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CONFIDENTIAL

EXAMINATION OF HIGH QUALITY EXPERIMENTAL 1/2" HOMOGENEOUS PLATE

By

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WATERTOWN ARSENAL
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[redacted]

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Purpose

The purpose of this investigation was to determine some of the metallurgical characteristics of high quality homogeneous armor plate.

Conclusions

The following characteristics are desirable in armor plate to obtain optimum ballistic properties:

a. A thoroughly deoxidized steel, resulting in a fairly clean steel, free from segregations of non-metallic inclusions.

b. A fine, uniform grain after proper heat treatment, resulting in a uniform distribution of carbides in the microstructure.

c. Brinell hardness of 418-444.

Introduction

In connection with the program on the development of homogeneous armor plate, two 1/2" plates of the standard chromium-molybdenum-vanadium composition, manufactured by the Henry Disston & Sons, Inc., were heat treated by two different methods at Watertown Arsenal, in order to produce a fine, uniform grain. These plates were given a penetration test at Aberdeen Proving Ground. (See A.P.G. Partial Report No. 117).

The ballistic limit of the heat treated plates was 2650 f/s, Cal. .30 A.P. M1922 ammunition, which is 100 f/s in excess of that specified for half-inch plate in Specification AXS-54K - Rev. 3.

Since the ballistic limits of these plates were the highest on record at this arsenal, it was believed advisable to study the metallurgical properties of the plates, in order to establish a better understanding of the factors which contribute to the manufacture of high quality plate.

Test Procedure and Materials

Two annealed homogeneous armor plates 10x12-1/2" were obtained for this test from the Henry Disston & Sons, Inc.

These plates were .541" thick.

1. Chemical Analysis

Chemical analysis was made on this material.

2. Heat Treatment

a. Plate No. 1 was heated to 1650°F, held 2 hours, quenched in oil, drawn to 925°F for 2 hours, air cooled.

b. Plate No. 2 was heated to 1600°F, held at that temperature for 2 hours, slowly cooled in furnace to 1400°F, quenched in oil, and drawn to 925°F, for 2 hours, followed by air cooling.

3. Macroscopic Examination.

Macroscopic examination was made on samples cut parallel to and at right angles to the direction of rolling.

4. Microscopic Examination.

A study of the uniformity of structure and of the grain boundary conditions was made on samples cut from the plates.

5. Hardness.

Hardness tests were made on these plates after these heat treatments.

6. Ballistic Tests.

Preliminary ballistic tests were made at Watertown Arsenal. Since the plates could not be penetrated by the ammunition at Watertown Arsenal, they were sent to Aberdeen Proving Ground for the final ballistic test. Ballistic tests were made normal to plate with Cal. .30 A.P. ammunition.

Results

1. Chemical Analysis.

The chemical composition of this steel is given below:

C	Mn	P	S	Si	Cr	Mo	V
.455	.58	.018	.019	.275	1.13	.55	.25

2. Macroscopic Examination.

The macrostructure of the plate both in the direction of rolling and at right angles to the direction of rolling consisted of a uniform banded structure, see Fig. 2.

3. Microscopic Examination.

Figs. 1, 3 and 4 illustrate the microstructure of plates Nos. 1 and 2.

4. Hardness Tests.

The Brinell Hardness of the plates is shown below:

Plate No. 1 --- - 444

Plate No. 2 ---- 444.

5. Ballistic Tests.

Plates Nos. 1 and 2 were tested at Watertown Arsenal and found to defeat Cal. .30 A.P.M. 1922 ammunition, having a striking velocity of 2600 f/s.

The results of the ballistic tests made at Aberdeen Proving Ground are:

Table I

	Ballistic Limit Cal. .30 A.P.M. 1922	Remarks
Plate No. 1	2720 f/s *	No spalls
Plate No. 2	2718 f/s *	No spalls.

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* These ballistic limits were made on plates .541" thick. The ballistic limit was calculated for .500" thick plate on the basis of ballistic data in W.A. Report No. 710/356 - "A Comparison of the Ballistic Efficiency of Recent Face Hardened & Homogeneous Armor Plates". This average value was found to be 2650 f/s.

Discussion

The heat from which this steel was made was thoroughly deoxidized and sufficiently cropped, thereby eliminating laminations and segregations of non-metallic inclusions (see Fig. 1a). Apparently this heat was deoxidized with Titanium, since remnants of deoxidation products (titanium cyanonitride inclusions) were uniformly distributed in the microstructure. The characteristic shape of one of these inclusions at X1000, is shown in Fig. 1.

The plates were thoroughly cross rolled as noted in the macroscopic study (see Fig. 2).

The microstructure of Plate No. 1, quenched and drawn according to the normal practice, consisted of a fine uniform troostito-sorbite structure (see Fig. 3). No continuous chains of grain boundary carbide were evident (see Fig. 4). Such grain boundary conditions have been shown to be related to spalling in homogeneous armor plate.

The microstructure of Plate No. 2, heat treated according to the delayed quenching method had a fine troostito-sorbite structure, like that of Plate No. 1 (Fig. 3). No segregations of the objectionable grain boundary carbide were evident (Fig. 4).

The ballistic limits of these two plates were 100 f/s above that specified for half inch plate in Specification AXS-54E Rev. 3. No evidence of spalling was noted.

This material responded satisfactorily to the delayed quenching method. It is claimed that this method of heat treatment eliminates residual quenching strains. The ballistic limit obtained by this method was nearly the same as that obtained by the standard quench and draw method.

The Brinell hardness of these plates was 444, the maximum required for high quality homogeneous plate.

Summary of Results

The subject armor plate possesses the following metallurgical properties:

a. Uniform distribution of fine nonmetallic inclusions.

b. Uniform troostito-sorbitic structure.

c. Uniform distribution of fine carbides.

d. Brinell hardness of 418-444.

Respectfully submitted,

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Approved:

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FIGURE 1

Plate #2

Uniform distribution of small non-metallic inclusions.

X25 MA2029

Uniform distribution of small non-metallic inclusions.

X100 MA2060

Typical titanium cyanonitride inclusions in the steel.

X1000 MA2061

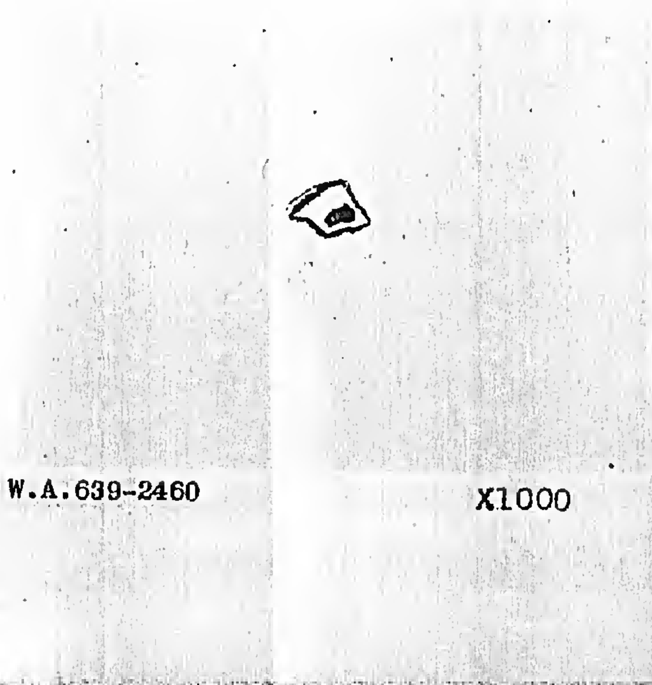
Specimen unetched.

FIGURE 1
Plate #2

Specimen unetched

X25

X100



W.A.639-2460

X1000

FIGURE 2

Plate #2

These micrographs are also typical of Plate No. 1, since both plates are from the same heat.

Uniform, banded structure in the direction of rolling.

Longitudinal.

Macrostructure of section at right angles to the direction of rolling.

Transverse.

Etched in Oberhoffer's Reagent

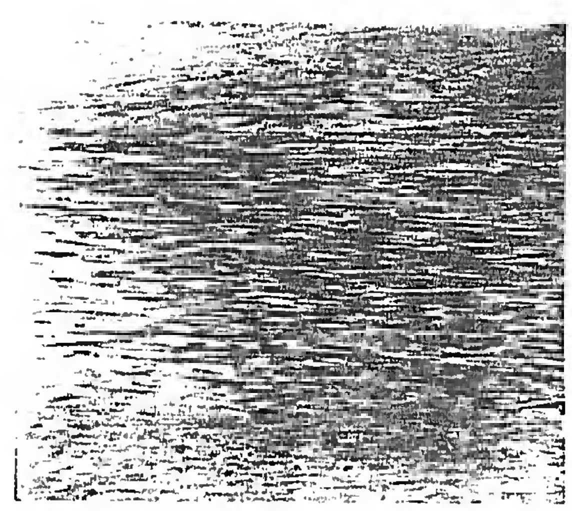
Longitudinal section, X5 - MA2062

Transverse section, X5 - MA2059

FIGURE 2
Plate #2

Etched in Oberhoffer's Reagent

Longitudinal



Magnified 5 Diameters

W.A.630-2461

FIGURE 3

Plate #1

Uniform troostito-sorbitic structure in the quenched and drawn plate.

X1000 MA2058

Plate #2

Uniform troostito-sorbitic structure in the plate, heat treated by the delayed quench method.

X1000 MA2057

Both specimens etched in 1% nital.

FIGURE 3
Etched in 1% Nital

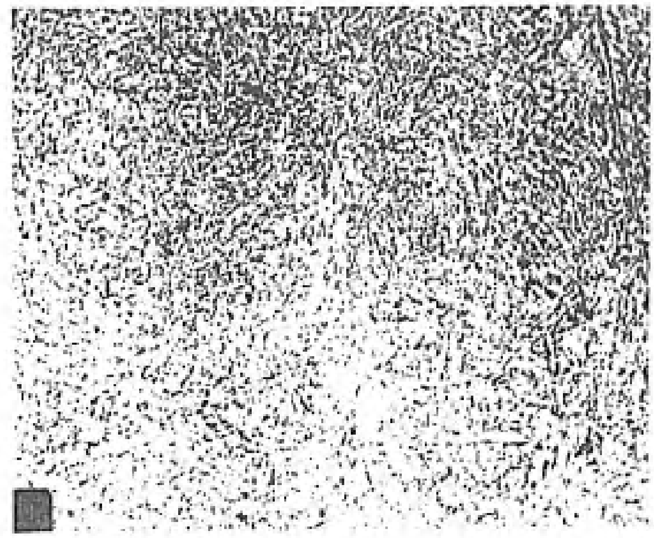


Plate #1

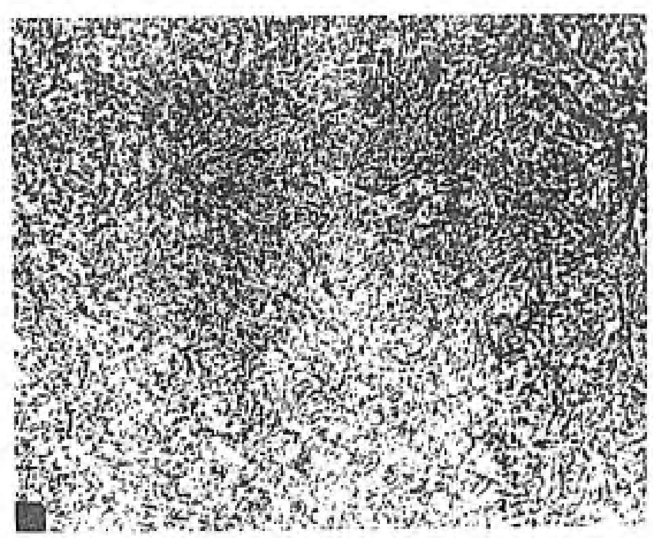


Plate #2

Magnified 1000 Diameters
W.A.639-2462

FIGURE 4

Plate #1

Uniform distribution of fine carbide. This condition is found in high ballistic plate.

X1000 MA2063

Plate #2

Uniform distribution of fine carbide. This condition is found in high ballistic plate.

X1000 MA2051

Specimens etched for 12 minutes in hot solution of Murakami's reagent.

FIGURE 4
Etched in Murakami's Reagent

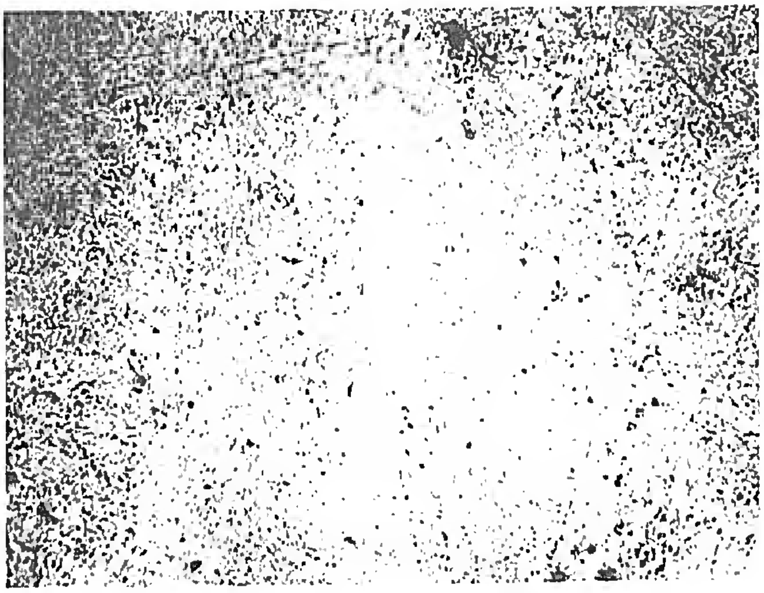


Plate #1

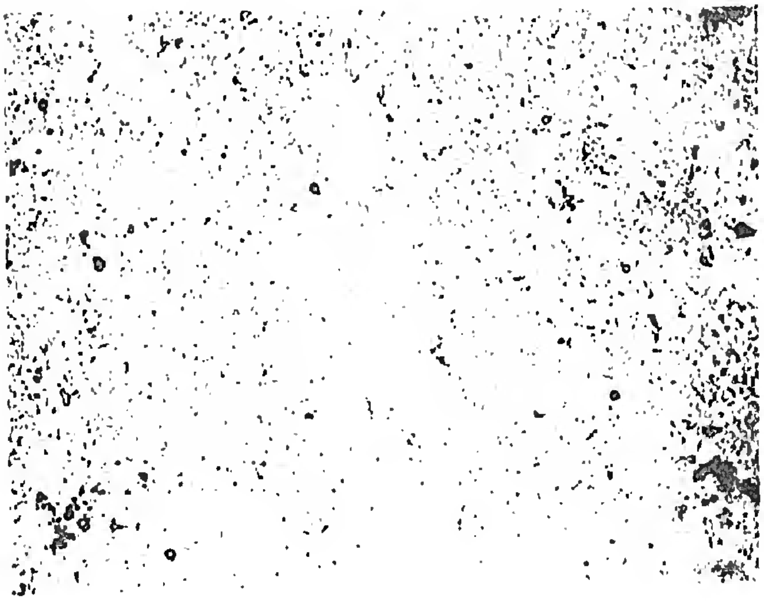


Plate #2

Magnified 1000 Diameters

W.A.639-2463