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WATERTOWN ARSENAL LABORATORY

EXPERIMENTAL REPORT

NO. WAL. 710/346

ARMOR PLATE

Metallurgical Examination of German Aircraft Armor
from Heinkel III and Junkers 87 Planes

BY

P. V. Riffin
Pvt., Ord. Dept.

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DATE 22 November 1944

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Watertown Arsenal Laboratory
Report No. WAL 710/346
Problem No. B-3.4

22 November 1944

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The OBJECT is

To conduct a metallurgical examination of eight (8) sections of German Aircraft Armor from Heinkel III and Junkers 87 planes.

SUMMARY OF RESULTS

The armor plates examined were composed of approximately .45% carbon steels containing wide variations in alloy content; specifically Cr-Mo-V, Si-Cr-Mo, Mn-Si, and Si-Cr-V types were used. The plates were made from good quality steel (except for plates 1A, 1B, 4, and 10A) heat treated to hardnesses ranging from 388-514 Brinell. As shown by the fracture test, the impact resistance of the plates from the JU87 plane and some of the plates from the Heinkel planes was inferior to that obtained in good quality American aircraft armor of the thickness employed (5-8 mm.). This agrees with the ballistic results in which it was found that the plates exhibited high resistance to penetration but inferior resistance to shock.

Although only a limited amount of information is available from this and previous investigations of German armor examined in 1941 and 1942, it is apparent that there has been a definite trend by German armor manufacturers toward the use of the less strategic alloying elements manganese and silicon as a substitute for nickel and molybdenum to promote hardenability in steel.

P. V. Riffin
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Pvt., Ord. Dept.

APPROVED:

N. A. MATTHEWS
Major, Ordnance Dept.
Acting Director of Laboratory

INTRODUCTION

In accordance with a request[1] from the Office, Chief of Ordnance, samples of German aircraft armor were subjected to a metallurgical examination at this arsenal after having been tested ballistically at the Ordnance Research Center, Aberdeen. (Reported in A.P.G. Report No. AD-684).

The samples were listed as:

Item 1 - 5/16" homogeneous armor from an Heinkel plane. Location - belly protection. Four sections submitted.

Item 2 - 5/16" homogeneous armor from an He III plane. Location - port.

Item 4 - 5/16" homogeneous armor from an He III plane. Location - middle of fuselage.

Item 10 - 5/16" homogeneous armor from a JU-87 plane. Location - rear of pilot. Two sections submitted.

The samples from Item I were designated with the numbers used by the Ordnance Research Center which are the following:

1 - 11"x32" plate subjected to the 20 mm. HE shock test (Army Mk.1 fuse). A fragment of the broken plate was received.

1A - 8-7/8"x32" plate subjected to Cal. .30 tests.

1B - 5-3/8"x32" plate subjected to Cal. .50 penetration tests (a back spalling tendency was observed).

1C - 5-3/8"x32" plate subjected to Cal. .50 penetration tests.

Two plates were submitted under Item 10, one of which (marked 10A) was an irregularly shaped 21"x28" plate which exhibited cracking and some spalling under ballistic tests.

Several investigations of German aircraft armor have been conducted in England[2]. These investigations have shown that a wide variety of compositions similar to those observed in this study were used. The carbon content varied from .29% to .54%, although in most cases, it was about .50%.

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1. OO 386.3/1988 - Wtn 386.3/239(r), See Appendix A.

2. OO 470.5/1145 - Wtn 470.5/4479 dated 21 May 1942.

An investigation[3] was conducted at this laboratory in 1941 on German aircraft armor (.290" thick) taken from a JU-88 plane. The plate was made from a .40% carbon-nickel-chromium-molybdenum steel heat treated to a hardness of 555 Brinell. From the present investigation it is apparent that the compositions and hardnesses of German aircraft armor have changed considerably from that of three years ago.

TEST PROCEDURE

Samples for hardness surveys (Rockwell C and Brinell), chemical composition, fracture tests for steel soundness and fibre, macroetch tests, and microscopic examination were obtained from each plate.

Fracture bars for the steel soundness tests were tempered to a hardness of approximately 300 Brinell, notched (unnotched area - 2"xThickness), and broken under a press. Fibre fracture bars were notched to an area of 3/4"x Thickness and broken under a drop weight machine. Surfaces were prepared for the Brinell tests by grinding .050" from one face of each plate.

RESULTS AND DISCUSSION

1. Visual Examination

The samples submitted had been covered with an adherent paint which had been worn off at several of the holes and edges, permitting these areas to rust.

Markings were observed on several of the items as follows:

ITEM NO.	MARKING
1B	E8036
1C	E7982
1C	8036
2	E8103 18
10A	0602 AAJ331209 1941

3. WAL 710/380 - "Metallurgical Examination of German Aircraft Armor" by E. L. Reed, 28 July 1941.

[redacted]

Thickness measurements were obtained at three locations and the average thicknesses of the plates are as follows:

ITEM NO.	Thickness Inches	Thickness MM.
1	.215	5 mm.
1A	.222	"
1B	.199	"
1C	.208	"
2	.332	8 mm.
4	.335	"
10A	.316	"
10B	.333	"

2. Chemical Analyses

Results of the chemical analyses of the items submitted are given in Table I.

TABLE I

Chemical Composition

Item No.	C	Mn	Si	S	P	Ni	Cr	Mo	V	Al	Cu
1	.49	.62	1.60	.023	.019	trace	.85	.19	trace	.02	.12
1A	.46	.80	.82	.021	.017	.36	1.37	.26	.13	.01	.14
1B	.45	.59	1.45	.023	.019	trace	.90	.22	trace	.015	.12
1C	.47	.77	.84	.024	.026	"	1.56	.23	.10	.025	.12
2	.48	.73	1.80	.027	.015	"	.94	.19	trace	.015	.13
4	.47	1.54	1.80	.027	.012	"	.15	.10	trace	.025	.06
10A	.47	.64	2.02	.020	.016	"	1.34	nil	.35	.025	.115
10B	.39	.63	1.99	.019	.010	"	.49	.28	trace	.025	.13

The compositions observed were quite varied being of four principal types namely: Cr-Mo-V, Si-Cr-Mo, Mn-Si, and Si-Cr-V steel. The high silicon steels have not been used with much success in this country whereas the .45% carbon Cr-Mo-V type steel is used quite extensively for aircraft armor at the present time.

There appears to be a definite trend toward the use of the less strategic elements manganese and silicon instead of the scarcer nickel and molybdenum for promoting hardenability in aircraft armor by the German manufacturers.

3. Hardness Tests

The results of Brinell hardness tests on the surface and Rockwell C hardness surveys along the cross sections of each plate are shown in Table II.

TABLE II

Hardness Surveys

Item No.	Surface BHN Readings	Surface BHN Ave.	Cross Section Rockwell C Readings	Cross Section Rockwell C Ave.	Cross Section Rockwell C BHN (Converted)	Reported by APG BHN
1	388,388,388	388	42.5, 43, 43.5	43	418	387/444
1A	411,437,437	428	44, 45.5, 46.5	45	432	"
1B	437,411,411	420	40.5, 44, 43	43.5	424	"
1C	388,388,388	388	43, 43, 43.5	43	418	"
2	429,429,429	429	42.5, 43, 43.5,43	43	418	444/460
4	429,429,429	429	42, 43, 43, 43	43	418	364/387
10A	495,495,477	489	47, 50, 47.5,47	47.5	470	460/477
10B	514,514,514	514	40.5, 47.5, 48,47.5	47.5	470	"

In several cases a low Rockwell hardness reading was observed near one of the faces of the plate because of decarburization, but this reading was not included in the average hardness value.

The items 1, 2, and 4 possessed a hardness of roughly 418/432 Brinell, a value which is used, for the most part, in this country for light gauge aircraft armor. Item 10 was heat treated to a considerably higher hardness which was undoubtedly responsible for the brittleness observed on the shock test and the inferior penetration resistance of overmatching projectiles (Cal. .50 AP ammunition).

4. Fracture Tests

Fracture tests for steel soundness were conducted in both the

[redacted]

transverse and longitudinal direction, and the fibre fracture test in only one direction. The results are shown in Table III.

TABLE III

Fracture Test Results

Item No.	Steel Soundness* Longitudinal	Steel Soundness* Transverse	Fibre**
1	B	B	Fc tr
1A	B Woody	B Woody	Fc 1/2
1B	B Woody	B Woody	Fc tr
1C	B	B	Fc 1/2
2	B	B	Cbf 1/2
4	D	C	Cbf 1/2
10A	D	D	Cb
10B	C	C	Cb

* Steel soundness ratings of Armor Specification AXS-488, (Rev. 2) in which D or worse is rejectable.

** Symbols for fracture rating:

Fc - Fibrous matrix containing speckles of crystallinity.
Cbf - Bright crystalline zone with a fibrous border.
Cb - Bright crystalline fracture.
Fraction refers to the amount of crystallinity present.

The steel quality of all plates except 4 and 10A are considered to be acceptable. Plates 1A and 1B, although they do not exhibit any excessive laminations, possess a very woody structure which appears to have been responsible for the back spalling tendency observed.

In the fibre fracture test, all the plates exhibited some crystallinity, a condition which is associated with inferior toughness or poor shock resistance under ballistic tests. The thinner plates of item 1 possessed considerably less crystallinity than the remaining plates.

[redacted]

5. Macroscopic Examination

Hot acid etched cross sections of the plates did not reveal any pronounced segregations of nonmetallic inclusions except in plate 10A which exhibited a sharply delineated band in the center of the plate.

There was little difference in etching characteristics in the transverse as compared to the longitudinal section indicating that the plates had been thoroughly cross rolled.

6. Microscopic Examination

The microstructure of typical plates are shown in Figures 1 and 2. The nonmetallic inclusions in all the plates was of the silicate and sulphide type. Figure 1A is typical of the worst segregations of inclusions observed in the group of plates. Plate 1B also possessed a considerable amount of yellow nitride type inclusions.

Item 1. The microstructure of all four sections was that of tempered martensite with varying degrees of undissolved carbides. It was observed that a greater amount of undissolved carbides was present in the plates 1A and 1C containing a high chromium content. It is apparent that the austenitizing temperature employed was lower than is required to completely dissolve carbides. It is considered that the inferior impact properties of these plates are attributable, at least in part, to the lack of homogeneity resulting from the presence of undissolved carbides.

Item 2 possessed a tempered martensitic structure which should exhibit satisfactory properties. It is possible that the poor fracture of this steel was associated with temper brittleness which would be manifested in the plate when tempered at about 1000°F. in obtaining a hardness of 400 Brinell.

Item 4 possessed a tempered martensitic structure quite like that of item 2. The analysis differed from the previous item in that high manganese was used instead of the 1.34% chromium.

Item 10A exhibited a very unusual microstructure. A heterogeneous structure of ferrite, carbides and tempered martensite extended from the edge almost to the center. The central 1/8" of the plate possesses a banded structure of undissolved carbides in tempered martensite. It appears that incomplete austenitizing of this markedly segregated plate was responsible for the presence of the ferrite patches. A section was reaustenitized at 1600°F

[redacted]

for 1 hour and tempered to 1100°F to determine whether this plate could be heat treated to a homogeneous structure. Examination of the structure revealed that the ferrite, except for decarburization at the edges, was eliminated, and the undissolved carbides were substantially decreased. A Vickers hardness survey showed a hardness variation of from 376 VPN (352 Brinell) near the edge to 405 VPN (388 Brinell) at the center indicating that the plate could be heat treated to give fairly uniform physical properties. A fracture made at this hardness as well as 300 Brinell exhibited a large amount of crystallinity indicating that this composition is not readily heat treatable to yield optimum toughness at 300-400 Brinell.

Item 10B was composed of a tempered martensitic structure. The toughness, however, as indicated by the fracture test was poor as heat treated to a hardness of 400 Brinell. When tempered at 1100°F to a hardness of 320 Brinell the fracture was fibrous. It appears that the inferior toughness of this plate as well as several of the others is probably a result of temper embrittlement, a phenomenon which occurs in some steels when a tempering temperature of approximately 400°F. to 1000°F. is used irrespective of the method of cooling from the temper. An extended discussion of temper brittleness has been made by Carpenter and Robertson[4] who summarize some of the work of Greaves and Jones as well as other investigators.

6. Discussion

a. Metallurgical Considerations

All the plates exhibited inferior toughness though the lack of toughness was most prominent in items 10A and 10B which were heat treated to the unusually high hardness of 470 Brinell. It should be noted that plate 10A which had not been subjected to ballistic tests was very poorly heat treated in that the ferrite solution was not completed during austenitizing. Plates 1, 1A, 1C and 10A contained undissolved carbides which are an indication of incomplete austenitization. As a result the alloy content was not completely utilized and the resulting steel did not possess optimum toughness.

Except for item 10 which was at a hardness of 470 Brinell, the plates were heat treated to the hardness (380-420 Brinell) now in use in this country for aircraft armor. The ballistic efficiency (resistance to

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4. Carpenter, Sir H., and Robertson, J. M. - "Metals" Volume II, Pages 1110-1114, Oxford University Press 1939.

penetration) of these plates[5] was quite comparable to that obtained in American aircraft armor, but the resistance to cracking in several cases, was markedly inferior to that obtained with good quality armor. The latter consideration is associated with the inferior toughness observed in the fracture test. The back spalling condition observed in plates 1A, 1B, and 103 was a reflection of the presence of laminations in this high hardness armor.

b. Economic Considerations

A variety of compositions was used in this group of plates, most of which depended largely upon silicon and manganese for hardenability. Apparently the Germans have resorted to the use of these elements because of the shortage of nickel and molybdenum. This condition was also observed in the plates examined by the British[6]. The use of high silicon steels for armor has not been employed to any extent in this country because it has been observed that inferior impact properties have been obtained in silicon containing steels.

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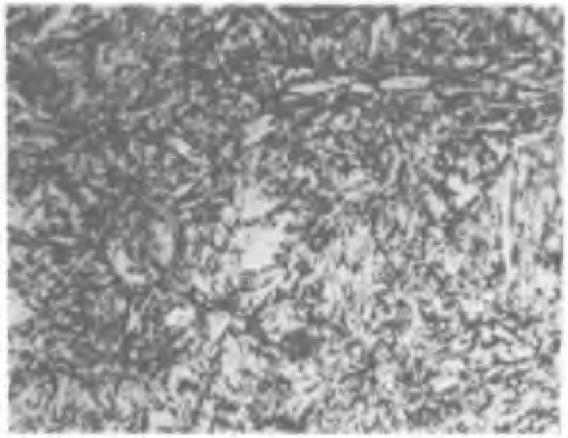
5. A.P.G. Armor Report No. AD-684.

6. See footnote 2, page 2

[redacted]

<u>Microstructure of German Aircraft Armor</u>

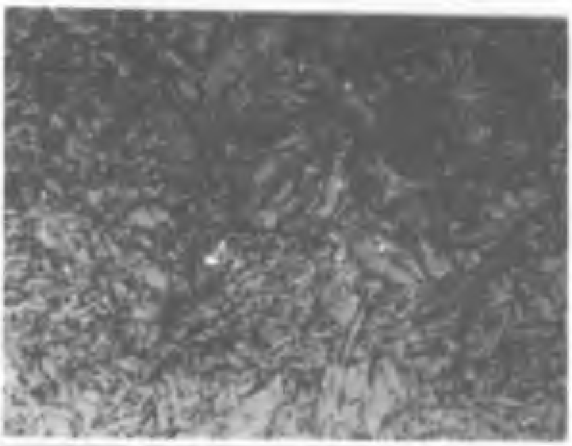
X100 A Unetched
Plate 1B - Nonmetallics in longitudinal section.



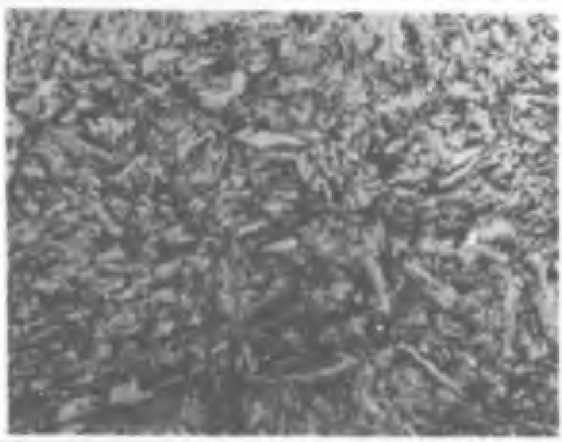
X1000 B Picral
Plate 1B - Tempered martensite.

X1000 C Picral
Plate 1A - Tempered martensite with undissolved carbides.

X1000 D Picral
Plate 1C - Tempered martensite with undissolved carbides.



X1000 E Picral
Plate 2 - Tempered martensite.

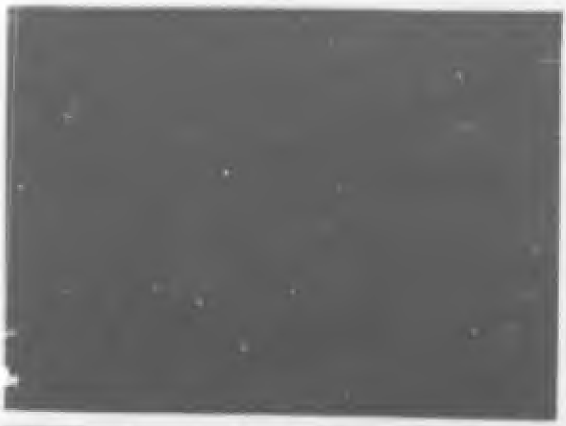


X1000 F Picral
Plate 4 - Tempered martensite.

<u>FIGURE 1</u>

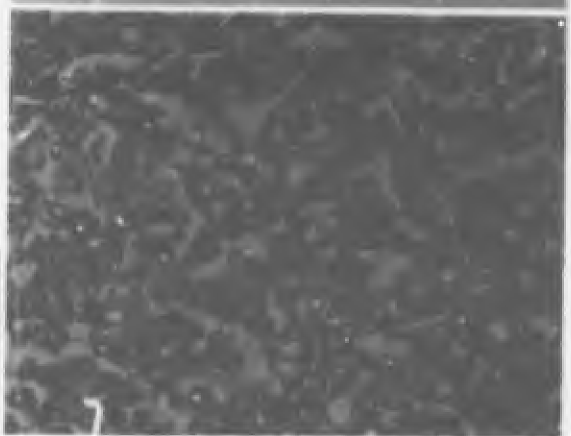
Microstructure of German Aircraft Armor

X1000 A Picral
Plate 10B - Tempered martensite.



X100 B Picral
Plate 10A - Outer third of plate containing banded ferrite patches.

X100 C Picral
Plate 10A - Center of plate containing alloy and nonmetallic segregations.



X1000 D Picral
Same area as B - containing ferrite and undissolved carbides.

X1000 E Picral
Same area as C - containing carbides in tempered martensite.

FIGURE 2

APPENDIX A

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Campbell/ajs
4451

WAR DEPARTMENT
OFFICE OF THE CHIEF OF ORDNANCE
WASHINGTON, D. C.

OO 386.3/1988
Attention of
SPOTC

28 August 1944

Subject: German Aircraft Armor Plate

To: Commanding Officer
Watertown Arsenal
Watertown, Mass.

Attn: Colonel H. H. Zornig

1. There were shipped to Watertown Arsenal on 25 August 1944 by the Ordnance Research and Development Center, Aberdeen Proving Ground, the following samples of German Aircraft Armor:

a. Item 1—5/16" homogeneous armor from a German Heinkel Plane. Location—for belly protection.

b. Item 2—5/16" armor from port location in HE-III Plane.

c. Item 4—5/16" armor from middle of fuselage in HE-III Plane.

d. Item 10-5/16" armor from rear of pilot in JU-87 Plane.

2. The above listed items when subjected to ballistic tests at Aberdeen Proving Ground indicated a performance at least equal to or superior to the average performance obtained with homogeneous aircraft armor produced in the United States. It is therefore requested that these samples of German Aircraft Armor be subjected to tests for the purpose of determining their chemical composition and metallurgical properties.

[redacted]

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To: Watertown Arsenal, Mass. 28 August 1944

3. Upon completion of all tests, it is further requested that the results be reported in accordance with Ordnance Department Order No. 327, Change 1.

By order of the Chief of Ordnance:

/s/

HORACE A. QUINN
Colonel, Ord. Dept.
Assistant

[redacted]

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