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REPORT NO. 710/380

CONFIDENTIAL

METALLURGICAL EXAMINATION OF

GERMAN AIRCRAFT ARMOR

ORDNANCE
TECHNICAL SUBJECT

NO. MS-B710/380

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By

E. L. Reed
Research Metallurgist

July 28, 1941

WATERTOWN ARSENAL
WATERTOWN, MASS.

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Metallurgical Examination of

German Aircraft Armor

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Purpose

The purpose of this investigation was to determine the metallurgical characteristics of a sample of armor plate taken from a captured German airplane, model JU88.

Conclusions

1. The material is a homogeneous plate containing:

| <u>C</u> | <u>Mn</u> | <u>P</u> | <u>S</u> | <u>Si</u> | <u>Ni</u> | <u>Cr</u> | <u>Mo</u> | <u>V</u> | <u>W</u> |
|----------|-----------|----------|----------|-----------|-----------|-----------|-----------|----------|----------|
| .415 | .58 | .010 | .026 | .30 | 2.48 | 2.41 | .64 | nil | nil |

2. The Brinell hardness of the face was 555 and the back, 555.
3. Macro and microscopic examination indicated that the material was rather uniform throughout. The plate was rolled from a fairly clean heat of steel.
4. The ballistic limit of the plate was 2356 f/s, Cal. .30 A.P. but was too brittle to qualify under the existing specifications.

Introduction

Major Horace A. Quinn submitted to this Arsenal with his letter of June 3, 1941, a small irregular piece of armor plate, .290" thick, taken from a captured German airplane, model JU88. This plate formed part of a

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bulkhead behind the crew's compartment. In addition, the pilot's seat was made of what appeared to be similar armor plate.

Results

1. Chemical Analysis

The chemical analysis of the sample is given below:

| <u>C</u> | <u>Mn</u> | <u>P</u> | <u>S</u> | <u>Si</u> | <u>Ni</u> | <u>Cr</u> | <u>Mo</u> |
|----------|-----------|----------|----------|-----------|-----------|-----------|-----------|
| .415 | .58 | .010 | .026 | .30 | 2.48 | 2.41 | .64 |

a. Spectrographic Examination

Spectrographic examination indicated traces of Cu, V, Al, and Sn. No traces were found of Co, W, Cb, Ti, B, Ta, and Zr.

2. Macroscopic Examination

a. Deep Etch

The etched sections show a rather uniform condition throughout with practically no dendritic structure indicating thorough working. The partially etched out nonmetallics are well distributed. (See, Figure 1).

b. Oberhoffer's Etch

There is a slight amount of uniform fine banding present in sections cut at right angles to each other. (See Figure 2). This is considered reasonably good quality material.

3. Microscopic Examination

The nonmetallic inclusions are well distributed in this material. The steel is relatively clean. (See, Figure 3).

Banding is evident in the central portions of the cross section while near the surface the structure is uniform. The material had a fairly coarse martensitic structure. (See, Figure 4).

No grain boundary carbides were evident. (See, Figure 5).

4. Hardness Surveys

a. Front and Rear Face Hardness

Hardness surveys made on the front and rear face are reported below.

Brinell Hardness

| <u>Reported in A.P.G. Firing Record</u> <u>No. 23879-A831</u> | <u>Determined at</u> <u>Watertown Arsenal</u> |
|--|--|
| 653 Face | 555 Face |
| 555 Back | 555 Back |

b. Hardness Survey across the Cross Section

Figure 6 illustrates this hardness survey. A hardness survey made across a cross section of the plate indicated that there was some evidence of decarburization at both surfaces.

5. Ballistic Tests

The results of the ballistic tests as recorded in the A.P.G. Firing Record No. 23879-A831 dated May 31, 1941 are given below:

| <u>Thick- ness</u> | <u>Angle of Plate</u> | <u>Projec- tile</u> | <u>Low Com- plete Pene- tration</u> | <u>High Par- tial Pene- tration</u> | <u>Bal- listic Limit</u> | <u>Speci- fica- tion</u> | <u>Shock Test</u> | <u>Remarks</u> |
|------------------------|-------------------------------|-------------------------|---|---|----------------------------------|----------------------------------|-----------------------|---|
| .295" | normal | Cal..30 A.P.M2 | 2332 | 2319 | 2326 | (Army and Navy) | | Plate cracked with Caliber .30 A.P. M2, & broke with Caliber .50 A.P. M2 |
| | | Cal..50 A.P. M2 | --- | 1700* | --- | | | |

*Estimated Velocity

Test Procedure and Materials

A small irregular sample .290" thick was submitted for metallurgical examination, which included chemical analysis, macro and microscopic examination, hardness surveys, and ballistic tests conducted at Aberdeen Proving Ground.

Discussion

The chemical composition of this homogeneous plate is typical of Krupp armor plate covered by German patent 666,251, Oct. 14, 1938 (Cl. 72g.301) addn. to 642,927 issued to Fritz Rittershausen and also of German torpedo forgings noted in a report on German shell, bombs, and torpedo forgings recently submitted by Lt. Col. A. H. Musson, Director of Inspection, New York, Inspection Board of United Kingdom and Canada, 15 Broad Street, New York, N. Y., with his letter of July 7, 1941.

The Brinell hardness of the armor plate from the JU88 was determined at this Arsenal as 555 face and 555 back. These values are in disagreement with those reported by Aberdeen Proving Ground in which the face hardness was reported as 653 Brinell and the back 555 Brinell.

The hardness of the armor plate from the JU88 is typical of other compositions used on some of the German aircraft. For example, in the report submitted by Lt. Col. A. H. Musson, the Brinell hardness of 555 was noted on a 5-1/2 mm. bullet proof plate from a Junkers 97.

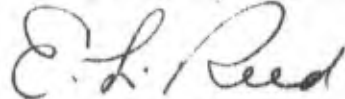
Ballistic tests made at Aberdeen Proving Ground showed that this plate had a ballistic limit of 2356 f/s with Cal. .30 A.P. The section was too small to permit the firing of a shock test. However, a shot of .50 Cal. A.P. with an estimated striking velocity of 1700 f/s. broke the plate.

It was noted in the .30 Caliber firing that the plate spalled to the extent that it would have failed to qualify.

It is worthwhile to note that the armored sections from the JU88 which were tested at Aberdeen Proving Ground were equipped with hinges (see photos A.P.G. #46665 and #46666, 6/6/41, A.P.G. Firing Record No. 23879-A831). This construction permits damaged sections to be easily replaced when necessary.

Mr. M. Bolotsky made the metallurgical examination covered in this report.

Respectfully submitted,



E. L. Reed,
Research Metallurgist.

APPROVED:

S. B. RITCHIE,
Lt. Col., Ord. Dept.,
Director of Laboratory.

Figure 1

Macroscopic Examination - Deep Etch

Section "A"

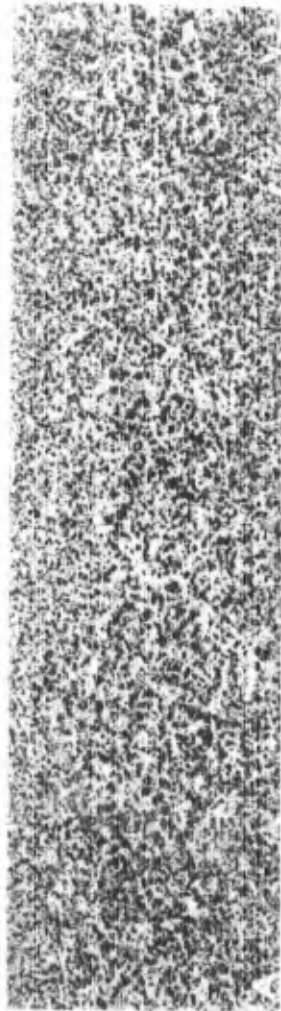
This section shows a rather uniform condition throughout with practically no dendritic structure. The partially etched-out nonmetallics are well distributed.

Magnified 5 Diameters

Section "B"

This section was cut at right angles to section "A". Macrostructure same as section "A".

Magnified 5 Diameters



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GERMAN JUNE 21, 1941 AIRCRAFT ARMOR X5 W.A. 710-1287

Figure 2

Macroscopic Examination - Oberhoffer's Etch

Section "A"

This section shows a fine uniform banded structure.

X5

MA-3111

Section "B"

This section was cut at right angles to section "A".
Macrostructure same as section "A".

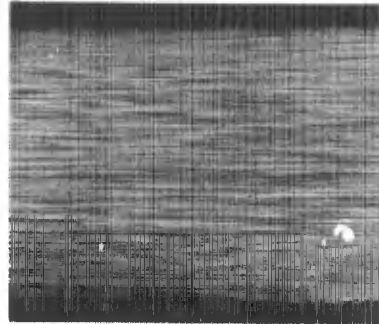
X5

MA-3112

Figure 2

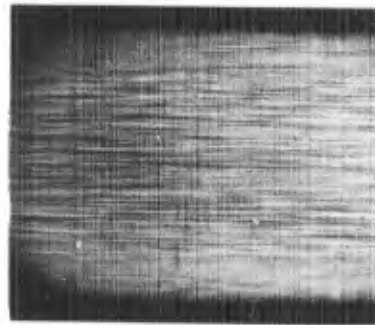
Macroscopic Examination - Oberhoffer's Etch

Section
"A"



Magnified 5 Diameters

Section
"B"



Magnified 5 Diameters

Figure 3

Nonmetallics

- (a) Fairly clean heat of steel. Average amount of non-metallic inclusions present in section parallel to ripples on surface of plate.

X25

MA-3037

- (b) Same as (a).

X100

MA-3039

- (c) Fairly clean heat of steel. Average amount of non-metallic inclusions present in section perpendicular to ripples on surface of plate.

X25

MA-3036

- (d) Same as (c).

X100

MA-3038

All above unetched.

Figure 3
Nonmetallics

(a) Magnified 25 Diameters

(b) Magnified 100 Diameters

(c) Magnified 25 Diameters

(d) Magnified 100 Diameters

All above unetched.

Figure 4
Microstructure

Typical microstructure near the surface of the plate.
Slight banding in the interior layers.

X100

MA-3106a, b

Microstructure of internal section of plate. White
bands - martensitic areas.

X1000

MA-3107

Microstructure near the surface. Fairly coarse
martensite.

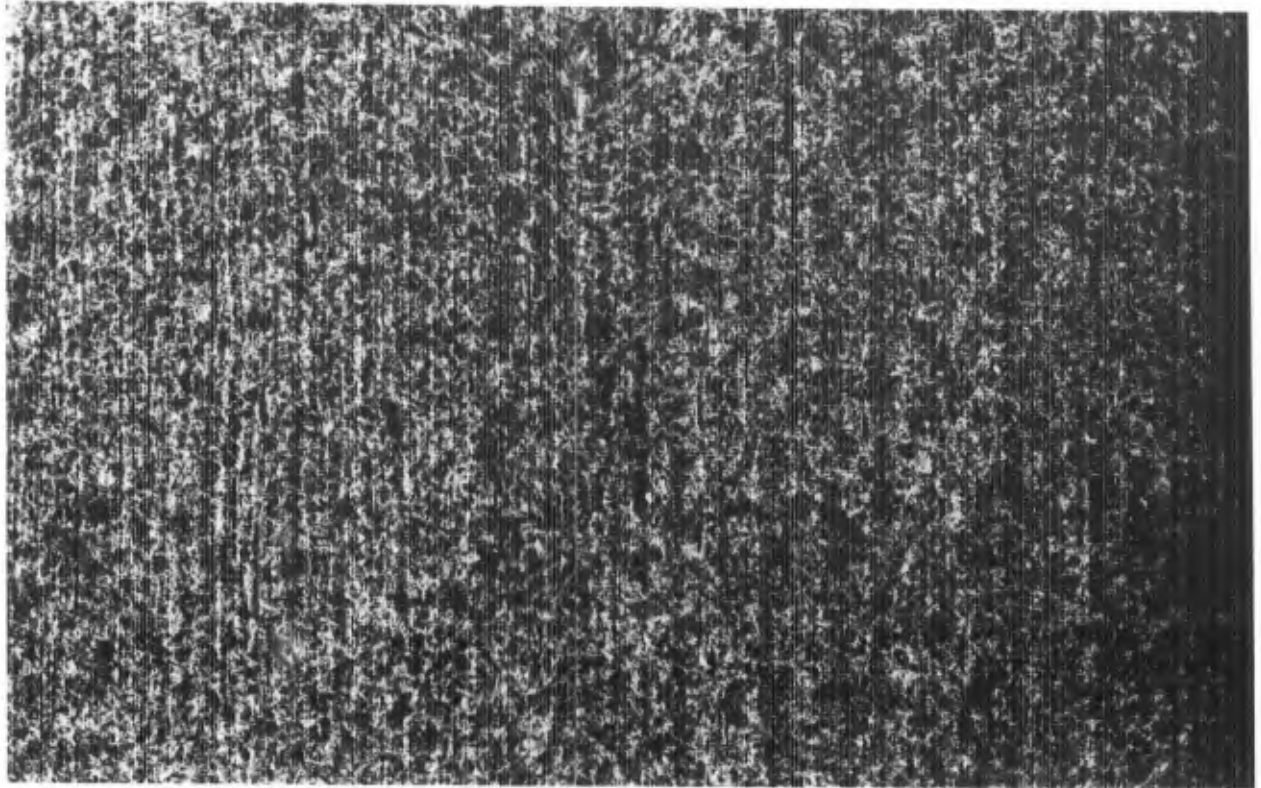
X1000

MA-3108

All above etched in 1% Nital.

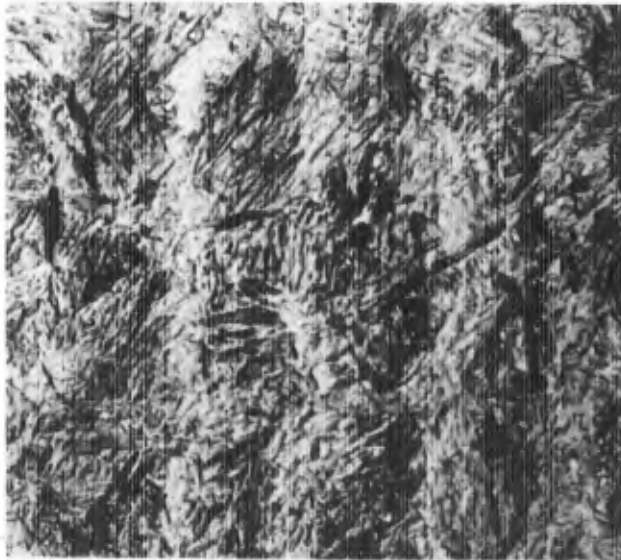
Figure 4

Microstructure



Magnified 100 Diameters

Surface



Magnified 1000 Diameters



Magnified 1000 Diameters

All above etched in 1% Nital.

W.A. 639-3368

Figure 5

Carbide Distribution

(a) Average distribution of carbides.

X500

MA-3109

(b) Average distribution of carbides.

X1000

MA-3110

All above etched in Murakami's Reagent.

Figure 5

Carbide Distribution



(a) Magnified 500 Diameters



(b) Magnified 1000 Diameters

All above etched in Murakami's Reagent.

VICKERS BRINELL HARDNESS



VARIATION IN HARDNESS
ON CROSS SECTION OF
HOMOGENEOUS GERMAN AIRCRAFT ARMOR
SPECIMEN NO. GA
290" THICK

FIG 6

04 08 12 16 20 24 28 32
DEPTH IN INCHES

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~~g. H.~~
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