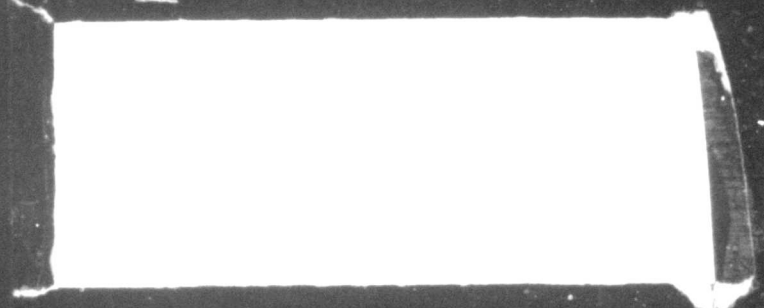

RESEARCH AND DEVELOPMENT DEPARTMENT

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ACF Industries, Incorporated
Research and Development

Weldability of Rare Earth Treated Homogeneous Armor Steel Plate
Interim Report No. 1

Contract No. DA-36-034-ORD-1423RD

February 14, 1955 Major Report No. 207

by
William G. Smith

Approved by: George Reed

Approved by: J. M. Gruitch

Major Report No. 207

INTERIM REPORT NO. 1

Contractor:	ACF Industries, Incorporated
Contract Number:	DA-36-034-ORD-1423RD
Title of Report:	Weldability of Rare Earth Treated Homogeneous Armor Steel Plate. Interim Report No. 1
File Number:	WAL 642/218-1
Date:	February 14, 1955
Agency:	Army Ordnance Department, Watertown Arsenal.
Technical Supervision:	Watertown Arsenal Laboratory.
Ordnance District:	Philadelphia
Author:	William G. Smith
Object:	To determine the relative weldability of rare earth metal treated, rare earth oxide treated, and normal production manganese-molybdenum composition wrought homogeneous armor steels.
Summary:	Navy circular patch plates for determination of minimum size patch permissible for satisfactory welding, circular patch plate design explosion bulge plates, straight butt welded explosion bulge plates, cruciform test plates and H plates were welded of each of the three materials involved in this investigation for determination of relative weldability. All welding was accomplished with low hydrogen ferritic electrodes, MIL-986A Class MIL-230-15. Results of the laboratory phases of this investigation, the explosion bulge testing and the ballistic tests will be contained in later reports.
Conclusions:	Evaluation of the materials by the number of weld defects observed in the preparation of the test plates indicates that rare earth metal treated manganese-molybdenum armor is similar to normal production manganese-molybdenum armor in weldability. Rare earth oxide treated armor exhibited improved weldability although the results obtained may have been influenced by lower chemistry and hardenability of the rare earth oxide armor heat subjected to tests.

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Introduction

1. For the past number of years wrought homogeneous armor of 1/2-inch thickness has exhibited a tendency toward low or borderline toughness qualities. Under Specification AXS 495 and later Specification 57-115-11 and 57-115-11, Amendment 1, wrought homogeneous armor was subjected to projectile-through-plate tests with excessive exit diameters resulting unless toughness was maintained at the maximum obtainable when hardness values were at a minimum commensurate with penetration requirements.

2. On the issuance of Specification 57-115-11, Amendment 2, in April 1949, the projectile-through-plate test requirements were superseded by Charpy V-notch impact toughness requirements. A significant percentage of 1/2-inch armor failed to meet the specified notch toughness requirement, and to make possible the procurement of sufficient quantities of 1/2-inch armor for the maintenance of vehicle production during the Korean crisis, it was necessary to issue Engineering Change Order 35140-1 dated January 23, 1952, lowering the Charpy V-notch requirements on 1/2-inch wrought homogeneous armor by 3 ft.-lbs. Specification 57-115-11, Amendment 2, has since been superseded by Specification MIL-A-12560 and Engineering Change Order 35140-1 has been rescinded although 1/2-inch wrought homogeneous armor still exhibits low or borderline notch toughness values.

3. During the past few years it has been determined that the addition of rare earth elements is beneficial in increasing the notch toughness of cast steel as cerium additions markedly change the nature of the sulfide inclusions by the destruction of the sulfide envelopes and the reduction of the sulfur content of the steel.

4. In the effort to improve the Charpy V-notch toughness of 1/2-inch wrought homogeneous armor, a number of experimental and production heats have been made with the addition of rare earth elements. On some heats, notch toughness values were markedly improved, in others, there was no noticeable difference, with the variations apparently being due to the method of making additions and the amount of retained rare earth elements. The use of rare earth treated armors in the production of armored vehicles has resulted in some fabricators claiming that an increased tendency for cracking is promoted in the weld fusion and heat affected zones. These claims have resulted in the Watertown Arsenal Laboratory being requested by the Ordnance Advisory Committee on the Welding of Armor to determine the physical and weldability characteristics of rare earth treated wrought homogeneous armor steel. This investigation is a portion of the over-all study and was contracted to ACF Industries, Incorporated, under date of June 30, 1953.

Scope of Investigation

5. In its entirety this investigation includes all pertinent phases of laboratory determinations, weldability, ballistic and explosion bulge tests concerned in the evaluation of the relative characteristics of three heats; one a rare earth metal treated, another a rare earth oxide treated, and the third a normal production wrought homogeneous armor steel of manganese-molybdenum composition.

6. This is Interim Report No. 1 and is specifically concerned with the following items:

A. Materials received for test and the identification and cutting of the material.

B. The preparation and evaluation of 3, 4 and 5 inch patch diameter Navy circular patch test plates of each material for the determination

Scope of Investigation (Cont'd.)

of relative crack sensitivity and to determine the technique and patch diameter for use in the preparation of circular patch test plates for explosion bulge testing.

C. The preparation of nine 20" x 20" circular patch test plates of each material for explosion bulge testing.

D. The preparation of a minimum of 24 weldments from each of the three materials for explosion bulge testing. These weldments consisting of two 10" x 20" plates joined by a double V butt weld to form 20" x 20" test plates.

E. The preparation of twelve 20" x 20" unwelded test plates of each material for the evaluation of the prime plate properties by explosion bulge test.

F. The preparation and evaluation of weldability of two "cruciform" tests on each material.

G. The preparation of four "H" plates of each material. The scope of the original contract included the preparation of a minimum of one "H" plate on each of the three materials, however, the contract was later supplemented to provide for the preparation of three additional "H" plates for each heat.

7. Interim Report No. 2 will cover the steel mill operating records and laboratory phases of this investigation and a final report will be issued summarizing these two interim reports and giving the results of explosion bulge tests and ballistic tests to be conducted on the plates prepared and reported on in Interim Report No. 1.

Materials

Base Plate

8. For purposes of this investigation, Watertown Arsenal procured from the Jones and Laughlin Steel Corporation quantities of manganese-molybdenum type wrought homogeneous armor steel representative of rare earth metal treated, rare earth oxide treated and normal production practices. The plate was subsequently furnished to ACF.

9. The scope of the investigation, exclusive of the "H" plates covered by Supplemental Agreement No. 1, necessitated the procurement of additional quantities of plate material of each of the three armors involved. The additional armor was purchased directly from the Jones and Laughlin Steel Corporation by ACF Industries, Incorporated.

10. The plate material required for "H" plates, under Supplemental Agreement No. 1, was also procured directly from the Jones and Laughlin Steel Corporation by ACF Industries, Incorporated.

11. Base plate materials procured were as follows:

Materials (Cont'd.)

A. Plates from Heat JL 0681 with rare earth metal addition:

1) * 3 plates 1/2" x 68" x 108" from Ingot #1, cuts 1, 2 and 5.
2) ** 2 plates 1/2" x 68" x 108" from Ingot #1, cuts 1 and 2.
3) *** 3 plates 1/2" x 37" x 42" from Ingot #2, cut 1.

B. Plates from Heat JL 0724 with rare earth oxide addition:

1) * 3 plates 1/2" x 57" x 196" from Ingot #3, cuts 1, 2 and 5.
2) ** 1 plate 1/2" x 57" x 195-3/4" from Ingot #3, cut 4.
3) *** 3 plates 1/2" x 37" x 42" from Ingot #2, cut 4.

C. Plates from Heat JL 0823, normal production armor:

1) * 3 plates 1/2" x 71" x 101-3/8" from Ingot #3, cuts 1, 2 and 5.
2) ** 2 plates 1/2" x 71" x 101-3/8" from Ingot #3, cuts 1 and 2.
3) *** 3 plates 1/2" x 37" x 42" from Ingot #3, cut 3.

* Plates furnished by Watertown Arsenal.
** Plates purchased by ACF for original investigation.
*** Plates purchased by ACF for additional "H" plates.

Electrodes

12. All electrodes used in the investigation were 5/32" and 1/4" diameter of the low hydrogen ferritic type conforming to Specification MIL-E-986, Grade 230-15 and were Tensilend 100 secured from the Arcos Corporation. All the 5/32" electrodes were from Alloy No. E3264 B101 Process No. 69538X and the 1/4" electrodes were from Alloy No. 63302 A101 Process No. F95328B1. The electrodes were supplied in 10-pound sealed cans. The containers were opened only as necessary and, once opened, were stored at 230° F. The electrodes were then withdrawn only in small lots to keep moisture pickup at a minimum.

Discussion

Identification and Cutting

13. All plates as received from Watertown Arsenal and Jones and Laughlin Steel Corporation were identified by heat number, ingot number and slab (cut) number. For the purpose of maintaining these identifications and the recording of the position of each piece cut for test, a detailed cutting diagram was prepared for each plate. The cutting diagrams are shown in Figures 1 to 8 inclusive. Identification numbers were paint stenciled on each piece parallel with the rolling direction with identification letters "A", "B", and "C" representing, respectively, Jones and Laughlin Steel Corporation heat numbers JL 0681 (rare earth metal treated), JL 0724 (rare earth oxide treated), and JL 0823 (normal production armor). Only those portions of the plates which were ultimately incorporated in test plates or are covered in these reports are identified on the cutting diagrams.

14. All plates were cut and bevels made by the oxy-acetylene gas cutting process. In cutting and beveling the circular patch test plates a rotating positioner was used with the plate held and rotated on the table and the cutting torch mounted on a post as

Discussion (Cont'd.)

illustrated by Figure 9. A 1/8" hole, drilled perpendicular to the face of the plate in the line of cut was used as a starting point for cutting the circle and the first step was removal of the circle using a 90° cut. Bevels were then cut on the outer section by positioning of the torch. The circular patch was then positioned on a magnet at the center of the rotator, located by means of a locating disc, and the bevels cut. Figure 10 illustrates this operation. All cut surfaces were ground for removal of scale and oxide prior to welding.

Welding

15. On all weld joints, design and welding procedures were in accordance with ACF standard weld joint procedures as used with low hydrogen ferritic electrodes conforming to Specification MIL-E-986A, Class MIL-230-15. The weld joints were of double V butt type design, with 45° included angles, 3/16" root gap, and no land. Copper back-up bars were used for all first pass welds. This joint design, the welding pass sequence and other pertinent data are shown in Figure 11.

16. All weldments made during the investigation were produced by two welders qualified under the requirements of Specification MIL-W-12518. These welders previously had several years' experience in the welding of armor steels and, in addition to production welding, had produced a number of test weldments including many "H" plates. They are considered to be excellent welding operators who have proven by past performance that they are capable of producing good and consistent weldments. In a further effort to reduce the effect of welding operator characteristics, only the standard type explosion bulge plates were prepared by both men. All other plates were welded by one welder.

Circular Patch Test Plates

17. For the determination of the relative crack sensitivity of the three materials and to determine the technique and patch diameter to be used in the preparation of circular patch design explosion bulge test plates, 12" x 12" circular patch test plates of 3, 4 and 5 inch patch diameter were prepared and evaluated.

18. The standard joint design shown by Figure 11 was used for the circular patch test plates and all welding was in accordance with provisions for such test plates as set forth in Specification MIL-E-986A (Ships) dated 1 October 1951, i.e., patches were divided into quadrants and welding of each quadrant completed before starting the next. The sequence used in the welding of the quadrants was such that after the completion of the first quadrant the quadrant diametrically opposite was welded next. The third and fourth quadrants were completed in a like manner. All welds were deposited in a clockwise direction.

19. The first pass starting temperature on all welds was 80° F (minimum temperature used by ACF in the welding of test plates) and, in accordance with the requirements of Welding Specification covering Welding of Homogeneous Armor with Ferritic Electrodes MIL-W-12518, the interpass temperatures were not more than 25° greater than the starting temperature (105° F maximum).

20. All plates were subjected to radiographic examination and the results of the examination are shown in Table I. In the evaluation of the weldability of the three materials by circular patch test plates, it is apparent that the tendency for porosity,

Discussion (Cont'd.)

slag and undercutting is similar and it is therefore indicated that the addition of rare earth elements has not affected the frequency of occurrence of these defects. In the welding of the 3" diameter circular patch test plates, cracking occurred in plates of all three materials. In the welding of the 4" diameter patches, cracking occurred in three of four "A" series and "C" series plates respectively; no cracking occurred in the 4" patch "B" series plates.

21. In the welding of the 5" diameter circular patch test plates, cracking occurred in two of three "A" series plates. No cracking occurred in the "B" or "C" series plates.

22. In the welding of the 5" diameter circular patch test plates, it was found that the length of quadrant was too great to complete the root pass with one 5/32" electrode and on the first three 5" patch plates of each series, the remainder of each quadrant of root pass was deposited by the back-step technique with a considerable amount of slag and porosity resulting from the extra stops. Therefore, another group of 5" diameter patch plates were welded with the balance of each root pass quadrant being made straightway, and while the occurrence of slag and porosity was not reduced, incidence of cracking increased with one of two "A" and "B" series plates indicating cracking, and three of three "C" series plates indicating cracking.

23. An over-all summary of all circular patch test plates involved showed that seven of twelve (58%) "A" series plates indicated cracking, two plates in eleven (18.2%) of the "B" series plates indicated cracking, and eight of thirteen (61%) "C" series plates indicated cracking. From this evaluation it is indicated that plates of series "A" and "C" are of relatively equal weldability and that "B" series plates are of improved weldability with a lesser susceptibility to cracking.

24. Also from the evaluation of welding of the circular patch test plates, it is indicated that "B" series plate material can be fairly consistently welded crack free in 4" diameter size patch while series "A" and "C" plates cannot be welded crack free in 4" or 5" patch diameter although the incidence of cracking is somewhat lower in the 5" diameter plates than on the 4" diameter.

25. As the 5" diameter patch plates of series "A" and "C" were not crack free and since the 5" patch diameter exhibited a greater tendency for porosity and slag inclusions due to the greater number of starts necessitated by the fact that the 5/32" electrode was not long enough to complete a quadrant, it was deemed advisable to use the 4" diameter patches for explosion bulge plates on all three series even though incidence of cracking for this patch diameter is rather high for "A" and "C" series plate material. The 3" diameter patch plates were not further considered as the incidence of cracking was high for all three plate materials. The circular patch plates were welded in a random order so that welding proficiency acquired through experience with welding circular patch test plates would not affect the evaluation of crack susceptibility of the various heats.

Circular Patch Explosion Bulge Plates

26. Nine circular patch explosion bulge plates were prepared from each of the three materials involved. The plates were 20" x 20" with all patches being of 4" diameter and were prepared in the same manner as 12" x 12" circular patch test plates. All welding was accomplished by the same procedures used in the welding of the 12" x 12" plates. The plates were subjected to radiographic inspection and the results of this radiographic inspection are shown in Table II. Limits as prescribed by Standard II of Military

Discussion (Cont'd.)

Specification MIL-R-11468 were used as the criteria of inspection as this Standard is generally used in the inspection of welds in 1/2" homogeneous armor plate in the construction of Ordnance vehicles. Plates not meeting these requirements were repaired by re-welding the defective areas after removal of the defects by grinding in cases where defects were shallow and by the arc-air method for defects of greater depth. It was found necessary to replace one plate from series "A" (heat JL 0681) and two plates from series "C" (heat JL 0823) as in each case cracks or laminations propagated into the plate material in such a manner that the direction of repairs would have been radial to the center of the patch and no practical guide could have been used in the evaluation of explosion bulge plate test results. Defects on these three plates were traced to laminations or grinding procedure and were not considered indicative of the comparative weldability of the steels.

27. In the welding of the circular patch explosion bulge test plates cracking occurred in five of nine series "A" plates, three of nine series "B" plates, and three of nine series "C" plates.

Explosion Bulge Plates

28. A minimum of 24 explosion bulge test plates were fabricated from each of the three heats under investigation with each plate consisting of two 10" x 20" plates welded together to form a double vee butt welded plate 20" x 20" with the joint design and welding procedures as shown in Figure 11. All welds are parallel to the direction of rolling and two electrodes were required for each pass. The back-step technique of weld deposition was used with the starts on small tabs at the plate ends which were later removed. Each root pass was inspected for defects by the magnetic particle crack detection method and any defects removed before deposition of cover passes.

29. Completed weldments were subjected to radiographic examination with the results shown in Table III. Incidence of weld zone cracking on these plates was found to be inconsistent with that experienced with circular patch test plates since cracking occurred on six of 24 "B" series plates and on only one of 24 and 28 "A" and "C" series plates, respectively.

30. As each of the plates is composed of two individually numbered pieces, the procedure in radiographic inspection consisted of placing the plates stencilled side up with the lower numbered section above the higher numbered section. Plate ends were stencilled A and B to conform with the radiograph identification.

Unwelded Explosion Bulge Test Plates

31. Twelve 20" x 20" explosion bulge test plates were cut from each of the three materials under test for evaluation of prime plate characteristics. The plates were stencilled with numbers running parallel to the rolling direction.

"H" Plates

32. One "H" plate from each heat was fabricated under the terms of the original contract, and three additional "H" plates on each heat were fabricated under Supplemental Agreement No. 1. Plate preparation, joint design and welding procedure are shown in Figure 11. Although all welding was done by a qualified welder who had successfully welded the majority of "H" plates prepared by ACF during the past three years, in the welding of the twelve "H" plates required for this program considerable unexplained

Discussion (Cont'd.)

difficulty was encountered with each of the three heats involved. On heat JL 0681 it was necessary to scrap plate No. A115 for laminations, with replacement being made from other available material. Of the twelve plates completed, considerable cracking difficulty was encountered with one plate from each of the three heats and under ordinary circumstances these plates would have been scrapped and replaced, however, in an effort to furnish the full complement of four plates of each heat, the plates were subjected to repeated repairs until found to be radiographically acceptable. Figures 12 through 19 show the defects and number of repairs required on each of the twelve plates. It will be noted that in all cases considerable difficulty was encountered with slag porosity, and cracking.

Cruciform Tests

33. Cruciform tests were run as an additional check on the relative weldability of the three armors involved in the investigation. This test consisted of two plates 1/2" x 4" x 10" attached to a 1/2" x 8" x 10" plate by four 1/4" single pass fillet welds in such a manner that a 90° cross is formed as shown in Figure 19. Welds were made with 5/32" electrode and were deposited and numbered in a counter-clockwise sequence. Plate temperature at the beginning of the first pass was 80° F and on each succeeding pass was 105° F. Two cruciform test plates were made on each of the three armors.

34. After the completed weldments were stress relieved at 1100° F for prevention of propagation of any inherent or incipient cracks, seven one-inch slices were cut from the center of each weldment with both ends being discarded. The slices were surface ground, etched with nital and subjected to macroscopic examination for detection of evidence of cracking and the results of this examination are shown in tabular form in Table IV.

35. In this test the No. 4 weld is the most significant as it is made under the condition of greatest restraint. On the plates of the "A" and "C" series materials cracking occurred in the heat affected zones and fusion zones in twelve of the fourteen sections examined on each material. On plates of the "B" series material cracking occurred at this location in eight of the twelve sections examined. Cracking also occurred in the No. 1, 2, and 3 welds on ten of the fourteen sections of "A" series material, five of twelve sections of "B" series material and seven of fourteen sections of "C" series material. Therefore, on the basis of cruciform test, it is indicated that series "A" and "C" material are of approximately equal weldability with the "C" material being somewhat superior. Series "B" material is the most superior in weldability.

Conclusions

36. Evaluation of the relative weldability of rare earth metal treated, rare earth oxide treated and normal production manganese-molybdenum rolled homogeneous armor plate by means of incidence of cracking occurring in 3, 4 and 5 inch diameter circular patch test plates indicates that rare earth metal treated armor is similar to normal production armor in weldability and rare earth oxide treated armor is of superior weldability; however, the results may be influenced by the lower chemistry and hardenability of the rare earth oxide treated heat submitted for test (see Interim Report No. 2).

37. A four-inch patch diameter was used for circular patch explosion bulge test plates on all three armors although rare earth metal treated and normal production armors cannot be welded crack free in this patch diameter. Incidence of cracking in five inch diameter patch plates of these two materials was found to be not materially reduced and additional

Conclusions (Cont'd.)

starts required by inability to complete a quadrant with one 5/32" electrode introduced additional defects.

38. In the welding of circular patch test plates incidence of cracking was highest on the rare earth metal treated armor.

39. In the welding of "H" plates, cracking occurred on plates from each of the three armors although the incidence was somewhat lower on plates from the rare earth oxide treated material.

40. Cruciform tests indicated the rare earth metal treated and normal production armors to be of approximately equal weldability and the rare earth oxide treated armor to be of superior weldability.

Table I

12" x 12" Circular Patch Test Plates

Heat No.	Plate No.	Patch Dia.	Defects and quadrant locations				Remarks
			Cracks	Porosity	Slag	Undercut	
JL 0681	A6	3"	FZ, 3				Plate not completed.
	A8	3"				1, 4	
	A9	3"		1, 2, 3		1, 3, 4	
JL 0724	B5	3"	C 1-3			1, 2, 3	
	B6	3"	Tr 1-4			1, 2, 4	
	B8	3"				1	
JL 0823	C6	3"	Dia. 1-4				
	C7	3"	Dia. 1				
	C8	3"	Underbead 2				
JL 0681	A2	4"	Dia. 2-4	2		2, 4	
	A3	4"	Dia. 1	2	4		Crack removed after 2nd pass.
	A4	4"	Tr 2-4				Crack into plate after 2nd pass quadrant 4 plate not completed.
	A5	4"			2		
JL 0724	B2	4"				2	
	B3	4"			3, 4		
	B4	4"					
JL 0823	C2	4"	Dia. 2-3	1-3, z2-4	4		
	C3	4"	3	3			Crack in quadrant 3 removed after 2nd pass.
	C4	4"	2		2-4		Crack between 3 and 4 removed after 2nd pass quadrant 4.
	C5	4"			2		
JL 0681	A10	5"	FZ 2				Cracked after 2nd pass, plate not completed.
	A11	5"		2, 4		4	
	A12	5"	Tr 1-3, 2-3	4			
	A15	5"			1-3, 2-3	2	Arc blow quadrant 2 repaired.
	A16	5"		2		1, 2, 3	

Table I - Cont'd.

12" x 12" Circular Patch Test Plates

Heat No.	Plate No.	Patch Dia.	Defects and quadrant locations				Remarks
			Cracks	Porosity	Slag	Undercut	
JL 0724	B9	5"					
	B10	5"			2-3		
	B11	5"					
	B14	5"		1, 2	1	4	
	B15	5"	Tr 1	1, 2, 4		2, 4	
JL 0823	C9	5"				1, 2, 3, 4	
	C10	5"		1, 4		2	
	C11	5"			1, 4	1, 2, 3, 4	
	C17	5"	Tr 2	4	4	4	
	C18	5"	FZ 4	1-3			
	C19	5"	L 2				Longitudinal crack in root pass; plate not completed.

FZ - Fusion Zone
C - Crater
Tr - Transverse
Dia. - Diagonal
Long. - Longitudinal
Defect Locations, e.g., 3-4 between quadrants.

Table II

20" x 20" Circular Patch Test Plates

Heat No.	Plate No.	Patch Dia.	Cracks	Porosity	Slag	Undercuts	Remarks
JL 0681	A20	4"					
	A21	4"					
	A22	4"					
	A23	4"	Dia. 3				Repaired
	A24	4"	Tr 2-4		2-3		Repaired
	A39	4"	HAZ 4				Repaired
	A40	4"	Tr L3				Repaired
	A41	4"	In plate				Repaired
	A42	4"	L 1, 4				Repaired
JL 0724	B33	4"	L 4				Repaired
	B34	4"					
	B35	4"					
	B36	4"					
	B37	4"	Tr 4				Repaired
	B38	4"	L3				Repaired
	B39	4"					
	B40	4"	C 3				Repaired
	B41	4"	C 2-4	2-4			Repaired
JL 0823	C20	4"					
	C21	4"					
	C22	4"					
	C23	4"	Pl Cr 4 Tr 4				Repaired
	C24	4"					
	C39	4"	L 2 C 1-4				Repaired
	C40	4"					
	C41	4"					
	C42	4"	C3				Repaired

Dia. - Diagonal
Tr - Transverse
HAZ - Heat Affected Zone
L - Longitudinal
C - Crater

Table III

Explosion Bulge Plates (Welded)

Heat No.	Plate No.	Cracks	Other Defects	Remarks
JL 0681	A 25-A26			
	A 27-A28			
	A 43-A44			
	A 45-A46			
	A 49-A50			
	A 53-A54			
	A 55-A56			
	A 57-A58			
	A 59-A60			
	A 85-A86			
	A 87-A88	TC 4-1/2" from A end	Slag 6" from B end	Repaired
	A 89-A90			
	A 91-A92			
	A 93-A94			
	A 95-A96			
	A 97-A98			
	A 99-A100			
	A101-A102			
	A103-A104			
	A105-A106		Arc blow 2" from A end	Repaired
	A107-A110			
	A108-A109			
	A111-A112		Slag 6-1/2" from B end	Repaired
	A113-A114		Slag 6" from B end	Repaired
JL 0724	B 20-B21	1-1/2" from A end. FZ 12" from A end	Porosity 1-1/2" from A end	Repaired
	B 22-B23			
	B 24-B25			
	B 26-B27			
	B 28-B29			
	B 30-B31		Slag 4-1/2" from A end	Repaired
	B 42-B43	Dia. 4-1/2" from A end Dia. 6-1/2" from B end		Repaired
	B 45-B46			
	B 47-B48			
	B 49-B50			
	B 51-B52	Dia. 1" and 3" from B end		Repaired
	B 53-B54		Porosity 7" from B end	Repaired
	B 55-B56			
	B 87-B88			
	B 89-B90			

Table III - Cont'd.

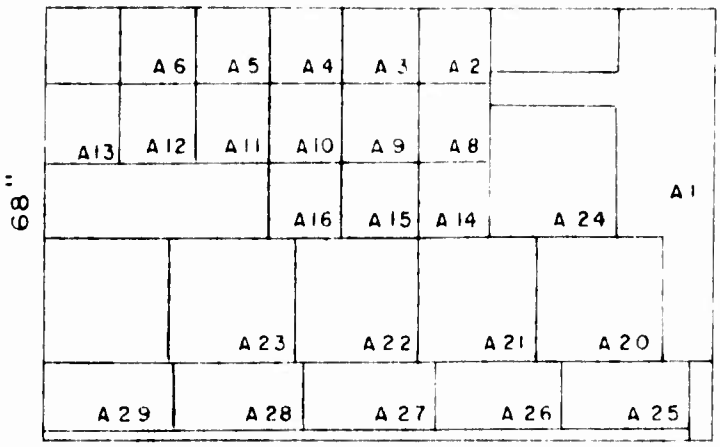
Explosion Bulge Plates (Welded)

Heat No.	Plate No.	Cracks	Other Defects	Remarks
JL 0724	B 91-B92			
	B 93-B94			
	B 95-B96			
	B 97-B98			
	B 99-B100	Tr 4" from A end		Repaired
	B101-B102			
	B103-B104	Dia. 1" from A end		Repaired
	B105-B106			
	B107-B108			
JL 0823	C 26-C27			
	C 28-C29			
	C 43-C44		Slag 4-1/2" from B end	Repaired
	C 45-C46			
	C 47-C48			
	C 49-C50			
	C 51-C52		Lack of fusion, both ends	Repaired
	C 53-C54			
	C 55-C56			
	C 57-C58			
	C 59-C60			
	C 61-C62			
	C 63-C64			
	C 66-C67			
	C 68-C69			
	C 70-C71		Undercut 6" from B end Undercut 10-1/2" from A end	Repaired
	C 72-C73			
	C 87-C88		Lack of fusion, B end	Repaired
	C 89-C90	Dia. 6" from B end	Undercuts 7-1/2" and 11-1/2" from A end	Repaired
	C 91-C92		Undercut 3" from B end	Repaired
	C 93-C94			
	C 95-C96			
	C 97-C98		Porosity on both ends	Repaired
	C 99-C100			
	C103-C104			
	C107-C108		Porosity 5" from A end	Repaired
	C109-C110			
	C111-C112		Porosity on A end	Repaired
	C113-C114			

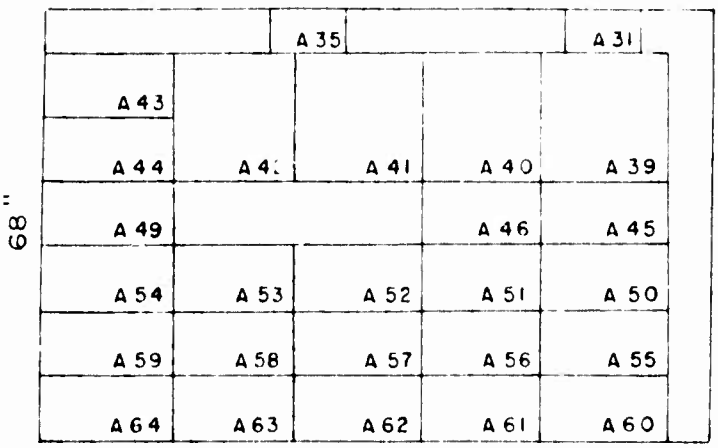
Table IV

Cruciform Test

Specimen Number	Section Number	Weld Numbers 1	2	3	4
A13	1A			HAZ	HAZ
	1B			HAZ	HAZ
	1C				
	1D			HAZ	
	1E				HAZ
	1F		HAZ		HAZ
	1G		HAZ		HAZ
A14	1A				HAZ
	1B				HAZ
	1C		HAZ		HAZ
	1D	HAZ			HAZ
	1E		HAZ		HAZ
	1F		HAZ		HAZ
	1G		HAZ		HAZ
B12	1A				HAZ
	1B				HAZ
	1C	HAZ	HAZ	Weld	
	1D				HAZ
	1E	HAZ			HAZ
	1F		HAZ		
	1G				
B13	1A	FZ		FZ	HAZ
	1B		FZ	FZ	HAZ
	1C				
	1D				HAZ
	1E				HAZ
	1F				
	1G				
C14	1A	HAZ	HAZ		HAZ
	1B	HAZ			HAZ
	1C	Toe			HAZ
	1D		FZ		HAZ
	1E			HAZ	HAZ
	1F		FZ & HAZ		HAZ
	1G		Plate		FZ & HAZ
C15	1A				FZ & HAZ
	1B				HAZ
	1C				FZ
	1D				
	1E				HAZ
	1F				HAZ
	1G				



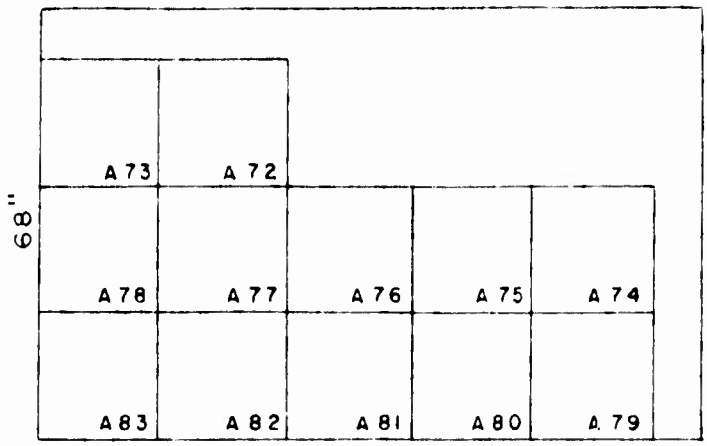
HEAT JL 0681
INGOT 1 CUT 1



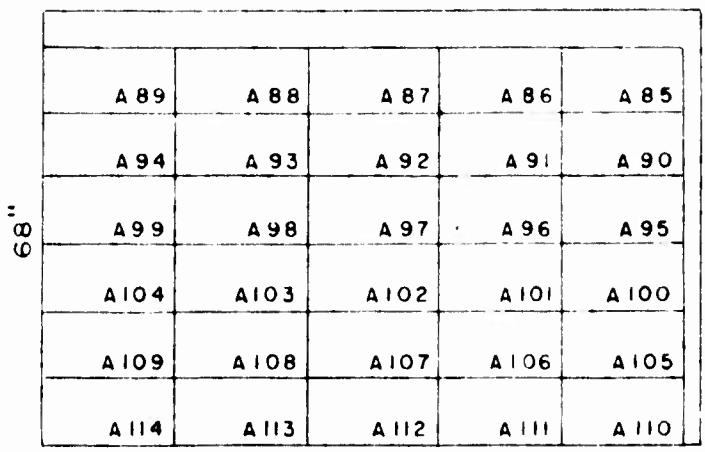
HEAT JL0681
INGOT 1 CUT 1

CUTTING DIAGRAM

Figure 1



HEAT JL 0681
INGOT 1 CUT 2



HEAT JL 0681
INGOT 1 CUT 2

CUTTING DIAGRAM

N

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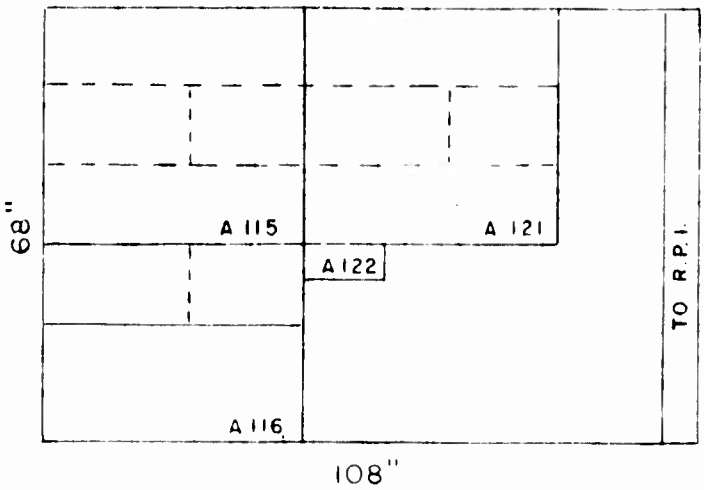
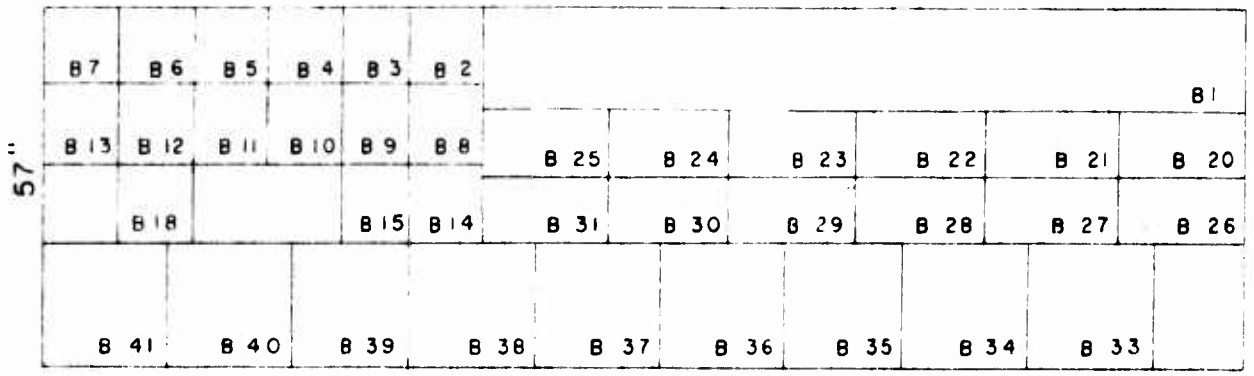
Figure 2



HEAT JL 0681
INGOT 1 CUT 5

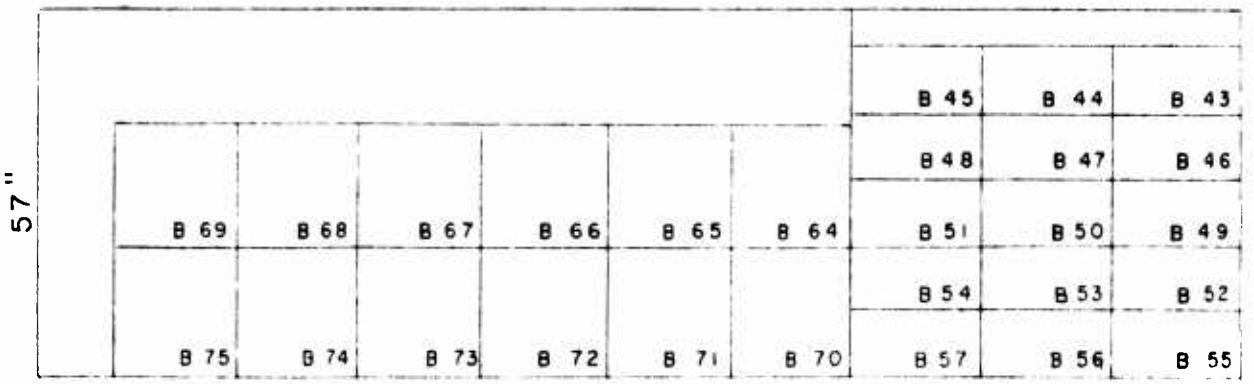
CUTTING DIAGRAM

Figure 3



196"

HEAT JL 0724
INGOT 3 CUT 1



196"

HEAT JL 0724
INGOT 3 CUT 2

CUTTING DIAGRAM

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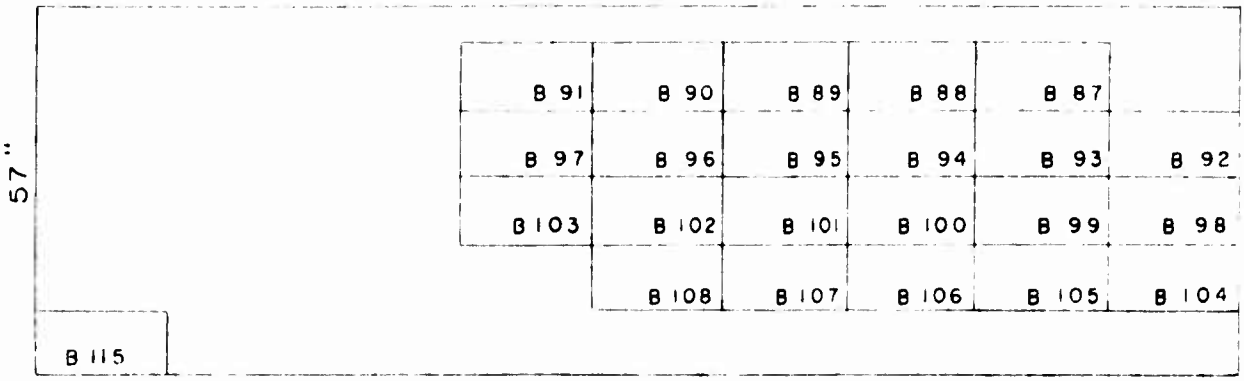
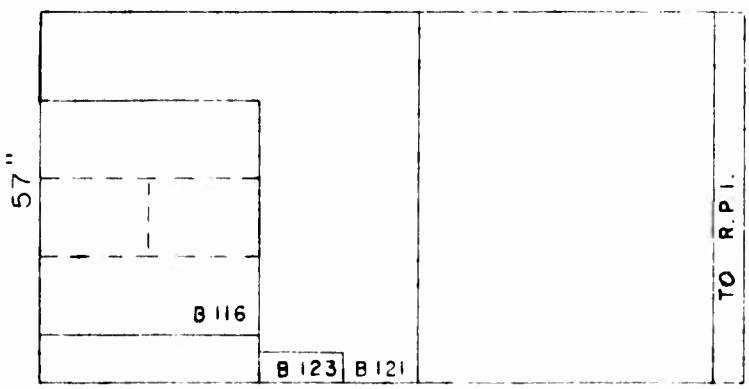
Figure 4



HEAT JL0724
INGOT 3 CUT 4



HEAT JL0724
INGOT 3 CUT 5

CUTTING DIAGRAM

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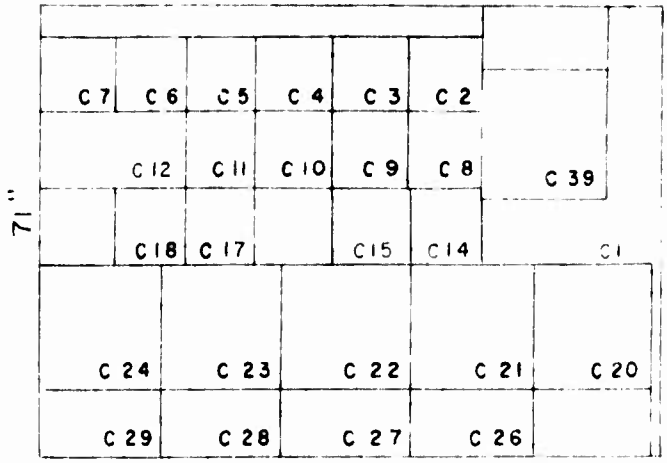
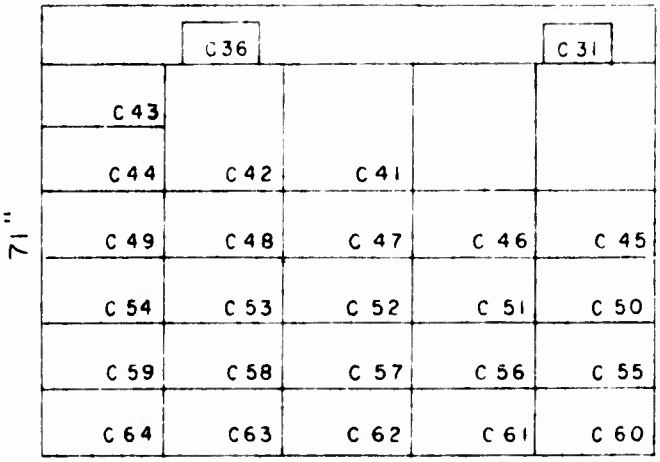
Figure 5



HEAT JL0823
INGOT 3 CUT 1



HEAT JL 0823
INGOT 3 CUT 1

CUTTING DIAGRAM

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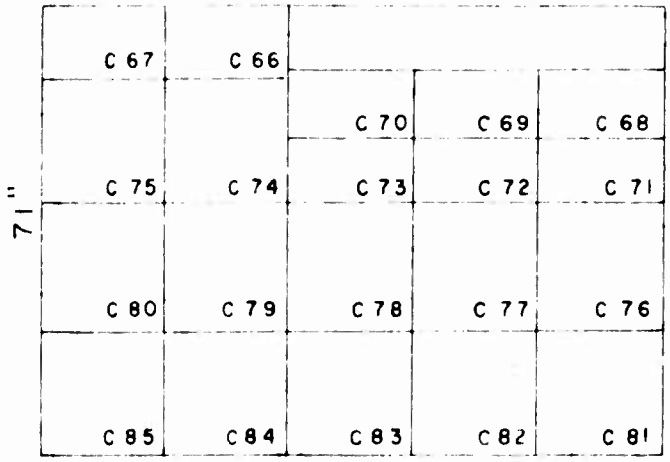
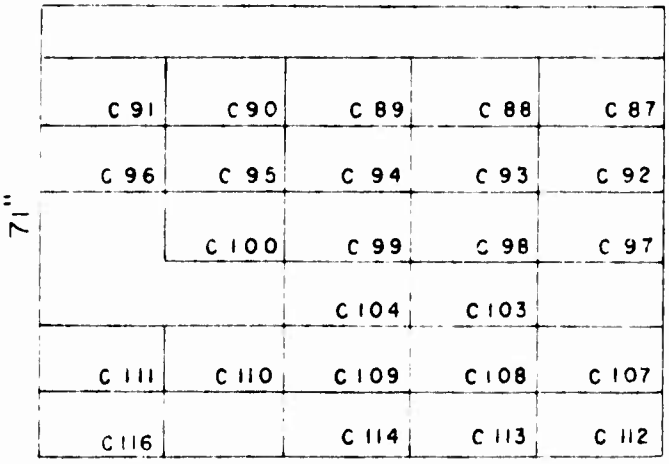
Figure 6



HEAT JL 0823
INGOT 3 CUT 2



HEAT JL 0823
INGOT 3 CUT 2

CUTTING DIAGRAM

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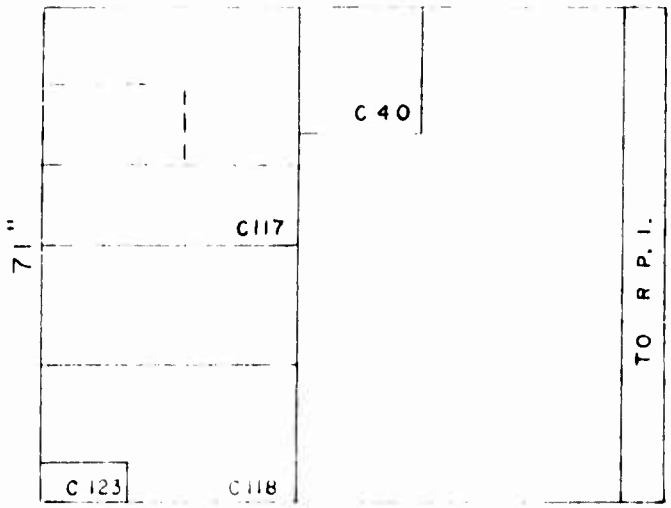
Figure 7



$101\frac{3}{8}$"

HEAT JL0823
INGOT 3 CUT 5

CUTTING DIAGRAM

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Figure 8

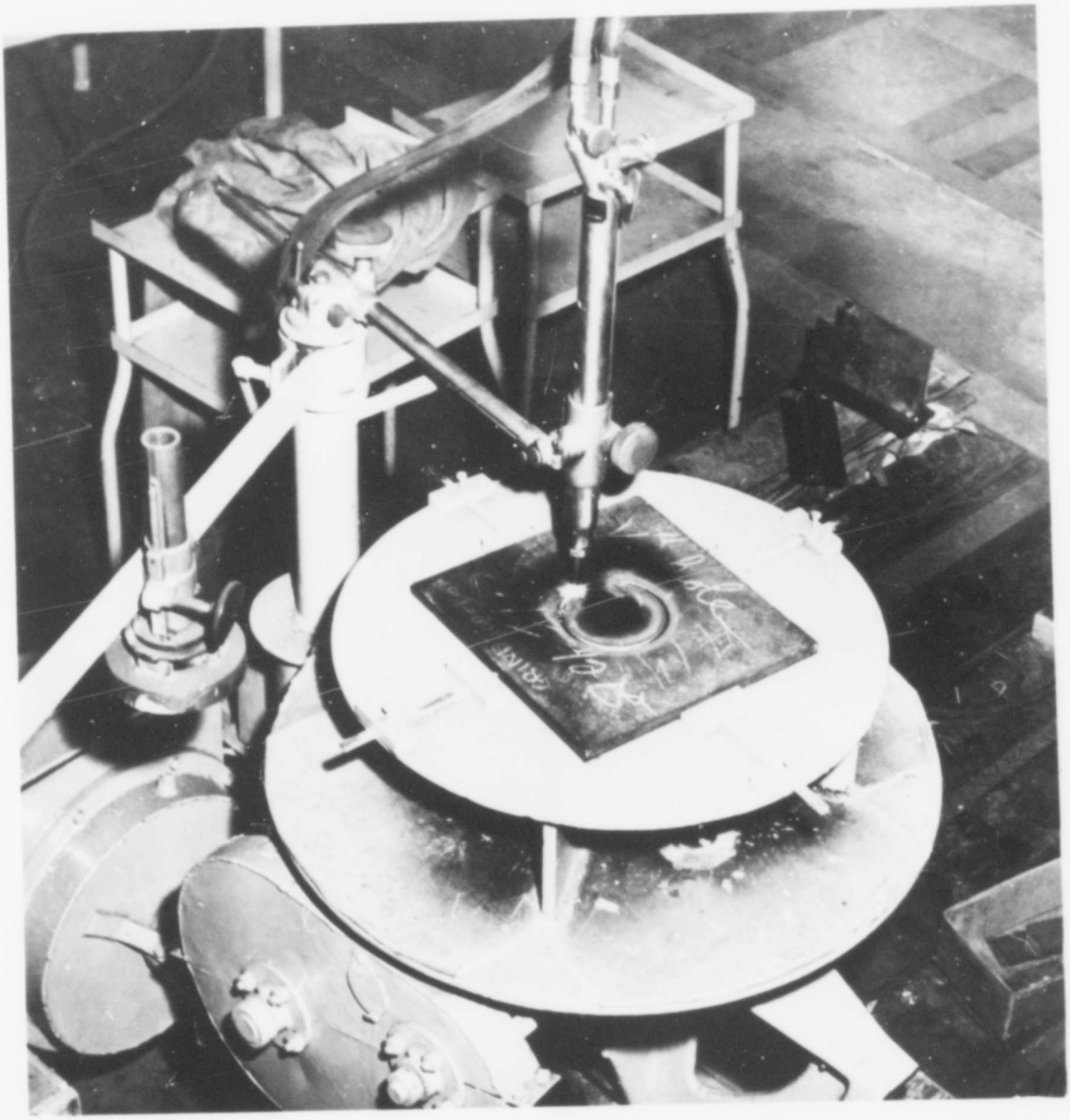


Figure 9

Equipment used in cutting circular patches.

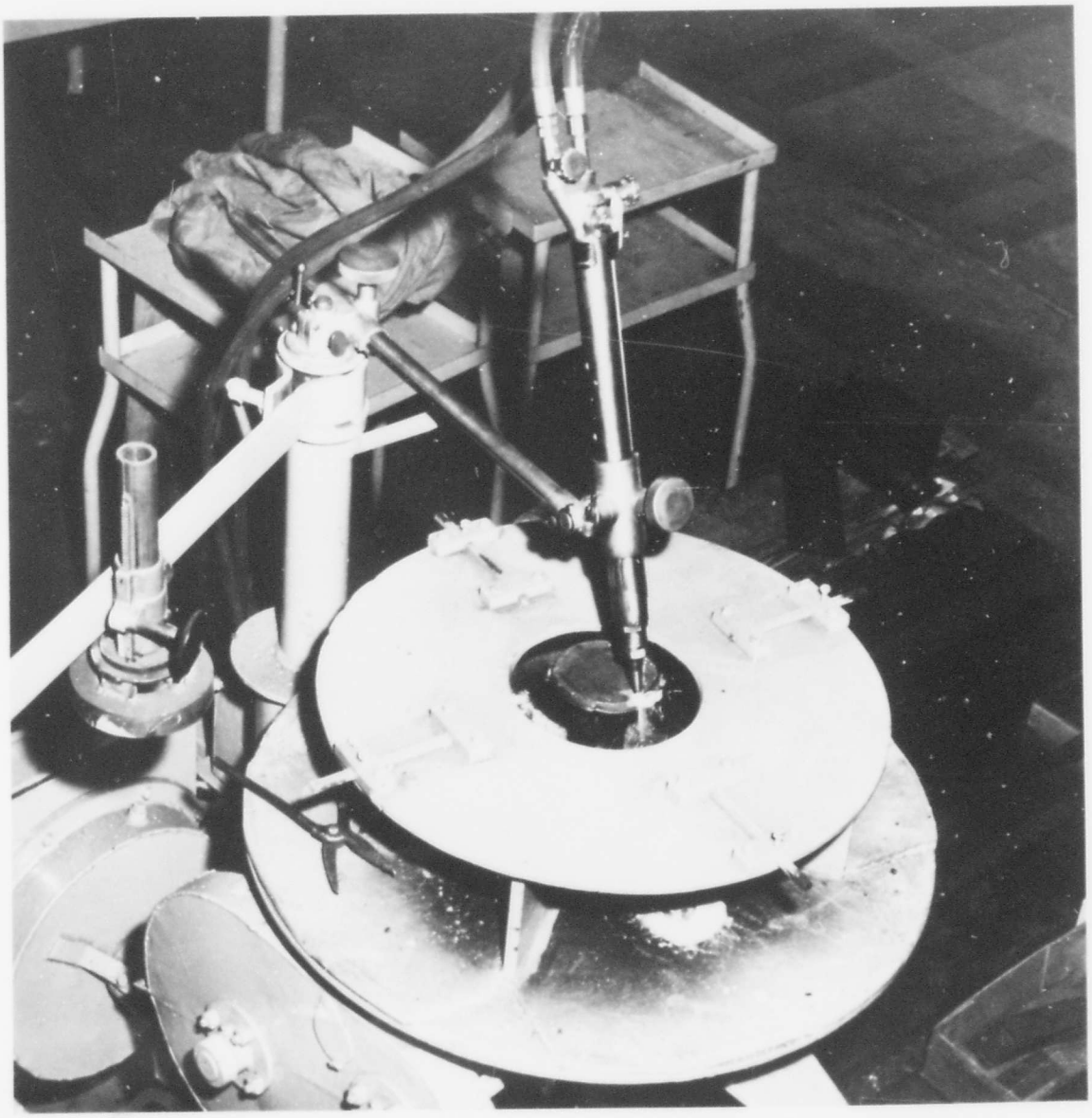
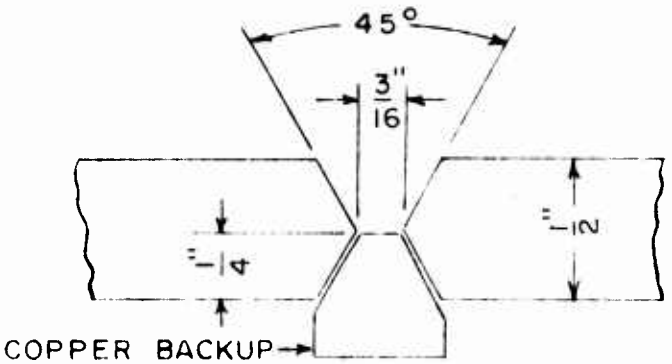
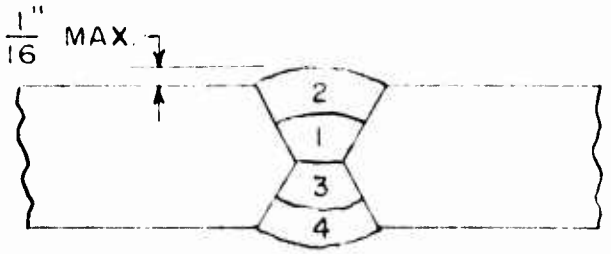


Figure 10

Equipment used to bevel circular patches.



JOINT DIMENSIONS



PASS SEQUENCE

PASS	DIA. ROD	AMPS	VOLTS	TYPE OF PASS
1	5/32	170	23	BEAD
2	1/4	290	24	BEAD
3	5/32	170	23	BEAD
4	1/4	290	24	BEAD

JOINT PROCEDURE

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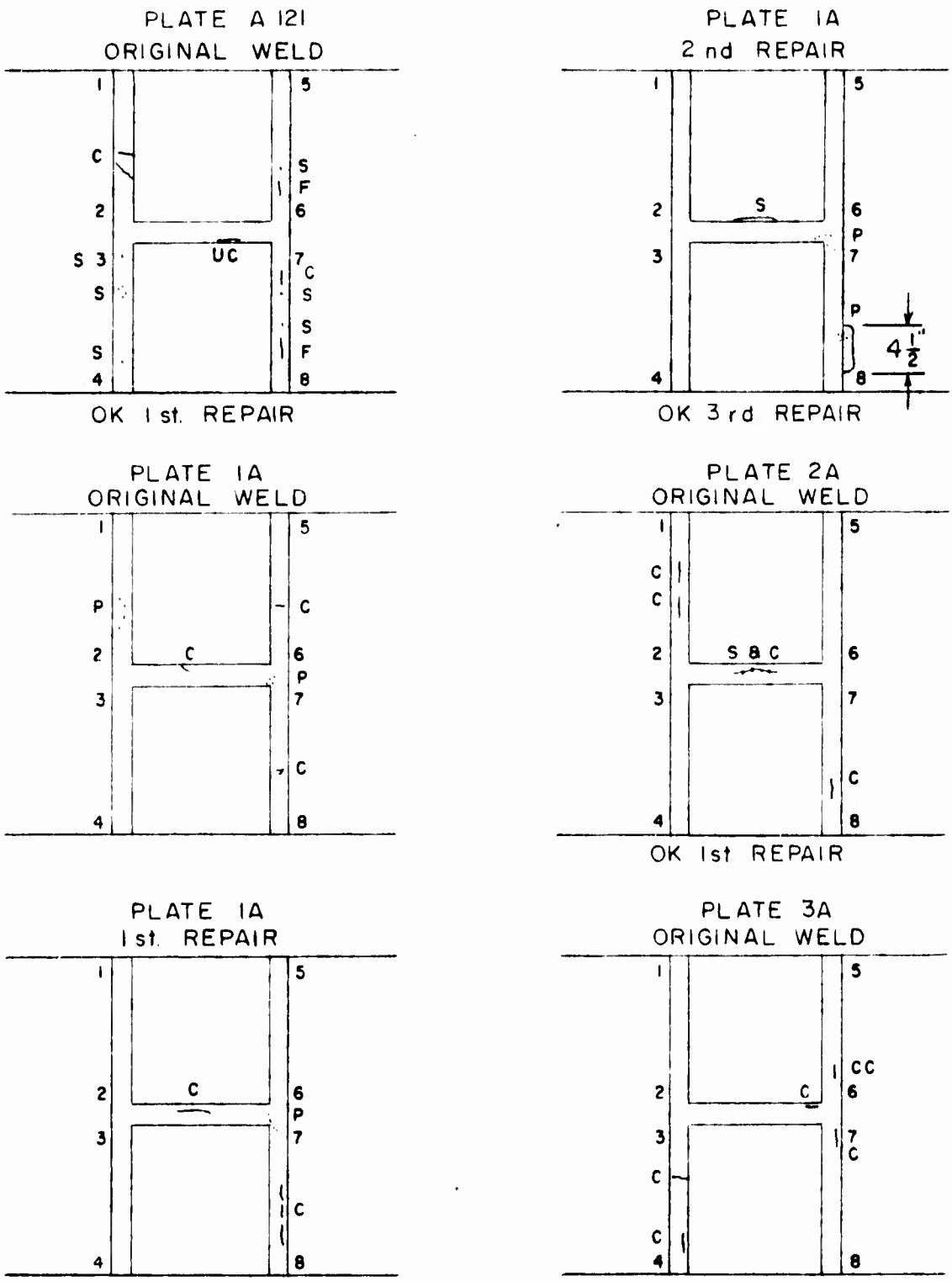
Figure 11



LEGEND
S - SLAG
C - CRACK
CC - CRATER CRACK
P - POROSITY
F - LACK OF FUSION
UC - UNDERCUT

"H" PLATE WELDING DEFECTS
HEAT JL 0681

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Figure 12

PLATE 3A
1st. REPAIR

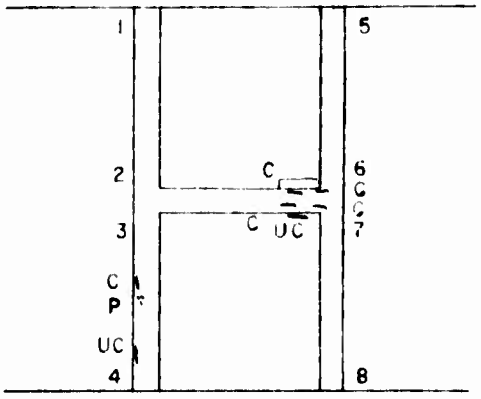


PLATE 3A
4 th. REPAIR

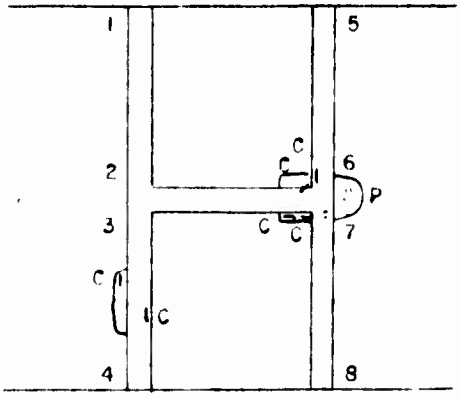


PLATE 3A
2 nd. REPAIR

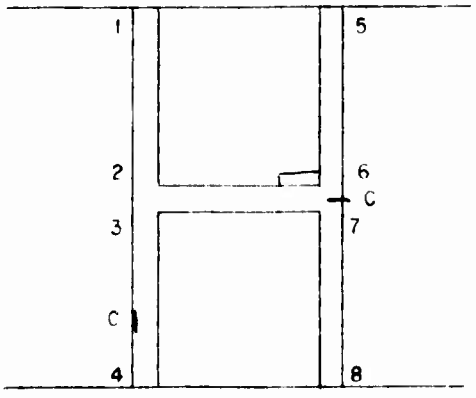


PLATE 3A
5th. REPAIR

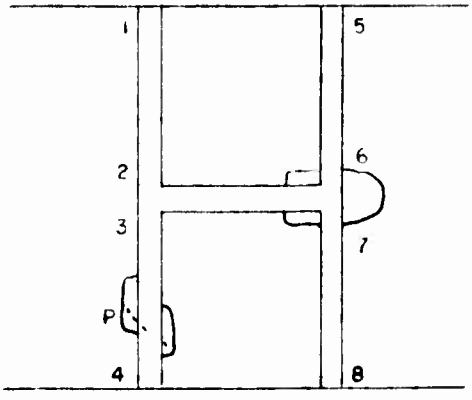


PLATE 3A
3 rd. REPAIR

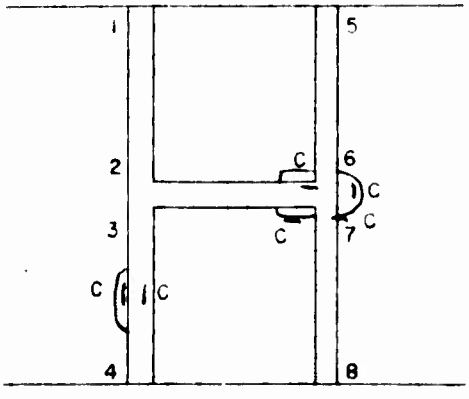
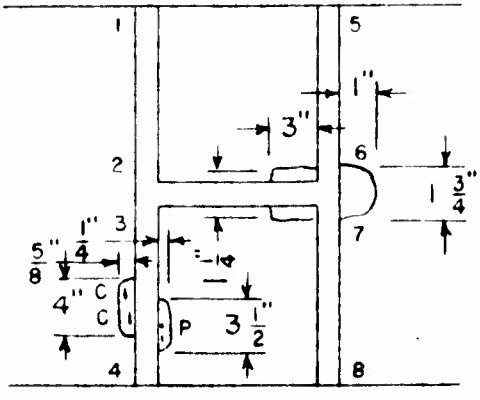


PLATE 3A
6th. REPAIR



OK 7 th. REPAIR

LEGEND

S - SLAG
C - CRACK
CC - CRATER CRACK
P - POROSITY
F - LACK OF FUSION
UC - UNDERCUT

"H" PLATE WELDING DEFECTS

HEAT JL 0681

ACF INDUSTRIES, INCORPORATED

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Figure 13

PLATE B116
ORIGINAL WELD

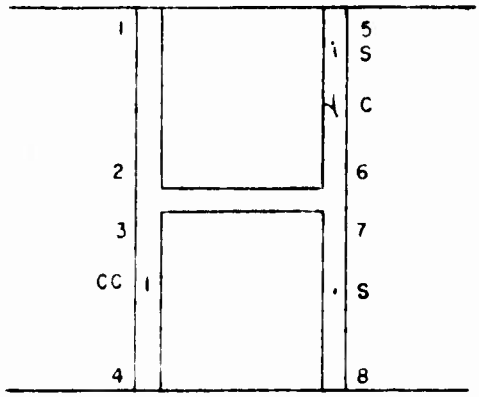


PLATE B116
3rd REPAIR

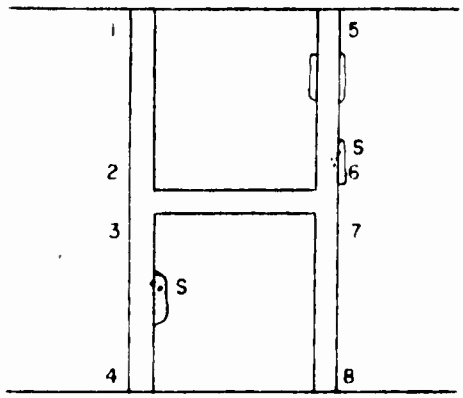


PLATE B116
1st REPAIR

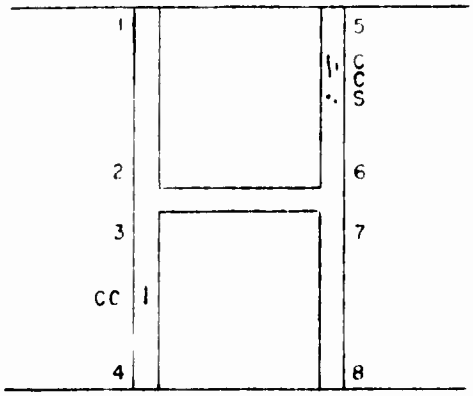


PLATE B116
4th REPAIR

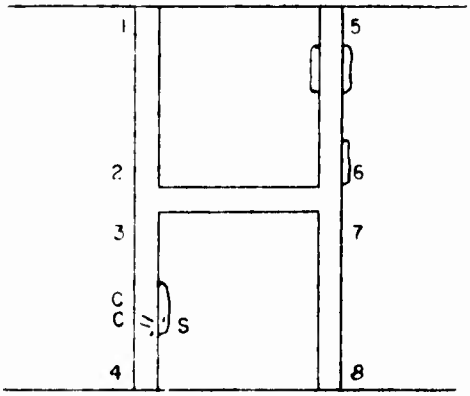


PLATE B116
2nd. REPAIR

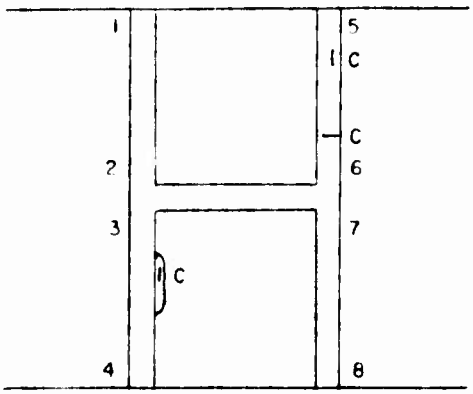
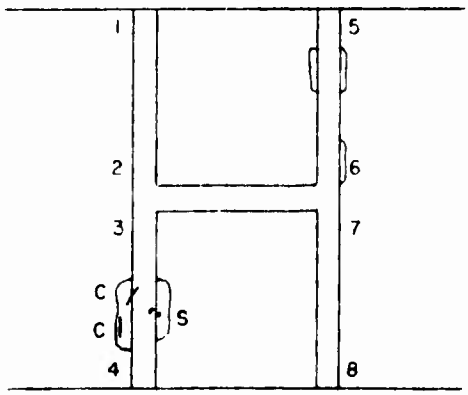


PLATE B116
5th REPAIR



LEGEND
S- SLAG
C- CRACK
CC- CRATER CRACK
P- POROSITY
F- LACK OF FUSION
UC- UNDERCUT

"H" PLATE WELDING DEFECTS
HEAT JL 0724

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Figure 14

PLATE B 116
6th. REPAIR

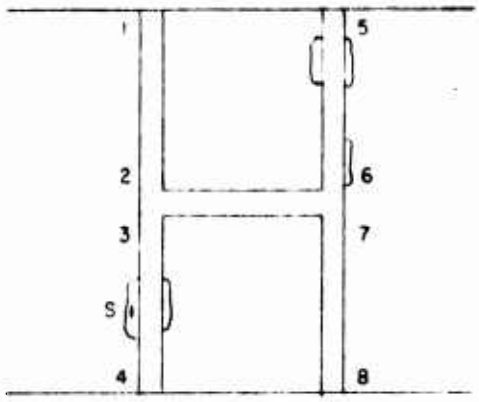
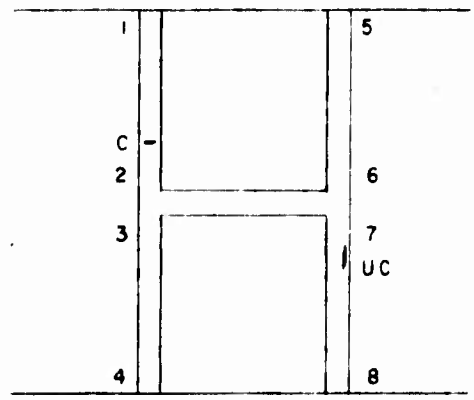
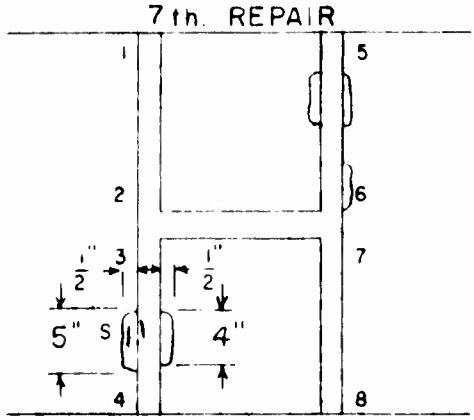


PLATE 1B
1st. REPAIR



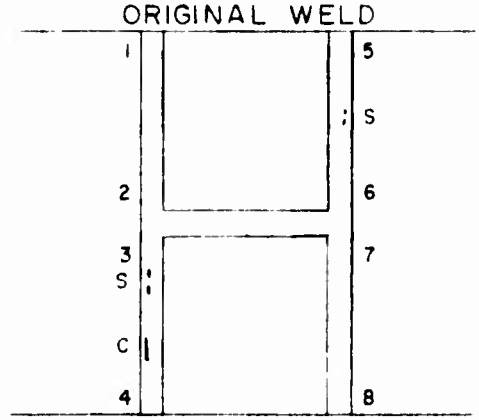
OK 2nd. REPAIR

PLATE B 116
7th. REPAIR



OK 8th. REPAIR

PLATE 2B
ORIGINAL WELD



OK 1st REPAIR

PLATE 1B
ORIGINAL WELD

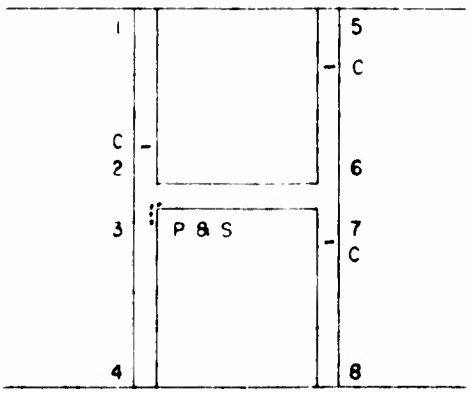
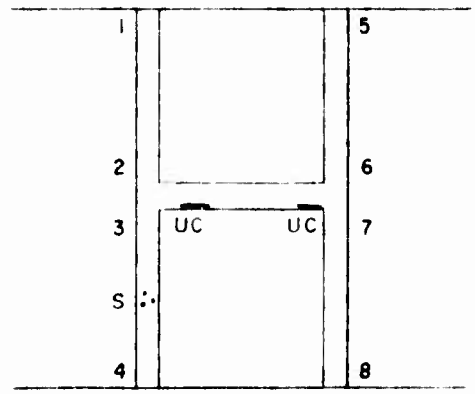


PLATE 3B
ORIGINAL WELD



OK 1st. REPAIR

LEGEND
S - SLAG
C - CRACK
CC - CRATER CRACK
P - POROSITY
F - LACK OF FUSION
UC - UNDERCUT

"H" PLATE WELDING DEFECTS
HEAT JL 0724

ACF INDUSTRIES, INCORPORATED
RESEARCH AND DEVELOPMENT DEPARTMENT

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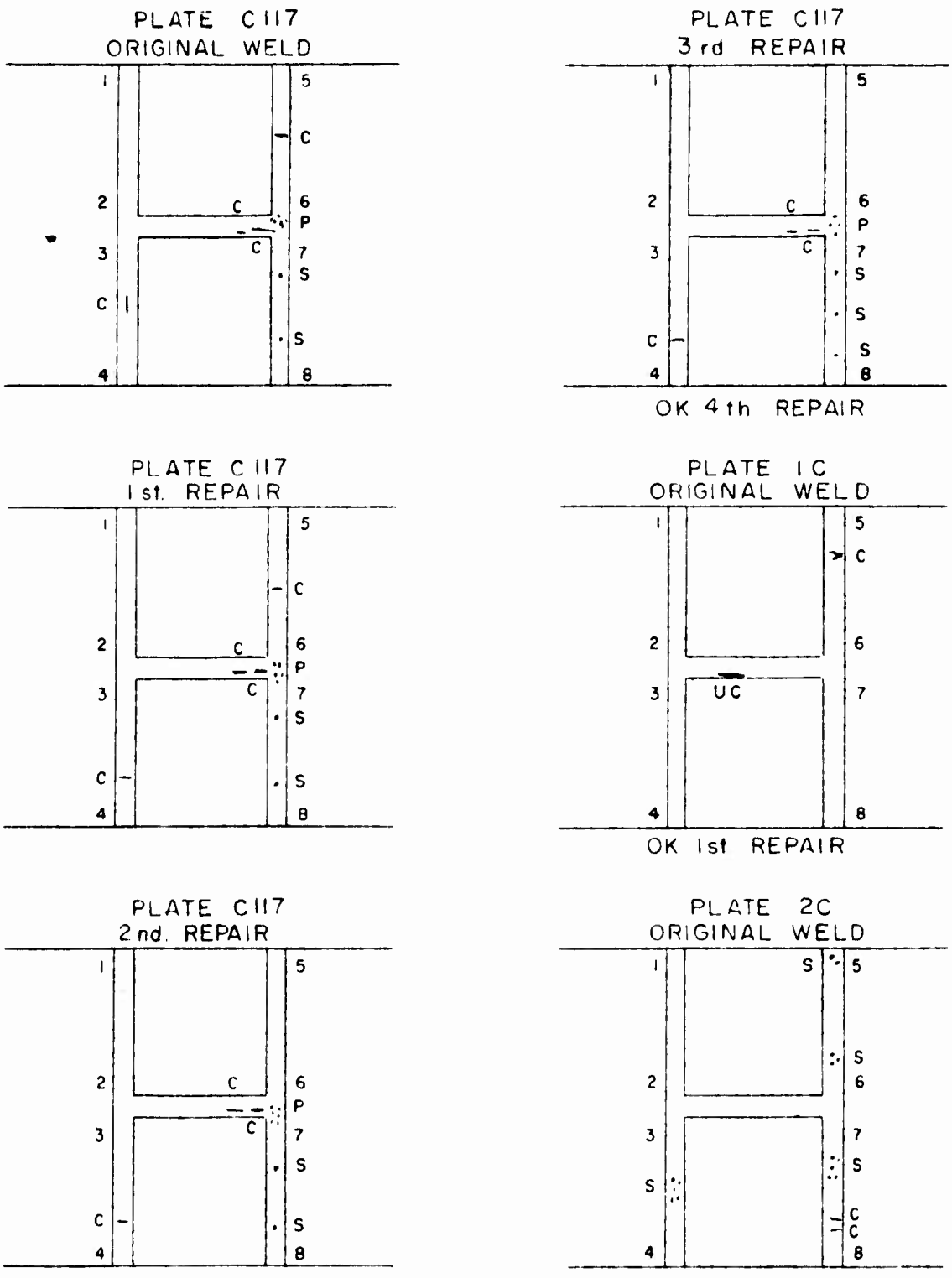
Figure 15



"H" PLATE WELDING DEFECTS

HEAT JL 0823

ACF INDUSTRIES, INCORPORATED

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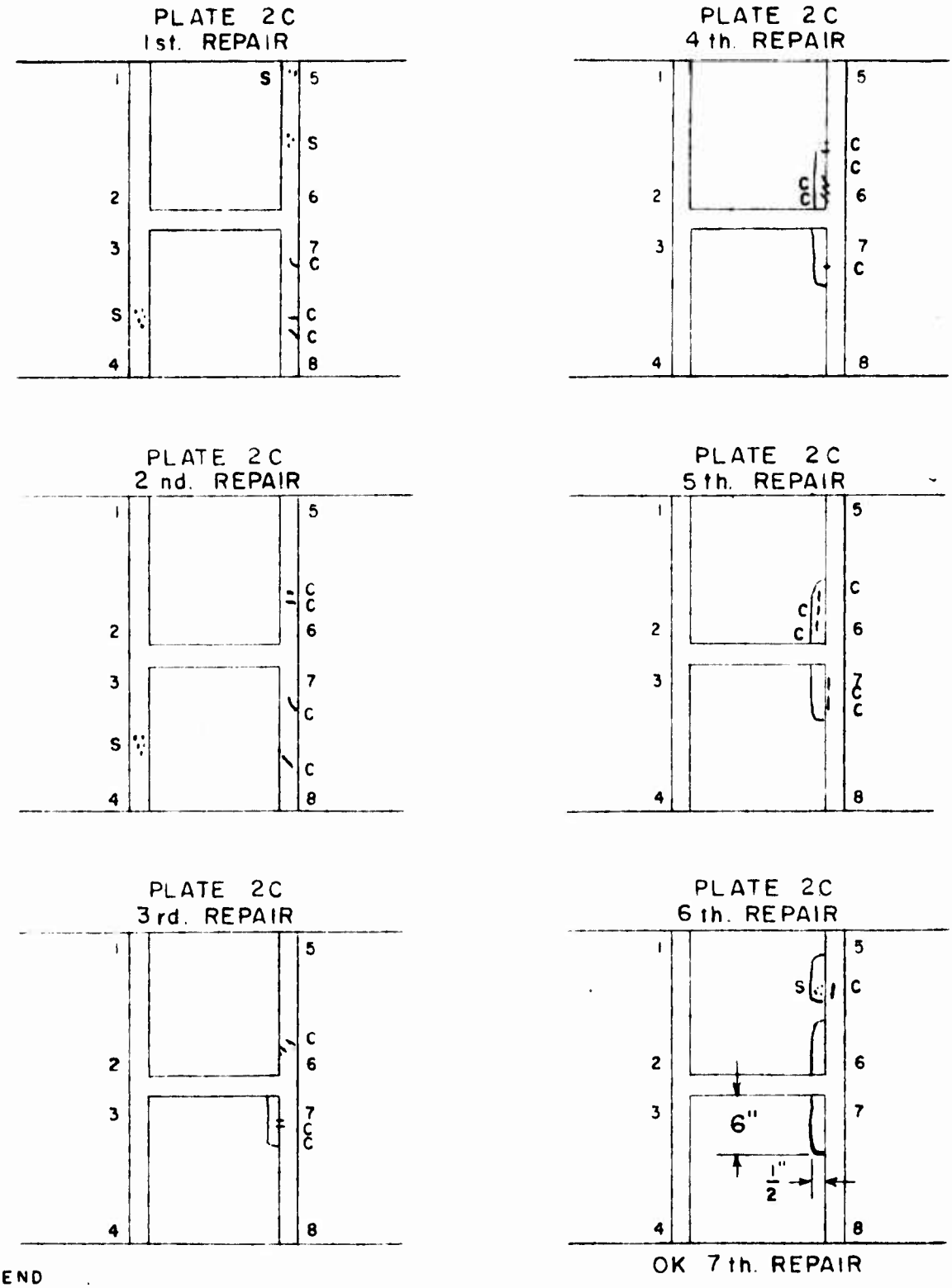
Figure 16



LEGEND
S - SLAG
C - CRACK
CC - CRATER CRACK
P - POROSITY
F - LACK OF FUSION
UC - UNDERCUT

"H" PLATE WELDING DEFECTS
HEAT JL 0823

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Figure 17

PLATE 3C
ORIGINAL WELD

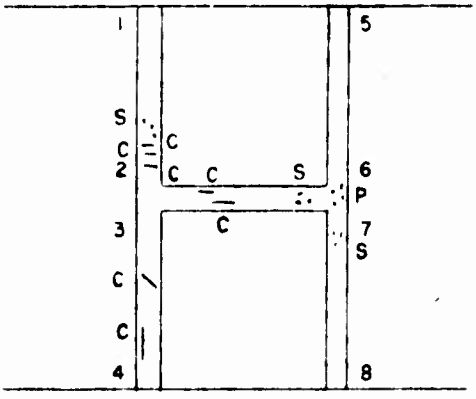


PLATE 3C
1st. REPAIR

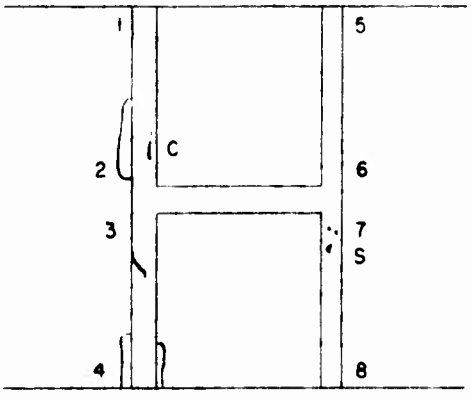
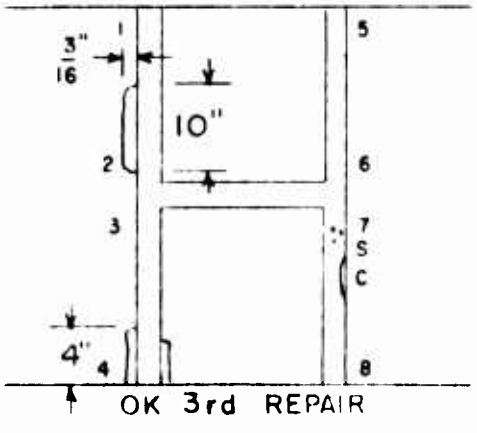


PLATE 3C
2nd. REPAIR



LEGEND

S-SLAG
C-CRACK
CC-CRATER CRACK
P-POROSITY
F-LACK OF FUSION
UC-UNDERCUT

"H" PLATE WELDING DEFECTS
HEAT JL 0823

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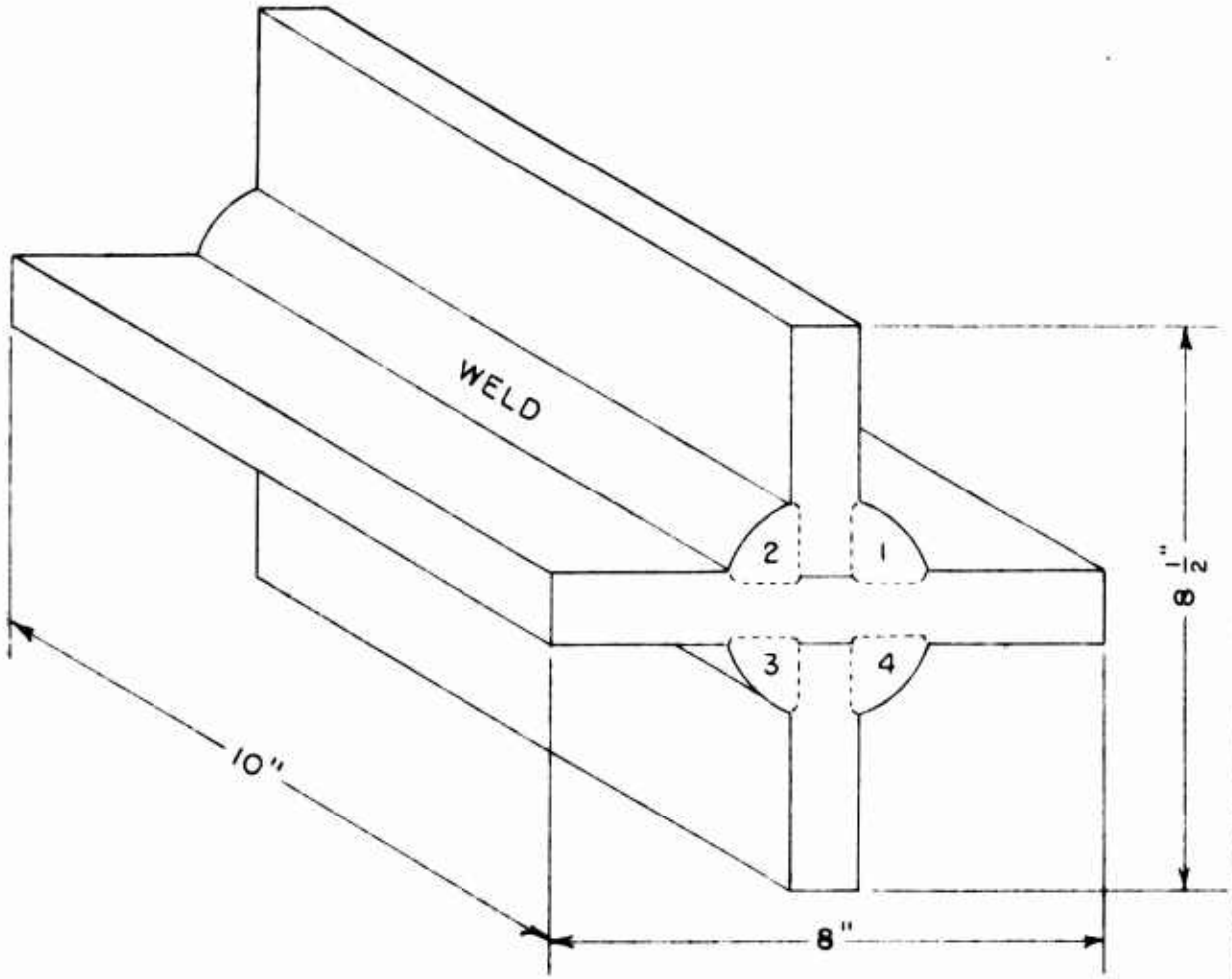
Figure 18



CRUCIFORM TEST

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Figure 19