[illegible] REPORT [illegible]

[illegible]

[illegible]

[illegible] ROLLED HOMOGENEOUS [illegible]

By

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[illegible] Physical Science Aide

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Welding Engineer

[illegible] 15, 19[illegible]

WATERTOWN ARSENAL
WATERTOWN, MASS.

Memorandum Report No. 648/4
Watertown Arsenal

November 15, 1941

Arc Welding of Armor

Butt Welds - 1" Rolled Homogeneous Armor

OBJECT

To determine whether satisfactory resistance to penetration could be obtained from a butt weld made in 1" armor plate with a modified 18/8 stainless welding electrode.

1. To determine the effect on the resistance to penetration of a butt weld made with 18/8 stainless welding electrode when a hard facing weld metal is deposited on the last layer of the butt weld.

2. To determine the effect on the resistance to penetration of a butt weld made with 18/8 stainless welding electrode when different amounts of molybdenum and vanadium are present in the electrode.

CONCLUSIONS

According to the tests covered by this report the following have been noted as applying to butt welds in rolled homogeneous armor of high carbon content:

1. The resistance to penetration of a butt weld made in 1" armor plate with a modified 18/8 stainless welding electrode is approximately 2250 ft./sec. with .50 caliber A.P. ammunition at 100-yard range.

2. The resistance to penetration of a butt weld made in 1" armor plate with modified 18/8 stainless electrode and a hard facing weld metal on the last layer of the butt weld is approximately 2450 ft./sec. with .50 caliber A.P. ammunition at 100-yard range.

3. The resistance to penetration of a butt weld in 1" armor plate made with modified 18/8 stainless welding electrode containing different percentages of molybdenum does not vary appreciably with a change in molybdenum content. (Molybdenum 2½% and 1.8%)

4. The resistance to penetration of a butt weld in 1" armor plate made with a modified 18/8 stainless welding electrode containing approximately 1.0% vanadium is the same as the resistance to penetration of a butt weld made with a modified 18/8 stainless welding electrode containing molybdenum.

5. Cracks due to welding occur in the surface layer of the hard facing electrode used, but not in the weld metal of the modified 18/8 stainless electrode.

6. The hardness of the heat-affected zone set-up in a plate when a pad is used at the root surface of the joint is less than the hardness of the heat-affected zone when no pad is used.

7. There is apparently no difference in the resistance to penetration of a double vee joint and a single vee joint.

MATERIALS AND METHODS

The plates used in these tests were butt welded without preheating. The types of butt joints used were the 60° single vee and double vee. Two double vee butt joints were made with padding on the root face of the plates before the joint was welded. In both cases the same type of electrode was used to make the joint and apply the padding.

The plate material used was of the following approximate composition:

C	Mn	Si	P	S	Cr	Mo	V
0.49	0.56	0.23	0.019	0.019	1.22	0.60	0.20

The welding data and the types of joints used with the different electrodes are given in Table 1.

TABLE I

Welding Data

Plate	Electrode	Size	Joint	No. of Passes	Amp.	Volts
R1	Resistal 18/8 + 2.5% Mo	1/8"	Pad	3	75	21
	"	5/32"	Double Vee	4 front	125	21
	"	"		6 back	165	21
	Hartung	"		2 face	140	21
Box 6 End 11	Resistal 18/8 + 2.5% Mo	3/16"	Single Vee	8	185	21
	Dymonhard #65	5/32"		2 face	160	20
Box 6 End 12	Resistal 18/8 + 2.5% Mo	3/16"	Single Vee	12	180	21
Box 6 Side 1	Resistal 18/8 + 1.81% Mo	5/32"	Double Vee	4 front	140	21
				5 back	135	22
	Hartung	5/32"		1 face	135	21
Box 6 Side 2	Resistal 18/8 + 1.81% Mo	5/32"	Double Vee	6 front	145	22
				6 back	150	22
V1	Resistal 18/8 + 1% V		Double Vee With Pad	Not Welded at Watertown Arsenal		

It will be noted in Table I that two double vee butt joints were made with a hard facing electrode on the surface layer. In the different plates the 18/8 electrodes used contained different percentages of molybdenum. After welding, the plates were radiographed and then subjected to a firing test with .50 caliber A.P. ammunition at 100-yard range. Cross sections for macroexamination and hardness surveys were taken from the tested plates.

RESULTS

Radiographic tests showed all butt welds, with one exception, to be sound. The 18/8 electrode produced a sound weld, but one type of hard facing weld metal over the 18/8 had a network of fine cracks over its whole area and small amounts of porosity. (Box 6 End 11, Figures 3-4)

The data from the firing tests are shown in Table II.

TABLE II

Penetration Tests

Plate	Ballistic Limit		Specified Limit (Minimum)	Bal. Eff.	Type of Joint & Electrode
	Cal..50 AP TIE 9 On Plate	On Weld			
R1	2350 f/s	2450 f/s	2250 f/s	109%	Double Vee Padded and Surfaced With Hard Facing
Box 6 End 11	2400 f/s	2450 f/s	2250 f/s	109%	Single Vee 18/8 - 2.5% Mo and Hard Facing
Box 6 End 12	2200 f/s	2250 f/s	2250 f/s	100%	Single Vee 18/8 - 2.5% Mo
Box 6 Side 1	2250 f/s	2250 f/s	2250 f/s	100%	Double Vee 18/8 - 1.81% Mo and Hard Facing
Box 6 Side 2	2350 f/s	2250 f/s	2250 f/s	100%	Double Vee 18/8 - 1.81% Mo
V1	2350 f/s	2250 f/s	2250 f/s	100%	Double Vee With Pad 18/8 - 1% V

The firing tests showed that the plates welded with 18/8 containing molybdenum, both with single vee and double vee butt joints, had a slightly higher resistance to penetration when a hard facing weld metal was used on the surface layer. It is also noted that the 18/8 with 2.5% molybdenum has a slightly higher resistance to penetration than 18/8 with 1.81% molybdenum although a hard facing electrode was used in both cases. This difference in resistance to penetration may be partly due to the padding on the root surface of the plate.

Cross sections of the specimens were polished and etched in 1% nital for hardness surveys and macroexamination.

The data on the average maximum hardness of each cross section are given in Table III.

TABLE III

Hardness Surveys

Plate		Weld Metal	Heat-Affected Zone	Base Metal
R1	Face	525*	575	415
	Back	225	545	415
Box 6 End 2	Face	190	675	355
	Back	225	500	350
Box 6 End 12	Face	235	510	325
	Back	230	675	315
Box 6 Side 1	Face	490	600	340
	Back	225	400	325
Box 6 Side 11	Face	705*	675	345
	Back	245	515	330
V 1	Face	275*	645	375
	Back	270	690*	375

*Cracks

The macroexamination showed that cracks and porosity occurred in the hard facing electrode (Box 6 End 12, Figure 5) but ended at the boundary of the 18/8 electrode.

The heat-affected zone of the 18/8 with 1% vanadium showed long cracks in the fusion zone due to the firing test.

DISCUSSION

From the welding data given in Table I it may be noted that two double vee butt joints were made with 18/8 containing different percentages of molybdenum and a hard facing electrode on the last face layer. In one of these plates a pad of 18/8 with molybdenum was put on the root face of the plates before welding. The plates treated in this manner and welded with 18/8 containing the greater percent of molybdenum had a higher resistance to penetration.

The double vee butt joints made without the hard facing electrode, but with molybdenum in one stainless electrode and vanadium in the other, had the same resistance to penetration regardless of the padding used in the latter case.

The firing tests showed that the plates welded with 18/8 electrode containing molybdenum both with single vee and double vee butt joints had a higher resistance to penetration when the hard facing electrode was used on the last pass. It is to be noted, however, that this condition existed only when the 18/8 with 2.5% molybdenum was used as the specimen made with the 18/8

and 1.81% molybdenum and hard facing electrode had a lower ballistic efficiency.

Radiographs after welding showed a network of cracks in one of the hard facing electrodes. (Box 6, End 11, Figures 3-4-14A & B) Macroexamination of this particular piece indicated that the cracks occurred only in the hard facing weld metal and ended definitely at the boundary of the 18/8 metal which showed no cracking. This hard facing electrode showed severe spalling in the firing test. (Figure 14)

The heat-affected zone of the 18/8 with 1% vanadium shows long cracks close to the fusion zone due to the firing test. Some of these cracks extend into the weld metal.

The maximum hardness for the hard facing electrode is much higher than that for 18/8 with molybdenum. (Charts in Figures 2-4-6)

In one case the hardness of the weld metal exceeds that of its heat-affected zone. (Figure 4). The size of the heat-affected zones in the specimen is small due to the multiple beads. The heat-affected zones of the 18/8 with vanadium is greater than that with molybdenum although multiple beads are used in both cases.

In comparing the 18/8 stainless welding electrode with the 25/20 stainless welding electrode it was noted by the welder that this type of modified 18/8 stainless electrode was much easier to handle than any 25/20 stainless electrode that has

been used in tests here at Watertown. The handling characteristics noted in these tests were ease of maintaining a stable arc, freedom from spattering, and the ease of removing slag from the bead. These three characteristics are essential to making a good weld as they enable the welder to concentrate on other factors while making a joint. Another characteristic of this modified 18/8 stainless welding electrode is its freedom from crater cracks that are characteristic of 25/20 stainless welding electrode in many cases.

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Jr. Physical Science Aide

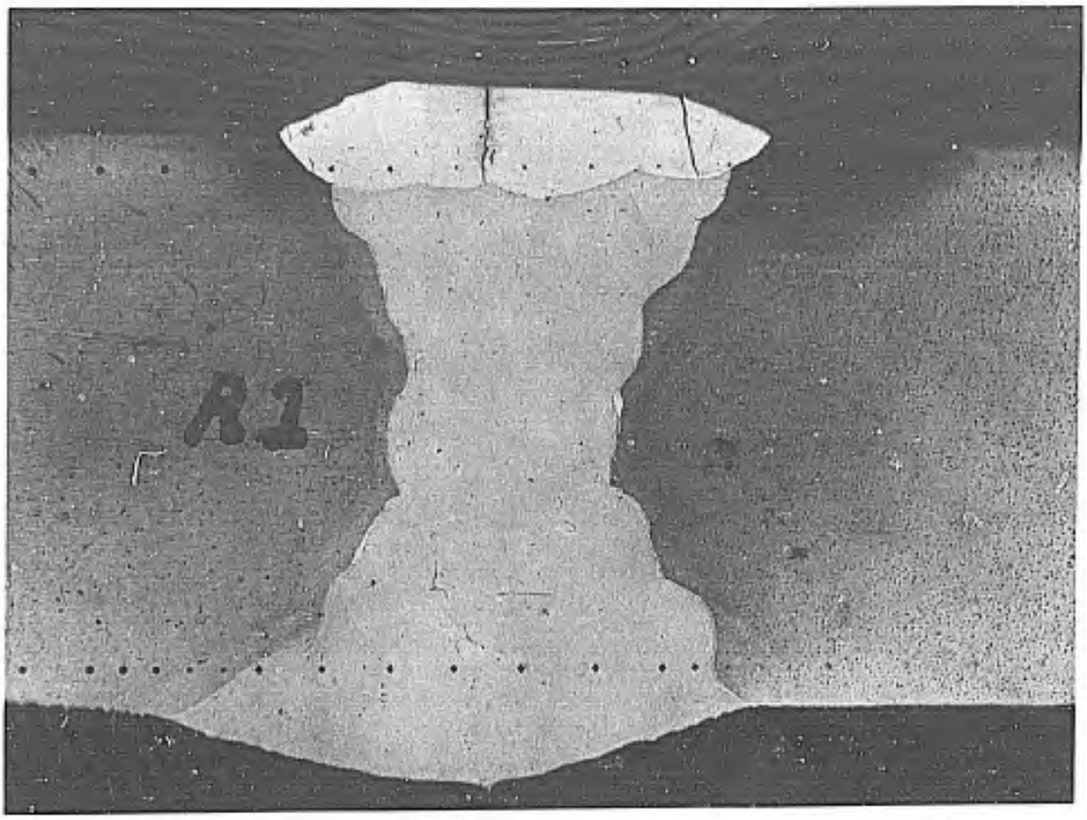
W. L. Warner
Welding Engineer

APPROVED:

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

Macro Photographs and Hardness

Surveys of Joint Cross Sections



R 1

DOUBLE "VEE" BUTT WELD WITH ROOT EDGES BUILT UP AND A HARD FACING ELECTRODE ON THE FACE SIDE OF THE WELD

FIG. 1

W.A.639-3656


VICKERS BRINELL HARDNESS
100
200
300
400
500
600
100
200
300
400
500
600

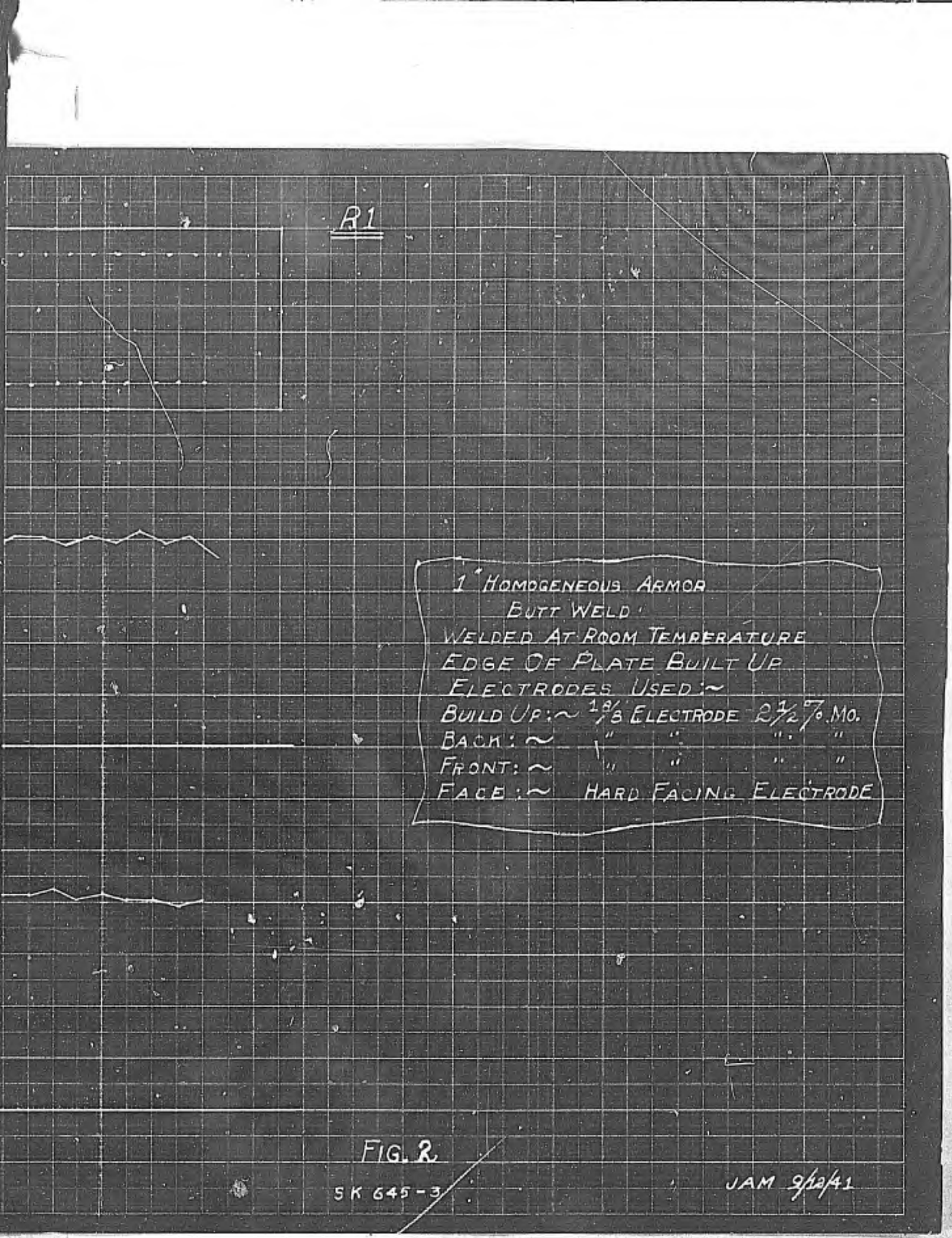
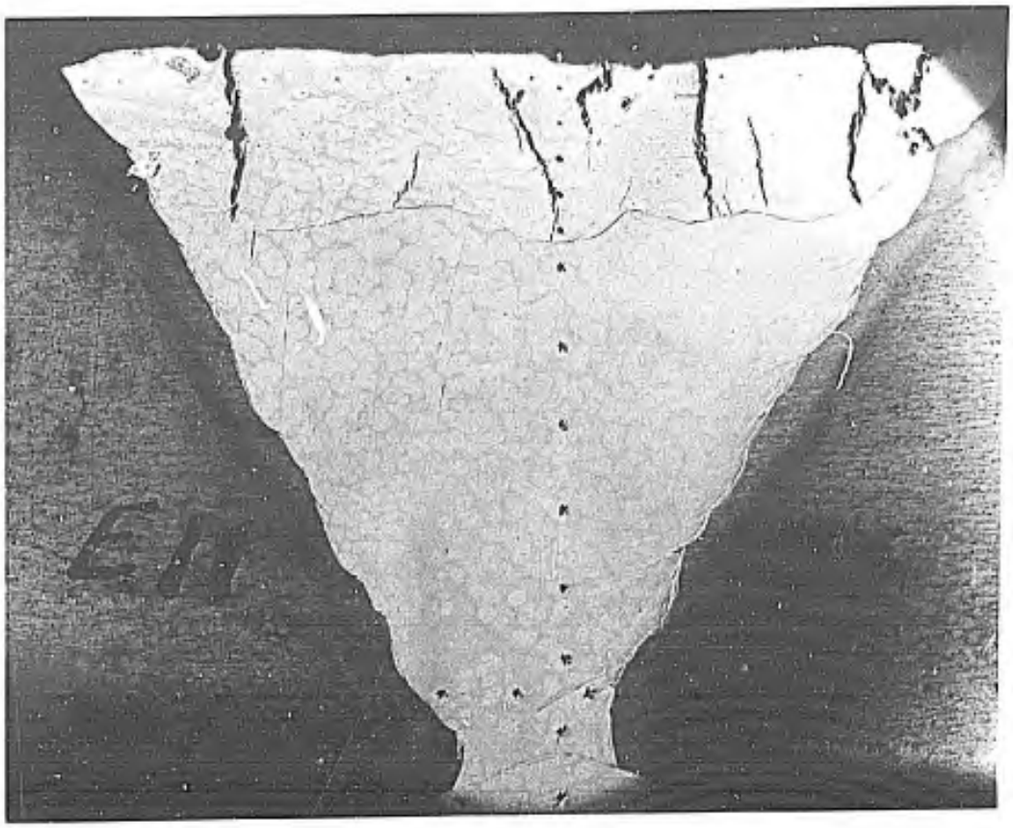


FIG. 2.

SK 645-3

JAM 9/12/41

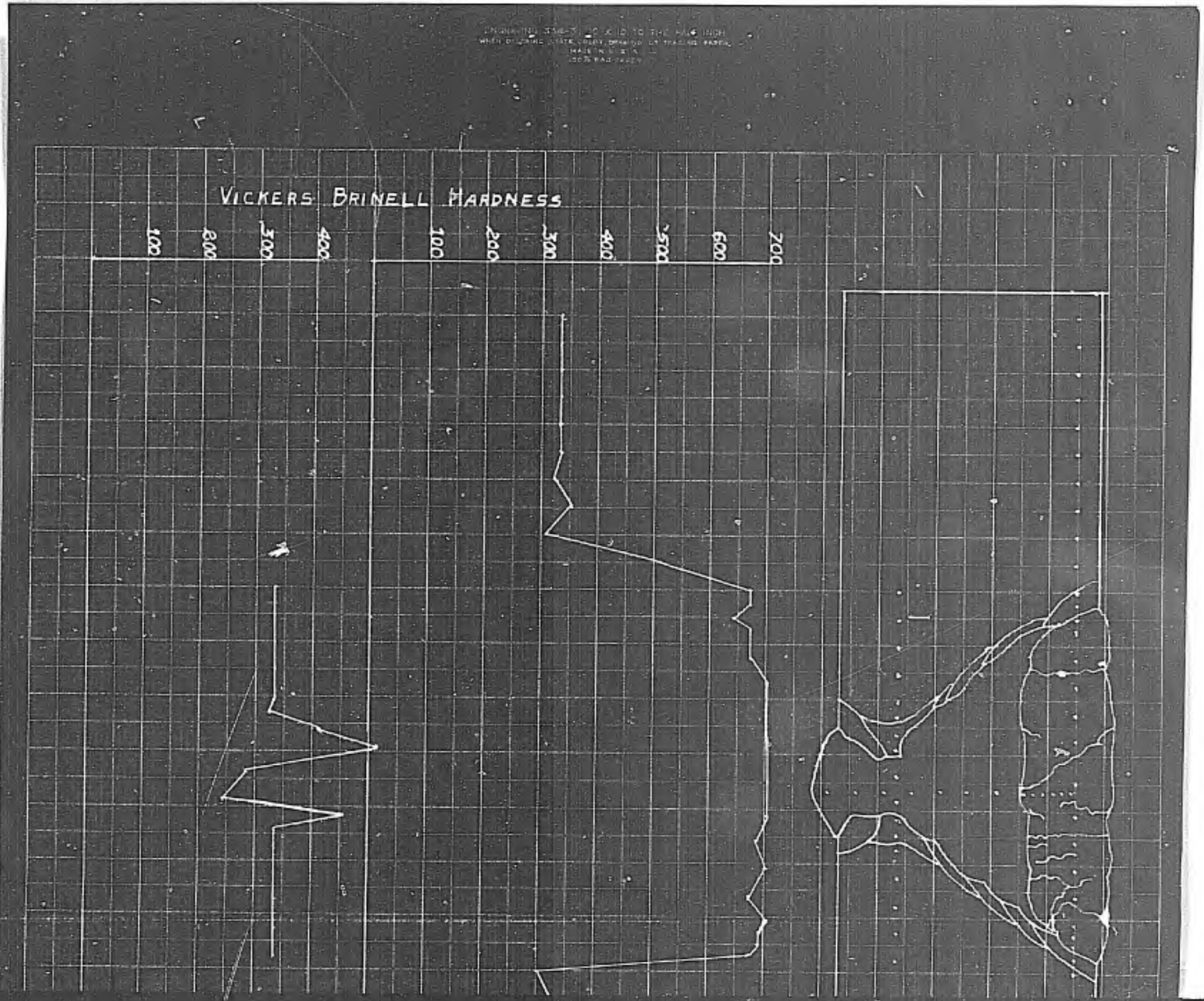


END II – BOX 6

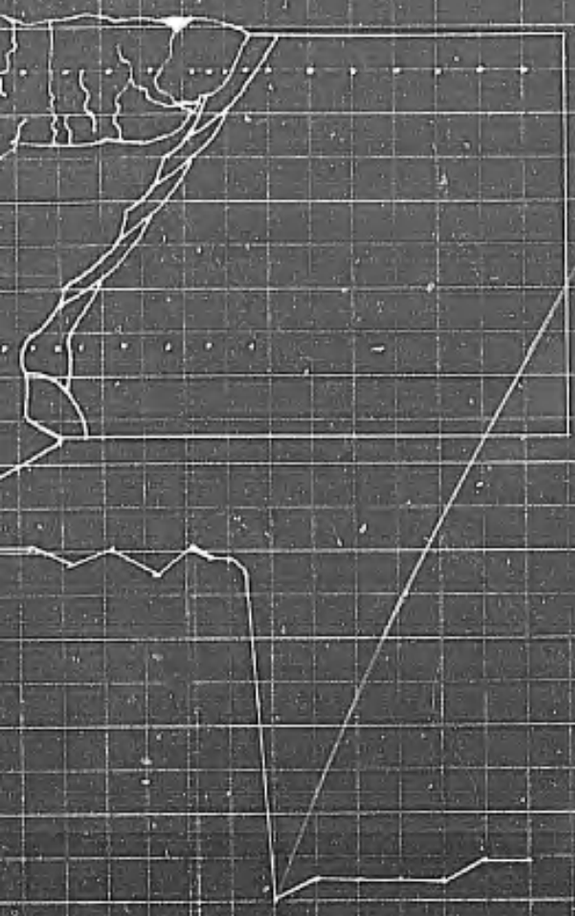
SINGLE "VEE" BUTT JOINT WITH HARD FACING ELECTRODE ON THE FACE LAYER. NOTE CRACKS AND POROSITY

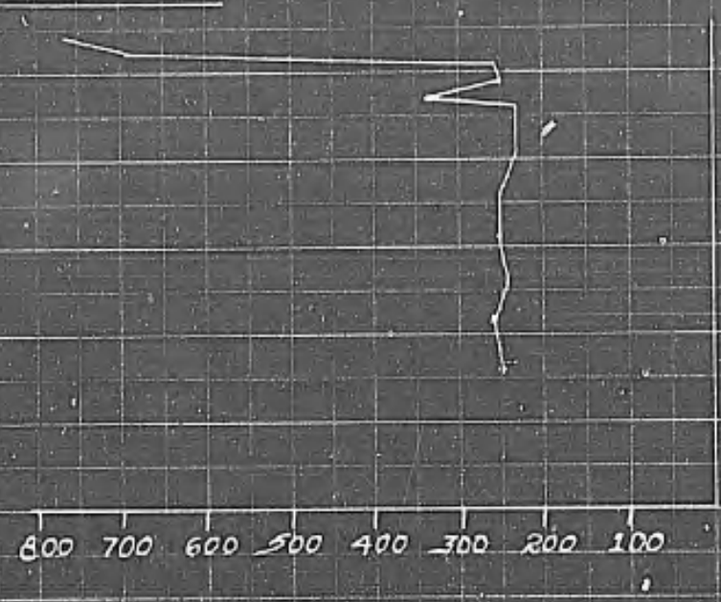
FIG 3

W.A.639–3657


VICKERS BRINELL HARDNESS
100
200
300
400
500
600
700
100
200
300
400

F11 Box 6



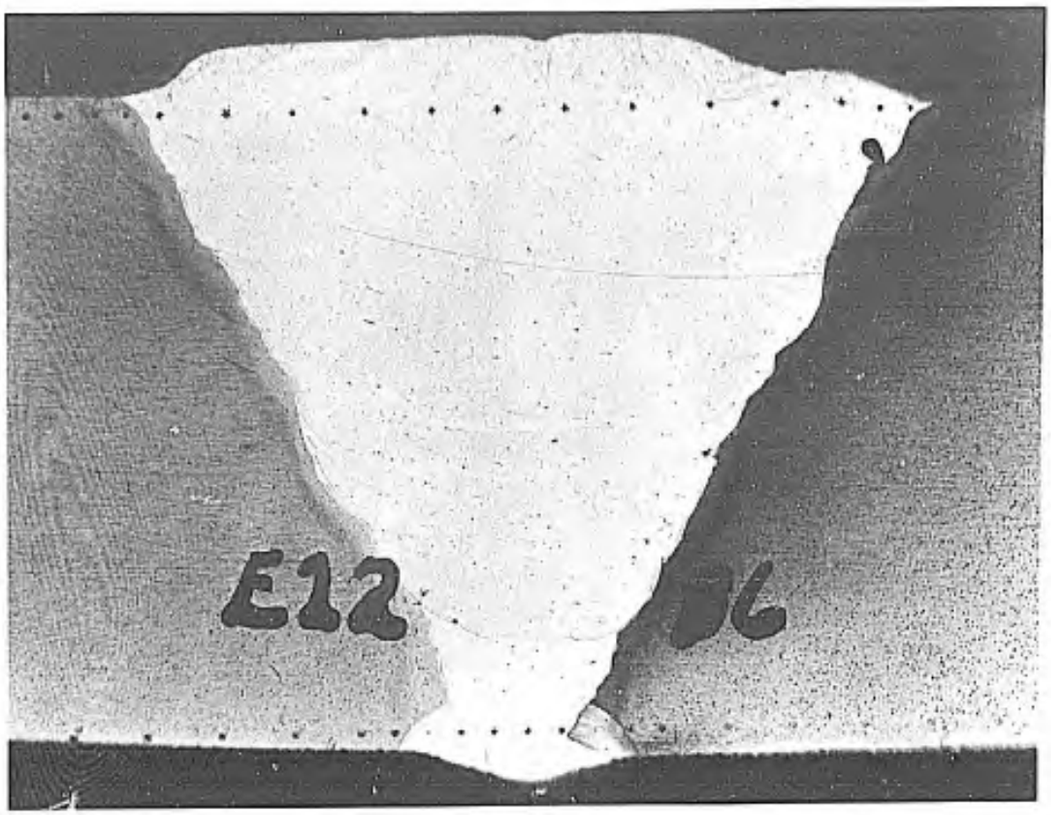


1" HOMOGENEOUS ARMOR
BUTT WELDED
WELDED AT ROOM TEMPERATURE
ELECTRODE:~
1⅜ AUSTENITIC 2½% MOLY.
HARD FACING

FIG. 4

SK 645-5

JAM 9/12/41

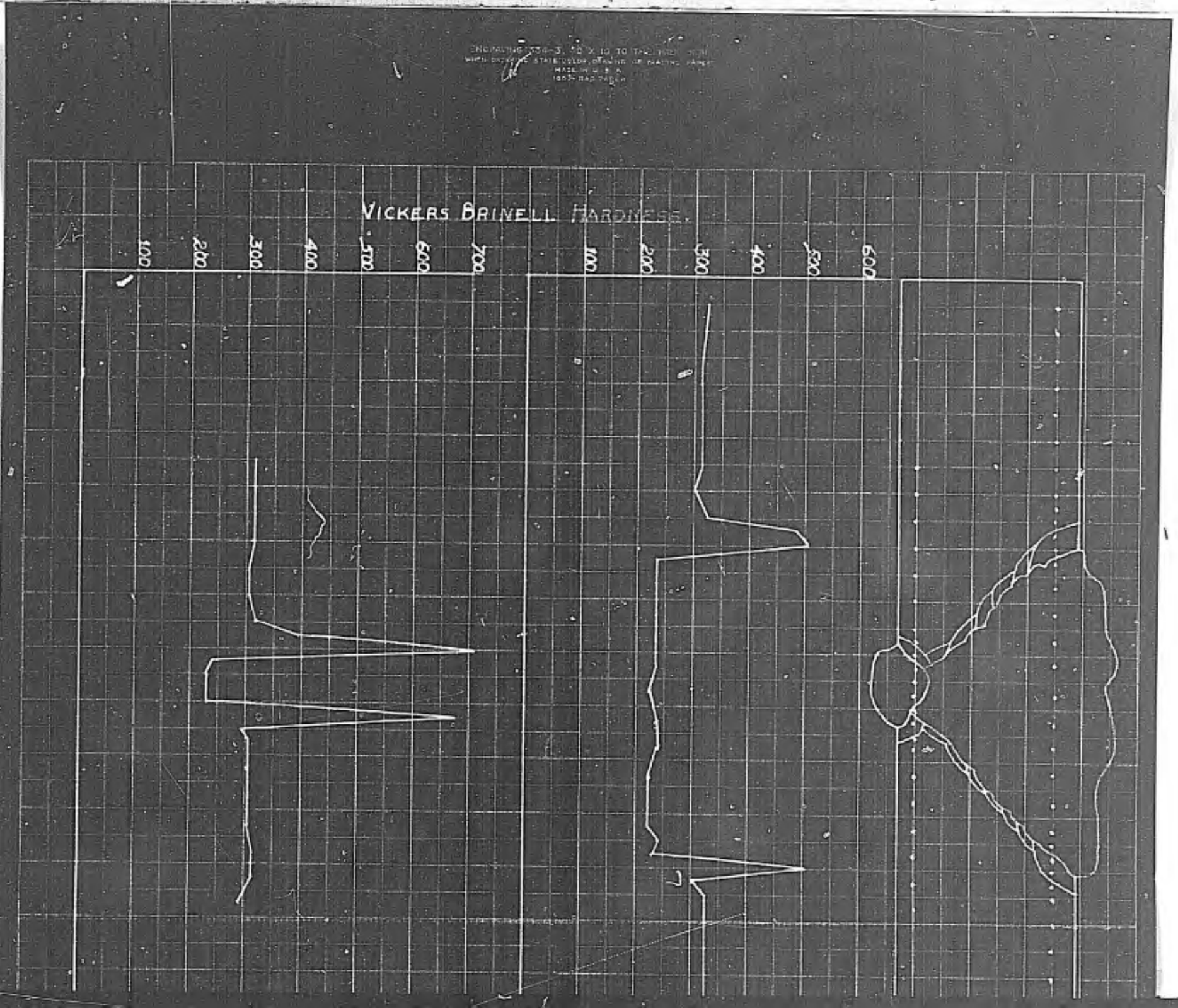


END 12 – BOX 6

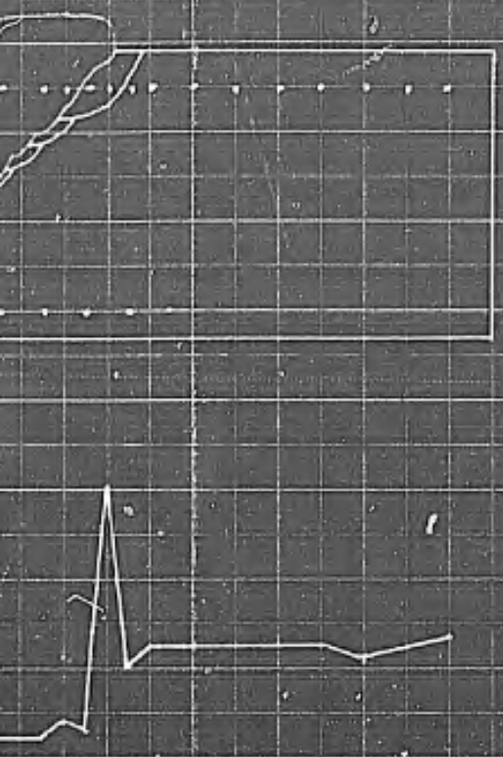
SINGLE "VEE" BUTT JOINT WITH 18/8 ELECTRODE CONTAINING 2.5% MOLYBDENUM.

FIG. 5

W.A.639-3658


VICKERS BRINELL HARDNESS.
100
200
300
400
500
600
700
100
200
300
400
500
600

F12 BOX 6

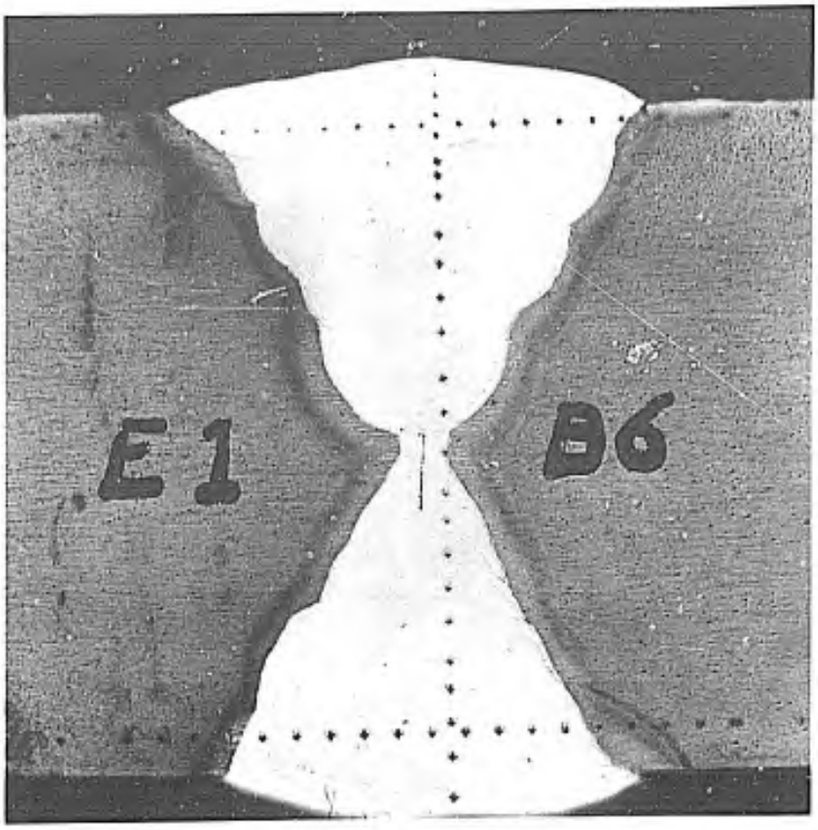


1" HOMOGENEOUS ARMOR
BUTT WELDED
WELDED AT ROOM TEMPERATURE
ELECTRODE :~
18/8 AUSTENITIC 2½% MOLY.

FIG. 6

SK 645-G

JAM 9/12/41

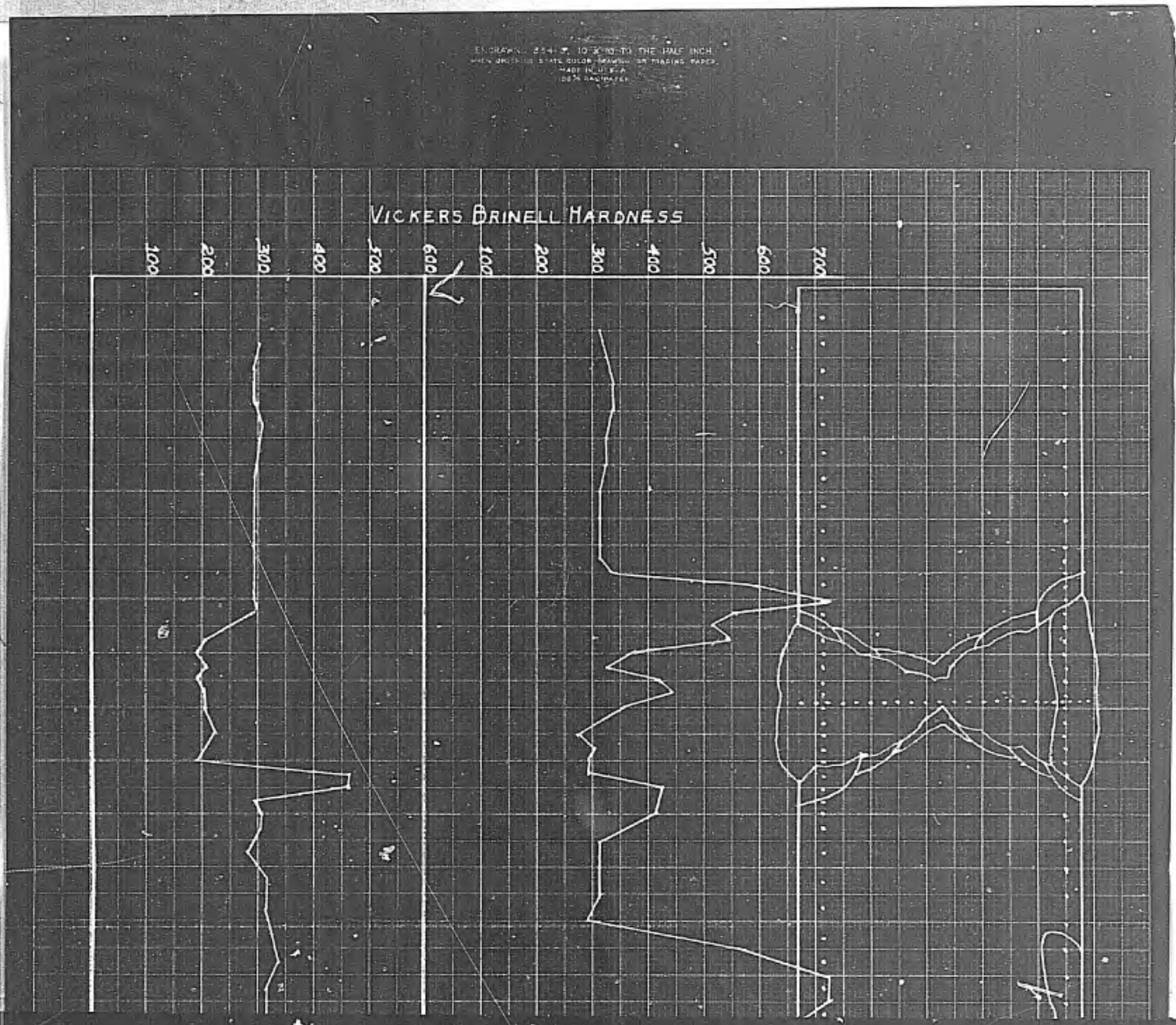


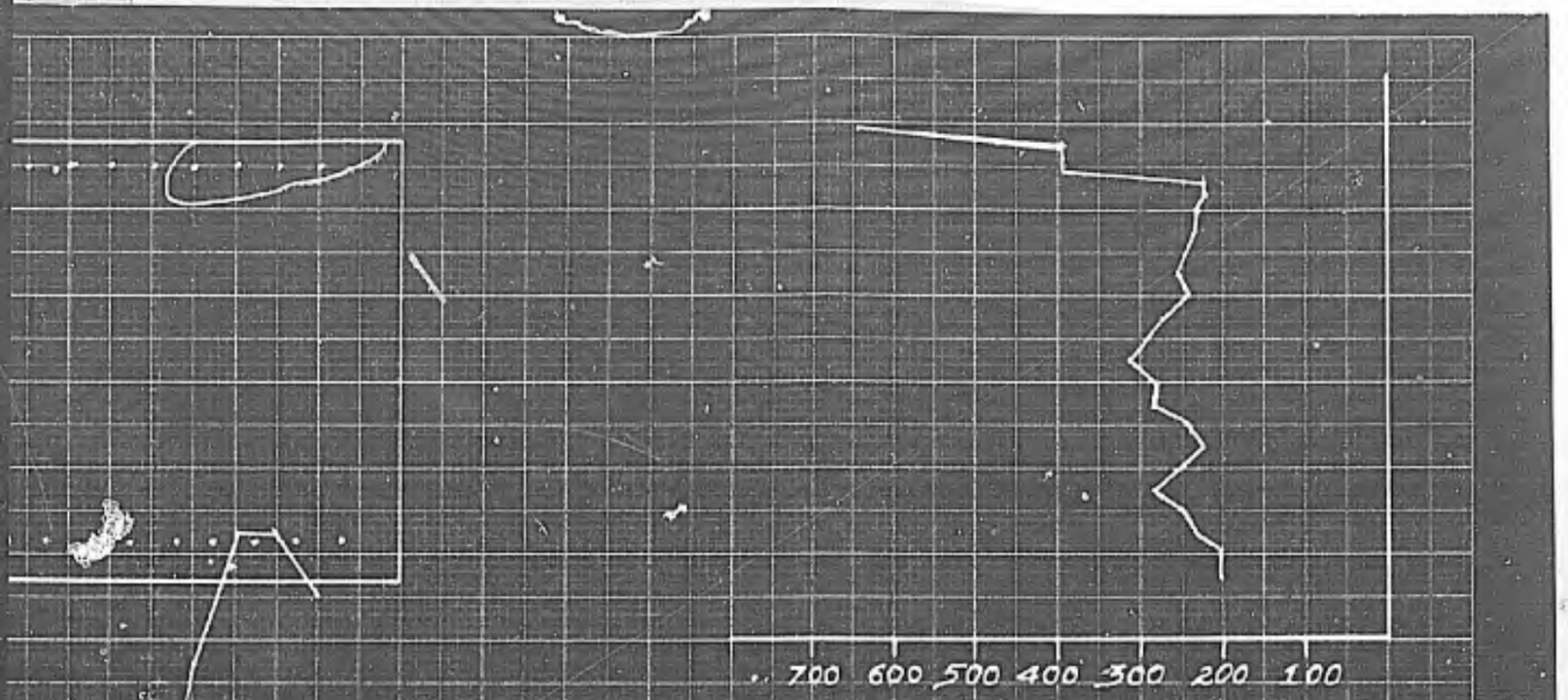
END I – BOX 6

DOUBLE "VEE" BUTT JOINT WITH HARD FACING ELECTRODE ON 19/8 CONTAINING 1.81% MOLYBDENUM.

FIG 7

W.A.639-3659


VICKERS BRINELL HARDNESS
100
200
300
400
500
600
100
200
300
400
500
600
700



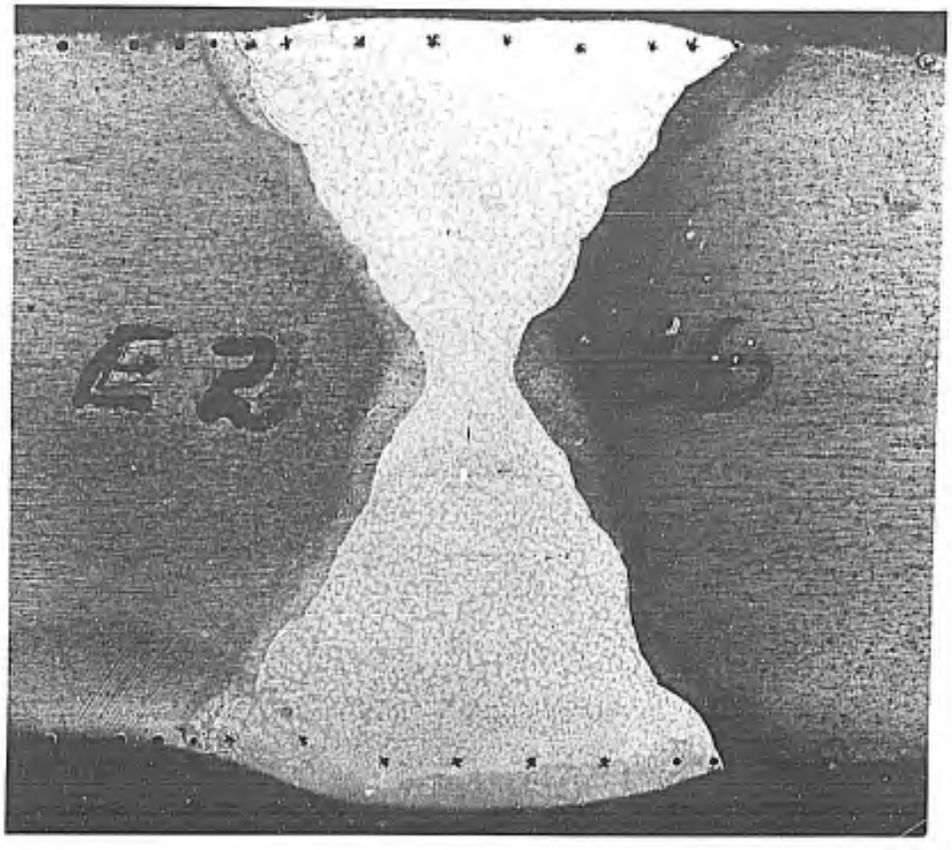
E1 Box 6

1" Homogeneous Armor
Butt Welded
Welded At Room Temperature
Electrode :~
18/8 Austenitic 1.81 % Moly.
Hard Facing

FIG. 8

SKG45-4

JAM 9/13/41



END 2 – BOX 6

DOUBLE "VEE" BUTT JOINT WITH 18/8 CONTAINING 1.81% MOLYBDENUM

FIG. 9

W.A.639–3660

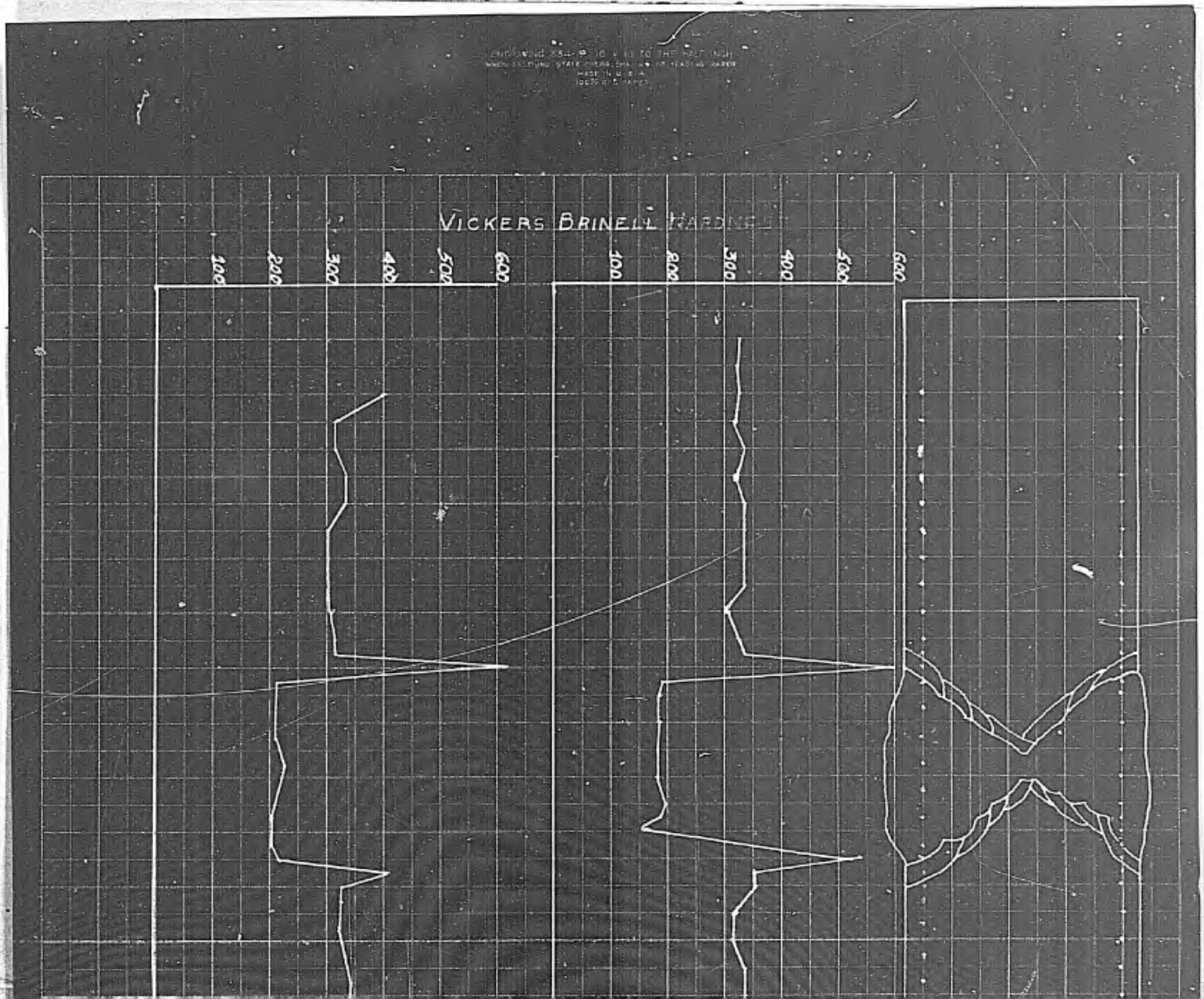
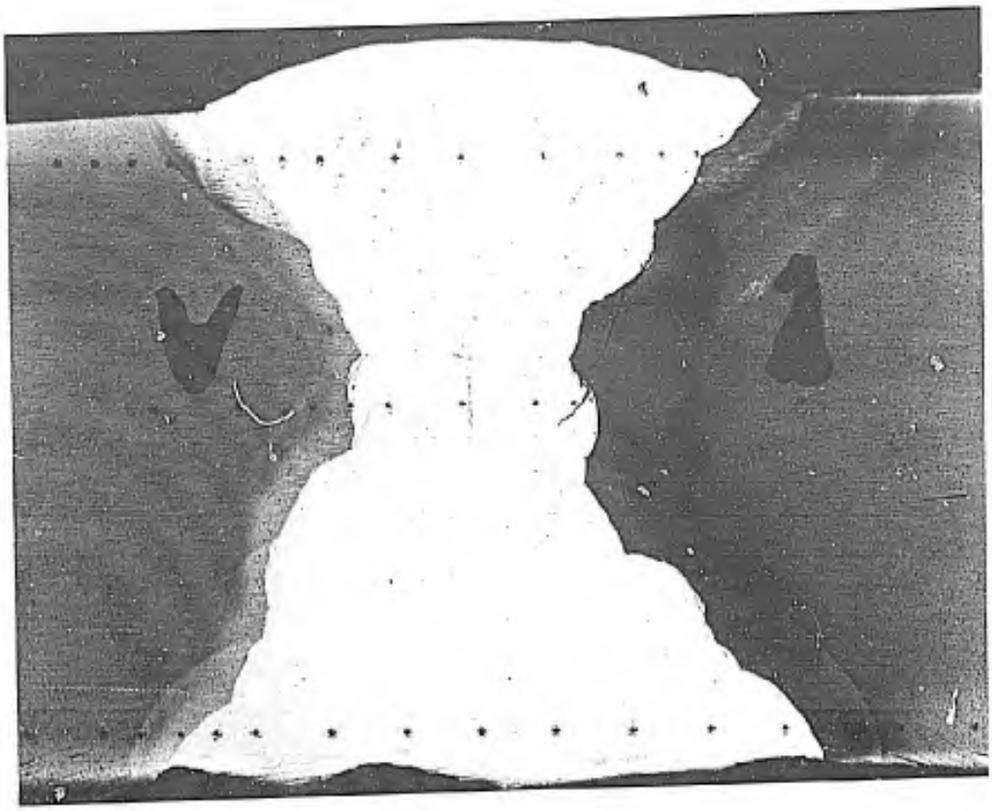

VICKERS BRINELL HARDNESS
100
200
300
400
500
600
100
200
300
400
500
600

FIG. 10

SKC45-7

JAM 9/13/41

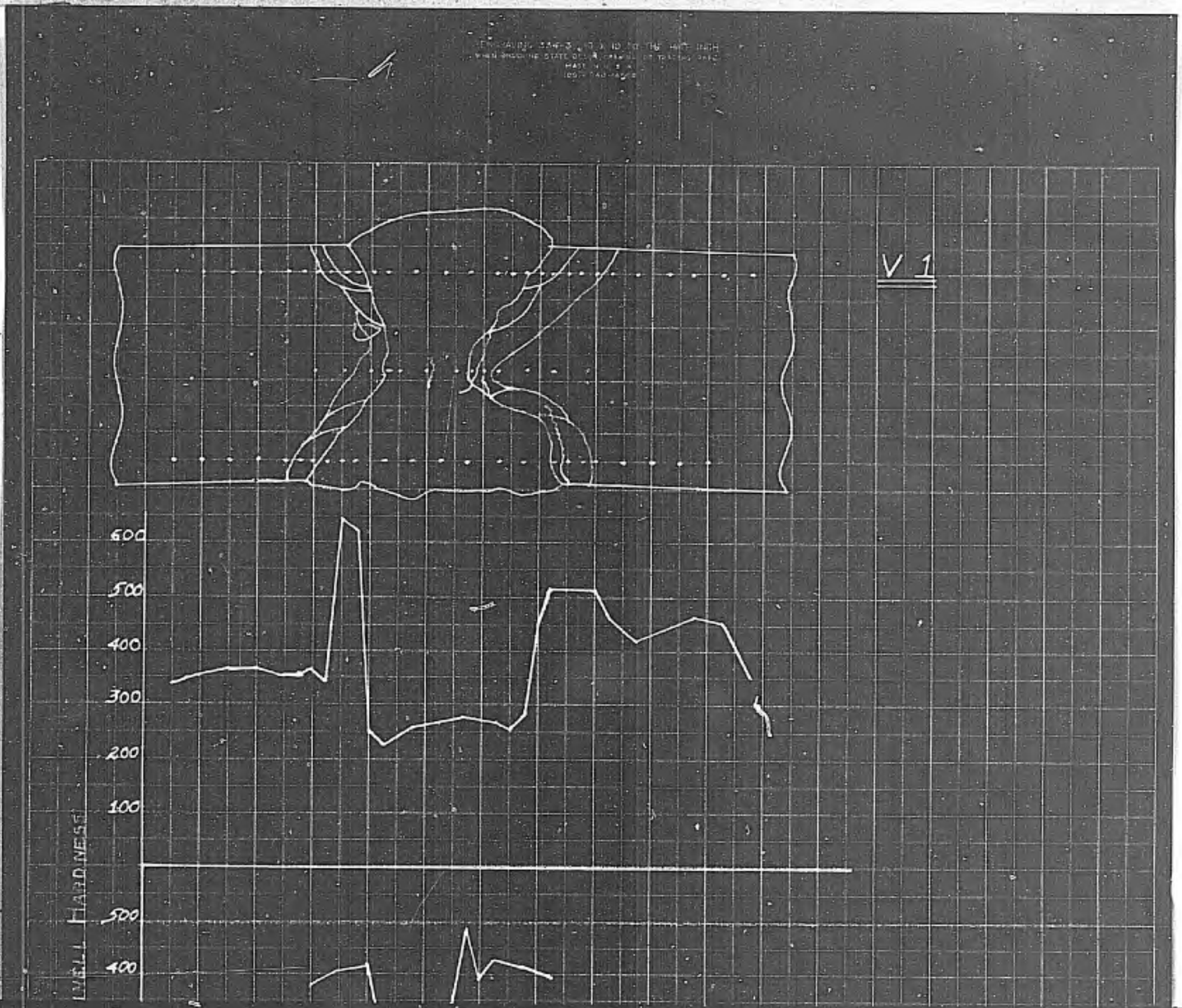


VI

DOUBLE "VEE" BUTT JOINT WITH 18/8 ELECTRODE CONTAINING 1% VANADIUM ROOT EDGES OF PLATE ARE PADDED

FIG. 11

W.A.639-3661


V 1
600
500
400
300
200
100
500
400
WELL HARDNESS

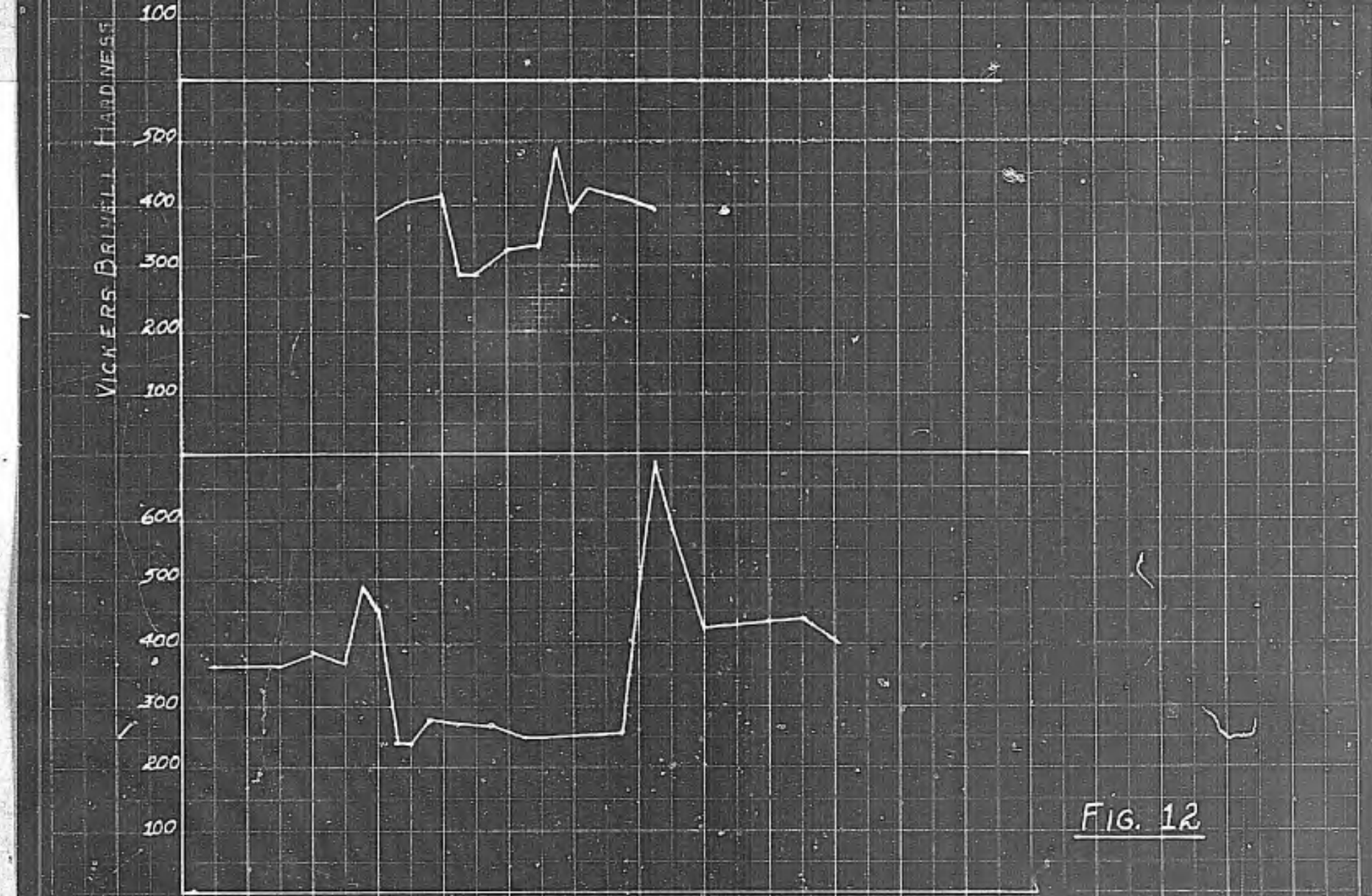


FIG. 12

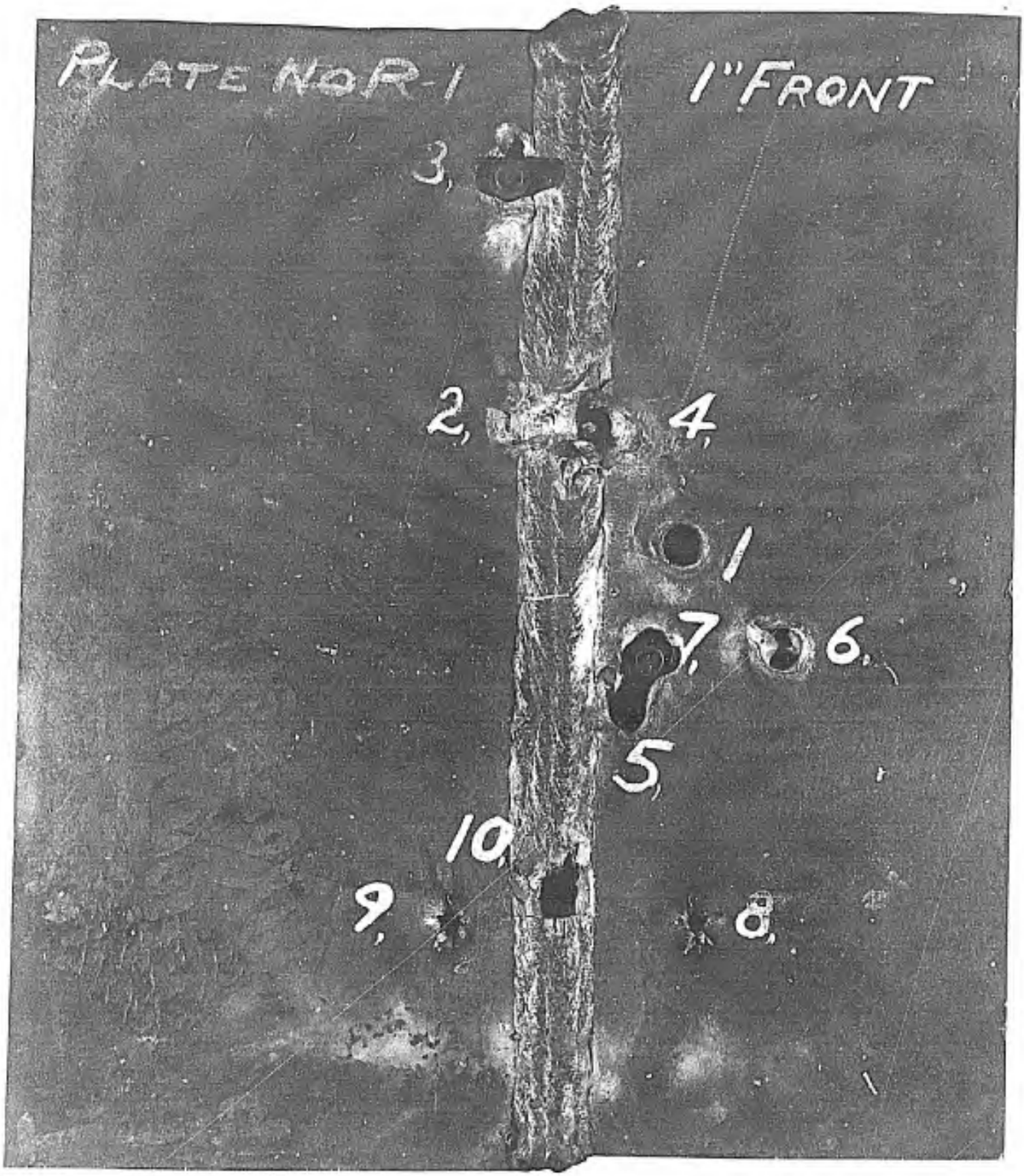
1" ROLLED HOMOGENEOUS ARMOR
BUTT WELDED. DOUBLE VEE JOINT
ELECTRODE :~
18/8 AUSTENITIC WITH 1% VA.

SH 615-8

J.A.M 9/24/41

Photographs of Welded Joints

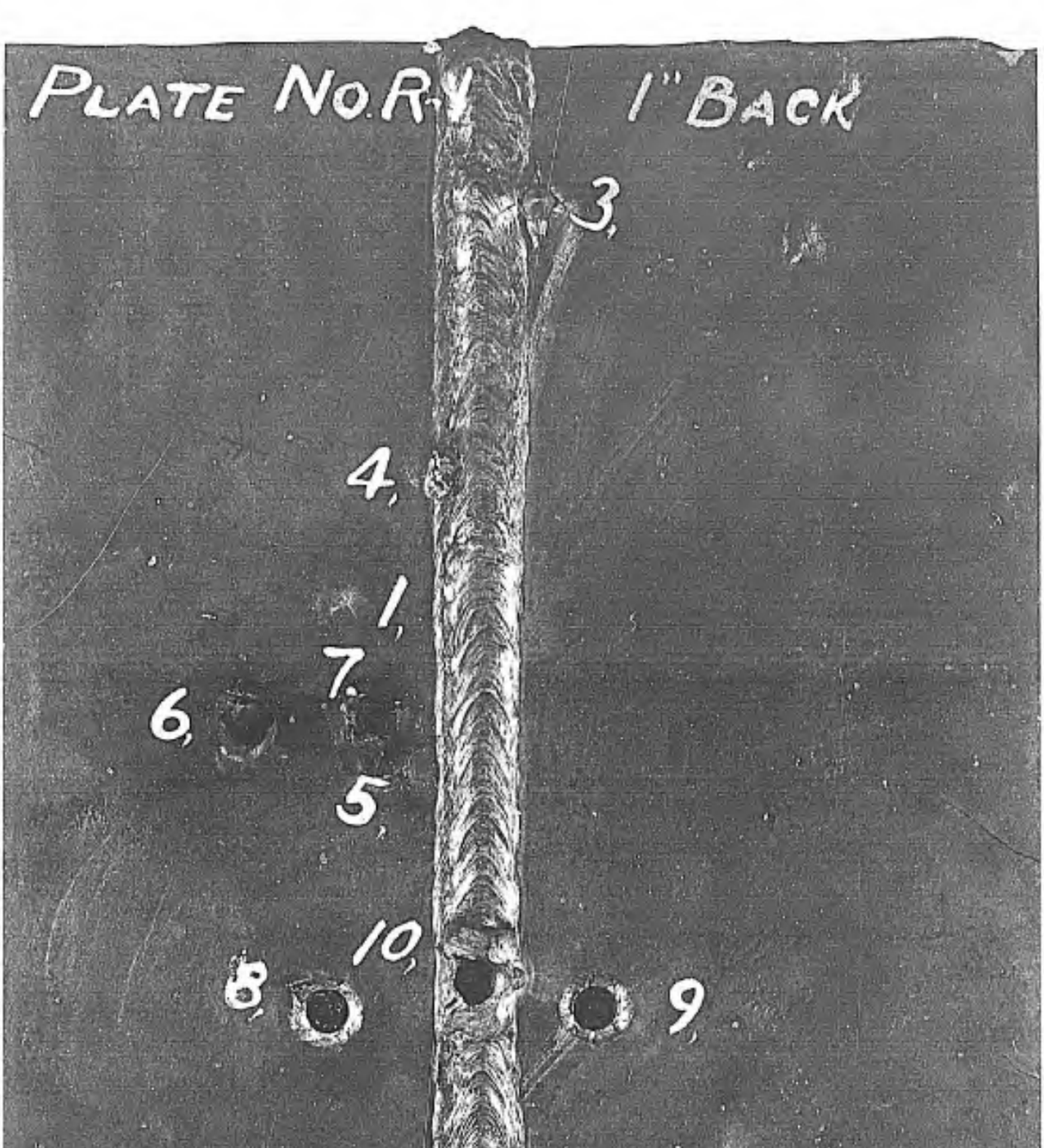
After Penetration Tests



INCHES 1 2 3

ORDNANCE DEPT U.S.A.
WATERTOWN ARSENAL
1" BUTT WELDED HOMOGENEOUS ARMOR
JULY 21, 1941 W.A. 71-1533

FIG. 13a

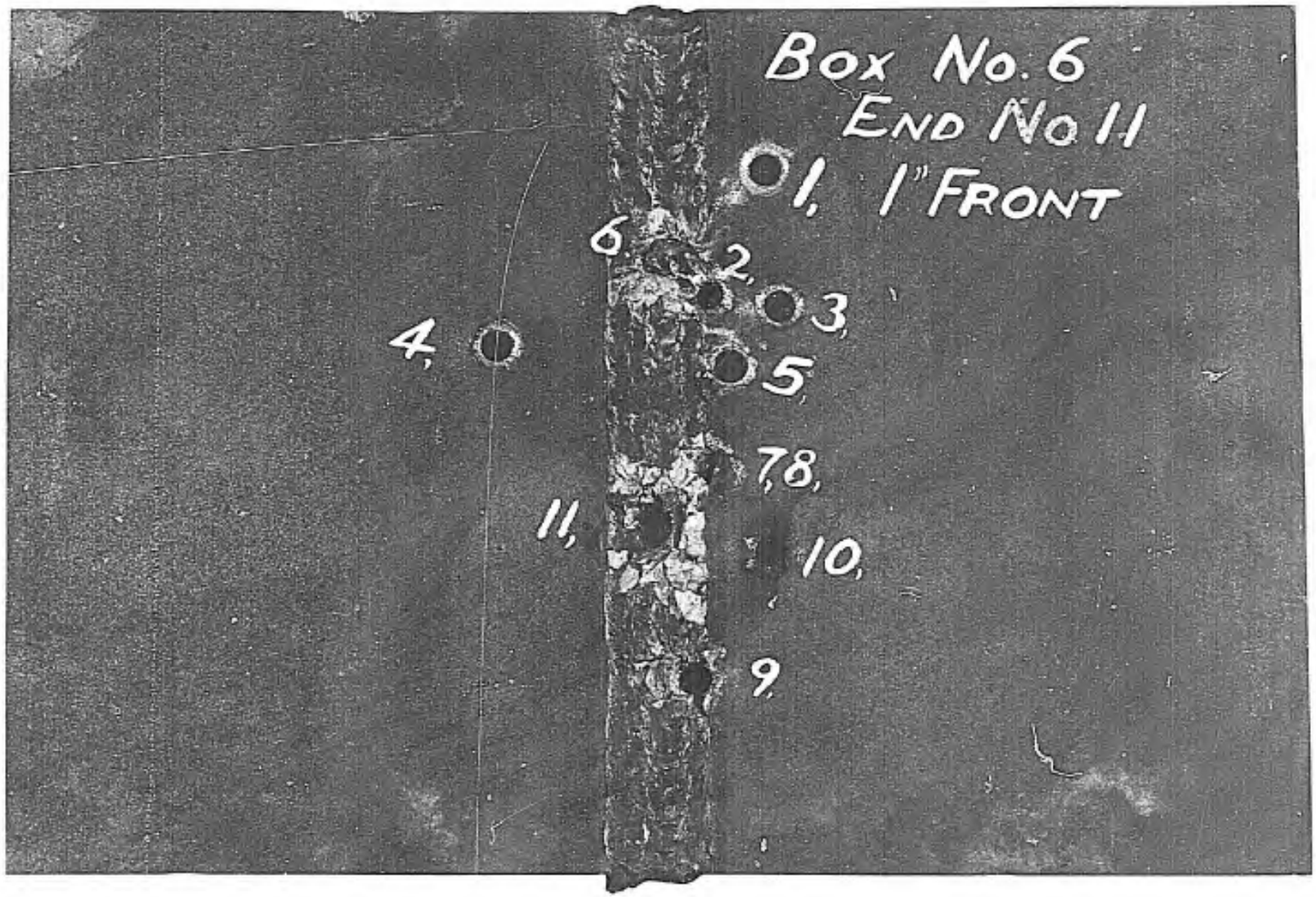


INCHES 1 2 3

ORDNANCE DEPT U.S.A.
WATERTOWN ARSENAL

1" BUTT WELDED HOMOGENEOUS ARMOR
JULY 21, 1941 W.A. 71-1334

FIG. 13b


Box No. 6
End No 11
1, 1" Front
6
2,
3,
4,
5,
7,8,
11,
10,
9,

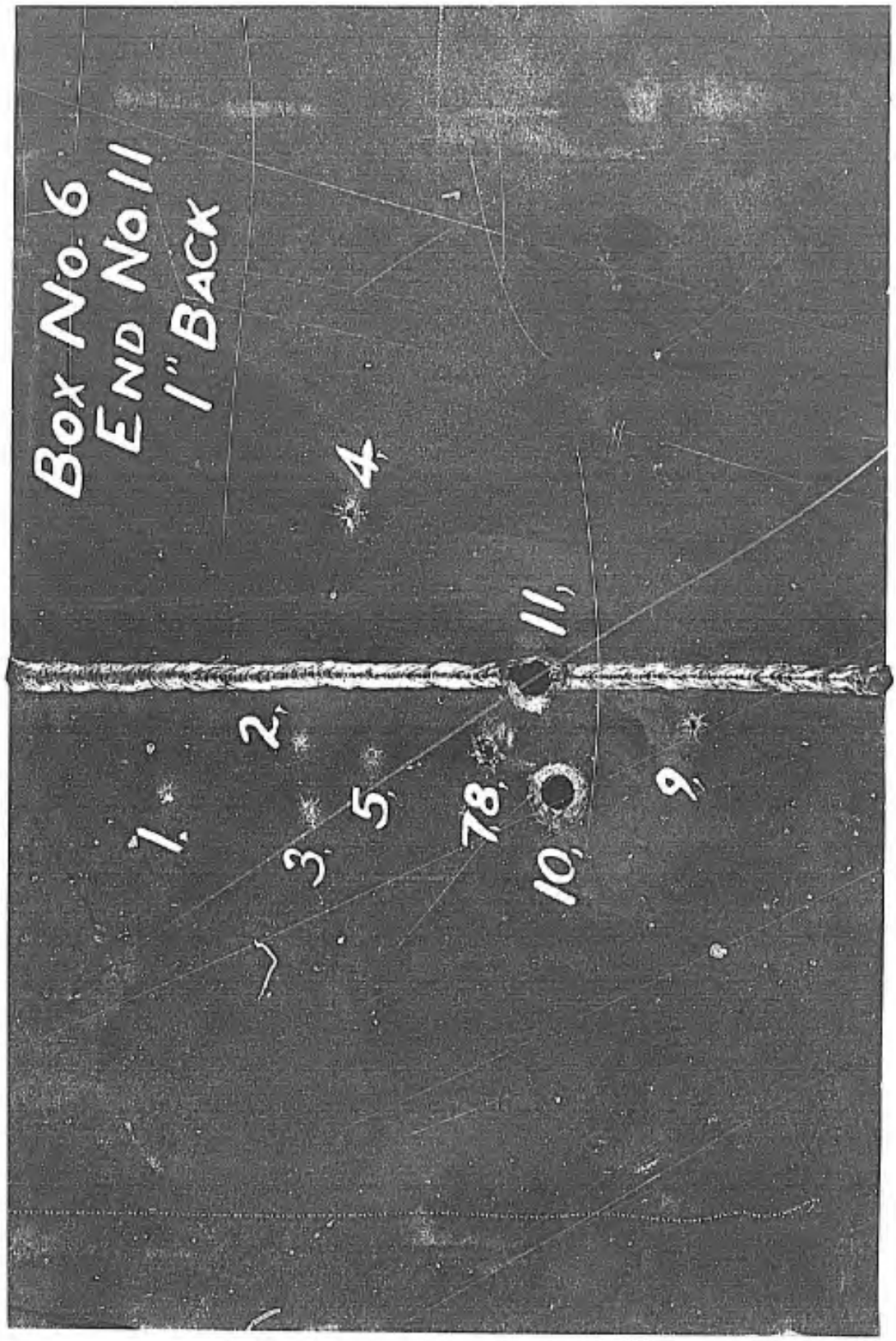


FIG. 14b

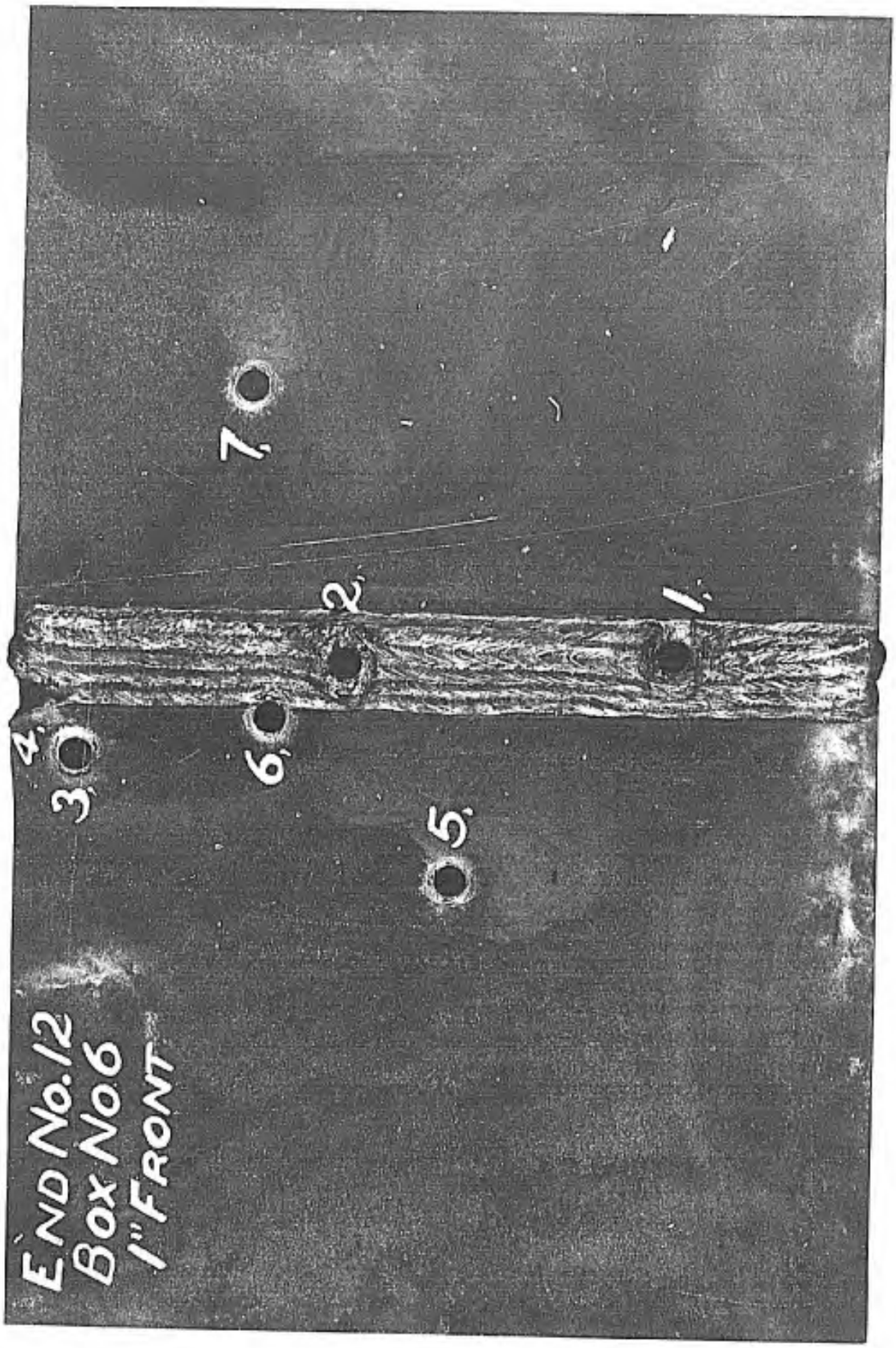


FIG. 15a

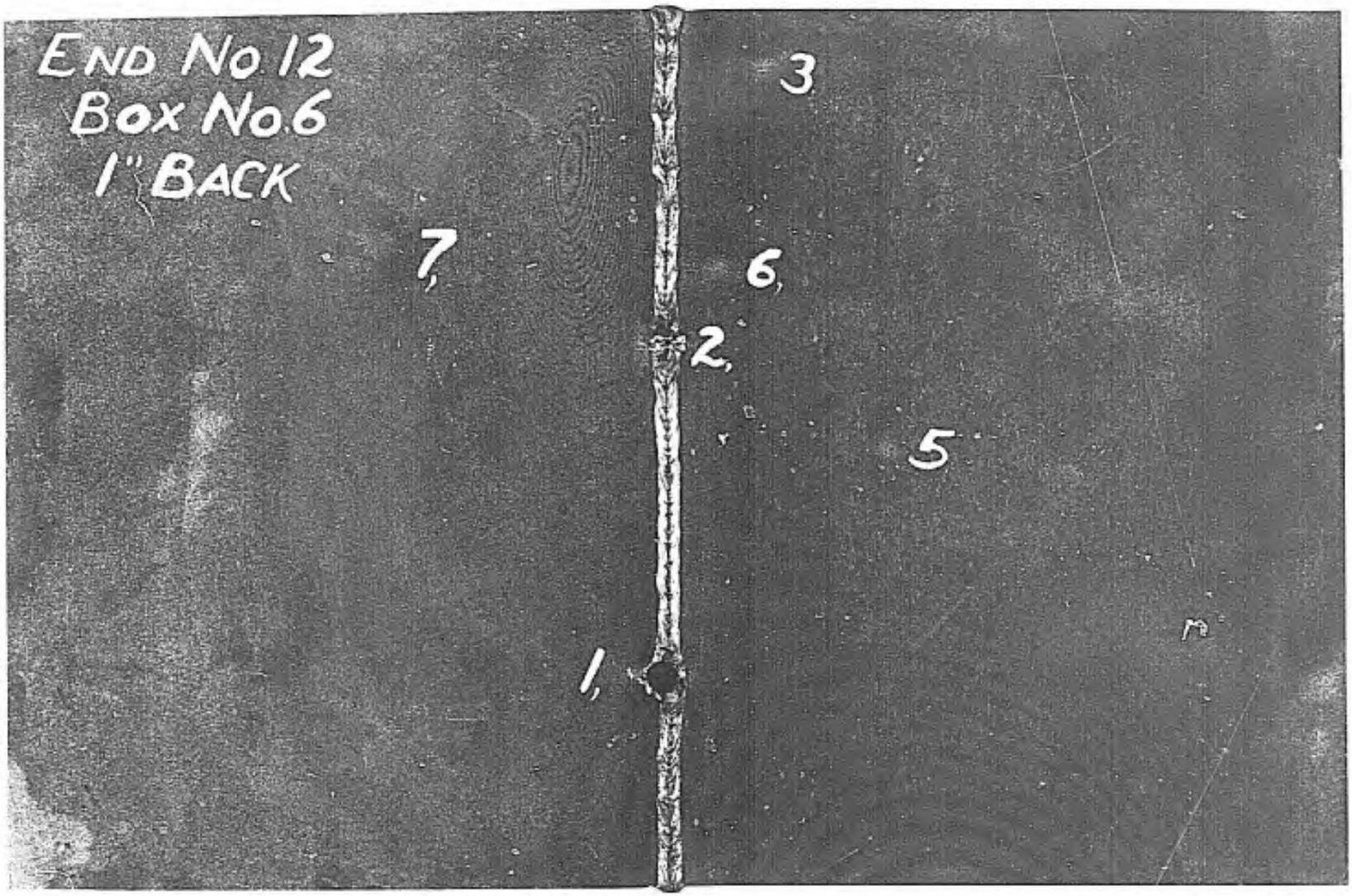
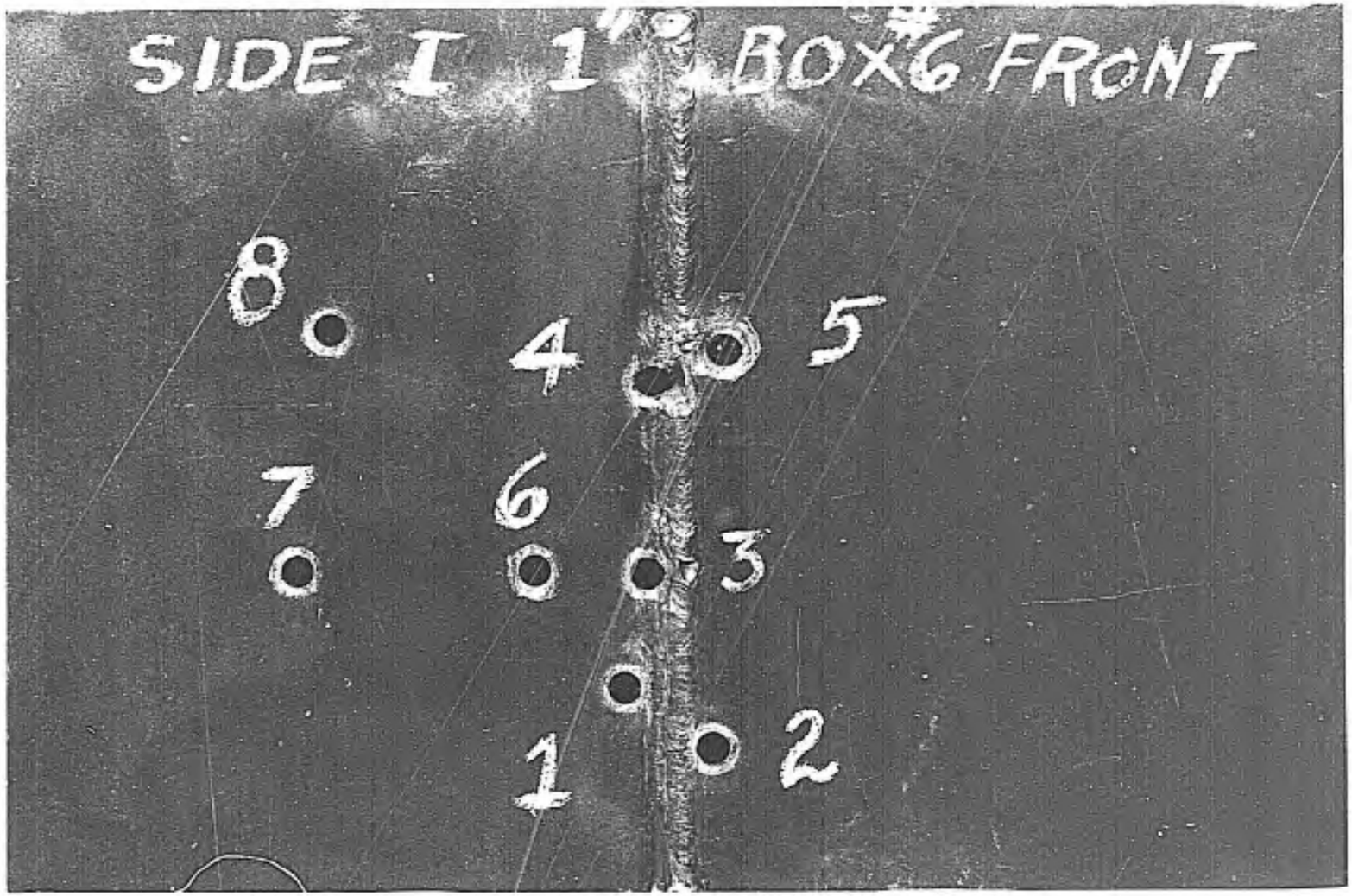

END No 12
BOX No 6
1" BACK
7
3
6
2
5
1

FIG. 1a



WATERTOWN ARSENAL

1" HOMOGENEOUS ARMOR PLATE. SIDE 2, BOX #6
AUG. 16, 1941 LENGTH, 18" W.A.71C-1339

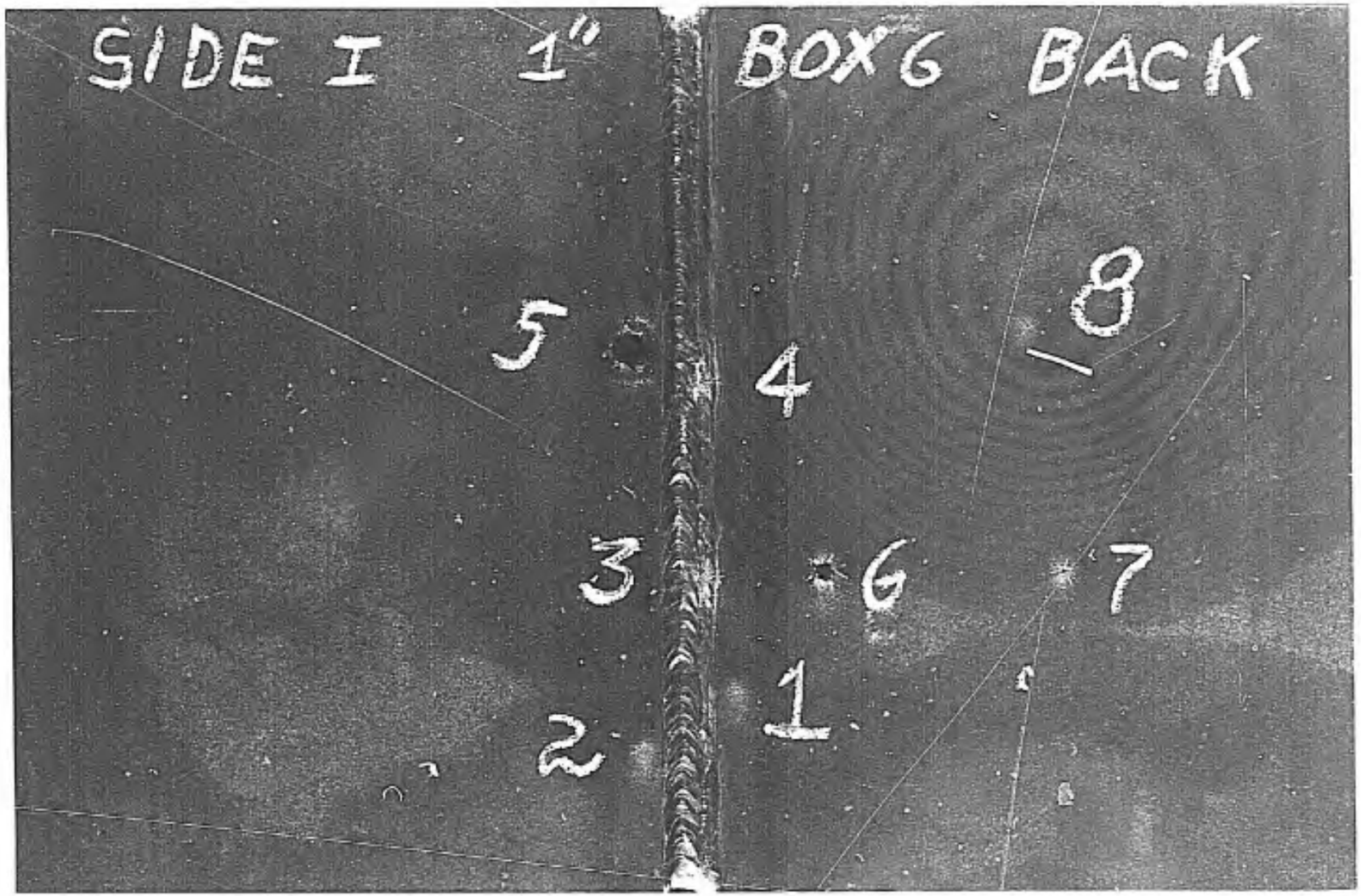


FIG. 16b

WATERTOWN ARSENAL

1" HOMOGENEOUS ARMOR PLATE. SIDE 2, BOX #6
AUG. 16, 1941 LENGTH, 18" W.A. 710-1840

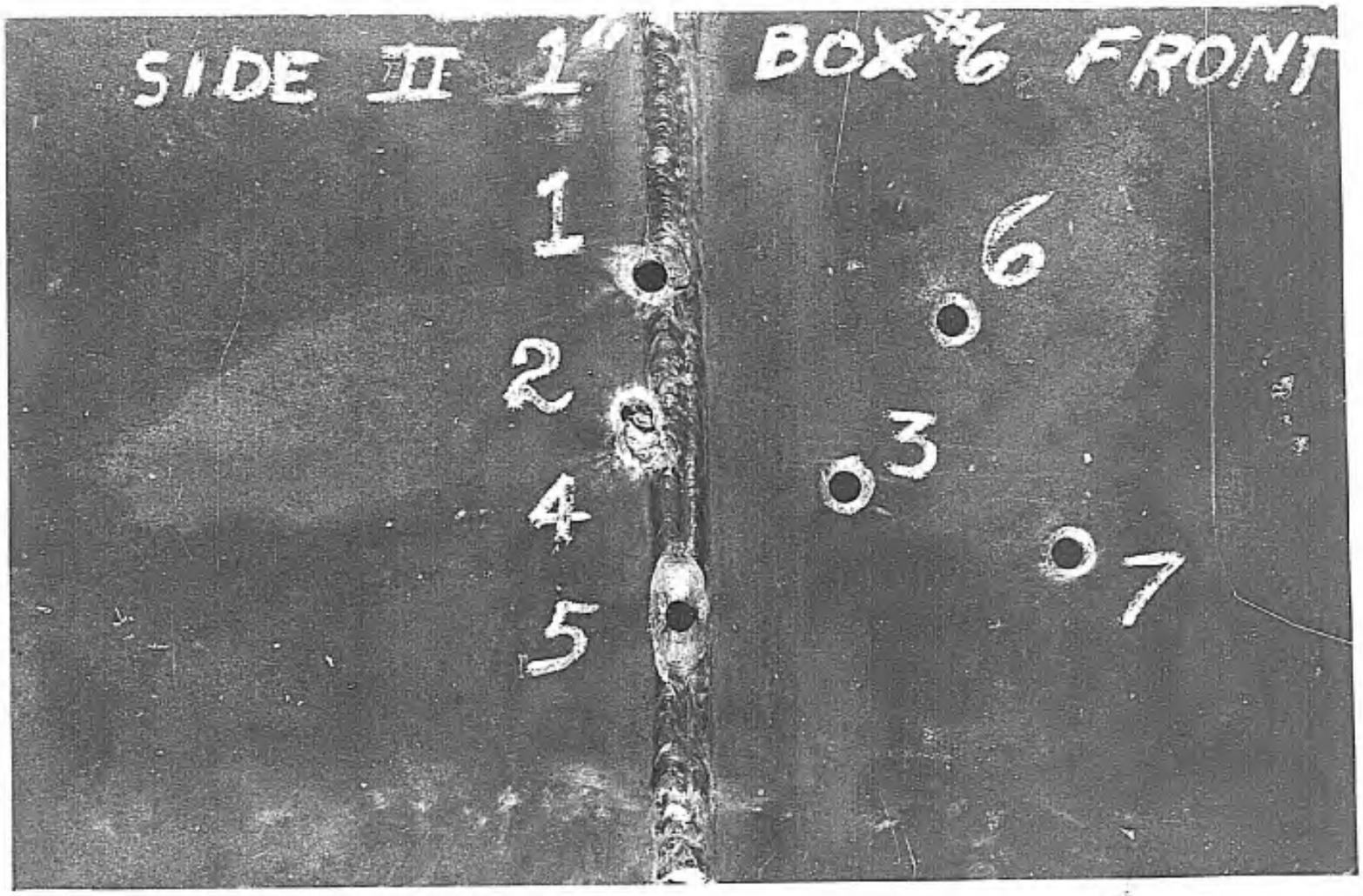


FIG. 17a

WATERTOWN ARSENAL

1" HOMOGENEOUS ARMOR PLATE. FRONT SIDE, BOX #6
AUG. 16, 1941 LENGTH, 18" W.A. 71C-1342

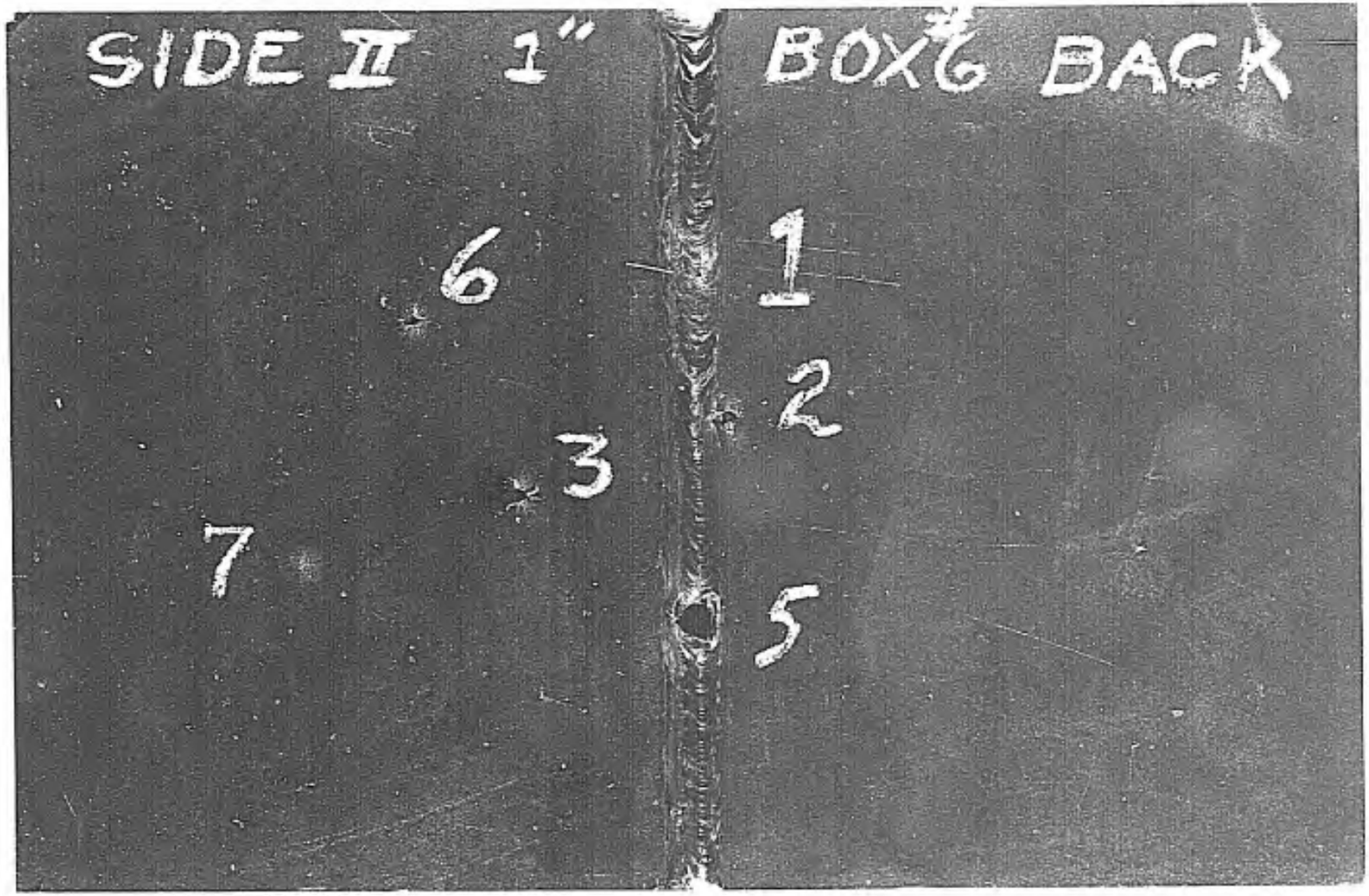


FIG. 178

WATERTOWN ARSENAL

1" HOMOGENEOUS ARMOR PLATE. FRONT SIDE, BOX #6
AUG. 16, 1941 LENGTH, 18" W.A. 710-1341

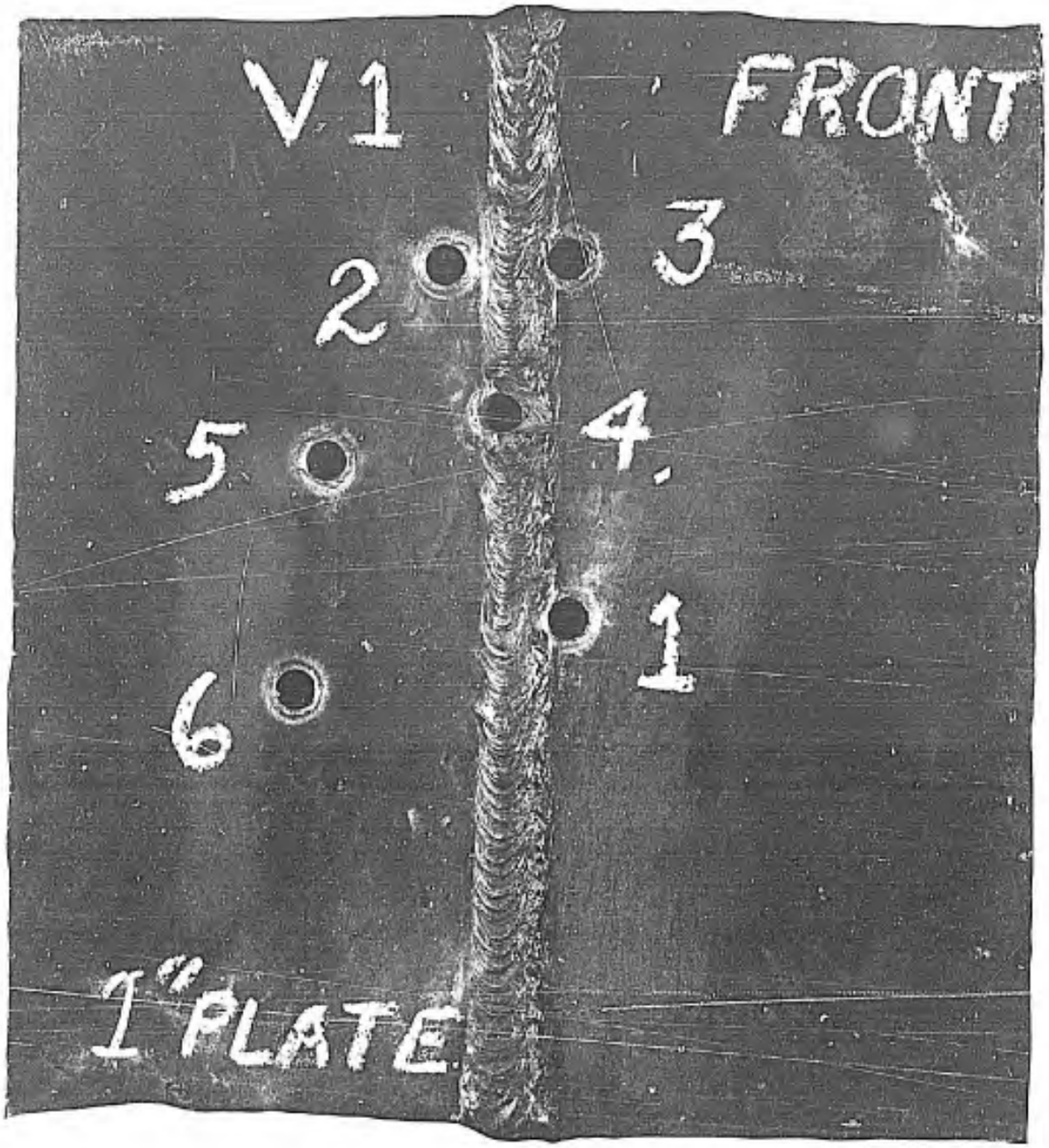


FIG. 1da

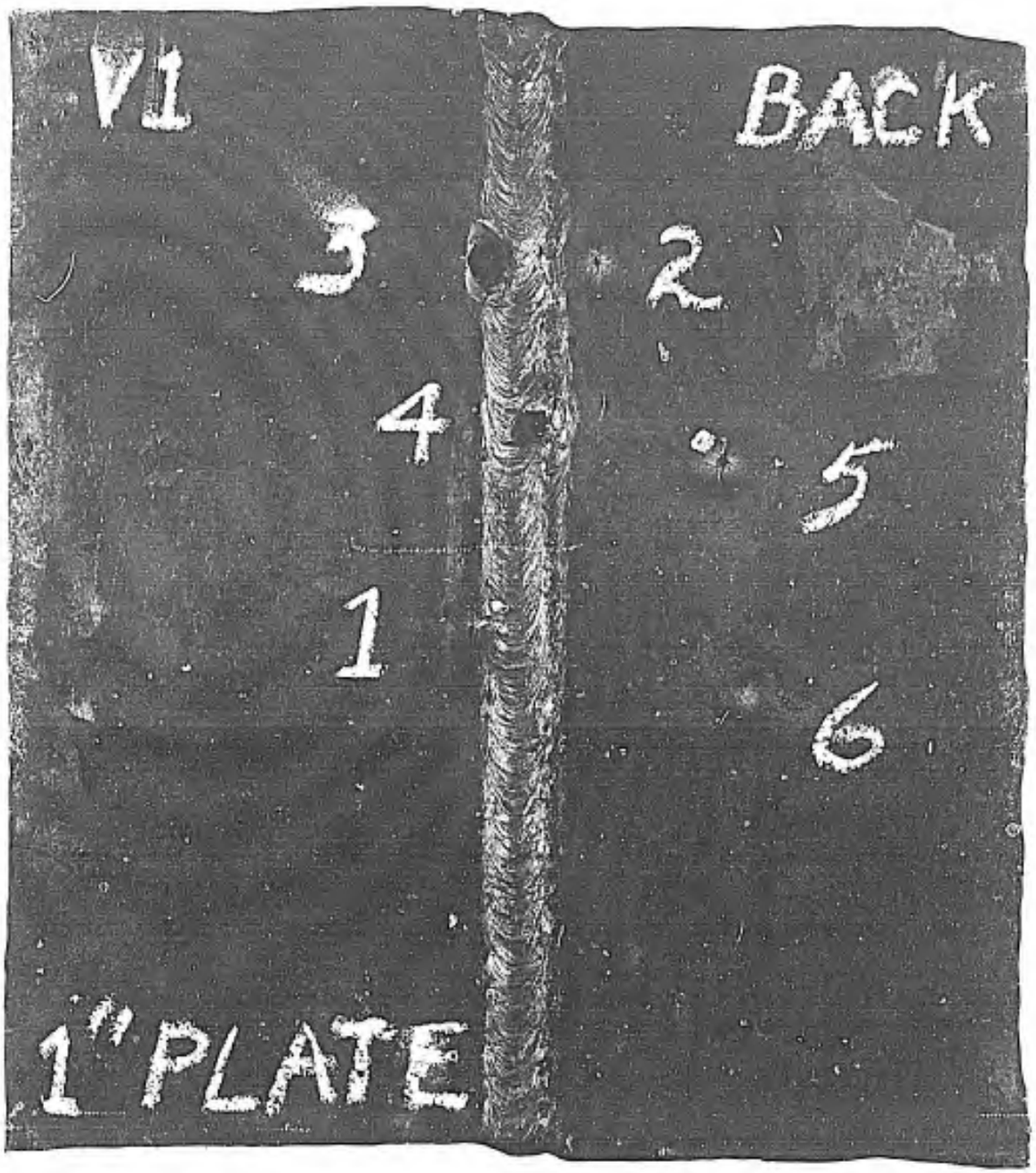


FIG. 16b