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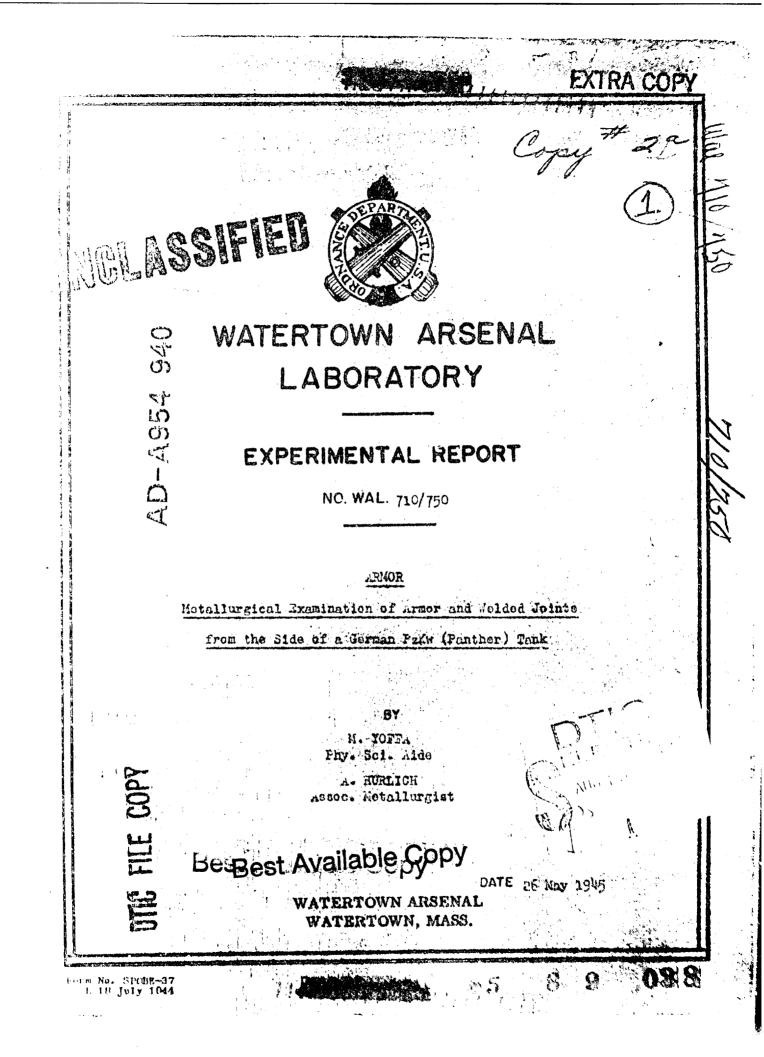
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# AUTHORITY

E.O. 10501, 5 Nov 1953; APG 30 Nov 1965

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Watertown Arsenal Laboratory Report No. Wal 710/750 Problem B-4.74

26 May 1945

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Metallurgical Examination of Armor and Welded Joints from the Side of a German PzKw V (Panther) Tank

To conduct a metallurgical examination of a two inch thick section of armor broken from the side of a German tank during ballistic testing.

### SUMMARY OF RESULTS

Armor

1. The cross-rolled homogeneous armor was processed from steel of relatively poor quality with respect to nonmetallic segregations. The analysis is as follows:

 $\frac{C}{.44} \quad \frac{14n}{0.9} \quad \frac{Cr}{1.7} \quad \frac{V}{0.1}$ 

2. The armor has the following physical characteristics:

	V-Notch Charpy Impact at								
	Brinell	+70°F	-40°F		men	sile Prop	erties		
Thickness	Hardness	Ft.Los.	Ft.Lbs.		Y.S.	T.S.	%El.	ZR.A.	
·····					psi	psi			
2.04"(52mm)	293-302	7•9-9•5	2•2-3•2			143,750 143,500			

3. The extremely poor shock properties are traceable to the nonmartensitic microstructure resulting from hardenability inadequate to permit full hardening upon quenching. The steel has been heat treated to a tempered bainitic microstructure containing banded segregates rich in ferrite.

### Welding

1. The two weld deposits were made with electrodes of the following composition:

Weld No.	ype and Location of Welded Joint Cr Ni M	<u>Mo</u>
1	Single fillet tee joint on surface of plate. 12 4.5 3.0	)
2	Two bead corner joint. (15) 1645 3.5	

2. Both weld No. 1 and the first bead of weld Ho. 2 to be deposited are magnetic, having microstructures consisting of autenite and large amounts of ferritic decomposition products (probably low carbon martensite). The second bead of weld No. 2 is nonmagnetic and essentially austenitic. The electrode used to made weld No. 1 is insufficiently alloyed to form austenitic deposits even upon the first pass. The electrode of weld No. 2, although more highly alloyed than the former electrode, deposits an austenitic bead which can be readily decomposed by the tempering action of subsequent weld beads.

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3. The nature of the fractured weld joints indicate both welds to be somewhat brittle. Some dendritic boundary type of cracking was observed in the lower bead of weld No. 2. No base metal cracking was present in the heat affected zones of the armor. The welds appear to have been deposited, without preheat, upon the armor in the final heat treated condition.

## Economic Considerations

1. The complete elimination of molybdenum as an alloying agent in the subject armor may be significant in reflecting a critical shortage of this ver/ important element. The very poor shock properties of the armor are, in fact, traceable to the lack of nardenability occasioned by the elimination of molybdenum. The analyses of the seni-austenitic weld deposits reflect an attempt to conserve nickel by replacing it with the more available manganese. In addition, the chromium contents of the weld deposits are considerably lower than used in American practice. In comparison with American standards the German electrodes are considered unsatisfactory because the weld deposits are not completely austenitic, tend to be brittle, and are prone to develop cracks during welding.

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APPROVED:

N. A. MATTHEWS Lt. Col., Grd. Dept. Director of Laboratory

## INTRODUCTION

In accordance with instructions from the Office, Chief of Ordnance<sup>1</sup>, a sample from the side of a PzKw V (Panther) tank was submitted to this arsenal for metallurgical examination.

According to the basic letter, all of the armor on the tank from which the sample was removed was extremely brittle under the attack of American armor piercing projectiles. The submitted section of plate was actually blown from the side of the tank by a 75mm H.E. round.

Inferior toughness<sup>2,3,4</sup> as evidenced by brittle fractures and low impact resistance has been reported in several investigations of German armor that were 2" and greater in thickness. The inferior toughness was traced in some instances to an inadequate hardening treatment, and in others to temper brittleness combined with incomplete quench hardening.

### MATERIALS AND TEST PROCEDURE

The armor section, marked  $\#_3-6-45$ , was roughly triangular in shape, being  $21\frac{1}{2}$ " long at the base and having an altitude of  $18\frac{1}{2}$ ". The thickness was 2.04" (52mm); the plate probably being produced to the nominal thickness of 50mm.

The submitted sample contained two weld deposits, one along the  $2l\frac{1}{2}$ <sup>n</sup> long edge apparently from a corner joint which had the second welded member broken away, and the second deposit running across the surface of the plate perpendicular to the first weld and appearing to be from a single fillet tee joint with the second welded member also broken away. The major portions of the weld deposits appeared, in both cases, to have remained on the submitted sample.

1. APG 470.5/1279 - Wtn 386.3/94, Appendix A.

- Watertown Arsenal Laboratory Report No. WAL 710/715, "Metallurgical Examination of a 3-1/4" Thick Armor Plate from a German PzKw V(Panther) Tank", P. V. Riffin, 18 January 1945.
- Watertown Arsenal Laboratory Report Fo. WAL 710/542, "Metallurgical Examination of Armor and Welded Joints from German PzKw VI Tank. P. V. Riffin and S. A. Herres, 23 February 1944.
- 4. Minutes of 22nd Meeting of the Technical Co-ordinating Committee on Fank Armor, 8 June 1944, Minute 178(c) (British Report).

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The armor was subjected to chemical analysis, hardness survey, fracture test, tensile tests, impact tests, microscopic and macroscopic examination, and reheat treatments to determine the response to hardening and tempering treatments. The welds were subjected to chemical analysis, hardness surveys, and microscopic examination.

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## DATA AND DISCUSSION

A. Armor

1. Chemical Composition

The chemical analysis of the armor is as follows:

<u>C</u> .	lin	Si	S	P	Cr	<u>v</u>	. <u>Cu</u>	Al	lio
•44	.86	•27	.017	.024	1.72	.10	.02	.015	Trace

A somewhat similar medium carbon, chromium-vanadium composition was discovered in a 3-1/4" thick section from the side of a PzKw V previously examined at this arsenal<sup>2</sup>. The lack of molybdenum, which has hitherto invariably been found in German armor, may possibly indicate a critical shortage of this strategic alloying element at the time of manufacture of the subject armor.

A distinct trend towards a reduction in the molybdenum content has, in fact, been observed in German armor. Prior to the end of 1943 German armor sections up to 2" in thickness which were examined at this arsenal generally contained from 0.30 to  $0.55_{7^{2}}$  molybdenum<sup>5,6,7</sup>. Armor sections in the same thickness range which were examined during 1944 contained molybdenum in the range of 0.15 to  $0.25\%^{3,8}$ , whereas the two most recently examined sections, one of which was 3-1/4" thick, contain no molybdenum<sup>2</sup>.

- 5. Watertown Arsenal Laboratory Report No. WAL 710/458, "Metallurgical Examination of Section of German Face Hardened Armor from the Front of a PzKw III Tank". 15 October 1942.
- 6. Watertown Arsenal Laboratory Report No. IAL 710/472, "Metallurgical Examination of Armored Vehicle Components (Armor Attachment Bolts and Welded Armor Sections) from a German PzKw III Tank". 2 January 1943.
- Watertown Arsenal Laboratory Report No. WAL 710/539, "Metallurgical Examination of Eleven Sections of Enemy Armor, Including Homogeneous, Flame Hardened, Carburized, and Welded Components". 25 October 1943.
- Watertown Arsenal Laboratory Report No. WAL 710/608, "Metallurgical Examination of Armor and Welded Joints from German PzKw IV Tank, Model GF-2", 4 April 1944.

## 2. Hardness Survey

Brinell hardness impressions at  $\frac{1}{2}$ " intervals through the thickness of the section yielded values of 302, 293, 302 and 302 Brinell.

## 3. Fracture Tests

... section cut from the sample was notched and fractured. The fracture was extremely brittle in nature, with a bright flat crystalline surface. It was consequently impossible to rate the steel with respect to cleanliness since laminations traceable to nonmetallics do not develop when steel fra.tures in a brittle manner.

A second section was reheat treated as follows:

1600°F - 2 hrs. - water quenched 1250°F - 2 hrs. - water quenched Brinell hardness - 275 BEN

When notched and fractured, the reheat treated section developed a fibrous fracture. The steel quality rating was "D" (U. S. Army Specification AXS-488, Revision 2), which is borderline acceptable. Fairly extensive laminations were observed approximately one third of the thickness from both surfaces. The occurrence of the laminations coincides, as will be subsequently shown, with the ingot pattern developed upon the hot acid etching of a transverse section of the armor.

4. Tensile Tests

Tensile test specimens 0.505" in diameter were machined from locations halfway between the surface and the center of the armor sample. The tensile properties are given in Table I.

#### TABLE I

Tensile Properties of German Armor

	Yield Strength 0.1% offset p.s.i,	Tensile Strength	Elongation	Red. of area
Longitudinal "	123,750 123,125	144,250 143,250	19.0 16.5	53.0 53.0
Transverse	125,000	143,750	16.5	51.9
n	125,000	143,250	16.5	53.0

The equality of the longitudinal and transverse tensile properties indicate that the material had been relatively uniformly cross-rolled.

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## 5. Notched Bar Impact Tests

V-notch Charpy impact specimens were machined from the midsection of the submitted armor sample and were tested as indicated in Table II. In the as-received condition, the impact energy is extremely low and confirms the conclusion drawn from the ballistic test in regard to the brittleness of the armor.

To ascertain to what extent, if any, temper brittleness was a factor responsible for the poor impact resistance, a 2"x4"x8" section was tempered at 1150°F and water quenches. The slight improvement in impact resistance which resulted from this treatment, see Table II, was probably for the most part due to the decrease in hardness from 300 BHN to 277 BHN. It may be concluded that temper brittleness is not responsible to any significant extent for the very poor shock properties.

#### TABLE II

Notched Bar Impact Tests of German Armor

		<b>Tirection</b> of	V-Notch Charry Impact Data (Average of two tests)				
Heat Treatment	BHN	Test Specimen in Relation to Rolling Direction	Tested at +70°F Ft.Lbs.	-		Fract.* Rating	
As-Received	300	Longitudinal Transverse	9•5 7•9	Ср Ср	2•2 3•2	Съ Съ	
2"x4"x8" Section Tempered at 1150°F-2 hrs. Vater Quenched	277	Longitudinal	12.4	СЪ	6.7	Ср	
2"x4"x8" Section 1600°F-2 hrsMater Quenched 1200°F-2 hrsmater Quenched	321	Transverse	24.7. (;	Fc Laminated	l) <sup>3.9</sup> (La	Cb minated)	

\*Cb - Bright crystalline Fc - Fibrous matrix with crystalline patches.

A 2"x4"x5" section was reheat treated as indicated in Table II. The room temperature impact energy was raised, but the low temperature value is still extremely poor. It is concluded that the hardenability of the subject armor is insufficient to permit the quenching to a completely martensitic structure of even the relatively small section used for the experimental heat treatment. Chromium is very effective in preventing the formation of pearlite because of its displacement of the curve representing the austenite-pearlite decomposition in such a manner that the time necessary for the reaction to start is greatly increased. The bainite reaction is not, however, similarly affected by chromium<sup>5</sup>; consequently considerable amounts of bainite are formed when a chromium steel is quenched in a 2" thick section. Bainitic

5. Watertown Arsenal Laboratory Report No. WAL 310/47, "The Hardenability Concept". J. H. Hollomon.

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steels have been found to be increasingly brittle with increasing hardness above approximately 260 BHN. High impact resistance can be developed in a steel of the composition and thickness of the subject German armov only by tempering to hardnesses considerably lower than those customarily employed in German armov of equivalent thickness.

## 6. Macroetch Test

Photographs of the hot acid etched sections are shown in Figure 1. The transverse section indicates the ingotism pattern previously mentioned in regard to the steel soundness fracture test. The weld bead of the single tee joint is shown in the upper photograph and that of the corner joint is shown in the lower photograph of Figure 1.

### 7. Licroscopic Examination

The microstructure of the armor consists of highly spheroidized carbides and ferrite segregated in alternate light and dark etching bands. The light etching bands contain greater amounts of ferrite than are found in the dark etching bands, see Figures 2A, 3, and C. It is surmised that the steel had probably been oil quenched and tempered at approximately 1200°F. The hardenability characteristics of the steel are such that a predominately bainitic structure was probably formed upon quenching. The microstructure is characteristic of tempered bainite.

## 8. General Considerations (Armor)

The composition of the subject armor represents a deviation from the more conventional Cr-Ho steel customarily employed for armor by the Germans. The replacement of 0.50% melybdenum by 0.10% vanadium results in a serious decrease in the hardenability of the steel; the decrease being sufficient to prevent the transformation of a 2" thick section to an essentially martensitic structure even when drastically quenched.

The inferior shock properties of the armor are traceable to the lowered hardenability. The impact properties of bainitic steels at hardnesses in the vicinity of 300 BrN have been repeatedly found to be very poor.

The quality of the steel is not as satisfactory as that of the average German armor previously investigated at this arsenal.

### B. Weld Buads

## 1. Chemical Composition

The chemical analyses of the two weld beads are as follows:

Weld No.	Type and Location of 'elded Joint	<u> </u>	Mix	Si	Ni	Cr	Mo
1	Single fillet tee joint on surface of plate	•19	3.18	.26	4.54	12.08	Nil
2	Two Bead corner joint	•21	3.78	.40	6.61	15.06	.11

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The analyses indicate that the electrodes used to make the welds were of somewhat similar type, representing a modification of the 18 Cr - 8 Ni type in which manganese replaces some of both the nickel and the chromium.

## 2. Microscopic Examination

The 12% Cr, 4.5% Ni, 3% in single bead weld deposit (weld deposit No. 1) is strongly magnetic. The microstructure consists of austenite and ferritic decomposition products (probably mainly low carbon martensite) with nonmetallics segregated in the austenitic regions. The austenite, being richer in alloying elements, was the last metal to solidify and is consequently segregated in the dendrite fillings, see Figures 22 and F.

The 15% Cr, 6.5% Ni, 3.5% Mn weld deposit was laid on in two beads. The first bead which was deposited is quite strongly magnetic while the second bead is nonmagnetic. Spectographic analysis verified that both beads are of identical analysis. The microstructure of the first bead consists of austenite and ferritic decomposition products (probably martensite as in the case of weld No. 1), Figures 3B and C. again, the austenite occurs at the dendrite grain boundaries. The second bead is essentially austenitic, with nonmetallics distributed throughout the grains and nonmetallics and carbides outlining the grain boundaries, Figures 3D and E.

The difference in microstructure between the two beads of weld No. 2 is believed due to the tempering of the first bead by the deposition upon it of the second bead. An austenitic alloy of 15% Cr, 6.5% Ni, and 3.5% In would be expected to be rather unstable and subject to decomposition upon heating to moderately elevated temperatures. Since weld No. 1 is even lower in alloy content than weld No. 2, the stability of the austenitic phase of the former weld would be even less than that of the latter, as was demonstrated by the fact that weld No. 1 suffered considerable decomposition to the ferritic phase upon deposition.

No cracks were observed in either weld deposit No. 1 or in the top bead of weld deposit No. 2. Gracking was observed in the lower bead of weld No. 2, being associated with the heavy precipitate occurring at the dendrite boundaries. No cracks were found in the base armor in the vicinity of the welds.

3. Hardness Survey

The results of Vickers-Brinell hardness surveys of the weld deposits of the heat affected zones are shown graphically in Figure 3 and are summarized in Table III.

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## TABLE III

## Hardness Surveys of Welded Joints

	Weld Meta	l Hardness	Weld Heat Affected Zone Kaximum Hardness			
Weld No.	Vickers	Brinell*	Vickers	Brinell*		
1	258-306	258-306	690	614		
2 (Bead No. 1)	232-342	232-322	657	587		
2 (Bead No, 2)	198-262	198-255				

\*Converted from Vickers-Brinell to Standard Brinell (Tungsten Carbide Ball, 3000 Kg load).

The top bead of weld No. 2, being essentially austenitic, is considerably softer than weld deposit To. 1 and the bottom bead of weld No. 2, both of which contain considerable quantities of low carbon martensite.

The hardnesses of the heat affected zones of the base armor approach that of fully quenched martensite of a .45% carbon steel. The heat affected zone beneath the first weld bead applied to weld ro. 2 has been tempered by the application of the second weld bead; the hardness being reduced from 600-650 Vickers to 400-450 Vickers. The welds appear to have been deposited, without preheat, upon the armor in the final heat treated condition.

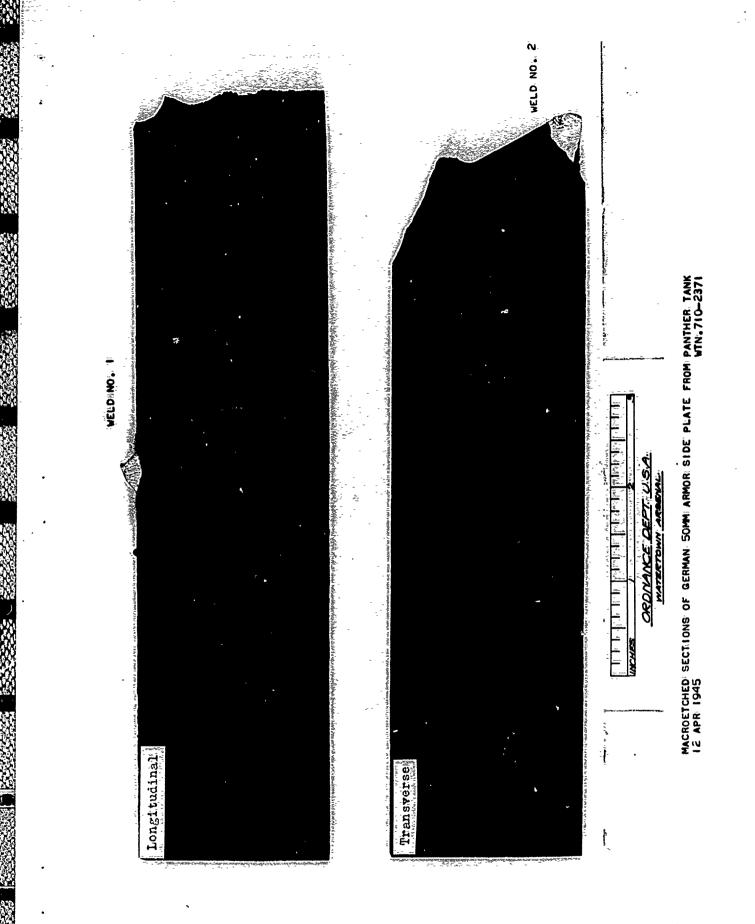
## 4. General Considerations (Welding)

Since both welds were fractured through the joints and since the members which were welded to the 2" armor section are missing, no statements regarding joint design and preparation of edges to be welded can be made.

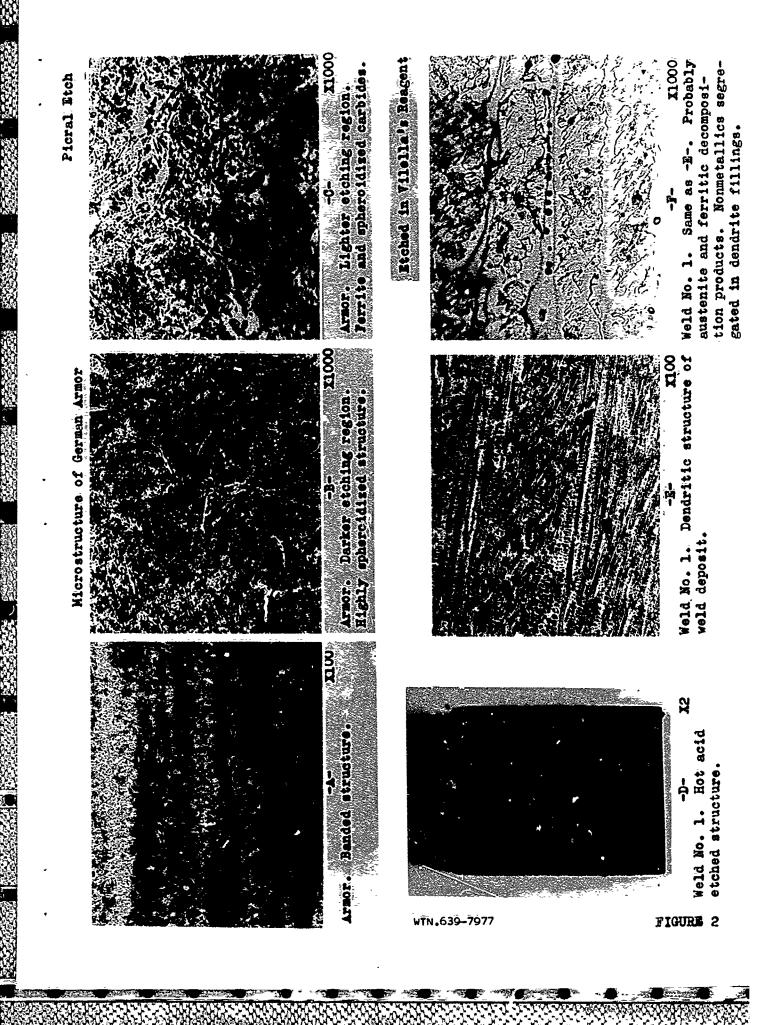
The use of 12% Cr, 4.5% Ni, 3.0% Mn and 15% Cr, 6.5% Ni, 3.5% Mn electrodes does not appear to give particularly desirable results as demonstrated by the instability of the austenitic phases of these alloys, the dendrite boundary cracking observed in the lower bead of weld No. 2, and the apparent brittleness of the welds, which were presumably fractured during ballistic testing.

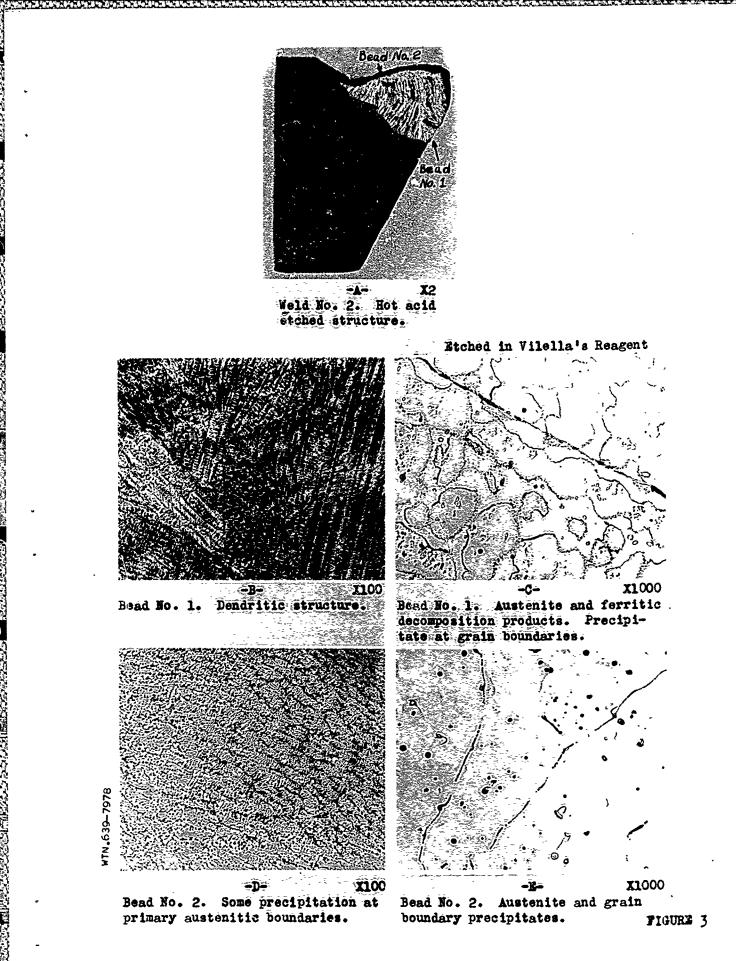
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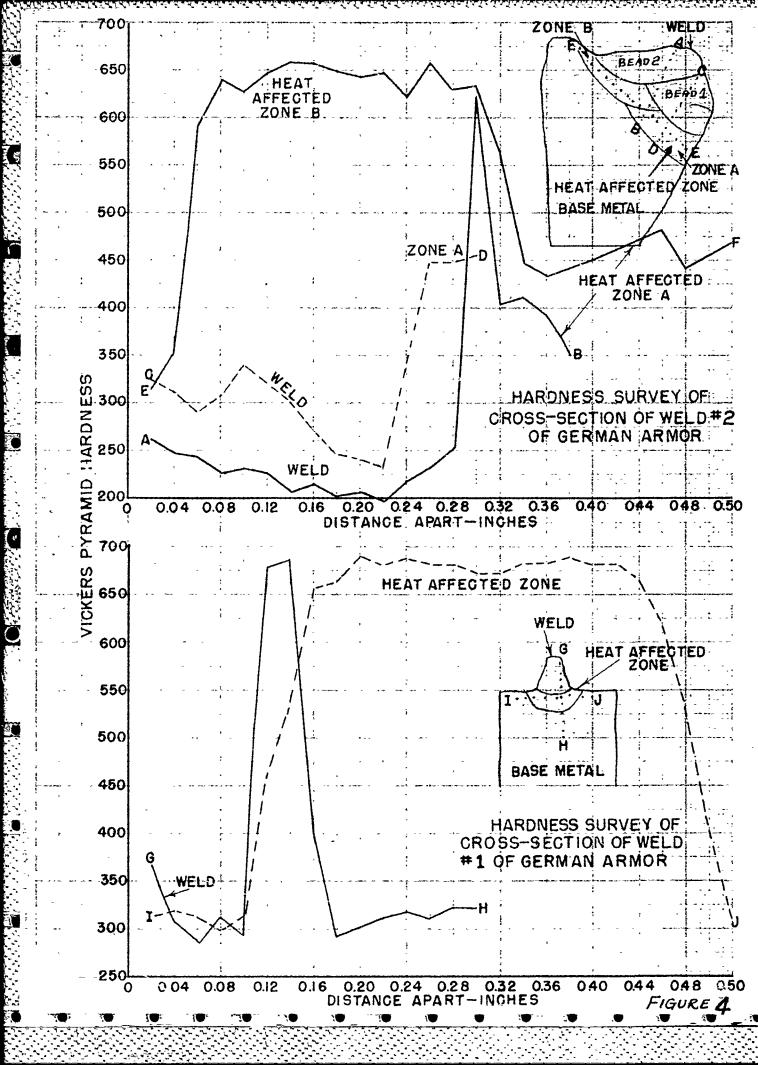
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APPENDIX A

## Correspondence

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## ARMY SERVICE FORCES ORDNANCE DEPARTMENT ABERDEEN PROVING GROUND MARYLAND

APG 470,5/1279 Attn; SPOTZ-F

10 March 1945

Subject: Metallurgical Examination of German Armor

To: Commanding Officer Watertown Arsenal Watertown 72, Massachusetts

Attention: Lt. Col. Matthews

1. A section of German armor is being forwarded to your station for metallurgical examination. The sample is marked #3-6-45. This plate is from the side of a Panther tank.

2. All of the armor on this vehicle when impacted with A.P. projectiles exhibited a very brittle structure. The particular : section of the plate which you will receive was actually blown from the side of the tank by a 75 mm. H. E. round.

3. It would be appreciated if your station would obtain whatever metallurgical information you feel necessary. It is requested that a copy of your report be forwarded to Aberdeen.

FOR THE COMMANDING GENERAL:

(S/T) G. G. EDDY Col., Ord Dept Director, Ord. Res. and Dev. Center

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