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REPORT NO. 710/363

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EXAMINATION OF

TWO EXPERIMENTAL CAST ARMOR PLATES

SUBMITTED BY [illegible] STEEL FOUNDRY

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Report No. 710/383
Watertown Arsenal

October 21, 1940

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Examination of

Two Experimental Cast Armor Plates

Submitted by Lebanon Steel Foundry

Purpose

The purpose of this investigation was to study the variations in the structure and the physical properties of a satisfactory and an unsatisfactory cast armor plate in order to explain their diverse ballistic properties.

Introduction

Two cast one-inch armor plates of exceptionally high ballistic limits showed considerable difference under shock tests. Both plates were cast from the same heat and subjected to approximately the same heat treatments, but one plate was satisfactory while the other was quite brittle and failed to pass Specification RIXS-72B.

Conclusions

1. The unsatisfactory plate had coarser grains, more continuous chains of carbides in the grain boundaries, and a more brittle structure (acicular martensite) than the satisfactory plate.

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2. The hardness (Brinell 477) of the unsatisfactory plate was greater than that found in good quality armor plate.

Results (Watertown Arsenal)

Structure

1. Photographs of the micro- and macrostructure are shown in Figures I to V.

Physical Properties

1. Brinell Hardness

Plate No. 1 - Poor - 477
Plate No. 2 - Good - 444

2. Tensile Tests

Speci-men Mark	Sect. Area Sq.In.	Y.S.P. lbs./sq.in.	Tensile Strength lbs./sq.in.	Elon. %	Red. %	Break	Appearance of Fracture
1-A	.1"	176,500	201,000	.7	2.7	Middle third	Irregular 90° break, lustrous cavities, dendritic structure, somewhat woody
1-B	"	176,500	201,000	.7	1.6	Outer third	" "
2-A	"	183,000	211,500	2.1	3.3	"	Irregular 90° break, coarse dendritic structure, lustr.cavs.
2-B	"	188,000	197,000	.7	2.2	Middle third	" "

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Test Procedure and Materials

Two cast armor plates one-inch thick were received at this arsenal after firing test had been completed at Aberdeen Proving Ground. Specimens about 1" x 1" x 1" were cut from approximately the center of each plate, avoiding areas too close to penetrations. Brinell hardness readings were made on each of these specimens, which were then polished and subjected to microscopic examination.

Test bars for tensile tests were turned from each plate as close to the micro specimens as was practical. The two bars of each plate were cut from mutually perpendicular directions and designated A and B for identification purposes.

Chemical analyses, heat treatments, and some tests of physical properties were reported by the Lebanon Steel Foundry, and they, together with the ballistic data given below, are taken from the Aberdeen Partial Report #176, Second Report on Experimental Cast Armor Plates.

Chemical Analysis of Heat #AW-6692

Carbon 0.47, Chromium 1.17, Nickel 2.20, Molybdenum 0.60, Vanadium 0.21.

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Heat Treatments (By Lebanon)

Plate	Heated to	Hold	Remarks
AW-6592, 1 & 2	2000°F	8 hrs.	Transferred to furnace at 1550°F and slowly cooled.
	1650°F	5 hrs.	Furnace cooled.
	1500°F	3 hrs.	Quenched in oil.
AW-6592, 1	800°F	5 hrs.	" " "
AW-5492, 2	1000°F	5 hrs.	" " "

Physical Tests* (By Lebanon)

Specimen	Brinell Hardness	Elastic Limit lbs./sq.in.	Tensile Strength lbs./sq.in.	% Elon.	% Red.
#1	378	190,000	231,500	4.0	5.8
#2	363	176,000	210,500	6.0	10.0

* These physical tests are not typical of the plate since they were made on test bars which did not have the same Brinell hardnesses as the actual castings.

Ballistic Data**

Plate	Brinell Hardness	Caliber of Shot	Ballistic Limit ft./sec.	Remarks
AW-6592-#1	460	Cal. .50 M1	2879	Unsatisfactory, cracks developed on shock test.
AW-6592-#2	444	" " "	2690	Satisfactory.

** Values reported by Aberdeen Proving Ground.

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Discussion

The microstructures of these plates are shown in Figures I - V, and the macrostructure in Figure VI. Both are discussed in detail opposite each photograph.

In general, the heat treatment given Plate No. 2 is superior to that given No. 1 in that a less brittle structure, i.e., a combination of troostite and martensite (Plate No. 2) as against the harder acicular martensite of Plate No. 1, has been found more effective in resisting shock tests. Also, the finer grain found in Plate No. 2 produces a more homogeneous medium which also promotes ballistic ductility. However, the micro segregation found in Plate No. 2 makes for lack of homogeneity, and an improvement in this would be desirable. This is the one instance in which the structure of Plate No. 1 is superior to Plate No. 2.

The microstructures of both could be improved by a heat treatment designed to eliminate the formation of chains of carbide.

The high hardness value of Plate No. 1 bears out the findings of the micro-examination that the ultimate structure of Plate No. 1 is harder and therefore more brittle than Plate No. 2.

It has been pointed out* that other conditions, such as composition, dirt content, carbides, etc., being equal,

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* W.A. Report #710/261

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the armor plate with the lower Brinell Hardness will show the greater ballistic ductility, (i.e., less tendency to spall, crack, button, etc.). However, it must be also borne in mind that plates with too low a Brinell reading will not have sufficient hardness to resist penetration at the specified velocities.

The physical tests made at this Arsenal (Page 2) resulted in widely different values from those reported by the Lebanon Steel Foundry (Page 4). Since the tests made by the company were carried out on .505 test bars specially cut from heat treated coupons with Brinell hardnesses considerably less than those of the actual plates used in ballistic testing, the values reported by them have little bearing on the true physical properties of the armor plates tested. The values obtained at this Arsenal on bars cut from the portion of the plate subjected to ballistic tests are more indicative of the actual properties of these plates.

Respectfully submitted,

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APPROVED:

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Figure I

Both plates show the same amount of dirt in about the same distribution. Extremely fine dirt in chain formation evident in the background of Plate No. 1 is also found in Plate No. 2 when subjected to careful examination. The lack of prominence of this fine dirt in the photograph of Plate No. 2 is attributed to differences in the polishing of the specimens.

The large, irregular black areas found in both specimens are porous areas. These are shown in greater detail in Figure II.

Specimens unetched, magnified 25 diameters.

Plate No. 1 - MA1957
Plate No. 2 - MA1956

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FIGURE I

Specimens Unetched - Magnified 25 Diameters

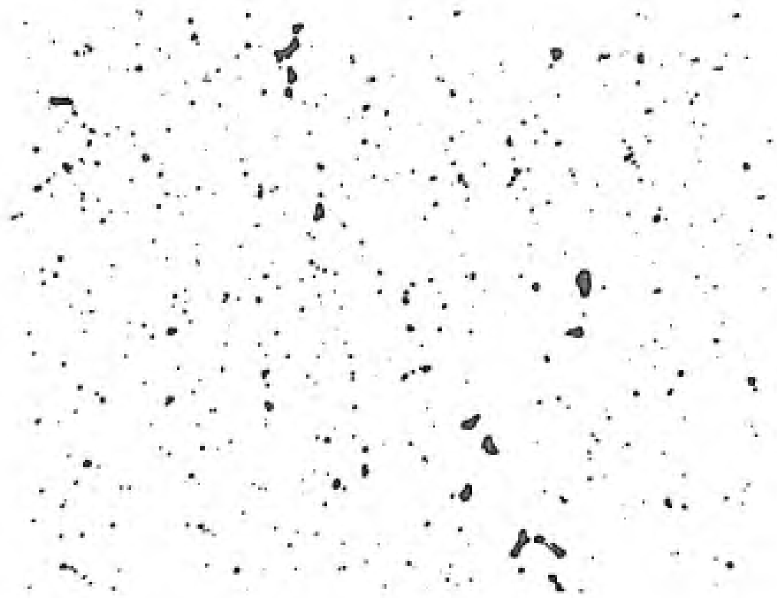

Plate #1

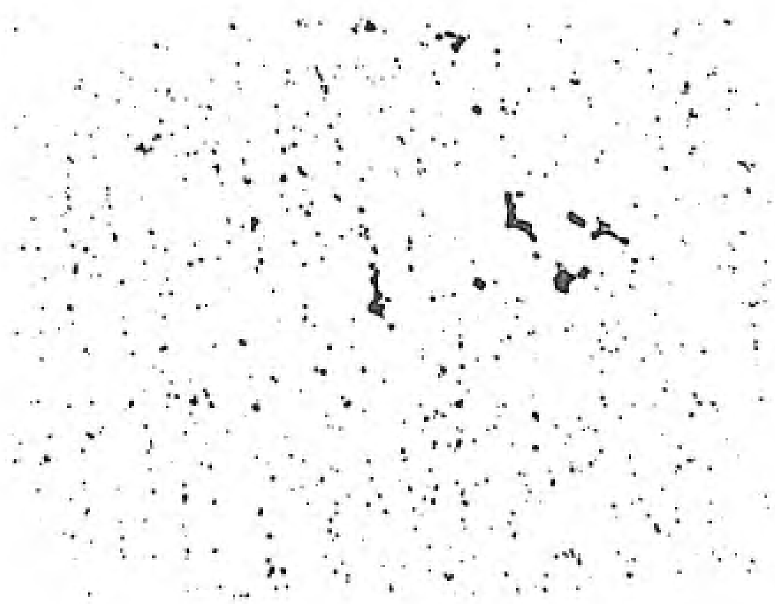

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Plate #2

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Figure II

Plate No. 1

The voids seen here are the porous areas mentioned in the description of Figure I. They occur most often near the edges of the casting and always in the interdendritic fillings. This etching reagent (Stead's) reveals segregates impurities (light areas) at the boundaries of the dendrites. The segregations are the same throughout the specimen.

Etched in Stead's Reagent. X100 MA1968-I

Plate No. 2

Again the voids occur in the segregates areas near the edge of the casting. The segregations which occur throughout the specimen are much more pronounced in this plate than in Plate No. 1.

Etched in Stead's Reagent. X100 MA1969-I

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FIGURE II

Etched in Stead's Reagent

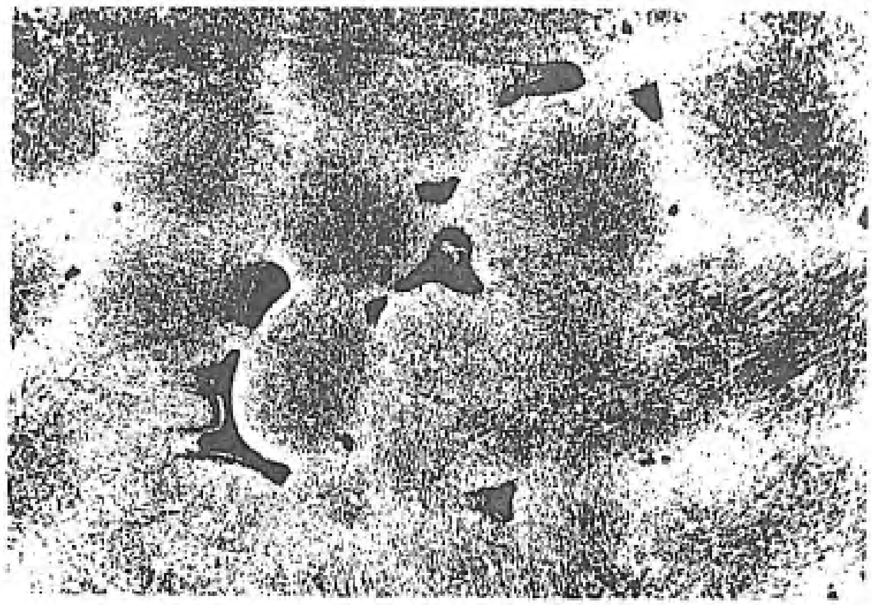

Plate #1

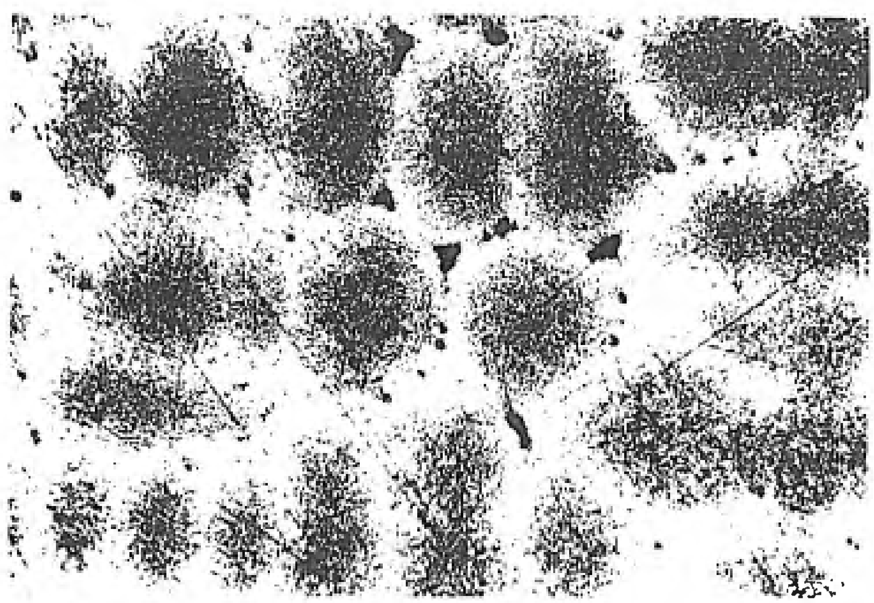

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Plate #2

Magnified 100 Diameters

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Figure III

<u>Plate No. 1</u> - Brinell 477

The structure of this plate is martensitic.

Etched in 1% Nital. MA1961

<u>Plate No. 2</u> - Brinell 444

This plate is also martensitic, but the dark areas outlining quite small grains are troostitic. This amount of troostite indicates a softer structure than that of Plate No. 1.

Etched in 1% Nital. MA1960

FIGURE III

Etched in 1% Nital

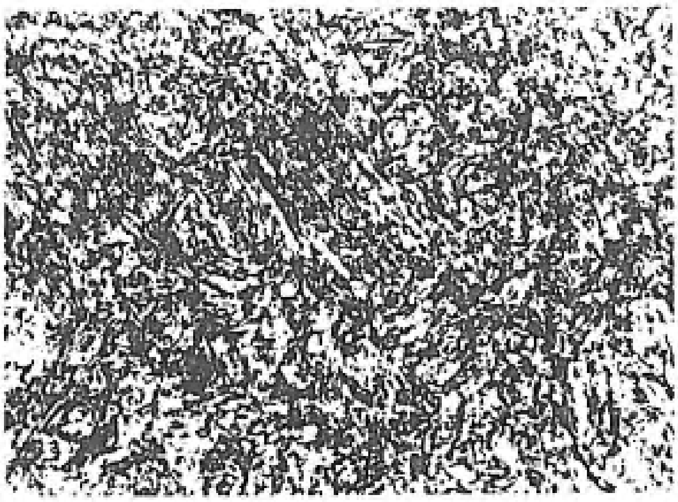

Plate #1

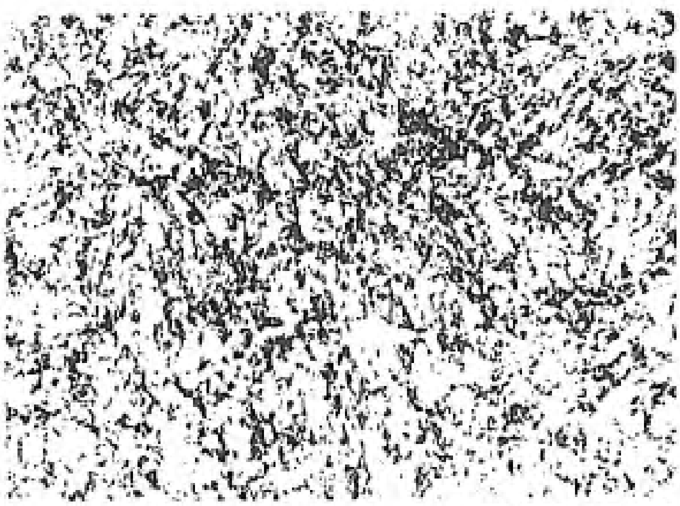

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Plate #2

Magnified 1000 Diameters

Figure IV

Plate No. 1

The carbides are outlining grain boundaries in fairly continuous chains. A good many of these grain boundary carbides are larger than the background carbides which indicate more minute grains within the grosser outlines. These are revealed by a 15-minute etch in Murakami's reagent, which stains carbides black, leaving other constituents unetched.

MA1962-1 & 2

Plate No. 2

The carbides show a tendency to outline grains, but the chains are not nearly as continuous as they are in Plate No. 1. These outlines show a tendency to be more prominent near the voids shown in Figures I and II. The carbides in the chain are often larger than those found in Plate No. 1, whereas the background carbides are definitely finer than those in Plate No. 1

Etched 15 minutes in Murakami's reagent. MA1963-1 & 2

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FIGURE IV

Etched in Murakami's Reagent

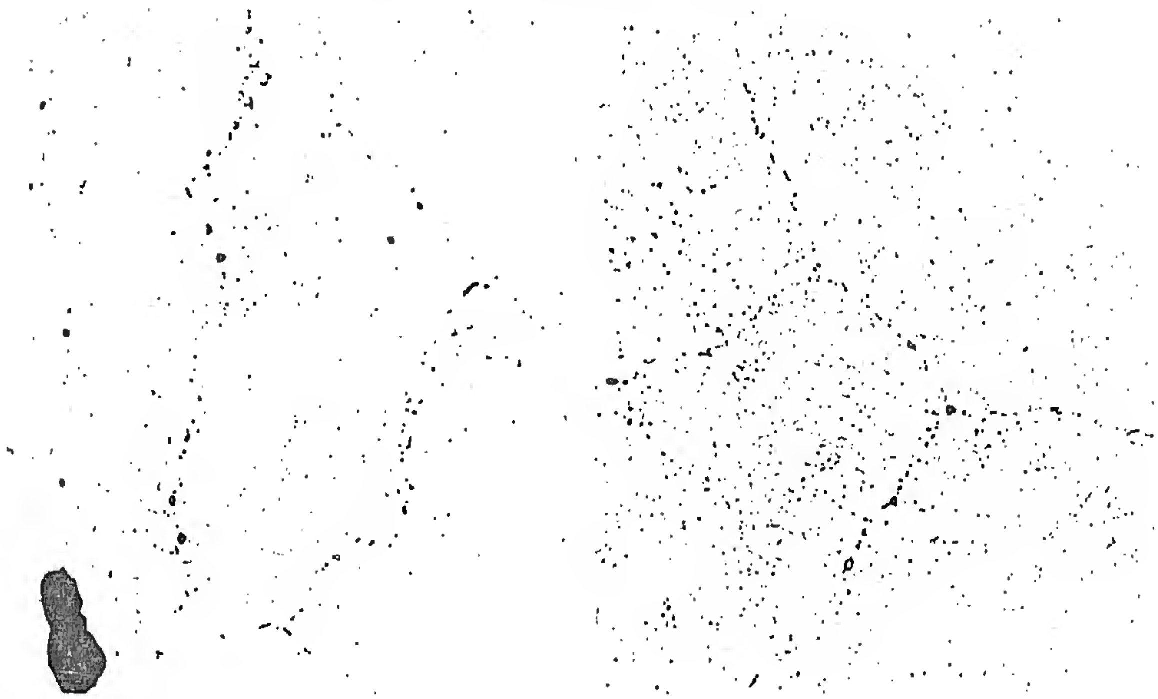

Plate #1

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Plate #2

Magnified 1000 Diameters

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Figure V

Plate No. 1

The coarse grains in this plate are very evident even at this low magnification.

Etched in 1% Nital. MA1966

Plate No. 2

The grains in this plate can also be seen, but not so clearly. They are obviously finer.

Etched in 1% Nital. MA1967

Plates No. 1 and 2

The dendritic patterns are very pronounced in both plates.

Etched in Oberhoffer's Reagent. MA1970 & MA1971

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FIGURE V

Etched in 1% Nital — Magnified 5 Diameters

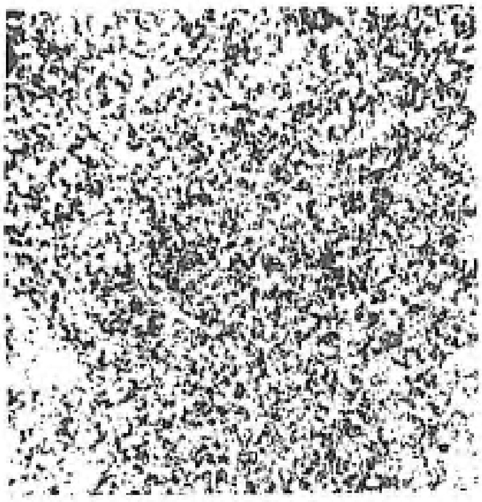

Plate #1

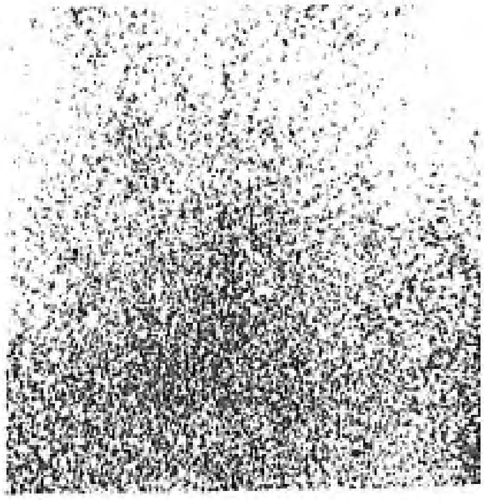

Plate #2

Etched in Oberhoffer's Reagent — Magnified 3 Diameters

Plate #1

Plate #2

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Figure VI

Macrostructure

Characteristics:

#1 - The plate shows a prominent, dendritic structure throughout, with some segregated carbides. The nonmetallics present are well scattered.

#2 - The section has a somewhat coarse, dendritic structure and the partially etched-out carbides and non-metallic segregates are slightly coarser than those found in specimen #1.

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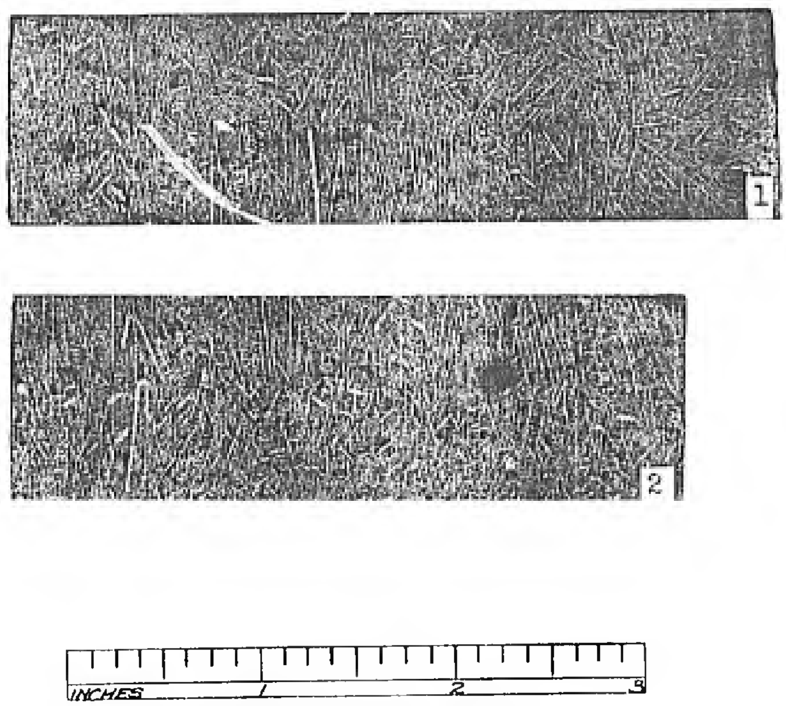

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ARMOR PLATE

May 2,1940 W.A.710-447

Fig. VI

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