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Report No. 710/472

ARMORED VEHICLE COMPONENTS

Metallurgical Examination of
Armored Vehicle Components (Armor Attachment Bolts
and Welded Armor Sections) from a German PZKW III Tank.

By

P. V. Riffin
Asst. Metallurgist

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January 2, 1943

WATERTOWN ARSENAL
WATERTOWN, MASS.

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Report No. 710/472
Watertown Arsenal
Problem B-26

January 2, 1943

ARMORED VEHICLE COMPONENTS

Metallurgical Examination of
Armored Vehicle Components (Armor Attachment Bolts
and Welded Armor Sections) from a German PZKW III Tank.

OBJECT

To conduct a metallurgical investigation of the armored vehicle components to include chemical analyses, hardness surveys, physical properties, and macroscopic and microscopic examination.

REFERENCES

W.A. 470.5/5447
A.P.G. 470.5/4183

The basic correspondence pertaining to this report is contained in Appendix A.

SUMMARY OF RESULTS

1. Armor Attachment Bolts

a. The bolts were processed from a medium carbon Cr-Mo-V type steel heat treated to a hardness of Rockwell "C" 40-42 (372-393 Brinell).

b. The bolts were forged from a relatively poor quality bar stock, machined, "roll" threaded, and heat treated. The hardness is higher than would normally be used for such applications where maximum toughness is desired.

2. Armor

a. The 11-mm homogeneous armor was cross-rolled from a good quality steel and heat treated (quenched and drawn) to a hardness of 320-340 Brinell.

b. The armor composition, which is similar to SAE 4150 with carbon on the high side, is clearly not a steel adapted to welded fabrication. It is quite similar to a composition which has been used in this country for some time and which was produced in considerable quantity by the Henry Disston and Sons, Inc. for riveted and bolted fabrication. As an armor material, such a composition is unsurpassed from a purely resistance to penetration standpoint.

c. Fragments of the armor attached to the weld metal section were of high hardness (690 Vickers) and consisted of the heat affected zone resulting from a single pass welding technique.

3. Weldments

a. The weld metal deposits were of three (3) definite chemical types as follows:

Type	C	Mn	Si	Ni	Cr	Mo	V	W	Vickers Hardness
1	.12	.31	.17	2.46	1.1	.27	Tr	.52	446
2	.35	1.67-2.00	.20	2.38-3.05	1.4-3.5	.57-.64	Tr	.20-.36	437-464
3	.23	4.81		.81	10.36	Tr	.32		370-421

b. From the limited study possible, no definite evaluations may be made of the three types of weld rods used. However, it is believed that modifications of the high chromium-manganese type analysis with varying amounts of manganese and nickel may offer promise as substitutes for the modified 18-8 austenitic varieties now used in this country, since x-ray diffraction revealed the deposit to be mainly austenitic. The other two compositions may well have been deposited as field repair welds since the quality of welding is extremely poor. These analyses would not seem to possess any particular virtue for either field repair or fabrication welding.

c. The German concept of an armor weldment is quite different from that recognized in this country. An effort is apparently made to develop equivalent hardness in the weld deposit as compared to the base metal.

P. V. Riffin
P. V. RIFFIN
Assistant Metallurgist

APPROVED:

H. H. ZORNIG
Colonel, Ordnance Dept.
Director of Laboratory

INTRODUCTION

In accordance with instructions received from Aberdeen Proving Ground, armored vehicle components from a German PZKW III tank have been subjected to a metallurgical examination.

The components included two armor attachment bolts similar to others which were sheared off during the ballistic tests, a weld metal section which broke loose during the ballistic tests, and a welded armor section which broke away from the carrier of the roof of the tank.

TEST PROCEDURE

The bolts, weld metal section, and welded armor section were studied as individual units according to the following procedure:

1. Armor Attachment Bolts

The small bolt was sectioned longitudinally for a hardness survey, macroexamination, and microscopic examination. The large bolt, except for the head, was machined into a .357" physical test bar, and the remaining portion was sectioned longitudinally for macroexamination and microexamination.

2. Weld Metal Section

The sample was sectioned transversely for hardness surveys, macroexamination, and microexamination, and the remaining portions were used for chemical analyses.

3. Welded Armor Section

Longitudinal and transverse sections were cut for hardness surveys, macroexamination and microscopic examination. The compositions of the armor and as many weld deposits as possible were determined.

RESULTS AND DISCUSSION

1. Armor Attachment Bolts

a. Visual Examination

The bolts were painted completely with a dull black paint, and no visible markings were observed. The sizes of the bolts were 4"x.625"D and 2-3/4"x.546"D for the large and small bolt respectively, see Figure 1.

b. Chemical Analyses

The chemical analyses of the bolts are as follows:

	C	Mn	Si	S	P	Ni	Cr	Mo	V	Cu
Large bolt	.44	.81	.28	.029	.021	.12	1.20	.34	.125	.155
Small bolt	.38	.64	.28	.019	.020	.16	1.25	.28	.135	.155

This Cr-Mo-V type composition is relatively high in alloy content for the given application, considering the fact that aircraft quality bolts of maximum toughness are made from a lower alloy, S.A.E. 6150 steel. The high residual alloys indicate that the steel was melted in a furnace charged with appreciable quantities of alloy scrap.

c. Mechanical Properties

The physical properties of the large bolt are as follows.

T.S.	Y.P.	Elong.	R.A.
192,000psi.	186,250psi.	13.6%	49.8%

The bolts possess a uniform hardness which averaged 41.5 Rockwell "C" for the large bolt and 41 Rockwell "C" for the small bolt. This hardness is considered excessive for satisfactory toughness.

d. Macroexamination

In Figure 2 is shown the macroetched longitudinal sections of the bolts on which the hardness impressions are still visible. The bolts were both forged (as observed from the grainflow) from relatively poor quality bar stock. They were then machined and the threads formed by rolling (indicated by the deformation adjacent to the threads) prior to heat treatment.

e. Microscopic Examination

Both bolts are made from steel having a large amount of nonmetallic stringers, Figure 3A. The microstructure consists of tempered martensite, Figures 3B and C, with excess undissolved carbides which were especially prominent in the smaller bolt.

In Figure 3E is shown the cross section of a thread revealing the slight decarburization and the local deformation of the metallic and nonmetallic segregations resulting from the thread "rolling" operation. This offers further evidence that the bolts were forged, machined, threaded, and heat treated in that order.

2. Weld Metal Section

a. Visual Examination

The section, which was from a V-type joint, broke loose upon ballistic impact. It consists of a rather porous weld with some base metal clinging to both sides of the weld metal. On one side the fracture occurred through the heat affected zone whereas the fracture at the other side was through the line of fusion and the heat affected zone, See Figure 4.

b. Chemical Analysis

The analyses of the weld and the base metal at (B) in Figure 5A are as follows:

	C	Mn	Si	Ni	Cr	Mo	V	W	Cu
Weld Metal	.12	.31	.17	2.46	1.1	.27	trace	.52	.15
Base Metal	.44		.255	trace	1.3	.50	.17	nil	.18

The composition of the weld metal is markedly different from those used for welding armor in this country, and is interesting because of the high alloy content in this ferritic type weld.

The analysis of the base metal was not complete as there was very little material from which to obtain a sample. The composition is definitely not adaptable for welding, even with practicable preheating temperatures.

c. Hardness Survey

Several Vickers hardness readings were obtained in the weld metal and the base metal heat affected zones clinging to it. The maximum hardnesses observed are as follows:

Area	VPN
Weld metal	446
Base metal A	690
Base metal B	681

The hardnesses observed are much greater than the limit (500VPN) prescribed for good armor welding practice. This would indicate that the welding was carried out with little or no preheat and probably under field conditions.

d. The structure of the weld metal specimen is shown in Figure 5. The excessive amount of porosity present was most prominent at the fusion line and between the two weld layers, see Figure 5A. The welding procedure employed is rather difficult to determine although it is believed that there were two single-pass layers. A lack of fusion was especially noticeable between the base metal (B) and the first pass.

The weld metal is composed of a low carbon martensite of fairly high hardness. The base metal fragments attached are also martensitic but of a much higher hardness. Heat affected zone B (Figure 5D) which was analyzed, contains undissolved carbides in martensite. The other heat affected zone (Figure 5C) consists of an acicular martensite having very little undissolved carbide present.

e. General Considerations

The weldment, which was probably a hurried field repair job, was very unsatisfactory. Weld metal was porous and did not adhere well to the base metal. The extreme hardness in the heat affected zones indicated that no attempt was made to either preheat or postheat the weld and thereby reduce its susceptibility toward cracking.

In the German concept of welding, an attempt is apparently made to obtain hardnesses in the weld metal equivalent to the base metal hardness. On that basis, the weld rod used has some merit although the hardnesses developed are excessive for satisfactory toughness.

3. Welded Armor Section

a. Visual Examination

The triangularly shaped section shown in Figure 6 was broken from the carrier of the roof of the tank. It consisted of an 11 mm (.426" actual) armor section with weld deposits on the three edges as well as one across the back of the plate. The armor was painted on the back with a dull black paint which was flecked with rust. On the face this paint was covered with a thick iron oxide type paint. Stamped on both the face and back of the plate was the following:

W
8131099
E02247

The failure of the weldments generally occurred through the weld metal, although some lack of fusion was apparent in the fracture at one edge, see Figure 6.

b. Chemical Analyses

The composition was determined for the base metal and as many of the types of weld metal as possible. Incomplete analyses indicate that insufficient chips were obtained for a complete wet analysis although several elements were analyzed on the spectrograph.

The analyses of areas located on Figure 6 are as follows:

Section	C	Mn	Si	S	P	Ni	Cr	Mo	V	Cu	W	Al
Base Metal	.55	.54	.59	.018	.015	-	1.14	.27	trace	.08	-	.03
Weld at C	.36	1.93	.20			2.38	3.44	.57	trace	.33	.20	
Weld at D	.35	2.00	.19			2.44	3.54	.58	trace	.31	.36	
Weld at E	.37	1.67	.17			3.05	1.40	.64	trace	.31	pres.	
Weld at F	.23	4.81				.81	10.36	trace	.32	.3	-	

The steel is a typical hard homogeneous armor composition, although the carbon is higher than would be used in this country because of the poor welding characteristics of such a material.

The two or three types of weld rods used are quite different from those generally in use for welding armor in the United States. The high alloy Cr-Mn-V type (F) was found deposited on the edges as well as on the back of the plate. The only weld metal of this type analyzed was that deposited on the back. The vanadium may have been added to increase the ductility and workability as well as to refine the grain size of the weld metal.

The other weldments, which were apparently repair welds deposited over the high alloy original deposits, contained over 6% of strategic alloys. This type alloy possesses no apparent merit for use either in the field or for primary fabrication.

c. Vickers Hardness Surveys

Hardness surveys were obtained every .03" across the heat affected zones as shown in Figure 8D and 9A. Subsequent readings were taken on other specimens to verify the original surveys.

Maximum hardnesses obtained in the weld metal, base metal, and heat affected zones are as follows:

Area	Hardness VPN
Base Metal	340-360
Heat Affected Zones	
C	376
D	394
E	370
F	370
Low Alloy Weld Metal	
C	455
D	437
E	464
High Alloy Weld Metal	
D	450
E	421
F	370

As in the weld metal section discussed previously, the hardness of the weld is relatively high. This may be accounted for by the high carbon content present (.35%). The only explanation apparent for this high hardness is that the same order of hardness was maintained in the weld metal as was present in the base metal.

The hardnesses in the heat affected zones were not excessive, although the composition was such that high hardnesses would be encountered if no tempering was employed, thus indicating the use of preheating or postheating. Cracks were observed which were not compatible with the relatively low hardnesses in the heat affected zones. This aspect will be discussed more fully under microstructure.

d. Macroexamination

The macroetched sections in both the longitudinal and transverse directions is shown in Figure 7. The etching characteristics were similar in both directions indicating that the steel was cross-rolled. The armor was made from god quality steel as indicated by the freedom from nonmetallic segregations in the two sections examined.

The high alloy weld metal, which resists the attack of the microetching reagents was rapidly attacked by the hot acid etchant.

e. Microscopic Examination

The microstructure of the sections A-A and B-B indicated in Figure 6 are shown in Figures 8 and 9.

The structure of the base metal is a typical tempered martensite, Figure 9D, containing some undissolved carbides and indicating incomplete heat treating. At low magnification banding or alloy segregation is observed. The similarity of the etching characteristics in both the longitudinal and transverse directions indicates that the steel was cross-rolled. The distribution of nonmetallics in the longitudinal direction is shown in Figure 9B. The general freedom from nonmetallic segregations observed here is typical of German armor which has been previously studied at this Arsenal*.

The low alloy weld metal was almost completely martensite with small amounts of retained austenite. See Figure 8F and H. The high alloy Cr-Mn weld metal was almost entirely austenite with bands of an acicular transformation product, probably bainite. See Figure 9C and E. The presence of austenite was substantiated by x-ray diffraction.

Several cracks were observed in the heat affected zones of the base metal in an area adjacent to the high alloy weld metal. See Figures 8A and B. The extension of one or two of these cracks was associated with the line of fusion of the high alloy weld metal. The low alloy weld metal, on the other hand, formed a very good bond with the base metal and it was difficult to distinguish the line of fusion between the two. There was also a satisfactory bond between the two types of weld metal although, in one case, a crack formed in the first pass of the low alloy weld metal. See Figure 8C. Another defect observed was the lack of fusion at the toe of welds and the general poor quality of the welding technique as a probable result of welding under field conditions.

Considering the composition of the base metal, excessive hardnesses were expected in the heat affected zones. Their absence may be accounted for by the fact that the weld metal was deposited in layers,

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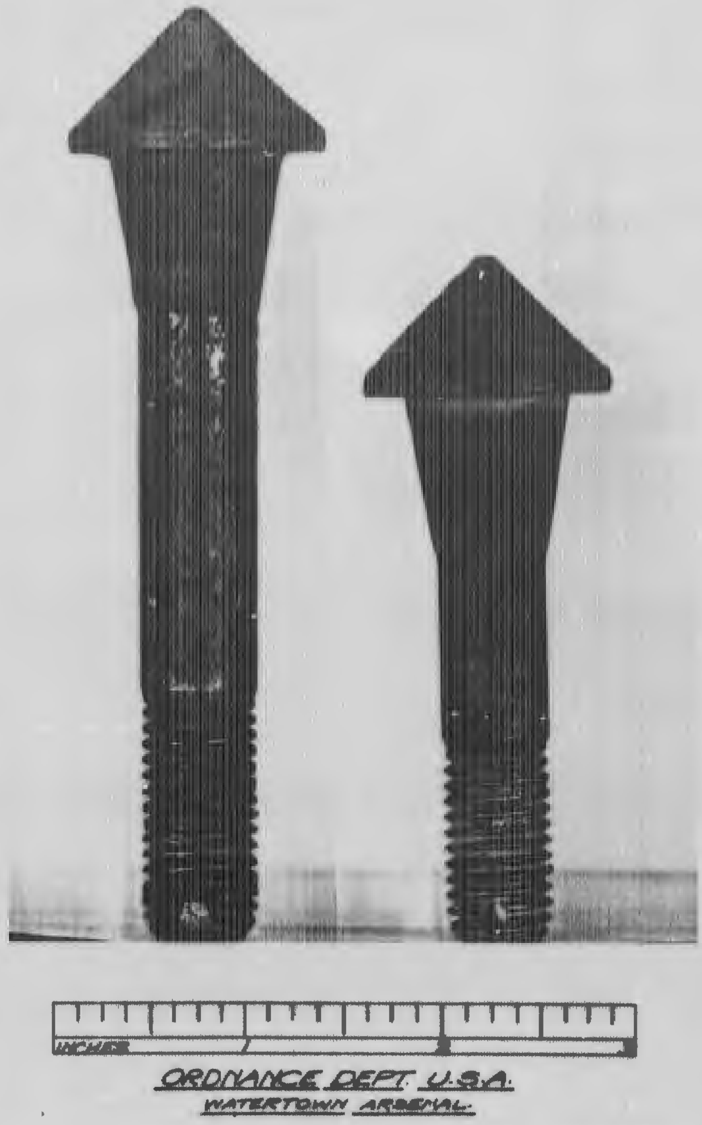
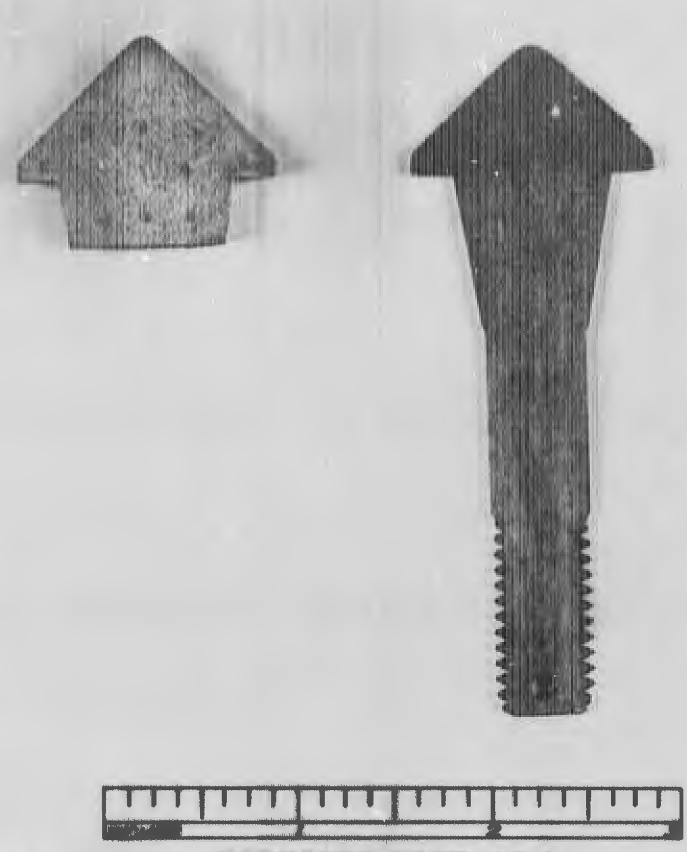
*NOTE: Report 710/458 - Metallurgical Examination of Section of German Face Hardened Armor from the Front of a PZKW III Tank.

each pass subsequent to the first one tempering the original heat affected zone. However, this technique did not prevent the formation of cracks in the areas adjacent to the original pass.



ARMOR ATTACHMENT BOLTS FROM A GERMAN PZKW III TANK
NOVEMBER 5, 1942 WTN. 710-1951

FIGURE 1



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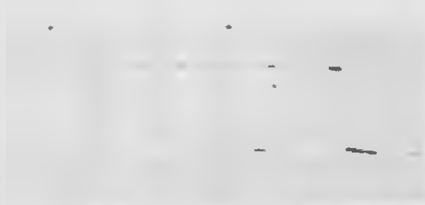
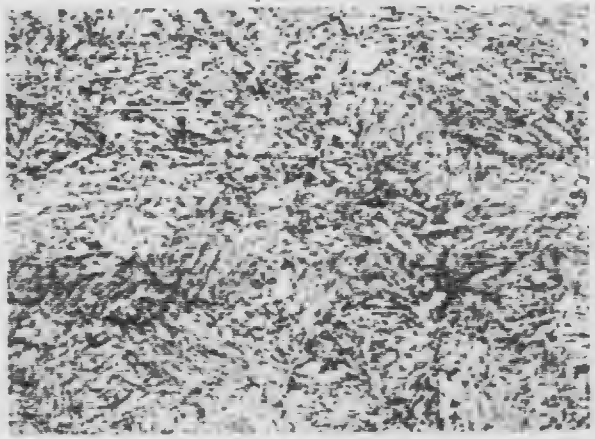
MACROETCHED LONGITUDINAL SECTIONS OF ARMOR ATTACHMENT BOLTS FROM A GERMAN PZ KW III TANK. NOVEMBER 18 1942 WTN.710-1958

FIGURE 2

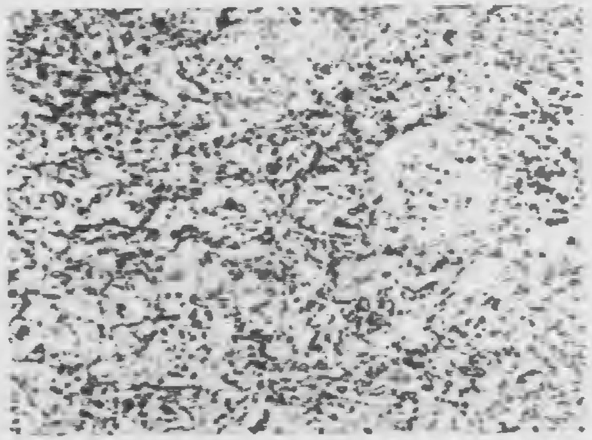
WTN.639-4769



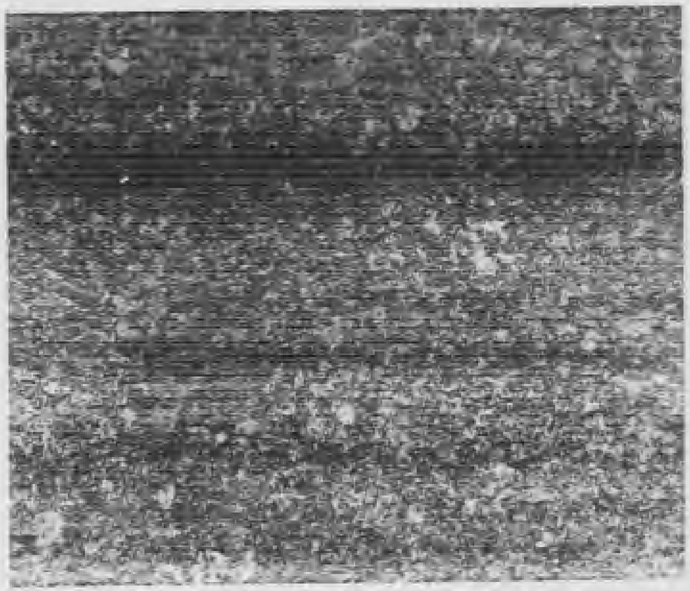
X100 A Unetched
Small bolt: Distribution of non-metallics - undesirable silicate type stringers



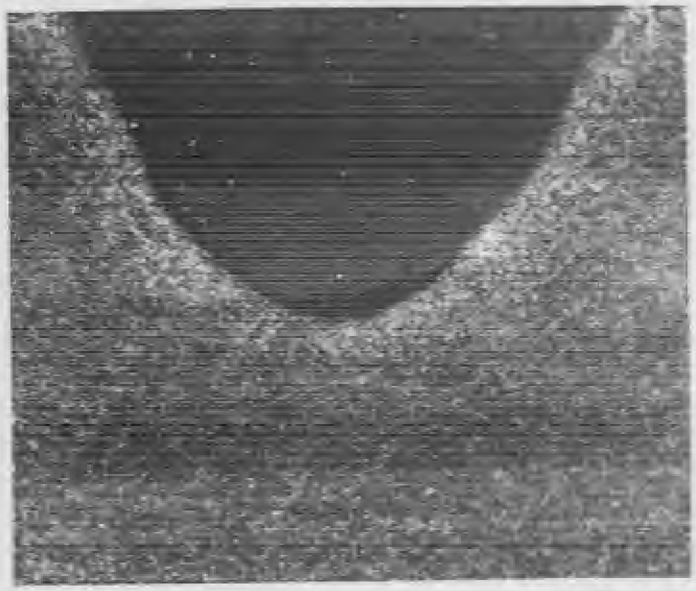
X1000 B Picral-nital
Large Bolt: Tempered martensitic structure



X1000 C Picral-nital
Small bolt : Tempered martemsitic structure and undissolved carbides



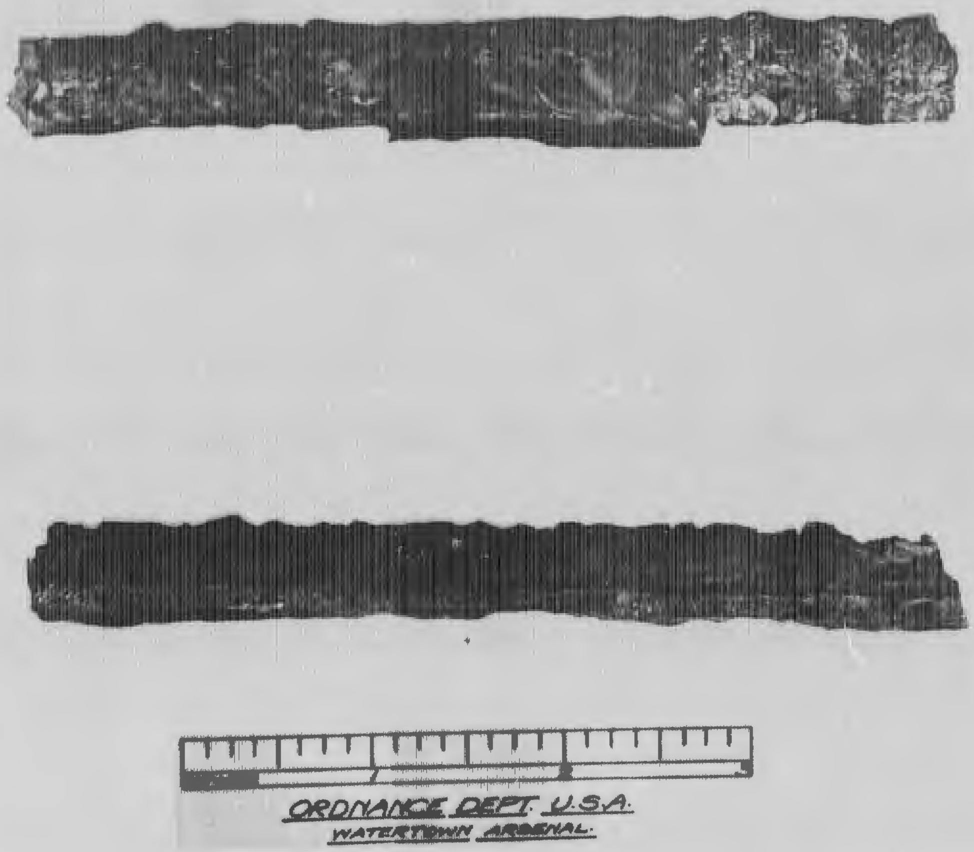
X100 -D- Picral Nital
Large Bolt: Banding in longitudinal direction.



X100 -E- Picral Nital
Small Bolt: Decarburization and cold ~~rk at root of rolled threads

ARMOR ATTACHMENT BOLTS
FROM A
GERMAN PZKW III TANK

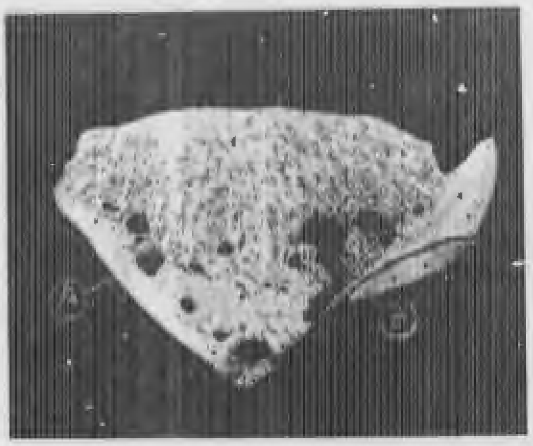
Figure 3



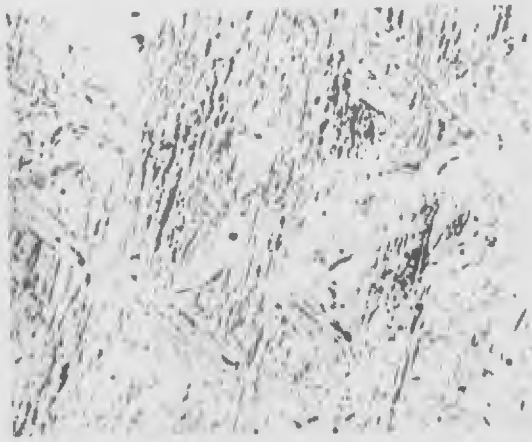
WELD METAL SECTION FROM BASIC HOMOGENEOUS ARMOR OF A GERMAN P Z K W III TANK KNOCKED LOOSE BY A BALLISTIC IMPACT ON FACE PLATE. NOTE POROSITY IN THE WELD METAL

NOVEMBER 6 1942 WTN.710-1953

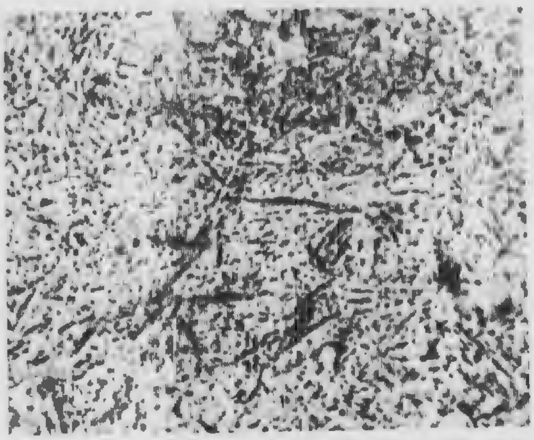
FIGURE 4



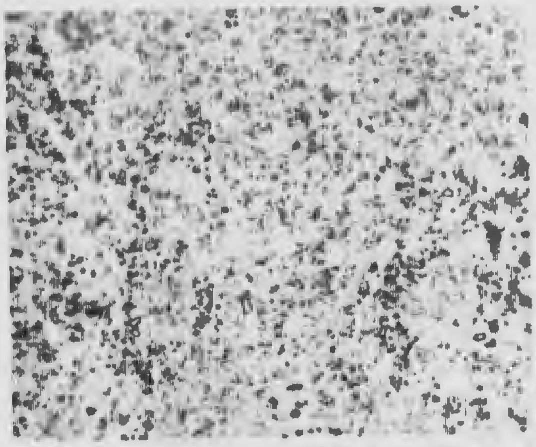
X3 -A- Picral-Nital
Cross Section of Weld



X1000 -B- Picral-Nital
Weld Bead: Low carbon martensite



X1000 -C- Picral-Nital
Heat affected zone A: Martensite



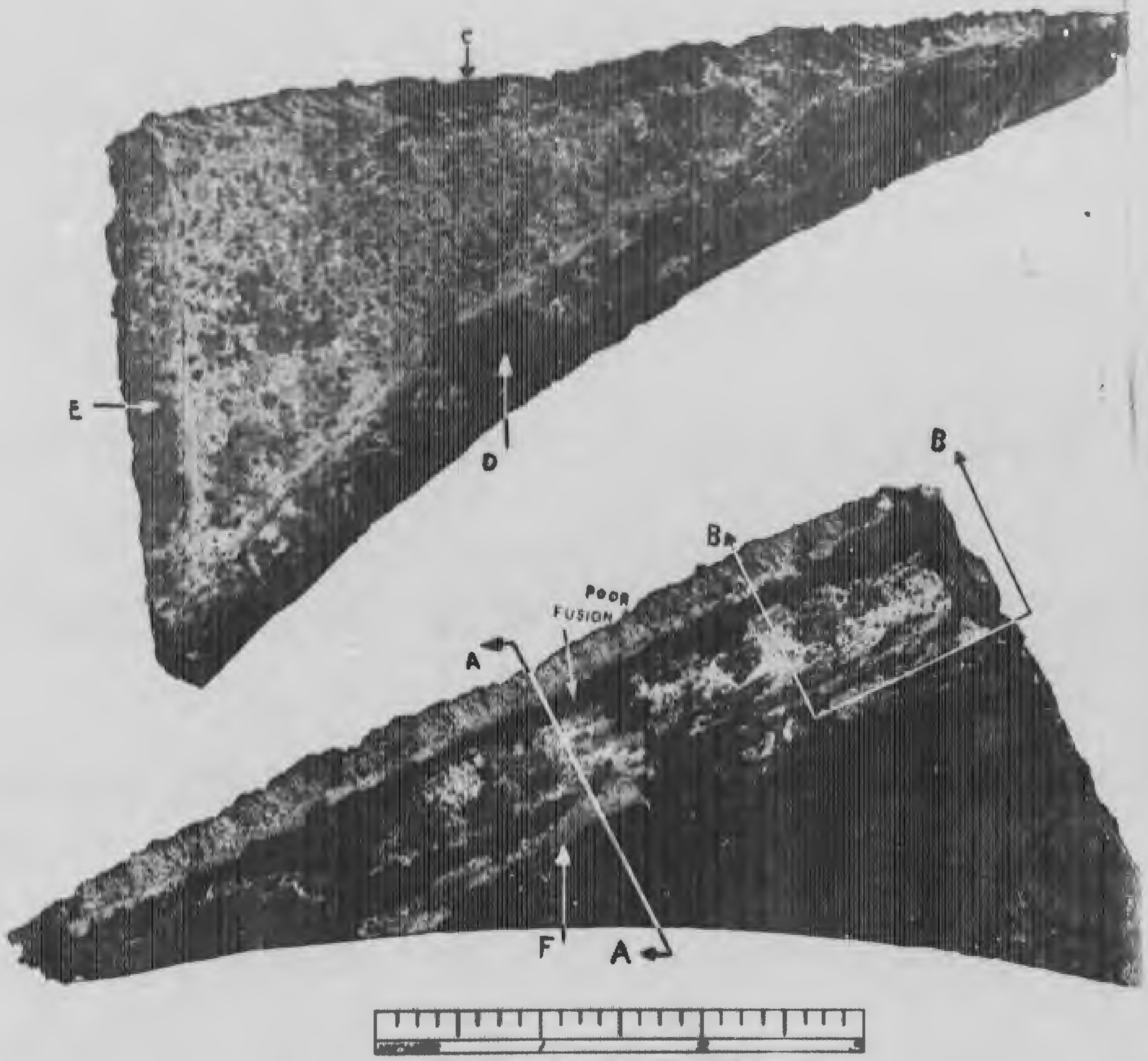
X1000 -D- Picral-nital
Heat affected zone B: Martensite and undissolved carbides

WTN.639-4770

X100 -E- Picral-Nital
Fusion zone B: Porosity in weld and crack in heat affected zone

WELD METAL SECTION
FROM A GERMAN
PZKW III TANK

Figure 5



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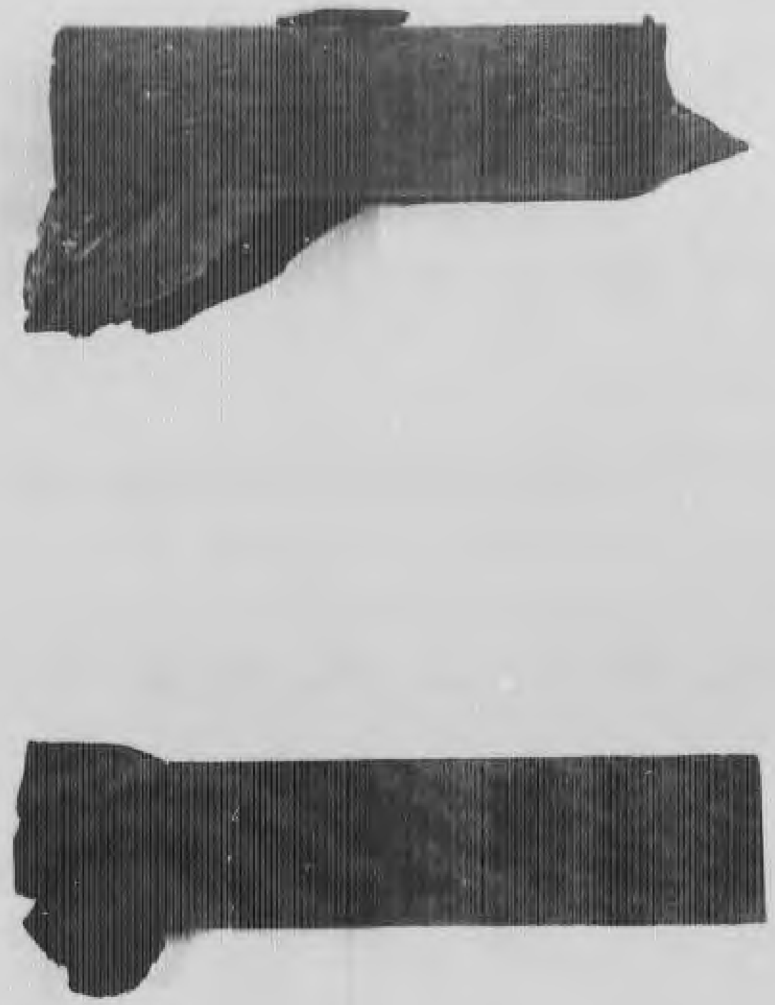
WELDED ARMOR SECTION FROM THE CARRIER OF THE ROOF OF A GERMAN P Z K W III TANK
NOVEMBER 6 1942

WTN.710-1952

FIGURE 6

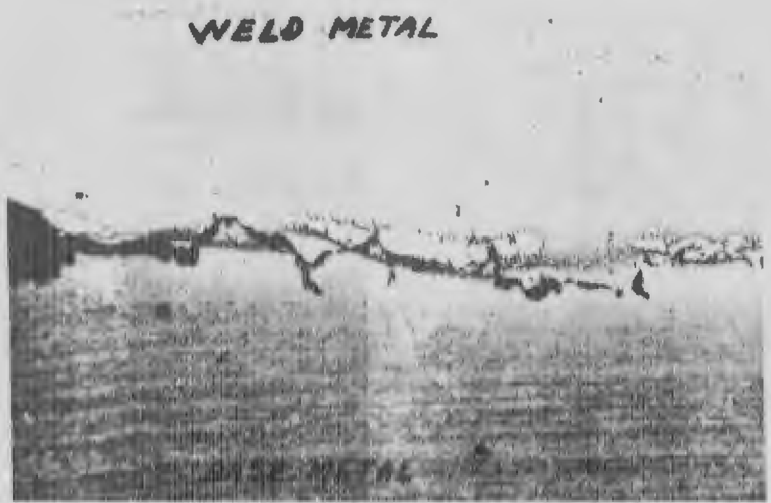


WATERTOWN ARSENAL

MACROETCHED SECTIONS OF A WELDED ARMOR SECTION FROM THE CARRIER OF THE ROOF OF A GERMAN PZKW III TANK. MAG. X2
TOP: LONGITUDINAL SECTION — BOTTOM: TRANSVERSE SECTION
DECEMBER 15 1942 WTN.710-1981

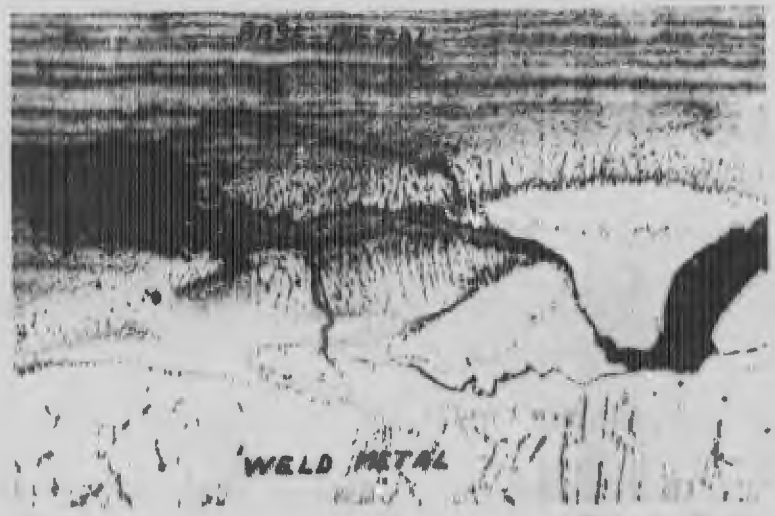
FIGURE 7

WELDED ARMOR SECTION FROM THE ROOF OF A GERMAN PZKW III TANK



X100 -A- Picral Etch

Fusion Zone at 1. High alloy weld bead. Lack of fusion and cracking at the toe.



X100 -B- Picral Etch

Fusion Zone at 2. High alloy weld bead. Cracking in Heat affected zone.

VTN.630-4771

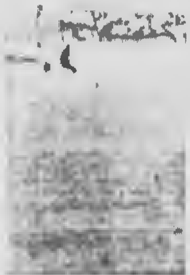
X100 -C- Picral Etch

Fusion zone at 3 between low and high alloy weld metal. Note cracking in low alloy weld zone.

VTN.630-4772

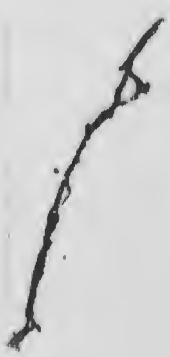
1of2

OOF OF A



Picral Etch
bead.
toe.

cral Etch
bead.



OW
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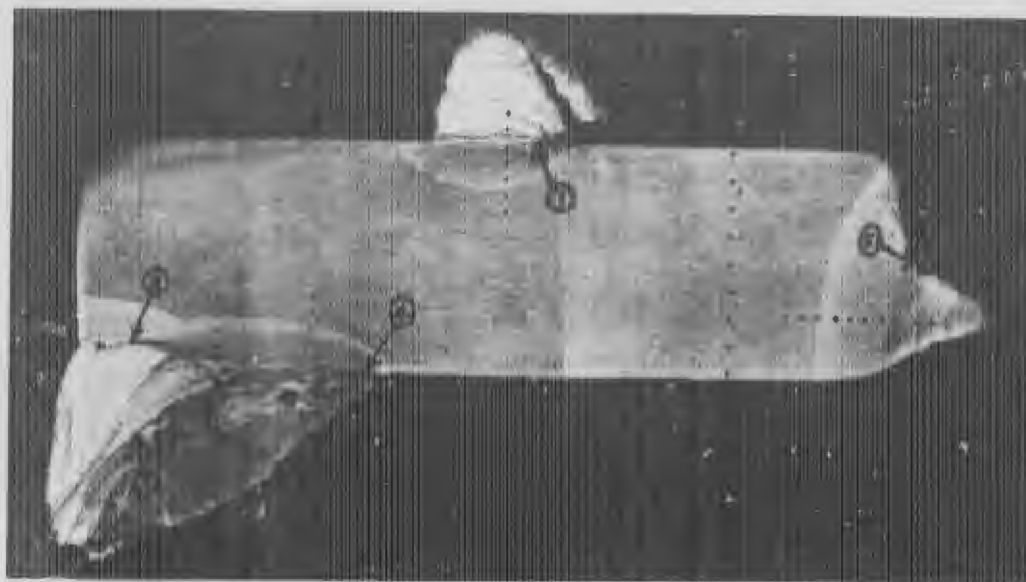
alloy
lloy

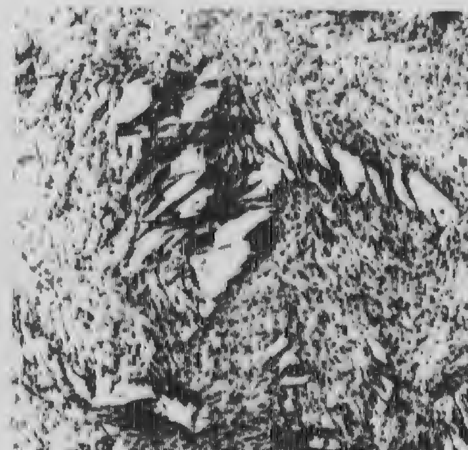


X3 D Nital Etch

Section A-A in Figure 6: Position of the vickers surveys and photomicrographs

X100 -E- Picral Etch

Fusion zone at 5. Note fracture in the high alloy weld bead



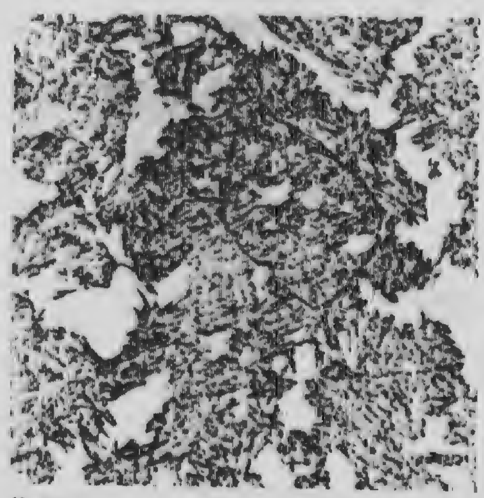
X1000 -F- Nital Etch

Martensite and austenite in low alloy weld at 5.

WTN.639-4772

X100 -G- Picral Etch

Fusion zone at 4. Low alloy weld bead showing very good fusion except at the toe.



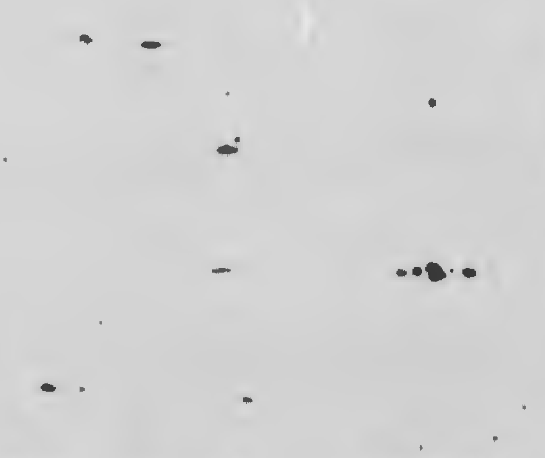
X1000 -H- Nital Etch

Martensite and austenite in low alloy weld at 4.

Figure 8

WELDED ARMOR SECTION FROM THE ROOF OF A GERMAN PZKW III TANK

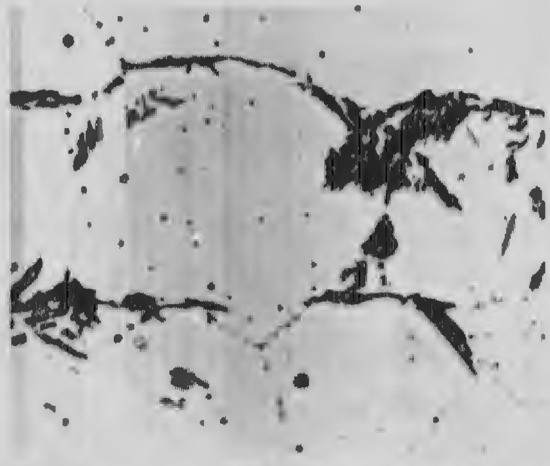
X3 A Nital Etch
Section B-B in Figure 6: Position of Vickers surveys & photographs



X100 B Unetched
Base metal: Distribution of nonmetallics

X100 C Chromic acid Etch
Weld metal at 6: Bainite in high alloy weld

X1000 D Picral Etch
Base metal: Martensite and undissolved carbides



X1000 E Chromic acid Etch
Weld metal at 6: Bainite at grain boundaries of high alloy weld

Figure 9

APPENDIX A

COPY

War Department
The Proving Center
Aberdeen Proving Ground
Maryland

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Armor Division
Project A-1
Pless/hlc

A.P.G. 470.5/4183
W.A. 470.5/5447

Subject: Metallurgical Analysis of German Armor

To: The Commanding Officer
Watertown Arsenal
Watertown, Massachusetts

Attn.: Col. G. L. Cox

1. This station is forwarding several small samples from a German PZKW III tank for metallurgical analysis. The samples include a section of weld metal, a piece of armor with some weld metal clinging to it, and two bolts used for attaching additional armor to the tank. It is requested that a full metallurgical examination be given these samples.

2. This station is interested in the chemical analysis of the weld metal and the armor plate, as well as the welding procedure used, if it is possible to determine this. Any other metallurgical information concerning these samples which can be furnished will be of great value. Two copies of the report of the examination of these samples will be needed by this station. It is asked that this examination be completed at the earliest possible moment.

For the Commanding General:

G. G. EDDY
Col., Ord. Dept.
Assistant

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