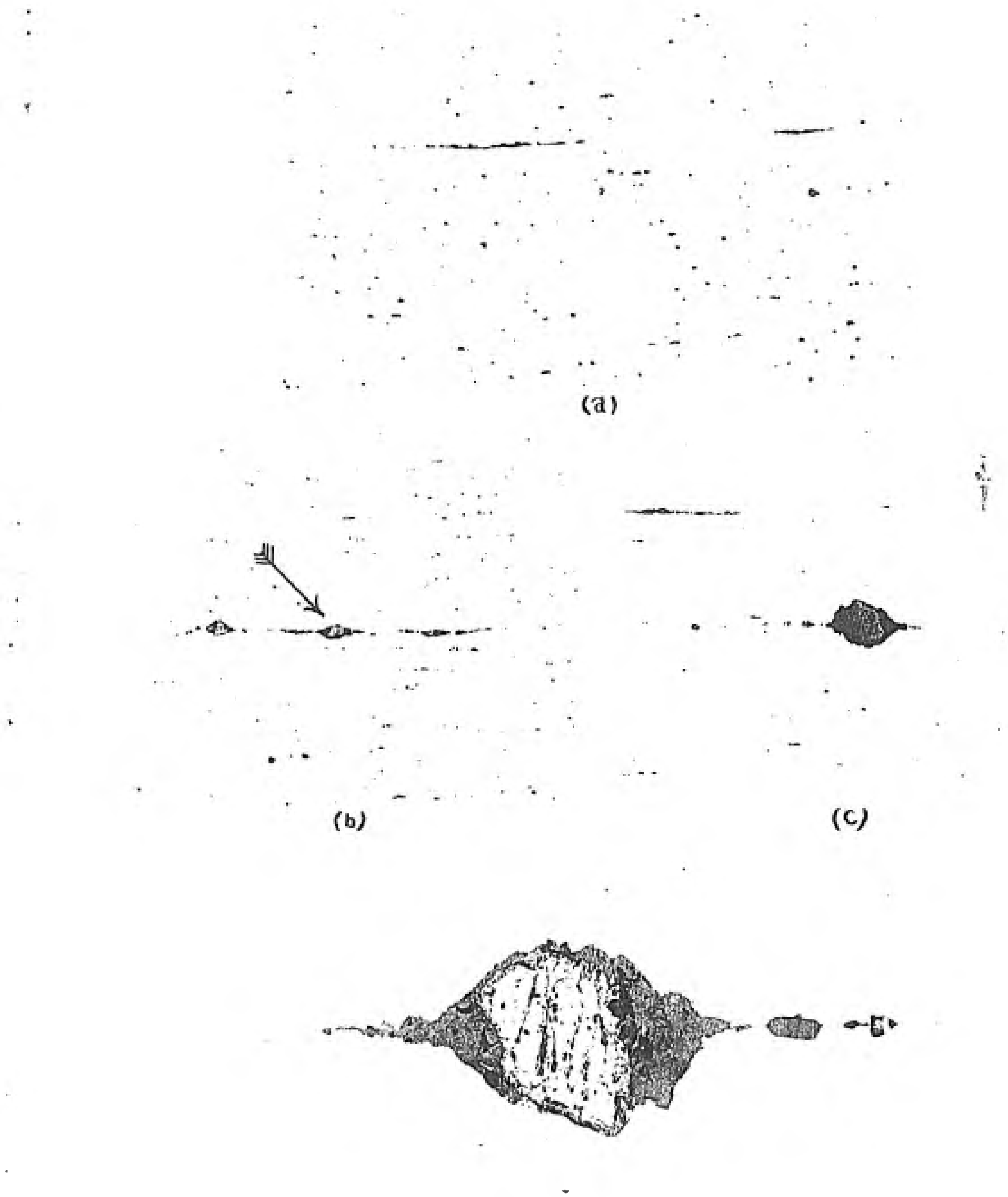


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Figure 5

Distribution of Nonmetallic Inclusions

(a) Homogeneous ~~Carburized~~ plate No. 18340-3 - Typical elongated nonmetallic inclusions.

X100 MA-3060

(b) Homogeneous plate No. 963-D1 - Numerous rounded nonmetallic inclusions fairly well distributed.

X25 MA-2982

(c) Same as (b). Showing a streak of nonmetallics which have the appearance of alumina, only two of these streaks were found in the specimen examined.

X25 MA-2983

(d) Homogeneous plate No. 963-D2 - Fairly clean heat.

X25 MA-2984

All specimens unetched.

Figure 5

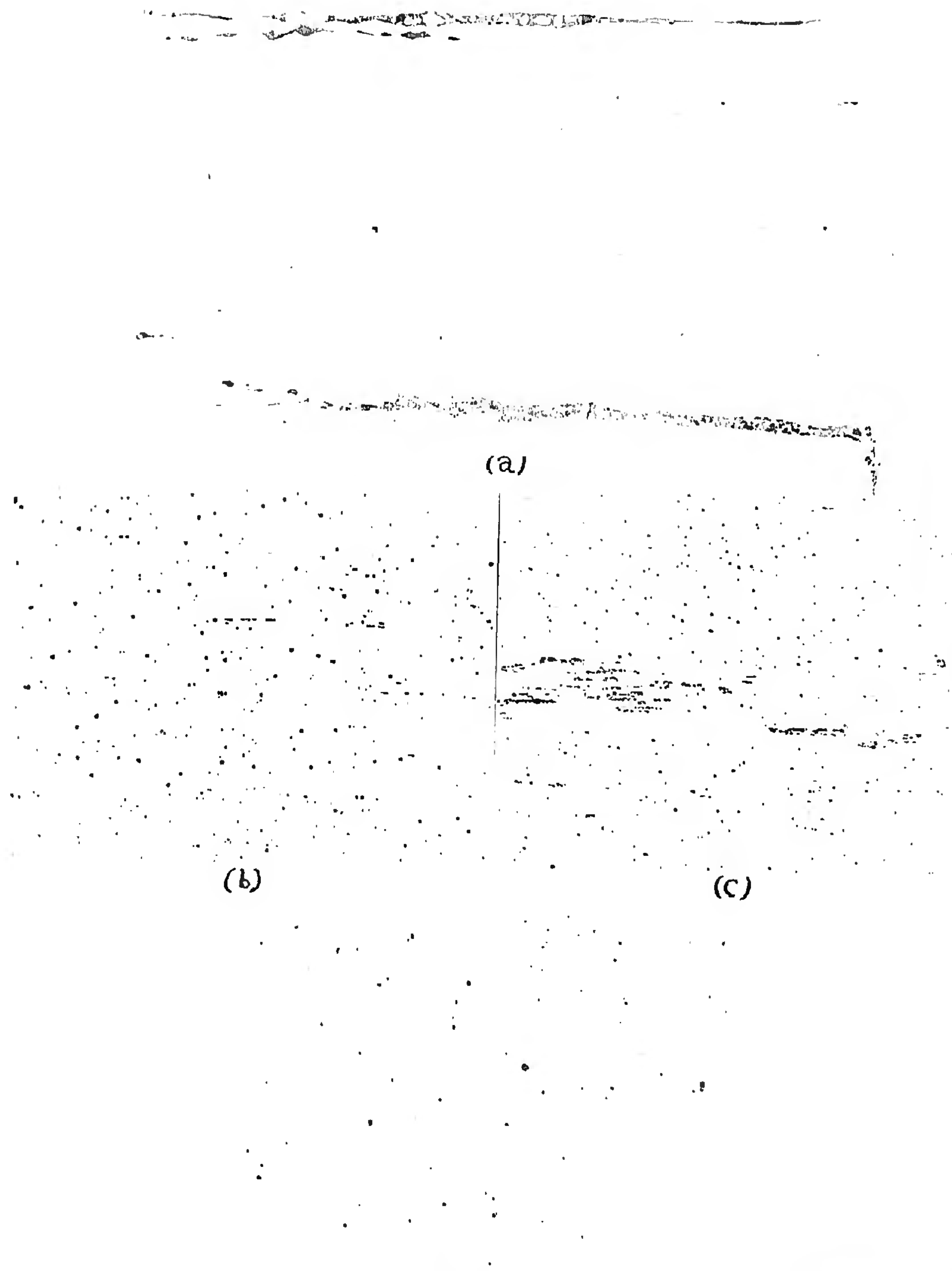

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Figure 6

Distribution of Nonmetallic Inclusions

(a) Homogeneous ~~Carburized~~ plate No. 18340-3 - Same nonmetallic inclusion shown (by arrow) in Figure 4b under higher magnification.

The white constituent is aluminum oxide while the gray constituent is made up of silicates.

X100 MA-2986a, b, c, d

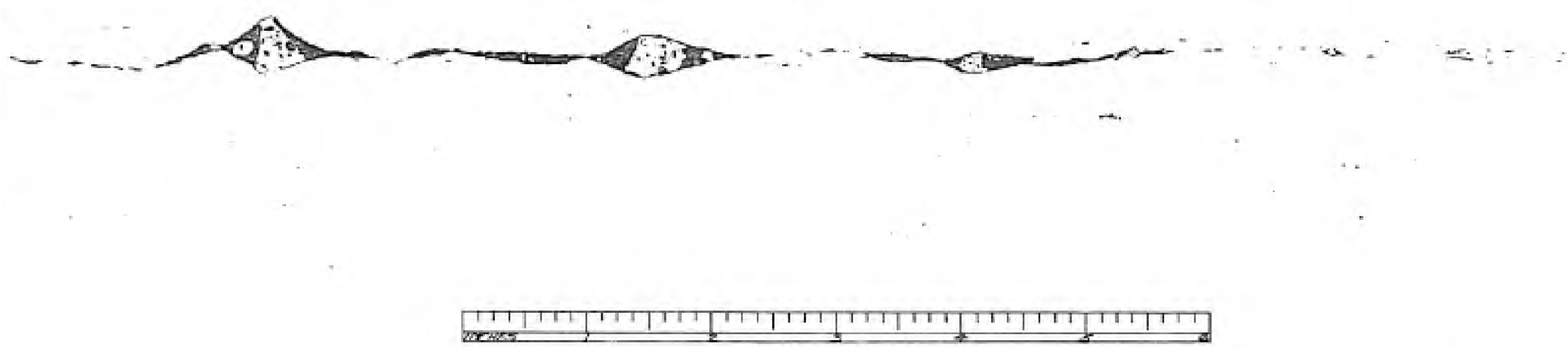


Figure 6

W.A.639-3370

Figure 7

Structure of Rear Face

(a) Carburized Plate 18340-1

Presence of mill scale at outer rear surface. Total decarburization in this particular area .085". Severely decarburized 0.015".

X100 MA-3007

(b) Same as in (a) only taken under high magnification, decarburization and oxidized grain boundaries near rear surface. Width of this area - .005 inch.

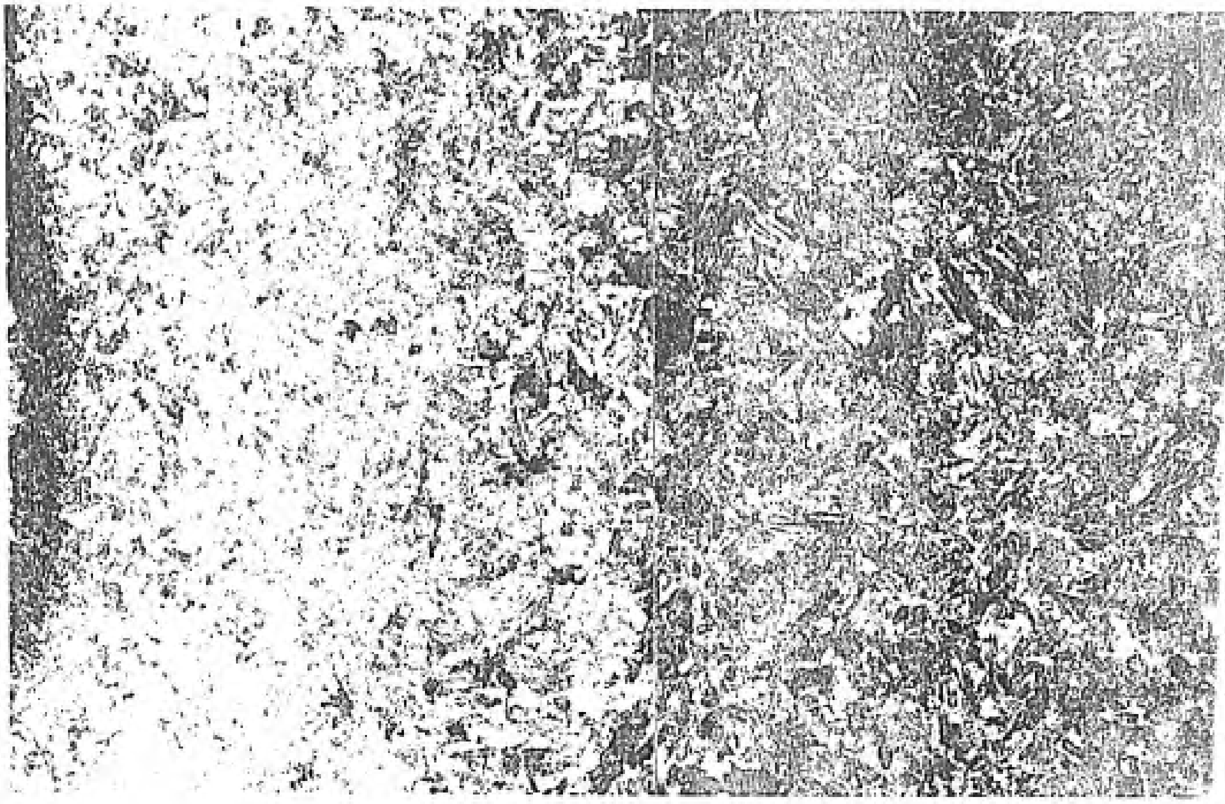
X1000 MA-2997

(c) Same as in (a) only taken under high magnification showing oxidized grain boundaries and decarburization.

X1000 MA-2998

Etched in 1% Nital.

Figure 7



(a)

(b)

(C)

W.A.651-1

Figure 8

Structure of Rear Face

(a) Homogeneous Plate 18340-2

Slight decarburization on rear face. Total decarburization 0.018". Severely decarburized 0.007".

X100 MA-3042

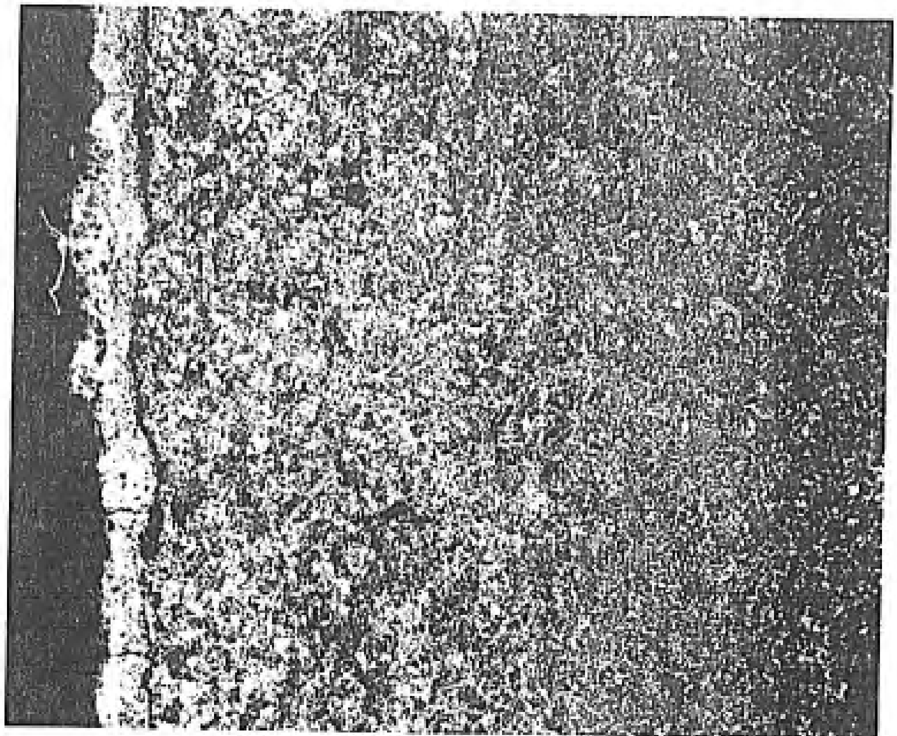
(b) Homogeneous Plate 18340-3

Slight decarburization on rear face. Total decarburization .02". Severely decarburized .008".

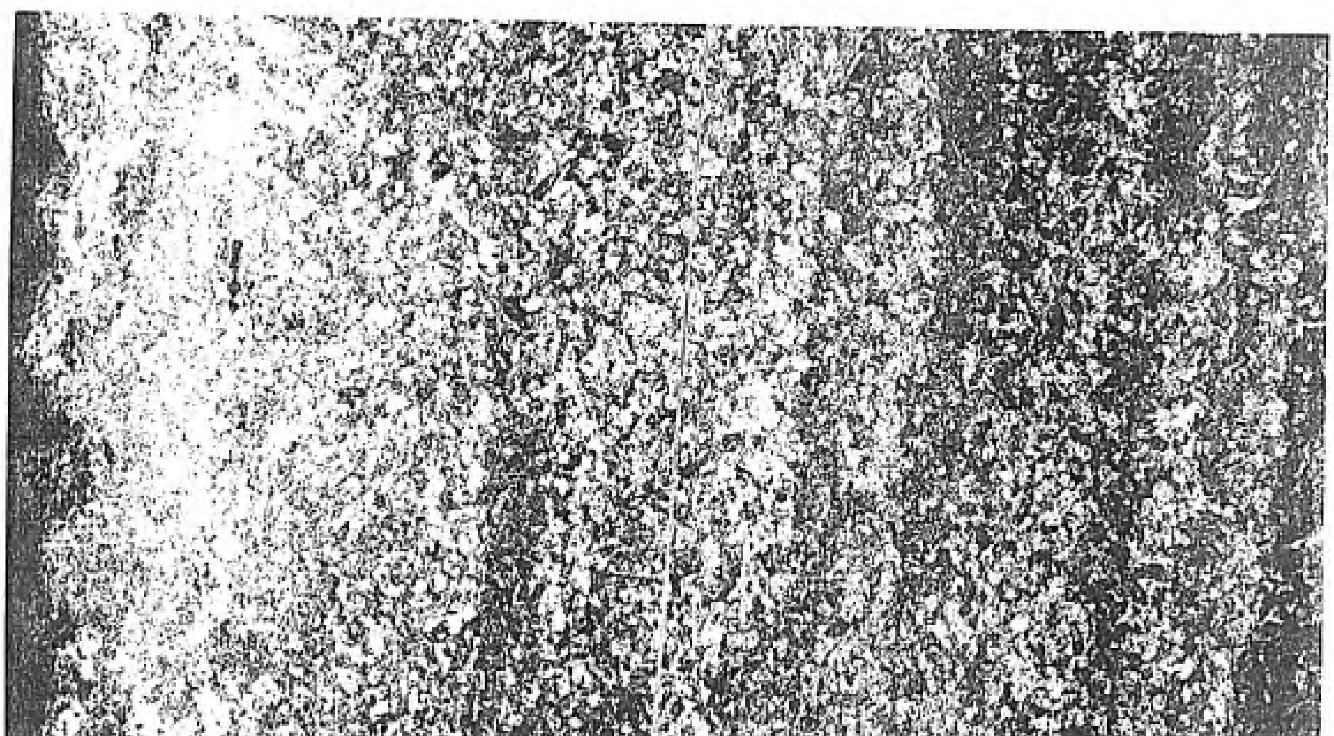
X100 MA-3043

Etched in 1% Nital.

Figure 6



(a)



(b)

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Figure 9

Structure of Carburized Case

(a) Carburized Plate 18340-1

Microstructure .016" below surface. Some excess grain boundary carbide in a fine tempered martensitic matrix.

X1000 MA-2992

(b) Same a (a). Microstructure .060" below surface. Grain boundary carbide in a fine tempered martensitic matrix.

X1000 MA-2995

(c) Same as (a). Microstructure .080" below surface. Trace of grain boundary carbide in a tempered martensitic matrix.

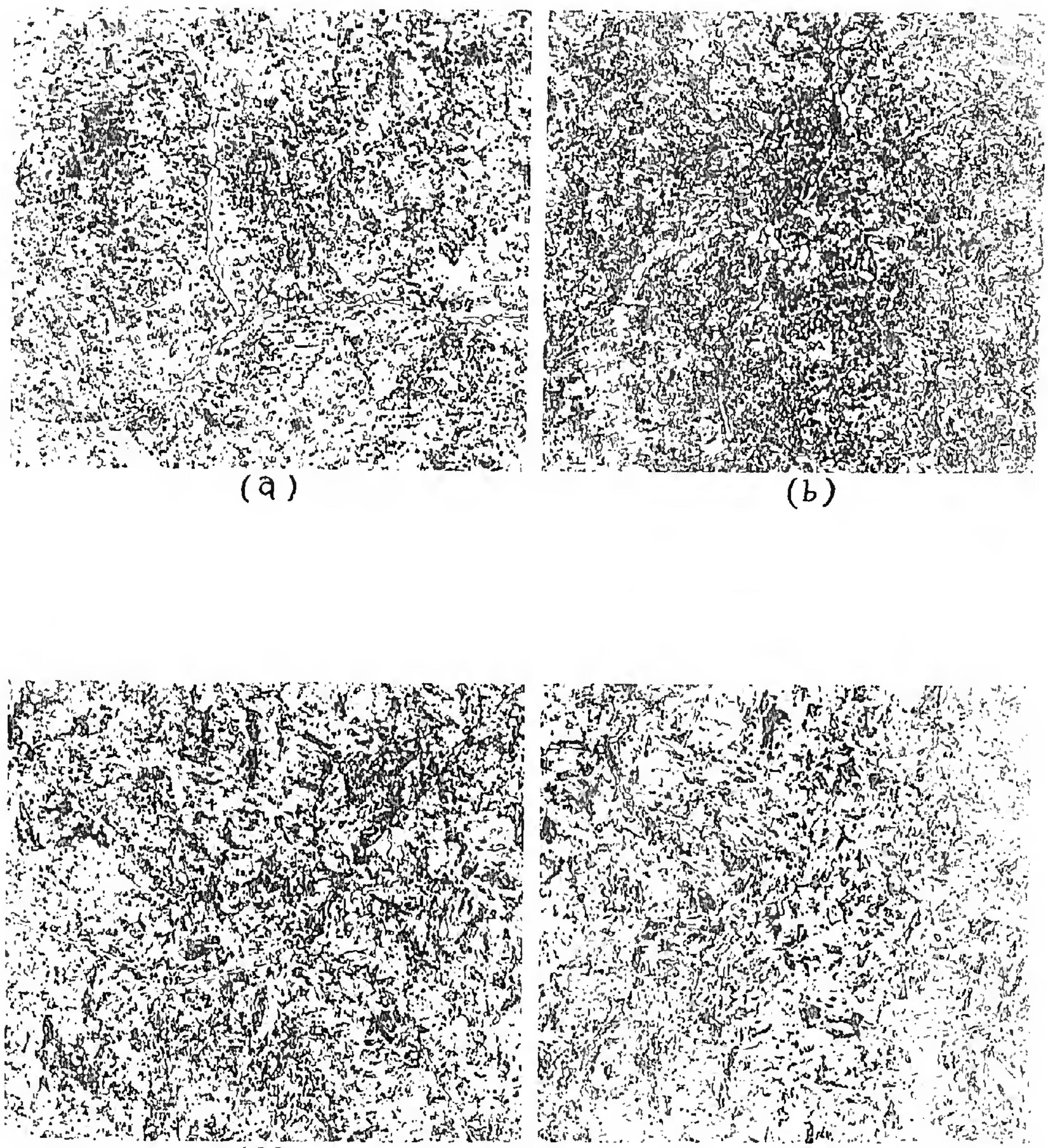
X1000 MA-2994

(d) Same as (a). Microstructure .120" below surface. Slight trace of grain boundary carbide in a tempered martensitic matrix. Carbide network existed to about .140" below surface.

X1000 MA-2993

Etched in 1% Nital.

Figure 9



(a) (b)

(c) (d)

W.A.639-338

Figure 10

Structure of Carburized Case

(a) Carburized Plate 18340-1

Continuation of series in Figure 9, tempered martensite in core just below case.

X1000 Etched in 1% Nital MA-2996

(b) Same as (a). Structure of core - tempered low carbon martensite. ASTM grain size No. 6.

X1000 Etched in 1% Nital MA-2999

(c) Carburized Plate 18340-1

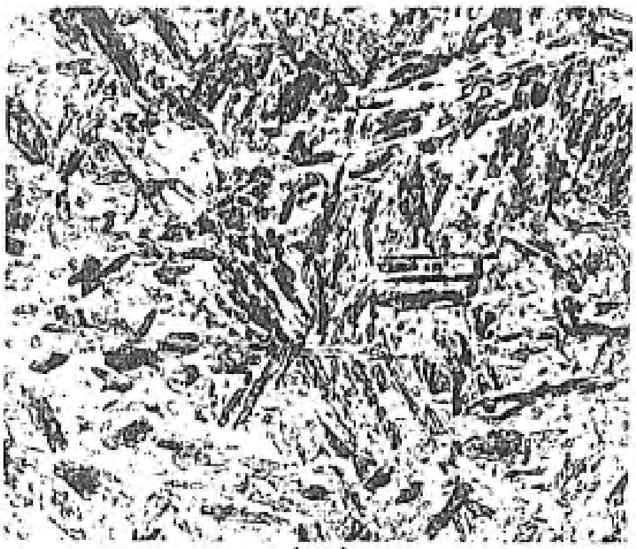
Grain boundary carbide in carburized case .024" below surface.

X250 Etched in Murakami's Reagent MA-3048

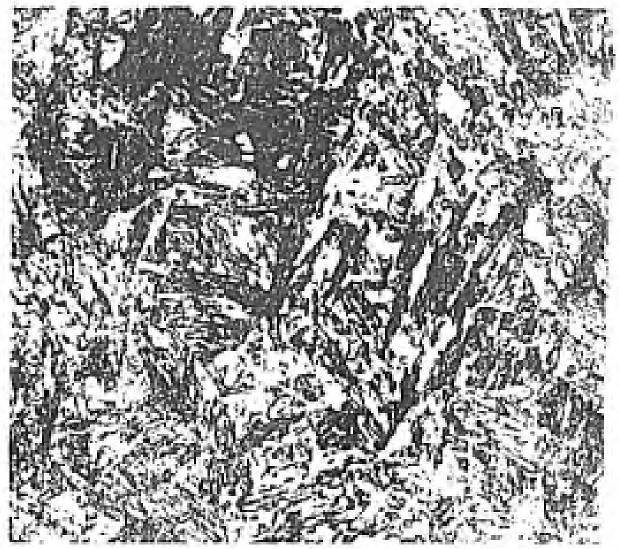
(d) Same plate as in (c). Carbide distribution in core.

X1000 Etched in Murakami's Reagent MA-3057

Figure 10



(a)



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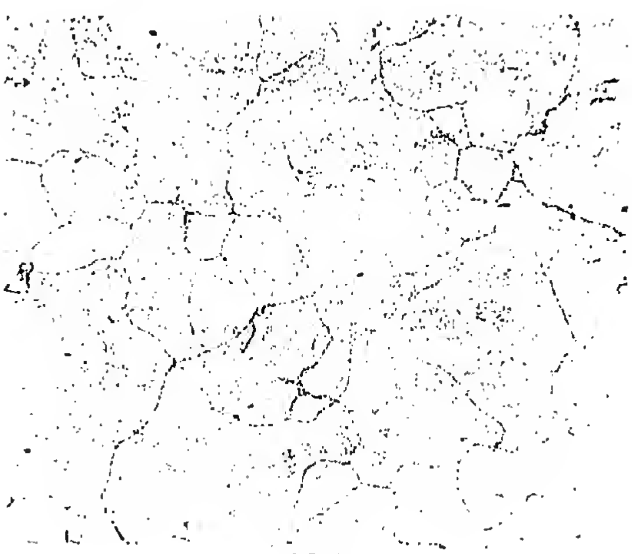
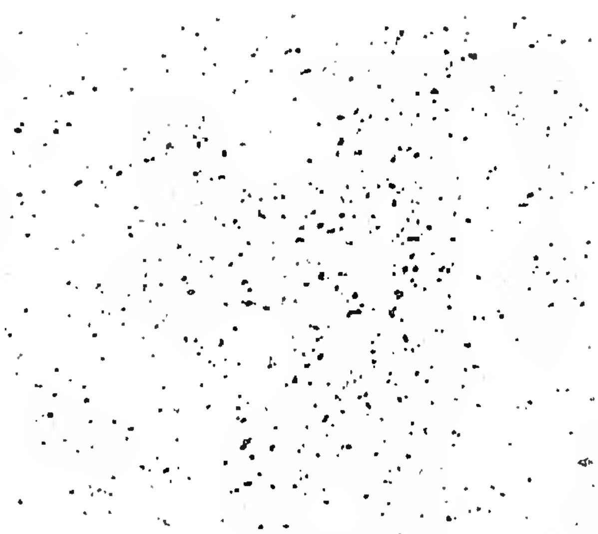


(c)



(d)

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Figure 11

Structure of Homogeneous Plates

(a) Homogeneous Plate 18340-2

Sorbite with evidence of troostite. A cubic titanium cyano-nitride inclusion is evident. ASTM grain size No. 7.

X1000 Etched in 1% Nital. MA-3001

(b) Same as in (a). Another area - uniform sorbite, acicular structure.

X1000 Etched in 1% Nital. MA-3000

(c) Homogeneous Plate 18340-3

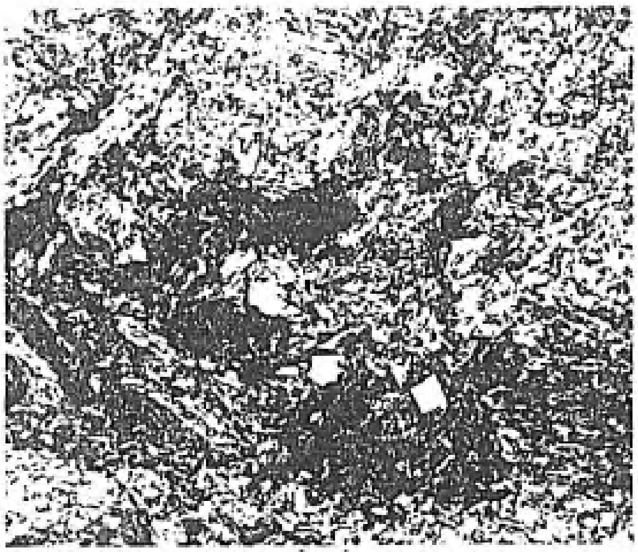
Typical coarse sorbite - acicular structure. ASTM grain size No. 7.

X1000 Etched in 1% Nital. MA-3002

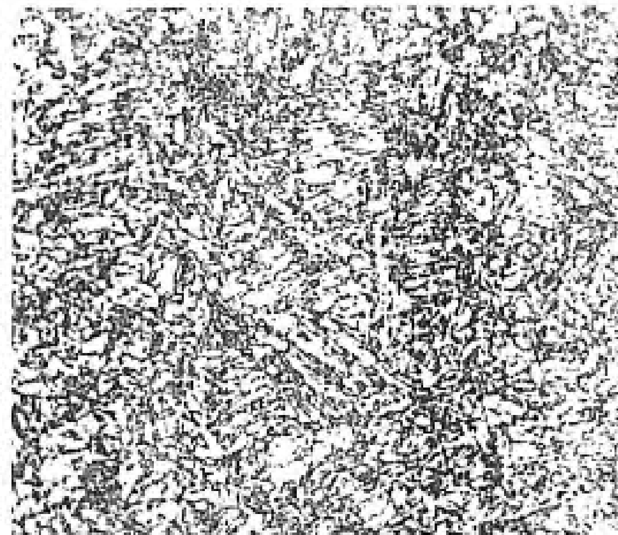
(d) Same as in (c). Carbide distribution. Also typical of homogeneous plate No. 18340-3.

X1000 Etched in Murakami's Reagent MA-3059

Figure 11

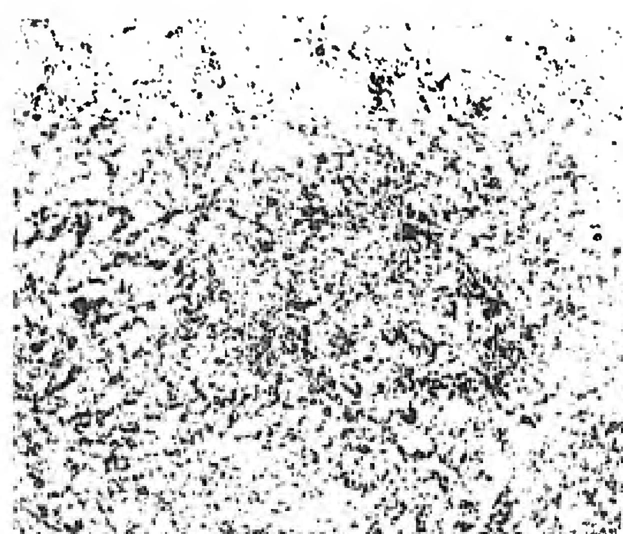


(a)



(b)

(c)



(d)

W.A.639-3384

Figure 12

Structure of Steel Base

(a) Homogeneous Plate 18340-3

Pronounced banded structure in plate. More banding was found in this plate than in the other plates.

X100 MA-3006

(b) Same as (a). Showing flow lines around nonmetallic inclusions in plate. (Same nonmetallic shown in Figure 4d).

X100 MA-3005

(c) Homogeneous Plate 963-D1

Fine martensite. ASTM grain size No. 8.

X1000 MA-3004

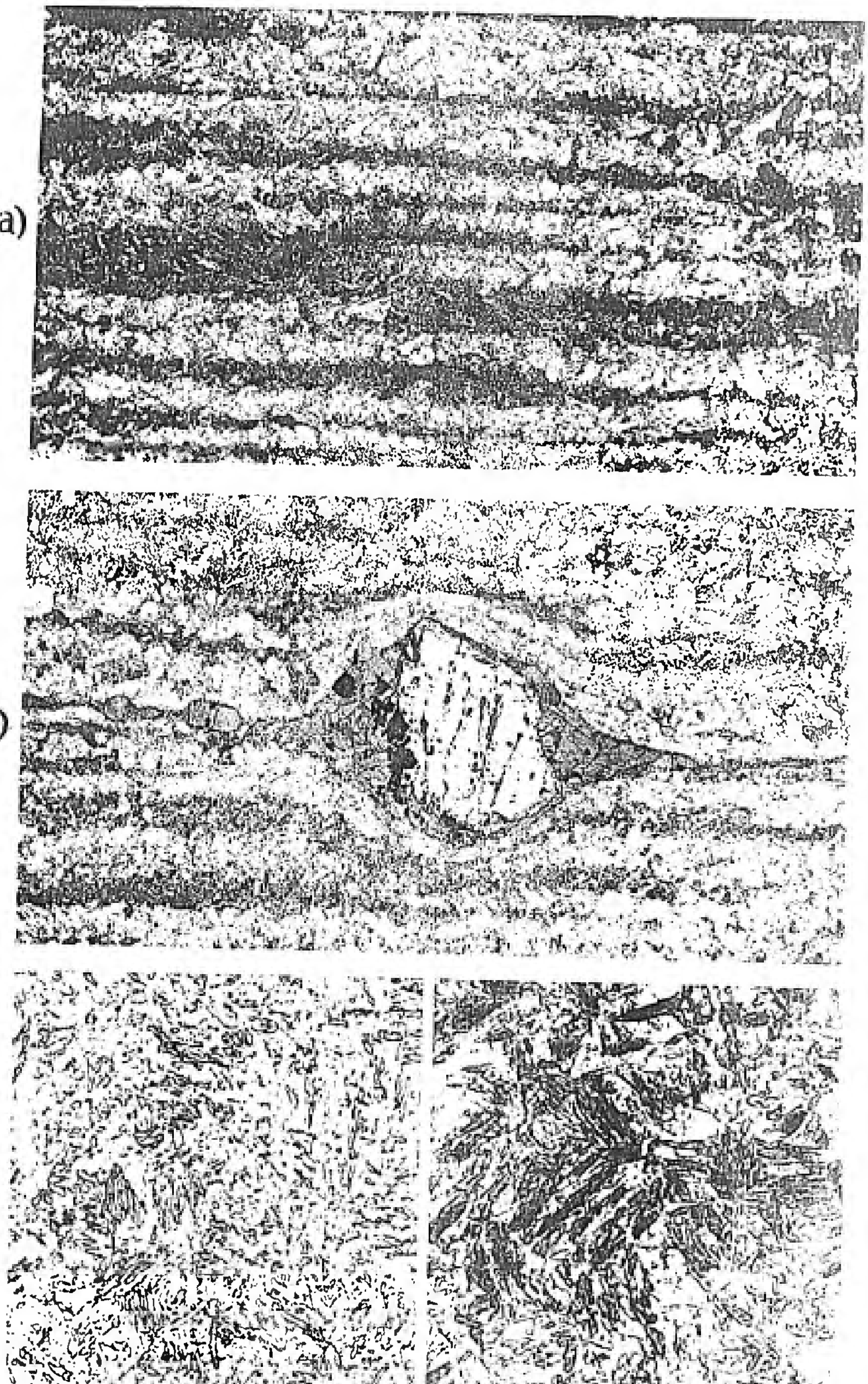
(d) Homogeneous Plate 963-D2

Coarse tempered martensite. ASTM grain size No. 8.

X1000 MA-3003

All etched in 1% Nital.

Figure 12



(a)

(b)

(c) (d) W.A.639-3385

Figure 13

Relation of Grain Boundary Carbide and Crack Systems in Carburized Case

(a) Carburized Plate 18340-1

Showing the progress of crack systems following grain boundary carbide.

X250 MA-3050

(b) Same as above.

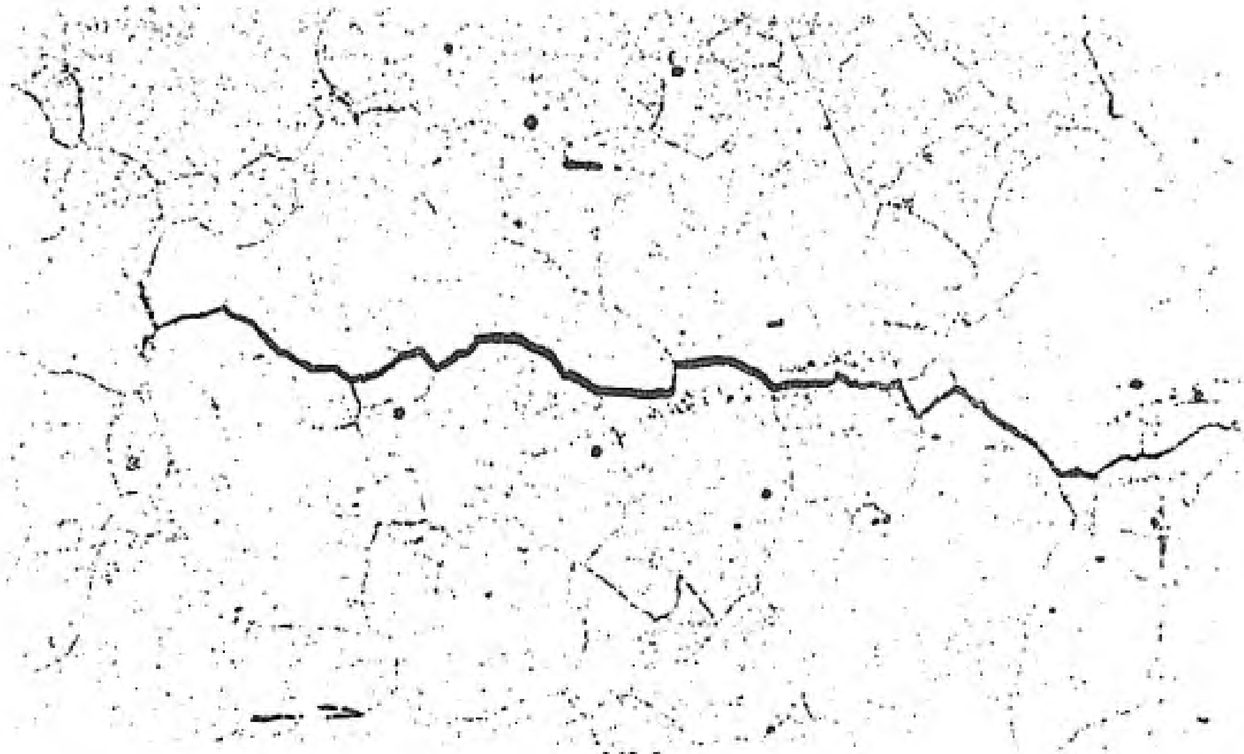
X1000 MA-3052

(c) Same as above.

X1000 MA-3053

Etched in Murakami's Reagent.

Figure 13



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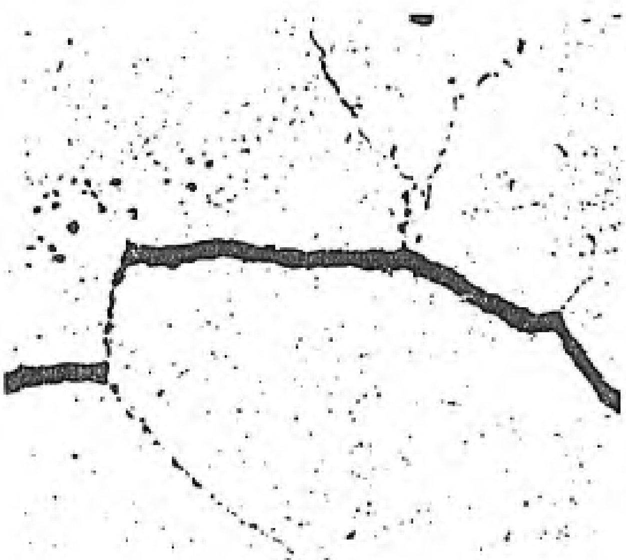
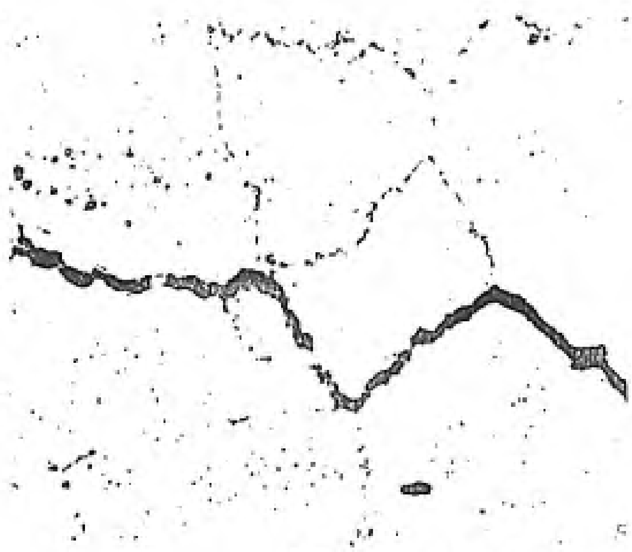


(b)



(C) W.A.639-3386

Figure 14

Macrostructure

The plate stamped 18340-1 shows a rather prominent interdendritic structure throughout and the nonmetallics present are well distributed.

The specimens stamped 18340-2 and 18340-3 show near the top and bottom surfaces remnants of a well-broken dendritic structure and within this location some elongated streaks of impurities which might be termed 'fine laminations" are found.

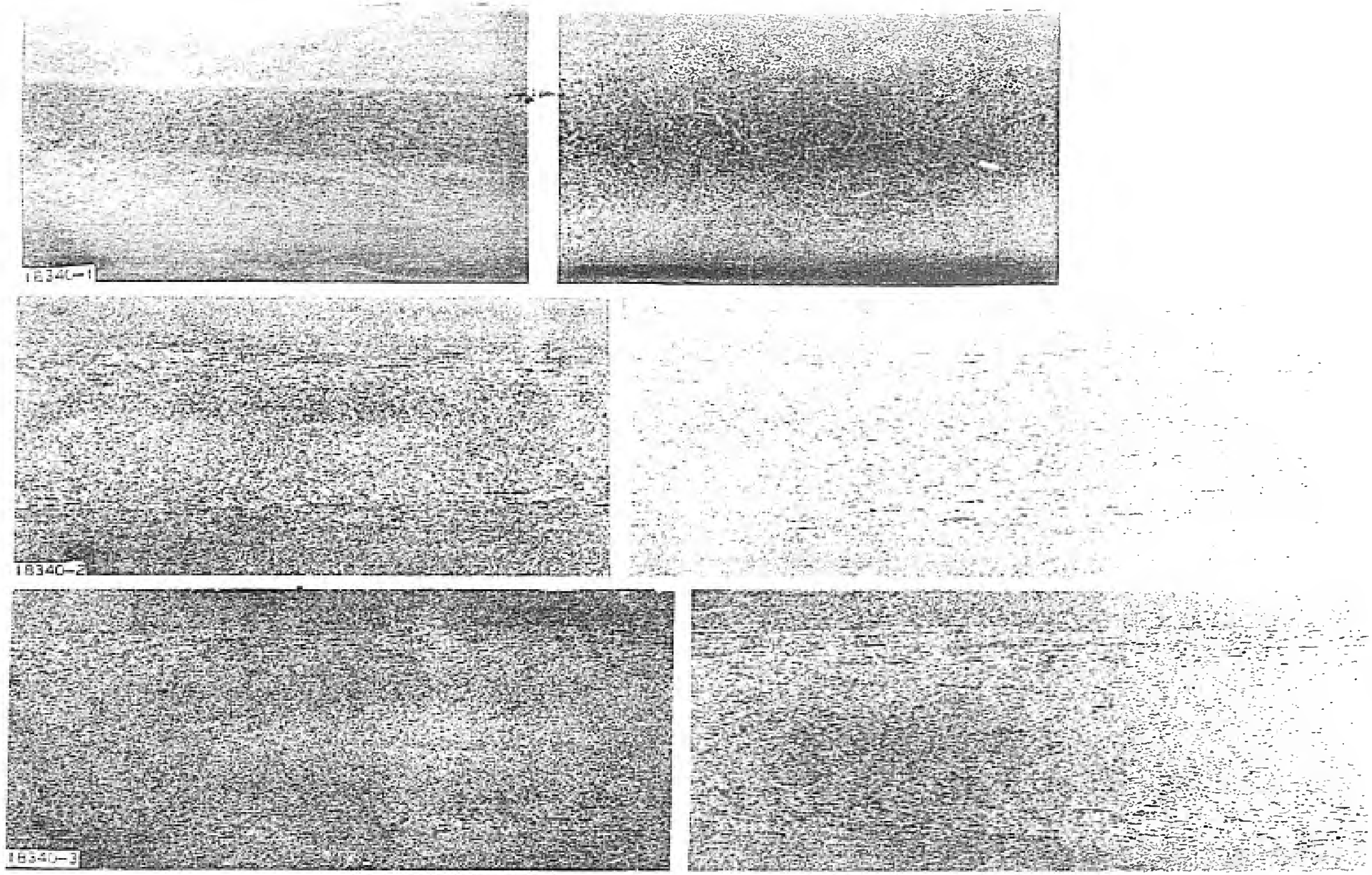


FIG. 14

INCHES 1 2 3

ORDNANCE DEPT. U.S.A.
WATERTOWN ARSENAL.

2" ARMOR PLATE
AUGUST 6, 1941 W.A.710-1336