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WATERTOWN ARSENAL LABORATORY

EXPERIMENTAL REPORT

NO. WAL. 640/140

WELDING OF ARMOR

.40% C Experimental 1-1/2 Inch Thick
Rolled Homogeneous Armor Plate

BY

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Watertown Arsenal Laboratory
Report No. WAL 640/140 UNCLASSIFIED 9 November 1944
Problem No. D-13.1

WELDING OF ARMOR

.40% C Experimental 1-1/2 Inch Thick
Rolled Homogeneous Armor Plate

OBJECT

To determine ballistic shock performance of subject armor as welded with a commercial austenitic electrode and an experimental ferritic electrode.

SUMMARY OF RESULTS

1. Two .40% C "H" Plates welded with a commercial 19% Cr, 9% Ni austenitic electrode (no preheat) and the usual type of butt weld armor joint design, showed excessive ballistic cracking in the weld metal immediately adjacent to the weld-plate interface. A .26% C "H" plate with an identical weld joint design failed in a similar manner by fusion zone cracking. It is not believed that these failures were associated with base metal composition or properties.

2. Two .40% C "H" plates welded with the same austenitic electrode (no preheat) and having a weld joint design modified to decrease susceptibility to fusion zone failure had extremely good ballistic shock resistance. A .26% C "H" plate similarly welded also performed exceptionally well.

3. None of the austenitic welded "H" plates (four .40% C and two .25% C) passed radiographic inspection, but none of the radiographic defects appeared to influence ballistic performance. There may be a greater tendency for development of fine weld metal cracks (not discernible until radiographic inspection) during welding of .40% C steel, but this cracking should be avoidable by slight modification in the welding technique or electrode composition.

4. Two .40% C "H" plates welded with an alloy (2% Mn, .4% Mo) ferritic electrode with a stainless type coating showed very good ballistic shock resistance. However, it was necessary to preheat these plates to 300° F. in order to avoid weld metal cracking in the root bead passes.

S. A. Herres

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APPROVED:

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

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INTRODUCTION

An important consideration in the specification of armor for Ordnance fabrications is weldability, but since almost any steel can be welded satisfactorily provided enough precautions are observed, the adoption of exact specification limits for armor to be welded by practical commercial procedures is a difficult matter. Since increase in carbon content of any steel is accompanied by a decrease in the ease of welding, a maximum carbon content is a primary consideration. In accordance with the best opinion of industrial representatives and Ordnance Department personnel a limit of .30% maximum C (ladle analysis) has been adopted in the specification for armor plate; Steel, Rolled, Homogeneous (AXS-488), which covers all armor over 1/2 inch gage which is to be fabricated by metal arc welding.

This limit is believed by many to be an unnecessary restriction on steel-making practice and best ballistic properties of armor for certain applications. The establishment of the .30% C limit was undoubtedly influenced by the knowledge that underbead cracking difficulties increase markedly with higher carbon contents in hardenable alloy steels welded with heavily coated ferritic electrodes. Since this type of cracking has been demonstrated to be associated with the cellulose and moisture contents of the electrode coating[1] this consideration can be discounted for welds made with electrodes having suitable (lime or titania base) stainless electrode type coatings. On the other hand, it has been shown[2] that the tendency to develop intergranular "hot tears" in the weld heat-affected base metal of very high carbon and alloy steels (.52 C, .6 Mn, 2.5 Cr, .6 Mo) necessitates preheating even when welding with austenitic electrodes.

Recent evaluations[3, 4] of shock properties of a number of welded armor joints indicate that ballistic shock failures in current armor compositions can be associated with definite metallurgical and joint design factors, none of which are associated directly with excessive carbon or alloy content of the armor plate. While a number of armor weldments have been made from relatively high carbon armor plate

(1) Report No. WAL 642/115, "Arc Welding of Alloy Steels - Study of Base Metal Cracks Associated with Effects of Arc Welding Process," S. A. Herres, 12 June 1943.
(2) Report No. WAL 710/542, "Armor and Welding - Metallurgical Examination of Armor and Welded Joints from German PzKw VI Tank," P.V. Riffin and S. A. Herres, 23 February 1944, p. 11.
(3) Report No. WAL 648/5, "Evaluation of Shock Properties of Welded Armor Joints - Examination of Samples from 33 Commercially Welded, Ballistically Shock Tested 'H' Plates," S.A. Herres and A.M. Turkalo, 10 June 1944.
(4) Report No. WAL 648/6, "Evaluation of Shock Properties of Welded Armor Joints at Subnormal Temperatures - Examination of Samples from 31 Commercially Welded 'H' Plates Ballistically Shock Tested as part of the 1942-1943 Canadian Cold Test Program," S.A.Herres and A.M. Turkalo, 9 August 1944.

(e.g. .50 C Cr-Mo-Va homogeneous armor, series of .42 C Mn-Cr-Mo-Si armor H plates ballistically tested during winter of 1942-1943, and present grades of aircraft armor), the circumstances of welding and testing have not permitted adequate comparisons with ballistic shock performance of armor grades covered by Specification AXS-488. The purpose of the subject investigation was to determine ballistic shock characteristics of 1-1/2 inch thick rolled homogeneous armor of approximately .40% C as welded with commercial austenitic electrodes and an experimental Mn-Mo ferritic electrode having a stainless type coating.

DATA AND DISCUSSION

Primary Armor Test Data

Steel of 1-1/2 inch gage for test plates was procured from Republic Steel Corporation from a heat of type NE-8740 with a check analysis of .405% C. Complete data as to chemical composition and processing, together with results of ballistic tests of unwelded plate, are given on the first data sheet of Appendix A. This steel had a fracture test rating of B (small laminations present but well distributed and not concentrated in any one plane; no lamination exceeding 1/2 the thickness of plate) which indicates relatively good steel quality. As heat treated to approximately 269 Brinell the steel was entirely satisfactory in primary ballistic tests for penetration and shock.

For comparison purposes, 1-1/2 inch gage Jones & Laughlin Mn-Mo .26% C plate was used. Complete data as to chemical composition, processing and results of primary ballistic testing of this steel are given on the second data sheet of Appendix A. Fracture test rating was B, and as heat treated to approximately 277 Brinell, the steel was entirely satisfactory in primary ballistic tests for penetration and shock.

Welded Armor Test Data

On Charts 1 through 4 (Appendix A) are tabulated welding procedure and ballistic test data for the six .40% C and the two .26% C H plates fired under this program. Also included in Appendix A are a key to tabulation methods and symbols and a summary of current specification requirements (AXS-497, Rev. 5, December 1943) for H plates welded with austenitic electrodes. There follows a narrative discussion of the welding and ballistic test program.

The first welding was attempted with a lot of an approved brand of 19% Cr, 9% Ni, Mo modified electrode. It was found impossible to deposit the root of the weld because of excessive root bead weld metal cracking. Subsequent tests proved that this electrode could not even be used for 1015 steel and the shipment was returned to the electrode manufacturer who reported (Wtn. File No. 470.5/9180) that the core wire of this shipment was outside their specification for the Cr-Ni ratio. Plate WA1 was partially welded and scrapped in the course of experiments with this electrode brand.

Plates WA2 and WA3 were welded with the electrodes and welding procedures indicated on Chart 1 (Appendix A). Joint design is shown in more detail on extract from WAS-2 Forms (Appendix A). The joint set-up and welding procedure was selected by the Watertown Arsenal representative and Mr. A. J. Raymo, who supervised the welding of these two plates at Baldwin Locomotive Works, as typical of the best armor welding practice. The use of nose beads at the root of the weld was intended to minimize weld metal cracking in this zone.

On ballistic shock testing at Aberdeen Proving Ground excessive cracking developed in the fusion zone of the weld (see Chart 1). The plates were unsatisfactory on radiographic inspection because of small weld metal cracks, which were not detected during welding. These cracks did not appear to influence the path or extent of ballistic fracture in any way.

The plates were returned to Watertown Arsenal Laboratory for examination. Figure 1 shows a macroetched transverse section through the ballistic fracture, an edge photograph of a ballistic fracture (weld metal side), and a macroetched section through an undamaged portion of the weld. Bend fracture tests* were made on bars taken across undamaged sections of the welds in these plates. These bars reproduced the ballistic fracture which proceeded almost entirely through weld metal, approximately .002 inches from the bond metal. A thin scale of weld metal was visible on the plate metal side of the fracture (see Figures 1 and 2). This type of failure has been identified in two other investigations of samples from commercially welded armor joints[5], and found to proceed through an area where very fine nonmetallics are precipitated parallel to the fusion line in austenitic weld metal (Figure 2). This condition, which will be discussed more fully in a forthcoming report, does not appear to be related to the carbon content or hardenability of the experimental .40% C armor plate.

Almost identical fractures were obtained in bend fracture tests from joints made with similar joint design and welding procedure in Carnegie and Jones & Laughlin armor plates of approximately .26% C. An attempt was next made to improve the bend fracture by changes in the joint design. The use of a 60° rather than a 45° included angle did not change the type of failure. The use of larger beads (3/16 instead of 5/32 inch diameter electrodes) at the weld plate junction for both crowns of the double V joints, did effect considerable improvement both for .26% C Carnegie and Jones & Laughlin and the experimental .40% C armor plates. A further improvement was brought about by grinding additional bevels (1/4 inch wide) at the top corners of the crowns, and continuing the use of the 3/16 inch diameter electrode for the corner beads. Photographs of three bend fracture bars from this series of welds are shown in Figure 3. The improvement is obviously a result of relocating the stress-concentrating notch, which is unavoidably present at the junction of the weld and plate surfaces, so that failure is not initiated in the fusion zone, and of breaking up the straight line fusion zone contour observed in the photomacrographs of Figures 1 and 2. It is well established that if ballistic cracking is

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* Test method described in Appendix B.

(5) See Footnotes 3 and 4.

forced into tough austenitic weld metal or properly made armor plate, the extent of failure will be markedly reduced.

It was therefore decided to weld two additional H plates of .40% C experimental armor with the improved joint design developed in the bend fracture tests and two H plates of .26% C Jones & Laughlin armor (see preceding section on primary armor test data) - one with joint design used on first two plates and one with improved joint design. Two H plates (WA5 and WA6) welded at Baldwin Locomotive Works were not ballistically tested because small weld metal cracks disclosed in radiographic examination were unsuccessfully repair welded.

"H" plates WA9 and WA11 of .40% C Republic armor plate and plate WA12 of .26% C Jones & Laughlin armor plate were welded at Watertown Arsenal with the improved geometry described in Charts 2 and 3 (Appendix A). Joint design is shown in more detail in extracts from WAS-2 Forms (Appendix A). Plate WA10 of .26% C Jones & Laughlin armor was welded with the same crown bead technique employed for plates WA2 and WA3.

On ballistic shock testing at Aberdeen Proving Ground the Jones & Laughlin plate with original joint geometry developed excessive ballistic cracking in the fusion zone, while the two experimental .40% C and the one .26% C Jones & Laughlin plates made with improved joint geometry showed very superior ballistic shock resistance. The maximum length of cracking was 3 inches for any one of a total of twelve impacts placed on the latter three plates with 75 mm. test projectiles at 1200 f/s velocity.

Figures 4 through 9 show photographs of the two Jones & Laughlin and one experimental plates after ballistic testing; macroetched sections through ballistic impacts; macroetched sections through undamaged portions of welds; bend fracture tests from undamaged portions of Jones & Laughlin welds; and nick-break fracture*. The limited depth of ballistic cracks which appear to have initiated in the tempered band at the outer edge of the weld heat-affected base metal, and the favorable bend fracture for plate with improved joint design may be noted. The nick-break fracture test was made for comparison purposes and will be discussed in a later section on ferritic welds.

None of the austenitic plates was satisfactory on radiographic inspection because of small weld metal cracks and incomplete fusion which were not detected during welding, but these defects did not affect the ballistic shock test performance. It is probable that an increase in carbon content of the base metal would tend to increase root bead cracking, and in accordance with the current theory on this subject (6), a decrease in nickel content or an increase in Cr or Mo contents of the filler metal would tend to compensate for the increased C pickup and improve this situation. The use of Mo instead of Mn modified austenitic electrodes would be a desirable first step. Also, slight modification of the welding procedure, such as use of heavier root bead passes, might be effective. The

* Test method described in Appendix B.

(6) Field, A.L., F.K. Bloom, and G.E. Linnert (Rustless Iron & Steel Corp.), "Progress Report on Development of Armor Welding Electrodes: The Effect of Variations in Cr-Ni Ratio and Mo Content of Austenitic (20 Cr-10 Ni) Electrodes on Properties of Armor Weldments," OSRD 3034, Serial M-182, 14 December 1943.

four plates welded at Watertown Arsenal were held to a 150° F. maximum interpass temperature and allowed to cool to room temperature overnight between the three successive days of welding on each plate, which practice may have increased weld metal cracking tendency.

Two "H" plates, WA7 and WA8, were welded at Baldwin Locomotive Works with ferritic electrodes. The Harnischfeger AW2C electrode with stainless type (lime base) coating was used. Preliminary welding on plate WA4 indicated that a 200° F. preheat was insufficient to prevent excessive weld metal cracking (detectable during welding) and this plate was abandoned after being partially welded. The supervisor of welding research for the National Research Council was consulted since his office has sponsored a large amount of development welding with this electrode. Mr. H. J. Zoog of the N.R.C. Welding Research Staff was appointed to supervise welding of plates WA7 and WA8. The two plates were welded with a joint design and welding procedure (see Chart 4 and extract from WAS-2 Form - Appendix A) selected by Mr. Zoog. A preheat of 300° F. and an interpass temperature of 350° - 400° F. were maintained during this welding. Results of firing tests at Aberdeen Proving Ground indicated very excellent ballistic shock resistance for both of the plates (see Chart 4 - Appendix A). A photograph of one of the plates after ballistic testing is shown in Figure 10. Photographs of a macroetched section, and nick-break and bend-fracture specimens are shown in Figure 11. The bend-fracture showed weld metal failure after considerable deformation. The nick-break test was made to see if the relatively high preheat and interpass temperatures had caused loss of toughness in the heat-affected zone (as a result of slow cooling after being heated above the critical hardening temperature during the welding operation). However, comparison with the nick-break fracture specimen for the austenitic weld (Figure 9) indicates that this very severe test developed no crystalline (slack-quench, shock-deficient) structure in either weld heat-affected zone. The ferritic weld metal itself developed only a very small amount of crystallinity and may therefore be judges as relatively tough.

Plate WA8 passed radiographic inspection, but WA7 failed because of 3/4 inch of incomplete fusion. This defect happened to be immediately adjacent to ballistic impact No. 2; so three transverse sections 3/4 inch wide were taken through this impact, macroetched and photographed (see Figure 12). The defect may be observed at the root of the weld in two of the sections. The severe ballistic impact did not initiate cracking at this defect.

GENERAL COMMENTS

It is evident that ballistic failure of .40% C experimental 1-1/2 inch thick rolled homogeneous armor plate welded with austenitic electrodes is of the same type as that occurring in armor plate of .26% C and may, therefore, be minimized by the same precautions which should be used for weldments made with current armor compositions. Very excellent ballistic shock performance was obtained for "H" plates made with the subject .40% C armor and no tendency for ballistic failure associated in any way with the hardened weld heat-affected base metal observed.

A probable tendency for increased root bead cracking of austenitic weld metal during the welding of high carbon base metal may be disclosed by radiographic inspection. It is believed that such cracking may be prevented by observing established principles with regard to C-Ni-Cr-Mo balance in chemical composition of the weld metal.

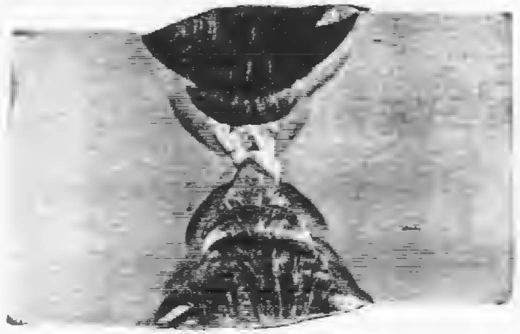
A tendency for increased root bead cracking of alloy ferritic weld metal when welding the .40% C armor plate may be prevented by utilizing slightly higher preheat and interpass temperatures. Very excellent ballistic shock performance was obtained for H plates of .40% C experimental armor welded with Mn-Mo ferritic electrode having a stainless-type (lime base) electrode coating.

Results of bend-fracture tests permit qualitative prediction of ballistic shock performance of 1-1/2 inch thick H plates.

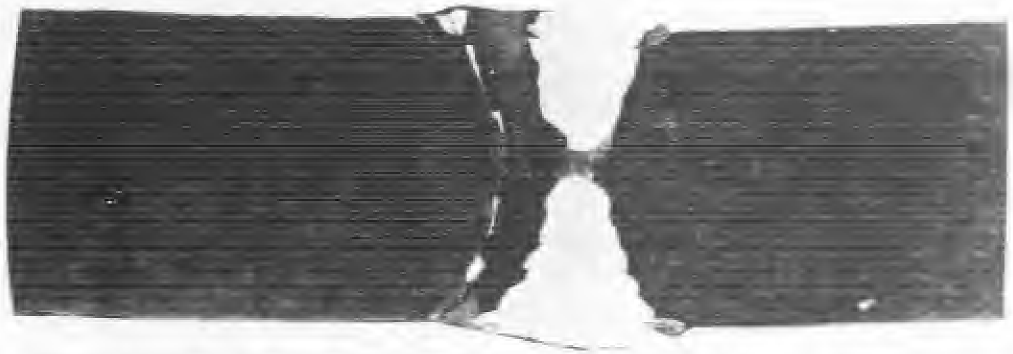
Minor radiographic defects which caused H plates welded under this program to be judged unsatisfactory on X-ray examination did not affect location or extent of ballistic cracking.

Acknowledgements

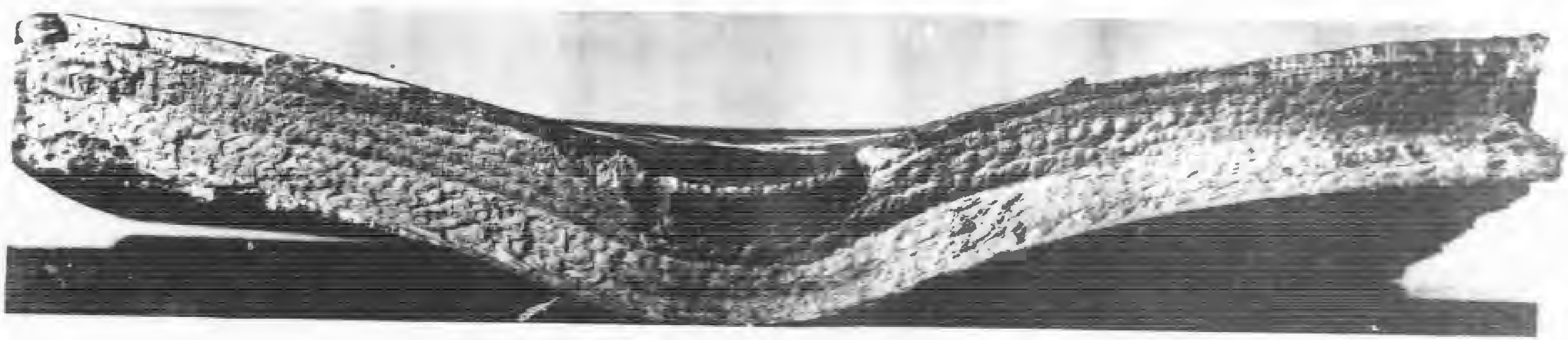
The assistance of Mr. A. J. Raymo, Welding Superintendant of Baldwin Locomotive Works, in supervising welding of plates in his shop, and of Mr. H. J. Zoog and Mr. G. S. Mikhalapov, of the Welding Research Staff of National Research Council, in supervising welding of the two plates welded with ferritic electrodes, is appreciated. Particular appreciation is expressed to Major N. A. Matthews of Watertown Arsenal for assistance in procuring the armor and for his interest and helpful suggestions.



Macroetched transverse section through undamaged portion of weld joint.



Macroetched transverse section through ballistic fracture.

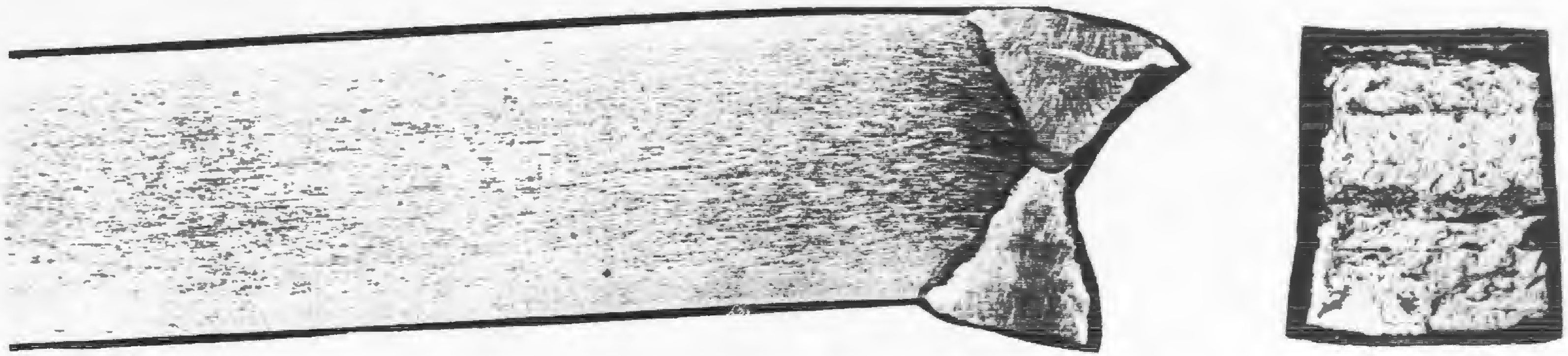


Ballistic fracture surface, weld metal side.

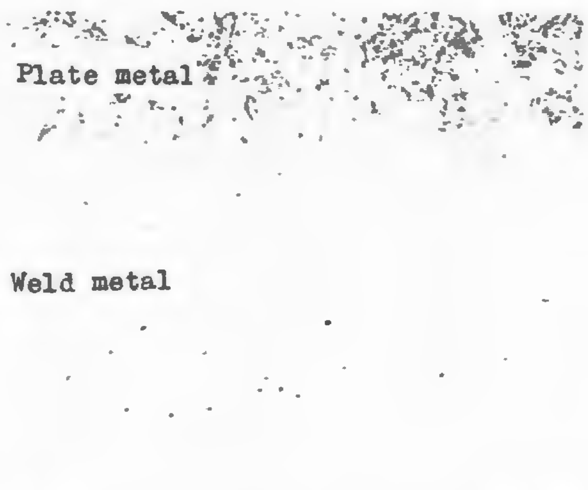
Macroetched Section and Ballistic Fractures from 1 1/2 Inch Thick Austenitic Hand Welded .40% C Republic Armor "H" Plates - Initial Joint Design.

WTN.639-7462

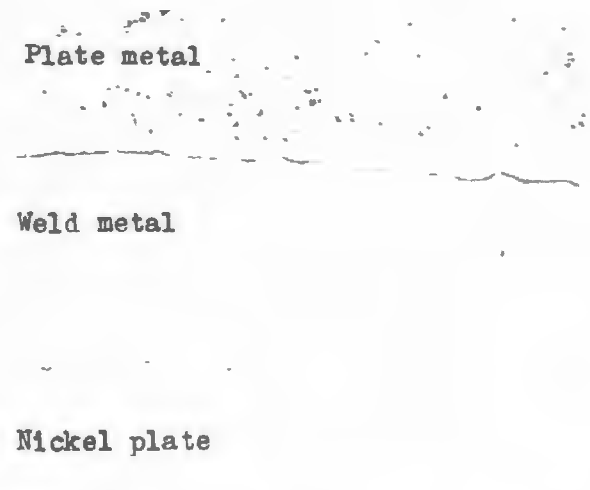
Figure 1



Bend bar fracture of 1-1/2 inch thick austenitic hand welded "H" plate WA-2



X500 Picral
Nonmetallics precipitated in austenitic weld metal near fusion line of weld joint in "H" plate WA-2.

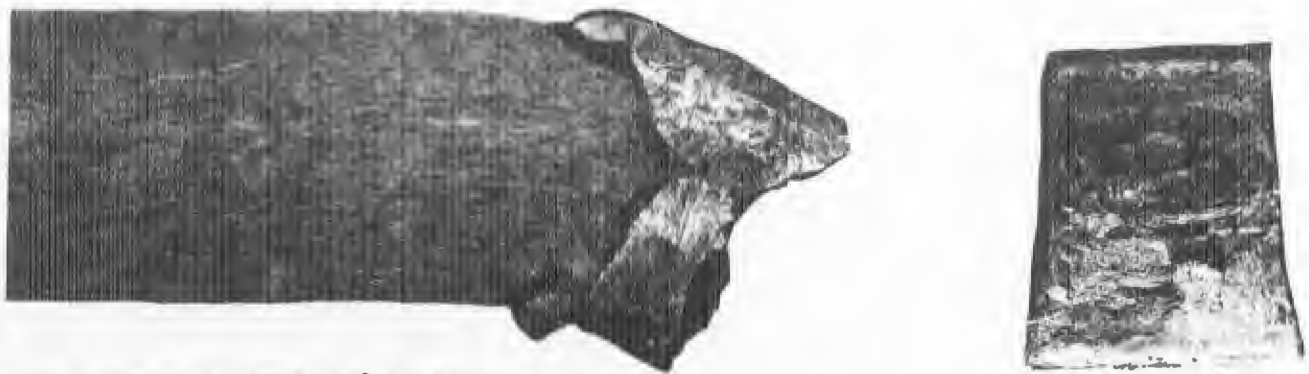


X500 Picral
Bend bar fracture path through area of nonmetallics.

WTN.639-7393

Figure 2.

.26 C JONES AND LAUGHLIN ARMOR –45° DV BEVEL –
GEOMETRY IMPROVED WITH LARGER ANNEALING BEADS.



.40 C REPUBLIC ARMOR –45° DV BEVEL
GEOMETRY IMPROVED WITH LARGER ANNEALING BEADS.

.40 C REPUBLIC ARMOR –45° DV BEVEL –
GEOMETRY IMPROVED BY BEVELING CORNERS TO
GIVE A $67\frac{1}{2}°$ ANGLE AT CROWN.

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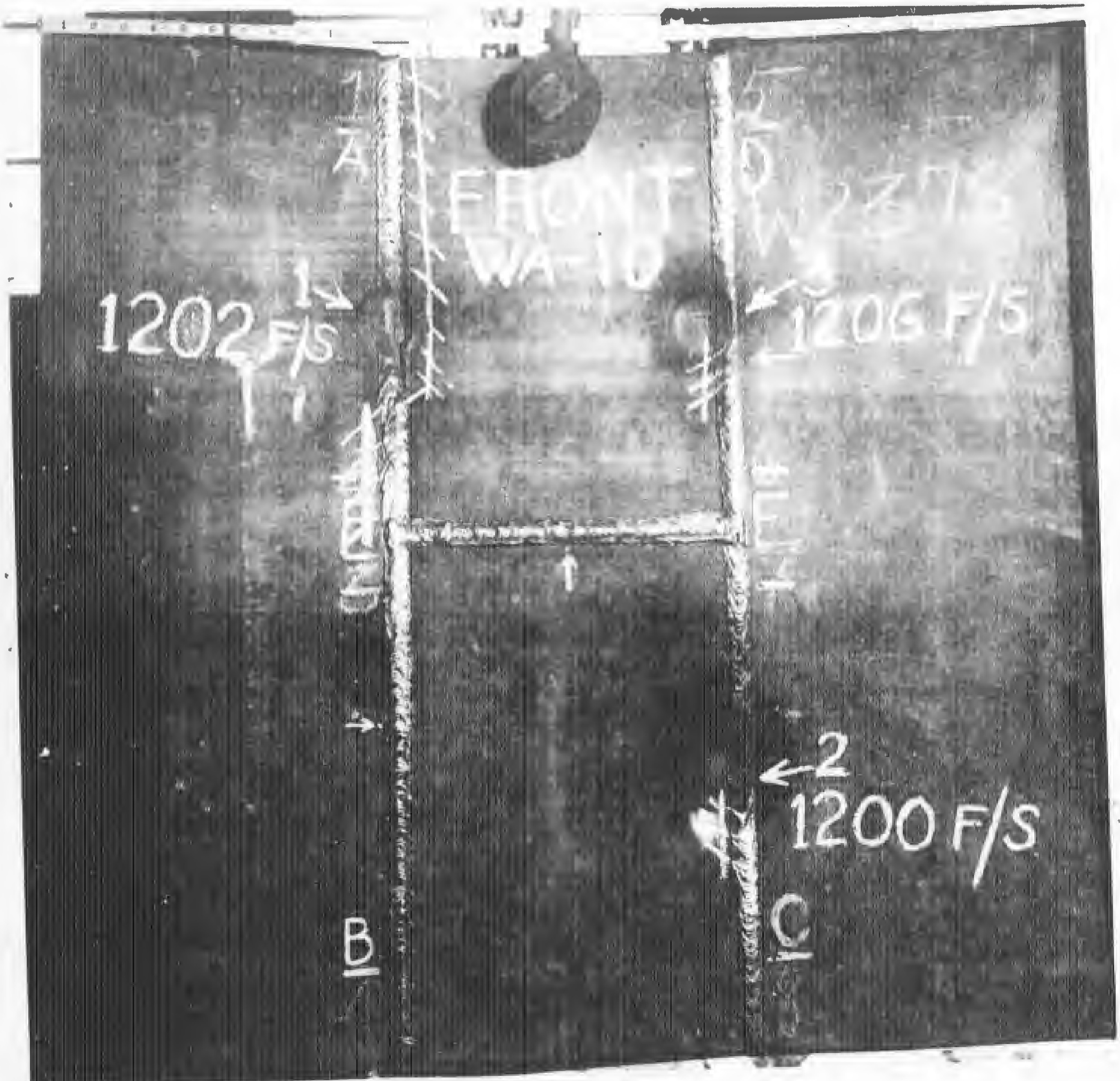
FIG. 3 BEND BAR FRACTURES OF $1\frac{1}{2}$ INCH THICK ROLLED AUSTENITIC HAND WELDED ARMOR PLATE SHOWING INFLUENCE OF WELD JOINT GEOMETRY ON PATH OF FAILURE. WTN.121–595



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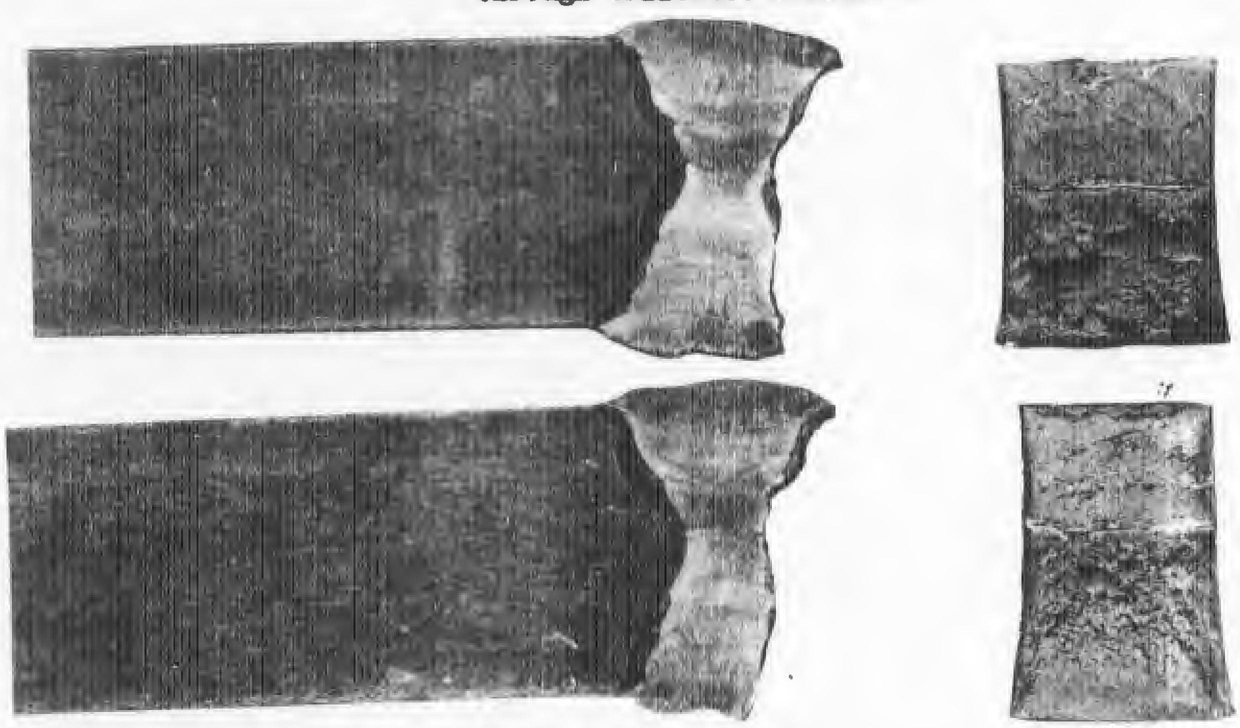
WA-10 H PLATE 1½" J&L ARMOR, STRAIGHT GEOMETRY BUTT JOINT DESIGN, WELDED WITH MCKAY A5 AUSTENITIC ELECTRODE. TESTED WITH 3 ROUNDS 75MM T21 PROOF PROJECTILE AT IMPACT VELOCITIES AS SHOWN. //// INDICATES LOCATION AND EXTENT OF CRACKING. TESTED 4 AUG 1944.

28 SEPT 1944 WTN.121-591

FIG. 4

Macroetched transverse section through
undamaged portion of weld joint.

Macroetched transverse section
through ballistic fracture.

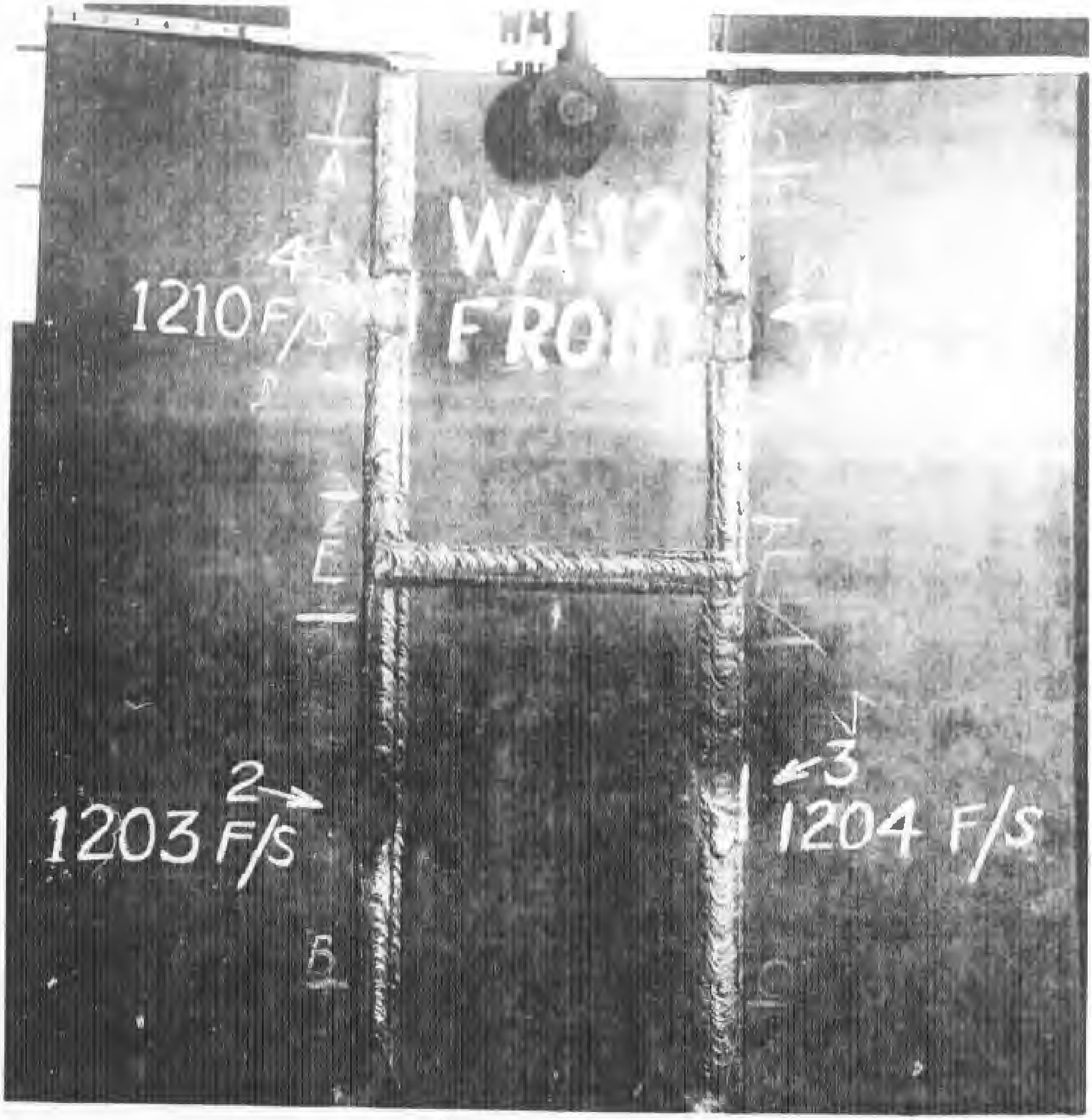


Bend bar fractures.

Macroetched Sections and Bend Bar Fractures from 1 1/2 Inch Thick
Austenitic Hand Welded .26% C Jones and Laughlin Armor "H" Plate
WA-10 - Initial Joint Design.

Figure 5

WTN.639-7463



WATERTOWN ARSENAL

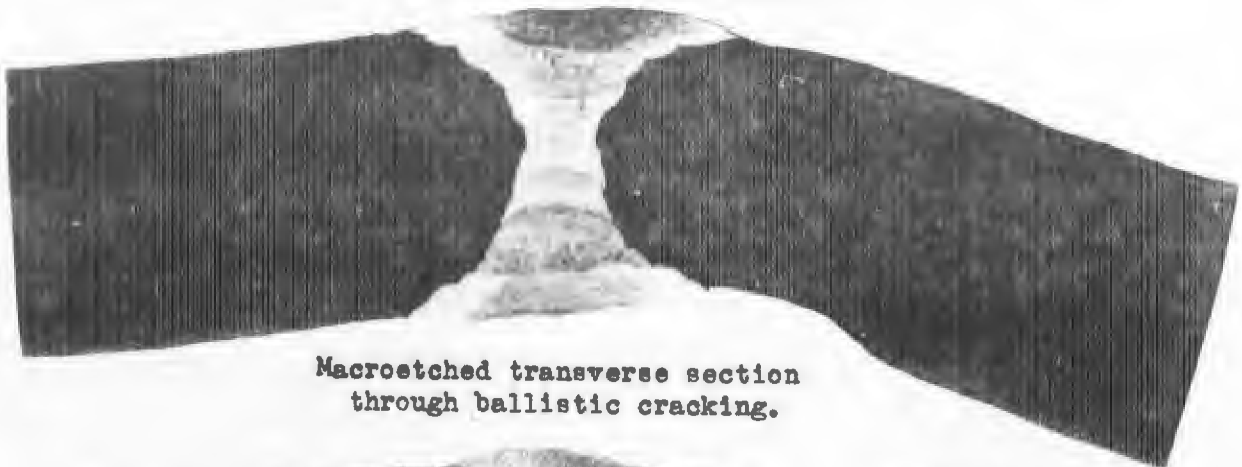
WA-12 H PLATE 1½" J&L ARMOR, IMPROVED BUTT JOINT DESIGN, WELDED WITH McKAY A5 AUSTENITIC ELECTRODE. TESTED WITH 4 ROUNDS 75MM T21 PROOF PROJECTILE AT IMPACT VELOCITIES AS SHOWN. ——— INDICATES LOCATION AND EXTENT OF CRACKING. TESTED 4 AUG 1944.

28 SEPT 1944

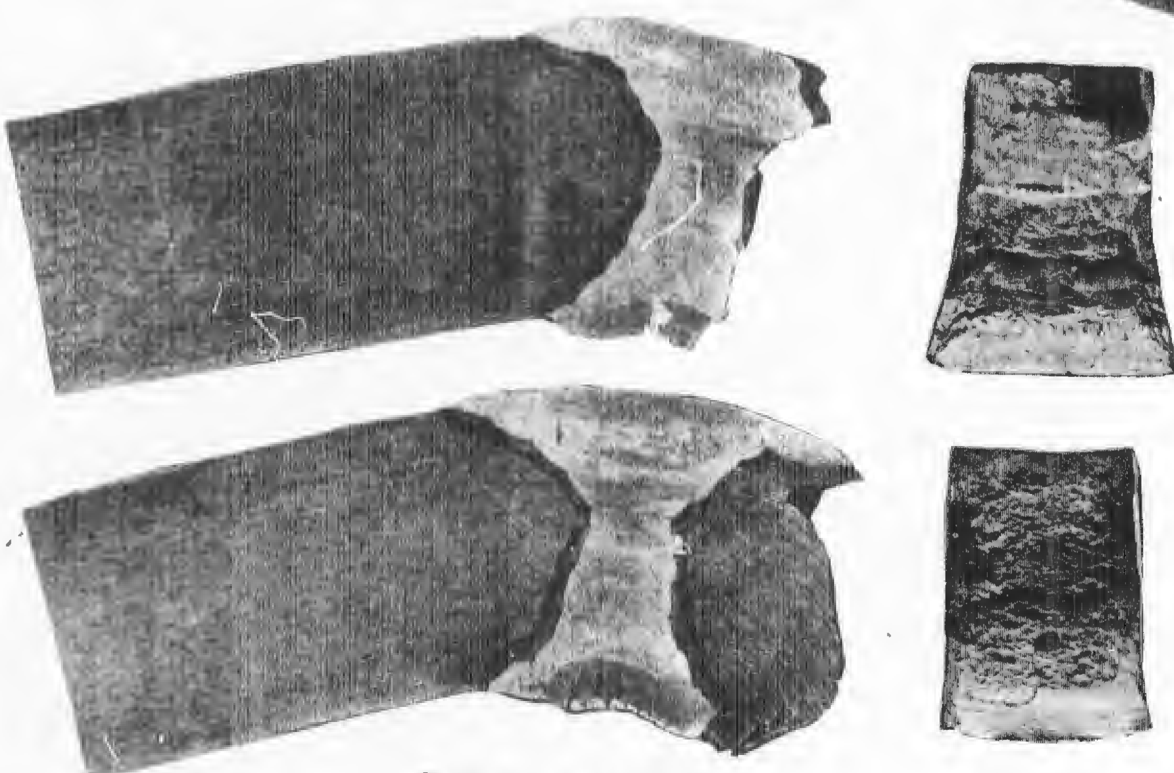
WTN.121-592

FIG. 6

Macroetched transverse section through
undamaged portion of weld joint.



Macroetched transverse section
through ballistic cracking.



Bend bar fractures.

Macroetched Sections and Bend Bar Fractures from 1 1/2 Inch Thick
Austenitic Hand Welded .26% C Jones and Laughlin Armor "H" Plate
WA-12 - Improved Joint Design.

WTN.639-7464

Figure 7

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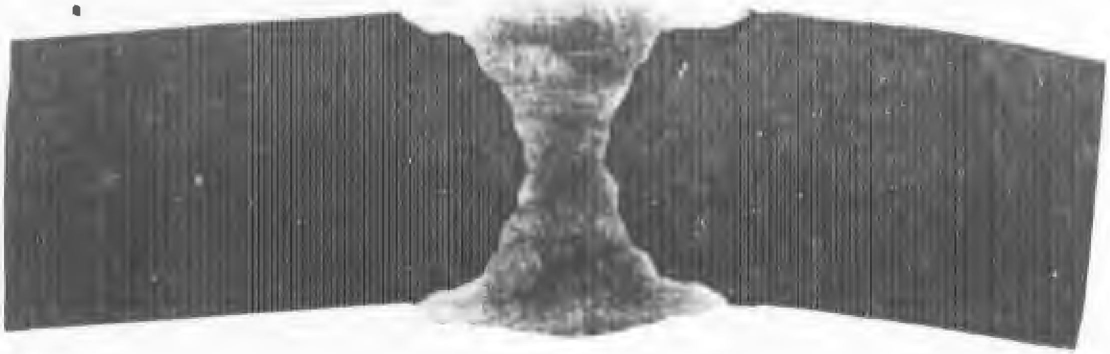
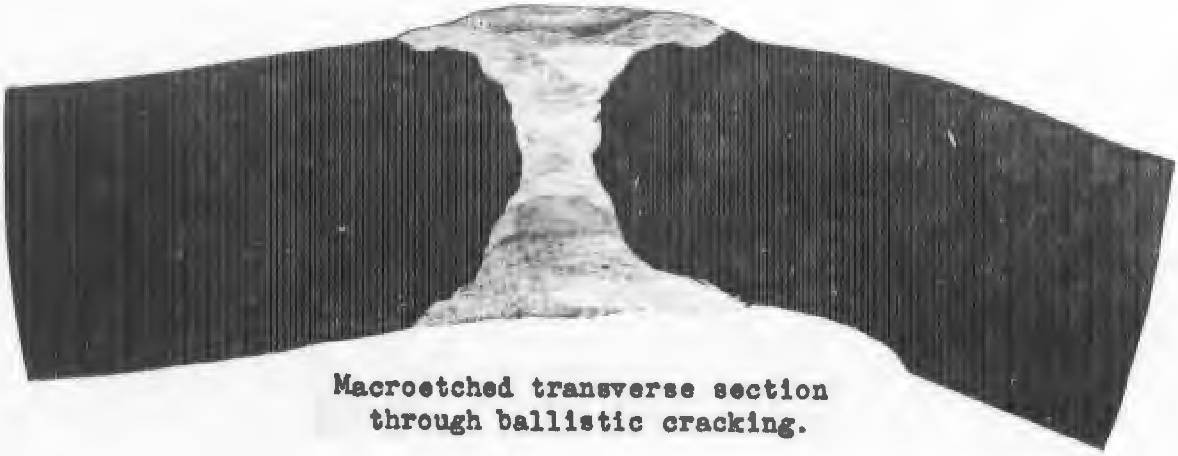
WA-9 H PLATE 1½" 0.40% C. EXPERIMENTAL ARMOR, IMPROVED BUTT JOINT DESIGN, WELDED WITH MCKAY A5 AUSTENITIC ELECTRODE. TESTED WITH 4 ROUNDS 75MM T21 PROOF PROJECTILE AT IMPACT VELOCITIES AS SHOWN 4 AUG 1944 ——— INDICATES LOCATION AND EXTENT OF CRACKING. 28 SEPT 1944 WTN.121-590

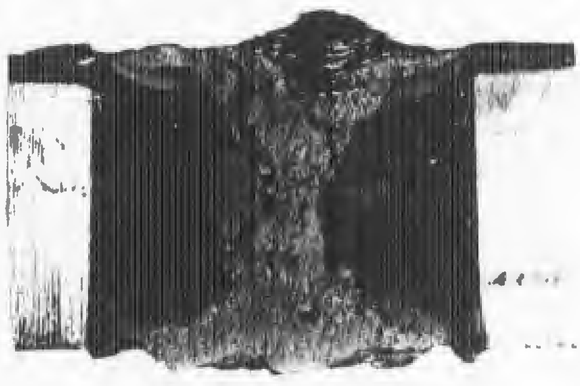
FIG. 8



Macroetched transverse section through
undamaged portion of weld joint.



Macroetched transverse section
through ballistic cracking.

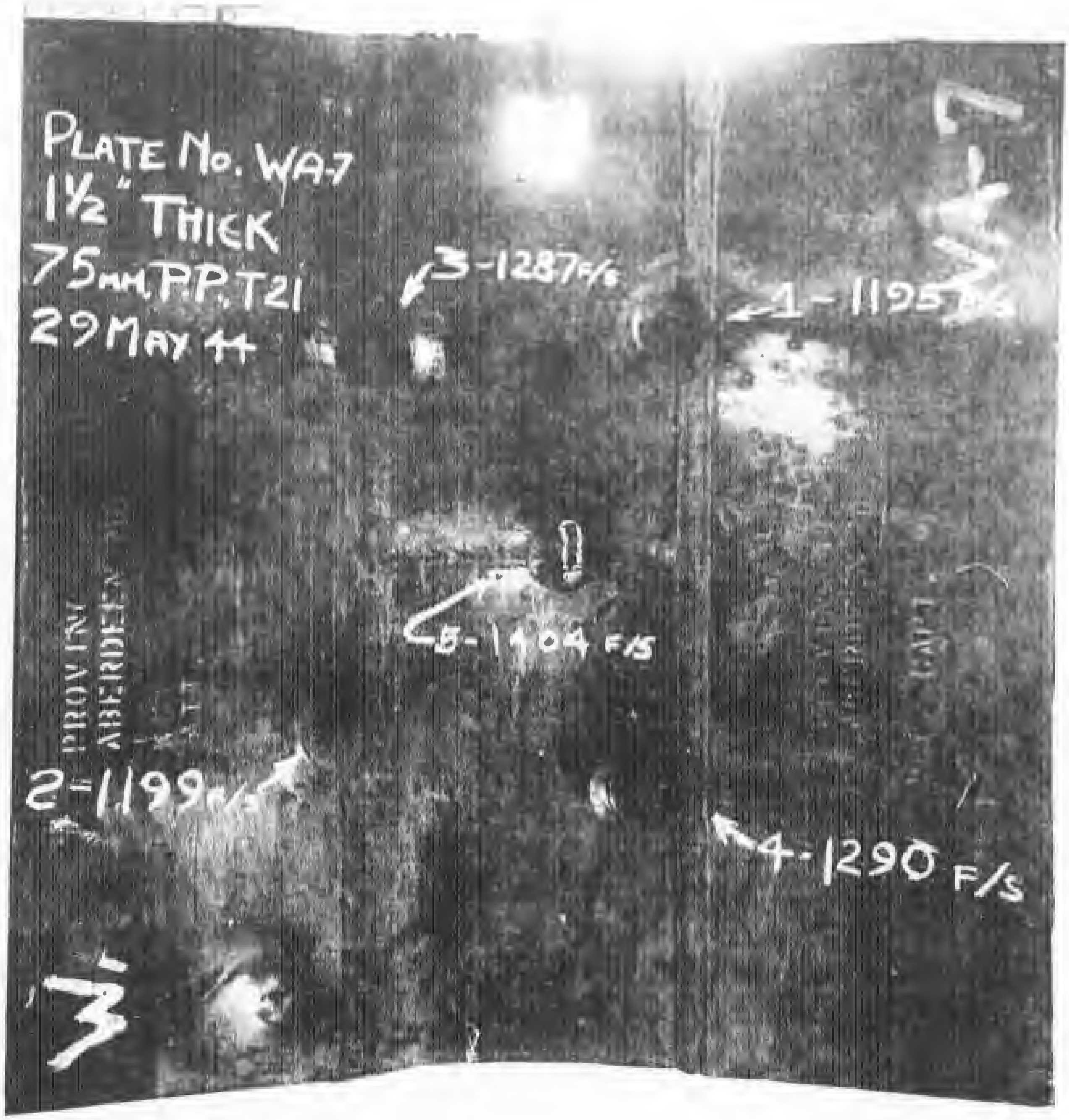


Nick-break fracture.

Macroetched Sections and Nick-Break Fracture from 1 1/2 Inch Thick - Austenitic Hand Welded .40% C Republic Armor "H" Plate WA-9 - Improved Joint Design.

Figure 9

WTN.639-7465

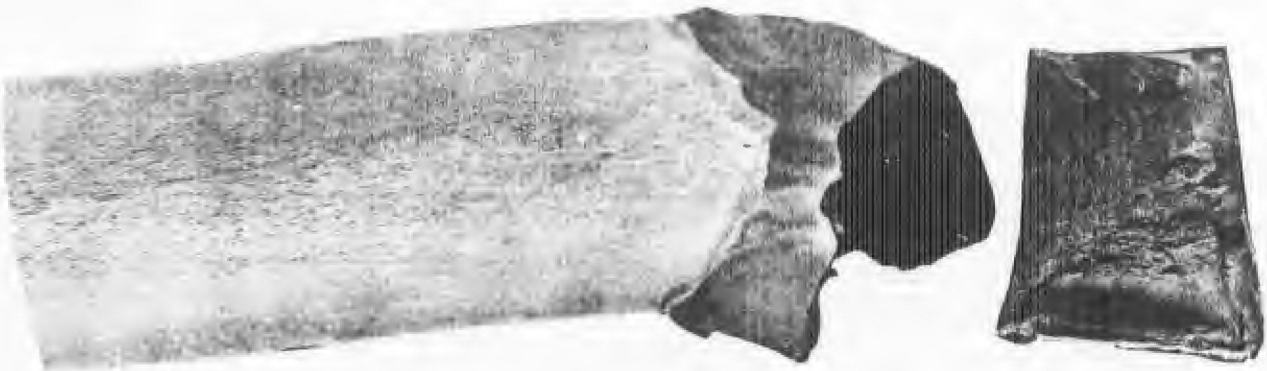


WATERTOWN ARSENAL

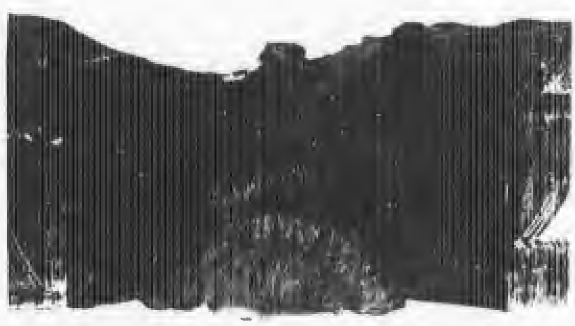
"H" PLATE 1½" 0.40% C EXPERIMENTAL ARMOR WELDED WITH HARNISCHFEGER AW-2C ELECTRODE. TESTED WITH 5 ROUNDS 75MM T-21 PROOF PROJECTILES.
1 JULY 1944 WTN.121-583

FIG. 10

Macroetched transverse section through
undamaged portion of weld joint.



Bend bar fracture.

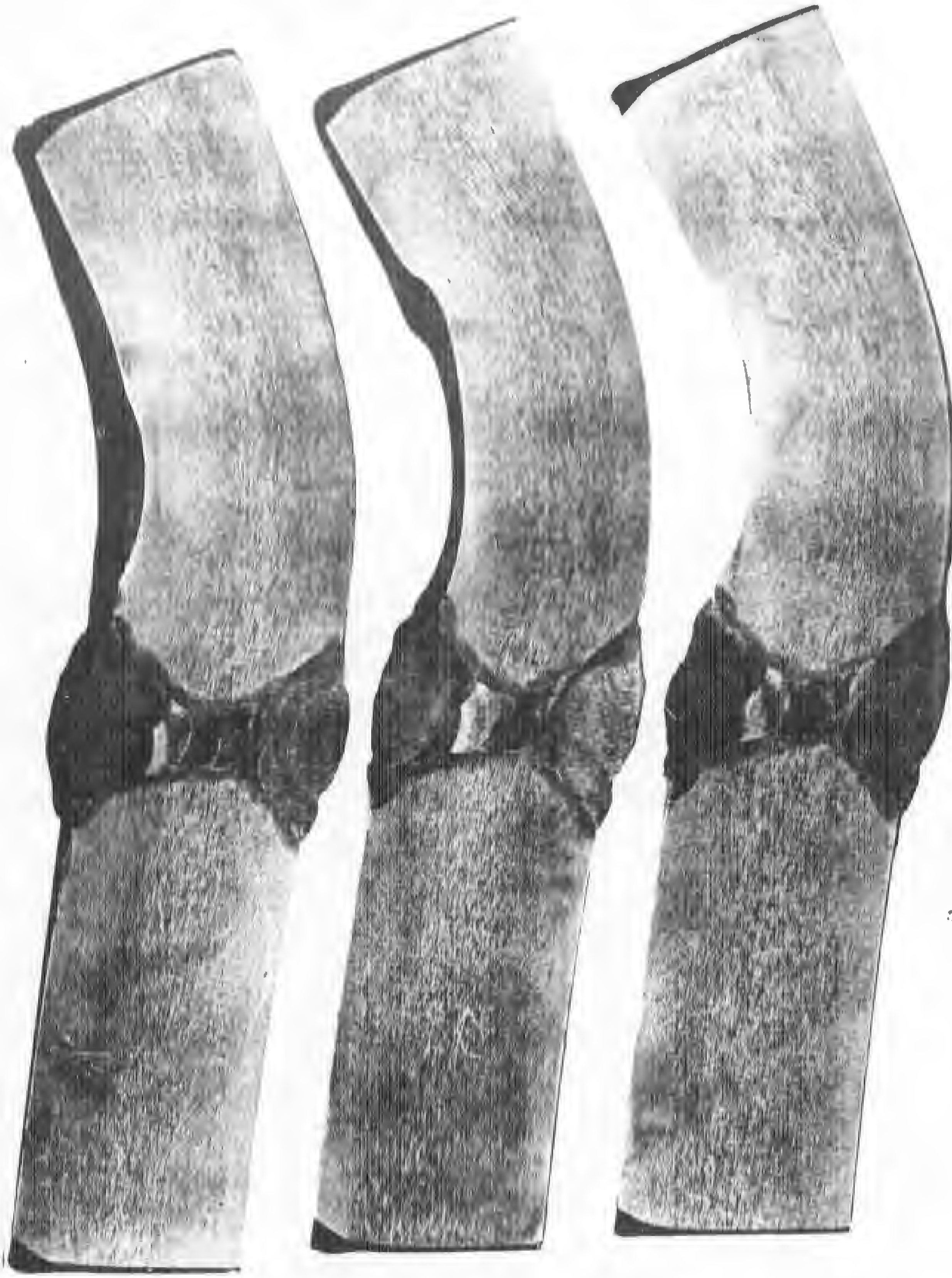


Nick-break fracture.

Macroetched Section and Fracture Specimens from 1 1/2 Inch Thick
Ferritic Hand Welded .40% C Republic Armor "H" Plate WA-7.

WTN.639-7466

Figure 11



WATERTOWN ARSENAL

SECTIONS THROUGH AREA OF INCOMPLETE PENETRATION AND ADJACENT BALLISTIC IMPACT IN $1\frac{1}{2}$ INCH THICK "H" PLATE WA-7 (.40C ARMOR AND AW-2C FERRITIC ELECTRODE; 75MM TEST PROJECTILE FIRED AT 1290 F/S.) MAG. X1. 24 AUGUST 1944 WTN.121-5E0

FIG. 12

APPENDIX A

1. Firing Record data for primary armor test plates.
   .40% C Republic
   .26% C Jones & Laughlin

2. Key to tabulation of H plate welding procedure and ballistic test data.

3. Specification requirements for H plates welded with austenitic electrodes.

4. Tabulation charts of Firing Record data for eight welded H plates.

5. Form No. WAS-2, Sheet 1 for WA2, WA8, and WA9.

Ord.Dist.Cleveland EPG

Rec'd 9/27/43

ARMOR DATA ~~RESTRICTED~~ ... A21008-145745

MFR Republic Steel Corp.

PRIMARY CONTRACTOR

DATE 9/24/43

LOC. Massillon, Ohio

AXS SPECIFICATION 488

DATE 9-16-43

SHP VIA ~~FRT EXP~~ TRK

TO ~~ARS~~ EPG

Watertown Arsenal

CONTRACT W952ord7736

TYPE HOMO ROLLED

STEEL SOURCE

Republic Steel Corp.
Canton, Ohio

SAMPLE PRIMARY

PERTAINS TO VEH OR PART

OBJ. ACCEPTANCE

	PROJECTILE	OBL	THICKNESS NOM	THICKNESS ACT	LOW C	HIGH P	B L	SPECIFIED LIMIT	SHOCK	B F	REMARKS
1	37mm M74AP	0°	1-1/2	1.52"	1414	1399	1406	1339			
	75mm T21	0°						1260	1247		Medium Bulge
	37mm M74AP	0°						2550		2518	Ex.Dia.2-5/16"x2-11/32"
	75mm T21	0°						1412	1405		L.B. 3" Horz.Crack
2											2

PROOF FACILITY SIGNATURE BY:

F. E. RUNDELL
Col.,Ord.Dept.
Commanding

C. L. Sidinger
C. L. SIDINGER
Major,Ord.Dept.
Chief Proof Officer

H. H. Abram
H. H. ABRAM
Capt.,Ord.Dept.
Proof Officer

POSITION OF PLATE | 1 TM.B 2 TM.B | 1ST INGOT 1ST INGOT | LAST INGOT LAST INGOT FOLD | WEIGHT PLATE REPRESENTS | NO1 NO2

CHEMICAL COMPOSITION

	C	MN	SI	S	P	CR	NI	MO	V	ELEC HEAT NO	(T)	PLATE NO. PATTERN OR SERIAL
1	.405	.84	.23	.018	.015	.55	.48	.28		RE 23693	P F	RH 693-9-1 Lot 1
											P F	
2											P F	2
											P F	

TEST PASSED OR FAILED

PHYSICAL PROPERTIES

	TS PSI	YP PSI	ELONG%2	R A %	CHARPY IZOD	B H N
1						269
2						2

CORE HARDNESS QUENCHED ROCKWELL "C"

COMMENTS

PLATE SIZE 1-1/2"

CARBURIZING

	TEMP	TIME	SOAK	COOLANT
A				
B				

HEAT TREATMENT PROCEDURE

Quench	A	1600	1-1/2	3	Water Spray
Draw	B	1200	1-1/2	7-1/2	Air
	A				
	B				
	C				

State of Ohio)
Stark County) ss
Sworn and subscribed to before me a Notary Public in and for Stark County this 4 day of September, 1943

SIGNATURE RESIDENT INSPECTOR James C. Evans/gw.

FILLED IN BY SUPPLIER — FILLED IN BY PROVING GROUND — FILLED IN BY SUPPLIER

ARMOR DATA ~~RESTRICTED~~ Sheet 1 of 1

TO BE FILLED IN ON TYPEWRITER (CARBON BACKED) OR BY HAND USING INDIA INK

APD 106 ICM 8-42 COPY - 11 November 1944-abk/ ~~RESTRICTED~~ / | | | | | | | | | | | |

Ord. Dist. Pittsburgh

ARMOR DATA-~~CONFIDENTIAL~~

FIRING RECORD NO. 146051

FILLED IN BY SUPPLIER		
MFR. Standard Steel Spring	PRIMARY CONTRACTORS	A 21053 DATE 9/23/43
LOC. Coraopolis, Pa.		SPECIFICATION AXS- SSS Spec. A cc. Spec.
DATE Sept. 21, 1943		OBJ. CONTRACT: Fire under AXS-488
SHP. VIA- ~~FRT. EXP.~~ TRK.		
TO ~~ARG~~ ~~RIA~~ ERIE		
TYPE ~~CAST~~ ROLLED HOMO. ~~FH~~		
SAMPLE PRIMARY ~~CHECK~~ ~~RETEST~~		OBJ. ACCEPTANCE

BALLISTIC RECORD

NO.	PERTAINS TO VEHICLE OR PART	PROJECTILE	OBL	THICKNESS NOM.	THICKNESS ACT.	LOW C.	HIGH P.	B.L.	SPECIFIED LIMIT	SHOCK	PTP	REMARKS
1	4	37 mm M74 AP	0°		1.50"	1413	1369	1391	1325			
		75 mm T21	0°						1250	1252		Medium Bulge
2		37 mm M74 AP	0°						2550		2556	Ex. dia. 2-3/32 x
		75 mm T21	0°						1400	1393		2-3/16. Large Bulge
3	5	37 mm M74 AP	0°		1.51"	1450	1412	1431	1332			
		75 mm T21	0°						1255	1248		Medium Bulge
4		37 mm M74 AP	0°						2550		2546	Ex.dia. 2-3/16 x
		75 mm T21	0°						1406	1367		2-5/32. Medium Bulge
5	6	37 mm M74 AP	0°		1.49"	1403	1380	1391	1312			
		75 mm T21	0°						1242	1255		Medium Bulge
6		37 mm M74 AP	0°						2550		2563	Ex. dia. 2-15/32 x
		75 mm T21	0°						1394	1394		2-1/2. Medium Bulge

FOLD

CHEMICAL COMPOSITION - %

NO.	C.	MN	Si	S	P	CR	Ni	Mo	V	B	HEAT NO. (O.H. ELEC. ACID BASIC)	T	PLATE NO. PATTERN & SERIAL
1	0.	.	0.	0.0	0.0	.		.	0.			P F	
2	0.	.	0.	0.0	0.0	.		.	0.			P F	
3	0.	.	0.	0.0	0.0	.		.	0.			P F	
4	0.26	1.70	0.21	0.016	0.019	.		.36	0.	Tr	J1142-1	P	SCJ 1142-1 T-1
5	0.26	1.70	0.21	0.016	0.019	.		.36	0.	Tr	J1142-1	P	SCJ 1142-1 M-1
6	0.26	1.70	0.21	0.016	0.019	.		.36	0.	Tr	J1142-1	P	SCJ 1142-1 B-1

PHYSICAL PROPERTIES

NO.	T.S. PSI	Y.P. PSI	ELON.%2"	R.A.%	IZOD	B.H.N.
1						F. B.
2						F. B.
3						F. B.
4						F. B. 277-285
5						F. B. 277-285
6						F. B. 277-285

TEST PASSED OR FAILED

PLATE SIZE- 1-1/2"

HEAT TREATMENT

		TEM.° F	HOURS RISE	HOURS SOAK	COOLANT
CARBURIZED ONE SIDE	A				
	B				
Harden	A	1650	1-3/4	1½	Water
Draw	B	1200	2	1½	Water
	C				
	D				
	E				

COMMENTS:

Signed and Notarized - 21 September 1943.

ARMOR DATA-~~CONFIDENTIAL~~

FORM NO. C.A.S. NO. 2

N.B. TO BE FILLED IN ON TYPEWRITER (CARBON BACKED) OR BY HAND USING INDIA INK.

SHEET ____ OF ____ SHEETS.

Key to Tabulation of "H" Plate Welding
Procedure and Ballistic Test Data

Armor Data

B.O.H.	-	basic open hearth.
B. Elec.	-	basic electric

Joint Design

DV	-	double vee

Deposition Types

Figure i shows how the weld is broken up into root, body, and crown types. Passes are divided into two kinds: (a) layer, if pass bridges the gap, and (b) bead, if the pass does not bridge the gap.

Ballistic Results

H	-	hit
F/S	-	feet per second
L.L.	-	left leg
R.L.	-	right leg
CB.	-	crossbar
LOC.	-	location
R	-	right of
L	-	left of
X	-	on weld
U	-	above
D	-	below
IMP	-	running from or through impact
O	-	not running from or through impact

Cracking Types

I	-	weld (includes weld, fusion zone, and heat-affected zone cracking within 1/8 inch from weld)
IV	-	star plate cracking
V	-	linear plate cracking

Cracking is measured on the back of the plate.

SPECIFICATION REQUIREMENTS FOR "H" PLATES WELDED WITH AUSTENITIC ELECTRODES

Figure ii shows the construction and intended aiming points for the ballistic shock test plate.

The requirements for the shock test at normal temperature as given by Specification AXS-497, Rev. 3, August, 1942, were as follows:

Armor	Projectile	Striking Velocity (±25 f/s)	Maximum Allowable Cracking Weld (inches)	Plate
1-1/2" rolled	75 mm. T21	1100	15	8
1-1/2" cast	"	1050	15	8
1" rolled	"	775	18	8

There were no requirements specified for 1/2 inch plate, but for these cold tests the 37 mm. M54 H.E. projectile at 2600 f/s velocity was used. A limit of 12 inches of weld cracking was used as a criterion of acceptability of the welded joint. The limit on plate cracking was 8 inches.

From 3 May 1944 to the present the following requirements have been in effect (as abstracted from Specification AXS-497, Rev. 5, 15 December 1943):

"F-3. Ballistic tests. Test plates required by paragraph F-2a(1)a shall be supported solidly on each of the two sides parallel to the longest welds and with these welds upright. The plate shall be tested for compliance with the requirements of Table II.

TABLE II

Thickness of shock test plate, inches	Type of homogeneous armor	Projectile	Striking velocity f/s, plus or minus 25 f/s	Allowable weld cracking, inches, maximum
1-1/2	rolled	75 mm. T21	1200	15
1-1/2	cast	"	1050	10
1	rolled	"	725	17
1	cast	57 mm. T1	975	6
3/4	rolled	"	800	12
1/2	rolled	37 mm. H.E. M54	2525	15

"F-3a. Cracks in the armor parallel to the weld and within 1/8 inch of the edge of the weld shall be considered in the total weld cracking.

"F-3b. All impact velocities specified for cast homogeneous armor are subject to variation depending on the actual armor thickness. This variation shall be based on the velocities specified for testing primary armor and results in velocity of 6 f/s for each increase of 0.01 inch in armor thickness.

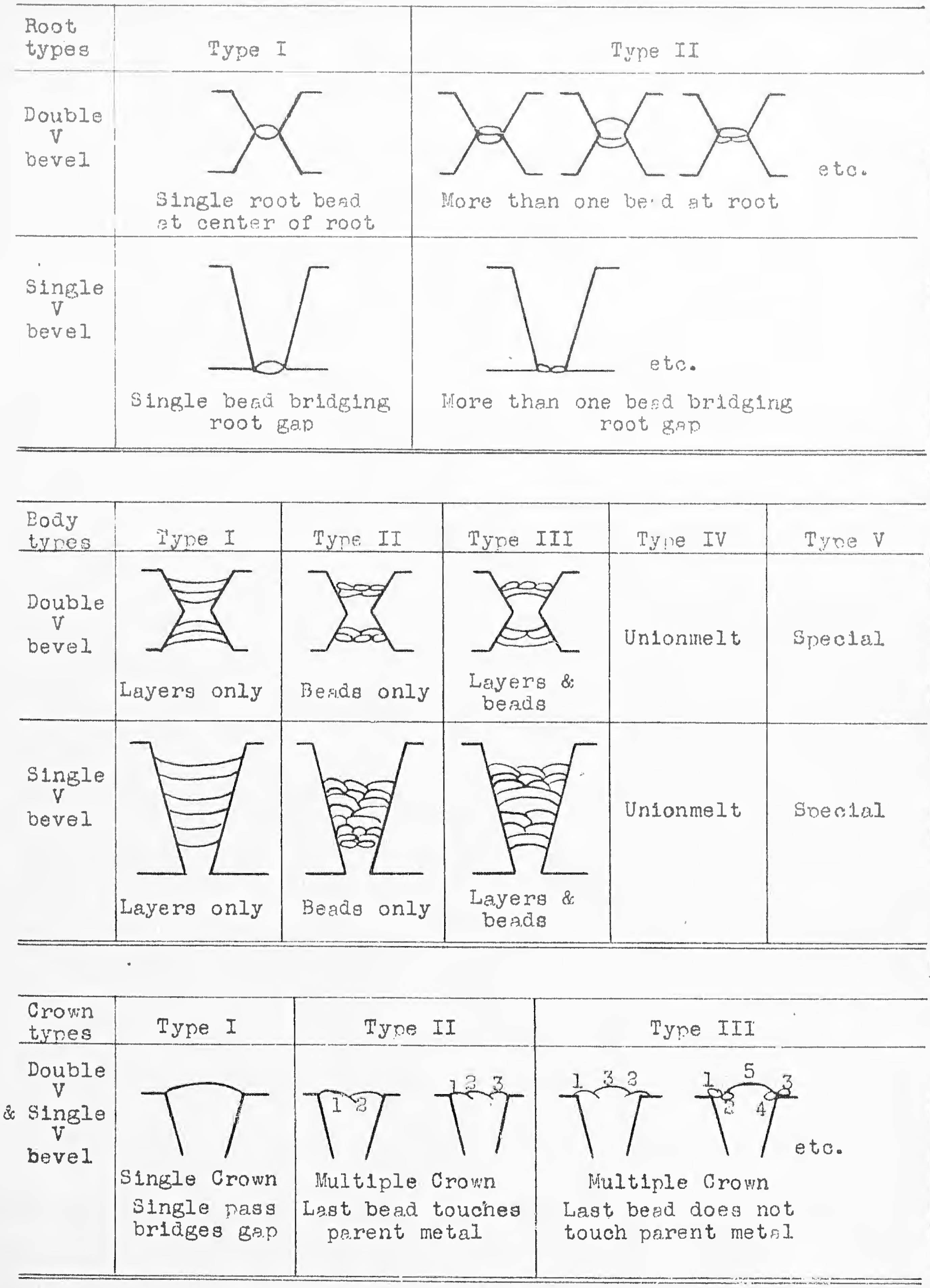
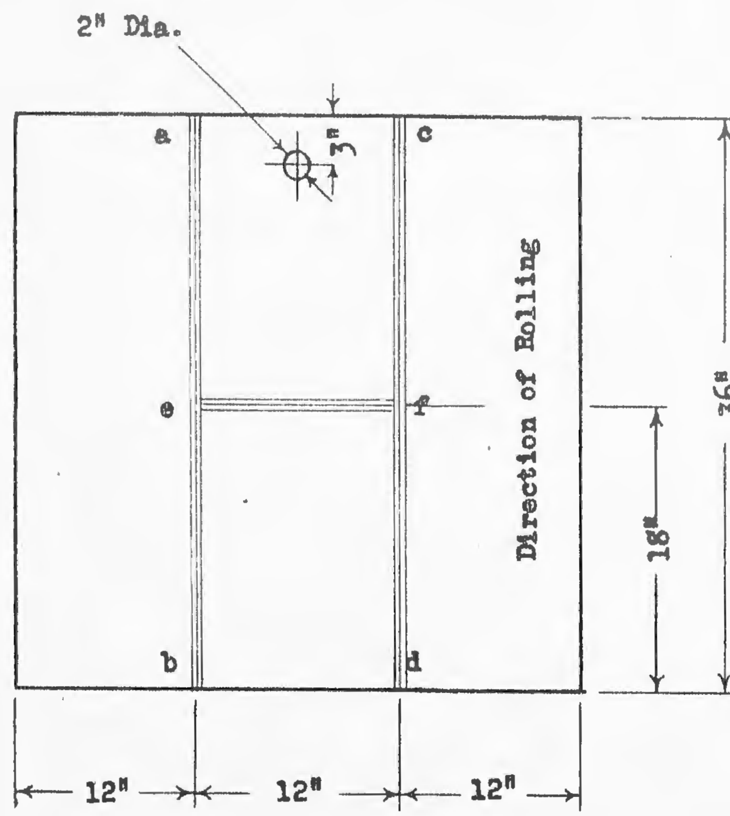
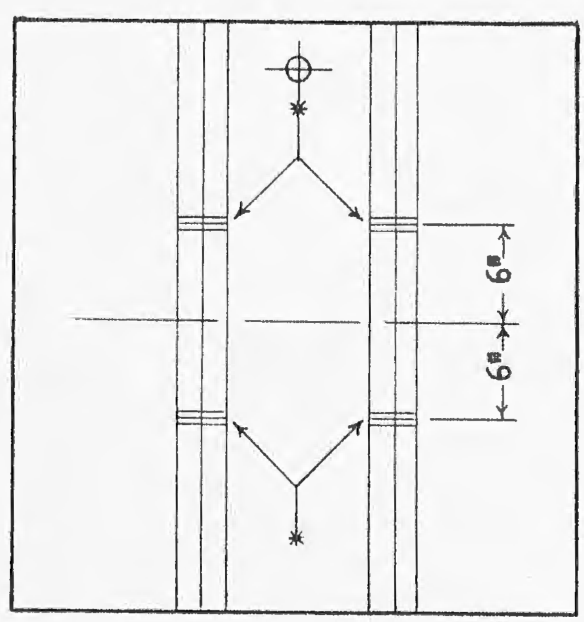


Fig. 1 Weld Metal Deposition Types

Weld Sequence:
ab, cd, fe.



QUALIFICATION SHOCK TEST PLATE



* Intended Aiming Points

FIG. 11

IDENTIFICATION A. FIRING RECORD NO. B. DATE OF TEST C. PLATE NO. D. ARMOR MANUFACTURER E. ELECTRODE MFGR. F. ARMOR FABRICATOR	ARMOR DATA A. PLATE THICKNESS B. TYPE C. CARBON CONTENT D. BHN E. PROCESS F. HEAT TREATMENT TEMP. TIME QUENCH HR.	ELECTRODE DATA A. TYPE B. TRADE NAME C. COATING D. CURRENT & POLARITY	JOINT DESIGN A. GROOVE. INCLUDED ANGLE. ROOT FACE B. ROOT GAP C. PLATE PREPARATION	WELDING PROCEDURE A. BACKING B. DEPOSITION SIZE EL. NO. TYPE AMP. V. (PASSES) 1. ROOT TYPE 2. BODY TYPE 3. CROWN TYPE C. TOTAL WELDING TIME & INTER PASS TEMPERATURE D. REMARKS	HEAT A. PRE B. POST	N	BALLISTIC RESULTS VEL. F/S	LOCATION OF N L.L.	R.L.	C B.	CRACKING LOC.	TYPE	AMT	REMARKS ON CRACKING RADIOGRAPHIC RESULTS, ETC.
A. A11310 B. 12/16/43 C. WA-2 D. Republic E. McKay F. Baldwin Locomotive	A. 1½" B. Rolled (Special) (.84Mn, .23Si, .018S, .015P, .55Cr, .48Ni, .22Mo) C. 0.40% D. 269 E. B.Elect. F. 1600^0 F. 3 H_2O 1200^0 F. 3½ Air	A. Austenitic B. Armorloy A5 (5/32" dia) (.14C 4.58Mn, .45Si, .013S, .025P 18.87Cr, 8.88Ni, .05Mo, .014V, .14Cu) Armorloy A6 (1/4" diam.) (.10C, 1.63Mn, .28Si, .010S, .034P, 16.43Cr, 9.6Ni, 1.86Mo, .32Cu) C. A-5 Lime, A 6 Ti D. DC Rev.	A. 45^0 DV B. ¼" C. Flame cutting, grinding; nose bead on one side	A. None B. Nose bead 5/32" 1b 125 26 1. II 5/32" 1a 125 26 1/4" 1a 280 28 2. III 1/4" 6a 280 28 4b 280 28 3. III 1/4" 2a 280 28 5/32" 4b 125 26 C. 14 hrs., 70^0 - 125^0F. D. 1-2" cracking in nose bead; back chipped out.	A. None B. None	1	1262		X	10" U	IMP	I	20½"	Failed
						2	1231	1½" R		7½" D	IMP	I	18" 38½"	Incomplete penetration and slag; 2¼" cracking in crossbar.
							75mm T21 Projectile							
A. A11310 B. 12/16/43 C. WA-3 D. Republic E. McKay F. Baldwin Locomotive	A. 1½" B. Rolled (Special) (.84Mn, .23Si, .018S, .015P, .55Cr, .48Ni, .22Mo) C. 0.40% D. 269 E. B. Elec. F. 1600^0F. 3 H_2O 1200^0F. 3½ Air	A. Austenitic B. Armorloy A5 (5/32" dia.) (.14C, 4.58Mn, .45Si, .013S .025P, 18.87Cr, 8.88Ni, .05Mo, .014V, .14Cu) Armorloy A6 (¼" dia.) (.10C, 1.63 Mn, .28Si, .010S, .034P, 16.43Cr, 9.6Ni, 1.86Mo, ..32 Cu) C. A-5 Lime, A 6 Ti D. DC Rev.	A. 45^0 DV B. ¼" C. Flame cutting, grinding; nose bead on one side	A. None B. Nose bead 5/32" 1b 125 26 1. II 5/32" 1a 125 26 1/4" 1a 280 28 2. III 1/4" 6a 280 28 4b 280 28 3. III 1/4" 2a 280 28 5/32" 4b 125 26 C. 14 hr; 70^0-175^0F. D. 1-2" cracking in nose bead; back chipped.	A. None B. None	1	1175		X	9½" U	IMP	I	18½"	Failed ½" crack in crossbar
						2	1190	½" R		8-3/8" D	IMP	I	14½" 3⅞ 36⅞"	
							75mm T21 Projectile							

1.

IDENTIFICATION	ARMOR DATA	ELECTRODE DATA	JOINT DESIGN	WELDING PROCEDURE	HEAT	BALLISTIC RESULTS								REMARKS ON CRACKING
A. FIRING RECORD NO. B. DATE OF TEST C. PLATE NO. D. ARMOR MANUFACTURER E. ELECTRODE MFGR. F. ARMOR FABRICATOR	A. PLATE THICKNESS B. TYPE C. CARBON CONTENT D. BHN E. PROCESS F. HEAT TREATMENT TEMP. TIME QUENCH	A. TYPE B. TRADE NAME C. COATING D. CURRENT & POLARITY	A. GROOVE. INCLUDED ANGLE. ROOT FACE B. ROOT GAP C. PLATE PREPARATION	A. BACKING B. DEPOSITION SIZE EL. PASSES NO. TYPE AMP. V. 1. ROOT TYPE 2. BODY TYPE 3. CROWN TYPE C. TOTAL WELDING TIME & INTER PASS TEMPERATURE D. REMARKS	A. PRE B. POST	H	VEL. F/S	LOCATION OF H L.L.	R.L.	C B.	CRACKING LOC.	TYPE	AMT	RADIOGRAPHIC RESULTS, ETC.
A. Ar-14427 B. 8/4/44 C. WA-10 D. Jones & Laughlin E. McKay F. Watertown Arsenal Laboratory	A. 1½" B. Rolled (1.70Mn,.21Si, .016S,.019P, .36Mo) C. 0.26% D. 269-285 E. B.O.P. F. 1650^{0}F ½ hr. H_2O 1150^{0}F1½ hr. Air	A. Austenitic (.14C, 4.58Mn, .45Si,.013S .025P, 18.87Cr, 8.88Ni,.05 Mo,.014V, .14Cu) B. A5 C. Lime D. DC Rev.	A. 45^0 DV B. 3/8" C. Flame cutting & grinding	A. Copper B. 1. II 3/16" 2a 160 24 2. I 1/4" 6a 240 24 3. III 5/32" 4b 110 22 1/4" 2a 240 24 C. —— ; 70^0 - 150^{0}F. D. Grinding on back of pass No. 3.	A. None B. None	1	1202	X		8¾" U	IMP	I	18½"	
												I	1½"	secondary crack
						2	1200		¾" L	9" D	IMP	I	3¼"	
						3	1206		¾" L	8⅜" U	IMP	I	3½"	
													28"	Failed Considerable Incomplete fusion; 1-1/8" cracking in crossbar.
							75mm T21 Projectile							
A. Ar-14427 B. 8/4/44 C. WA-12 D. Jones & Laughlin E. McKay F. Watertown Arsenal Laboratory	A. 1½" B. Rolled (1.70Mn,.21Si, .016S,.019P, .36Mo) C. 0.26% D. 269 - 285 E. B.O.P. F. 1650^{0}F. ½ hr. H_2O 1150^0 F. 1½ hr. Air	A. Austenitic ~~II~~ (.14C,4.58 Mn,.45Si, .013S, .025P, 18.87Cr, 8.88Ni, .05Mo,.014V, .14Cu) B. A5 C. Lime D. DC Rev.	A. 45^0 DV for body 67½^0 angle at crown B. 3/8" C. Flame cutting grinding	A. Copper B. 1. II 3/16" 2a 160/165 24/23 2. II 1/4" 3a 240/250 26/24 4b 240 24 3. III 3/16" 4b 155/160 22/24 1/4" 2a 240/245 24/23 C. —— ; 70^0 - 150^{0}F. D. Grinding on back of pass No. 3	A. None B. None	1	1195		X	9½" U			0	Failed
						2	1203	⅝" L		9⅜" D			0	Incomplete fusion and slag
						3	1204		⅝" R	8" D	IMP	I	3"	
						4	1210	¼" R		9½" U	IMP	I	2½"	
													5½"	
							75 mm T21 Projectile							

3.

4.

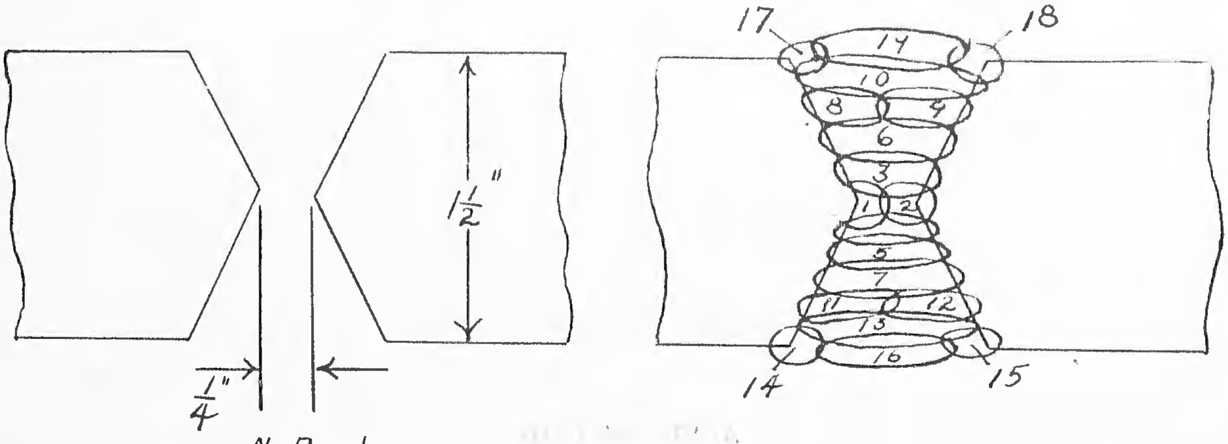
FIRING RECORD

DATE 10-22-43
PLATE NO. WA-2
TYPE Rolled Homogeneous
THICKNESS 1-1/2"
SPECIFICATION AXS-497-3
ORDNANCE
WELDED BY Carl Leimbach
OBJECT

Watertown Arsenal
Watertown 72, Massachusetts

The Baldwin Locomotive Works

ON A DIMENSIONAL ... (I) INDICATE THE DEPOSIT ... SPACER STRIP OR BACK-UP



No Back-up

PLATE PREPARATION FLAME XXXXXXXXXXXXXXXXXXX GRINDING
POSITION OF PLATE DURING WELDING Flat
XXXXXXXXXXXXXXX HAND WELDING XXXXXXX XXXXXXX DC
TOTAL WELDING TIME 14 hours GRINDING TIME 3-1/2 hrs.
PREHEAT None None
PEENING None Nose Bead (#1) on one side
TEMP. OF PLATE 70° F.

	PASS	ELEC. SIZE		AMP				PASS TEMP
	1	5/32"	B	125	26	1-2	Back-Chipped	70
	2	5/32	W	125	26	None	None	70
	3	1/4	W	280	28	"	"	125
	4	1/4	W	280	28	"	"	70
	5	1/4	W	280	28	"	"	125
	6	1/4	W	280	28	"	"	150
	7	1/4	W	280	28	"	"	175
	8	1/4	B	280	28	"	"	175
	9	1/4	W	280	28	"	"	175
	10	1/4	FW	280	28	"	"	175
	11	1/4	B	280	28	"	"	175
	12	1/4	W	280	28	"	"	175
	13	1/4	FW	280	28	"	"	175
17 & 18	14	5/32	S	125	26	"	"	175
	15	5/32	S	125	26	"	"	175
19	16	1/4	FW	280	28	"	"	175

* S- STRINGER, B- BEAD, W- WEAVE, FW- FULL WEAVE

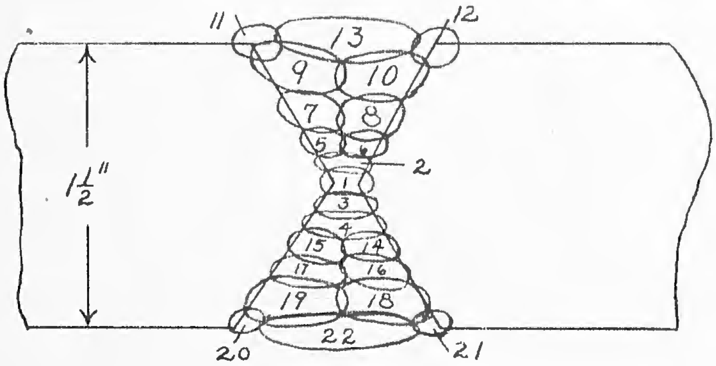
FORM NO. WAS-2 SHEET 42-4450

DATE: 30 June 1944
PLATE NO: WA-8
TYPE, Rolled Armor
THICKNESS: 1-1/2"
SPECIFICATION: AXS-488

SUBMITTED BY: Baldwin Locomotive Works
ADDRESS: Eddystone, Pennsylvania
CONTRACT NO.: W9520RD7736

ORDNANCE MATERIEL CONCERNED: AXS-488
WELDED BY: Robert Andrews OF Baldwin Locomotive
OBJECT: Development

ON A DIMENSIONED SKETCH OF THE [illegible]
DEPOSIT SEQUENCE (2) ADDITI[illegible]



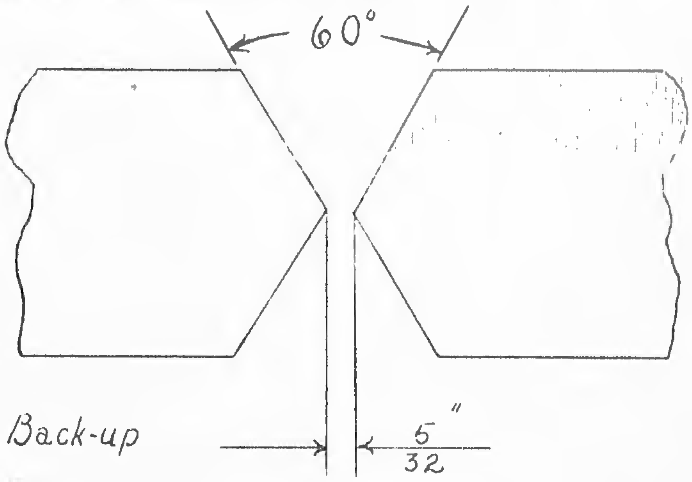


PLATE PREPARATION: FLAME [illegible]
POSITION OF PLATE DURING WELDING: Horizontal
AUTOMATIC OR HAND WELDING
TOTAL WELDING TIME 12 hrs. 8 hrs. 30 min.
PREHEAT: 300 degrees F. None
PEENING None None
TEMP OF PLATE AT TIME OF WELDING 300 degrees F.

	PASS	ELEC. SIZE	TYPE*	AMP	VOLT			
	1.	3/16"	W	210	28	None	Craters	400° F.
	2.	3/16"		"	"	"	"	"
	3.	3/16		"	"	"	"	"
	4.	3/16		"	"	"	"	"
	5.	1/4"		290	"	"	"	"
	6.	1/4"		"	"	"	"	"
	7.	1/4"		"	"	"	"	"
	8.	1/4"		"	"	"	"	"
	9.	1/4"		"	"	"	"	"
	10.	1/4"		"	"	"	"	"
	11.	3/16"		210	"	"	"	"
20 & 21	12.	3/16"		"	"	"	"	"
17 & 18	13.	1/4"		290	"	"	"	"
19 & 22	14.	1/4"		"	"	"	"	"
	15.	1/4"		"	"	"	"	"
	16.	1/4"		"	"	"	"	"

*S- STRINGER, B- BEAD, W- WEAVE, FW- FULL WEAVE

FORM NO. WAS-2 SHEET I

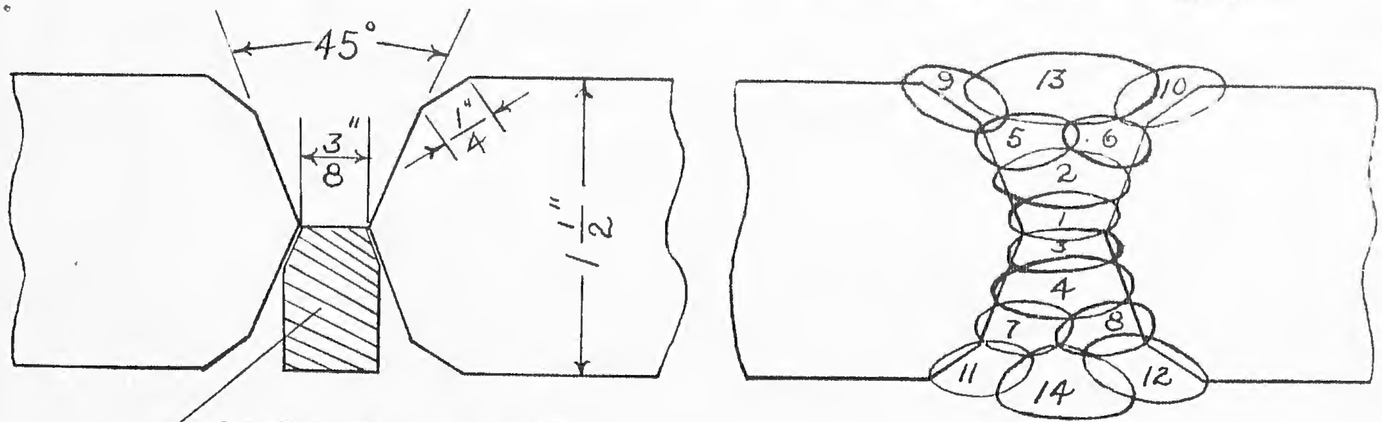
DATE 22 June 1944
PLATE NO. WA-9
TYPE Rolled Homogeneous
THICKNESS 1-1/2"
SPECIFICATION AXS-497-5
ORDNANCE MATERIEL

Watertown Arsenal Lab.
Watertown 72, Massachusetts

WELDED BY H.H. Strid
OBJECT Development

Watertown Arsenal

ON A DIMENSIONED ... WELDMENT INDICATE THE
DEPOSIT ... STRIP OR BACK UP



WELDING DATA

PLATE PREPARATION: FLAME CUTTING XXXXXXXXXXXXXXXXXX GRINDING
POSITION OF PLATE DURING WELDING Flat
XXXXXXXXXXXXXXX HAND WELDING POLARITY: XXXXXXX REV XXXXXXX DC
TOTAL WELDING TIME TOTAL CHIPPING OR GRINDING TIME:
PREHEAT None POSTHEAT None
PEENING None BUTTERING None
TEMP. OF PLATE AT TIME OF WELDING 70° F.

PASS	ELEC. SIZE	TYPE*	AMP	VOLTS	CRACKING	XXXXXXX GRIND	INTERPASS TEMP.
1.	3/16"	W	160	24	None	on back for No. 3	70° F.
2.	1/4"	W	240	24	"	None	100° F.
3.	1/4"	W	240	24	"	"	125° F.
4.	1/4"	W	240	24	"	"	150° F.
5.	1/4"	W	240	24	"	"	150° F.
6.	3/16"	W	160	24	"	"	150° F.
7.	1/4"	W	240	24	"	"	125° F.
8.	3/16"	W	160	24	"	"	125° F.
9.	3/16"	S	160	24	"	"	125° F.
10.	3/16"	S	160	24	"	"	150° F.
11.	3/16"	S	160	24	"	"	125° F.
12.	3/16"	S	160	24	"	"	150° F.
13.	1/4"	W	240	24	"	"	100° F.
14.	1/4"	W	240	24	"	"	125° F.
15.							
16.							

*S- STRINGER, B- BEAD, W- WEAVE, FW- FULL WEAVE

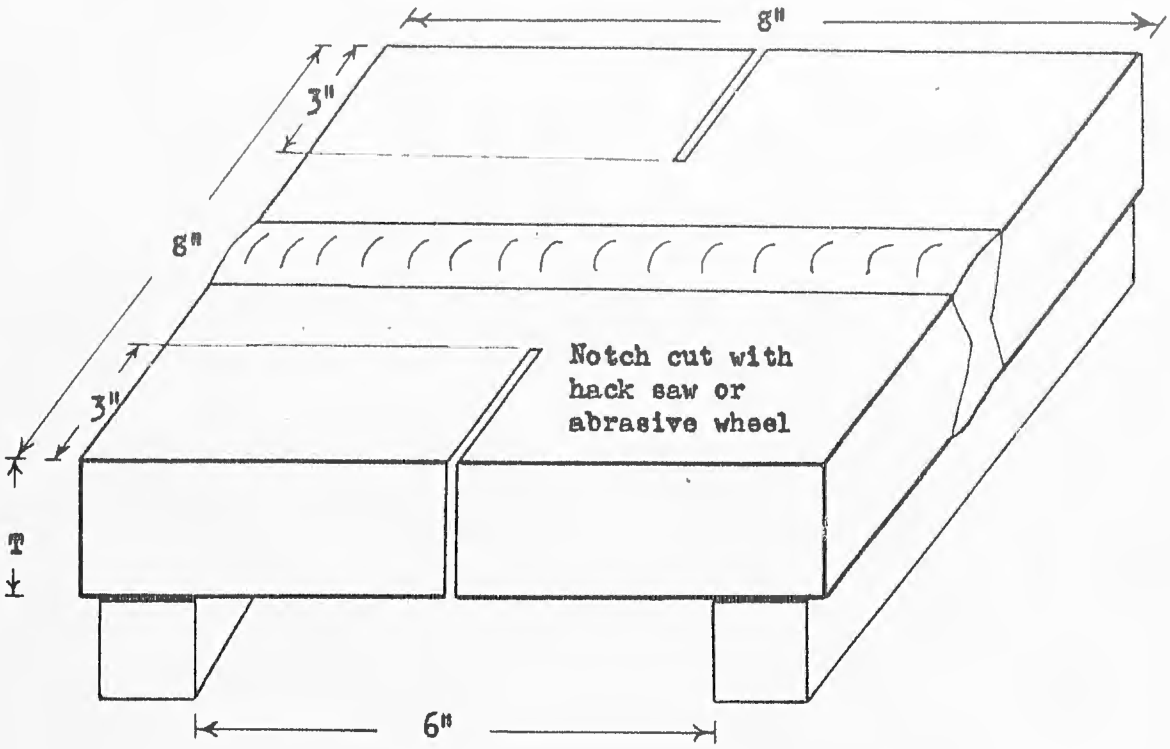
FORM NO. WAS-2 SHEET 1

42-4450

APPENDIX B

Description of Nick-Break and
Bend Fracture Tests

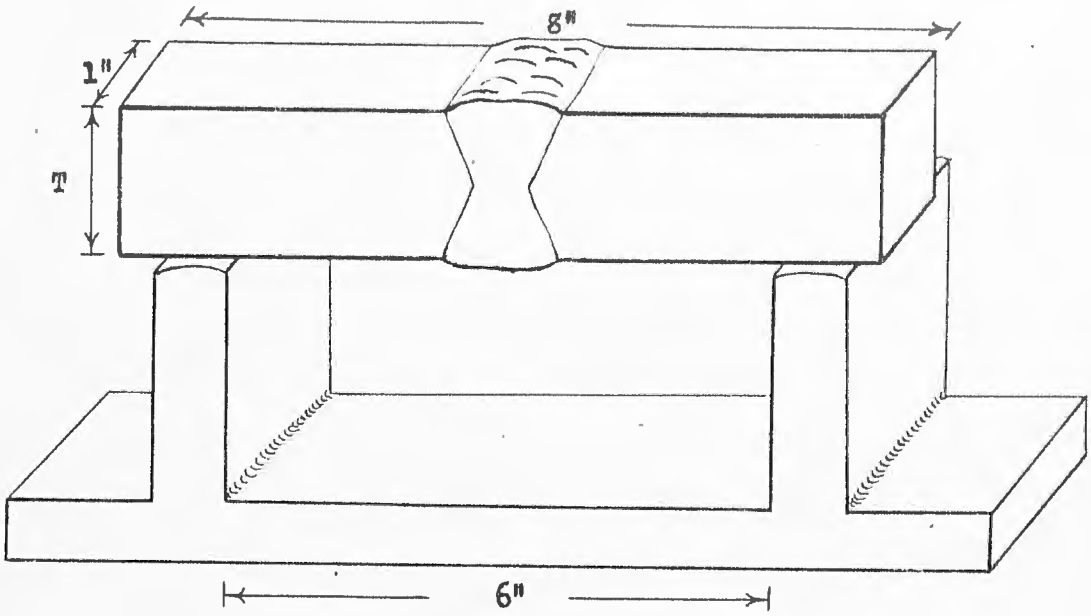
1/2 x 1/2 x 4 inch bar used as striking block. 1 x 6 x 6 inch plate placed on top of bar to prevent damage to steam hammer or drop weight.



Supported on six-inch span; broken with one blow of drop weight or steam hammer

Figure 1. Nick-Break Fracture Test of Weld Joint

Load applied to center of weld



Supported on six-inch span; bars of 1 inch and 1 1/2 inch thickness broken in a steam press; bars of lesser thickness broken with one blow of drop weight

Figure 2. Bend Fracture Test of Weld Joint