

WELDING LABORATORY
WATERTOWN ARSENAL

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W.A.A. 642/22



REPORT NO. 642/22

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ARC WELDERS OF ANODE

EUTECTIC IN 1-1/2" ROLLED HOMOGENEOUS ARMOR PLATE

WELDING LABORATORY
WATERTOWN ARSENAL

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James A. Macdonald, Jr.
Jr. Phys. Science Aide

W. L. Warner
Welding Engineer

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1. The tensile strength of a straight gap butt joint welded with a modified 18/8 stainless electrode, the plate edges having an applied root of weld metal on unsoftened flame cut scarf faces, is at least 102600 lbs./sq.in. (Two test specimens gave 102600 lbs./sq.in. and 104700 lbs./sq.in.)
2. The tensile strength of a straight gap butt joint welded with a modified 18/8 stainless electrode, the plate edges having an applied root of weld metal on flame softened flame cut scarf faces is at least 83400 lbs./sq.in. (Two test specimens gave 83400 lbs./sq.in. and 96700 lbs./sq.in.)
3. With a straight gap butt joint having flame softened edges and an applied root of weld metal the yield strength (divider) of the weld with 25/20 electrode is greater than that of the weld with modified 18/8 electrode.
4. With a straight gap butt joint having an applied root of weld metal the yield strength of the weld with 25/20 electrode on flame softened edges is approximately the same as the modified 18/8 electrode on unsoftened edges.
5. The ductility of the modified 18/8 weld metal is less than that of the 25/20 weld metal.
6. The plates with flame softened edges had a lower hardness value in the heat-affected zone than the plates with the unsoftened edges.
7. Macroexamination of the cross section showed that the heat-affected zone caused by welding on the unsoftened edges did

not dissipate the heat-affected zone set up by flame cutting.

8. Microexamination revealed a dendritic structure throughout the weld metal of both modified 18/8 and 25/20.

9. A narrow martensitic band in the plate metal at the fusion line was observed. This band was slightly narrower in the specimens with unsoftened plate edges.

10. The grains of the 25/20 stainless weld metal and the modified 18/8 are of an average size of .023 sq. mm.

James A. MacDonald, Jr.
Jr. Phys. Science Aide

APPROVED:

W. L. Warner
Welding Engineer

G. L. Cox
Major, Ordnance Dept.
Acting Director of Laboratory



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INTRODUCTION

In the three Y-type shock test plates of 1-1/2" thick rolled homogeneous armor examined, the study of which is covered by this report, the plate edges at the joints were gas cut and not bevelled. In two cases the plate edges were flame softened after gas cutting. The welded plates received were as shown below:

<u>Plate</u>	<u>Electrode</u>	<u>Scarfig</u>	<u>Plate Edge Flame Softened</u>
A	Armorweld	No	Yes
B	25/20	No	Yes
C	Armorweld	No	No

The welded plates submitted for tests were 36" x 36" x 1-1/2". Various tests were prescribed for the plates and specimens cut out as shown in illustrations of ballistic tests. (Figs. 31a, 32a, and 33a.)

The various tests to which the welded joints were subjected are as follows:

1. Radiographic examination.
2. Physical tests.
 - a. Weld metal tensile*
 - b. Cross weld tensile+
3. Hardness surveys of weld cross sections.
4. Macroexamination of weld cross sections.
5. Microexamination of weld metal and heat-affected zone.

* .505 Specimen as shown in Spec. QOM-151A Type I

+ Sketch of specimen shown in Plate 1.

Radiographic examination was made of the welded joints to determine the extent of weld defects and any indication of the effect of the shock test on such defects. After radiographic examination, the sections from which the test specimens were to be taken were laid out as shown in Figs. 31a, 32a and 33a.

An index to the marking of the specimens is given in the following table.

<u>Plate</u>	<u>Hardness*</u>	<u>Cross Weld Tensile</u>	<u>Weld Metal Tensile</u>	<u>Analysis</u>
A	AH1	ACT2-1	AT1	ASC2
	AH3	ACT2-2	AT4	
	AH5			
B	BH1	BCT1-1	BT5	BCS1
	BH3	BCT1-2	BT3	
	BH5			
C	CH1	CCT3-1	CT1	CC52
	CH4	CCT3-2	CT6	
	CH5			

Cross sections of the joints were polished and lightly etched in 1% nital for hardness surveys. These hardness surveys were made on a Vickers Brinell hardness machine using a special jig designed for making such surveys. After hardness surveys were completed, the specimens were given a light FeCl_3 etch for macroexamination and microexamination.

* Hardness specimen used for macro and micro examination.

RESULTS OF TESTS

It was noted on radiographic examination that many defects were present in the welds. The most prevalent defect was lack of fusion between the nose beads and the joining weld metal. Crater cracks and lack of penetration were the next most common defects.

The tensile specimens taken transverse to the joint gave the results shown in Table I.

Table I

CROSS WELD TENSILE TESTS

<u>Specimen</u>	<u>Weld Metal</u>	<u>Edge</u>	<u>Yield* Strength</u>	<u>Tensile Strength</u>	<u>% Elonga- tion 1"</u>	<u>% Elonga- tion 2"</u>	<u>Remarks</u>
		Flame					
ACT2-1	18/8	Softened	93,500	96,700	15.0	7.5	Break in weld. Lack of fusion. Coarse dendritic structure.
ACT2-2	18/8	"	81,500	83,400	15.0	7.0	
		Flame					
BCT1-1	25/20	Softened	86,400	111,400	26.0	13.0	Break in weld.
BCT1-2	25/20	"	80,700	105,400	24.0	12.0	Crater cracks.
CCT3-1	18/8	Unsoftened	86,200	104,700	22.0	11.5	Break in weld. Slag inclu- sions. Crack.
CCT3-2	18/8	"	90,000	102,600	16.0	9.0	

* Yield Strength by divider method.

The results of the all weld metal tension tests are given in Table II. The results shown in the table indicate certain inconsistencies in the tests that, on examination of the specimen fractures, appear to be due to defects occurring in the weld metal.

TABLE II

ALL WELD METAL TENSILE TESTS

<u>Specimen</u>	<u>Weld Metal</u>	<u>Sectional Edge Area sq. in.</u>	<u>Yield* Strength</u>	<u>Tensile Strength</u>	<u>% Elongation</u>	<u>% Reduction</u>	<u>Remarks</u>
AT1	18/8 Flame Softened	.2	82,500	98,000	9.5	32.7	Regular break. Fine Grains. Weld cracks.
AT4	18/8 " "	.2	78,500	105,500	22.0	37.2	
BT3	25/20 Flame Softened	.2	77,500	98,500	14.0	34.6	Regular break. Fine Grains. Fusion in weld metal.
BT5	25/20 " "	.2	70,000	93,500	27.0	40.3	
CT1	18/8 Unsoftened	.2	76,500	99,000	27.0	26.0	Regular break. Fine grains. Cracks in weld.
CT3	18/8 " "	.2	87,500	111,500	11.0	27.4	

* Yield Strength by divider method.

It was noted that, regardless of the variations in size of the heat-affected zones in the joints, the joint with unsoftened plate edges exhibited more ductility. It was also noted in the specimen with flame softened edges that some of the breaks started in the fusion zone approximately in the narrow martensitic band in the plate and extended into the weld metal. Table I, ACT2-1 and 2, COT3-1 and 2.

On inspection of the fractures of the tensile specimens, it was observed that the all weld metal specimens had fewer defects than the cross weld specimens.

It was observed in the hardness surveys of the weld cross sections that the hardness of the heat-affected zone of the joint with flame cut unsoftened edges was slightly greater than the hardnesses of the heat-affected zone of the joint with flame cut, flame softened edges. However, the general hardness survey of the weld cross

section revealed no excessive hardness; that is, the hardness of the heat-affected zone was not much higher than that of the plate except in the narrow martensitic zone that showed a maximum hardness of 425 to 475 Vickers Brinell.

In the macroexaminations of the weld cross sections, it was observed that there were no cracks or defects in the heat-affected zones of any of the specimens. However, crater cracks, lack of fusion, and lack of penetration were observed as indicated in photomicrographs. (See Figs. 1 to 16, Photographs and Charts.)

The FeCl_3 etch showed a needle-like grain structure in the weld metal and a fine grain structure in the heat-affected zones. The size of the heat-affected zone of the joint with flame cut unsoftened edges is approximately the same as that of the joint with flame cut, flame softened edges.

Microexamination revealed a dendritic structure throughout the weld metal. Transgranular cracks throughout the weld metal occurred parallel to the dendrites and it is quite probable that the occurrence and arrangement of these dendrites would cause such cracks. It was also observed that the grain size around the lack of fusion defects decreased considerably in size. (Note Fig. 24B.) Also, the modified 18/8 weld metal contained some slag inclusions, while the 25/20 weld metal did not. The narrow martensitic zone in the plate metal at the fusion line gave way to a tough troostite structure in the heat-affected zone farther away from the fusion line. This was apparently due to the buttering technique used in applying the root

of the double V as each succeeding weld bead changed the heat-affected zone of the previous bead. Multiple beads made it possible to keep the brittle martensitic structure in the plate to a minimum.

DISCUSSION

The purpose of this report is to investigate the quality of the weld used in the straight gap butt joint for welding armor. The buttering technique referred to means that the straight gas cut edges of the plate are built up with weld metal to form the root or "nose" of the double V for the butt joint.

The two types of electrodes used are a modified 18/8 stainless electrode, and a 25/20 stainless electrode. The compositions of the weld metal deposits are as follows:

	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Mo</u>	<u>V</u>
Mod. 18/8 -	.39	4.30	.50	8.80	18.19	--	.60
25/20 -	.15	1.50	.72	20.52	25.42	.60	.42

The weld defects of lack of fusion and slag or porosity did not apparently seriously affect the performance of the welded joints in the ballistic shock test as judged from the ballistic test report.

The plates were flame cut to form a "Y" joint. The edges of two of the plates were flame softened before the "nose" of weld metal was put on. The "nose" was put on in such a manner as to form a double V joint when the plate edges were put together.

Physical tests showed the modified 18/8 electrode to be as

good for fabrication with this joint as the 25/20 electrode due to its similar properties. Hardness values, being lower when the flame softened edges are used, decrease the tendencies of the plates to form welding cracks. This is shown by the fact that the plates were welded without a preheat and no cracks were found in the heat-affected zones.

Comparing these data with data obtained on other joints welded with a modified 15/8 electrode, the straight gap butt joint using a root built up by the buttering technique exhibits properties as satisfactory as the double V and single V butt joints.

In view of the properties observed in the tests, it would seem advisable to say that for production the straight gap butt joint would be satisfactory providing adequate fusion of weld metal to plate metal is obtained.

APPENDICES

WAR DEPARTMENT

OFFICE OF THE CHIEF OF ORDNANCE

WASHINGTON

O.O. 470.5/4861

August 11, 1941

Ind. Serv - Tank Div.

Subject: Qualification Weld Tests of "Armorweld" Electrode for
Armor Plate

To: Commanding General
Watertown Arsenal
Watertown, Mass.

Attn: Lt. Colonel S. B. Ritchie
Director of Laboratory

1. In the month of July, Mr. B. J. Brugge of the Lincoln Electric Company prepared five welded test plates at Aberdeen as follows:

- a. Y joint in 1-1/2" Disston armor plate, flame softened edges, no angular scarfing.
(1) Welded to get ballistic resistance of Lincoln "Armorweld" to 37 mm. and 75 mm. shock.
- b. Y joint in 1-1/2" Disston armor plate with unsoftened flame cut edges, no angular scarfing.
(1) Welded to get ballistic resistance of Lincoln "Armorweld" to 37 mm. and 75 mm. shock.
- c. Y joint in 1-1/2" Disston armor plate with Lincoln 25-20; flame softened groove, no angular scarfing.
(1) Welded to get ballistic resistance of plate to 37 mm. and 75 mm. shock on Lincoln 25-20.
- d. Y joint with Lincoln "Electweld" (mild steel) electrode in 1-1/2" Disston armor plate.
(1) Welded to get ballistic resistance of mild steel with square joint procedure.
- e. So called torture test consisting of slot in 1-1/2" Disston armor plate, welded with Lincoln "Armorweld"; flame softened single Vee groove.
(1) Welded to get physical properties of weld metal and to note behavior of joint in 1-1/2" of armor welding from one side only.

Aberdeen has been requested to send the four joints, a, b, c and e made with the Cr-Ni electrodes to Watertown for sectioning, mechanical

Subject: Qualification Weld Tests of "Armorweld" Electrode for Armor Plate

tests and metallurgical examination of those parts which were not destroyed or severely deformed by ballistic firings. Joint d failed in ballistic test and is not being sent you. A detailed report on the manner of welding will be forwarded by Aberdeen.

2. After the construction of the first welded M3 Medium Tank at Rock Island Arsenal, Mr. B. J. Brugge proposed that preparation of the groove for welding be performed without flame scarfing but with a buttering operation, a description of which is inclosed, (A). It is believed that this procedure reduces cracking of welds made with "Armorweld" electrode. It will be noted that the three Y joints, a, b, c, welded with "Armorweld" were all made without scarfing the welding groove. These tests at Aberdeen were performed to qualify the Lincoln "Armorweld" electrode for welding tanks and consequently should have been prepared with grooves similar to those used on the first M3 medium welded tank. Nevertheless, successful ballistic tests of this tank at Aberdeen Proving Ground qualify the electrode. This office is now taking steps to place orders for welded tanks and a decision must be made regarding the desirability of using edge preparation described in the inclosure as compared to double Vee, single Vee, U or other conventionally scarfed grooves.

3. The chief argument for "no edge preparation" is an increased amount of weld metal at the neutral axis of weld, hence, less dilution by the plate metal and greater ductility at this point. On the contrary, as is obvious, the buttering technique requires more weld metal than is necessary with single Vee grooves. Comparative data on this are given in inclosure (B).

a. The object of examining the Lincoln welded Y joints is to obtain data on the strength and other characteristics of welds produced by the buttering technique. It is believed that the Arsenal has data on scarfed joints prepared with an electrode similar to the "Armorweld" type for comparison. The torture test weld joint prepared with "Armorweld" will provide data on mechanical properties resulting from a locked up condition without ballistic deformation and in a scarfed single Vee joint.

4. It is appreciated that the welded ballistic test plates, a, b, and c, contain many undeformed areas for metallurgical examination, hence the extent and nature of tests is left to your choice. Hardness explorations across the welds and heat-affected zones, macroscopic and microscopic examinations and chemical analysis of the deposited weld metal are suggested as a minimum amount of work. Plate a will permit mechanical tests if judged desirable.

By order of the Chief of Ordnance:

(s/t) E. L. CUMMINGS
Major, Ordnance Dept.
Assistant

2 inclos -
1-(a) "Tank Armor Plate"
2-(b) Comparison sketch.

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APPENDIX II

TANK ARMOR PLATE

PROPOSED SQUARE TYPE WELD JOINT

B. J. Brugge, Engr.
The Lincoln Electric Co.

PROPOSED SQUARE TYPE JOINT FOR WELDING ARMOR PLATE

Some different factors are involved in making welds in armor plate and the experience gained welding the M3 hull indicate that a square cut type of joint has many advantages.

In armor welding it must be remembered that arc welding is being done on a hardened plate with a high yield strength and low ductility, and weld metal with lower yield strength and very high ductility is used. Hence all strains are thrown on the weld by the more rigid plate and are absorbed or equalized by the extremely ductile weld metal (40% in 2") that has a lower yield strength.

Because of this it is well to have a wide zone of weld metal at the root of the weld. If only a $1/8$ " gap is used the $1/8$ " gap will fail when it stretches 40% of $1/8$ " or .05". Whereas the weld would stretch on the 1" top side. 40% of 1" or .4" before failure. The narrow $1/8$ " gap is easy to use from an operators standpoint and speed of welding, because it is not difficult to bridge a $1/8$ " gap. If a wide root gap is used some means to get high welding speed and an easily bridged gap is necessary.

The square type of joint with a built up nose makes it easy and fast to weld with a wide root zone of ductile weld metal.

The high heat and rapid quench of a single bead of weld metal produces a hard zone adjacent to the bead in the armor plate, that is usually in the hard brittle range. When another bead is laid on top of the first bead this hardened zone is in effect given a high temperature draw and becomes less hard and quite tough and strong. Hence in armor-plate joints it is also desirable to have the fusion zone of the armor plate drawn or reheated below the critical and toughened before weld cooling stresses are applied i.e. if our fusion zones are tough before weld sides are joined together the chances of getting base metal cracks adjacent to the fusion zone are greatly reduced and a better weld joint results.

The square type joint with the built up nose gives us the above advantages because multiple beads are laid on each side of the joint before any plates are joined together and the fusion zones of the joint are in a tough condition before any stress is put on them.

Beads 1, 2 and 3 are applied before stress bead "a" is run. Stress bead "a" is easy and fast to run because of small gap.

Uniform section of weld metal at all points in the weld, root is same width as top of weld.

It is a remote possibility that less ductile weld metal than the expensive austenitic type could be used with this type of joint because of the advantages cited.

SHOWING NOSE BEADS APPLIED AND WELD SIDES READY TO BE JOINED BY FIRST BEAD LAID IN ROOT GAP.

Besides the above advantages the square type of joint has a number of production advantages that are unique to armor plate welding in tanks. Because the tank armor plates are not great in size and can be easily handled the nose beads can be applied by specially trained welders. The nose beads are easy to apply and the welders for this will be easy to train. As about 30% of the weld metal on the square joint is applied on the plate edges, the amount of welding necessary in the assembly jigs is reduced 30% and the number of assembly jigs is reduced 30%. This is due to the fact that the square joint, because it approaches the efficient U type joint does not use any more weld metal than a Vee type joint. Also all the nose beads are open to visual inspection before they are locked up in the final joint. It is not desirable to have more than two welders on any assembly jig, so time will not be wasted by men waiting for welds to be turned over. With the square type joint, welding is split up into nose welding on plate edges and the actual joint welding. Since the square plate edges are easily positioned $3/16$ electrode can be used and because of the open position welders will use their electrodes all up and waste will be held to a minimum (In a Vee type joint the first passes would be run with $5/32$ dia. electrode and because of the Vee longer lengths of electrode would be wasted.). With the square type joint no electrodes smaller than $3/16$ dia. would be used. The square type joint will increase welding speed about 14% and reduce losses of electrode about 8%.

Summary of Advantages of Square Type Joint

1. Increases speed of welding about 14%.
2. Reduces root grinding and chipping to minimum.
3. Reduces electrode loss about 8%.
4. Reduces assembly jigs necessary about 30%.
5. Nose beads are open to inspection.
6. Armor plate fusion zones are toughened by heat treatment before strain beads are applied.
7. Welders are easily trained for nose build up welding.
8. Less armor plate wasted in cutting out hull plates because plates can be nested closer.

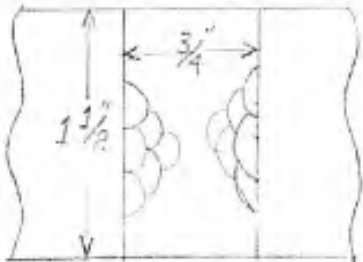
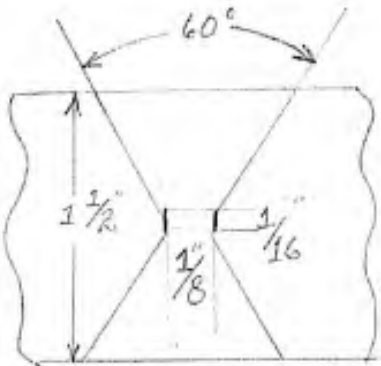
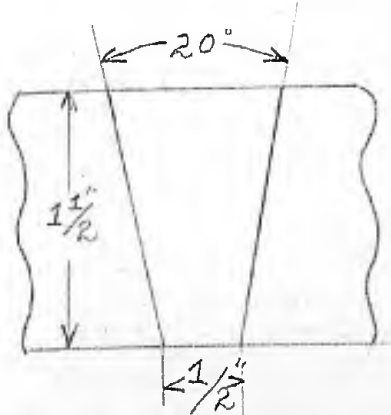
(t) B.J. Bruggee, Welding Engineer,

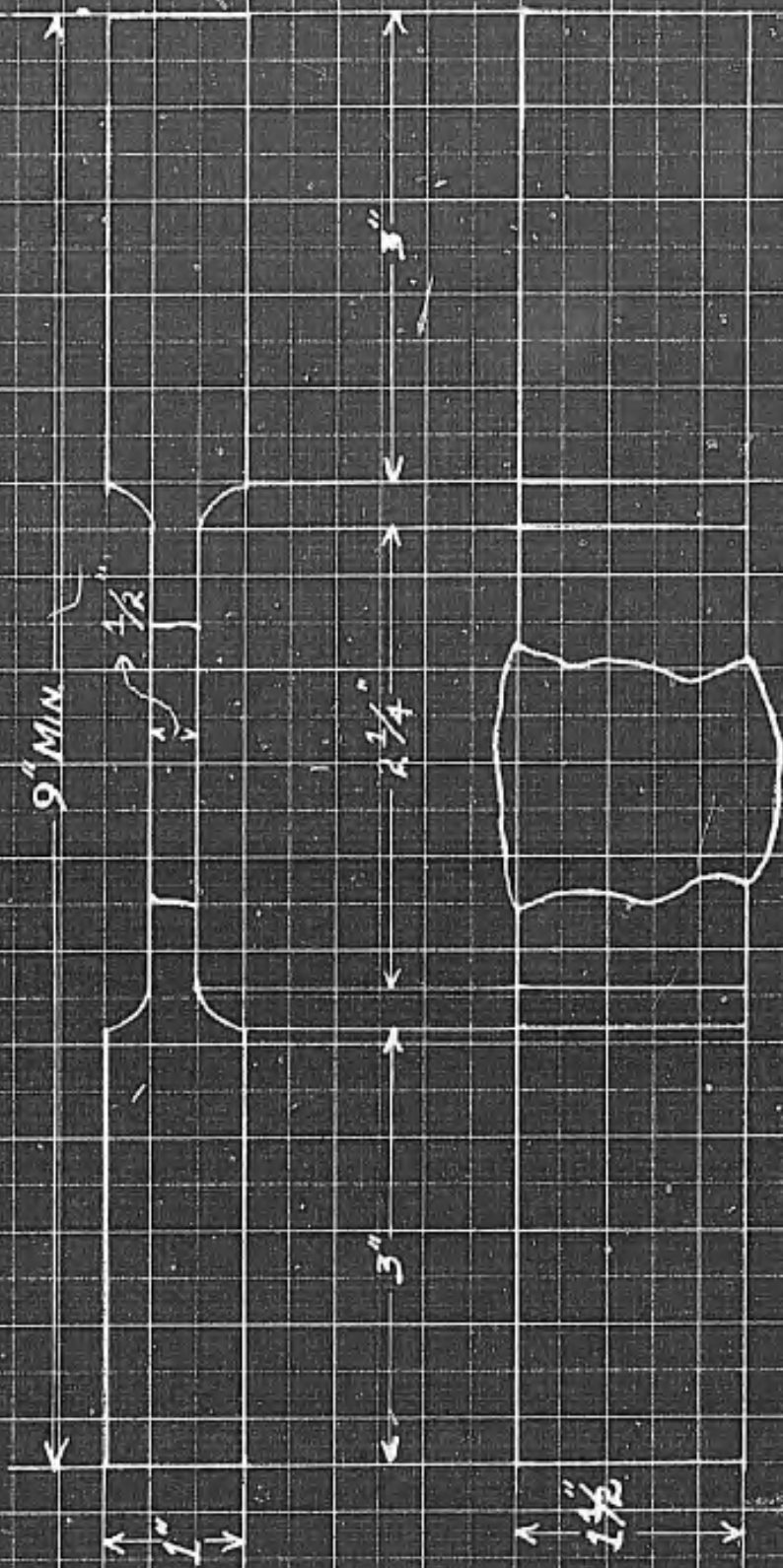
The Lincoln Electric Company,

June 25, 1941

APPENDIX III

Comparison of Cross Sectional Area of Lincoln Proposed
Butt Weld (no edge preparation) with Double and Single
Vee Butt Welds in 1-1/2" Thick Plate.

Weld	Cross Sectional Area	
	<u>Without Reinforcement</u> sq. in.	<u>With assumed Reinforcement</u> sq. in.
	1.125	1.218
	0.784	0.809
	1.14	1.23



TENSILE SPECIMEN
OF JOINT

PLATE I

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HARDNESS CHARTS AND

PHOTOMACROGRAPHS

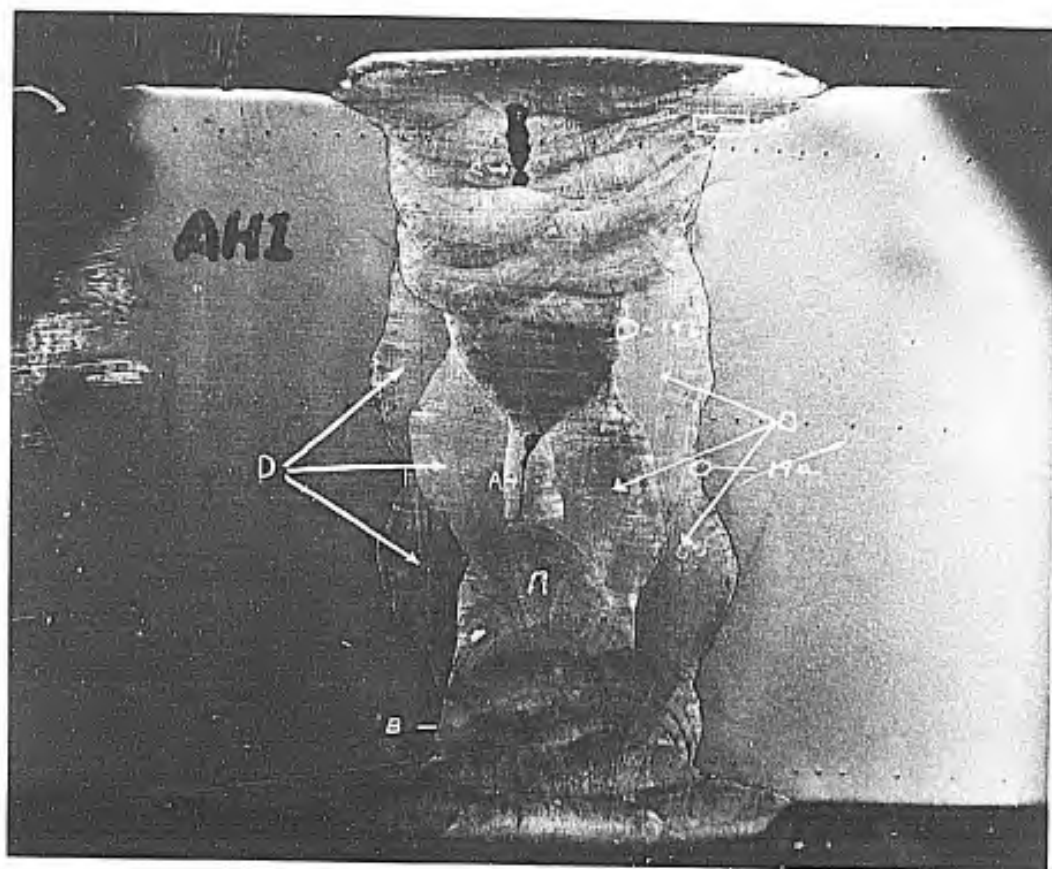


FIG 1

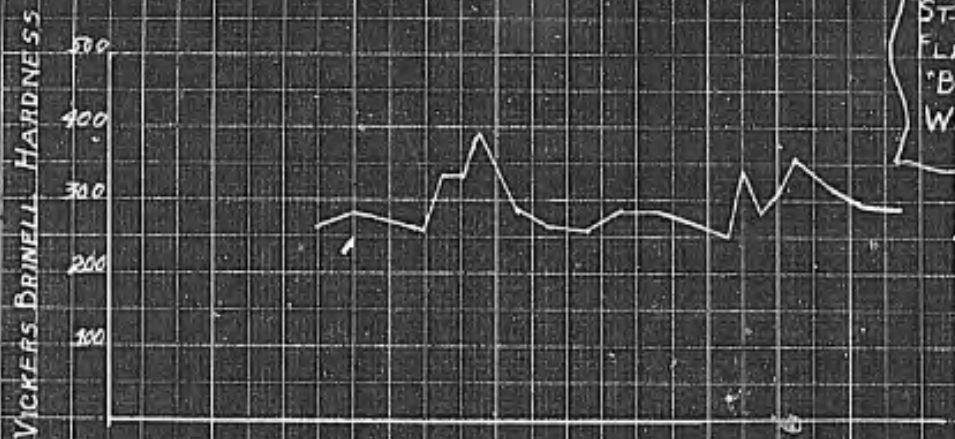
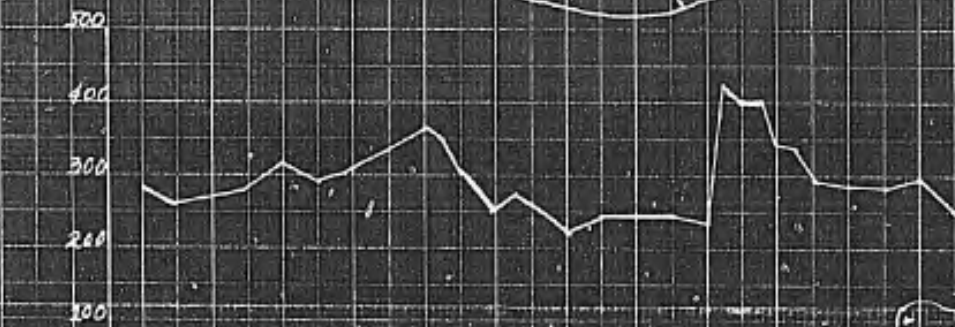
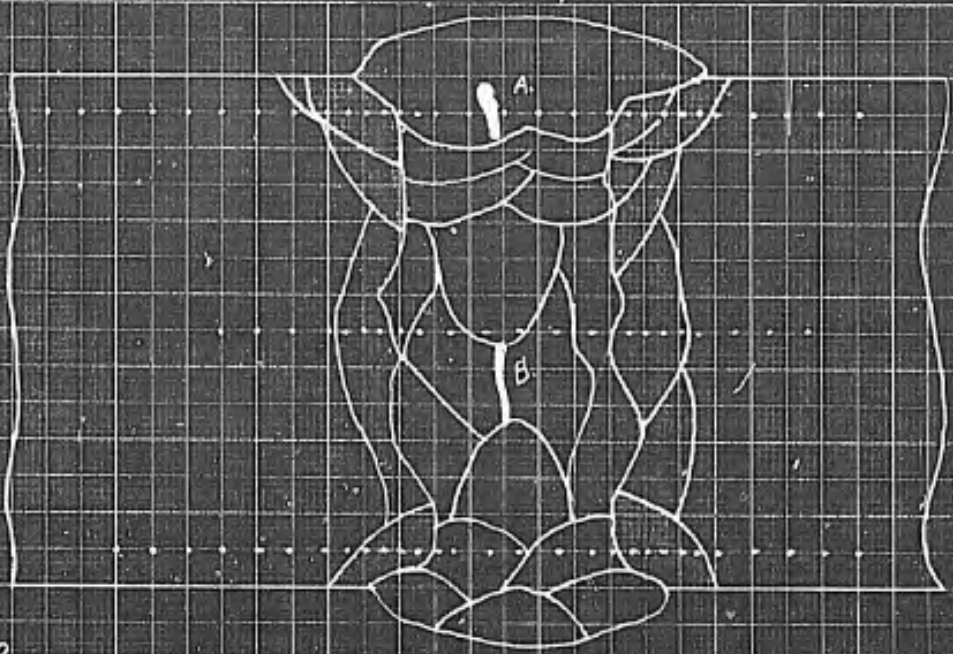
X 2½

CROSS SECTION, AREA #1, PLATE "A" (FIG 31A). FLAME SOFTENED
 EDGES. ELECTRODE, "ARMORWELD". SMALL CIRCLES INDICATE
 APPROXIMATE LOCATION OF PHOTOMICROGRAPHS.

- A - LACK OF PENETRATION
- B - LACK OF FUSION
- C - WORM HOLE
- D - BUTTERING LAYER

W.A.639-3682

PLATE A
AREA 1
AH 1



1 1/2 ROLLED HOMOGENEOUS
ARMOR PLATE
STRAIGHT GAP BUTT WELD WITH
FLAME SOFTENED EDGES AND
"BUTTERING"
WELDED WITH "ARMORWELD."

A. SLAG POCKET
B. PENETRATION LINE

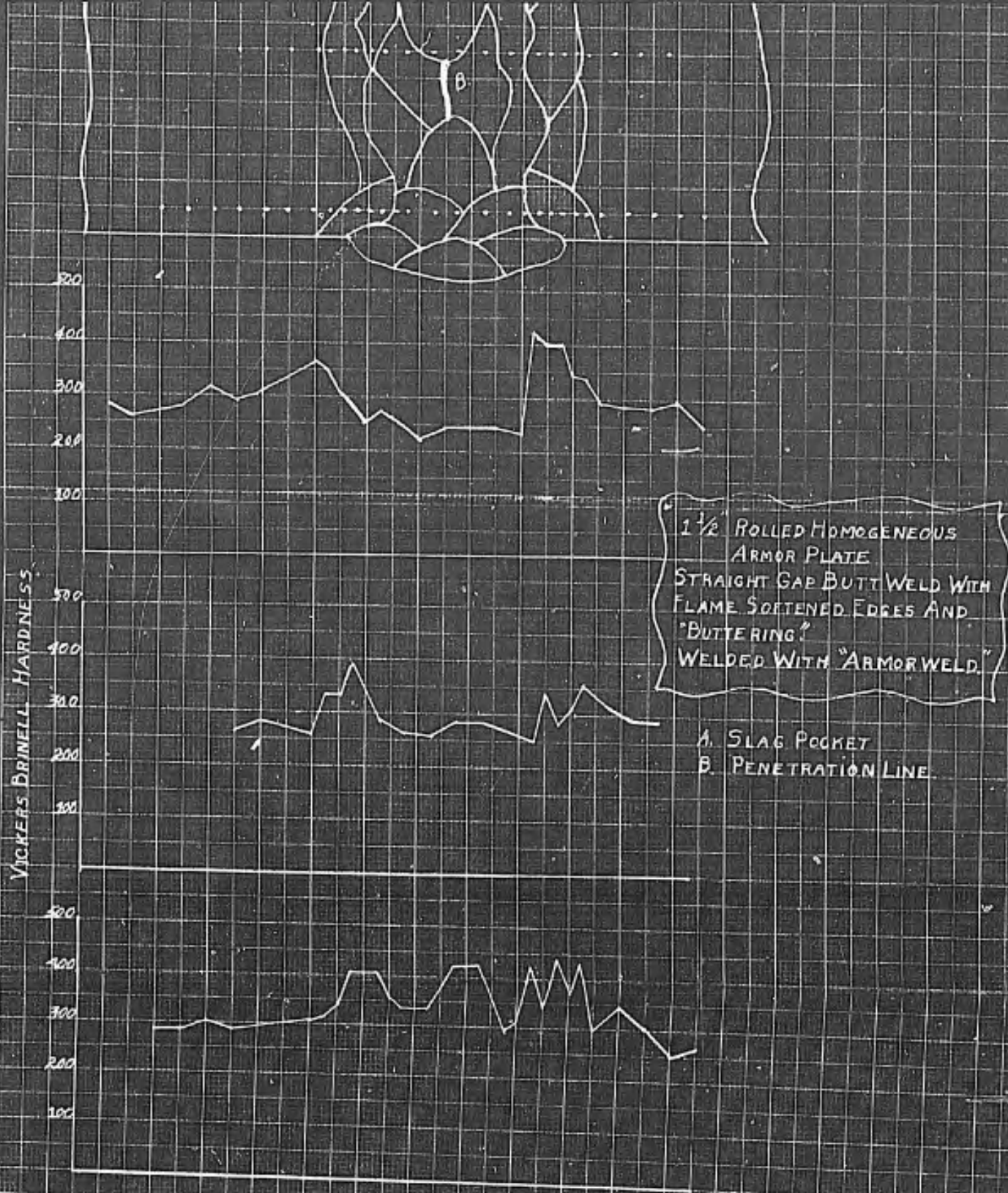


FIG. 2

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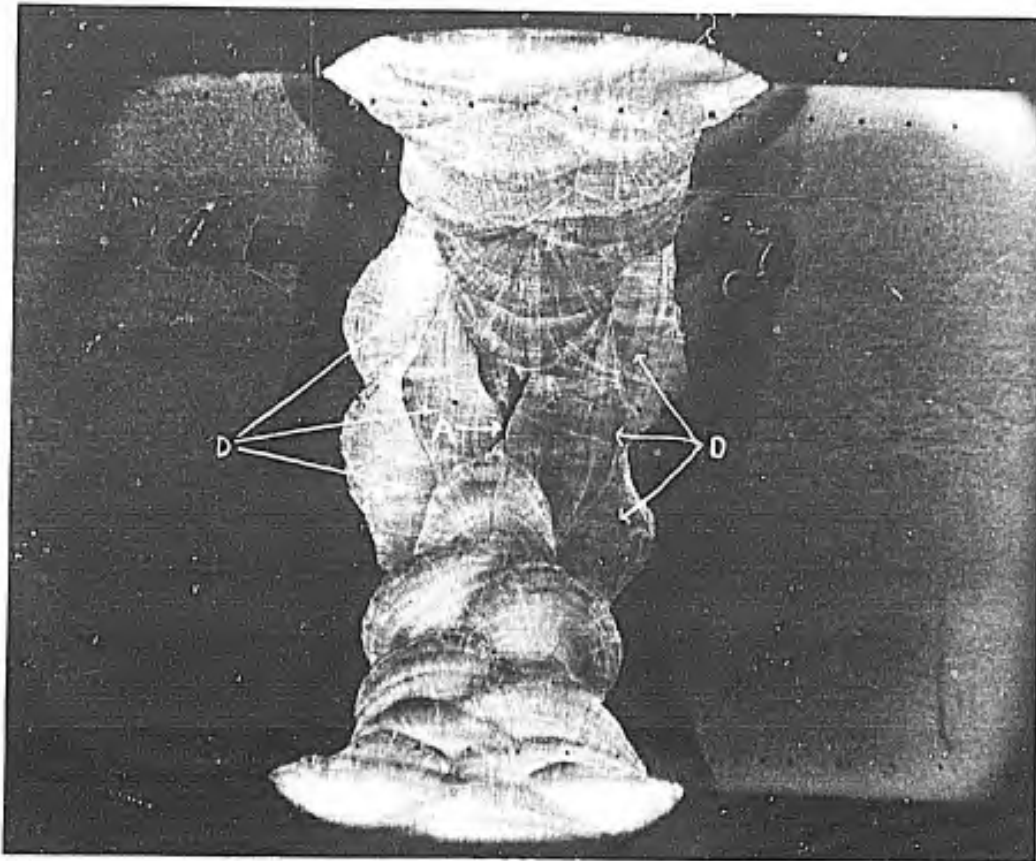


FIG 3

X $2\frac{1}{2}$

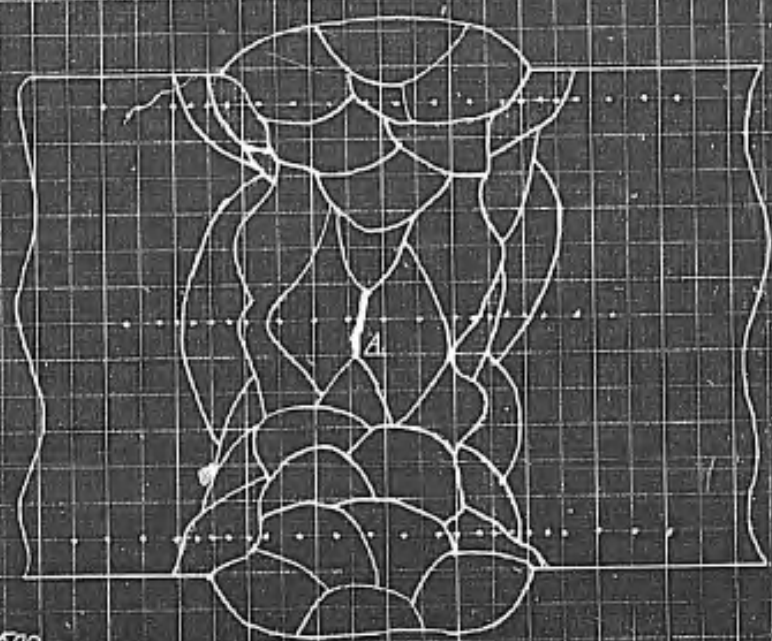
CROSS SECTION AREA #3, PLATE "A" (FIG 31A). FLAME SOFTENED EDGES. ELECTRODE, "ARMORWELD".

A - LACK OF PENETRATION
D - BUTTERING LAYER

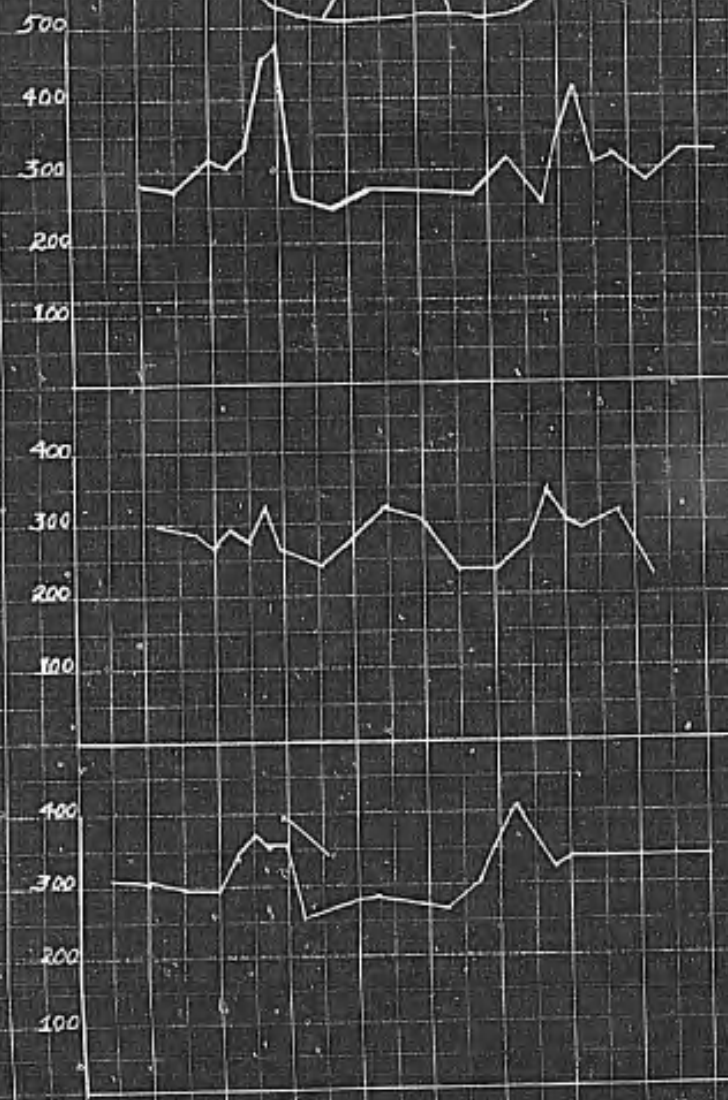
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WHILE USING THE STRENGTH OF THE WELDED JOINT
IN THE AREA OF THE WELDED JOINT

PLATE A
AREA 3
AM3



VICKERS DRINELL HARDNESS



1 1/2" ROLLED HOMOGENEOUS
ARMOR PLATE
STRAIGHT GAP BUTT
JOINT
FLAME SOFTENED EDGES
WITH BUTTERING
WELDED WITH "ARMORWELD"

A. PENETRATION LINE

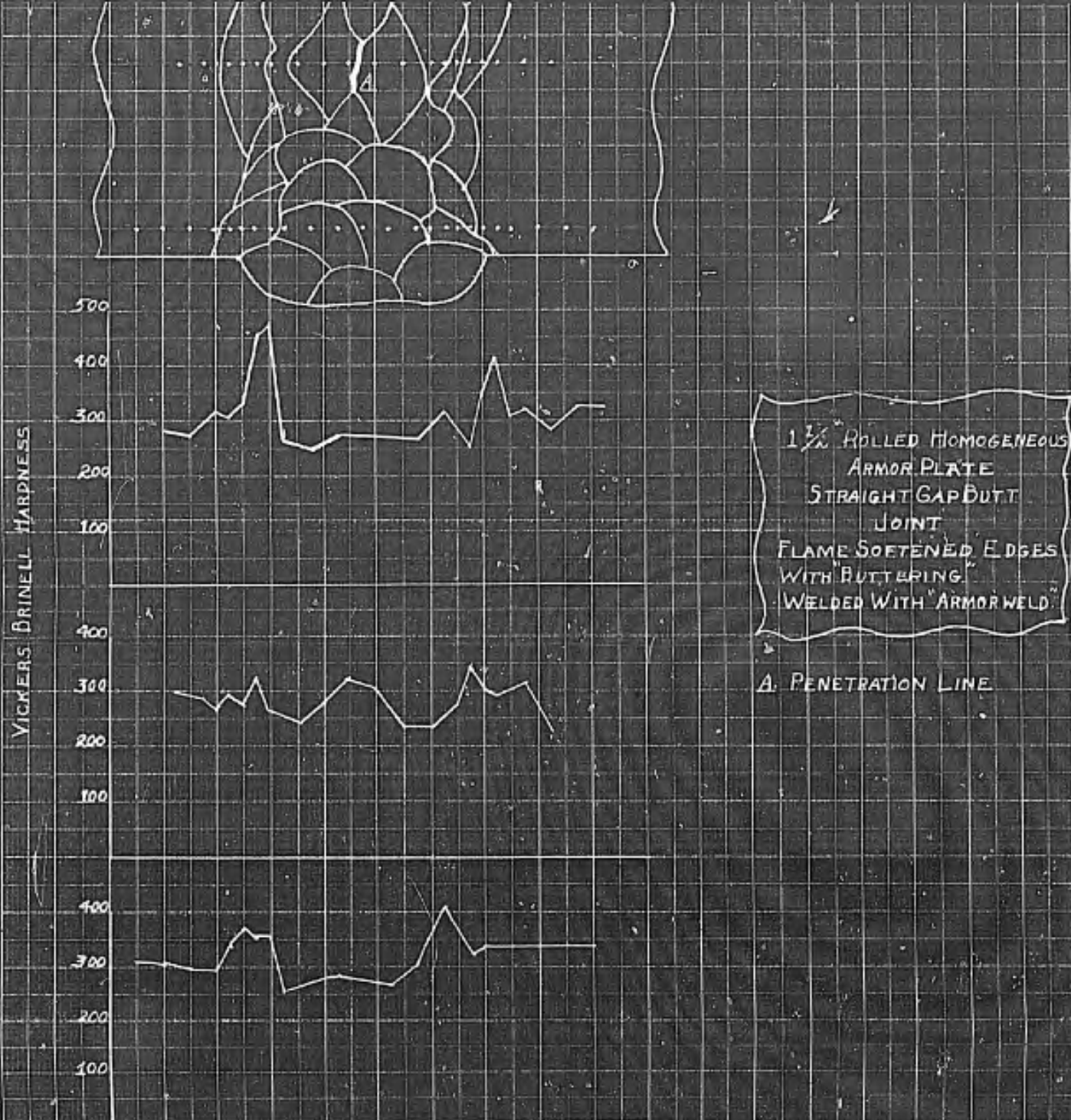


Fig. 4

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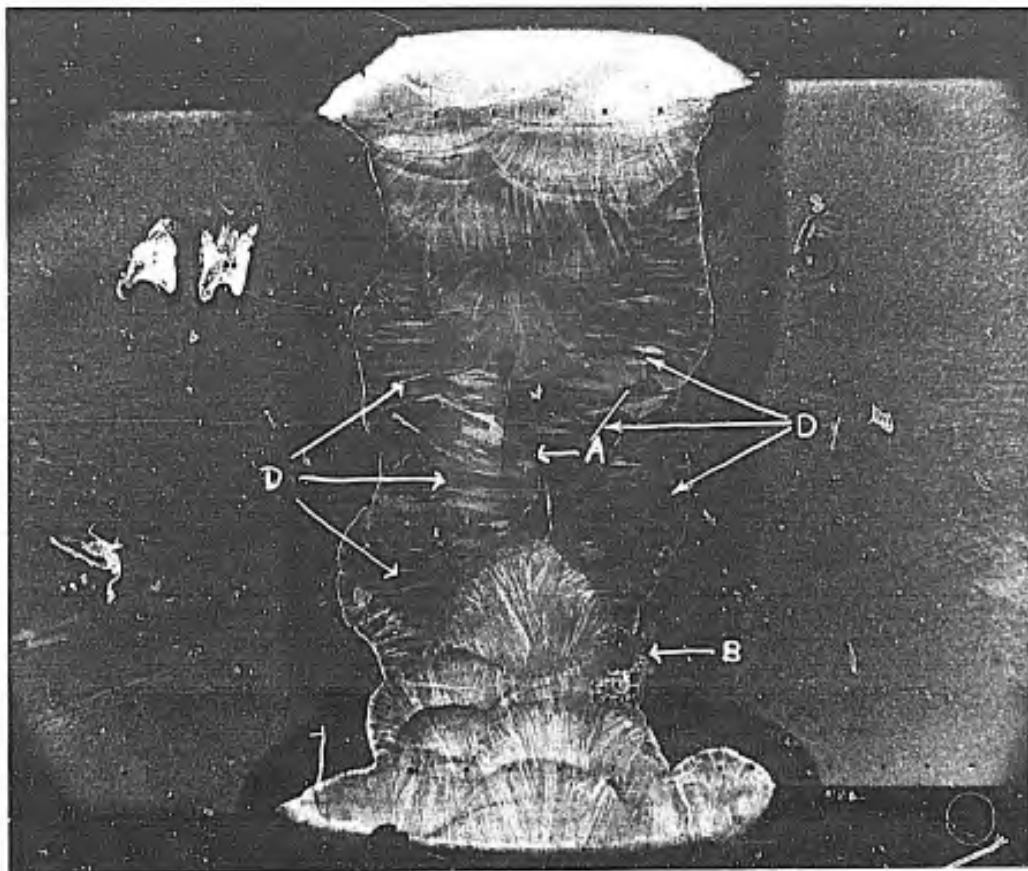


FIG 5

x 2½

CROSS SECTION AREA #5, PLATE "A" (FIG 31A). FLAME SOFTENED
EDGES. ELECTRODE, "ARMORWELD".

- A - LACK OF PENETRATION
- B - SLAG INCLUSION
- D - BUTTERING LAYER

W.A.639-3684

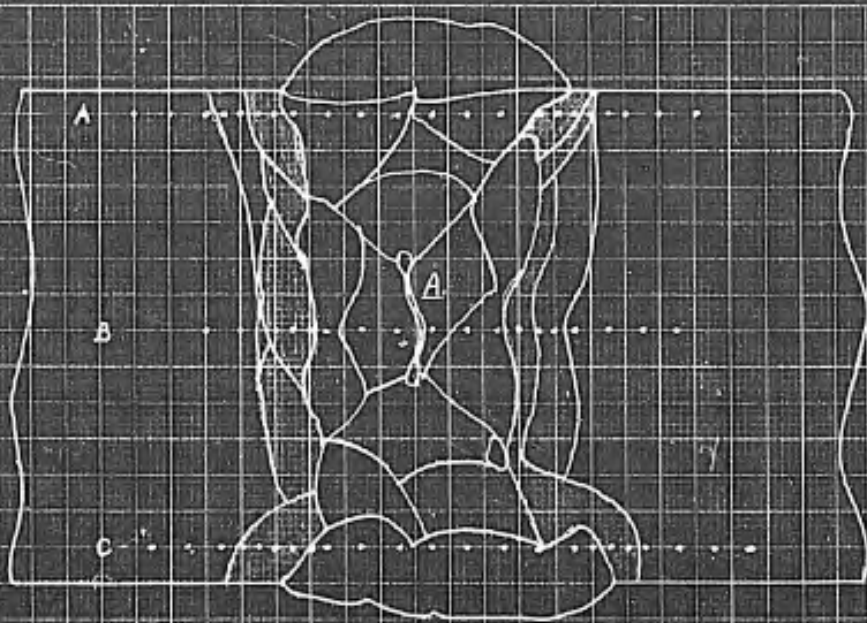
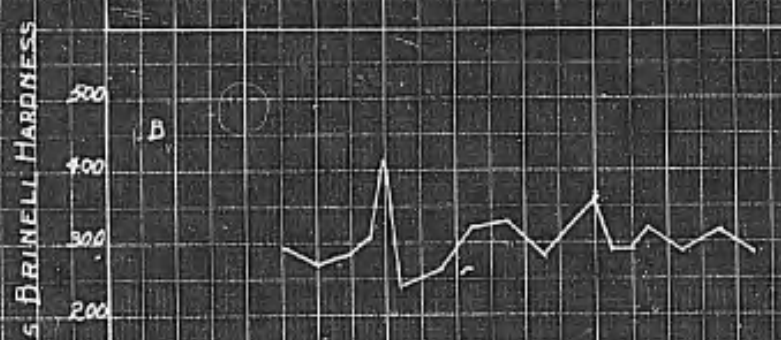
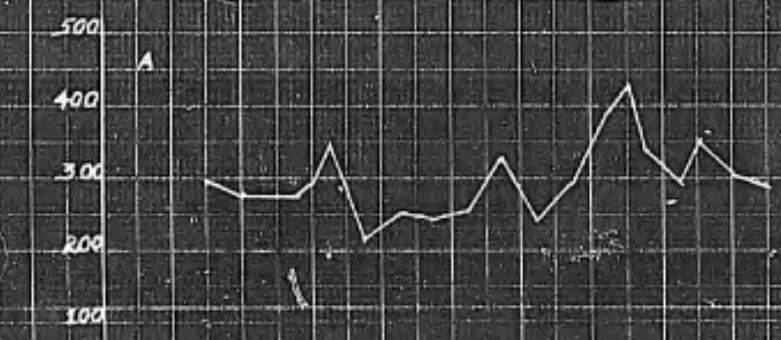
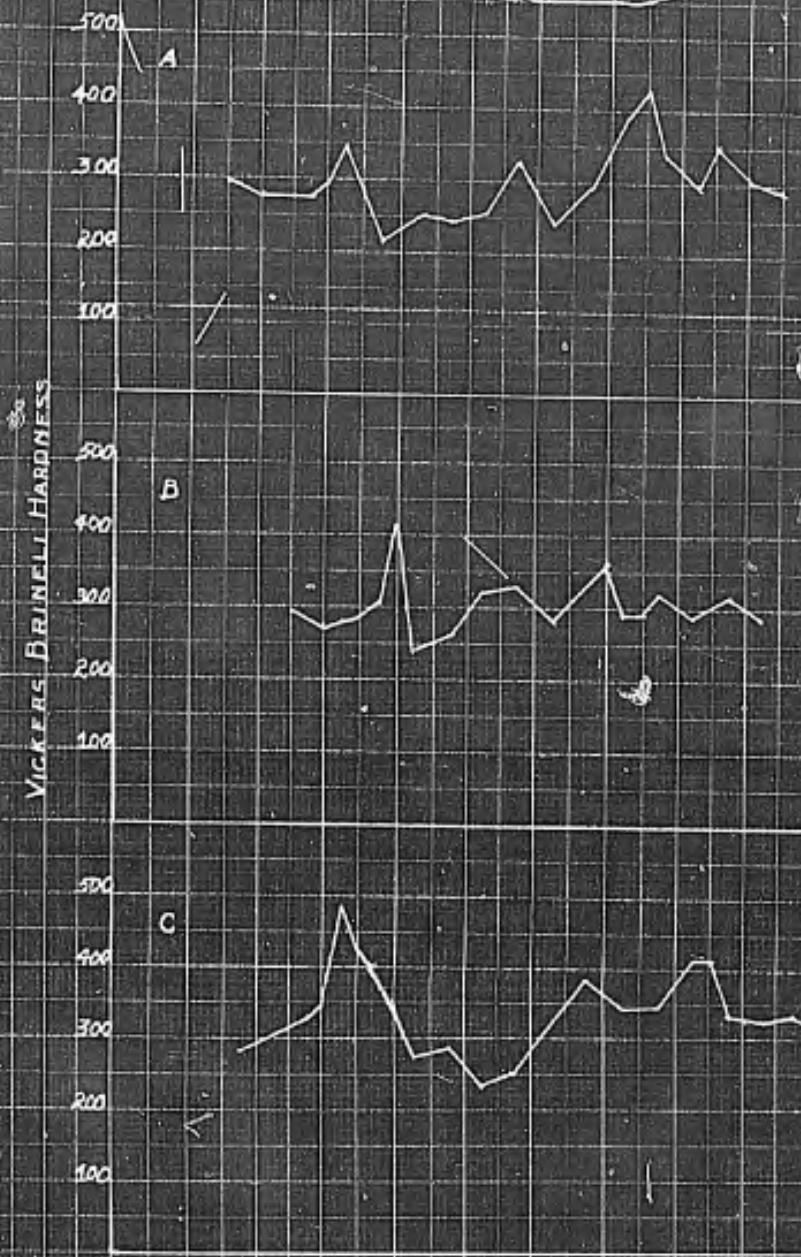
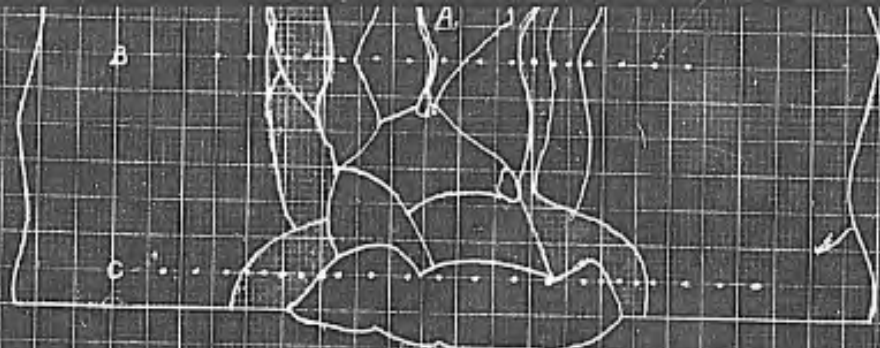


PLATE A
AREA 5
AM5



1 1/2" ARMOR PLATE
STRAIGHT GAP BUTT
JOINT
FLAME-SOFTENED EDGES
WELDED WITH "ARMORWELD"

A. LACK OF PENETRATION



1 1/2" ARMOR PLATE
 STRAIGHT GAP BUTT
 JOINT
 FLAME-SOFTENED EDGES
 WELDED WITH "ARMORWELD"

A. LACK OF PENETRATION

FIG. 6

SK 645-11

JAN. 11/25/41

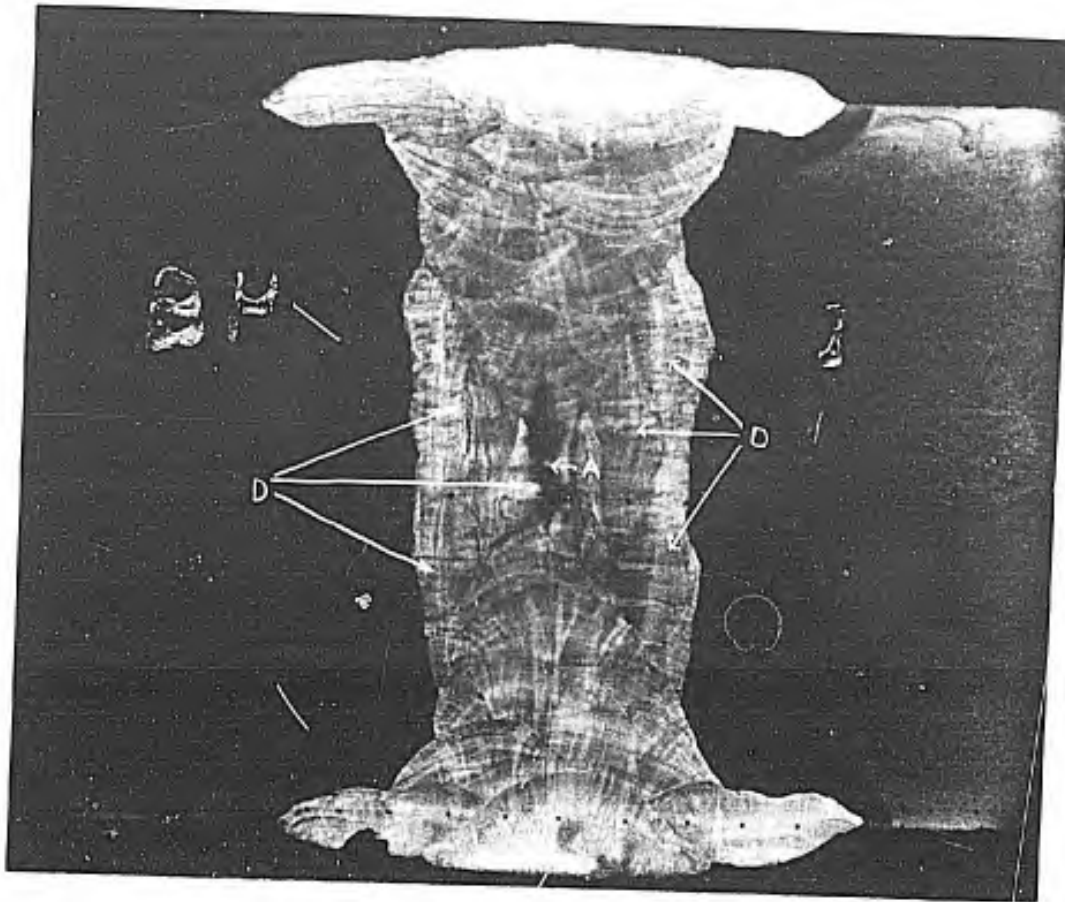


FIG. 7

x 2 $\frac{1}{2}$

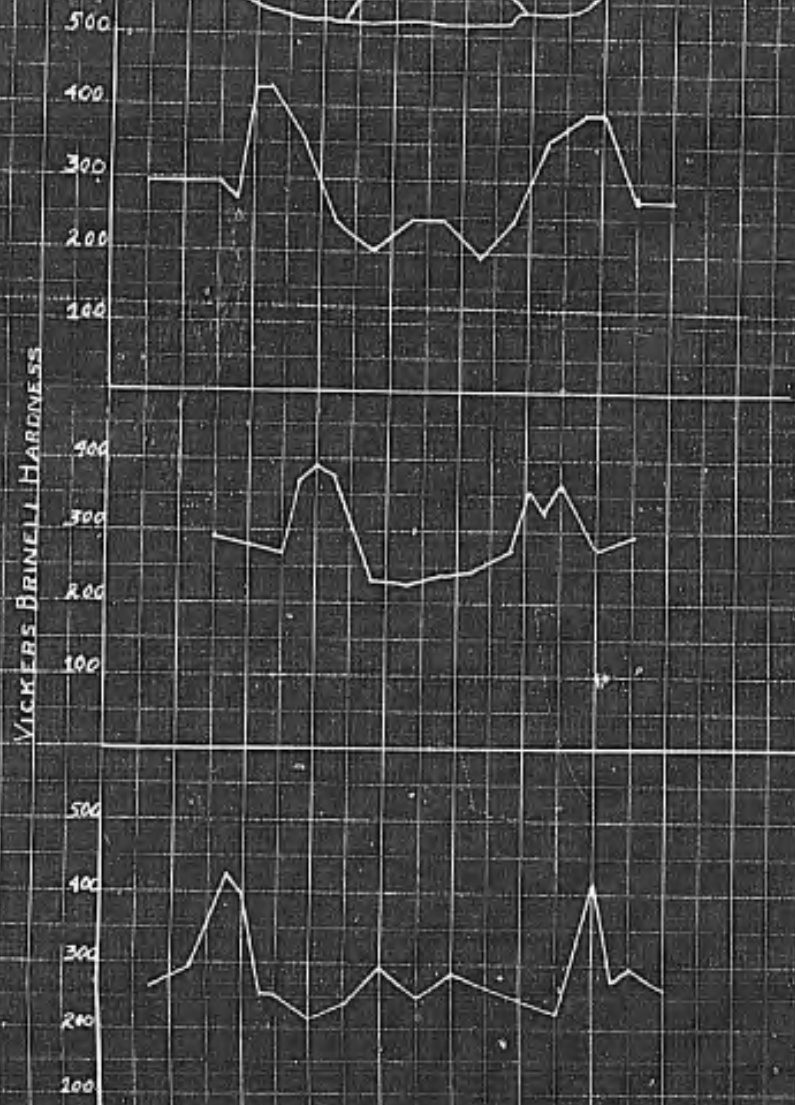
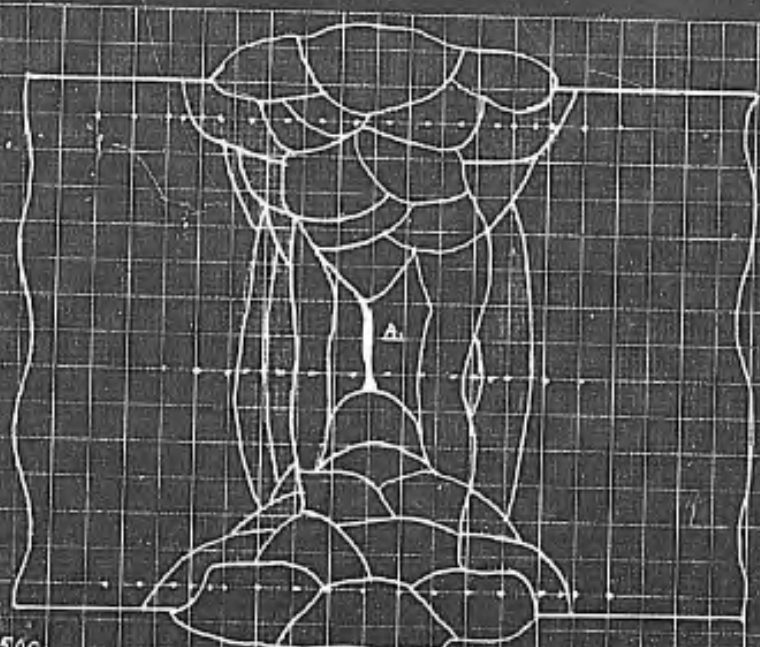
CROSS SECTION AREA #1, PLATE "B" (FIG 32A) FLAME SOFTENED.
ELECTRODE, 25/20 STAINLESS

A - LACK OF PENETRATION
D - BUTTERING LAYER

W.A.639-3685

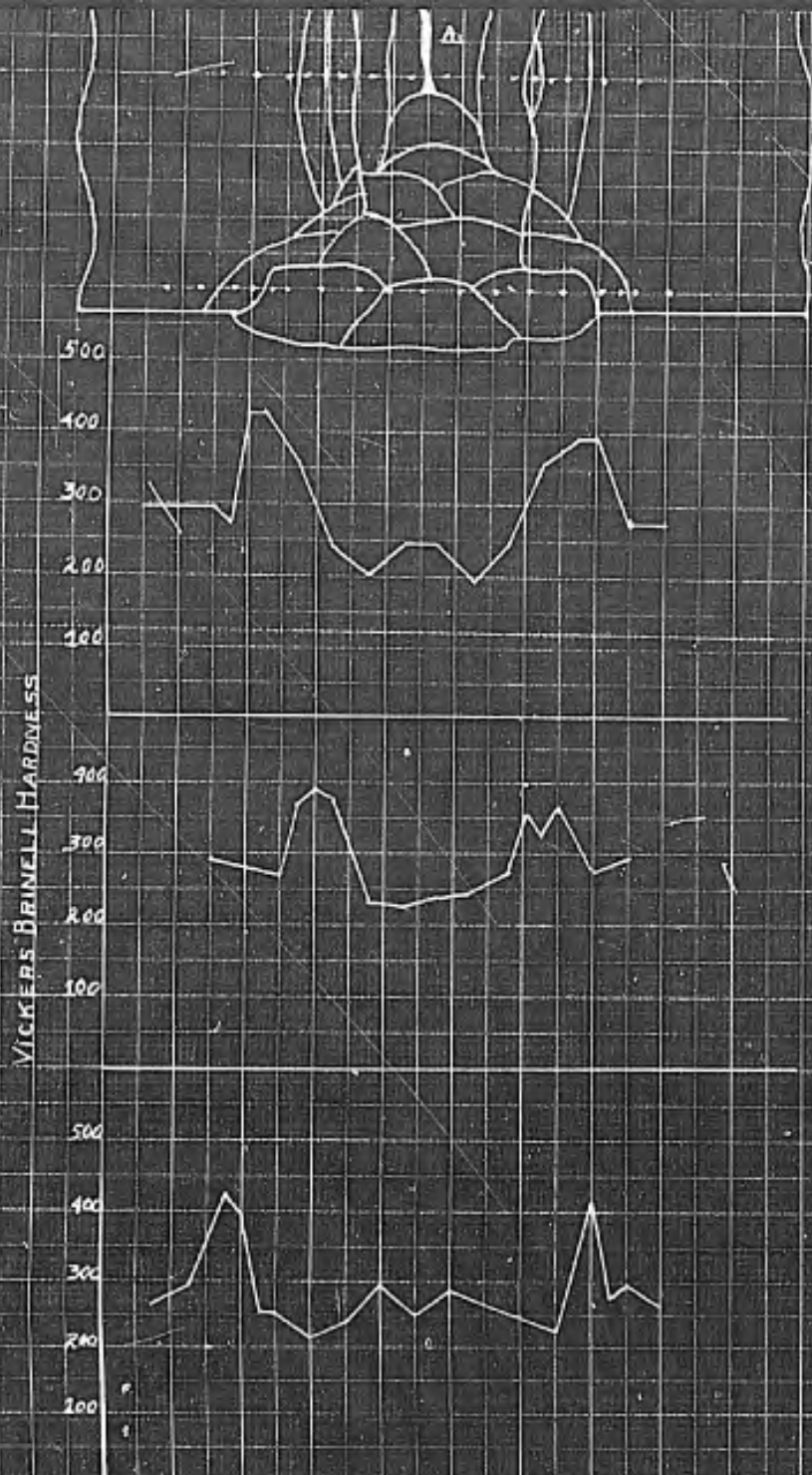
PHOTOGRAPHED BY THE U.S. ARMY
CORPORATION STATE PHOTOGRAPHY CENTER, WASHINGTON, D.C.
MADE IN U.S.A.
20 X 240 PAPER

PLATE B
AREA 1
BH 1



1 1/2" ROLLED HOMOGENEOUS ARMOR
STRAIGHT GAP BUTT JOINT.
FLAME SOFTENED EDGES WITH
'BUTTERING'
WELDED WITH *25% Ni*

A. PDDR PENETRATION



1 1/2" ROLLED HOMOGENEOUS ARMOR
 STRAIGHT GAP BUTT JOINT.
 FLAME SOFTENED EDGES WITH
 "BUTTERING"
 WELDED WITH *25/20*

A. PDBR PENETRATION

FIG. 8

SK 645-12

JAN 11/27/41

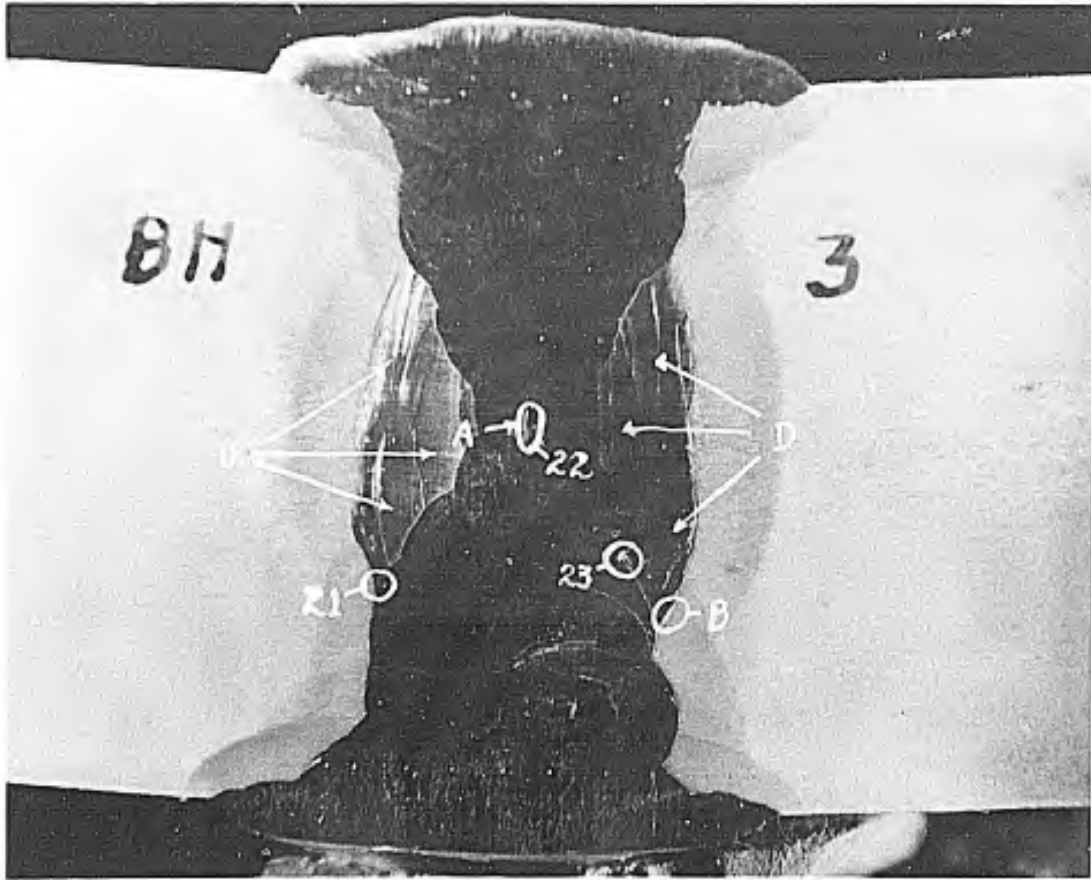


FIG. 9

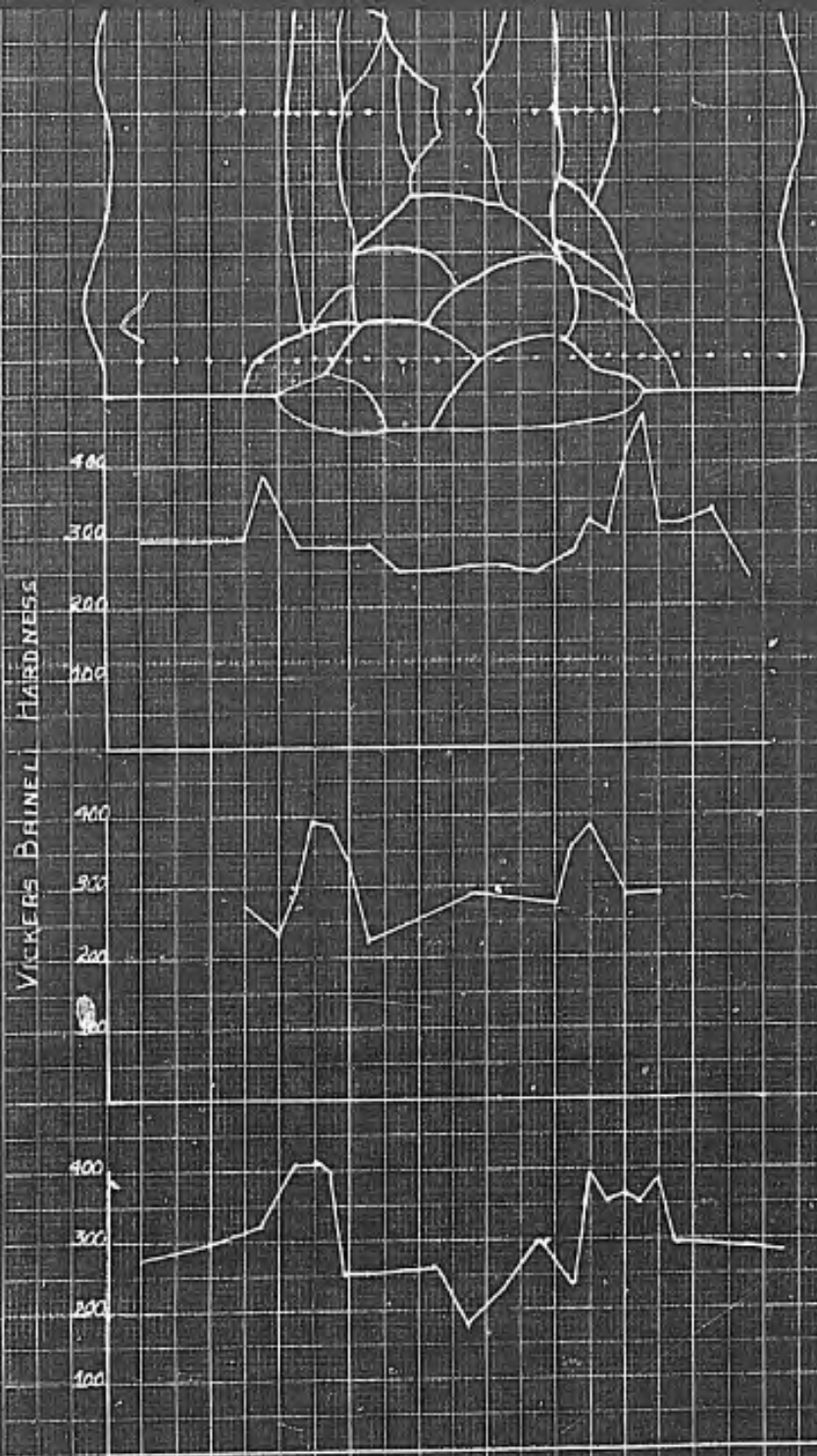
X 2½

CROSS SECTION AREA #3, PLATE "B" (FIG 32A) FLAME SOFTENED.
ELECTRODE, 25/20 STAINLESS

A - LACK OF PENETRATION
B - LACK OF FUSION
D - BUTTERING LAYER

(SMALL CIRCLES INDICATE APPROXIMATE LOCATION OF PHOTOMICRO)

W.A. 639-3686



$1\frac{1}{2}$ " ROLLED HOMOGENEOUS ARMOR
 STRAIGHT GAP BUTT JOINT
 WELDED AND BUTTERED
 WITH $\frac{1}{8}$ " 304 STAINLESS
 ELECTRODE.
 FLAME SOFTENED EDGES.

FIG. 10

JK645-13

JAN. 12/1/41

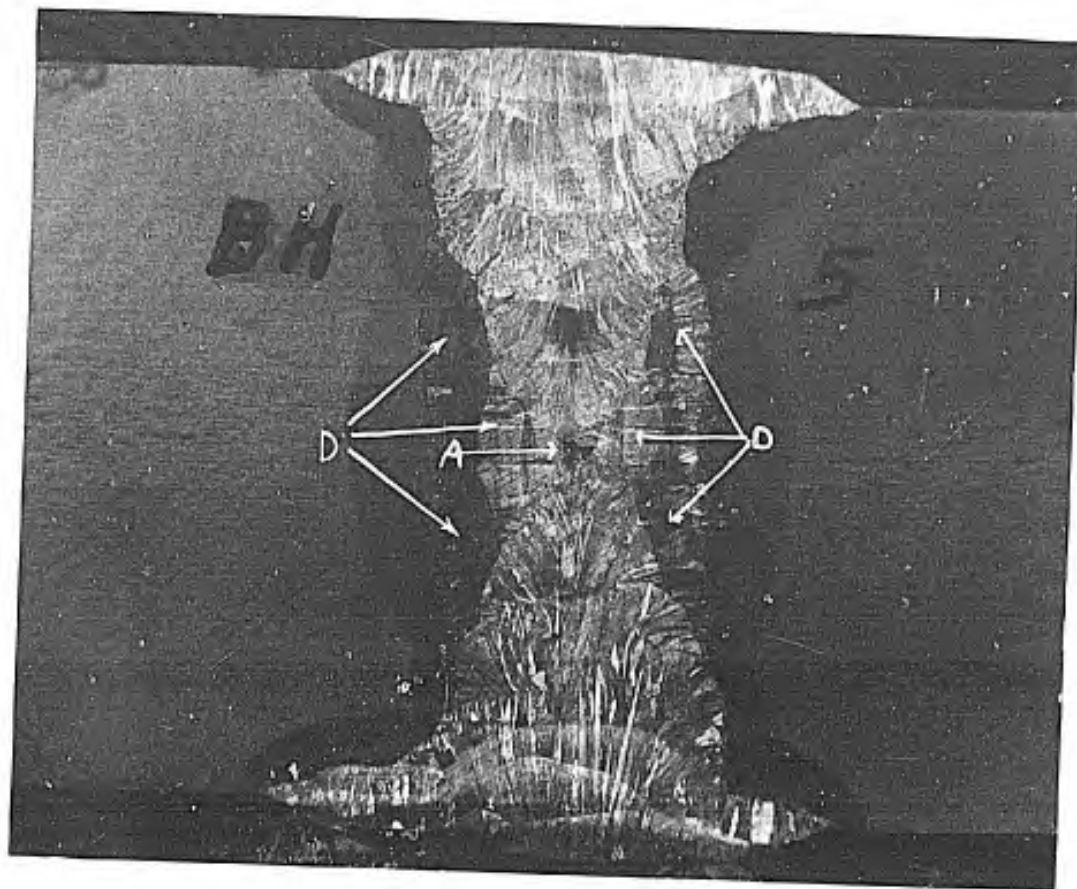


FIG. 11

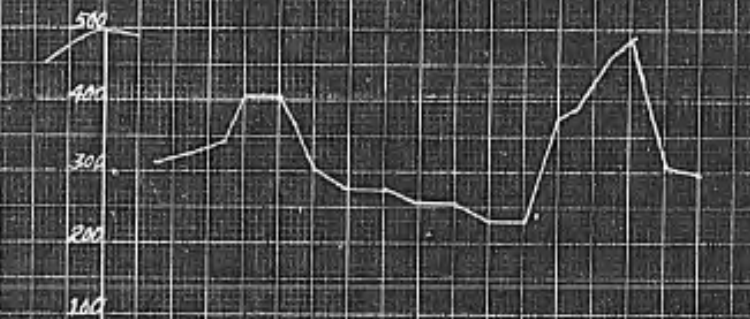
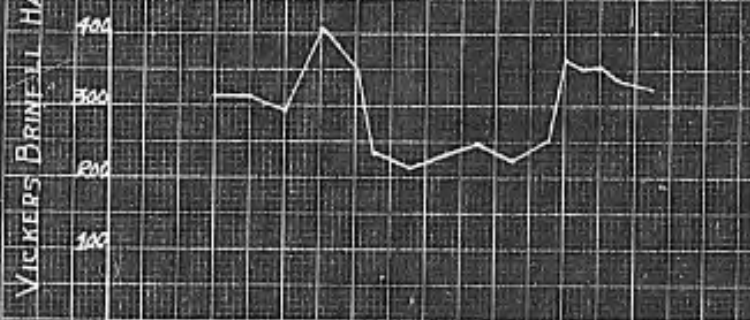
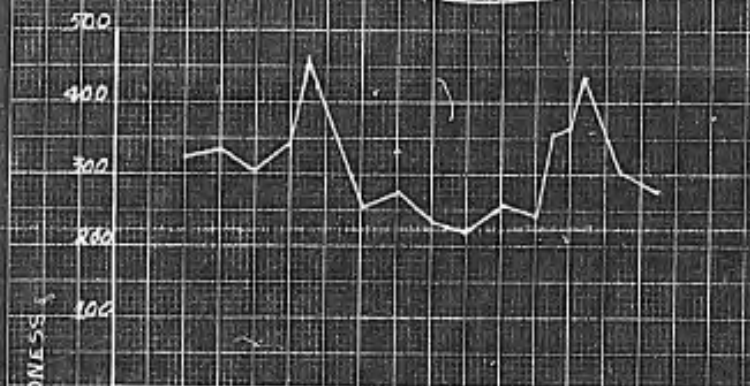
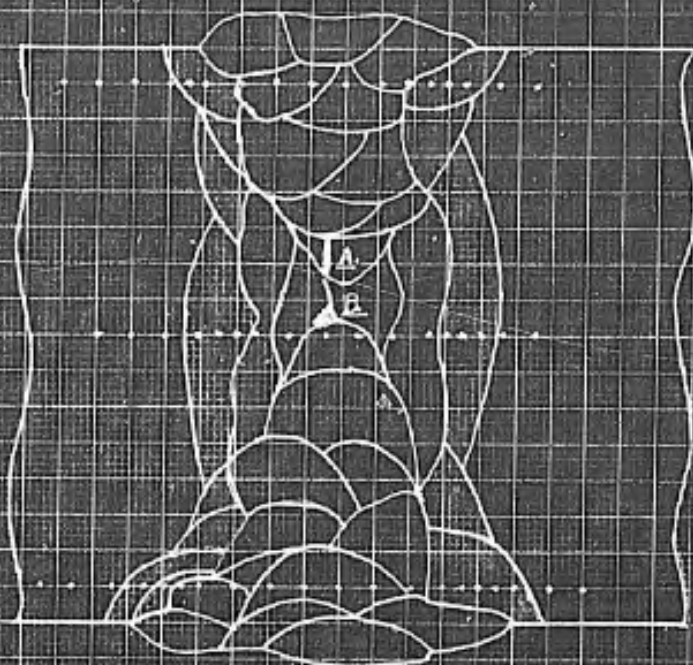
X 2 $\frac{1}{2}$

CROSS SECTION AREA #5, PLATE "B" (FIG 32A) FLAME SOFTENED.
ELECTRODE, 25/20 STAINLESS

A - LACK OF PENETRATION
D - BUTTERING LAYER

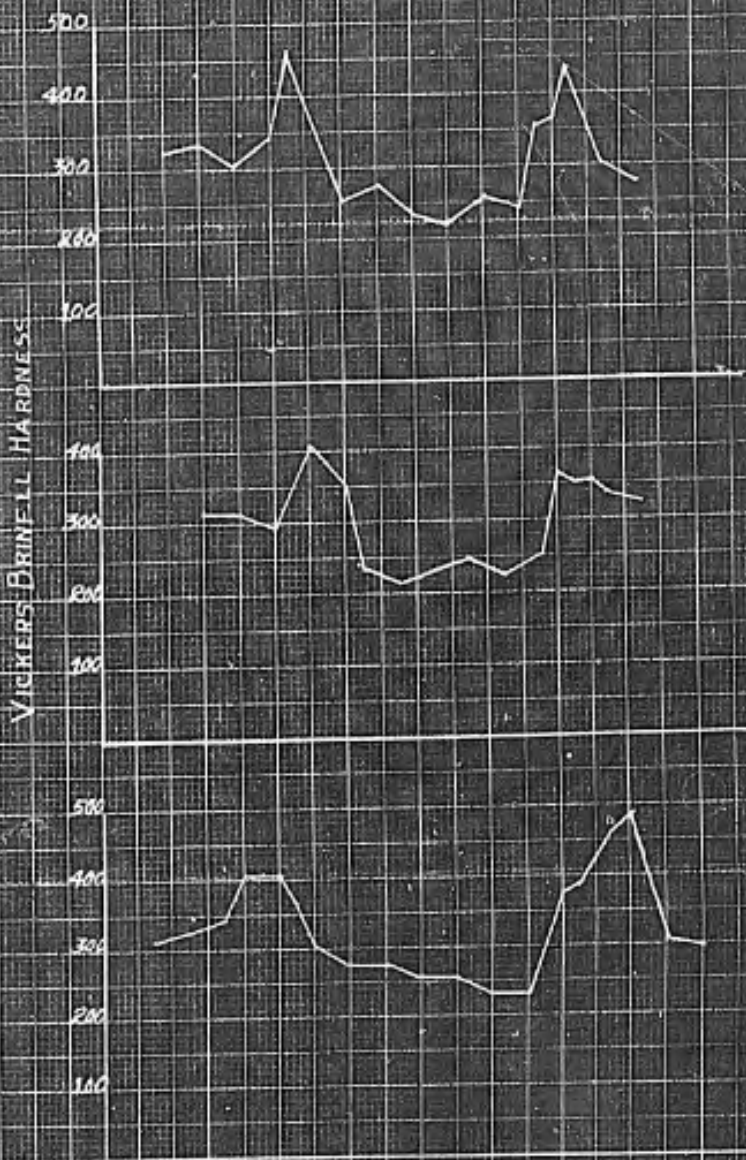
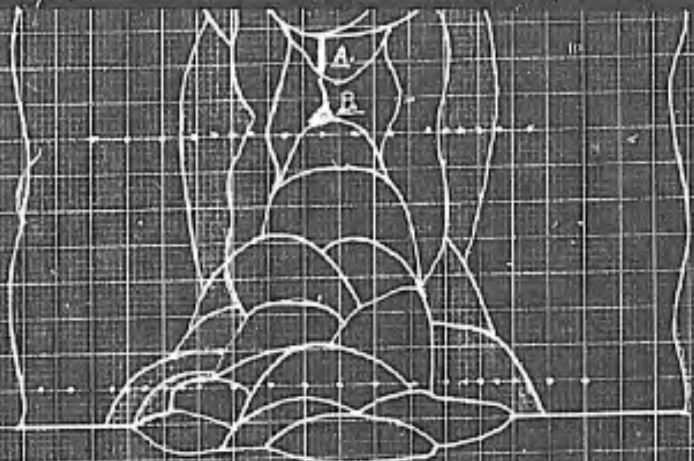
W.A.639-3687

PLATE B
AREA 5
BH5



1 1/2" ROLLED HOMOGENEOUS ARMOR
 STRAIGHT GAP BUTT JOINT
 WELDED AND "BUTTERED" WITH 85%
 FLAME SOFTENED EDGES

- A CRACK
- B LACK OF PENETRATION



1 1/2" ROLLED HOMOGENEOUS ARMOR
 STRAIGHT GAP BUTT JOINT
 WELDED AND "BUTTERED" WITH ~~25~~ 20
 FLAME SOFTENED EDGES

- A CRACK
- B LACK OF PENETRATION

FIG. 12

5K645-14

JAN 12/3/42

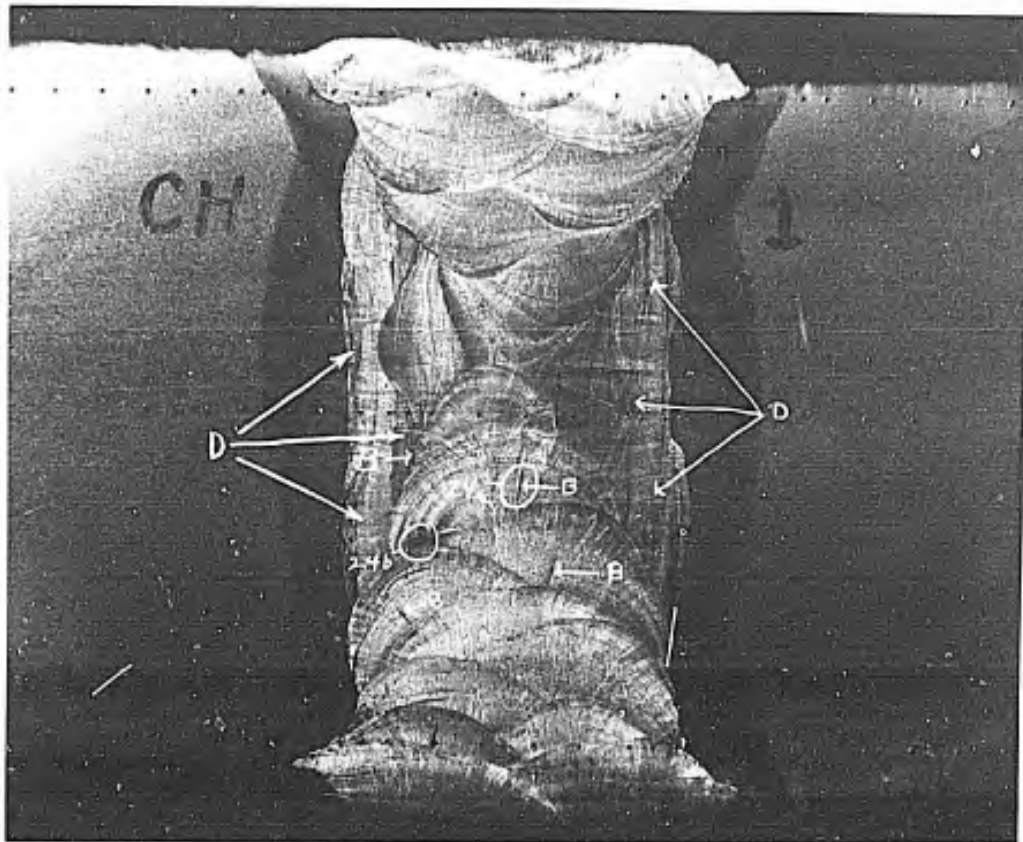


FIG. 13

x 2½

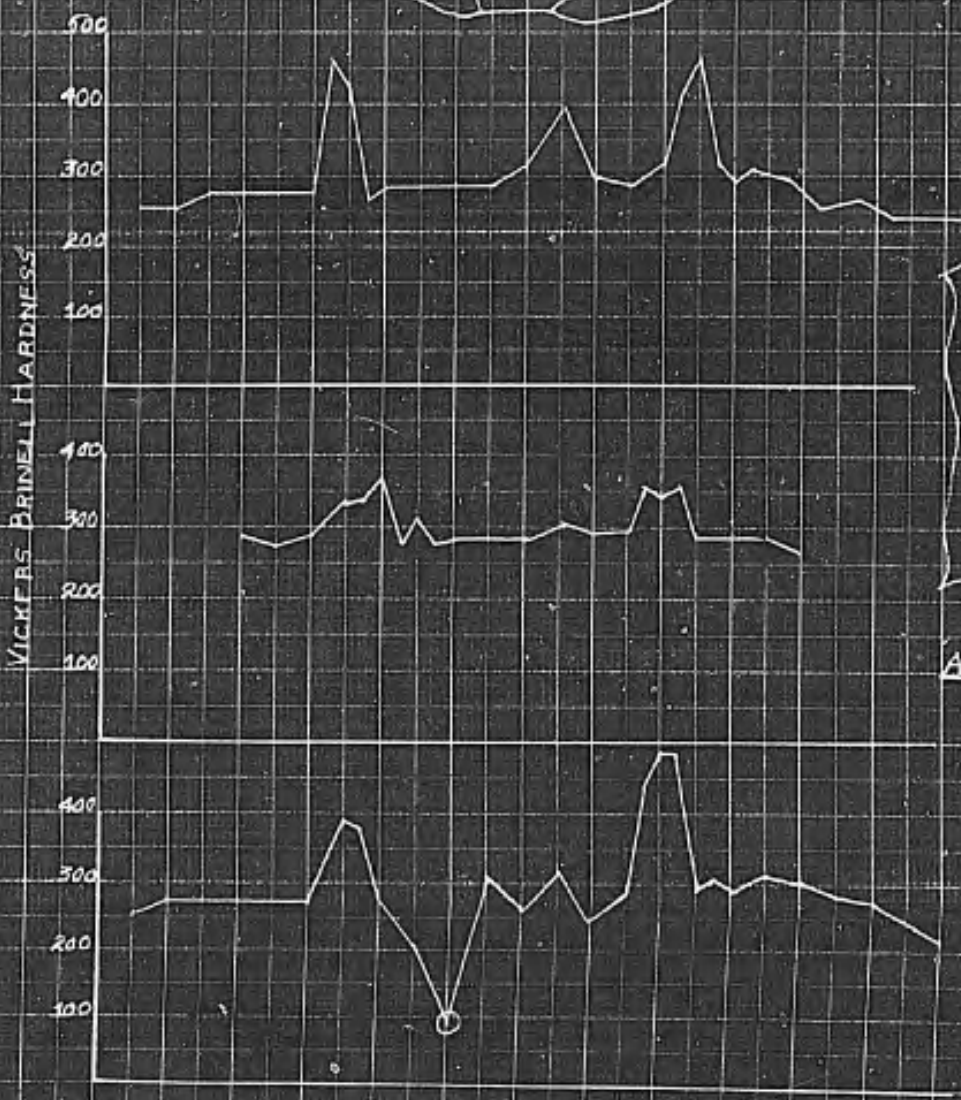
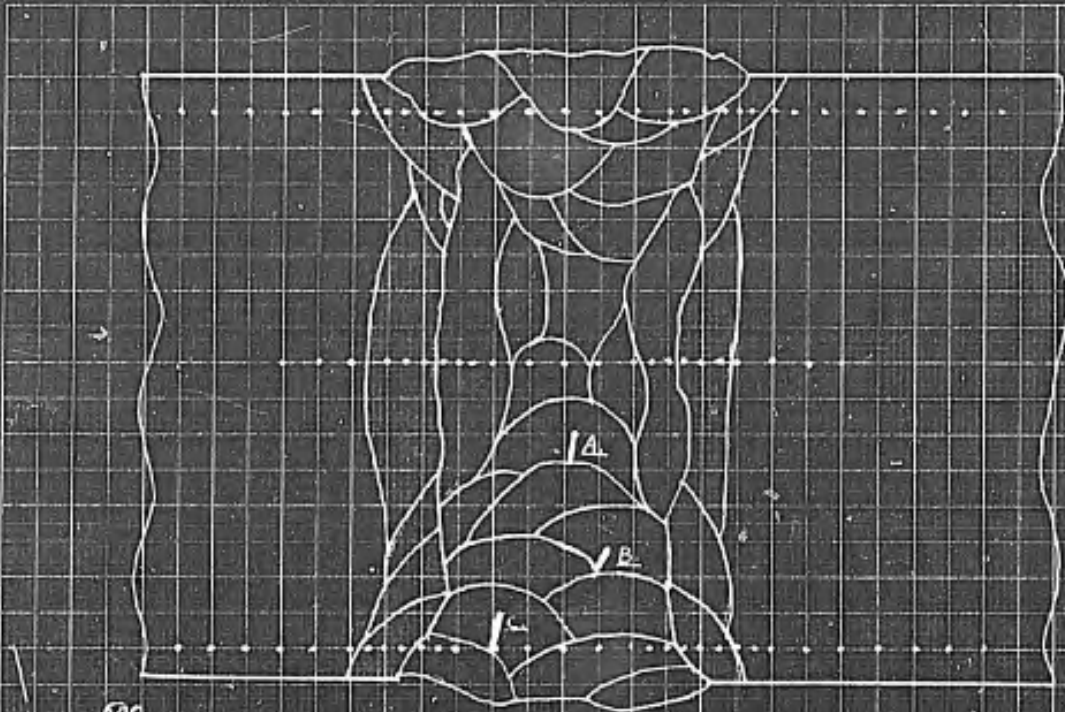
CROSS SECTION AREA # 1, PLATE "C" (FIG 33A) UNSOFTENED EDGES.
ELECTRODE - "ARMORWELD"

B - CRATER CRACKS
D - BUTTERING LAYER

(SMALL CIRCLES INDICATE APPROXIMATE LOCATION OF PHOTOMICROS)

W.A.639-3688

PLATE C
AREA 1
CH 1



1 1/2" ROLLED HOMOGENEOUS
ARMOR PLATE
STRAIGHT GAP BUTT JOINT
WELDED WITH "ARMORY
WELD"
FLAME CUT UNSCUTENED
EDGES
"BUTTERED" EDGES

A, B, C CRATER CRACKS

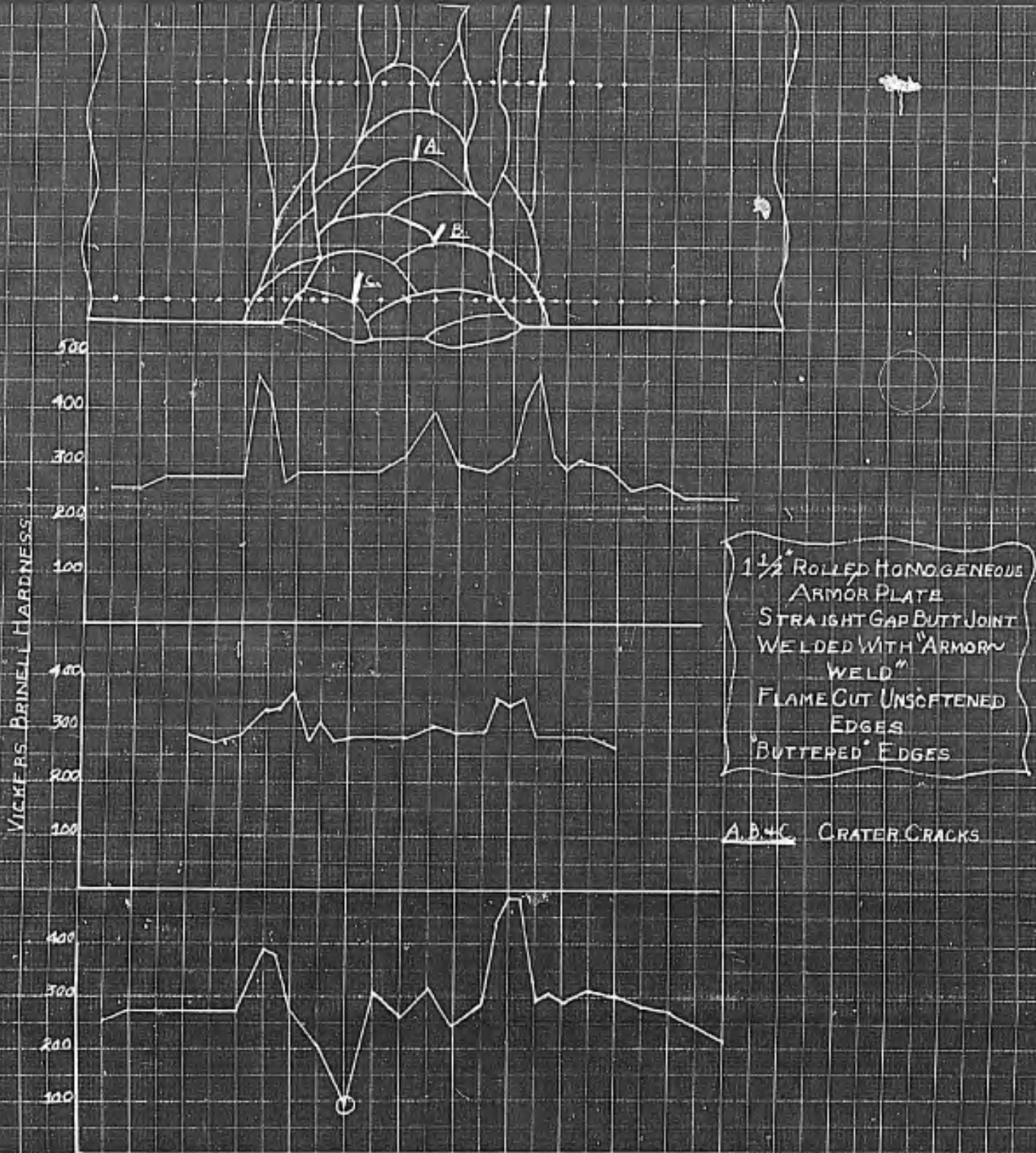


FIG. 14

SK 645-15

JAN 21/27/42

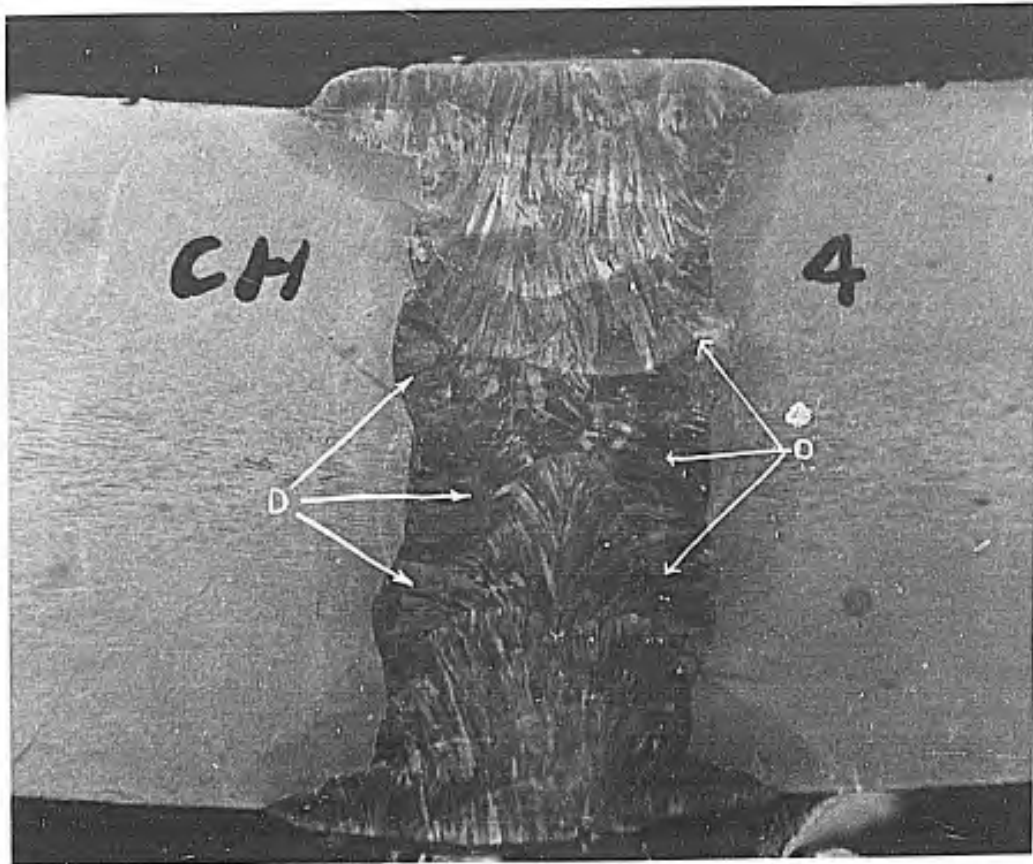


FIG. 15

X 2½

CROSS SECTION AREA # 4, PLATE "C" (FIG 33A) UNSOFTENED EDGES.
ELECTRODE - "ARMORWELD"

D - BUTTERING LAYER

W.A.639-3689

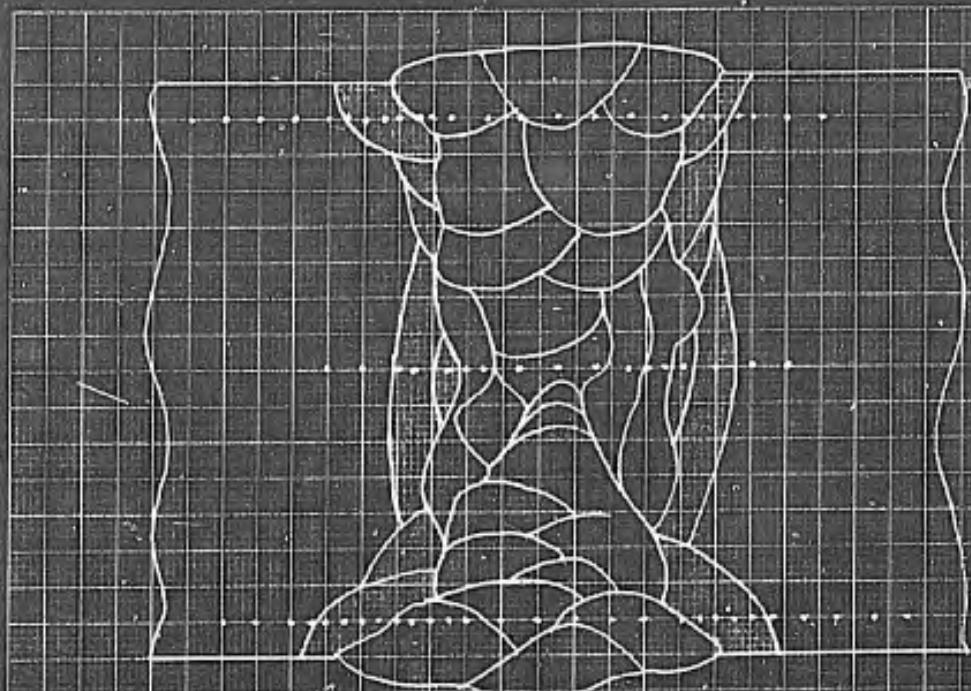
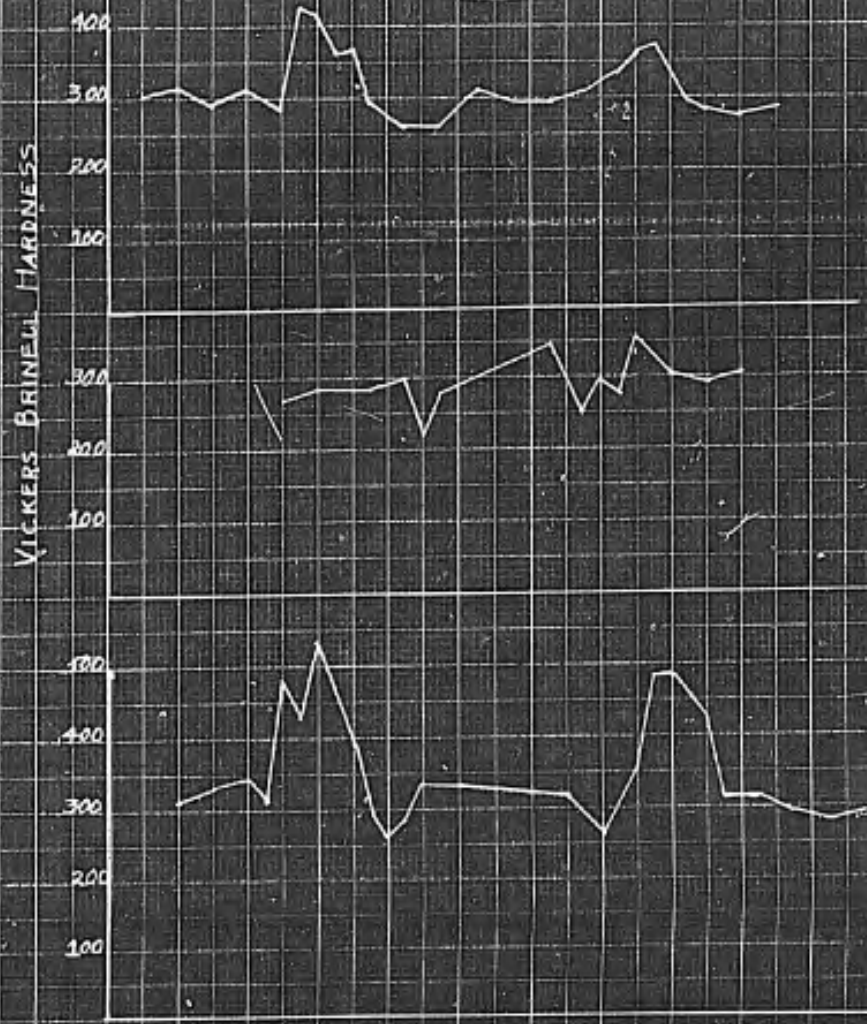


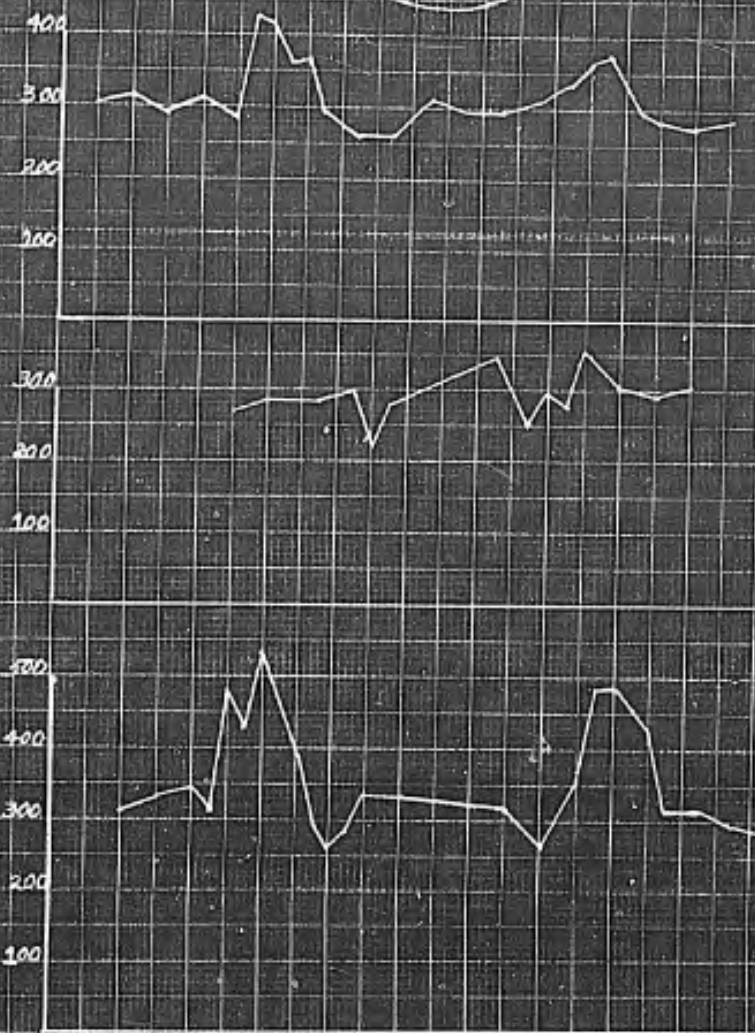
PLATE C
AREA 4
CH 4



1 1/2" ROLLED HOMOGENEOUS
ARMOR PLATE
STRAIGHT GAP BUTT
JOINT
WELDED WITH "ARMORWELD"
FLAME CUT UNSOFTENED
EDGES

FIG 16

VICKERS BRINELL HARDNESS



1 1/2" ROLLED HOMOGENEOUS
ARMOR PLATE
STRAIGHT GAP BUTT
JOINT
WELDED WITH "ARMORWELD"
FLAME CUT UNSOFTENED
EDGES

FIG 16

SK 645-16

JAN 12/1/41

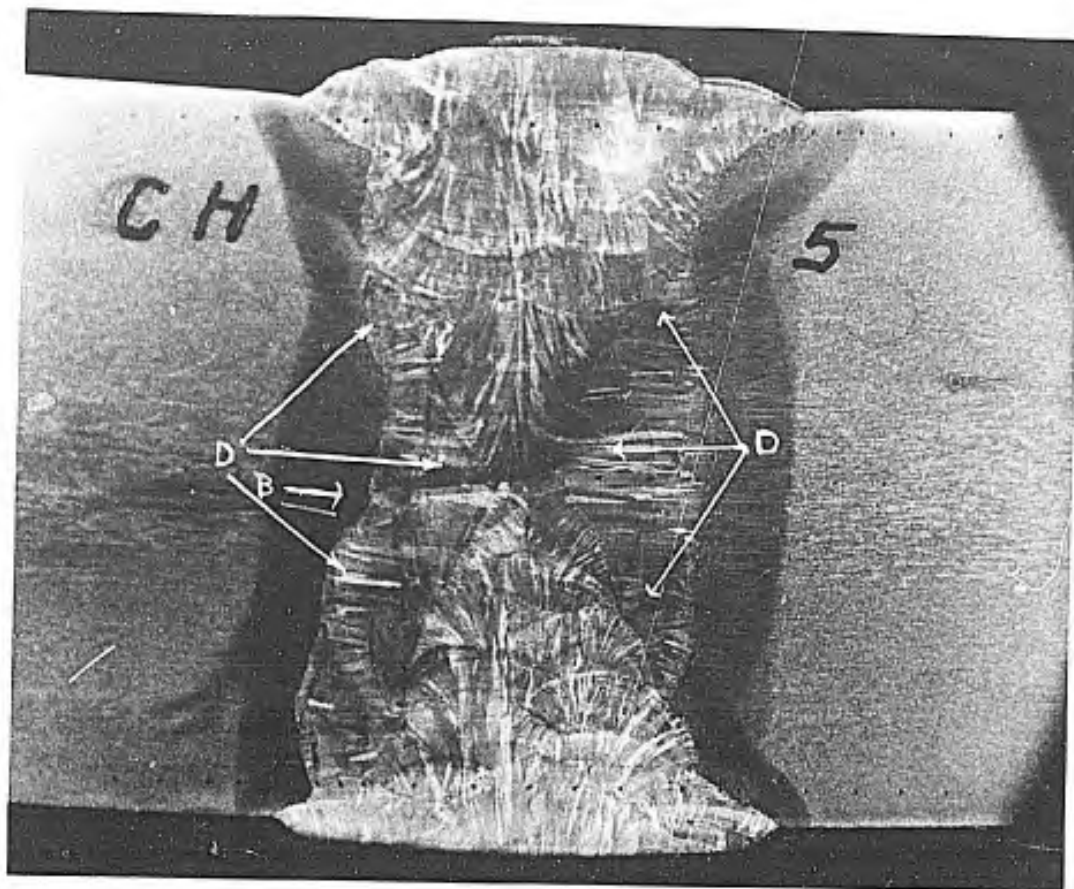


FIG. 17

x 2½

CROSS SECTION AREA # 5, PLATE "C" (FIG 33A) UNSOFTENED EDGES.
ELECTRODE - "ARMORWELD"

B - LACK OF FUSION
D - BUTTERING LAYER

W.A.639-3690

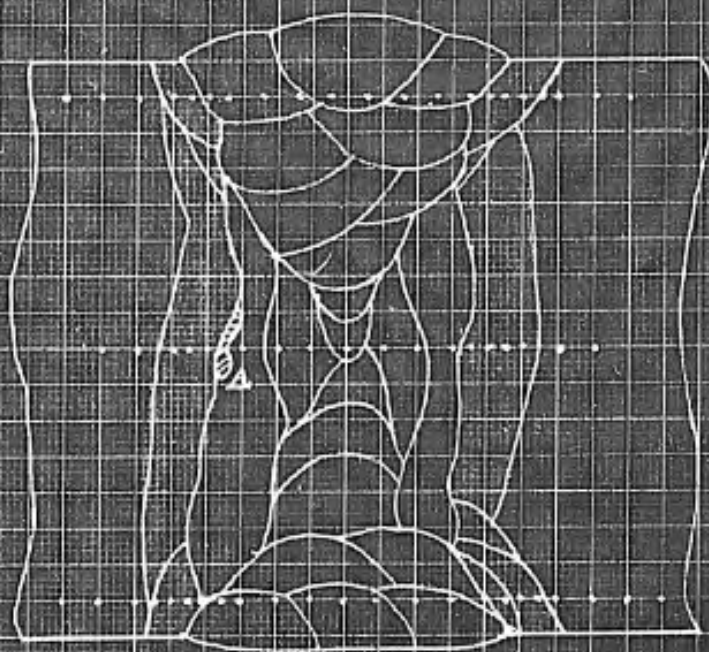
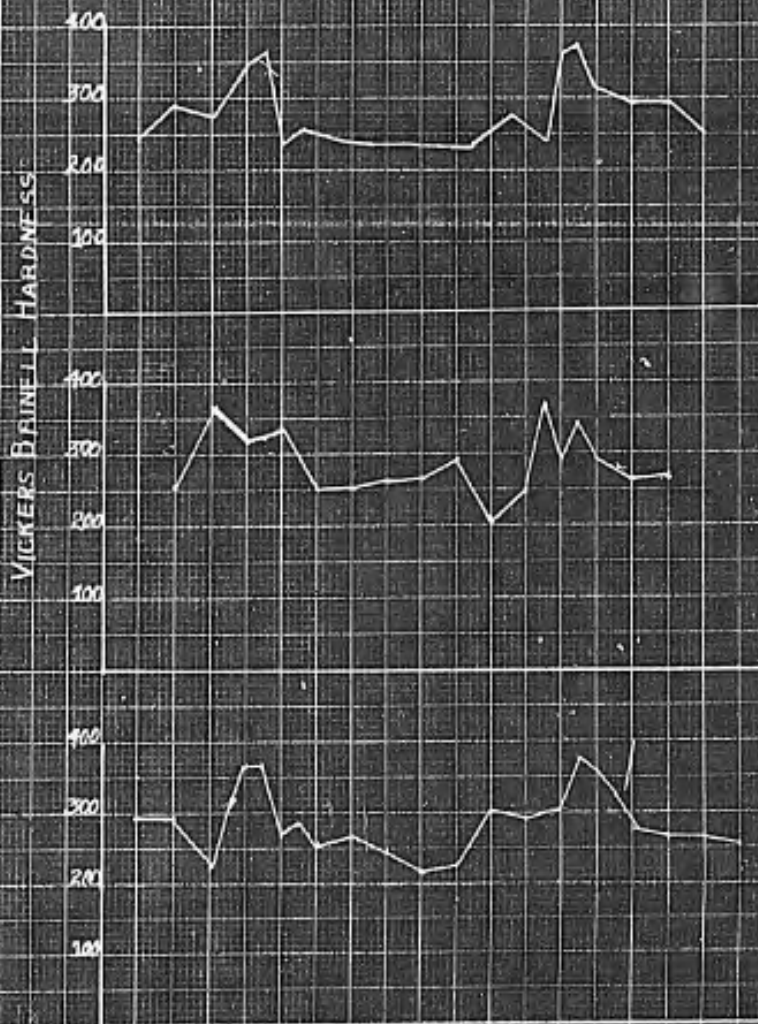
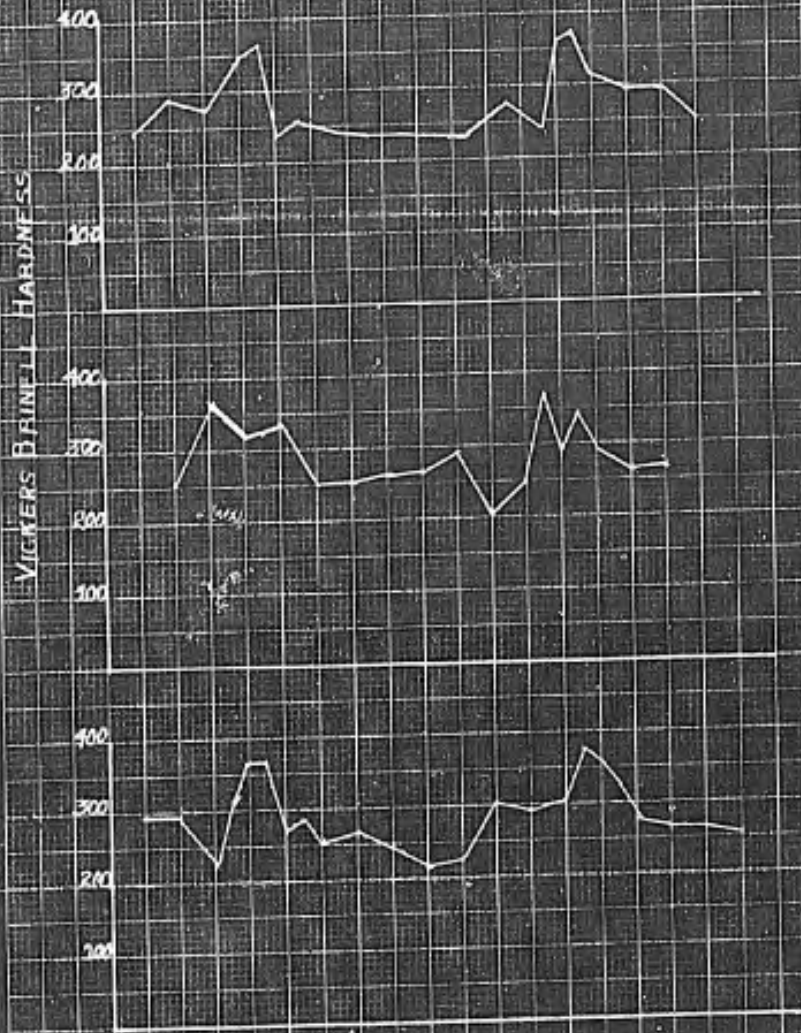
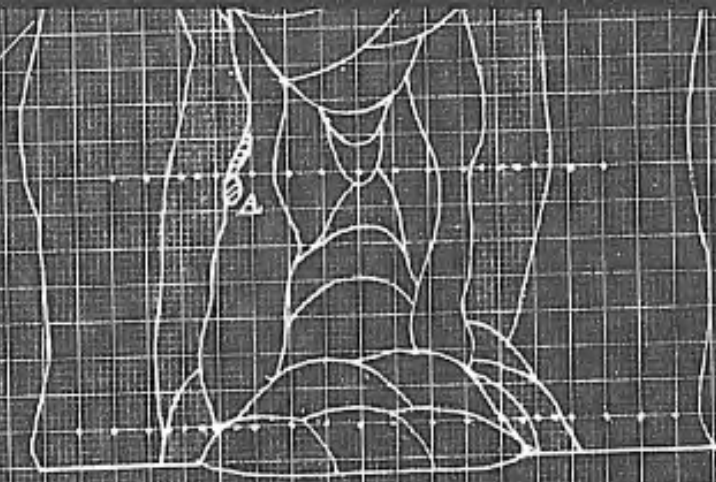


PLATE C
AREA 5
CH 5



$1\frac{1}{2}$ " ROLLED HOMOGENEOUS
 ARMOR PLATE
 STRAIGHT GAP BUTT JOINT
 WELDED AND "BATTERED"
 WITH "ARMORWEED"
 UNSOFTENED FLAME CUT EDGES

A. LACK OF FUSION



$1\frac{1}{2}$ " ROLLED HOMOGENEOUS
 ARMOR PLATE
 STRAIGHT GAP BUTT JOINT
 WELDED AND BUTTERED
 WITH "ARMOR WEED"
 UNSOFTENED FLAME CUT EDGES

A. LACK OF FUSION.

FIG. 18

PHOTOMICROGRAPHS OF

WELD CROSS SECTIONS

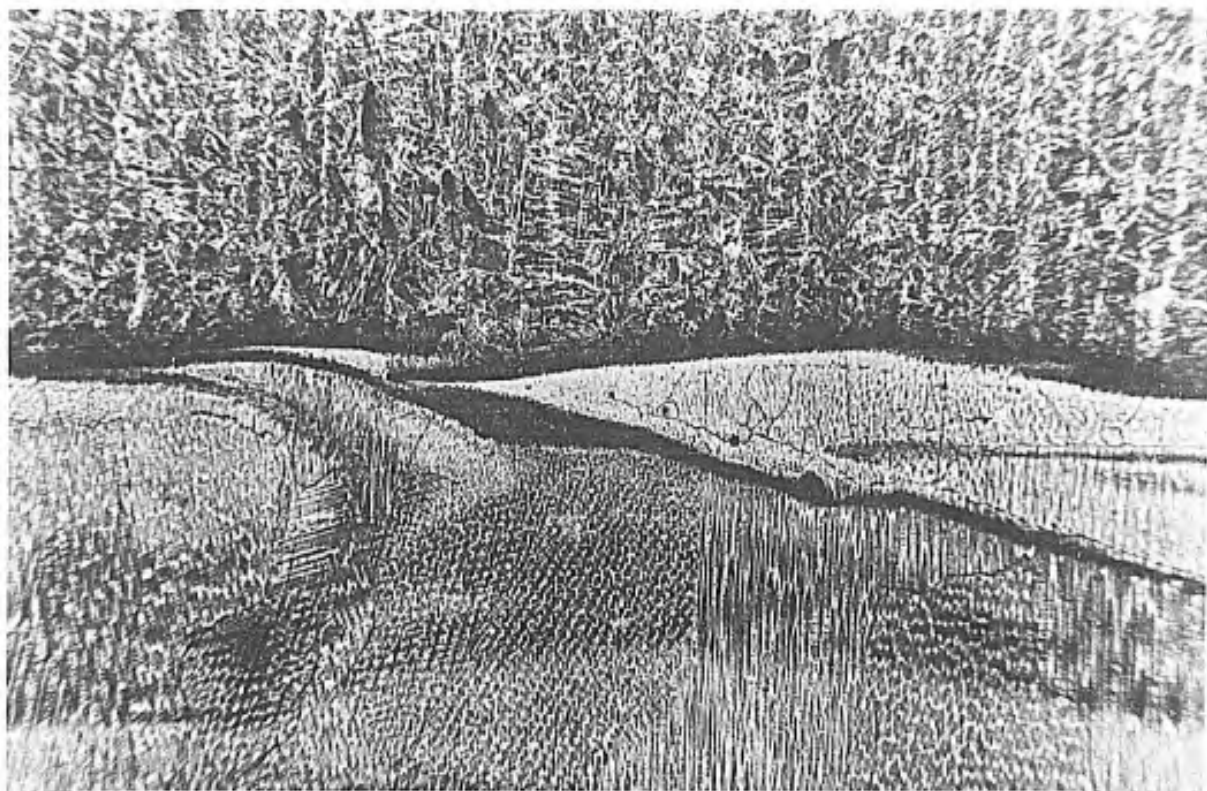


FIG 19A

ETCH, FECL X 100

BOUNDARY OF BASE METAL AND WELD METAL AT FIRST BUTTERING LAYER. NOTE DENDRITIC STRUCTURE, DILUTION OF BASE METAL IN WELD METAL AND DARK NARROW BAND AT FUSION LINE, POSSIBLY MARTENSITE. FLAME SOFTENED.

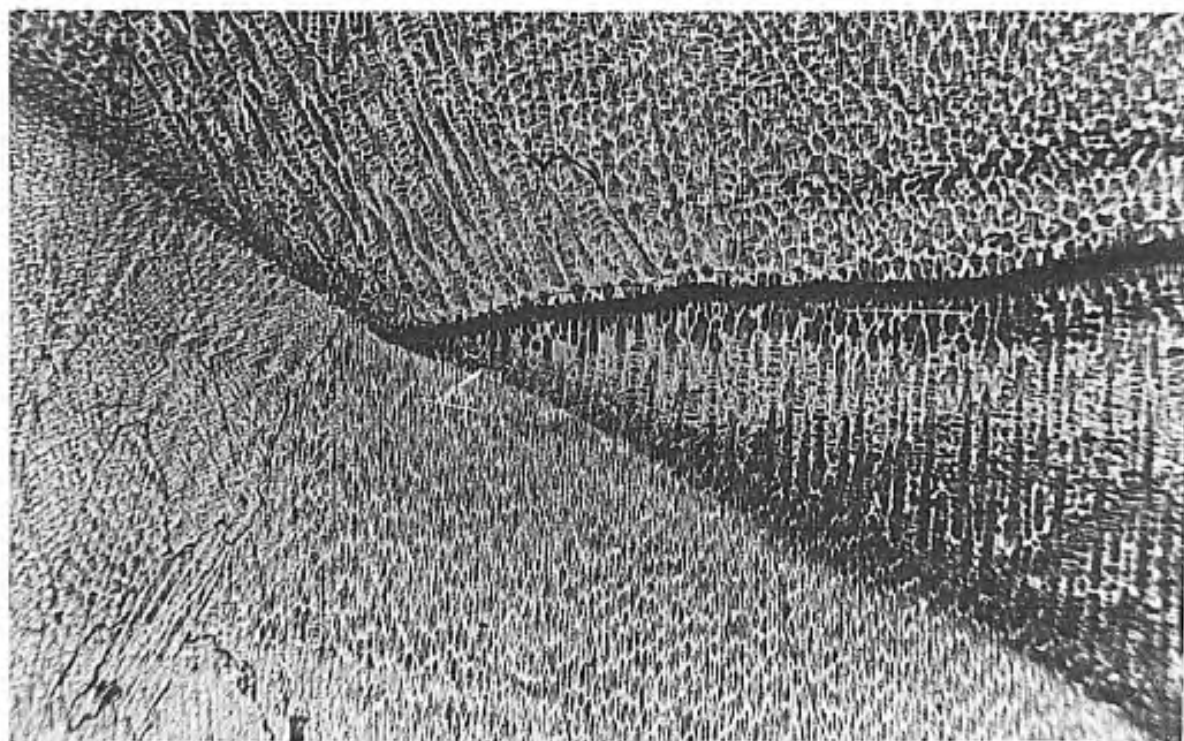


FIG 19B

ETCH, FECL X 100

BOUNDARY OF FIRST AND SECOND BUTTERING LAYERS SHOWING PARALLEL DENDRITIC STRUCTURE IN MODIFIED 18/8 WELD METAL. DECEMBER 12 1941

W.A. 639-3706



FIG 20

PANORAMA OF FUSION ZONE SHOWING DILUTION OF BASE METAL IN WELD
METAL AND DENDRITIC STRUCTURE OF WELD METAL.
DECEMBER 12 1941

W.A. 639-3705

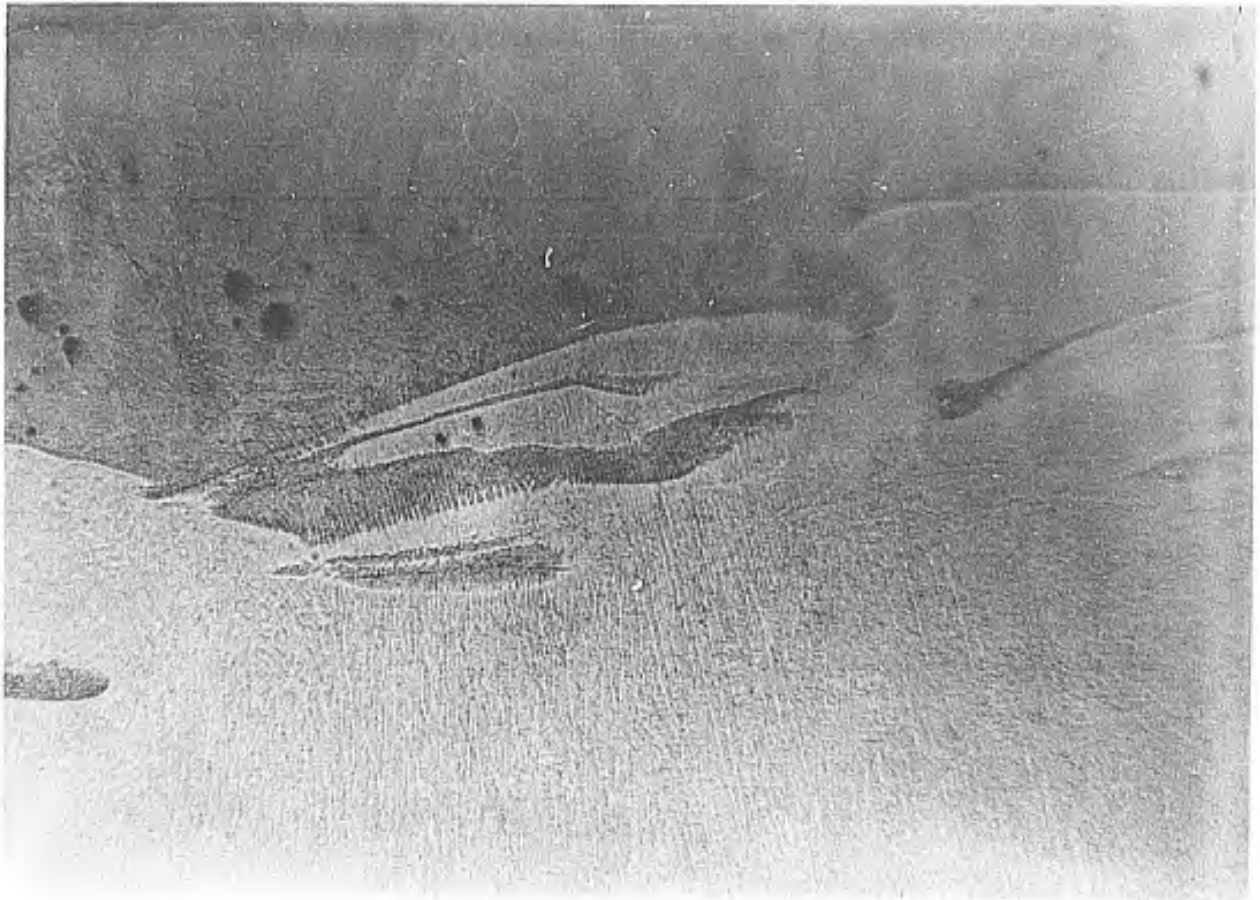


FIG 21
ETCH, FECL X 100
BOUNDARY OF BASE METAL AND 25/20 STAINLESS WELD METAL
AT FIRST BUTTERING LAYER. NOTE DILUTION OF BASE
METAL AND DENDRITIC STRUCTURE OF WELD METAL.
DECEMBER 13 1941
W.A.639-3709

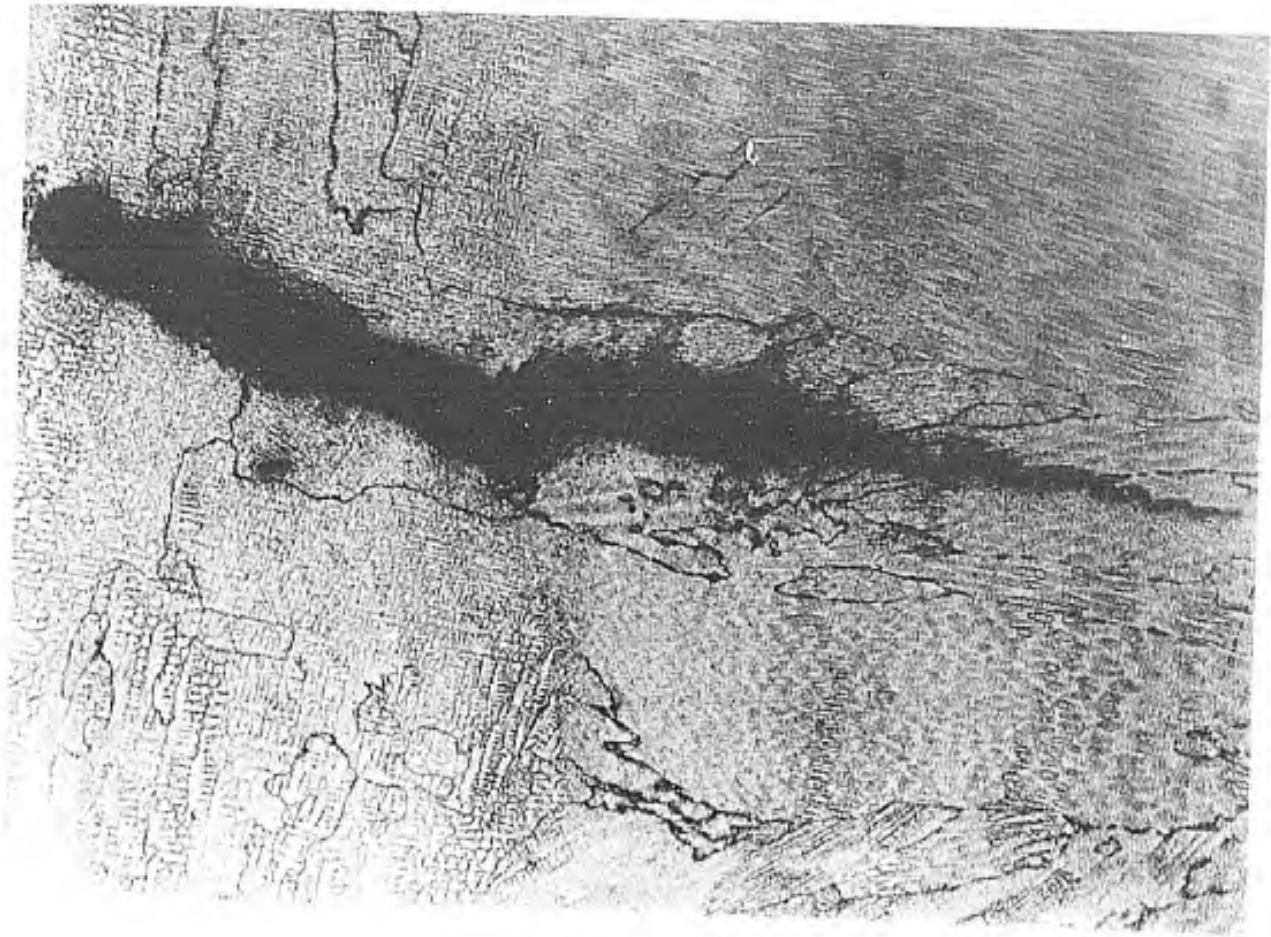


FIG 22

ETCH FECL X 100

SHRINKAGE CRACK IN ROOT ZONE OF WELD METAL. NOTE
PARALLEL DENDRITES IN RELATION TO CRACK.

DECEMBER 13 1941

W.A.639-3710

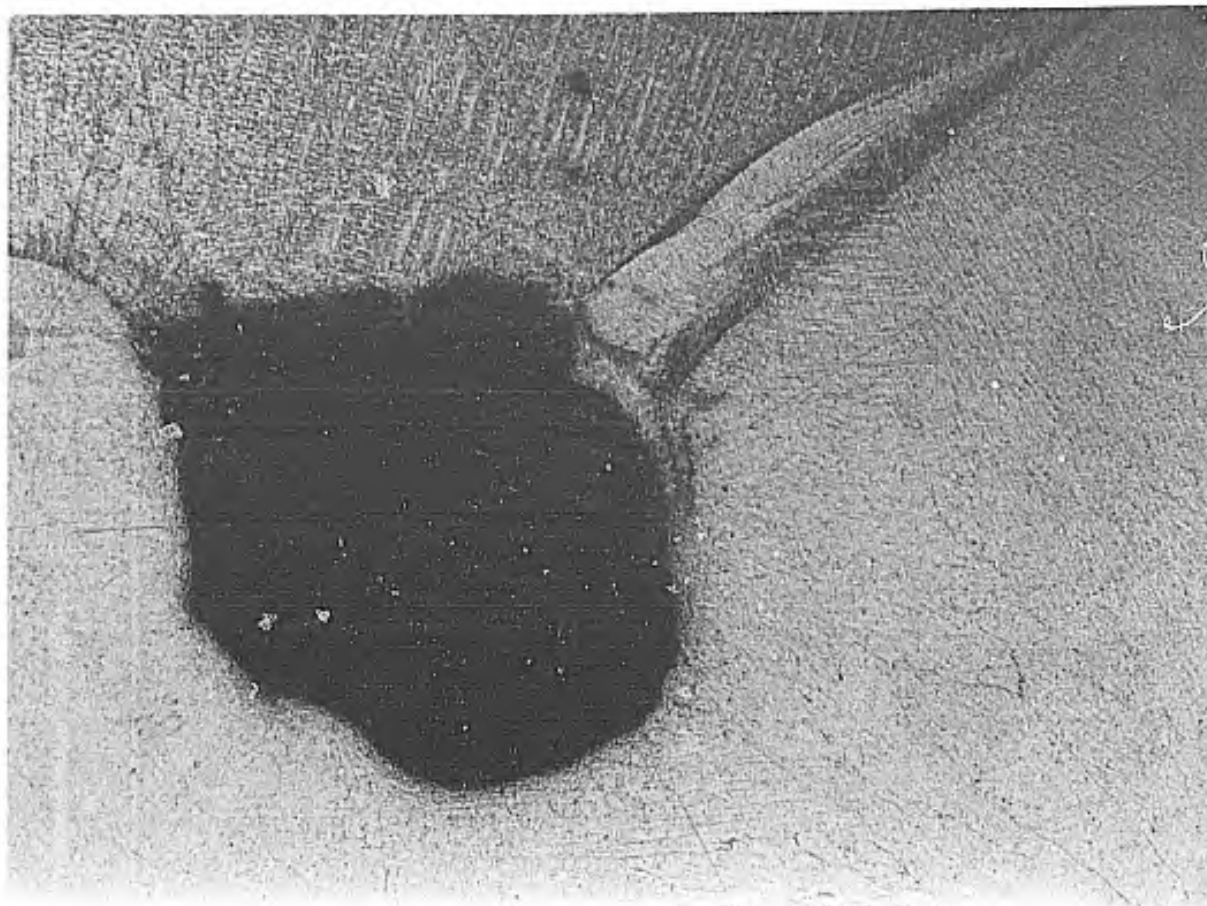


FIG 23A
LACK OF FUSION WORMHOLE BETWEEN BUTTERING NOSE BEAD
AND JOINING WELD METAL. DEC 13 1941 W.A.639-3711
ETCH FECL X 100

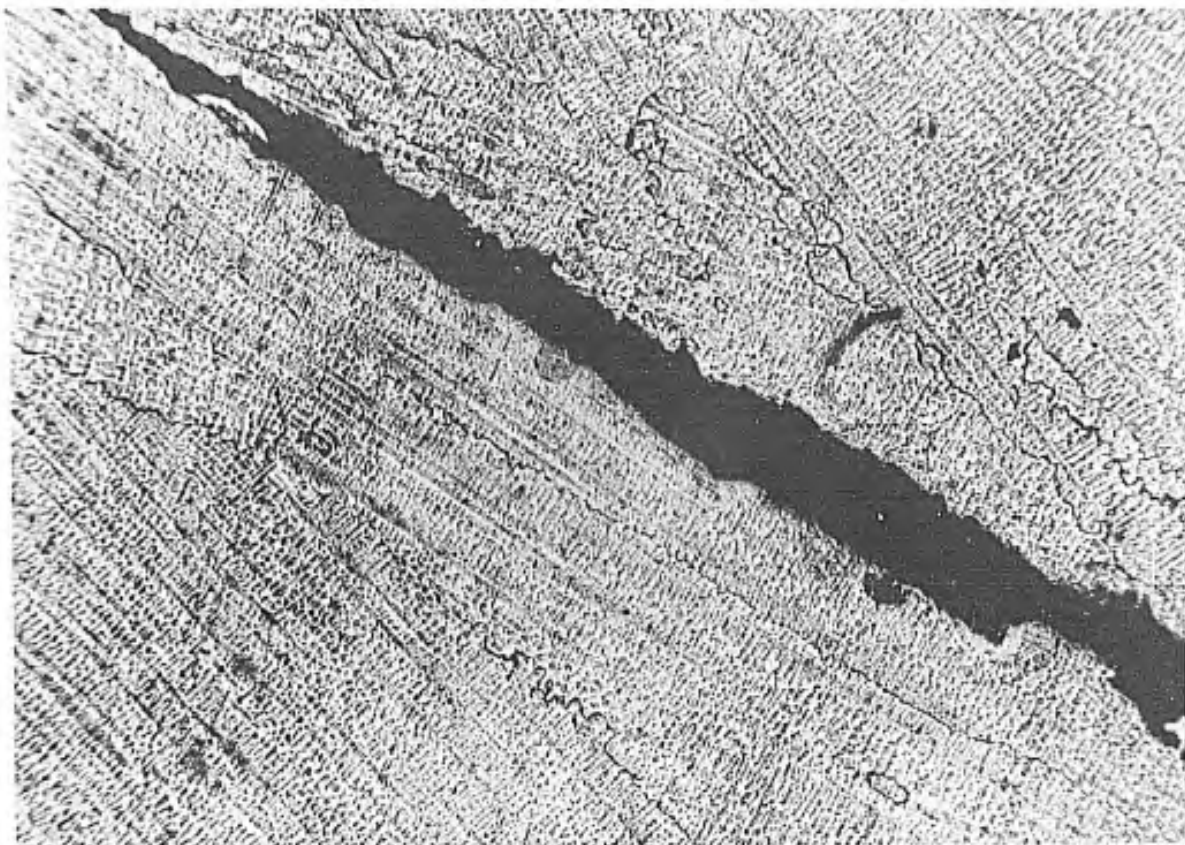


FIG 24A ETCH, FECL X 100
TRANSGRANULAR SHRINKAGE CRACK PARALLEL TO DENDRITES IN MODIFIED
18/8 WELD METAL. DECEMBER 12 1941 W.A.639-3707

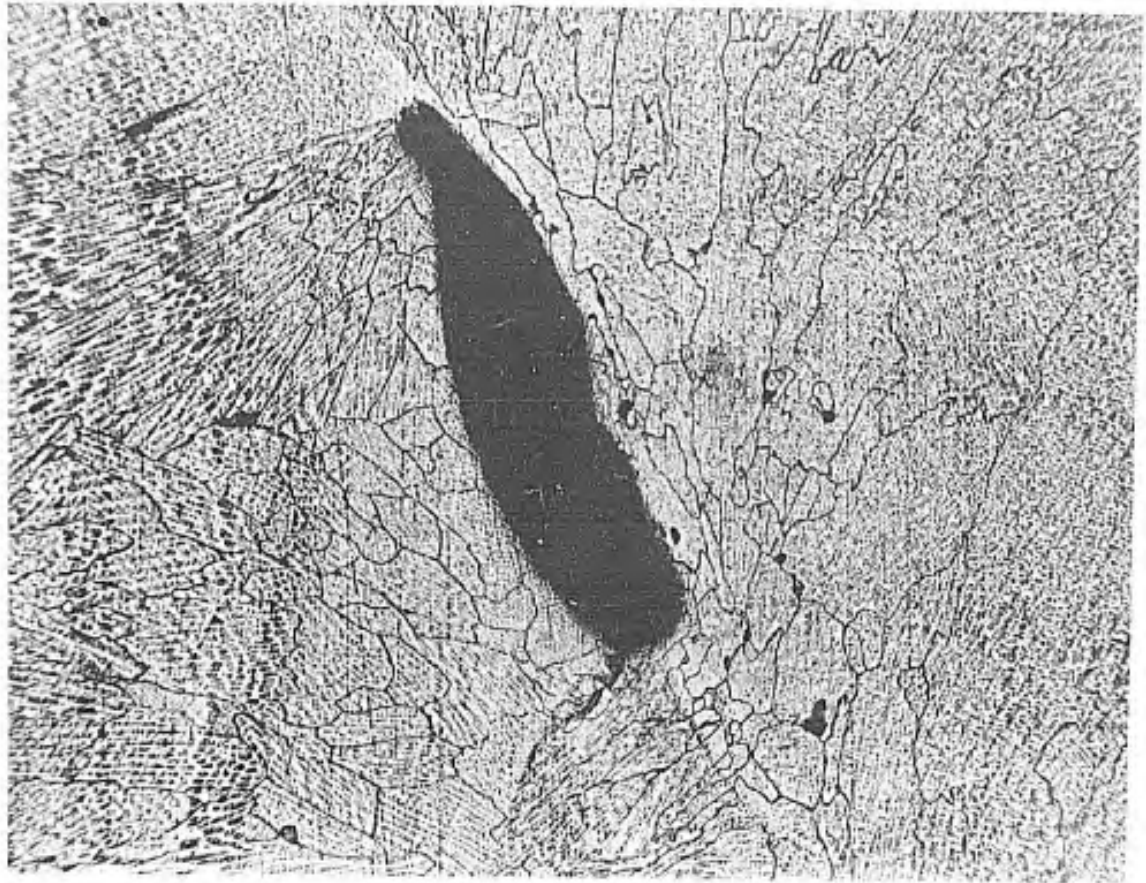


FIG 24B

SLAG INCLUSIONS IN MODIFIED 18/8 WELD METAL. NOTE SMALL SLAG SPOTS
AT GRAIN BOUNDRIES. DECEMBER 12 1941

W.A.639-3708

TENSILE TESTS OF

BUTT JOINTS

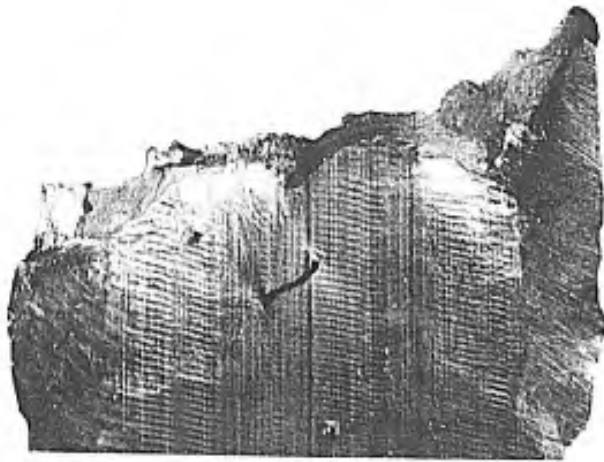


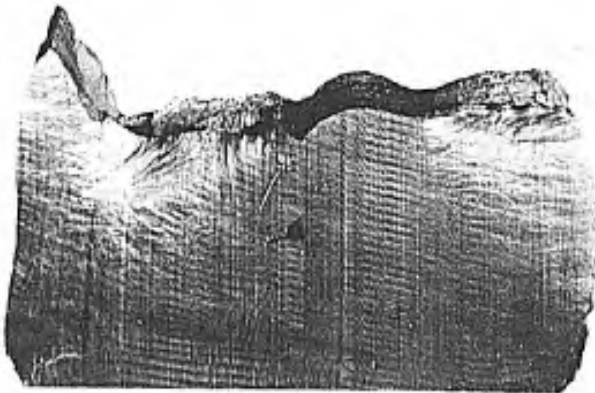
FIGURE 25

TENSILE SPECIMENS OF PLATE "A".
NOTE COARSE DENDRITIC STRUCTURE
AND LACK OF FUSION.

TOP
BOTTOM

ACT 2 - 1
ACT 2 - 2

W.A.639-3691



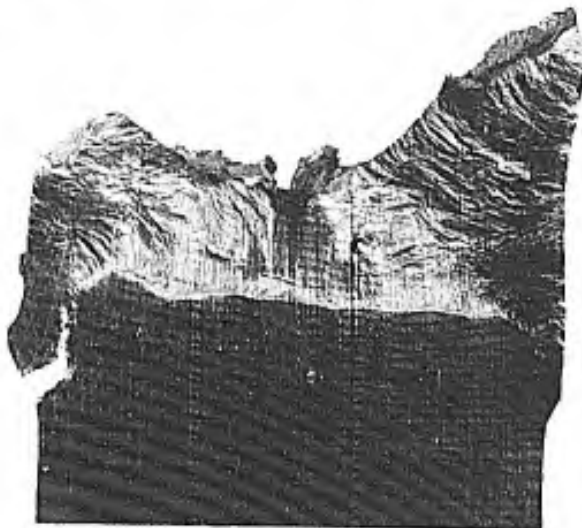
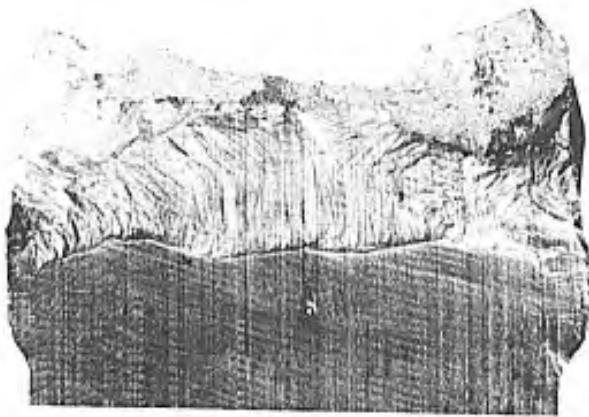


FIGURE 26

TENSILE SPECIMENS OF PLATE "B".
NOTE GAS CAVITIES AND CRACKS

TOP
BOTTOM

BCT 1 - 1
BCT 1 - 2

M.A.639-3692

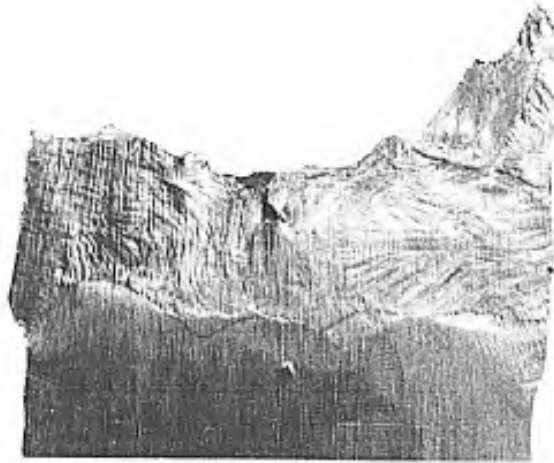


FIGURE 27

TENSILE SPECIMENS OF PLATE "C".
NOTE CRACK AND SLAG INCLUSIONS

TOP CCT 3 - 1
BOTTOM CCT 3 - 2

W.A.639-3693



TENSILE TESTS OF

WELD METAL

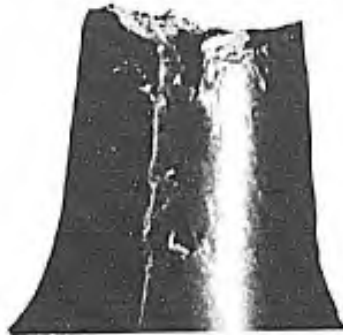


FIGURE 28

WELD METAL TENSILE SPECIMENS OF
PLATE "A" SHOWING CRACKS AND
GAS CAVITIES.

TOP
BOTTOM

AT - 1
AT - 4

W.A.639-3694

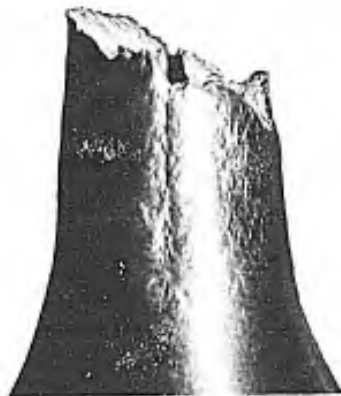




FIGURE 29

WELD METAL TENSILE SPECIMENS OF
PLATE "B" SHOWING FINE GRAIN
STRUCTURE AND SEGREGATIONS.

TOP
BOTTOM

BT - 3
BT - 5

W.A.639-3695



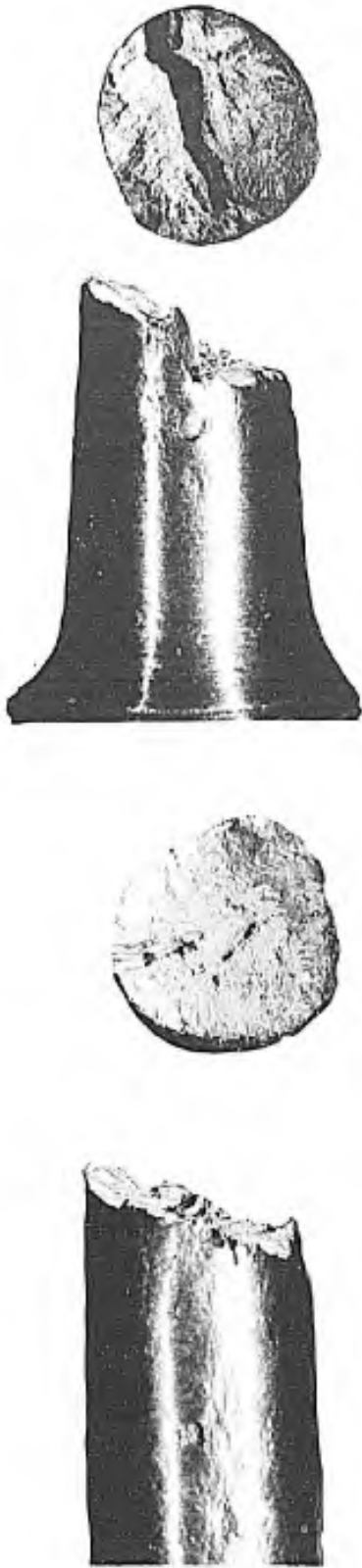
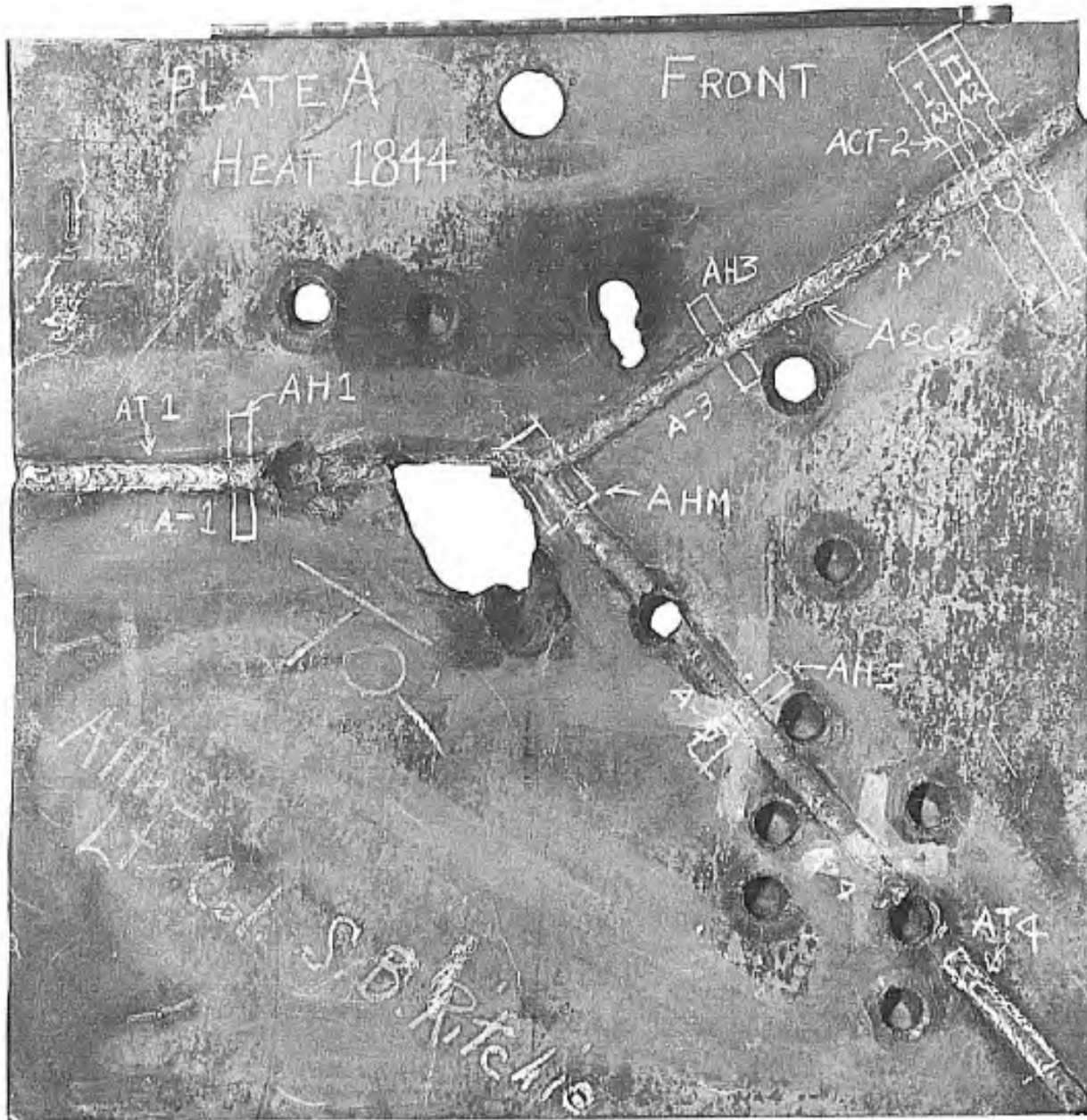


FIGURE 30
WELD METAL SPECIMENS IN PLATE "C"
SHOWING GAS CAVITIES AND CRACKS .
W.A. 639-3696

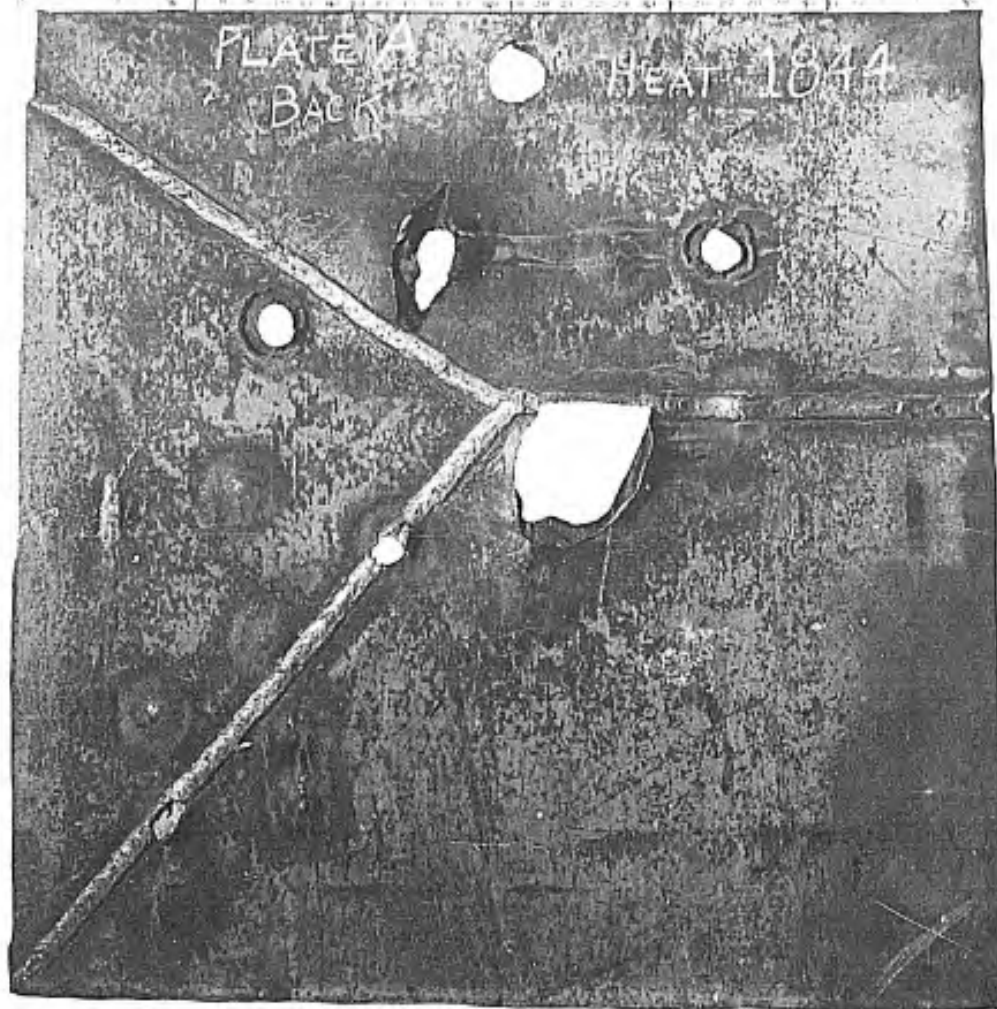
ILLUSTRATIONS OF
PLATES AS RECEIVED
AT
WATERTOWN ARSENAL
AFTER BALLISTIC TESTS
AT
ABERDEEN PROVING GROUND
(Note Specimen Layout)



WATERTOWN ARSENAL

1 1/2" ROLLED HOMOGENEOUS ARMOR 36" X 36". "Y" JOINT OF LINCOLN "ARMORWELD"
 FLAME SOFTENED EDGES. REF: A.P.G. REPORT PI15 A1144. HEAT #1844
 OCTOBER 1, 1941 W.A. 710-1437

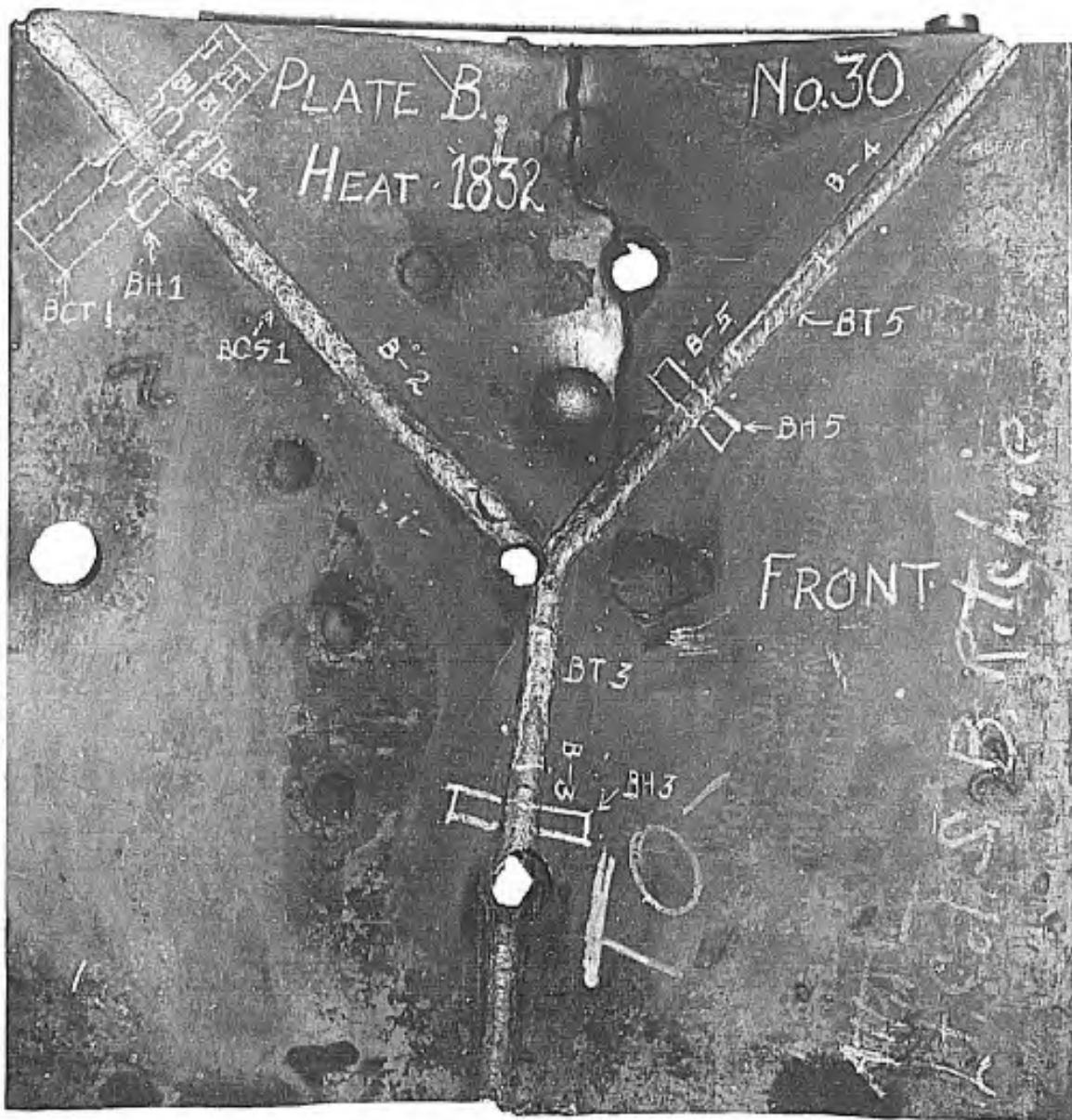
Fig. 31a



WATERTOWN ARSENAL

1 1/2" ROLLED HOMOGENEOUS ARMOR 36" X 36". "Y" JOINT OF LINCOLN "ARMORWELD"
FLAME SOFTENED EDGES. REF: A.P.G. REPORT P115 A1144. HEAT #1844
OCTOBER 1, 1941 W.A. 710-1442

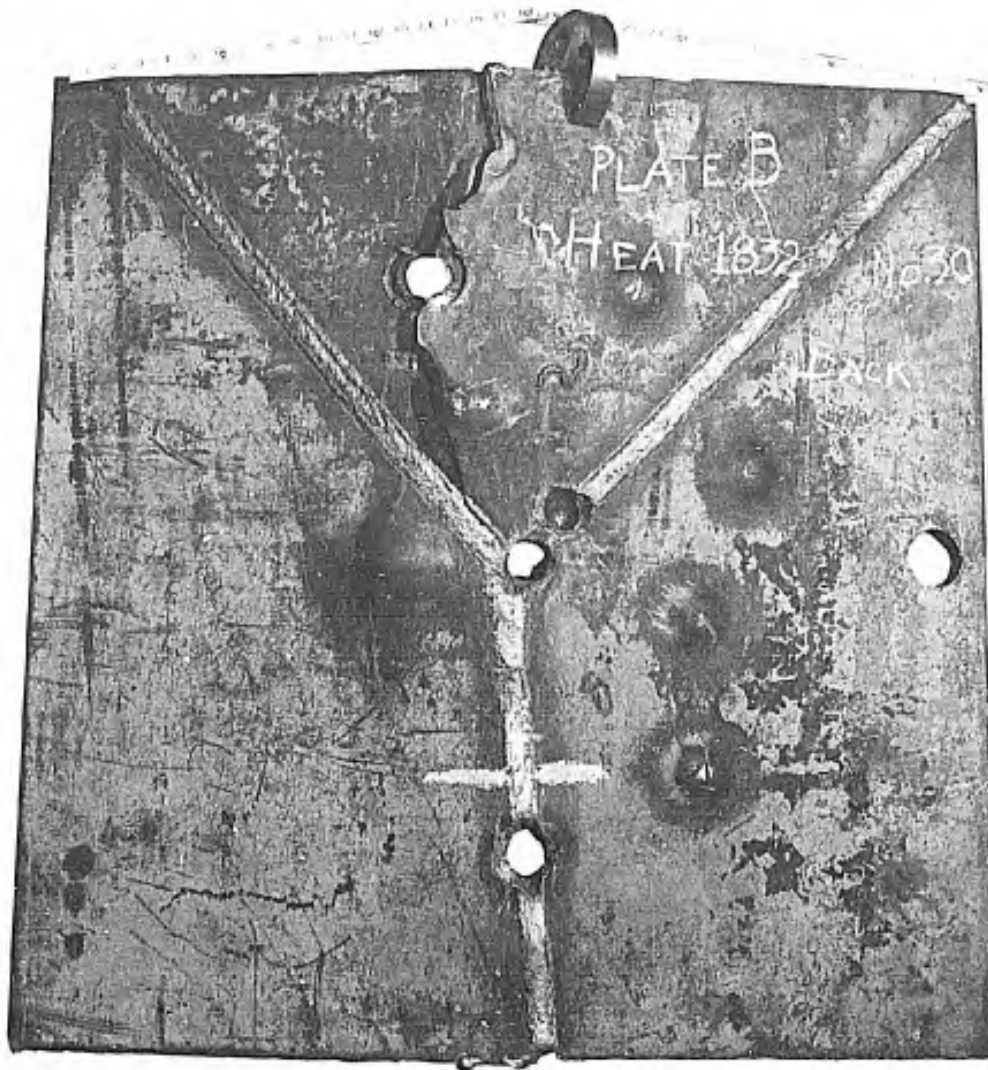
Fig. 31b



WATERTOWN ARSENAL

1 1/2" ROLLED HOMOGENEOUS ARMOR 36" x 36". "Y" JOINT OF LINCOLN 25/20
 FLAME SOFTENED EDGES. REF: A.P.Q. REPORT P115 A1144 HEAT #1832
 OCTOBER 1, 1941 W.A. 710-1438

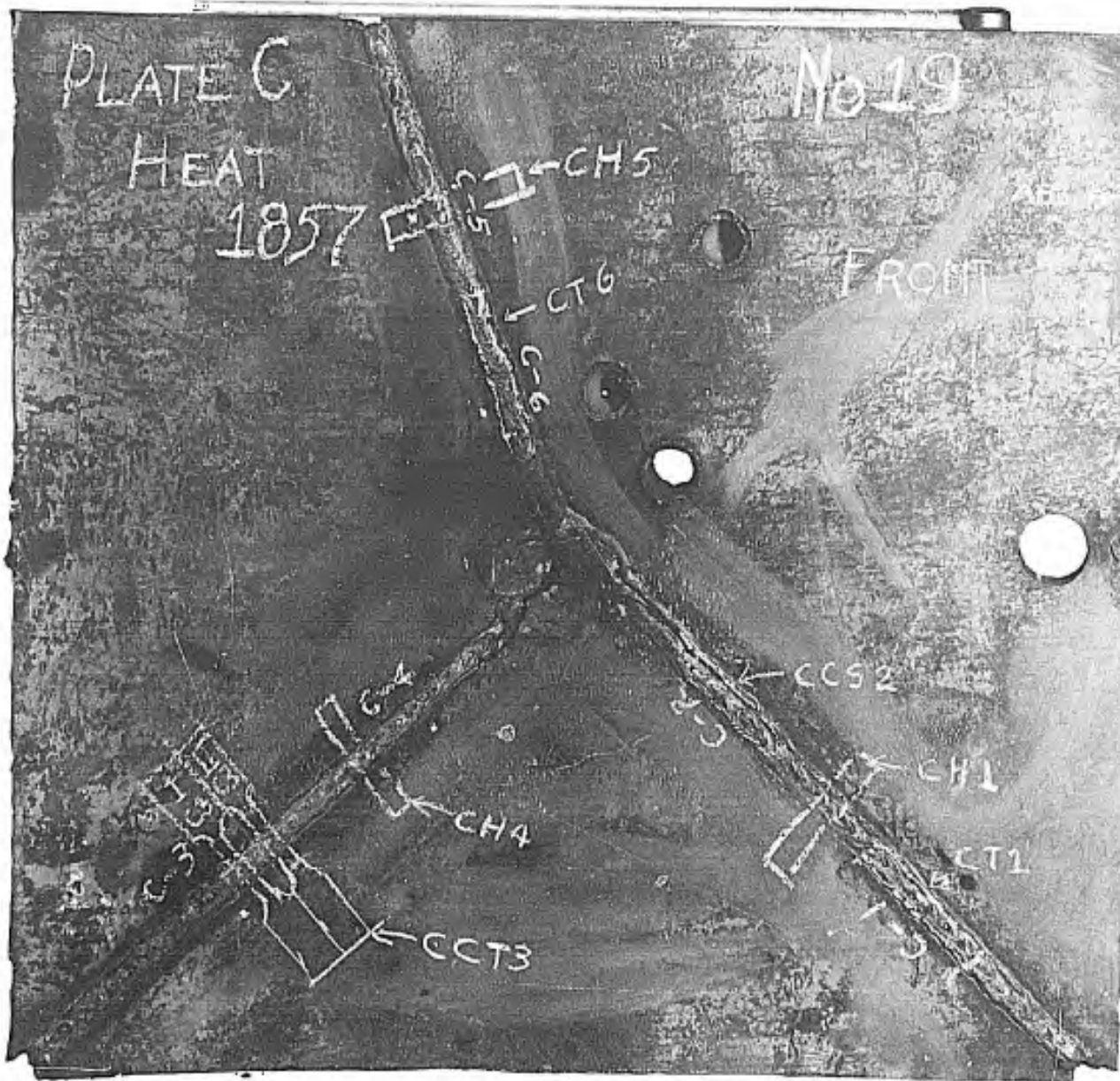
Fig. 32a



WATERTOWN ARSENAL

1 1/2" ROLLED HOMOGENEOUS ARMOR 36" X 36". "Y" JOINT OF LINCOLN 25/20
FLAME SOFTENED EDGES. REF: A.P.G. REPORT P115 A1144 HEAT #1632
OCTOBER 1, 1941 W.A.710-1443

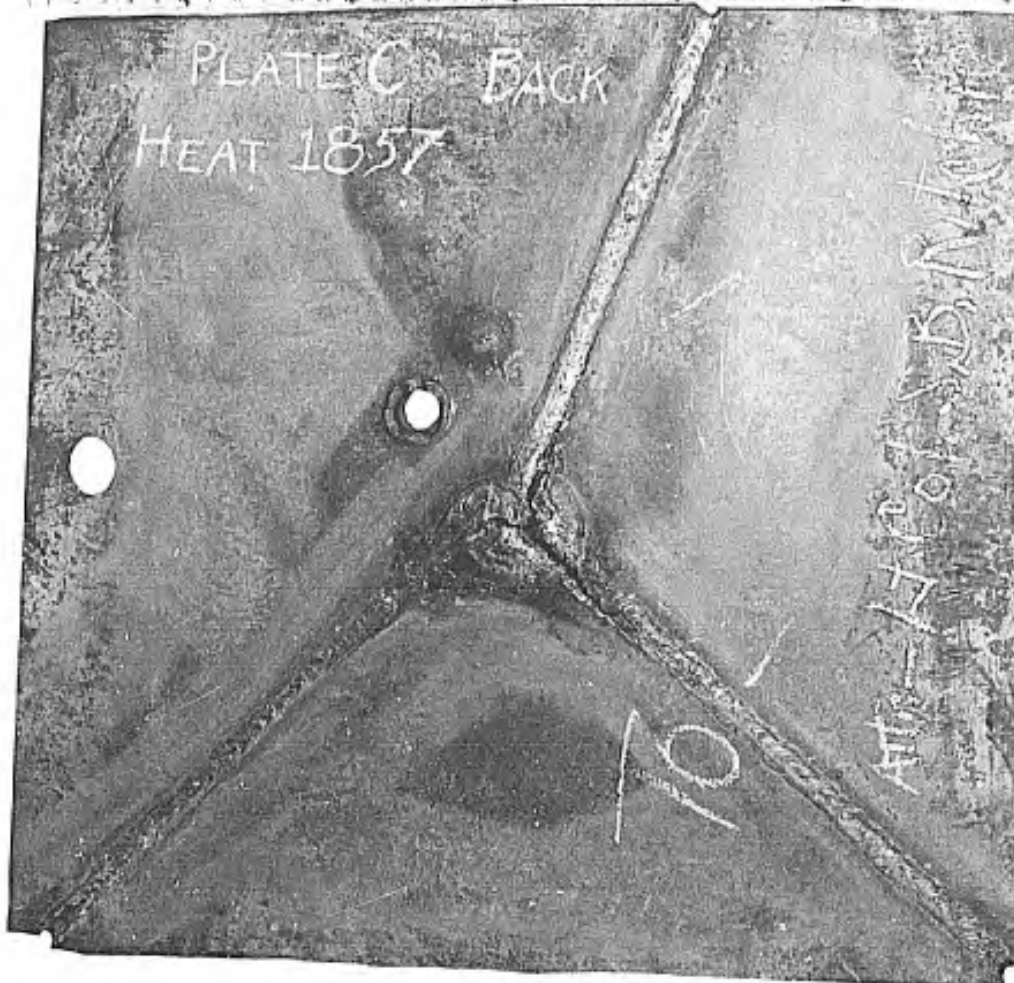
Fig. 32b



WATERTOWN ARSENAL

1 1/2" ROLLED HOMOGENEOUS ARMOR 36" x 36", "Y" JOINT OF LINCOLN "ARMORWELD"
 UNSOFTENED EDGES. REF: A.P.G. REPORT PI15 A1144 HEAT #1857
 OCTOBER 1, 1941 W.A. 710-1439

Fig. 33a



WATERTOWN ARSENAL

1 1/2" ROLLED HOMOGENEOUS ARMOR 36" X 36". "Y" JOINT OF LINCOLN "ARMORWELD"
UNSOFTENED EDGES. REF: A.P.G. REPORT P115 A1144 HEAT #1857
OCTOBER 1, 1941 W.A.710-1444

Fig. 33b