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CONSIDERATIONS ON REPEATED REPAIRING OF WELDMENTS IN INCONEL 718 ALLOY

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16. ABSTRACT

This report presents the results of a study to determine the effects of repeated weld repairs on the metallurgical characteristics, high cycle fatigue (HCF), and tensile properties of Inconel 718 butt weld joints. The study employed 1/4-in. and 1/2-in. thick plates, tungsten inert gas (TIG) welding, and Inconel 718 filler wire. Weld panels were subjected to 2, 6, and 12 repeated repairs and were made in a highly restrained condition. Post weld heat treatments were also conducted with the welded panel in the highly restrained condition.

The study concluded that no significant metallurgical anomaly was evident as a result of up to twelve repeated weld repairs. No degradation in fatigue life was noted for up to twelve repeated repairs. Tensile results from specimens which contained up to twelve repeated weld repairs revealed no significant degradation in UTS and YS. However, a significant decrease in elongation was evident with specimens (solution treated and age-hardened after welding) which contained twelve repeated repairs. The elongation loss was attributed to the presence of a severe notch on each side (fusion line) of the repair weld bead reinforcement. Basically, the weld joint tends to peak more and more with each successive repeated weld repair but due to a combination of an increase in back-side metal drop through and distortion restraint during repeated repairing, the peak projection develops as a shallow notch on each side of the weld repair. This study shows that the severity of these notches increases with increasing numbers of repeated repairs.

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INTRODUCTION

Inconel 718 is a nickel-base alloy which is widely used commercially in sheet, plate, bar, and forged or cast forms. The alloy is precipitation-hardenable and is suitable for services at temperatures from -423°F (-252°C) to 1200°F (649°C). The alloy may be joined by using conventional welding processes and, on post weld heat treatment, can attain room-temperature tensile properties of 100 percent joint efficiency [1].

Inconel 718 alloy is also similar to other nickel-base alloys in its inability to flow readily when molten. This sluggish flow necessitates good joint designs and precise welding techniques. Cleaning of joint areas in preparation for welding must be complete to avoid porosity. In addition, care must be exercised with regard to interpass cleaning and gas shielding to avoid oxidation and attendent lack of fusion. Failure to establish or adhere to proper weld procedures will most certainly result in weld defects, such as cracks, porosity, inclusions, and incomplete fusion. These defects are unacceptable in critical welds of aerospace components fabricated from Inconel 718 alloy [2].

In the case of a complex assembly, such as the Space Shuttle Main Engine (SSME), the large number and the difficult nature of the weldments involved in fabrication invariably result in weld defects. One of the key considerations in welding this hardware is the ability to repair defective weldments. In some cases, defects such as cracks, porosity or inclusions will develop into more gross defects during repair attempts. The more attempts to repair, the larger the defect can become, until repairing may result in a distortion problem. In addition, repeated repairs may also result in a degradation of weld joint strength. Any weld strength degradation would be the result of either the additional heat energy input required to complete the repair, joint geometry alterations during repair or a combination of both. The objective of this evaluation was to determine the effects that repeated weld repairs have upon joint structural integrity.

EXPERIMENTAL PANEL PREPARATION AND TESTING

The base material used in this evaluation was procured to specification AMS 5596C. The material was verified to be Inconel 718 by EDAX (energy dispersion X-ray analysis) technique. The chemical composition limits of Inconel 718 are presented in Table 1 [3]. The weld filler wire was Inconel 718. Argon was used as the weld shielding gas. Both the filler wire and shielding gas were procured to appropriate aerospace specifications.

The base material was resolution treated (ST) at 1900 ± 25°F (1038 ± 14°C) for a soak period of 25 min and cooled at a rate equivalent to air cool. Some of this material was age-hardened (to yield STA condition) at 1400 ± 15°F (760 ± 8°C) for 10 ± 1/4 hr, furnace cooled to 1200 ± 15°F (649 ± 8°C), holding at 1200°F (649°C) until a total precipitation heat treatment time of 20 ± 1/4 hr had been reached, followed by cooling at a rate equivalent to air cool [4]. These thermal treatments are consistent with SSME fabrication practices.

Weld panels used in this evaluation were fabricated from two base material thicknesses, 1/4-inch (0.63 cm) plate for tensile test coupons and 1/2-inch (1.27 cm) plate for fatigue test coupons in both the ST and STA conditions. The weld joint of the 1/4-inch thick plate consisted of a double U-groove and a land as shown in Figure 1. This particular joint configuration was used to minimize panel distortion upon completion of the initial weld. Welding and inspection was performed to weld specifications requirements. The 1/4-inch (0.63 cm) thick panels were butt welded by the DC straight polarity automatic TIG process using Inconel 718 filler wire and argon shielding gas. After the weld was penetrated, stringer beads were used to fill the groove. One panel for each condition (STA + weld and ST + weld + STA) was retained for baseline weld characterization. The remaining panels were tack welded to a 1-inch thick Inconel 718 plate (Figure 2) for restraining purposes, both during repair welding and, when applicable, during post weld heat treatment. All repeated repairs (up to 12) were accomplished using the DC straight polarity automatic TIG process with Inconel 718 filler wire and argon shielding gas. All repairs were made on one side of the weld joint to simulate typical SSME production. Figure 3 shows the groove configuration (depth of 50 percent of base material thickness) for each repeated repair. The following panels were completed in 1/4-inch thick plate:

Number Repeated Repairs	Heat Treat Condition When Welded	
	ST	STA
0	1	1
2	1	1
6	1	1
12	1	

Whenever welding was performed with the material in the ST condition the resulting panels were heat treated to the STA condition.

The length and spacing of each repeated weld repair was controlled (Figure 4) to obtain the desired number and type of test coupons. Figure 5 shows the location for the removal of three transverse weld tensile coupons, three longitudinal tensile coupons and a metallurgical coupon from each panel. The same format of the coupon removal was used with the two baseline weld panels. Transverse and longitudinal weld tensile specimen configurations are shown in Figures 6 and 7, respectively. Figure 8 shows the configuration of each metallographic sample. Tensile testing was conducted in a standard 60,000-lb Riehle Tensile Tester. Metallographic evaluations were made with conventional optical equipment.

The initial weld in each 1/2-inch thick plate was also completed by grooving and welding from each side (Figure 9) to minimize distortion. Each weld repair was approximately 1-inch long. Each repair weld was also centered within the base weld which was approximately 2-inch long, as shown in Figure 9. Again, all repairs were made on one side of the base weld. The following panels were completed in 1/2-inch thick plate:

Number Repeated Repairs	Heat Treat Condition When Welded	
	ST[a]	STA
Zero, Base Weld	2	2
2	1	
6	1	1
12	1	

a. Heat treated (STA) after welding operations.

Post weld inspection followed the same procedures used with 1/4-inch (0.63 cm) thick panels. The fatigue specimens were fabricated in the weld longitudinal direction with the repair weld totally contained within the center of the 2 inch (5.08 cm) gage length (1/2 of gage length base weld and 1/2 of gage length repaired). This was done to emphasize the effects, if any, at the ends of the repair during fatigue testing. Six fatigue specimens were removed from each experimental panel. The fatigue specimen configuration is shown in Figure 10. The specimens were tested at a stress ratio (R) of 0.03, using a MTS universal testing machine operating at approximately 30 cycles per second. Specimen diameters, test loads and stresses, and cyclic life data are summarized in Table 2.

DISCUSSION AND RESULTS

Inconel 718 is used extensively as an alloy of construction, including welded components, of the SSME. Approximately 90 percent of the welds on the SSME are made on material in the solution treated condition.

These materials/welds are subjected to a post weld thermal treatment to the STA condition to take advantage of the higher strength. A few of the welds are made in STA material and retained in the as-welded condition. Other material is welded in the STA condition and resolution heat treated and age-hardened after welding, again to increase strength. The purpose of this evaluation was to determine the effects, if any, that repeated weld repairs have upon tensile properties, fatigue properties, and metallurgical characteristics. The accent of this effort was focused on material that is welded in the ST condition, and subsequently given a post weld thermal treatment to the STA condition. This processing sequence included panels that were evaluated with the baseline welds and up to a maximum of twelve repeated weld repairs. In addition, material in the STA condition was welded, and these panels were retained in the as-welded condition for evaluation purposes. Experimental panels in the as-welded condition contained base weld, two repeated weld repairs, and six repeated repair welds.

The tensile properties of the 1/4-inch (0.63 cm) thick base material are shown in Table 3. These results represent material that was resolution heat treated and age-hardened (STA). These data will be used as an indicator of the welded joint efficiency for those welds subjected to post weld STA.

The transverse weld tensile properties are shown in Table 4. These data (post weld STA) exhibit essentially no alterations in ultimate tensile strength (UTS) and 0.2 percent offset yield strength (YS) whenever comparing baseline weld results to repaired weld results. As can be noted, the joint efficiencies of STA welds (base welds or repaired welds) are essentially 100 percent. However, the elongation value for the twelve-repair weld (post weld STA) displayed an appreciable reduction in elongation when compared to the elongation of the base weld as well as with the elongation of the six repair weld. This reduced elongation was attributed to the presence of notches (stress risers) on each side of the weld fusion line. The notches are actually shallow projections of weld peaking as a result of repeated weld repairing on one side of a highly restrained panel. The formation, as well as the severity, of these notches is also advanced by metal drop through on the weld back side with increasing numbers of repeated weld repairs, as shown in Figure 11. The photomacrographs of the weld cross-section shown in Figures 12 through 18 also delineate an increase in notch magnitude with increasing numbers of repeated weld repairs. At some notch severity (a result of more than six but less than 12 repeated weld repairs in this evaluation), the reduced elongation is caused because the tensile fracture location shifts from the base material to the notch location (weld fusion line) which acts as a stress riser.

The transverse weld tensile properties of the as-welded STA base material showed a slight increase in UTS and YS with increasing numbers of repeated repairs (Table 4). This slight increase in strength is probably due to increasing weld bead reinforcement build-up as a result of increasing numbers of repeated repairs. Tensile failures tended to occur in the center of the weld joint. The elongation values obtained with the as-welded test specimens display no trends with regard to numbers of repeated repairs. In general, no strength degradation is evident as a result of repeated weld repairs (up to 6) for as-welded joints of STA base material.

The UTS, YS and elongation values (Table 4) of the longitudinal tensile specimens (mostly all weld metal-post weld heat treated joints) exhibited random scatter regardless of the number of repeated repairs. In addition, these tensile results are in close proximity to the tensile results of the STA base material. Apparently, the base material (independent of the number of times remelted) of the fusion zone is quite responsive to the post weld heat treatment cycles.

The longitudinal weld tensile properties (Table 5) of the as-welded STA material displayed some decrease in UTS and elongation with increasing numbers of repeated repairs. These decreases were attributed to slightly greater percentages of the volume of remelted (cast) material being within the tensile specimen gage length (Figure 7). As the number of repeated repairs increased, the heat energy input for each repeated repair resulted in a slightly greater fusion zone width because of additional melting of base material and fill wire deposits. Cast material within a fusion joint is generally not as strong as the adjacent heat affected material. The slight differences noted in YS are considered as typical scatter for basically a composite of as-cast and heat affected material.

The macrostructure of each fusion zone (base weld and all repeated repairs) revealed no porosity, crack or lack of penetration. In addition, no anomalies were evident in the microstructure of any weld (base or repair) fusion zone or adjacent base material. The metallographic structures for each experimental weld processing sequence are presented in Figures 12 through 18.

The longitudinal high cycle fatigue test with the repair fully contained in the test section was taken as a test that would be representative of the behavior of repaired welds under cyclic loading conditions. The start and stop areas of the repair were included in the test section because of the propensity for weld defects to occur in those areas during weld repair operations. The high cycle fatigue test was chosen over the two alternatives, the low cycle fatigue test and the fracture mechanics test, because it was the only one of the three that could be applied without the results being obscured by the complex geometry of the critical repair/weld interface. The low cycle fatigue test was not used because it would have been difficult to control from diametral strain in that critical area. The fracture mechanics test specimens containing planar cracks were not considered appropriate for this application because only a very small area of the flaw periphery could be contained within the repair/weld interface.

High cycle fatigue test results are plotted in Figures 19 through 24. The base weld data for the as-welded and STA after welding conditions are shown in Figures 19 and 21, respectively. The solid lines shown on those plots are approximate lower bound curves which were made without the use of a formal data analysis program. The repeated repair specimen data are shown in Figures 20 through 24, with the appropriate lower bound curve from Figure 19, shown as a reference. It is seen that, with the exception the ST+R2+STA data (Figure 22), all of the repaired specimen data fall above the base weld curve indicating no degradation in fatigue strength attributable to repeated weld repairing. The exception in Figure 22 is most likely a result of normal data scatter; it is difficult to rationalize a reduction in fatigue strength after two repeated repairs and no reduction after six or twelve repeated repairs. Assuming that the fatigue strength is not degraded by the repeated repair welding, the data in Figure 22 (and all the repair data) should be included in the basic set, which would result in a lowering of the apparent lower bound curve to the line shown in Figure 22.

CONCLUSIONS

This evaluation showed no significant change in fatigue and tensile (UTS and YS) properties of repaired welds in tests with up to 12 repeated repairs. All welds (base and repaired welds that were STA after welding) showed tensile joint efficiencies that were considered to be 100 percent. However, a drop in elongation of approximately 50 percent was noted in tensile results from specimens which contained 12 repeated repairs (STA after welding). This loss in ductility was attributed to a notch (stress riser) which developed on each side of the weld during the repeated repair (greater than 6 to 12) operations. This notch effect was caused by a combination of (1) metal drop-through became more pronounced on the repair weld back side with each repeated repair and (2) each weld repair was made with the experimental panel in a highly restrained condition, as would be expected with hardware welds.

Metallographic examinations of weld samples removed from each experimental panel (up to 12 repeated repairs) revealed no anomalies with regard to the presence of porosity, cracks, lack of penetration or deleterious metallurgical grain structures (fusion zone and adjacent base material).

In summation, 12 repeated weld repairs are not detrimental to Inconel 718 alloy with regard to tensile UTS and YS, fatigue properties (neglecting joint distortion), resultant metallurgical joint grain structures, and the ability of the weld joint to respond to post weld heat treatments. However, it would be prudent to exercise caution during repeated weld repairing because of potential joint distortion. The number of repeated weld repairs should be limited to the extent that the structural integrity of a critical joint is not compromised by the severity of a mechanical effect. Such a condition (loss in ductility) was noted in this evaluation by a notch on each side of the weld after 12 repeated repairs.

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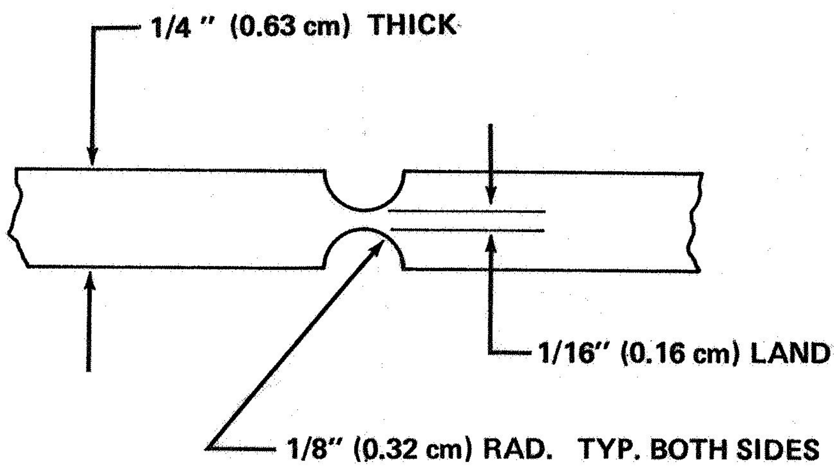


Figure 1. Base weld joint configuration.

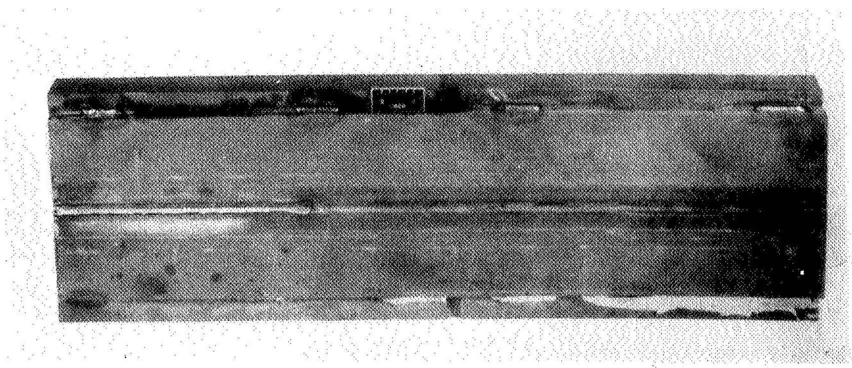


Figure 2. Experimental panel tack welded to a 1-in. (2.54 cm) thick plate prior to repair welding.

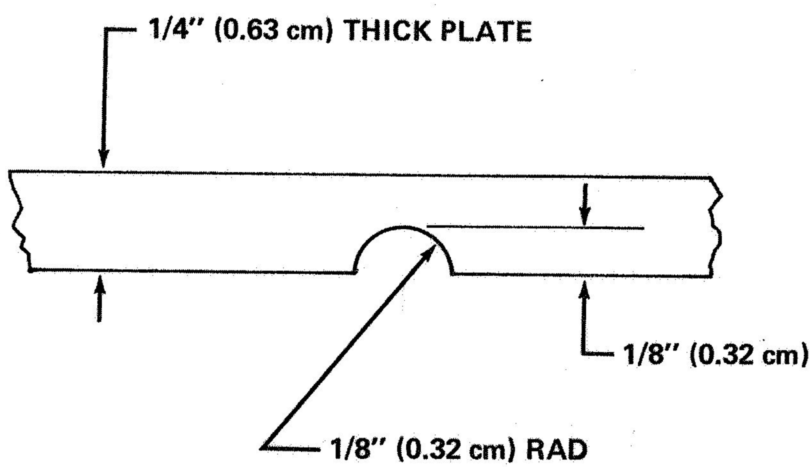


Figure 3. Repair groove configuration for 1/4-in. (0.63 cm) thick plate Inconel 718.

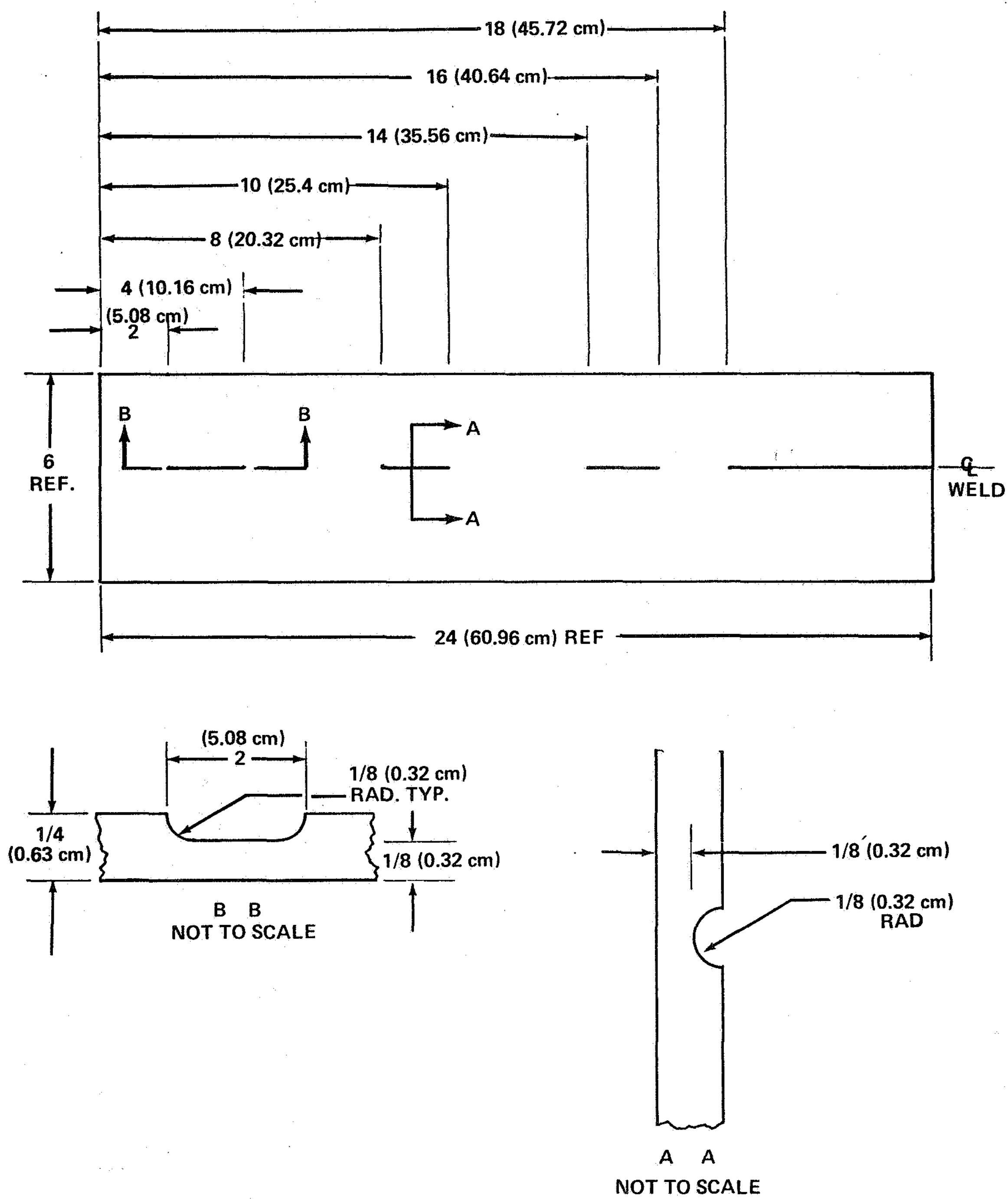


Figure 4. Repair locations within each panel of 1/4-in. (0.63 cm) thick plate Inconel 718.

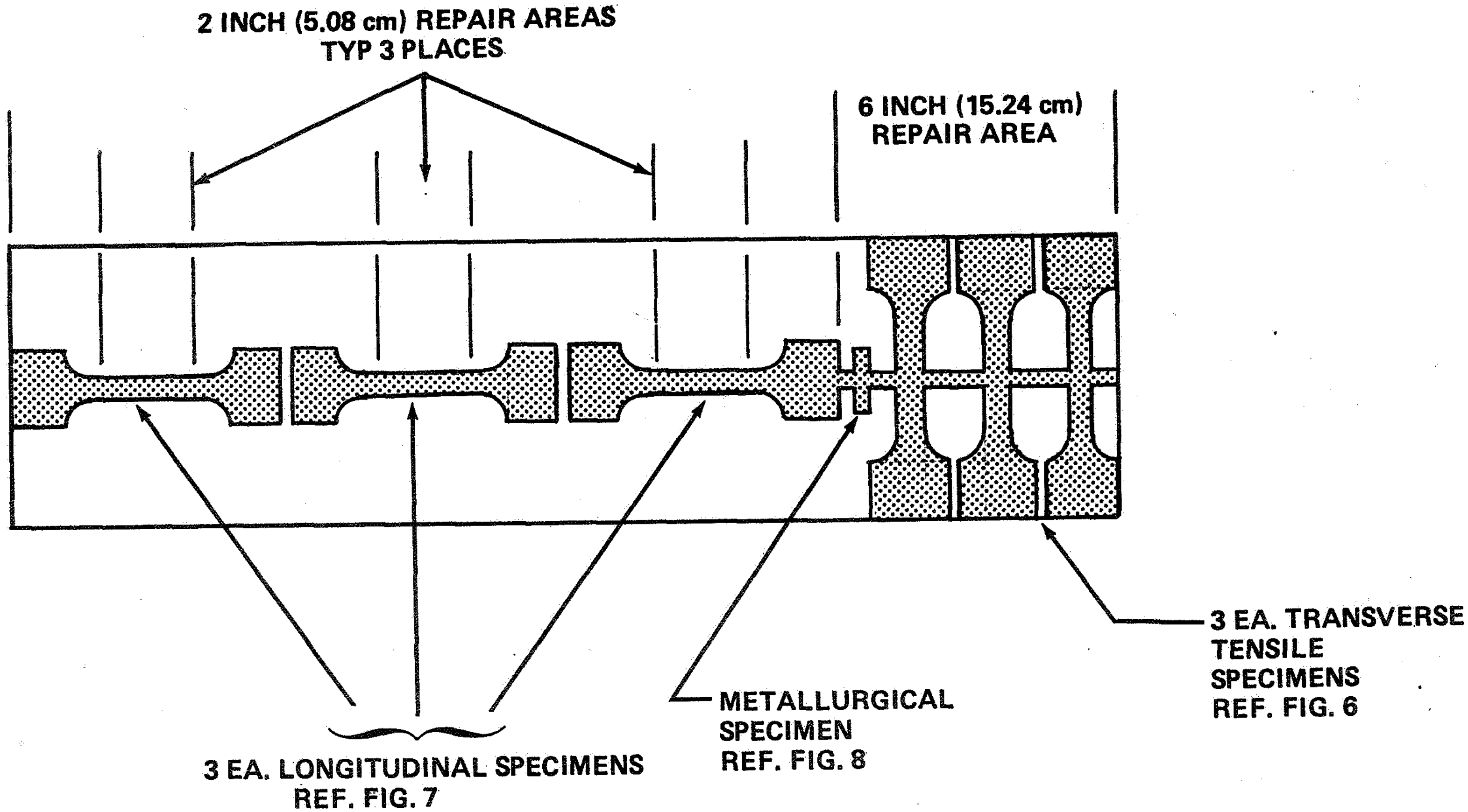


Figure 5. Scheme showing repaired weld tensile specimen removal areas for 1/4-in. (0.63 cm) thick plate Inconel 718.

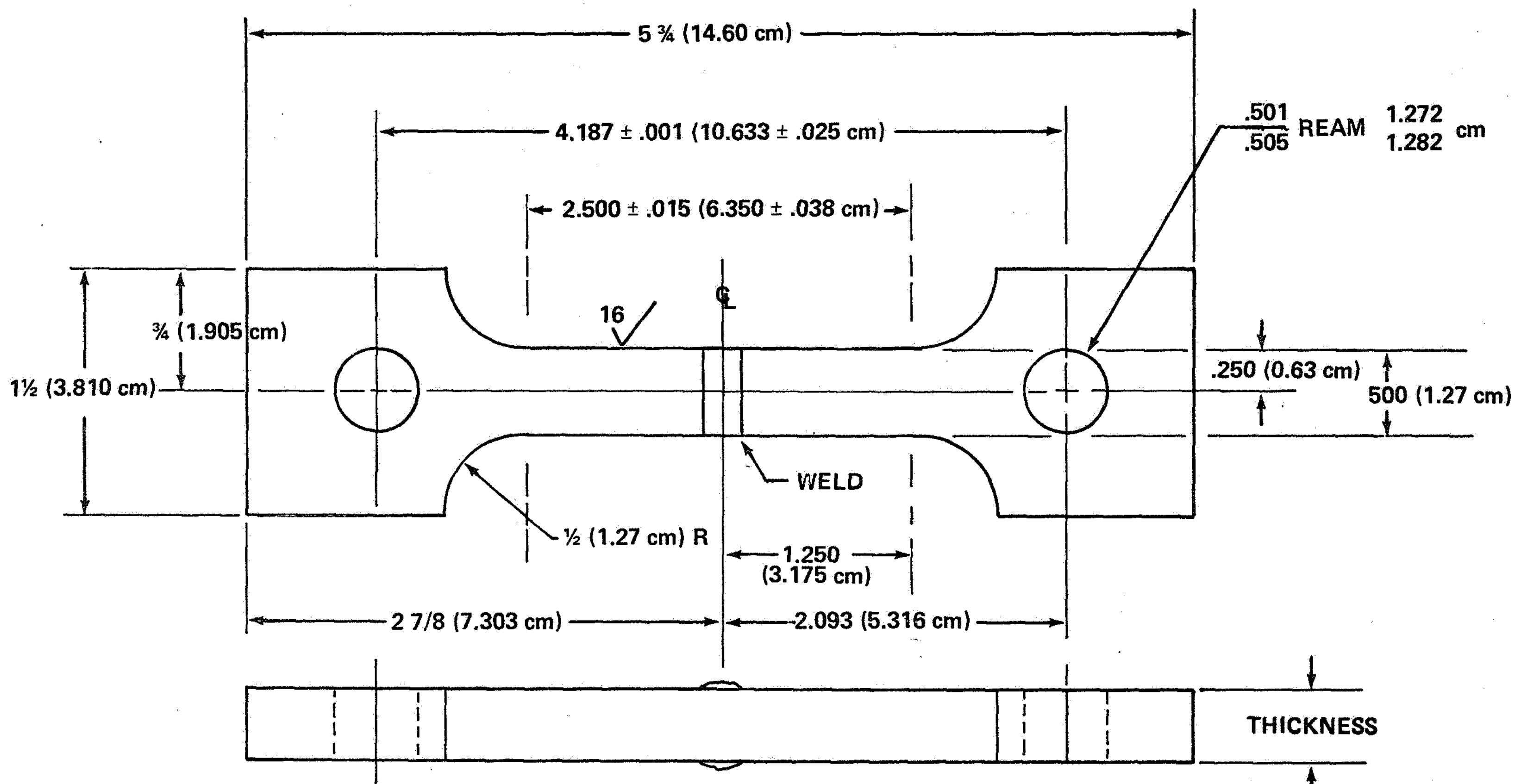


Figure 6. Transverse weld tensile specimen configuration.

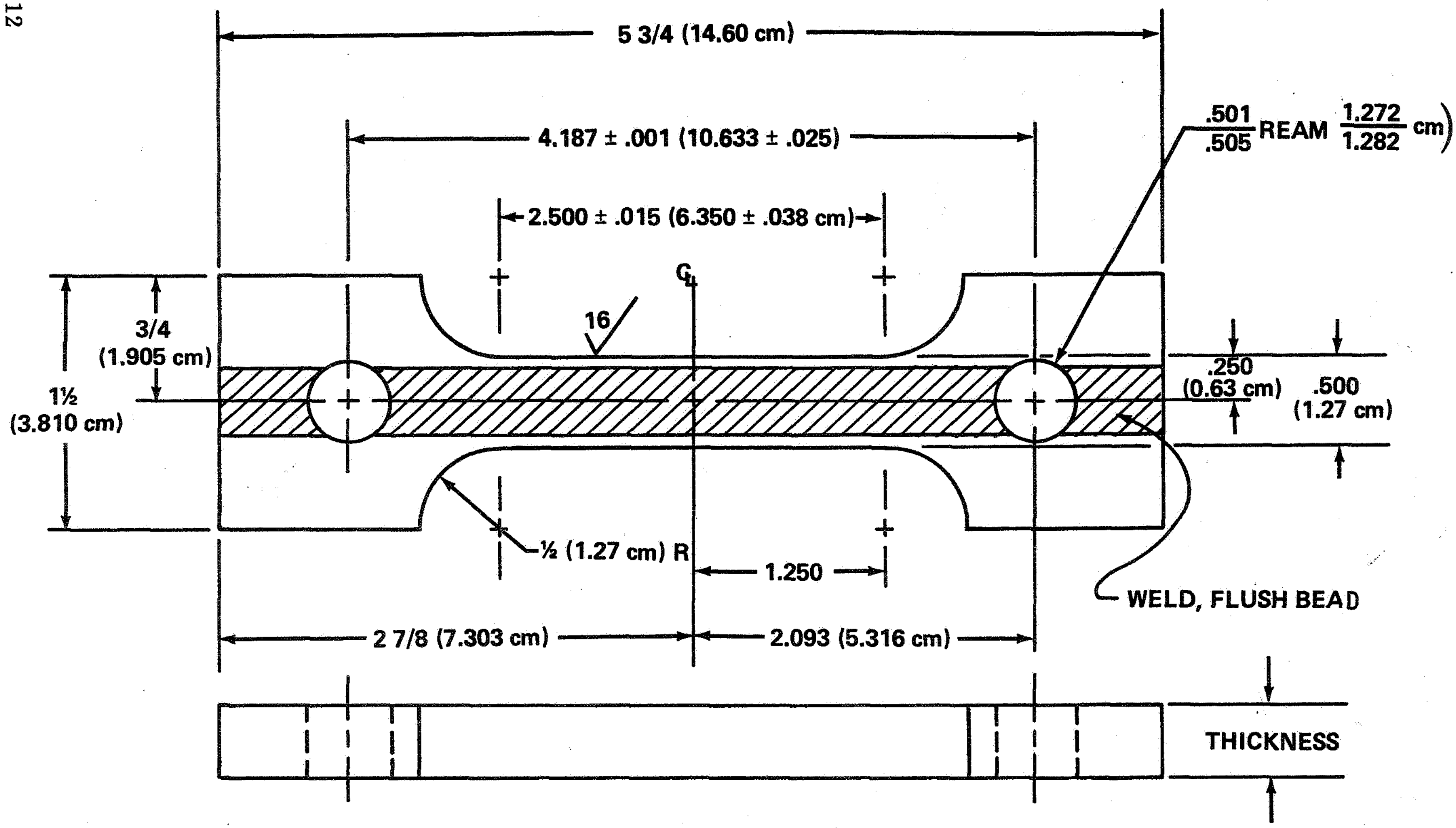


Figure 7. Longitudinal weld tensile specimen configuration.

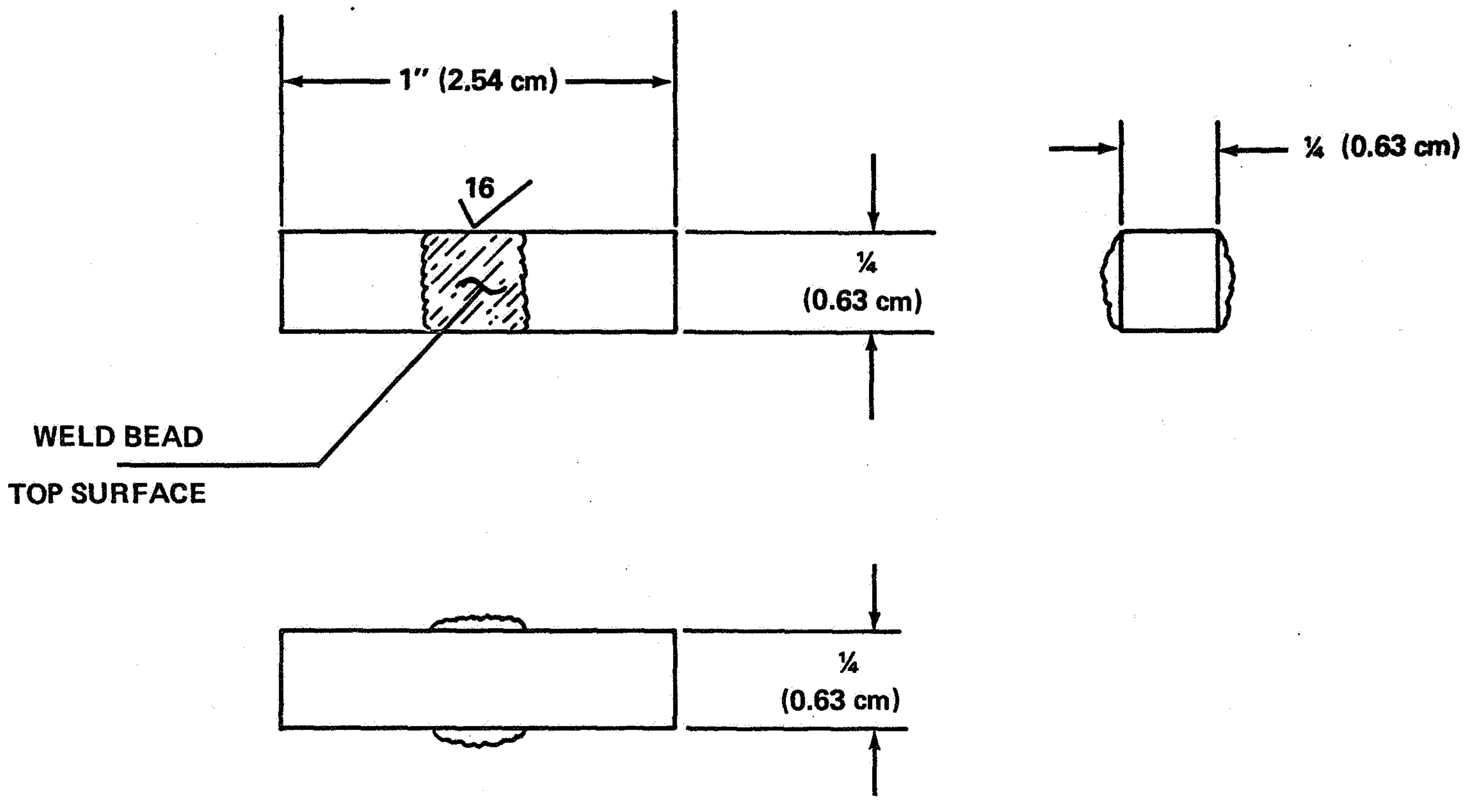


Figure 8. Weld sample configuration for metallurgical examinations.

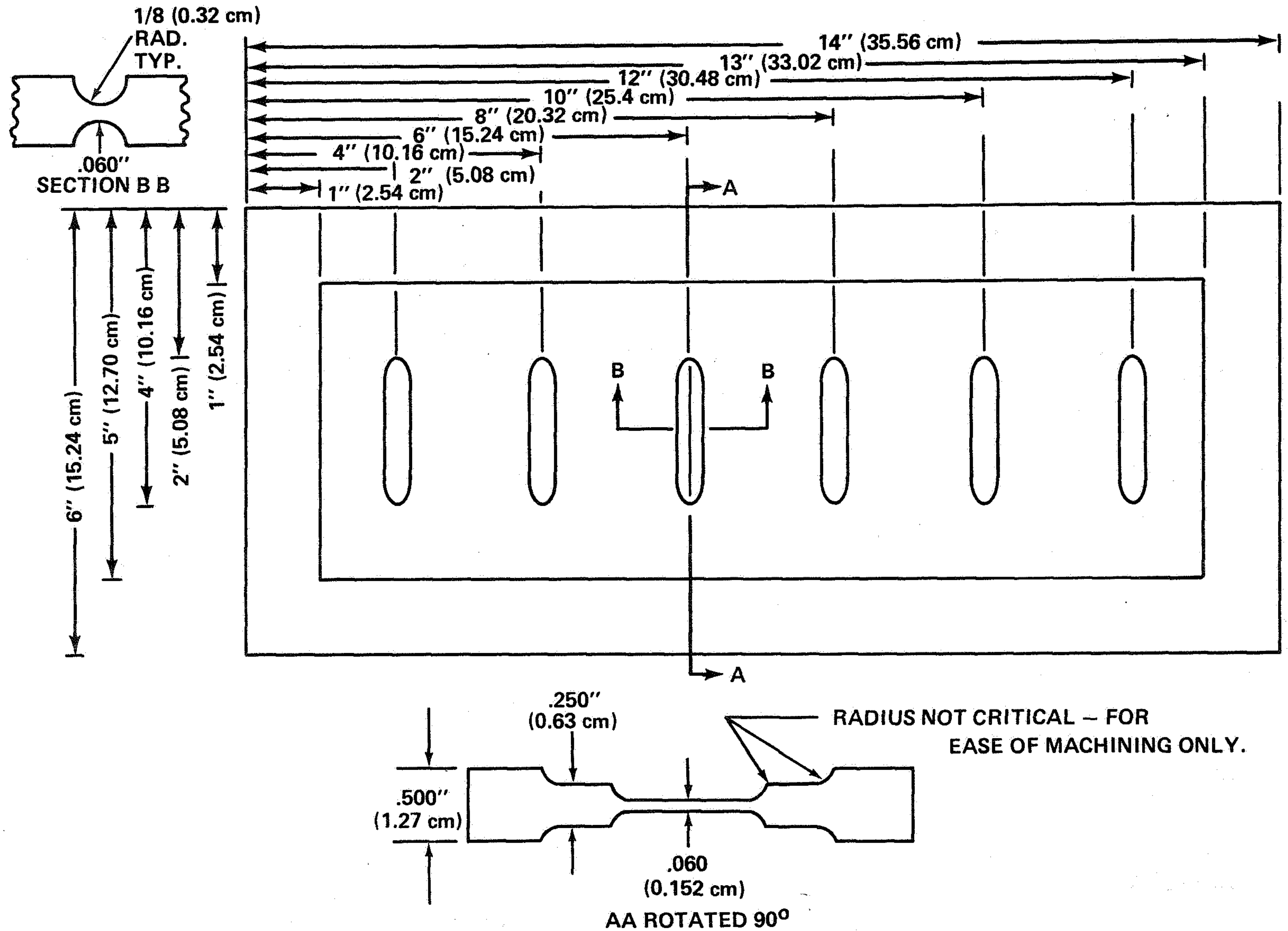


Figure 9. Scheme showing panel preparation and fatigue specimen removal areas for 1/2-inch (1.27 cm) thick plate Inconel 718.

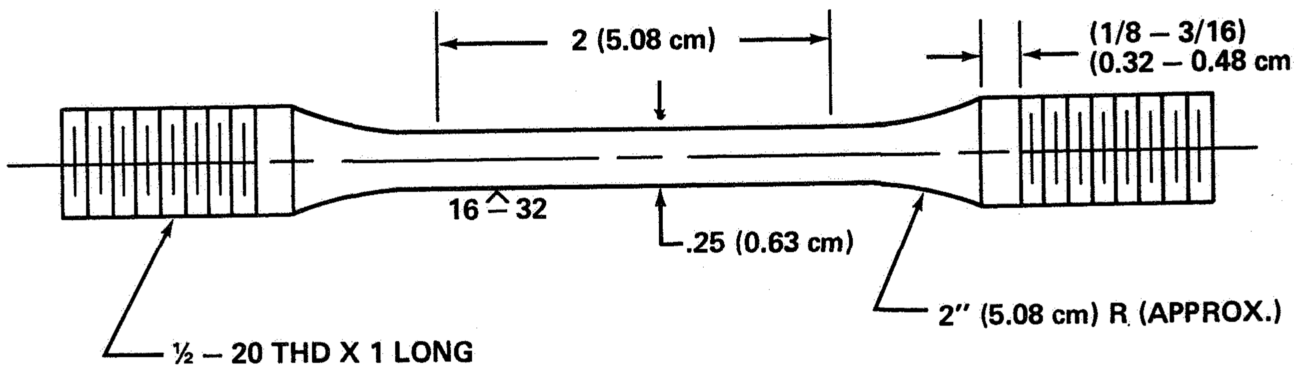


Figure 10. Fatigue specimen configuration.

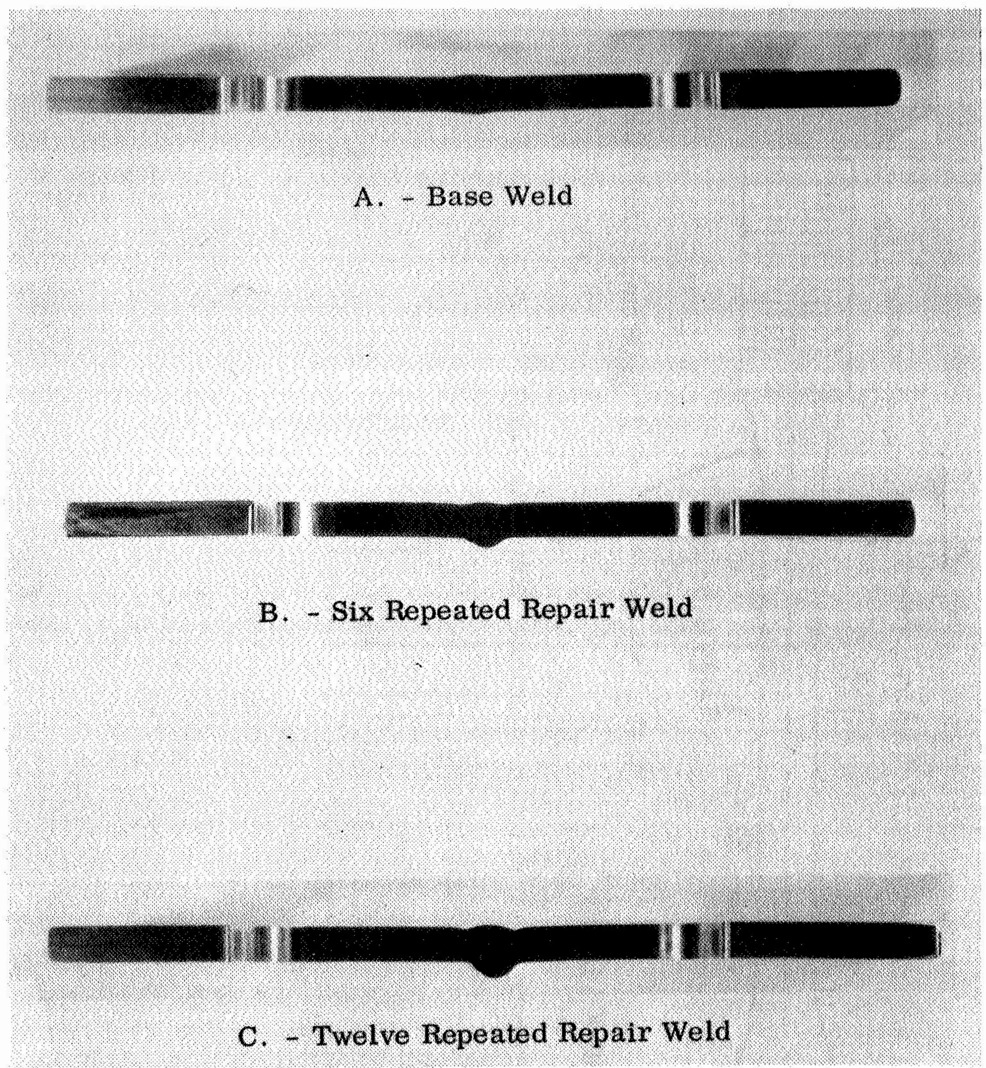
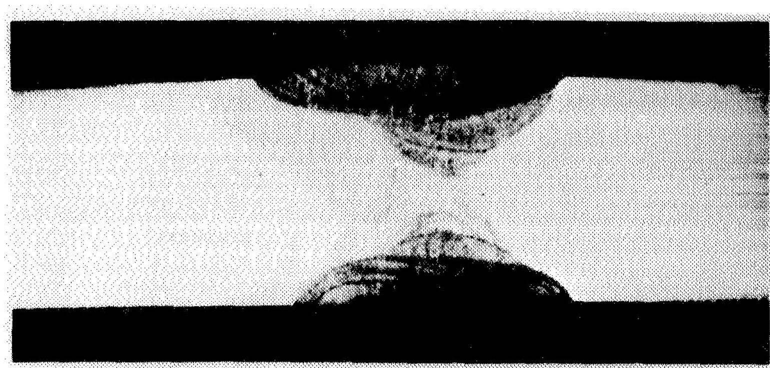
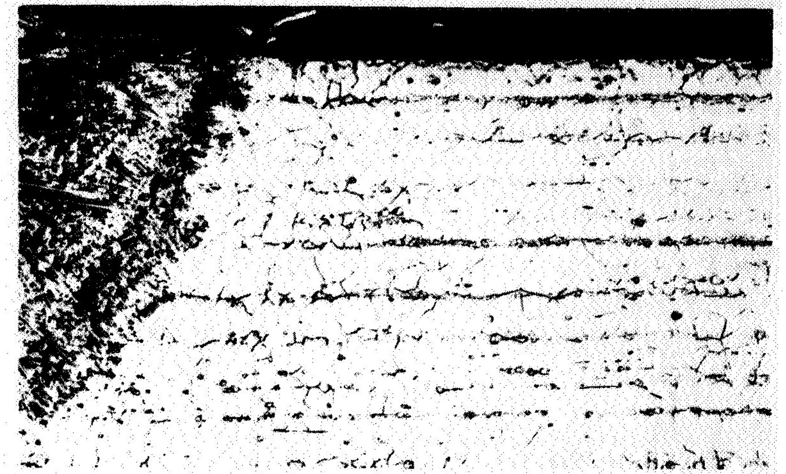


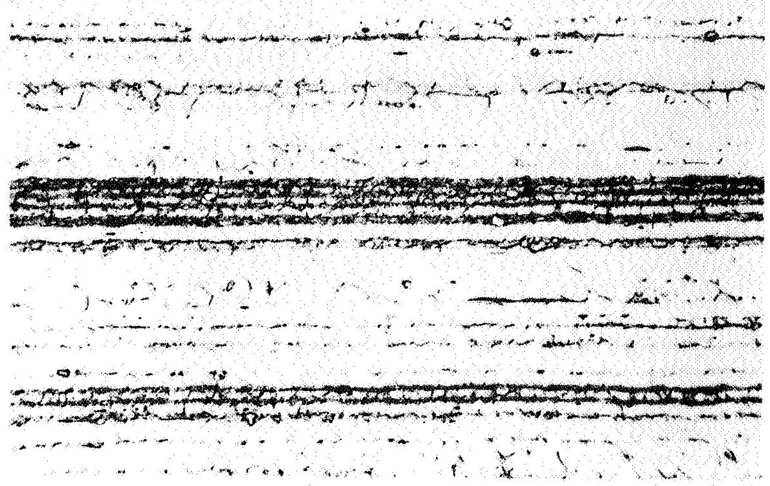
Figure 11. Weld joint cross sections showing alignment and distortion (samples removed from post weld STA panels).



A. - Cross Section of a Composite Base Weld Joint and Base Material Mag. 5X

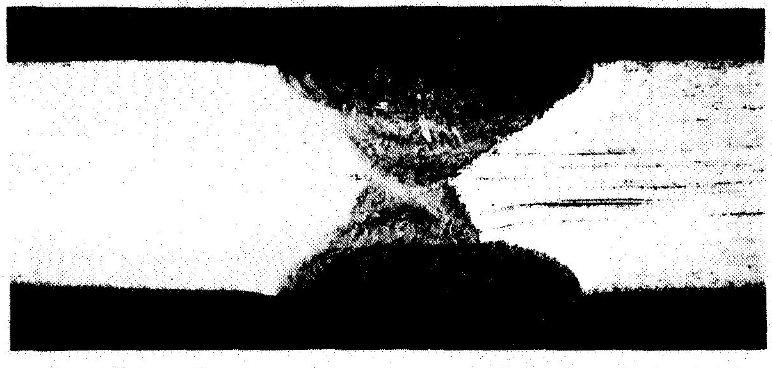


B. - Cross Section at Weld Interface: Cast Dendritic Structure of Weld at Upper Left Corner and Base Material Grain Structure at Right. Mag. 100X

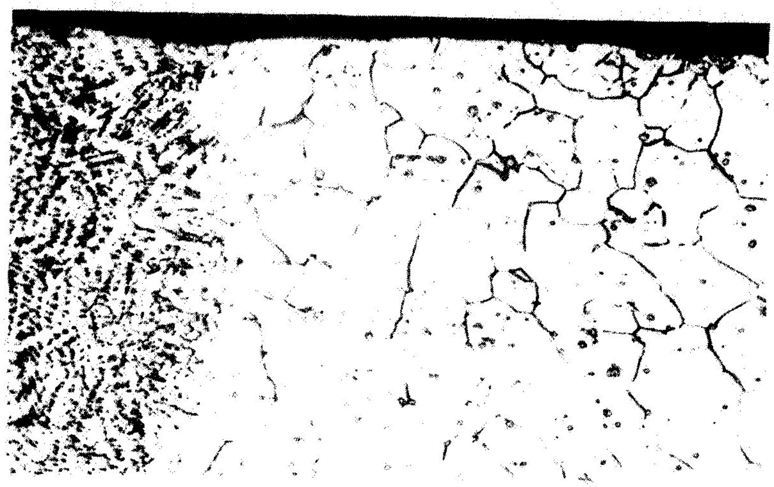


C. - Cross Section of Base Material Mag. 100X

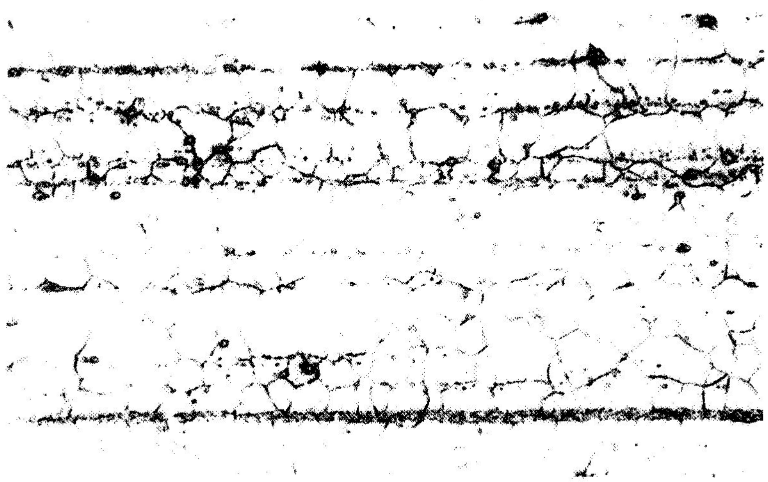
Figure 12. Metallographic structures of panel containing base welds: STA after welding [1/4-in. (0.63 cm) thick plate inconel 718].



A. - Cross Section of a Composite Repaired Weld Joint and Base Material Mag. 5X



B. - Cross Section at Weld Interface: Cast Dendritic Structure of Weld at Left and Base Material Grain Structure at Right Mag. 100X



C. - Cross Section of Base Material Mag. 100X

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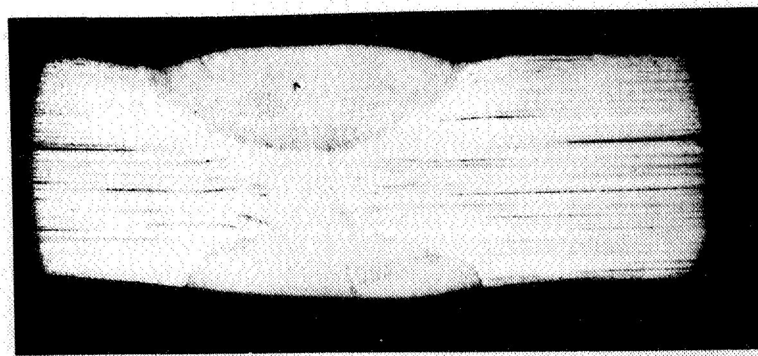
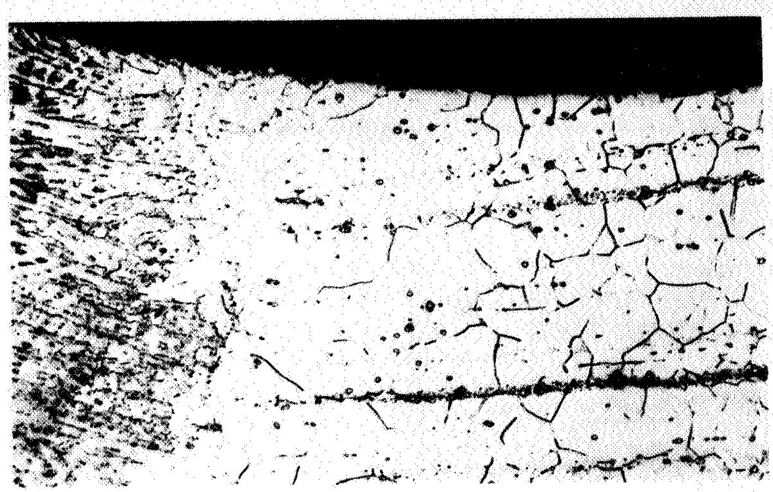
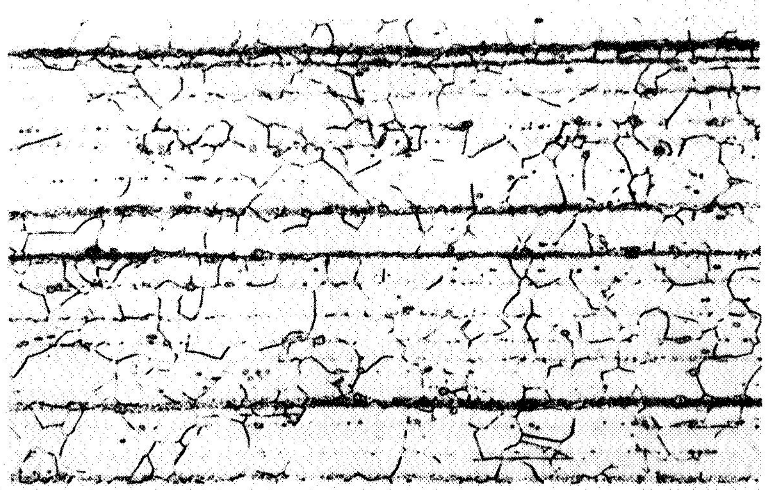
Figure 13. Metallographic structures of panel containing two repeated weld repairs: STA after welding [1/4-in. (0.63 cm) thick plate Inconel 718].



A. - Cross Section of a Composite Repaired Weld Joint and Base Material Mag. 5X

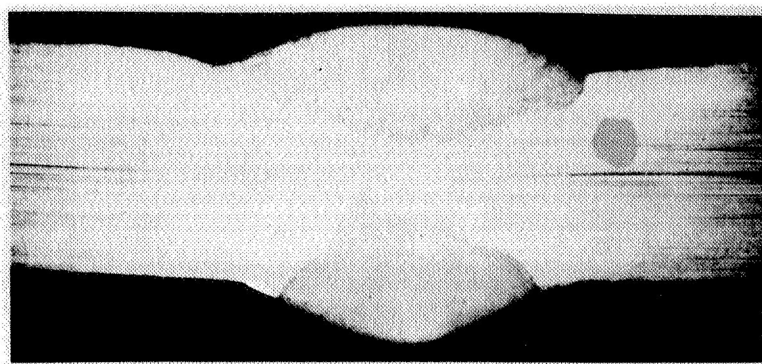


B. - Cross Section at Weld Interface: Cast Dendritic Structure of Weld at Left and Base Material Grain Structure at Right Mag. 100X



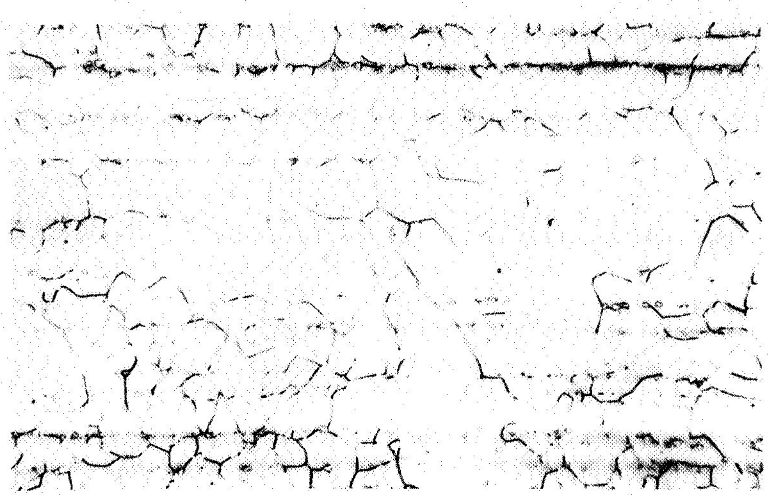
C. - Cross Section of Base Material Mag. 100X

Figure 14. Metallographic structures of panel containing six repeated weld repairs: STA after welding [1/4-in. (0.63 cm) thick plate Inconel 718].



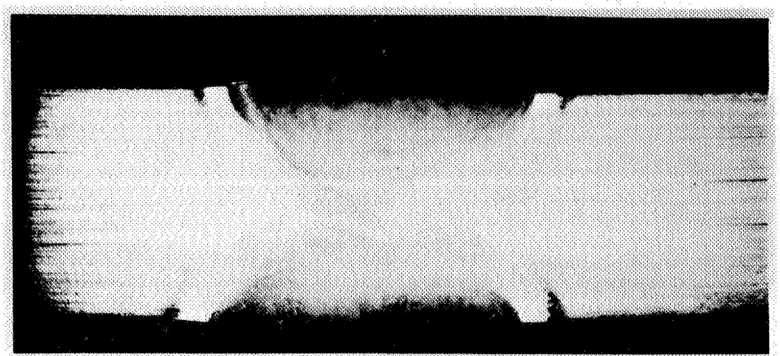
A. - Cross Section of a Composite Repaired Weld Joint and Base Material Mag. 5X

B. - Cross Section at Weld Interface: Cast Dendritic Structure of Weld at Left and Base Material Grain Structure at Right Mag. 100X



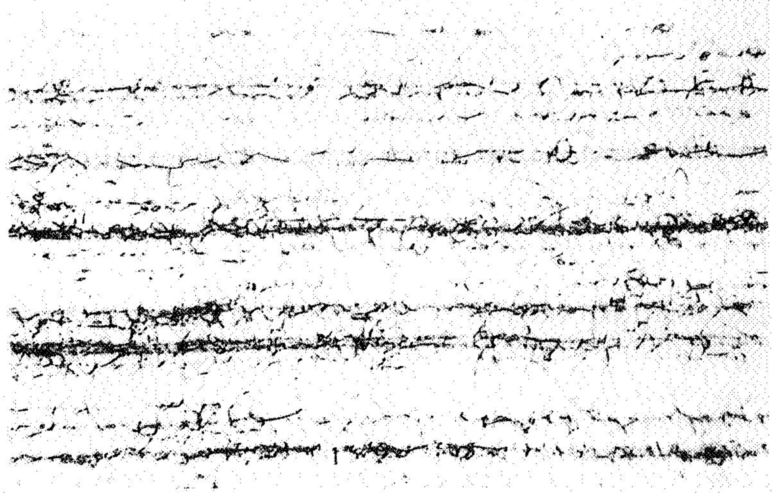
C. - Cross Section of Base Material Mag. 100X

Figure 15. Metallographic structures of panel containing twelve repeated weld repairs: STA after welding [1/4-in. (0.63 cm) thick plate Inconel 718].



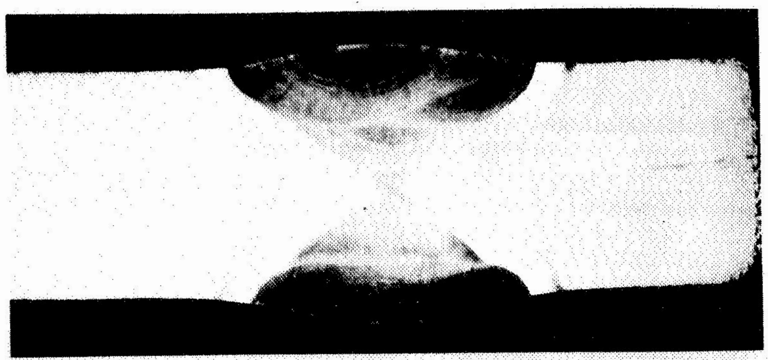
A. - Cross Section of a Composite Base Weld Joint and Base Material Mag. 5X

B. - Cross Section at Weld Interface: Cast Dendritic Structure of Weld at Upper Left Corner and Base Material Grain Structure at Right (HAZ) Mag. 100X



C. - Cross Section of Base Material Mag. 100X

Figure 16. Metallographic structures of panel containing base weld: As-welded STA base material [1/4-in. (0.63 cm) thick plate Inconel 718].

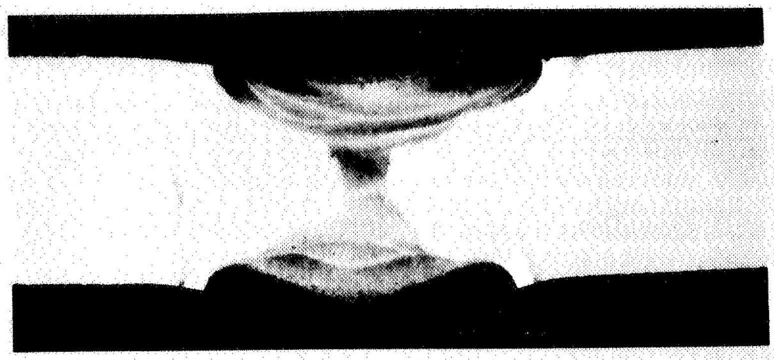


A. - Cross Section of a Composite Repaired Weld Joint and Base Material Mag. 5X

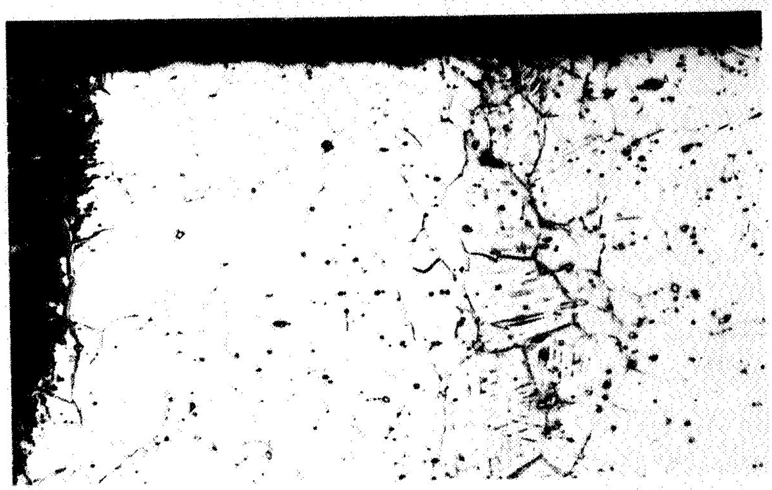
B. - Cross Section at Weld Interface: Cast Dendritic Structure of Weld at Upper Left Corner and Base Material Grain Structure at Right (HAZ) Mag. 100X

C. - Cross Section of Base Material Mag. 100X

Figure 17. Metallographic structures of panel containing two repeated weld repairs: As-welded STA base material [1/4-in. (0.63 cm) thick plate Inconel 718].



A. - Cross Section of a Composite Repaired Weld Joint and Base Material Mag. 5X



B. - Cross Section at Weld Interface: Cast Dendritic Structure of Weld at Left and Base Material Grain Structure at Right (HAZ) Mag. 100X

C. - Cross Section of Base Material Mag. 100X

Figure 18. Metallographic structures of panel containing six repeated weld repairs: As-welded STA base material [1/4-in. (0.63 cm) thick plate Inconel 718].

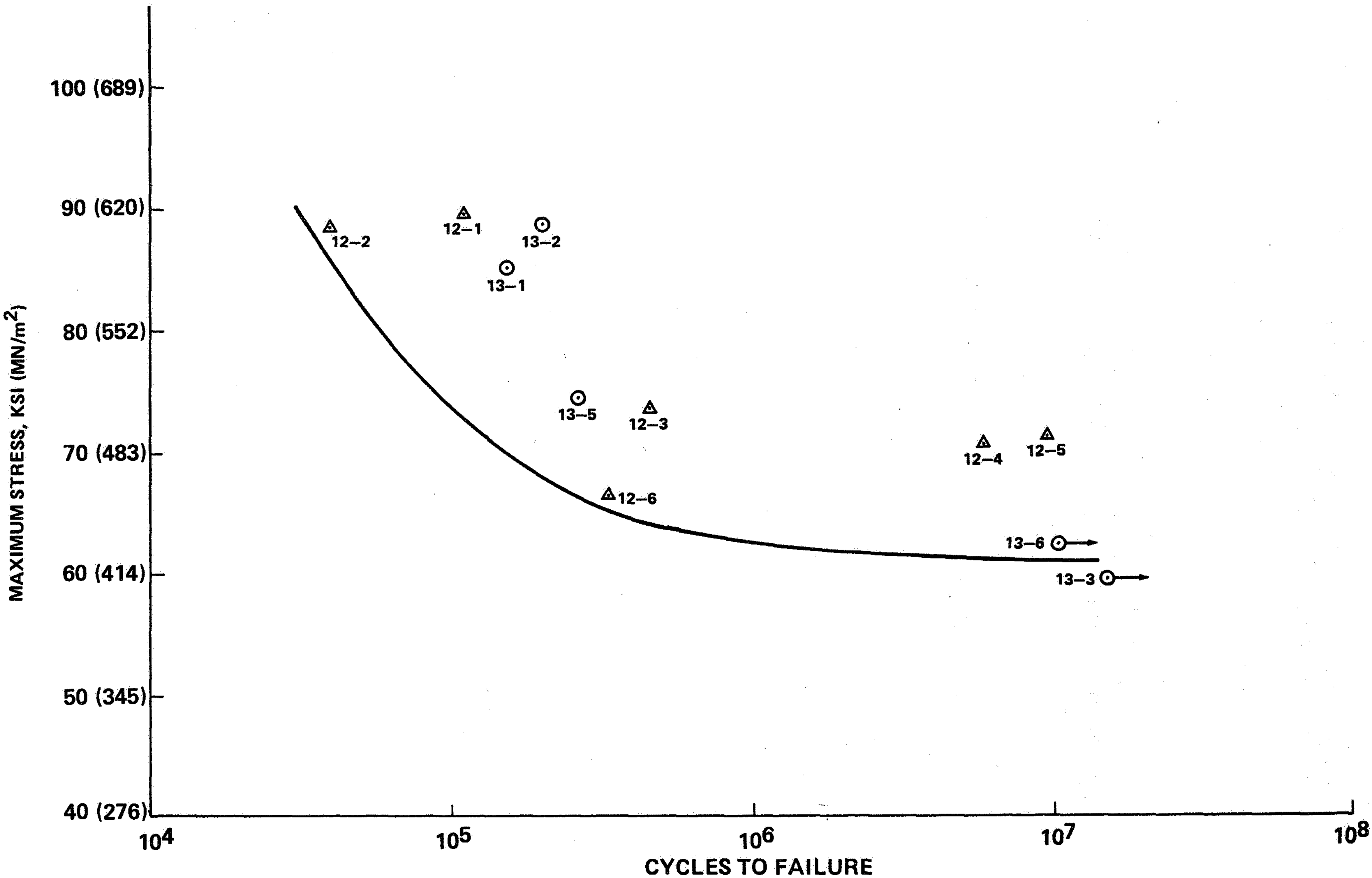


Figure 19. S-N plot showing fatigue data for STA material as-welded/base weld (STA + W).

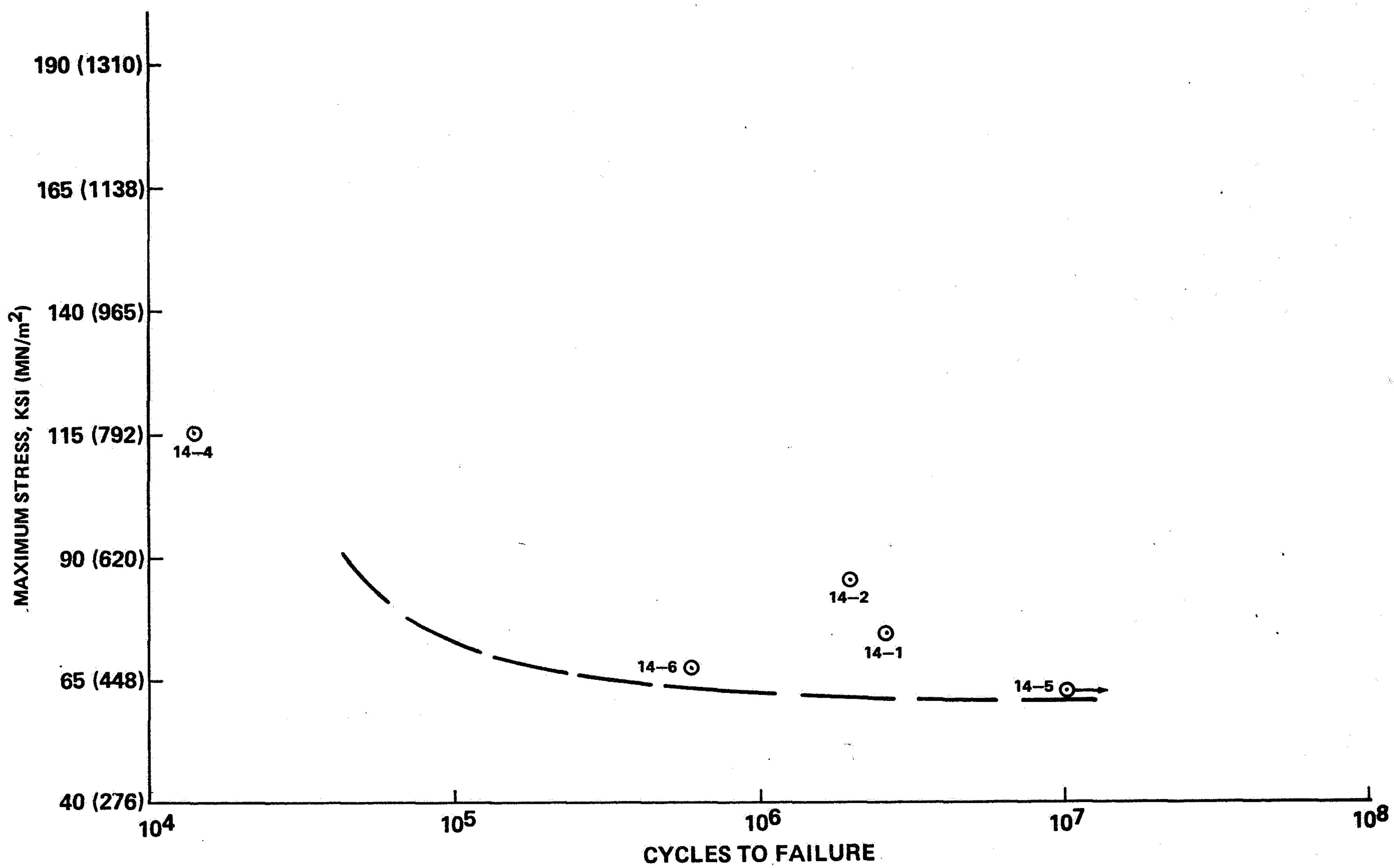


Figure 20. S-N plot showing fatigue data for STA material welded plus six repeated repairs (STA + R6).

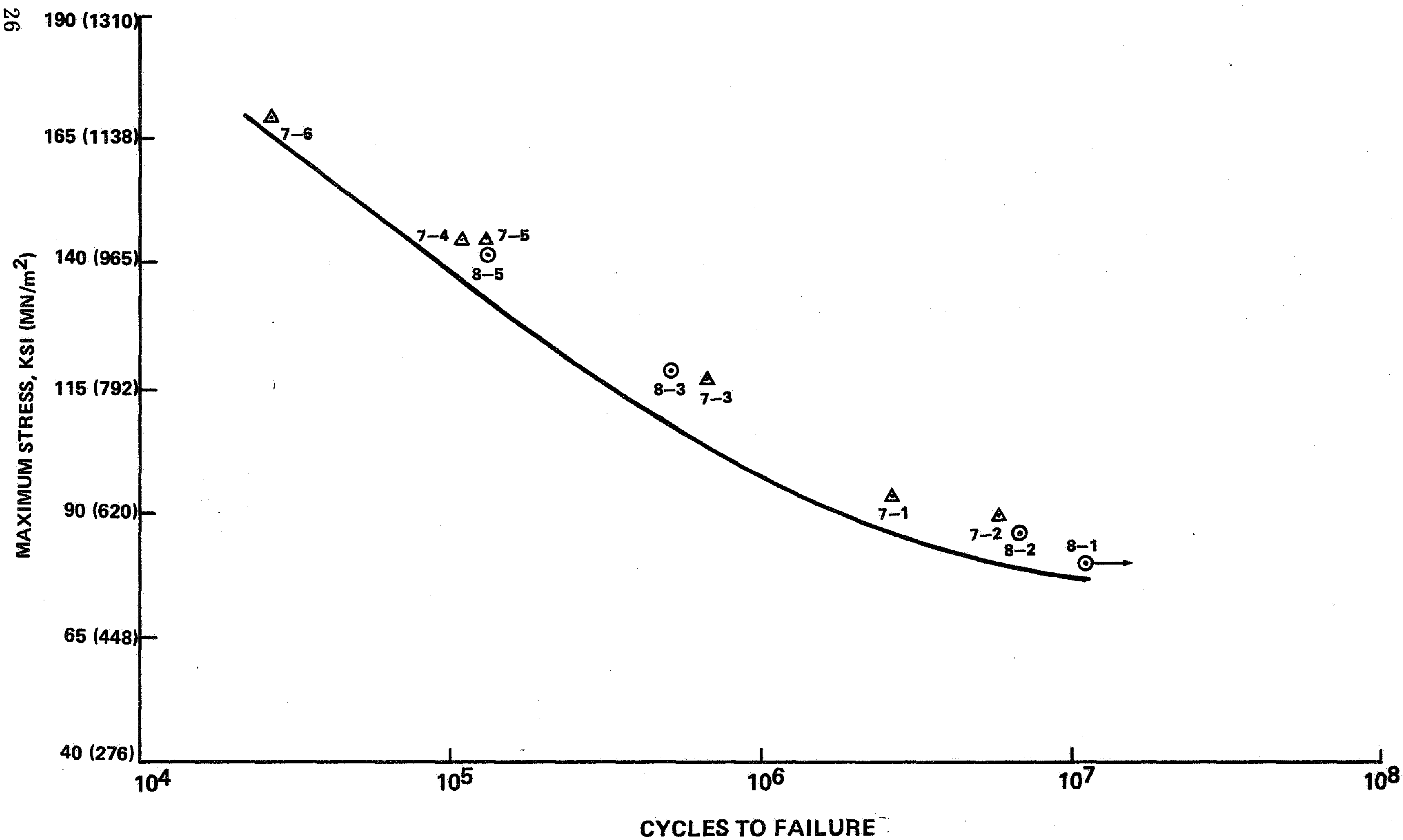


Figure 21. S-N plot showing fatigue data for ST material welded and STA after welding/base weld (ST + W + STA).

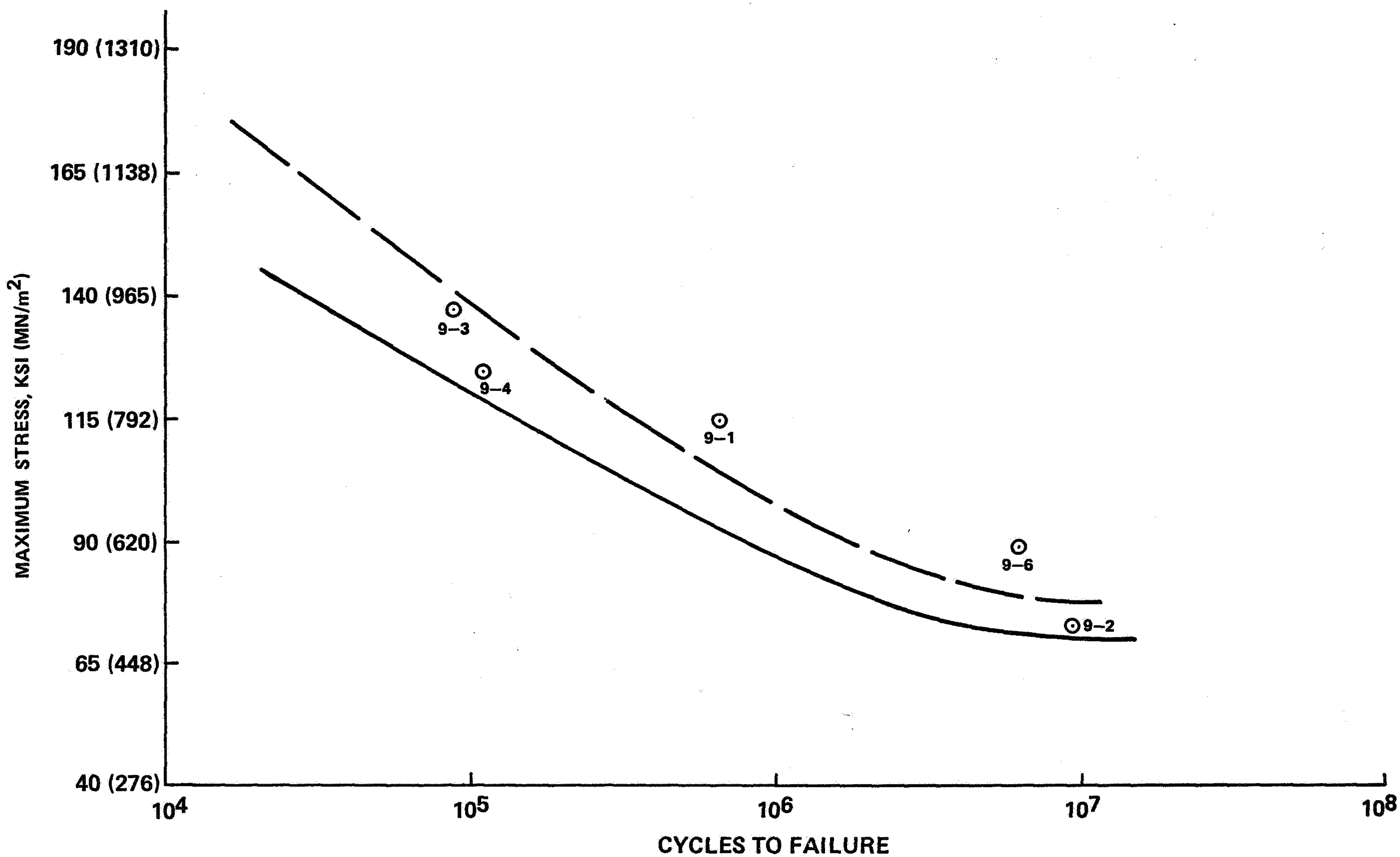


Figure 22. S-N plot showing data for ST material welded plus two repeated repairs and STA after welding (ST + R2 + STA).

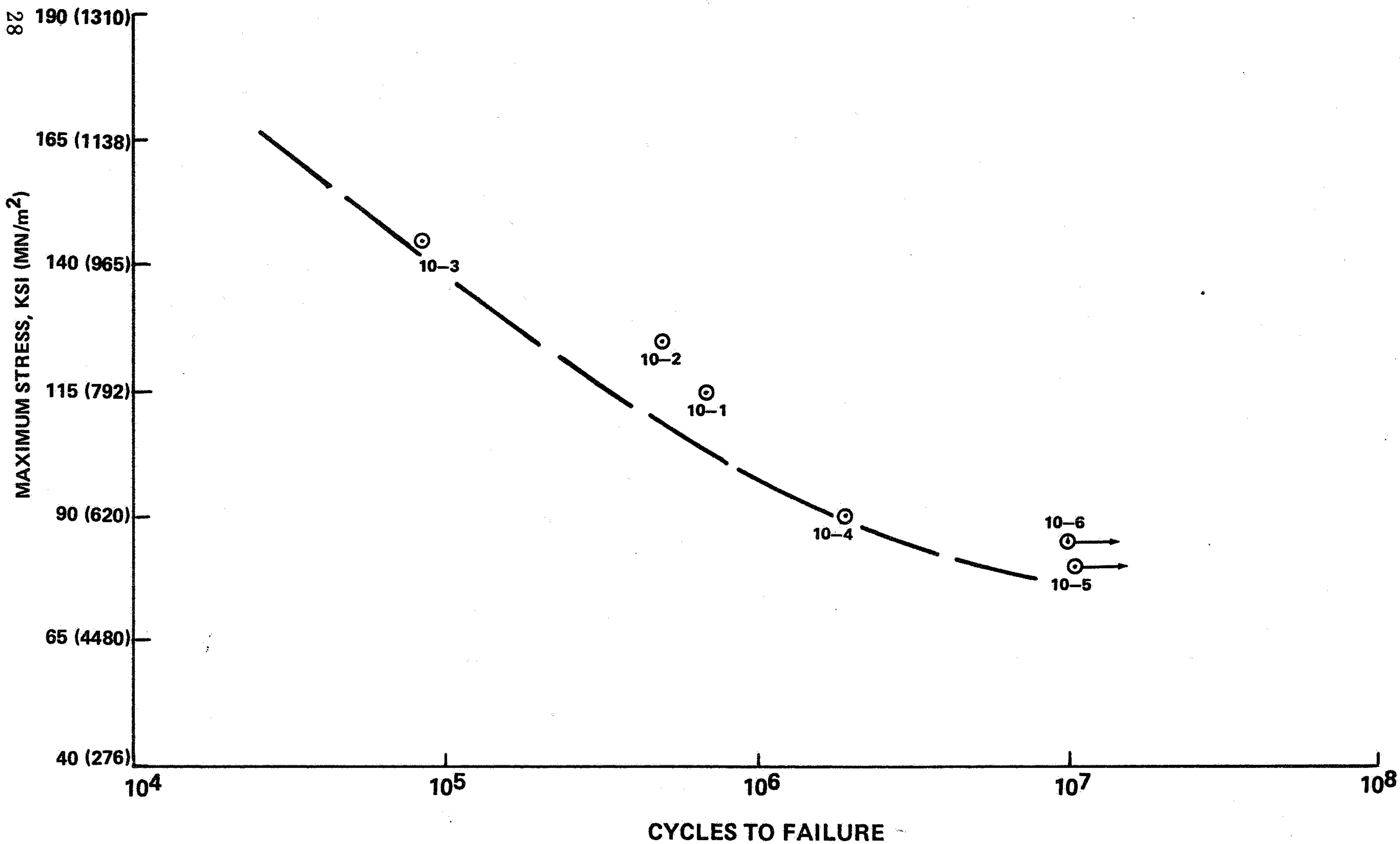


Figure 23. S-N plot showing fatigue data for ST material welded plus six repeated repairs and STA after welding (ST + R6 + STA).

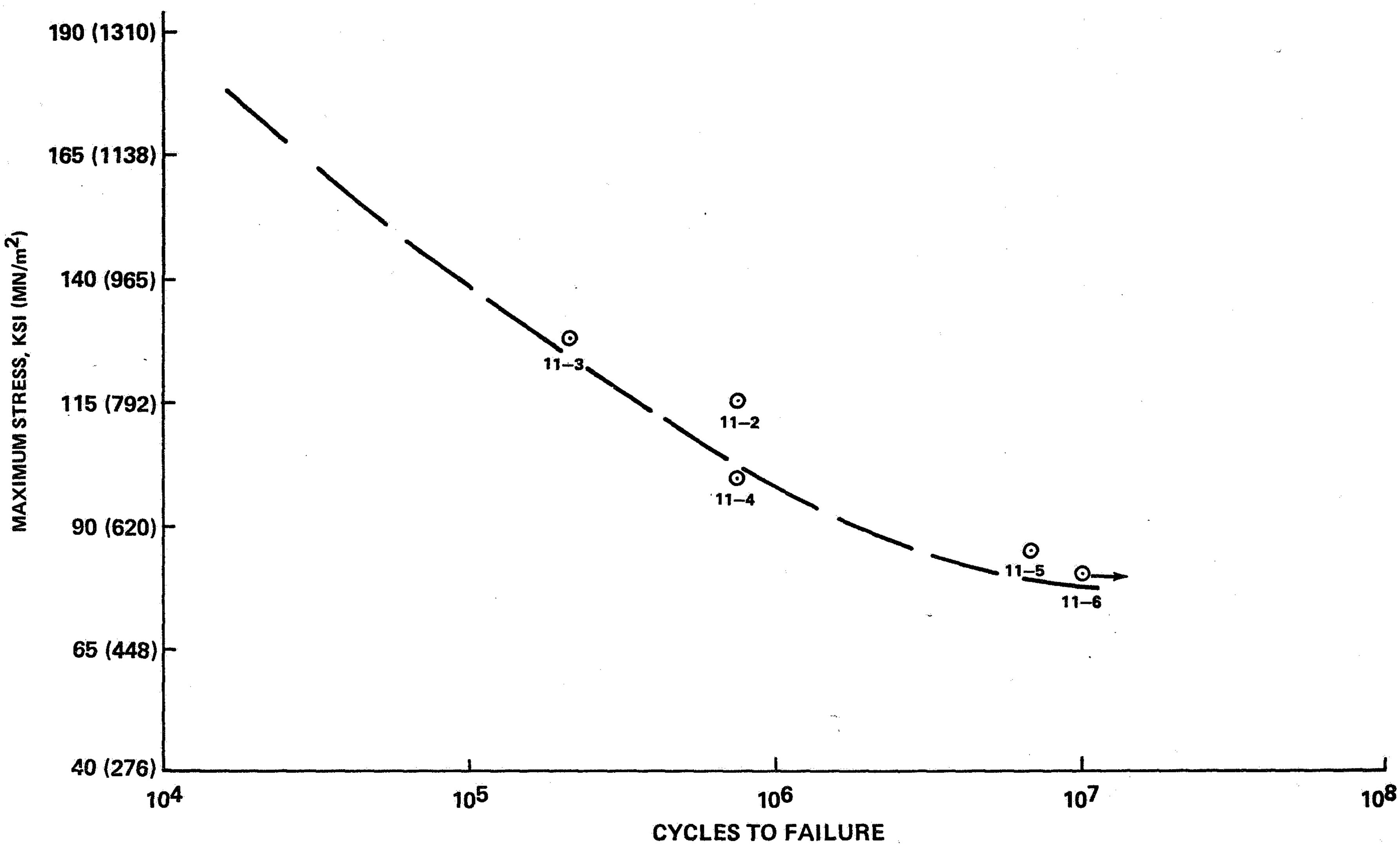


Figure 24. S-N plot showing fatigue data for ST material welded plus twelve repeated repairs and STA after welding (ST + R12 + STA).

TABLE 1. CHEMICAL COMPOSITION LIMITS OF INCONEL 718 (3)

Element	Specification (%)
Carbon	0.08
Manganese	0.35
Silicon	0.35
Phosphorus	0.015
Sulfur	0.015
Chromium	17.00-21.00
Nickel + Cobalt	50.00-55.00
Cobalt	1.00
Molybdenum	2.80-3.30
Columbium + Tantalum	4.75-5.50
Titanium	0.65-1.15
Aluminum	0.20-0.80
Boron	0.006
Copper	0.30
Iron	Remainder

(Maximum unless shown as a range)

TABLE 2. SUMMARY HCF TEST RESULTS - INCONEL 718 WELDMENTS/REPEATED REPAIR WELDMENTS

Specimen No.	Processing Sequence	Specimen Diameter (in.)	Specimen Diameter (mm)	Test Loads Static (lb)	Test Loads Static (kg)	Test Loads Dynamic (lb)	Test Loads Dynamic (kg)	Stress Ratio, R	Maximum Stress (Ksi)	Maximum Stress (MN/m^2)	Cycles to Failure x 10^3
7-1	ST+W+STA	0.243	6.17	2,225	1,011	2,095	952	0.03	93.1	642	2,512
7-2		0.250	6.35	2,225	1,011	2,095	952		88.0	607	5,418
7-3		0.247	6.27	2,883	1,310	2,725	1,239		117.1	807	648
7-4		0.248	6.30	3,599	1,636	3,405	1,548		145.0	1,000	121
7-5		0.248	6.30	3,599	1,636	3,405	1,548		145.0	1,000	105
7-6		0.250	6.35	4,276	1,944	4,055	1,843		169.7	1,170	25
8-1		0.246	6.25	1,954	888	1,840	836		79.5	548	10,363+
8-2		0.251	6.38	2,225	1,011	2,095	952		87.3	602	6,337+
8-3		0.246	6.25	2,883	1,310	2,725	1,239		118.1	814	481
8-4		0.247	6.27	3,599	1,636	3,405	1,548		146.2	1,008	127
8-5		0.249	6.32	3,599	1,636	3,405	1,548		143.8	991	125
8-6		0.246	6.25	4,676	2,125	4,426	2,012		191.7	1,322	8
9-1	ST+R2+STA	0.251	6.28	2,930	1,332	2,760	1,254		115.0	793	641
9-2		0.253	6.43	1,977	899	1,862	846		76.3	526	9,308
9-3		0.252	6.40	3,532	1,605	3,326	1,512		137.4	947	87
9-4		0.252	6.40	3,225	1,466	3,037	1,380		125.0	862	108
9-6		0.254	6.45	2,328	1,058	2,192	996		89.2	615	6,170
10-1	ST+R6+STA	0.252	6.40	2,967	1,349	2,795	1,270		115.0	793	671
10-2		0.254	6.45	3,264	1,484	3,074	1,397		125.0	862	498
10-3		0.252	6.40	3,727	1,694	3,510	1,595		145.0	1,000	83
10-4		0.253	6.43	2,341	1,064	2,205	1,002		90.0	620	1,871
10-5		0.251	6.38	2,048	931	1,929	877		80.0	551	10,000+
10-6		0.251	6.38	2,167	985	2,041	928		85.0	586	10,000+
11-2	ST+R12+STA	0.252	6.40	2,956	1,344	2,784	1,265		115.0	793	754
11-3		0.252	6.40	3,276	1,489	3,086	1,403		127.5	879	210
11-4		0.248	6.30	2,612	1,187	2,460	1,118		105.0	724	750
11-5		0.252	6.40	2,193	997	2,066	939		85.0	586	6,868
11-6		0.251	6.38	2,038	926	1,920	873		80.0	551	10,000+
12-1	STA+W	0.248	6.30	2,225	1,011	2,095	952		89.4	616	109
12-2		0.249	6.32	2,225	1,011	2,095	952		88.7	611	38
12-3		0.249	6.32	1,858	844	1,750	795		73.8	509	458
12-4		0.251	6.38	1,806	821	1,700	773		70.8	488	5,726
12-5		0.249	6.32	1,806	821	1,700	773		71.7	494	9,291
12-6		0.247	6.27	1,668	758	1,571	714		66.5	458	321
13-1		0.254	6.45	2,225	1,011	2,095	952		85.2	587	150
13-2		0.249	6.32	2,225	1,011	2,095	952		88.7	611	198
13-3		0.249	6.32	1,491	678	1,400	636		59.4	409	14,924+
13-5		0.245	6.22	1,806	821	1,700	773		74.4	513	260
13-6		0.247	6.27	1,542	701	1,452	660		62.5	431	10,000+
14-1	STA+R6	0.251	6.38	1,886	857	1,776	807		74.0	510	2,518
14-2		0.251	6.38	2,176	989	2,049	931		85.0	586	1,985
14-4		0.247	6.27	2,849	1,295	2,683	1,219		115.0	793	10
14-5		0.249	6.32	1,574	715	1,482	674		62.5	431	10,000+
14-6		0.241	6.12	1,586	721	1,494	679		67.5	465	591

TABLE 3. TENSILE PROPERTIES OF RESOLUTION HEAT TREATED AND AGE-HARDENED INCONEL 718 ALLOY, 1/4-in. (0.63 cm) THICK PLATE

	UTS		UYS	
	Ksi	MN/m	Ksi	MN/m
	196.4	1354	161.2	1111
	197.6	1362	159.7	1101
	197.2	1360	158.5	1092
Avg.	197.1	1359	159.8	1101

Note: The hardness of the material is Rockwell "C" 43.5.

TABLE 4. TRANSVERSE WELDMENT TENSILE PROPERTIES OF INCONEL 718 ALLOY, 1/4-INCH (0.63 cm) THICK PLATE

Weld	UTS Ksi (MN/m^2)	UYS 0.2 Offset Ksi (MN/m^2)	Elongation Percent 2-in. (5.08 cm) Gage Length	Joint Efficiency Percent
ST Base Material + Weld + STA				
Base	193.9 (1337)	159.9 (1102)	19.0	98.3
Two Repeated Repairs	194.3 (1340)	166.8 (1150)	16.7	98.6
Six Repeated Repairs	196.4 (1354)	154.8 (1067)	17.0	99.6
Twelve Repeated Repairs	192.6 (1328)	155.0 (1069)	9.7	97.7
STA Base Material + Weld				
Base	148.3 (1022)	89.4 (616)	8.2	
Two Repeated Repairs	153.6 (1059)	94.1 (649)	8.8	
Six Repeated Repairs	157.2 (1083)[a]	103.9 (716)[a]	8.3[a]	

a. Average value from 2 tensile results.

Notes:
1. Each value shown is the average of 3 tensile results.
2. Tensile tests were conducted with weld bead reinforcement intact.
3. All welding done by automatic TIG process with Inconel 718 wire.

TABLE 5. LONGITUDINAL WELDMENT TENSILE PROPERTIES OF INCONEL 718 ALLOY, 1/4-INCH (0.63 cm) THICK PLATE

Weld	UTS Ksi (MN/m^2)	UYS 0.2 Offset Ksi (MN/m^2)	Elongation Percent 2-Inch (5.08 cm) Gage Length
ST Base Material + Weld + STA			
Base	194.0 (1338)	159.4 (1099)	15.2
Two Repeated Repairs	195.7 (1349)	161.2 (1111)	12.3
Six Repeated Repairs	197.2 (1360)	153.6 (1059)	17.7
Twelve Repeated Repairs	196.0 (1351)	156.4 (1078)	15.3
STA Base Material + Weld			
Base	148.5 (1024)	95.3 (657)	31.0
Two Repeated Repairs	144.9 (999)	98.9 (682)	22.5
Six Repeated Repairs	142.4 (982)*	99.7 (687)*	21.5*

* Average value from 2 tensile results.

Notes: 1. Each value shown is the average of 3 tensile results.

2. All welding done by automatic TIG process with Inconel 718 wire.

APPROVAL

CONSIDERATIONS ON REPEATED REPAIRING OF WELDMENTS IN INCONEL 718 ALLOY

By E. O. Bayless, C. V. Lovoy, M. C. McIlwain,
and P. Munafo

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

R. J. Schwinghamer

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Director, Materials and Processes
Laboratory

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