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Rec'd from Frankford 4/18/44

Report No. 645/4
Watertown Arsenal

April 12, 1937.

Repair of Armor Castings by Welding

Progress Report #1

The experiment outlined in this report were concerned with the repair of armor castings by welding. These repairs are intended to salvage armor castings which had been rejected on X-ray examination because of cracks, pipes, or spongy spots.

The Armor Casting Material

The specified composition of these castings is:

C	Mn	Si	S	P	Mo	Cr	Va
0.35 / 0.40	0.50 / 0.80	0.15 / 0.35		Max. 0.03	0.60 / 0.80	1.10 / 1.30	0.20 / 0.30

The castings used for the tests outlined here were scrap castings which had been rejected on X-ray examination because of bad cracks, pipes, or a generally porous condition.

For the experiments in which the welds were X-rayed and tested for ballistic properties shield castings were used. Where hardness surveys of weld cross-sections were made a scrap carburetor cover #68 was used.

All of the shield castings used were, before welding, given a normalize and anneal as follows:

1150°C for 8 hours, air cooled to black
950°C " 5 " " " " cold
850°C " 5 " furnace cooled to cold.

Carburetor cover #68 was used throughout in the "as cast" condition.

Conclusions

1. It has been found possible to obtain passable ballistic properties in arc weld metal exposed directly to the bullet where the weld metal has penetrated only about half the wall thickness of the casting.

2. This arc weld metal which gives passable ballistic properties has not been free from cracks after welding.

3. The arc welding operation is performed most comfortably and expeditiously with a low preheat (under 400°C) or no preheat and the ballistic properties of the weld appear to be as satisfactory as those obtained with a higher preheat temperature.

4. When the weld is made with the arc on the inside surface of the casting and the weld metal does not penetrate over half the casting wall thickness the ballistic properties are satisfactory with any covered type of structural alloy steel electrode.

5. The Murex nickel-molybdenum electrode appears to deposit a weld metal having slightly higher ballistic properties than the Murex nickel-chrome electrode.

6. Satisfactory ballistic properties can usually be obtained by oxy-acetylene welding using a filler rod of approximately the same composition as the casting, (except carbon not over 0.35%) but the weld metal is not always free from cracks unless a relatively high preheating temperature is used (not less than 600°C) and the casting is maintained at temperature during welding.

7. In order to satisfactorily perform the operation outlined in (6) four provisions are essential:-

(a) Suitable table and heating equipment to maintain casting temperature.

(b) Welding torch provided with cooling apparatus to keep the tip from heating and causing flash-backs.

(c) Suitable protection for the welder from heat radiated from the casting and heating apparatus.

(d) Annealing furnace conveniently available so that the welded casting can, on completion of welding, be placed in the furnace at temperature and annealed without cooling down following the welding operation.

8. It is believed that where weld repairs are to be made on inside surfaces of a casting the arc method can successfully be used.

9. It is believed that the oxy-acetylene process should be used with a filler rod of composition similar to that of the casting for repair of defects on

exposed surfaces except that the arc method can be used for repairing shallow surface defects without seriously affecting ballistic properties of the casting.

Test Data

The results of the experiments covered by this report are shown by Tables I, II and III at the back of the report.

The Gas Welding Process

The method used to repair armor castings at Watertown Arsenal during 1935 and 1936 involved the use of a strongly carburizing flame with a filler rod obtained from Disston consisting of strips sheared from 1/4" homogeneous plate of approximately 0.45/0.50% carbon. No welding flux was used.

The procedure followed was to grind out the crack or defect with the casting in the annealed condition. Then the area of the repair was heated with the welding torch to a red heat before starting to weld. When the area of repair had been heated the filler metal was added in a manner similar to that used for any steel welding operation.

When welding was finished the casting was laid aside to cool in air but this practice was later changed to give a slower cooling rate by burying the hot casting in powdered lime immediately after welding.

With this procedure it was found that about half of the castings repaired were later rejected on x-ray examination because of cracks in the weld metal. Accordingly some experiments were made to determine whether improvements in the method of repair could be accomplished.

The experiments made with the gas welding process are listed in Table I and the notes here indicate quite clearly that a preheating temperature of about 800°C, with this temperature maintained approximately constant during welding is apparently successful when a filler rod of medium carbon content is used. In this particular case, however, it should be pointed out that the weld repair was made on the outside of the casting so that the welder and torch could be partially protected from the radiating heat and the welding was performed from start to finish without interruption. When these conditions are not obtained the success of the repair is questionable. It also appears desirable to have available a furnace - the furnace being used for preheating may be suitable - at annealing temperature so that the casting does not cool down after welding.

In Figure #1 are shown radiographs of shields #39B and #63B after welding. The radiograph of shield #88A is shown by Figure #2 and the fine hair cracks in the weld metal can be seen. All three of these castings were welded with the same composition (0.34% C) of filler rod and with the same preheat but the welding on #88A was not performed continuously due to interruptions caused by torch tip overheating.

Electric Arc Welding

The experiments made with the arc welding process involved the following electrodes, all of the Murex type furnished by the Metal & Thermit Corporation.

Cromansil	--	Carbon 0.26%
Ni.-Mo.	-	0.19% C, 2 1/2% Ni.,0.50% Mo.
Ni.-Cr.	-	0.15% C, 2% Ni. 1% Cr.
Car.-Mo.	-	0.40% C, 0.50% Mo.
Car.-Mo.	-	1.10% C, 0.50% Mo.

These electrodes were used on Carburetor Cover #68 to make weld deposits from which sections were cut (Fig. No.3) for hardness surveys and macro-examination. The preparation for making these weld deposits consisted of grinding a groove about one inch wide approximately half way through the casting wall. This groove was then filled up with weld metal and the sections for examination were cut at right angles to the groove.

In Table II are shown the results of hardness tests made on these weld deposits.

These electrodes enumerated above were used on a number of armor shield castings to make weld deposits for ballistic tests. The results of these tests are shown by Table III. In all cases the weld metal extended about half way through the casting wall and on all but two castings the welds were on the outside exposed to the bullet None of the arc welds were free from cracks. The form of these cracks is shown by Figures #4, 5 and 6.

Attention is called to the radiographs shown in Figure #4, 5 and 6 and the ballistic properties listed in Table III. All three of these castings - 60A, 30A, and 73A - were welded with the same two electrodes but under different degrees of preheat. The welds made with the high preheat - 30A, Fig.#5, show the least tendency to crack but the ballistic properties of the welds are not as good as those of the welds made with no preheat - 73A, Fig. #6.

All welds ballistically tested were annealed at 850°C before oil quenching from 1600°F and drawing at 925°F.

In all of these arc welding tests the effort was made to keep the weld from penetrating beyond the midpoint of the casting wall When the arc weld penetrates beyond this point it is believed that the ballistic strength is lowered but the amount is unknown. As long as this limit of penetration is not exceeded it is believed that the ballistic properties of the casting are not seriously affected.

This observation is particularly pertinent when the repair weld is made from the inside of the casting.

Respectfully submitted,

W. L. Warner

W. L. Warner
Welding Engineer

TABLE I

Oxy-Acetylene Welding - Armor Shield Castings- Ballistic Tests

Casting No.	Weld	Filler Rod - Analysis C	Mn	Si	Mo	Cr	Va	Filler Rod
68A	inside	0.49	0.71	0.17	0.66	1.13	0.24	Disston strip sheared from 1/4" homogeneous armor plate.
71B	"							
88A	"	0.32	weld metal analysis					
39B	outside	0.34	0.61	0.26	0.90	1.38	0.24	Cast rods from Arsenal foundry
63B	"	"	"	"	"	"	"	
68A	inside	0.34	0.61	0.26	0.90	1.38	0.24	Cast rods from the Arsenal foundry.
71B	"	"	"	"	"	"	"	
88A	"	"	"	"	"	"	"	

Casting No.	During Welding: Preheat	Temp. Maintained	Heat Treatment After Welding: Anneal	Quench	Draw
68A	850°C	No	850°C	1600°F	925°F
71B	"	"	"	"	"
88A	"	"	"	"	"
39B	800°C	Yes	850°C	1600°F	925°F
63B	"	"	"	"	"
68A	800°C	Yes	850°C	1600°F	925°F
71B	"	"	"	"	"
88A	"	"	"	"	"

T A B L E   I (con't.)

Casting No.	Radiographic Test	Ballistic Test -Remarks
68A	Fine hair cracks throughout weld metal - visual.	In this instance the casting remained red hot for about 10 min., only after removal from the furnace. It was therefor necessary to make the welds spasmodically between heatings. About three (3) heatings were necessary on each casting. No ballistic tests.
71B	Fine hair cracks throughout weld metal - visual.	
88A	Fine hair cracks throughout weld metal - x-ray.	
39B	No cracks -some fine porosity.	Passes Spec. WED-56 (B.R.#115/67).
63B	No cracks - considerable coarse porosity - weld not built up above casting SUrface.	Passes Spec.WED-56 (B.R.#115/68). If this weld had been properly reinforced and ground off the porosity would have doubtless disappeared.
68A	Fine hair cracks detected in the weld metal by visual inspection. These probably are caused by frequent melting and solidification of metal due to interruption.	No ballistic tests. Due to the high temperature and heat radiation from the castings frequent flash-backs occurred due to torch overheating. This caused very frequent interruptions to cool the torch tip. For this class of welding where the repair must be made on the inside of the casting a water-cooled torch tip and an asbestos suit for the welder are required.
71B	" "	
88A	" "	

TABLE II

Experimental Arc Welds - Carburetor Cover #68
Hardness Test

Weld	Analysis - Electrode: C Mn Si Ni Mo Cr	Analysis - Weld Deposit: C	Mn	Si	Ni	Mo	Cr	Va
#1	0.26 Murex Cromansil	0.12	0.55	0.14		0.76	0.42	0.07
#2	0.19 Murex Ni-Mo	0.10	0.48	0.15	1.91	0.78	0.28	
#3	0.15 Murex Ni-Cr	0.10	0.38	0.10	1.48	0.29	0.71	
#4	0.40 Murex Car-Mo	Not analyzed						
#5	1.10 Murex Car-Mo	Not analyzed						

Weld	Welding Procedure: Amp	Volts	Preheat	Temp. Held	Post Heat Treatment: Anneal	Quench	Draw
#1	200	28	none	none	850°C	1600°F	925°F
#2	225	26	"	"	"	"	"
#3	200	30	"	"	"	"	"
#4	200	30	"	"	"	"	"
#5	200	30	"	"	"	"	"

Weld	Weld Metal (Vickers Brinell): As Welded	Heat Treated	Weld Metal Brinell No.: As Welded	Heat Treated	Analysis of Casting: .32%C; .52%Mn; .21%Si; .79%Mo; .21%Va; 1.15%Cr; Casting welded throughout in the "As Cast" condition.
#1	315			280	No ballistic test
#2	267	305		244	Ballistic test of casting #59A-60A-30A-72B-73A-74A
#3	253	275		209	" " " " "
#4			212	262	Ballistic Test of casting #63A-38B
#5			255	298	" " "

T A B L E III

Arc Welding - Armor Shield Castings - Ballistic Tests

Casting No.	Weld	Electrode C	Electrode Trade Name
59A	Inside A	0.19	Murex Ni.-Mo.
	" B	0.15	" Ni.-Cr.
60A	Outside A	0.19	Murex Ni.-Mo.
	" B	0.15	" Ni.-Cr.
30A	Outside A	0.19	Murex Ni.-Mo.
	" B	0.15	" Ni.-Cr.
72B	Inside A	0.19	" Ni.-Mo.
	" B *	0.15	" Ni.-Cr.*
73A	Outside A	0.19	Murex Ni.-Mo.
	" B	0.15	" Ni.-Cr.
74A	Outside A	0.19	Murex Ni.-Mo.
	" B	0.15	" Ni.-Cr.
63A	Outside	0.40	Murex Car.-Mo.#50
38B	Outside	1.10	Murex Car.-Mo.#50

* Not Welded

Table III (con't.)

Cast. No.	Welding Procedure: Amp	Volts	Lay-ers	Pre-heat °C	Temp. held	Post Heat Treatment: Anneal °C	Quench °F	Draw °F
59A	200	28	5-6	400	Yes by using one gas burner	850	1600°F	925
60A	"	"	"	"		"	"	"
30A	175	30	6-7	800	Yes by using two gas burners	"	"	"
72B	"	"	"	"	"	"	"	"
73A	215	33	4-5	none	No	850	1600°F	925
74A	180	30	4-5	100/200°C	Cooled by jet of water at back.	"	"	"
63A	200	30	5-6	100	No	"	"	"
38B	220	30	5-6	100	No	"	"	"

T A B L E   III (con't.)

Radiographic Examination

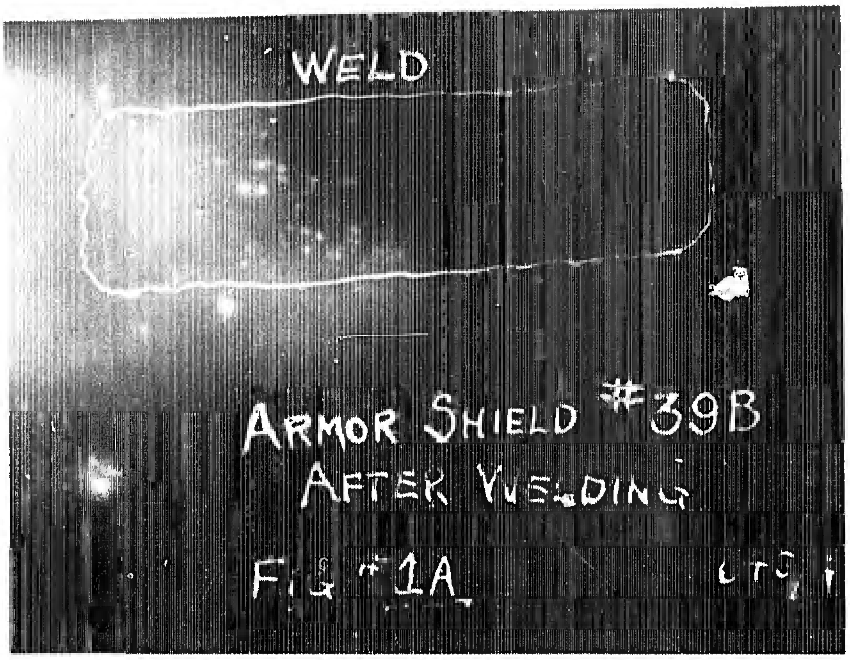
Casting No.	Weld	After Welding	After heat treatment	After ballistic test	Ballistic Test - Remarks
59A	Inside A	Star cracks	Same	Same	Passes Spec. WED -56 O.K. (B.R. #115/31, 32, 33).
	Inside B	Fewer cracks	"	"	" " "
60A	Outside A	Large star crack	"	"	Not quite passable (2300 F.S.) (B.R. #115/31, 32, 33).
	" B	Fewer cracks but very porous	"	"	" " " "
30A	Outside A	Considerable porosity with fine tails on some of the holes.	"	"	Passes Spec. WED-56 O.K. (B.R. #115/50)
	Outside B	Less porosity and more cracks.	"	"	Not passable (B.R. #115/49, 52).
72B	Inside A	Some porosity and fine cracks.	"	"	Passes Spec. WED-56 O. K. (B.R. 115/49, 52).
	Inside B	-----	---	---	High preheat -excessive time required -unable to finish.
73A	Outside A	Small fine crack	Same	Same	Passes Spec. WED -56 O.K. (B.R.#115/51) Superior to Weld B.
	" B	Several small cracks	"	"	Passes Spec. WED-56 O.K. (B.R. #115/53).
74A	Outside A	Some fine cracks but otherwise sound	Cracks more prominent	Same	Does not pass Spec. WED-56 (B.R. #115/72).
	Outside B	Fine cracks and some porosity		"	" " "
63A	Outside	Fairly sound - no cracks.	Prominent cracks.	Crack in rear face of casting.	Does not pass Spec. WED -56. (B.R.#115/70)weld brittle.
38B	Outside	One trans. crack	"	Same	Passes Spec. WED-56 (B.R.#115/71)

Casting #39B

Figure No. 1

Gas Weld - Preheat 800°C - Cast Filler Rod of Armor Composition, 0.34% C. Outside weld.

Casting #63B


WELD
ARMOR SHIELD #39B
AFTER WELDING
FIG #1A

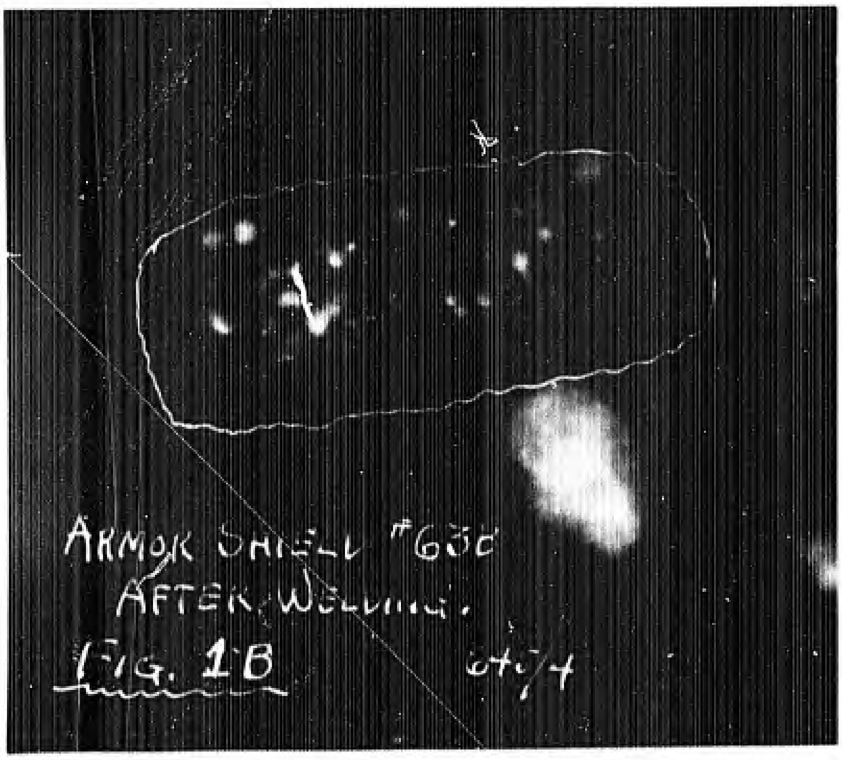

ARMOR SHIELD
AFTER WELDING.
FIG. 1B

Figure No. 2

Gas Weld - Preheat 800°C - Cast Filler Rod
of Armor Composition, 0.34% C. - Inside Weld.

Casting #88A


CRACK
WELD
FIG #2
ARMOR SHIELD #58A
AFTER WELDING

Figure No. 3

Arc Weld - Sections through weld metal, Weld #2, Table II - Carburetor Cover #68 - Vicker's Brinell Hardness Test. Electrode - Murex 2 1/2% Ni., 0.50% Mo.

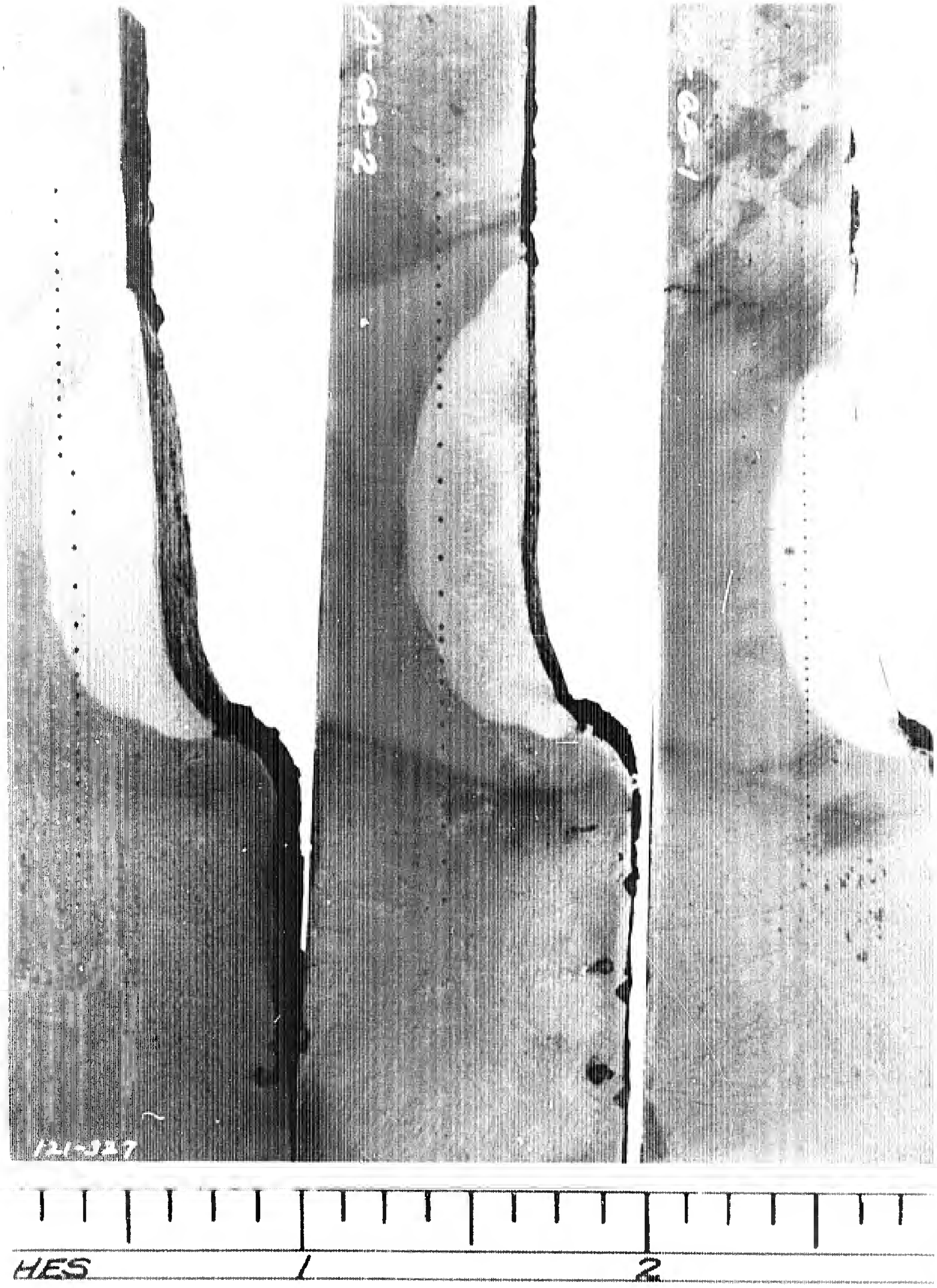


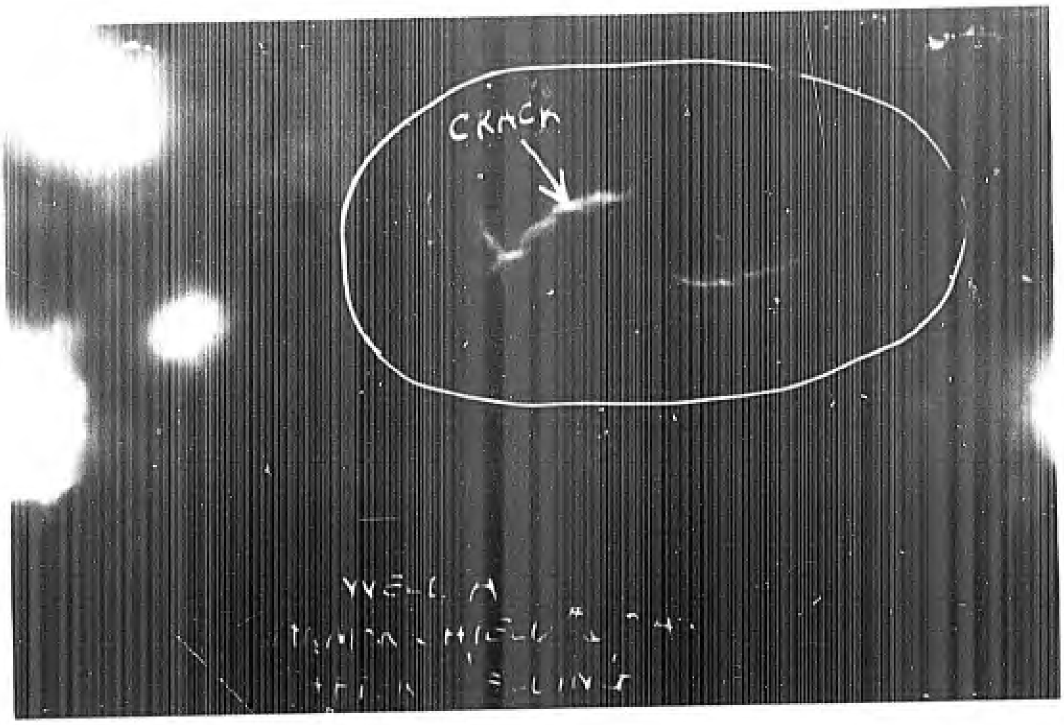
FIG. 3

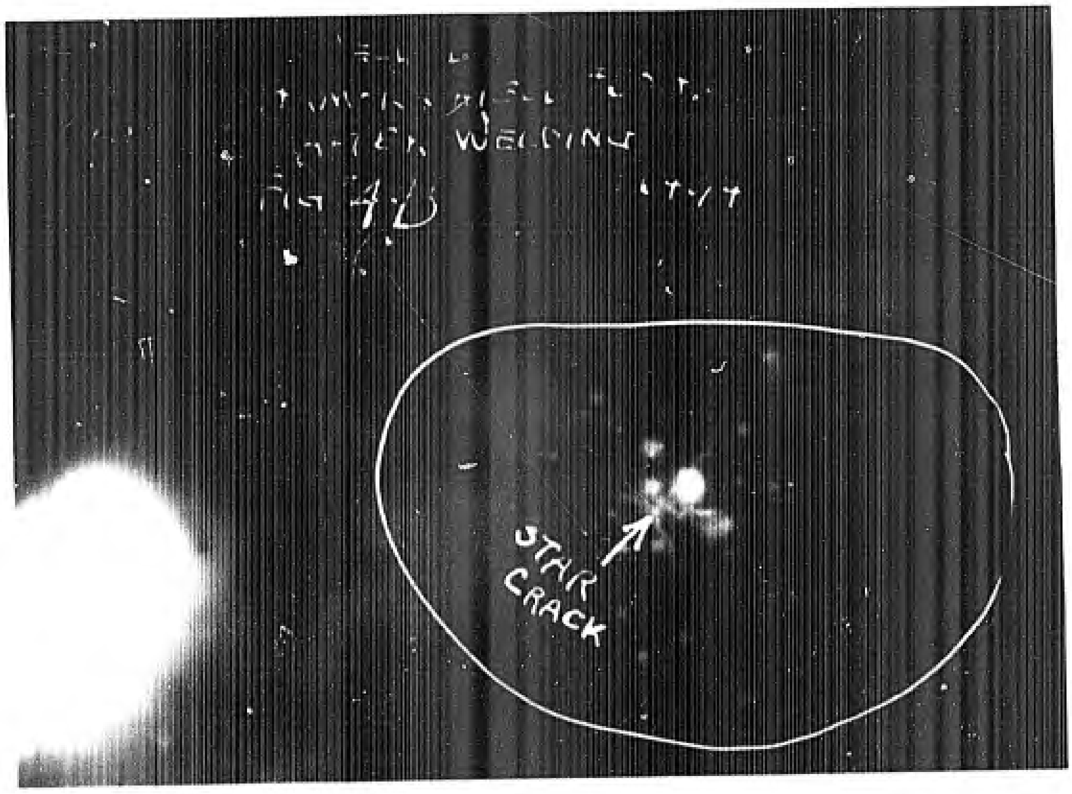
Weld A, Casting #60A

Figure No. 4

Arc Weld - Preheat 400°C - Electrode,
Weld A, Murex Ni.-Mo., Weld B, Murex Ni.-Cr.

Weld B, Casting #60A


CRACK

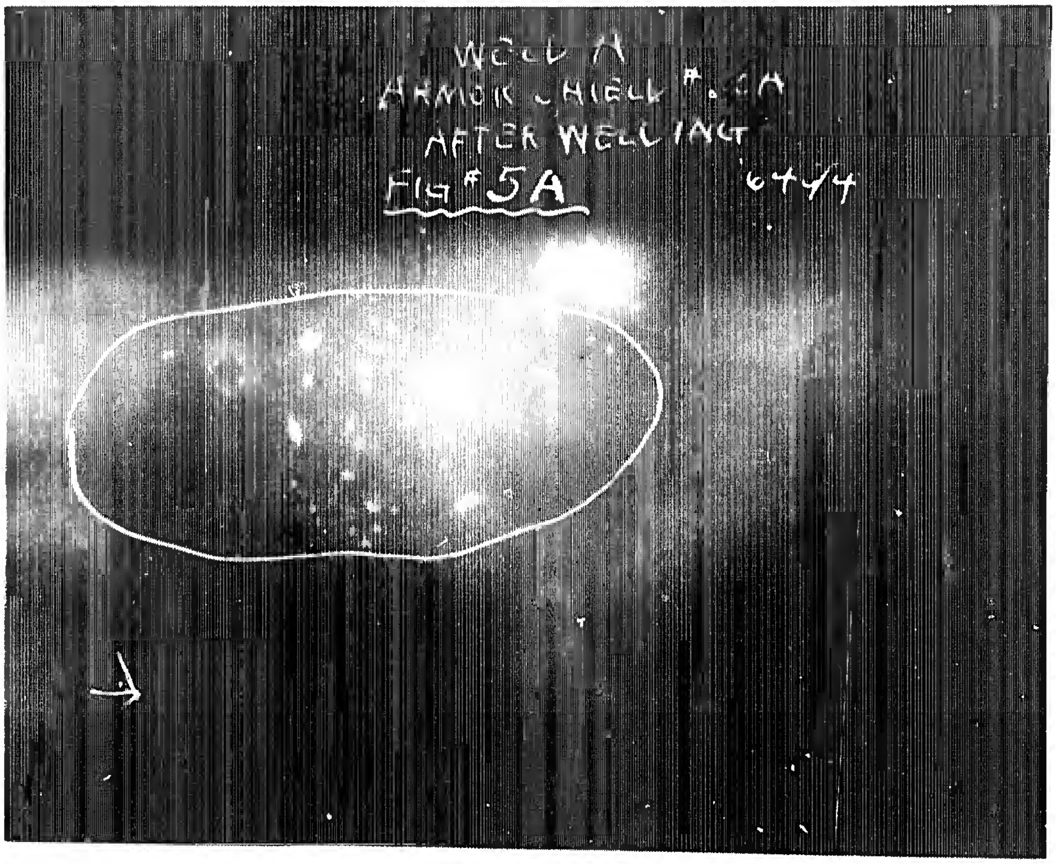

STAR
CRACK

Weld A, Casting #30A

Figure No. 5

Arc Weld - Preheat 800°C - Electrodes same as Figure No. 4.

Weld B, Casting #30A


AFTER WELDING
FIG #5A

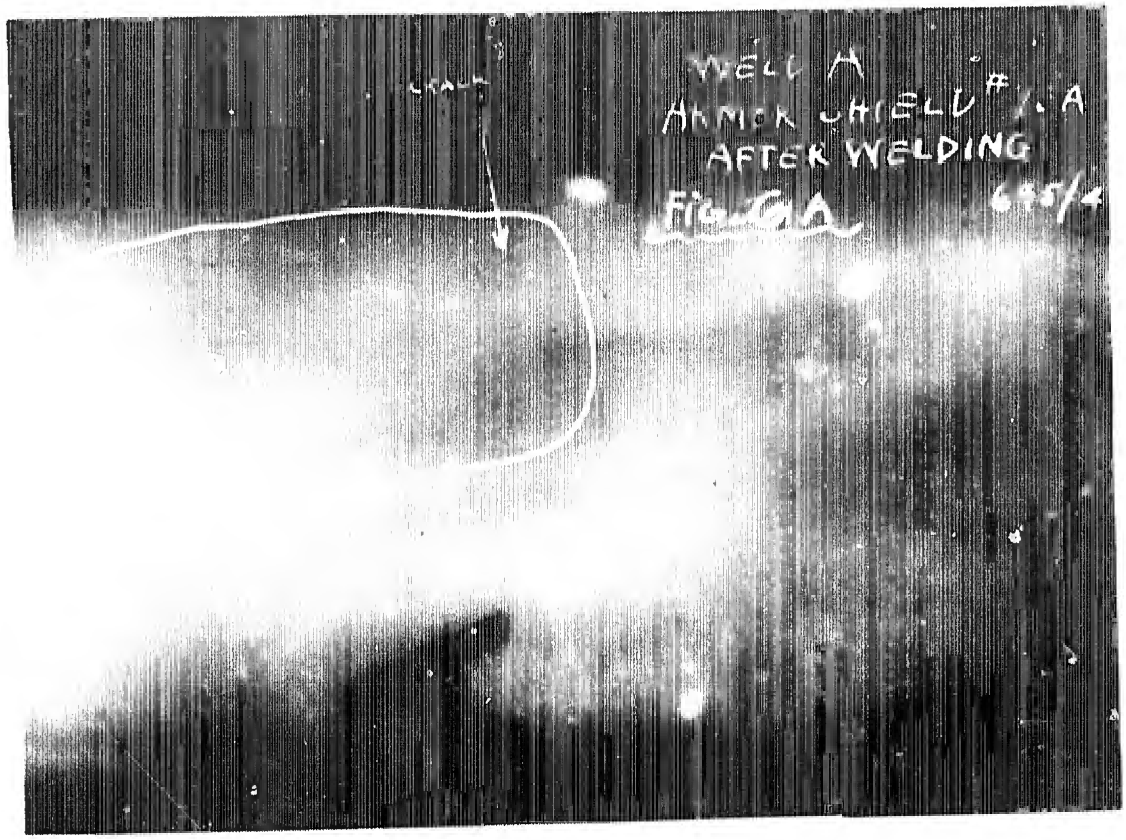

ARMOR SHIELD #30A
AFTER WELDING
FIG #5B

Weld A, Casting #73A

Figure No. 6

Arc Weld - No preheat - Electrodes same as
Figure No. 4.

Weld B, Casting #73A


AFTER WELDING

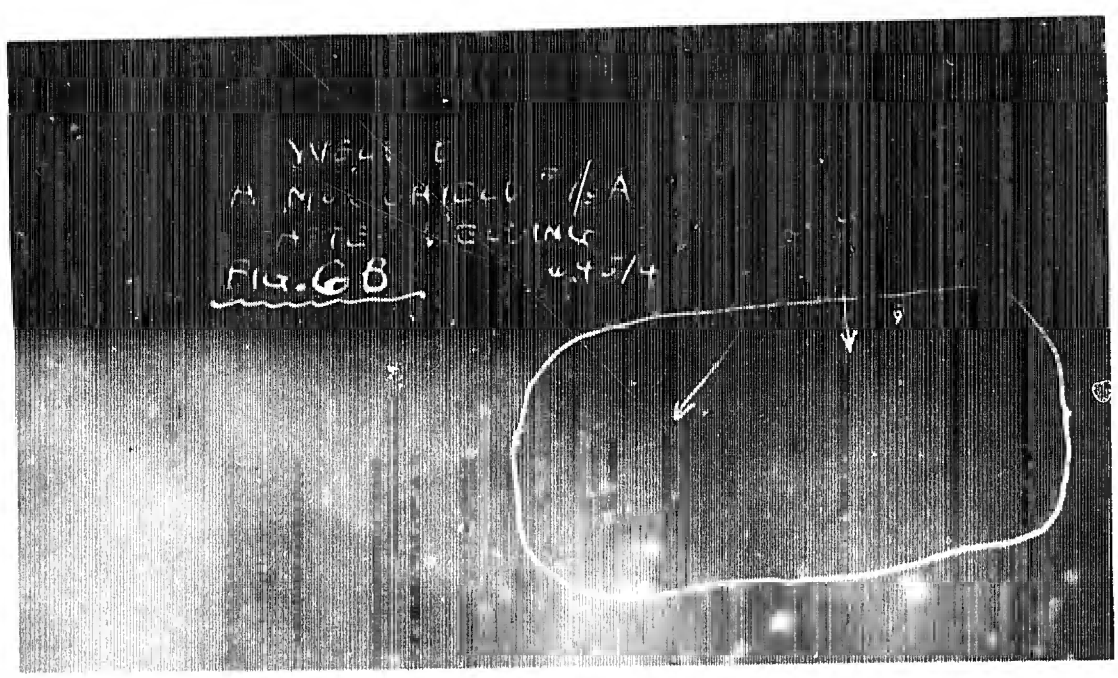


FIG. 6B