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WATERTOWN ARSENAL
WATERTOWN, MASS.



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WATERTOWN ARSENAL LABORATORY

EXPERIMENTAL REPORT

NO. WAL. 710/715

ARMOR

Metallurgical Examination of a 3-1/4" Thick armor Plate
from a German PzKw V (Panther) Tank

BY

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Pvt., Ord. Dept.

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DATE 18 January 1945

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INTRODUCTION

In accordance with instructions from the Office, Chief of Ordnance¹, a section from the front glacis plate of a German PzKw V (Panther) tank was submitted to this arsenal for metallurgical examination.

Examinations of German tank armor have been made previously at this arsenal^{2,3}, and the results show that German armor is generally of satisfactory soundness according to present Ordnance Department standards⁴, but the heat treatment employed has resulted in inferior toughness in the thicker plates according to the fibre fracture test or V-notch Charpy impact tests.

In several other investigations⁵, made by the British, it was found that the notched bar impact values of heavy German armor (2" and over) were considerably lower than that of comparable British armor. They reported that reheat treatment consisting of an austenitize, quench and temper resulted in considerable improvement. It was further stated that the poor impact properties of the German armor were probably a result of incomplete hardening during the quench. It was also reported that the heat treatment employed by the German manufacturer may have consisted of tempering "as-rolled" plates.

It will be shown that the extremely low toughness in the plate under investigation is a result, in part, of temper embrittlement, a factor which may have been partly responsible for the inferior toughness in the German armor previously investigated. Since the presence of temper embrittlement has been encountered quite frequently in domestic higher alloy armor plates examined in recent months, it is now customary to investigate armor exhibiting inferior toughness for this condition.

MATERIALS AND TEST PROCEDURE

The plate submitted was a 6" x 10" section which had been removed from the front glacis plate of the tank by flame cutting.

The examination of the armor consisted of a chemical analysis, hardenability test, cross section hardness survey, fracture test, notch bar impact test on specimens in the "as-received" and reheat treated condition, macroetch tests, and a microscopic examination.

RESULTS AND DISCUSSION

1. Chemical Composition

The analysis of the plate as obtained at this arsenal is as follows:

<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Ni</u>	<u>Cr</u>	<u>Mo</u>	<u>V</u>	<u>Al</u>	<u>Cu</u>
.50	.67	.32	.022	.015	nil	2.13	tr	.14	.01	.10

1. O.O. 470.5/15790 - Wtn. 470.5/846(r), See appendix 4.
2. Watertown Arsenal Laboratory Report WAL 710/542, "Armor and Welding, Metallurgical Examination of Armor and Welded Joints from German PzKw VI Tank" 23 February 1944.
3. Watertown Arsenal Laboratory Report WAL 710/608, "Armor and Welding, Metallurgical Examination of Armor and Welded Joints from German PzKw IV Tank, Model GF-2" 4 April 1944.
4. armor Specification AXS-488 (Rev. 2), 18 November 1943.
5. Minutes of 22nd Meeting of the Technical Co-ordinating Committee on Tank Armor, 8 June 1944, minute 178 (c). (An English report.)

The composition is a variation of the type found in heavy German armor examined previously^{2,3,5}, the vanadium being substituted for the .25-.60% molybdenum. It is probable that this substitution is due to a current shortage of molybdenum in Germany.

The carbon content as in most German armor is considerably higher than the maximum allowed in domestic armor which is to be welded.

2. Hardness

The results of Brinell hardness tests taken at 1/2" intervals across the 3-1/4" plate showed that it possessed a uniform hardness of 262-269 Brinell. The readings were as follows:

Distance from face	<u>3/8"</u>	<u>7/8"</u>	<u>1-3/8"</u>	<u>1-7/8"</u>	<u>2-3/8"</u>	<u>2-7/8"</u>
Hardness BHN	269	269	262	262	269	269

3. Hardenability

A Jominy type end-quench test was conducted to evaluate the hardenability of this steel. Austenitizing prior to the quench consisted of a soak at 1700°F. for 3 hours. There was very little drop in hardness between the water quenched and air cooled ends of the bar, Figure 1. However, since it is the transformation constituents which are primarily responsible for the toughness observed after tempering, the as-quenched microstructure was examined. It was found that about 15% nonmartensitic transformation constituents were formed at the air cooled end of the bar.

The cooling rate at the 20/16" location on the end-quenched bar is equivalent to that of the center of a 3-1/4" thick plate when water quenched. On the other hand, the cooling rate at the 32/16" location on the end-quenched bar is equivalent to that at the center of a 3-1/4" thick plate when oil quenched.⁶ The amount of transformation constituents in the plate appeared to be greater than should be expected by either water or oil quenching, indicating that a slow cooling medium such as air may have been used. It will be shown that there were sufficient nonmartensitic transformation constituents present in the plate as heat treated by the German manufacturer to cause inferior notch bar toughness at -40°F.

4. Fracture Tests

A section was flame notched on the two sides 2" deep (unnotched area = 2" x thickness) and broken under a forge hammer. The resulting fracture exhibited a rough crystalline surface indicative of low toughness. Since the fracture was crystalline it was impossible to determine the steel soundness. However an examination of the fibrous fractures obtained in the Charpy tests revealed no laminations of consequence.

2,3,5. See footnotes in Introduction.

6. according to conversion data from the chart "Hardenability Comparisons" by the Great Lakes Steel Corporation, 1942.

5. V-Notch Charpy Impact Tests

The results of notch bar tests at +70°F. and -40°F. are shown below.

V-Notch Charpy Impact Values

<u>Condition</u>	<u>Location</u>	<u>Tested at +70°F.</u>		<u>Tested at -40°F.</u>	
		<u>Ft.Lbs.</u>	<u>Fracture*</u>	<u>Ft.Lbs.</u>	<u>Fracture</u>
As-Received	Center of Plate	29.5	Cbf $\frac{1}{2}$	10.5	C
		32.5	Cbf $\frac{1}{2}$	13.5	C
As-Received	$\frac{1}{2}$ " from Surface	34.5	Cbf $\frac{1}{2}$	14.0	C
		30.0	Cbf $\frac{1}{2}$	15.0	C
**Retempered to Remove Temper Embrittlement	Center of Plate	54.5	F	28.0	Cbf 3/4
***Heat Treated in Small Sections		60.5	F	56.5	Fc 1/8

*Fracture symbols are:

F = Fibrous; C = Crystalline; Fc = Mixed, F with speckles of C;
Cbf = Mixed, C matrix with F edge.

**Heat treatment consisted of 1200°F. temper for two hours followed by a water quench.

***Heat treatment consisted of 1700°F. soak for 2 hrs., water quenched, tempered at 1240°F. for 3 hrs., water quenched.

The hardnesses of the reheat treated specimens were within 15 points BHN of the plate in the as-received condition.

It is apparent that during the tempering treatment the plate had been embrittled, a condition which was readily eliminated by retempering and quenching from the temper.

Basic information on temper embrittlement (mainly the work of Greaves and Jones) is summarized by Carpenter and Robertson⁷. In this summary it was indicated that the embrittlement results from either slow cooling; the steel from the tempering temperature or tempering in the embrittling temperature range of approximately 400°F. to 1000°F. Elimination of this embrittlement under normal testing conditions may be accomplished by tempering above 1100°F. to dissolve the constituent followed by a rapid quench. Even after removing the temper embrittlement, the plate possessed inferior toughness which is attributed to the presence of nonmartensitic transformation constituents.

7. Sir H. Carpenter and J. M. Robertson in "Metals," Vol. II, Page 1111, 1939, Oxford University Press.

6. Macroetch Test

The hot working of the plate did not completely eliminate the dendritic cast structure, Figure 2. The similarity of etched structure in the two rolling directions indicates that the plate had been uniformly cross-rolled. No segregations of inclusions were observed in the specimens examined indicating that the plate possessed satisfactory soundness, a condition generally found in German armor.

7. Microscopic Examination

An examination of the unetched cross section revealed the presence of a small number of silicate type inclusions but no undesirably long segregations.

The microstructure varied considerably from surface to center as shown in Figure 3. A distinctly acicular structure, probably bainite, was formed at the center of the plate upon quenching. It is felt that this constituent was responsible for the inferior notched bar values observed in the plate after the effect of temper embrittlement had been removed.

8. General Considerations

The plate was made from a .50% carbon, 2.0% chromium, .14% vanadium type steel heat treated to a hardness of 262-269 Brinell. This analysis is probably an adaptation of the Cr-Mo type previously examined, the vanadium replacing the more critical molybdenum.

The hardness has been lowered to the level generally employed in this country for heavy rolled homogeneous armor. The German manufacturer used a high carbon steel which is undesirable from a welding standpoint as well as being susceptible to quench cracking. The higher carbon steel requires less alloy for a given hardenability. However, it was found that the hardenability was not employed effectively because the plate was not quenched drastically enough to prevent the formation of nonmartensitic transformation constituents possessing inferior toughness. In addition, the plate was still further embrittled during the tempering treatment. As a consequence any advantages accruing from the use of the higher carbon composition were eliminated.

APPENDIX A

Correspondence

COPY

Brown/mes
74295

IMMEDIATE ACTION

RESTRICTED

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

9 October 1944

O.O. 470.5/15790
Attention of
SPOTB-Materials

Subject: armor from PzKw V (Panther) Tank

To: Commanding Officer
Watertown Arsenal
Watertown 72, Mass.

1. The Ordnance Research and Development Center, Aberdeen Proving Ground, Maryland, is shipping this date section of armor approximately 3" x 6" x 12" removed from the front glacis plate on the subject tank.

2. It is requested that a metallurgical examination be conducted on this sample as soon as possible. A letter report should be submitted to this office as soon as preliminary data including cross-sectional hardness survey and chemical analysis are available.

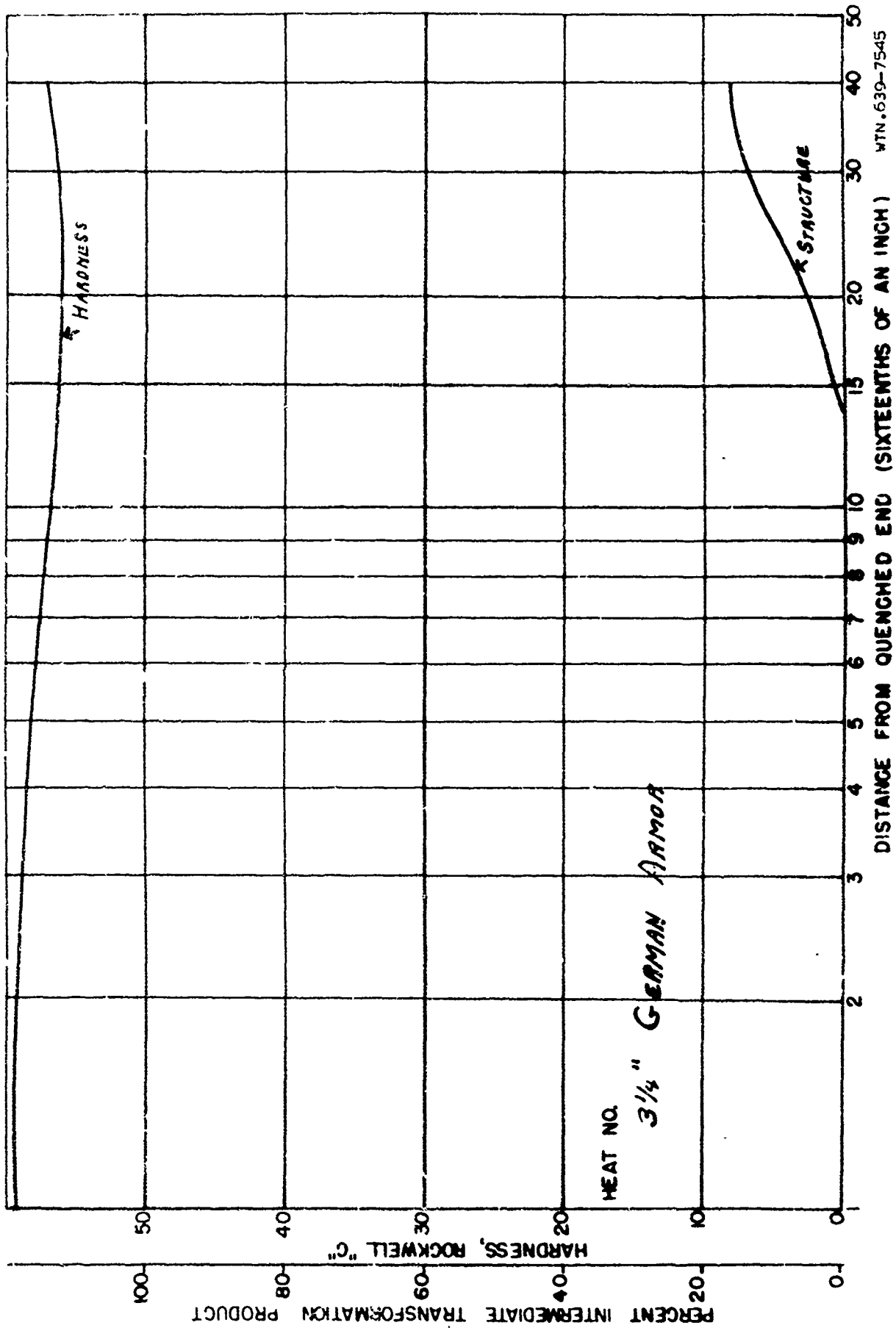
By order of the Chief of Ordnance:

(S/T) J. E. Frye
Colonel, Ord. Dept.
Assistant

RESTRICTED

IMMEDIATE ACTION

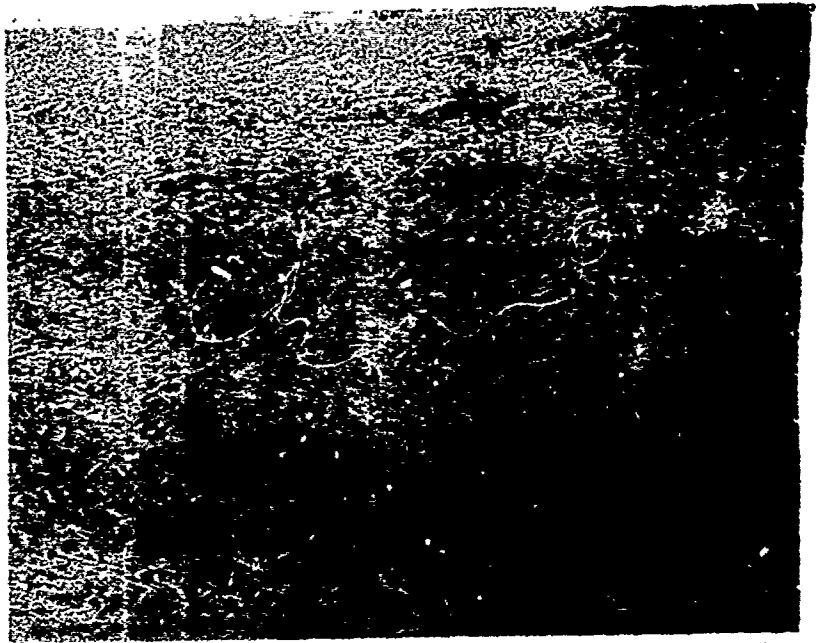
COPY



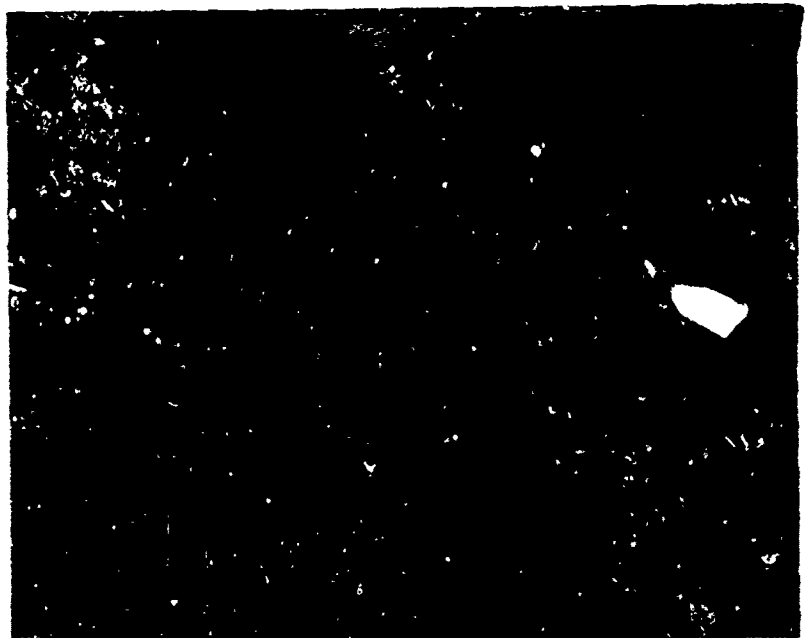
WTN.639-7545

FIG. 1

PERCENT INTERMEDIATE TRANSFORMATION PRODUCT



SECTION A



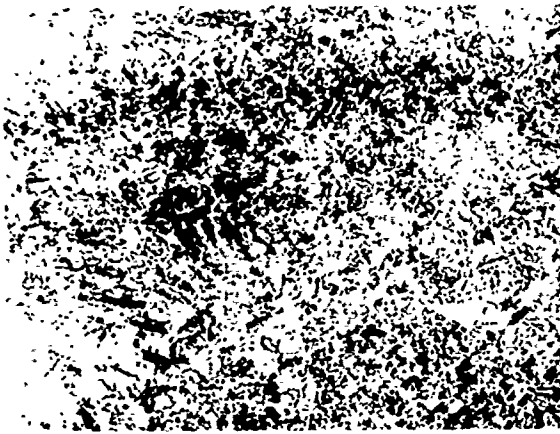
SECTION B - 90° TO R

WATERTOWN ARSENAL

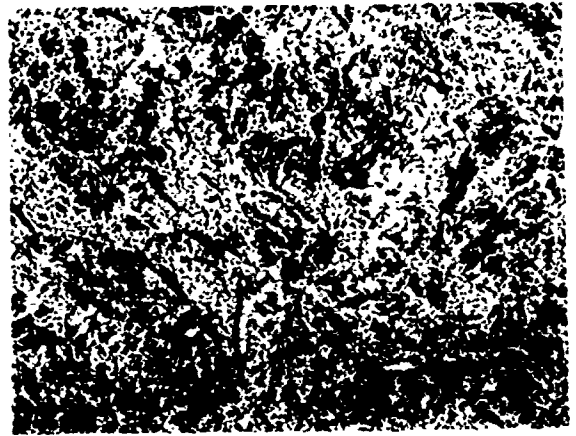
MACROETCHED SECTIONS FROM A $3\frac{1}{2}$ " HOMOGENEOUS ARMOR FROM A P2KW V TANK
3 NOV 1944 MAG. X 1 WTN.710-2338

FIG. 2

Microstructure of German Armor
 Sd.Kfz. Pz.Kw. V Tank



100x A Picral
 1/2" Iron Surface. - Tempered
 martensite with some undissolved
 carbides.



X250 B Picral
 Center. - Tempered martensite and
 intermediate transformation
 structure with some undissolved
 carbides.



1000 C Picral
 Same as A at high magnification.



X1000 D Picral
 Same as B at high magnification.