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IMPROVED TIG WELD JOINT STRENGTH IN ALUMINUM ALLOY 2219-T87 BY FILLER METAL SUBSTITUTION

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16. ABSTRACT

This report presents the results of an investigation of weld joint characteristics of aluminum alloy 2219-T87 in which five different alloys were utilized as filler material. The mechanical properties of the joints were determined at ambient and cryogenic temperatures for weldments in the as-welded condition and also, for weldments after elevated temperature exposures. Other evaluations included hardness surveys, stress corrosion susceptibility and to a limited extent, the internal metallurgical weld structures.

The overall results of this investigation indicate that M-943 filler weldments are superior in strength to weldments containing either the standard 2319 filler or fillers 2014, 2020, and a dual wire feed consisting of three parts 2319 and one part 5652. In addition, no deficiencies were evident in M-934 filler weldments with regard to ductility, joint strength after elevated temperature exposure, weld hardness, metallographic structures, or stress corrosion susceptibility.

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SUMMARY

Metallurgical evaluations were made of aluminum alloy 2219-T87 welded by the TIG process with filler wires 2319, 2014, 2020, M-934, and a dual feed consisting of three parts 2319 to one part 5652. The use of the TIG welding process, 2219 base alloy, and 2319 filler wire is consistent with fabrication practices and material which are used in the construction of aerospace hardware, such as propellant tankage. The other four filler wires were used in an attempt to increase the joint strength in alloy 2219.

A comparison of the five resultant welds was made using 2319 filler wire joints as a base line. In general, welds containing filler M-934 displayed ultimate tensile and yield strengths significantly greater than those displayed by welds containing 2319 filler. The range of strength increases in this evaluation varied from 7 to 18 percent at ambient temperature, and from 3 to 14 percent at cryogenic temperatures. All comparisons were made with joints which were made by using the same welding position as well as identical welding techniques. The elongation values obtained with M-934 filler weldments were comparable to values obtained with 2319 filler weldments at ambient temperature and only slightly less at -423°F (262.8°C). Hardness values across the weld showed the M-934 filler to be somewhat harder than welds with 2319 filler, a fact which is consistent with tensile data. Stress corrosion and metallographic evaluations of M-934 filler metal test samples displayed no deleterious characteristics. No significant advantages were evident when comparing the strength and metallurgical characteristics of welds containing 2319 filler to welds containing either filler 2014, 2020, or the dual wire feed of 2319 and 5652.

INTRODUCTION

The objective of this investigation was to increase the joint strength of tungsten inert gas fusion welds in aluminum alloy 2219-T87 by improving the performance of the weld wire when compared with the conventional type 2319 filler alloy . The strength increase, must necessarily be accomplished without sacrifice to the metallurgical characteristics normally associated with welds utilizing type 2319 filler. Any significant joint strength increase in a prime vehicle structural material would permit the use of higher design allowables, and subsequently result in increased payloads.

Aluminum alloy 2219 was developed by Alcoa as a heat treatable, high strength alloy. The alloy was introduced initially as an aircraft forging alloy for highly stressed parts operating at ambient and elevated temperatures. Later, the alloy was rolled in sheets and plates. The alloy displays a high propensity for strength retention after elevated temperature exposures of 300°F (149°C) for periods of as long as 1000 hours. The alloy contains copper as the major alloying element with small additions of manganese, titanium, vanadium, and zirconium. Other elements, such as iron, magnesium, zinc, and silicon, are present as undesirable impurities.

Thermal treatment of the alloy follows the general pattern used for other heat treatable, high strength aluminum alloys. The alloy is solution heat treated, quenched in cold water, cold worked to a reduction of approximately 8 percent and aged artificially to the -T87 temper condition (Ref. 1,2).

This alloy, 2219, can be fusion welded by the inert-gas metal-arc process using either consumable or nonconsumable electrodes. The nonconsumable electrode, tungsten, inert-gas arc process is the preferred aerospace joining method with aluminum alloys. The most commonly used filler metal is type 2319.

Alloy 2219 was the prime structural material for the S-IC propellant tanks. In general, this application was attractive because the alloy exhibited favorable characteristics with respect to (1) thermal hardening, (2) formability, (3) weldability, and (4) mechanical properties at both ambient and cryogenic temperatures. Many, if not all space shuttle design concepts, include an aluminum alloy construction for propellant tankage and/or other structures. Aluminum alloy 2219 is the prime candidate material selected by most designers for these applications. To support these designs, Materials Division initiated a program to determine if beneficial effects could be attained on the joint characteristics of TIG weldments from a modified and/or new weld filler alloy. This investigation was suggested due to previous experience with weldments in which aluminum alloy 2219 welded to aluminum alloy 2014 with type 2319 filler metal exhibited higher strength values than those obtainable with weldments of alloy 2219 to the same alloy 2219, using 2319 type filler metal. In addition to using 2014 and 2319 types, other fillers used in this evaluation were types 2020, M-943, and a combination wire feed of one part 5652 and three parts 2319. The reasons for these particular experimental selections were to yield deposited filler metal with various copper-magnesium contents, and a high copper-plus-lithium content. Comparisons were made of the results obtained from the five filler alloys: these comparisons included the resultant tensile data, hardness survey across the weldments, stress corrosion evaluation, and metallographic examinations.

EQUIPMENT AND TEST SPECIMENS

The welds were made by the TIG process on standard welding equipment which consisted of an Airco Function Controlled welding power supply, Model FCWS-3049 and Model HMW-E voltage controlled welding head. Work pieces were held consistently by clamping fixtures, and travel speeds were provided by a rack drive system. Welds were made in both down hand (flat) and horizontal positions while maintaining conventional and very consistent weld controls. Figures 1 and 2 show the welding setups.

The base materials (sheet and plate), three of the filler wires, and the shielding gases were all procured to appropriate aerospace specifications. Experimental filler wire types 2020 and M-934 were obtained on NASA development contracts. The chemical compositions of the base metal and filler wires are shown in Table I.

Tensile testing was conducted on a universal type Riehle testing machine, Model FS60, with a loading capability of 267 kn. Transverse weldment tensile specimen (weld bead intact) configurations consisted of simple strips with parallel edges (Figure 3) for ambient temperature testing, and a "dog bone" pin hole type specimen for cryogenic temperature testing (Figure 4). The all weld metal tensile specimens were fabricated in accordance with the drawing in Figure 5.

Hardness surveys across the weld were taken after the weld bead reinforcements (crown and root sides) were sanded flush with the base metal of selected samples to provide a smooth surface. Hardness values were obtained with a Kentrall Model M04 hardness tester.

Some joint strength tests were conducted after elevated temperature exposures of 300°F (149°C) and 350°F (177°C) for a period of 100 hours. This work was done to determine strength changes, if any, of welded alloy 2219-T87 components which may be cycled at elevated temperatures many times by repeated shuttle re-entries. These samples were temperature cycled in a Blue M Electric Company furnace, Model POM-206C.

Alternate immersion stress corrosion tests were made in a 3 1/2 percent sodium chloride solution. Each weld test specimen was immersed in solution for 10 minutes of each hour for a duration of either 90 days, or until failure, whichever occurred first. Applied stress level was 75 percent of the yield strength. Unstressed duplicate specimens were exposed under identical conditions for control purposes. Detailed descriptions of the specimen configuration, special fixtures, loading techniques, area applicable to a protective coating , and cyclic equipment are described in Ref. 3.

Metallographic examinations were conducted with equipment and etchant normally used with aluminum alloy welds. Radiographic inspection followed procedures which usually grade weldments to Class 1 per MSFC-SPEC-259A (Ref. 4).

RESULTS AND DISCUSSION

In welding most high strength aluminum alloys, aluminum filler wire of a different chemical composition is used primarily to dilute the base metal melted. Generally this decreases the degree of segregation on solidification and provides greater ductility. Thus, the weld zone can more readily absorb strains produced by the following: (1) thermal or metallurgical effects during the welding operation, (2) post weld heat treatment when applicable, (3) forming in some instances, and (4) Use under operational stresses. The increased ductility eliminates weld cracking, which is the primary objective, but it generally lowers strength. Aluminum alloy 2219 has been rather unique in that type 2319 filler wire, which very closely approximates the chemical composition of alloy 2219, has always been used as the filler metal during fusion welding. The 2319 filler wire is somewhat higher in titanium content than alloy 2219. Titanium basically acts as a grain refiner for the melted metal. This base metal and filler wire combination has performed admirably in aerospace applications, especially in the area of cryogenic propellant tank construction. Many space shuttle design concepts to date include aluminum alloy 2219-T87 for propellant tankage and other structures. To advance the "state-of-the-art" of these concepts this evaluation tested the hypothesis that TIG weldment strength could be increased by the use of a modified and/or new filler alloy without serious degradation to those metallurgical characteristics inherent to 2319 filler welds; namely, a favorable "trade-off" between weld strength and ductility.

Initially, experimental panels 6.35 mm thick plate were welded in the down hand position with stainless steel backing by the TIG process which utilized one pass over a square-butt joint with the following filler wires:

(1) 2319, 1.6 mm diameter

(2) 2014, 2.4 mm diameter

(3) 2020, 1.2 mm diameter

(4) M-934, 1.6 mm diameter

(5) Dual feed of 1 part 5652 + 3 parts 2319, each 1.2 mm. diameter.

Filler wire selection was based upon trace element content and ranges of alloying element content of most interest which for the most part represented the elements of copper, magnesium, silicon, manganese, and lithium. Copper (deposited by the filler wire and remelted base metal in all welds) is used as the major alloying element and is the primary strengthening constitutent. Small amounts of magnesium accelerate and increase the extent of natural aging but there is disagreement over the most desirable copper-magnesium ratio. Successively higher additions of magnesium first accelerate, and then retard, the rate of aging at elevated temperatures. The presence of silicon tends to increase the strength values and reduces the time to peak properties at elevated temperatures. This behavioral pattern may depend on the magnesium-silicon ratio. Manganese may withold other solute elements from solution by compound formation, or by limiting solubility. Reportedly, manganese appears to have little direct influence on the precipitation process (Ref. 5). The purpose of introducing lithium into the weldment was to increase the strength at elevated temperatures. This was done with regard to potential space shuttle applications where high temperature performance during reentry may be governing. However, the welds with filler metal containing lithium did not show any strength improvements as tested. They also showed undesirable microstructures, twinning, microporosity, and segregation. Therefore, further evaluation was not conducted at this time.

The weld seams of the initial panels were perpendicular to the grain direction of the 2219-T87 base metal. The weld parameters were conventional and are shown in Table II. These welds, as well as all subsequent welds, were graded to Class I per MSFC-SPEC-259A. The overall results from this group of panels show that transverse specimens containing M-934 filler are superior from a strength standpoint at +78^{o}F (25.6^{o}C), -320^{o}F (-196^{o}C), and -423^{o}F (-252.8^{o}C), to weldments containing either the standard 2319 filler or any of the remaining substitutional fillers. The elongation values (percent in 2 inch gage length) of the M-934 specimens displayed a slightly higher rate of decrease with temperature from +78^{o}F (25.6^{o}C) to -423^{o}F (252.8^{o}C) than test coupons containing the other filler metals. The all weld metal tensile specimens also showed M-934 filler material to be stronger and somewhat less ductile at ambient temperature. These data are shown in Table III and are depicted graphically in Figures 6-7. Hardness values obtained across the weldments show the melted and resolidified region to be harder with the M-934 filler metal than with the other filler metals. The widths of the resolidified area were only slightly different with the various filler alloys. This was expected because of the similar weld energy input. The hardness values are shown in Table IV and the corresponding hardness profile curves in Figure 8. Metallographic examinations revealed some twinning in weldments utilizing filler 2020 and the dual wire filler of 2319 + 5652. In addition, microporosity was evident in 2020 filler weldments. No metallographic anomalies were apparent in weldments containing either 2014, 2319, or M-934 filler alloy.

A typical microstructure of the base metal is shown in Figure 9. Figures 10-17 show typical photomacrographs and photomicrographs at various locations within each weldment cross section. Another group of tests was then conducted with weldments containing filler alloys 2014, 2319, and M-934.

The second group of panels (6.35 mm thick plate) utilized the TIG process (one pass) at two different speeds in the horizontal position with no backing. These welding parameters are shown in Table V. In general, the as-welded strength trends prevalent with these panels were similar to those noted with the initial panels which employed the same three filler alloys. The resultant tensile data are shown in Table VI. The mechanical properties of weldments containing each filler alloy (before and after elevated temperature exposures) are plotted as a function of test temperature in Figures 18-23.

Weldments were made by the TIG process in 3.18 mm thick sheet utilizing one pass with the work pieces mounted in the flat position. These weld parameters are shown in Table VII. The transverse weldment mechanical properties were determined from these panels in both the as-welded condition and after elevated temperature exposures of 300°F (149°C) or 350°F (177°C) for a period of 100 hours. The resultant cryogenic joint strength trends were again similar to those noted previously with M-934 weldments being the stronger of the three. After elevated temperature exposures, the percent increase in joint strength of both 2014 filler weldments and M-934 filler weldments was in general, slightly less than those of 2319 filler weldments. The resultant data are shown in Table VIII and presented graphically in Figures 24-26. Stress corrosion evaluations from this group of panels indicate that no significant deleterious effects took place as a result of the use of either substitutional filler alloy; these findings are apparent by comparing the stress corrosion test results shown in Tables IX and X.

The last group of panels in this evaluation utilized TIG weldments in 12.7 mm thick plate. These weldments were made in the horizontal position by using one pass on each side (see Table XI). The joint strength of the M-934 filler weldment was again stronger than either the 2014 filler weldment or the 2319 filler weldment. The resultant data are shown in Table XII and presented in bar form in Figure 27.

CONCLUSIONS

The overall results of this investigation indicated that M-934 filler weldments in aluminum alloy 2219-T87 are superior from a strength standpoint to weldments containing either the standard 2319 filler or fillers 2014, 2020, and a dual wire feed consisting of three parts 2319 and one part 5652. The range of strength increase between M-934 filler welds and 2319 filler welds varied from 7 to 18 percent at ambient temperature, and from 3 to 14 percent at cryogenic temperatures. In addition, no anomalies were evident in M-934 filler welds with regard to ductility results from ambient temperature to -320°F (-196°C), strength increases after elevated temperature exposure , metallographic structure , weld hardness, and stress corrosion susceptibility.

This evaluation shows that strengths of TIG weldments in aluminum alloy 2219-T87 are increased significantly by the use of type M-934 filler wire. However, in terms of statistical significance the test program was limited, and was inadequate to recommend implementation of the M-934 wire into hardware fabrication at this time. We plan now to make a complete investigation covering such items as weld repairability and other important design criteria; namely, those criteria which govern fracture mechanics, fatigue, biaxial stress, and crack sensitivity as normally associated with highly restrained weldments, before we can categorically recommend the use of M-934 filler wire in preference to any other. Nevertheless, in conclusion, the results to date are highly encouraging.

REFERENCES

1. Mayer, L. W.: Alcoa Aluminum Alloy 2219, Alcoa Green Letter, Revised January 1962.

2. "Aluminum Alloy, Al-96", Engineering Alloys Digest, Incorporated, October 1960.

3. Humphries, T. S.: Procedures for Externally Loading and Corrosion Testing Stress Corrosion Specimens, NASA TM X-53483, June 1966.

4. MSFC-SPEC-259A, Radiographic Inspection: Soundness Requirements for Fusion Welds in Aluminum and Magnesium Alloy Sheet and Plate Material (Space Vehicle Components), dated April 9, 1965.

5. Hardy, H. K: The Aging Characteristics of Some Ternary Aluminum-Copper-Magnesium Alloys with Copper: Magnesium Weight Ratios of 7:1 and 2.2:1, Journal of the Institute of Metals, 1954-55, Vol. 83, pp. 17-34.

TABLE I

CHEMICAL COMPOSITION OF BASE METAL AND FILLER METALS

Material	Si	Fe	Cu	Mn	Mg	Zn	Ti	V	Zr	Be	Cr	Others Each	Others Total	Al
2219*	0.20	0.30	5.8-6.8	0.20-0.40	0.02	0.10	0.02-0.10	0.05-0.15	0.10-0.25	-	-	0.05	0.15	Remainder
2319*	0.20	0.30	5.8-6.8	0.20-0.40	0.02	0.10	0.10-0.20	0.05-0.15	0.10-0.25	0.0008	-	0.05	0.15	Remainder
2014*	0.5-1.2	1.0	3.9-5.0	0.4-1.2	0.2-0.8	0.25	0.15	-	-	-	0.10	-	-	Remainder
5652*	0.40 Si & Fe		.04	.01	2.2-2-8	0.10	-	-	-	-	.15-.35	0.05	0.15	Remainder
2020**			4.5	0.5	-	-	-	-	-	-	-	1.1 Li	0.2 Cd	Remainder
M-934 **	2.05	0.15	6.7	.73	1.51	-	0.06	0.01	0.17	-	-	-	-	Remainder

* - - Maximum unless shown as a range

**- - Quantative analysis

Source of Data:

(1) Mayer, L. W.: Alcoa Aluminum Alloy 2219, Alcoa Green Letter, Revised January 1962

(2) Aluminum 14S, Al-17, Engineering Alloys Digest, Incorporated, June 1954

(3) Welding Kaiser Aluminum, First Edition, 1967

(4) Spuhler, E. H., Alcoa Alloy X-2020, September 1958

(5) Quantitative Analysis, M-934, Alcoa Letter to MSFC, dated April 24, 1967.

TABLE II

WELDING PARAMETERS FOR JOINING ALUMINUM ALLOY 2219-T87, 6.35 mm THICK PLATE
(FIRST GROUP OF PANELS)

Filler Wire	Diameter mm	Arc Amperage Amps	Arc Voltage Volts	Carriage Travel cm/Minute	Wire Feed Speed cm/Minute	Helium Gas Flow kl/hr.
2319	1.6	190	13	40.6	91.5	1.56
2014	2.4	200	13	40.6	35.6	1.56
M-934	1.6	200	12	40.6	91.5	1.56
2020	1.2	200	12	40.6	91.5	1.56
2319/5652*	1.2 each	200	12	50.6	69/23*	1.56

Notes:
1. A two percent thoria tungsten electrode (3.2 mm diameter) was used with the TIG process.
2. Flat weld position, stainless steel backing, single pass, square butt.
3. Grain direction of base metal perpendicular to weld seam.

*4. The last filler listed was a dual wire feed consisting of three parts 2319 and one part 5652.

TABLE III

LOW TEMPERATURE MECHANICAL PROPERTIES OF TIG WELDMENTS IN
ALUMINUM ALLOY 2219-T87, 6.35 mm THICK PLATE
(FIRST GROUP OF PANELS)

Test Temperature °F	2319 Filler			2014 Filler			M-934 Filler			2020 Filler			2319/5652 Filler		
	UTS MN/m^2	YS* MN/m^2	EL**	UTS MN/m^2	YS* MN/m^2	EL**	UTS MN/m^2	YS* MN/m^2	EL*	UTS MN/m^2	YS* MN/m^2	EL*	UTS MN/m^2	YS* MN/m^2	EL**
Transverse Weldment Intact Bead															
+78 (+25.6°C)	304	201	3.8	304	203	3.0	341	228	3.8	292	193	3.4	304	192	3.7
-320°F (-196°C)	398	252	3.3	423	272	4.2	427	295	2.8	391	243	3.5	421	259	4.2
-423°F (-252.8°C)	468	319	2.7	494	323	3.0	479	265	2.0	456	313	2.3	496	323	3.2
All Weld Metal															
+78 (+25.6°C	273	145	16.8	283	131	19.8	300	189	11.0	265	132	18.8	276	148	18.3

*YS at 0.2 percent offset
** Elongation percent in 5.08 cm gage length

Notes: 1. Flat weld position, stainless steel backing, single pass, square butt.
2. Grain direction of base metal perpendicular to weld seam.
3. The last filler listed: A dual wire feed consisting of three parts 2319 and one part 5652.

TABLE IV

HARDNESS SURVEY ACROSS THE WELD IN ALUMINUM ALLOY 2219-T87, 6.35 mm THICK PLATE

Distance from Center of Weld mm	2319 Filler		2014 Filler		M-934 Filler		2020 Filler		2319/5652 Filler	
	Crown Side	Root Side	Crown Side	Root Side	Crown Side	Root Side	Crown Side	Root Side	Crown Side	Root Side
25.4	102	102	102	102	102	102	102	102	102	102
22.2	102	102	102	102	102	102	102	102	102	102
19.1	102	102	102	102	102	102	102	102	102	102
17.5	102	102	101.5	102	102	102	102	102	102	102
15.9	102	102	101.5	101.3	102	102	102	102	101.8	102
14.3	101.5	102	100.8	100.5	102	102	101.8	101.8	101.5	101.5
12.7	100	100.5	98.8	98.5	101	101.3	100.3	100.8	100	100
11.1	97.5	97.5	95.5	96	99.5	100.3	98.5	99	97.8	97.5
9.54	94	95	93.5	94	96	97	96	95.5	94.8	95.5
7.95	91	92.5	90.5	91.5	93	94	92.5	93.3	93	93.3
6.35	87	89	85	87.5	88.5	91	88.5	89.5	89.3	89.8
4.8	85	85.8	82	85.5	85.5	86.3	85	85.8	85.3	86.5
3.2	72.8	85.5	78	84.8	85.5	86.3	74.5	85.5	76.3	85.5
1.6	71	73	75.8	76	83.3	84.3	70.5	72	74	75.8
Center of Weld	70	72	75	77	83	85.5	69.5	71	72	75

All are average values of Rockwell "F" from two tests

- - - - Resolidified weld metal
_______ Heat Affected zone

Notes:
1. TIG process, flat position, stainless steel backing, single pass, square butt.
2. Grain direction of base metal perpendicular to weld seam.
3. The last filler listed: A dual wire feed consisting of three parts 2319 and one part 5652.

TABLE V

WELDING PARAMETERS FOR JOINING ALUMINUM ALLOY 2219-T87, 6.35 mm THICK PLATE
(SECOND GROUP OF PANELS)

Filler Wire	Diameter mm	Arc Amperage Amps	Arc Voltage Volts	Carriage Travel cm/minute	Wire Feed Speed cm/minute	Helium Gas Flow kl/hr.
2319	1.6	150	10	15.25	45.7	1.68
2319	1.6	180	11	30.5	72.5	1.68
2014	2.4	155	10.5	15.25	55.9	1.68
2014	2.4	185	12	30.5	76.2	1.68
M-934	1.6	150	10	15.26	45.7	1.68
M-934	1.6	180	11	30.5	72.5	1.68

Notes:

1. A two percent thoria tungsten electrode (3.18 mm diameter) was used with the TIG process.
2. Horizontal weld position, no backing, single pass, 3.18 mm square butt.
3. Grain direction of base metal parallel to weld seam.

TABLE VI

LOW TEMPERATURE MECHANICAL PROPERTIES OF TIG WELDMENTS IN ALUMINUM ALLOY 2219-T87 6.35 mm THICK PLATE (SECOND GROUP OF PANELS)

Test Temperature °F	2319 Filler UTS MN/m^2	2319 Filler YS* MN/m^2	2319 Filler El**	2014 Filler UTS MN/m^2	2014 Filler YS MN/m^2	2014 Filler El**	M-934 Filler UTS MN/m^2	M-934 Filler YS* MN/m^2	M-934 Filler El**
Weldments Using 15.25 cm/minute Carriage Speed									
Transverse Weldment, Intact Bead									
+78 (+25.6°C)	294	177	3.3	302	197	3.0	331	197	4.1
-320 (-196°C)	385	243	3.2	388	262	3.0	401	278	2.8
-423 (-252.8°C)	419	305	2.0	446	317	1.8	457	338	2.2
After 350°F (177°C) for 100 Hours, Transverse Weldment Intact Bead									
+78 (25.6°C)	314	239	2.0	312	231	3.0	328	243	2.2
-320 (-196°C)	390	305	2.0	390	303	1.5	426	312	2.5
All Weld Metal, No Post Weld Treatment									
+78 (+25.6°C)	269	117	18.0	290	155	17.0	318	171	14.2
-230 (-196°C)	370	154	17.8	403	219	13.5	428	251	13.5
-423 (-252.8°C)	512	---	11.8	470	269	9.0	518	336	6.5
Weldments Using 30.5 cm/minute Carriage Speed, Transverse Weldment, Intact Bead									
+78 (+25.6°C)	279	183	2.8	302	206	2.8	325	214	3.2
-320 (-196°C)	389	253	3.0	380	276	2.3	412	296	2.8
-432 (-252.8)	410	312	1.7	431	343	1.7	460	361	1.7
After 350°F (177°C) for 100 Hours, Transverse Weldment, Intact Bead									
+78 (+25.6°C)	323	252	2.0	310	251	1.3	341	267	2.3
-320 (-196°C)	387	321	1.0	377	325	1.5	434	345	1.5
All Weld Metal, No Post Weld Treatment									
+78 (+25.6°C)	270	120	16.0	295	147	15.0	319	173	14.5
-320 (-196°C)	376	157	23.8	392	211	12.5	401	236	9.5
-423 (-252.8°C)	474	---	10.8	496	283	9.3	502	314	6.5

*YS at 0.2 Percent Offset
**Elongation Percent in 5.08 cm Gage Length

Notes: 1. Horizontal weld position, no backing, single pass, square butt.
2. Grain Direction of base metal parallel to weld seam.

TABLE VII

WELDING PARAMETERS FOR JOINING ALUMINUM ALLOY 2219-T87, 3.18 mm THICK SHEET

Filler Wire	Diameter Inches	Arc Amperage Amps	Arc Voltage Volts	Carriage Travel cm/Minute	Wire Feed Speed cm/Minute	Helium Gas Flow kl/ln
2319	1.6	110	10.5	43.2	109	1.68
2014	2.4	110	10.5	35.6	66	1.68
M-934	1.6	110	10.5	43.2	109	1.68

Notes:
1. A two percent thoria tungsten electrode (3.18 mm diameter) was used with the TIG Process.
2. Flat, weld position, no backing, single pass, square butt.
3. Grain direction of base metal perpendicular to weld seam.

TABLE VIII

LOW TEMPERATURE MECHANICAL PROPERTIES OF TIG WELDMENTS IN ALUMINUM ALLOY 2219-T87, 3.18 mm THICK SHEET

Test Temperature °F	2319 Filler UTS MN/m^2	2319 Filler YS* MN/m^2	2319 Filler El**	2014 Filler UTS MN/m^2	2014 Filler YS* MN/m^2	2014 Filler EL**	M-934 Filler UTS MN/M^2	M-934 Filler YS* MN/m^2	M-934 Filler EL**
As-Welded									
+78 (+25.6°C)	318	199	3.6	324	208	3.4	341	216	3.6
-320 (-196°C)	436	270	3.7	432	271	4.4	447	298	3.8
-423 (252.8°C)	505	---	2.4	520	355	2.5	519	370	2.8
After 300°F (149°C) for 100 Hours									
+78 (+25.6°C)	372	281	2.9	368	277	3.1	383	296	4.8
-320 (-196°C)	462	352	2.7	469	354	2.3	497	367	3.8
After 350°F (177°C) for 100 Hours									
+78 (+25.6°C)	356	265	5.3	350	259	4.8	352	267	3.9
-320 (-196°C)	474	336	4.2	465	328	3.8	470	335	3.9

*YS at 0.2 Percent Offset
**Elongation Percent in 5.08 cm Gage Length

Notes: 1. Transverse weld tensile specimen, intact bead.

2. Flat weld position, no backing, single pass, square butt.

3. Grain direction of base metal perpendicular to weld seam.

TABLE IV

RESULTS OF STRESS CORROSION TESTS OF TIG WELDMENTS
IN ALUMINUM ALLOY 2219-T87 3.18 mm THICK SHEET

			After Stress Corrosion Specimens Unstressed			After Stress Corrosion Specimens Stressed 75 of YS	
Filler Wire Alloy	Stress Corrosion Exposure Time, Days	UTS MN/m^2	YS, MN/m^2 0.2% offset	El., %cm 5.08 cm	UTS MN/m^2	YS MN/m^2 0.2% offset	El, %cm 5.08 cm
2319	90	248	172	2.5	188	152	2.0
2319	90	251	169	2.5	252	170	3.0
2319	90	263	177	2.5	252	179	2.0
2014	90	290	192	3.0	259	184	2.5
2014	90	263	179	3.0	240	178	2.0
2014	90	250	172	2.0	257	177	2.5
M-934	90	274	193	3.0	269	192	2.0
M-934	90	292	197	2.5	236	180	2.0
M-934	90	285	196	3.0	246	184	2.0

Notes: 1. S. C. Medium: Alternate immersion in a 3 1/2% salt solution

2. No failures occurred during the 90 day exposure period

3. Transverse weldment, intact bead specimen

4. Each value shown represents one test coupon

TABLE X

RESULTS FROM TIG WELDMENTS IN ALUMINUM ALLOY 2219-T87
3.18 mm THICK SHEET) SUBJECTED TO ELEVATED TEMPERATURE
EXPOSURES PRIOR TO STRESS CORROSION TESTING

Filler Wire Alloy	Prior Elevated Temperature °F (°C)/ Time (Hrs) Exposures	Stress Corrosion Exposure Time Days	After Stress Corrosion Specimens Unstressed: UTS MN/m^2	YS, MN/m^2 0.2% Offset	El., % In. 5.08 cm	After Stress Corrosion Specimens Stressed to 75 ° of YS: UTS MN/m^2	YS, MN/m^2 0.2% Offset	El. % In. 5.08 cm
2319	350 (177)/40	90	302	241	2.0	309	253	2.0
2319	350 (177)/40	90	312	247	2.0	288	245	2.0
2319	350 (177)/40	90	305	247	2.0	310	250	2.0
2014	350 (177)/40	90	274	228	1.5	275	245	1.5
2014	350 (177)/40	90	312	244	3.0	284	242	2.0
2014	350 (177)/40	90	318	245	2.5	307	240	2.0
M-934	350 (177)/40	90	321	256	2.5	316	256	2.0
M-934	350 (177)/40	90	327	256	2.5	299	258	1.5
M-934	350 (177)/40	90	263	254	0.5	310	263	2.0
2319	350 (177)/80	90	311	243	2.5	318	246	2.5
2319	350 (177)/80	90	327	252	3.5	298	240	2.5
2319	350 (177)/80	90	321	248	2.5	305	245	2.5
2014	350 (177)/80	90	323	246	3.5	315	245	2.5
2014	350 (177)/80	90	320	247	3.5	302	244	1.5
2014	350 (177)/80	90	313	239	3.0	308	243	2.5
M-934	350 (177)/80	90	320	248	3.5	264	250	1.0
M-934	350 (177)/80	90	314	254	2.0	310	248	2.5
M-934	350 (177)/80	90	316	254	2.5	290	253	1.5

Notes:
1. S.C. Medium: Alternate immersion in a 3 1/2% salt solution.
2. No failures occurred during the 90 day exposure period.
3. Transverse weldment, intact bead specimen.
4. Each value shown represents one test coupon

TABLE XI

WELDING PARAMETERS FOR JOINING ALUMINUM ALLOY 2219-T87, 12.7 mm THICK PLATE

Filler Wire	Diameter mm	Arc Amperage Amps	Arc Voltage Volts	Carriage Travel cm/minute	Wire Feed Speed cm/minute	Helium Gas Flow kl/hr
2319	1.6	270	13	30.5	45.7	1.68
2014	2.4	280	13	30.5	22.8	1.68
M-934	1.6	260	12.5	30.5	40.6	1.68

Notes:

1. A two percent thoria tungsten electrode (5/32" diameter) was used with the TIG process.
2. Horizontal weld position, no backing, two passes (one each side), square butt
3. Grain direction of base metal perpendicular to weld seam

TABLE XII

MECHANICAL PROPERTIES OF TIG WELDMENTS IN ALUMINUM ALLOY 2219-T87, 12.7 mm THICK PLATE

	UTS MN/m^2	YS, 0.2% Offset MN/m^2	Elongation % in 5.08 cm
2319 Filler			
First Panel	300	209	3.5
Second Panel	286	207	3.0
Third Panel	296	211	4.1
Average of Three	294	209	3.5
2014 Filler			
First Panel	320	214	3.5
Second Panel	314	211	3.5
Third Panel	311	214	3.3
Average of Three	315	213	3.4
M-934 Filler			
First Panel	315	230	3.4
Second Panel	341	230	3.7
Third Panel	342	232	3.4
Average of Three	333	231	3.5

Notes:
1. Transverse weld tensile specimen, intact bead
2. Five tensile specimens removed from each panel
3. Horizontal weld position, no backing, two passes (one from each side) square butt.
4. Grain direction of base metal perpendicular to weld seam.

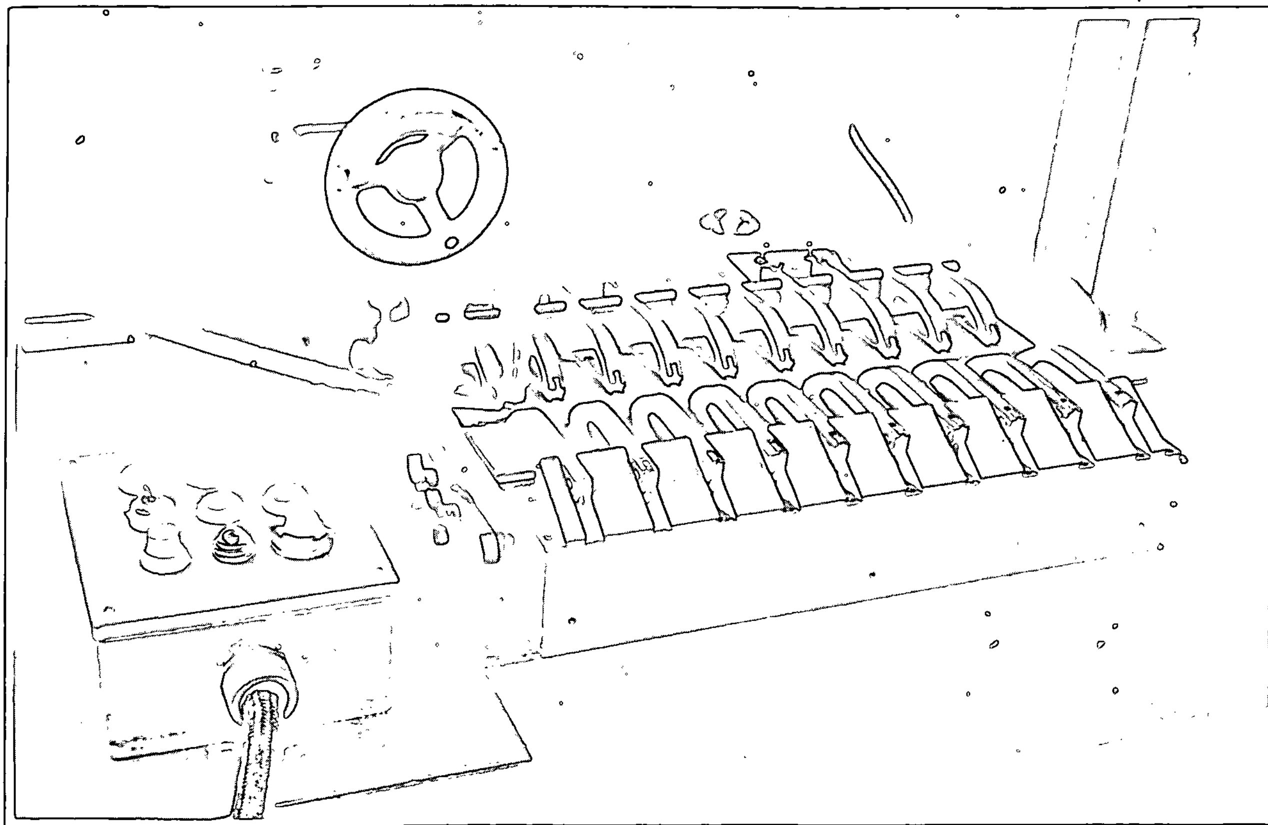


FIGURE 1 - FLAT WELD POSITION SETUP

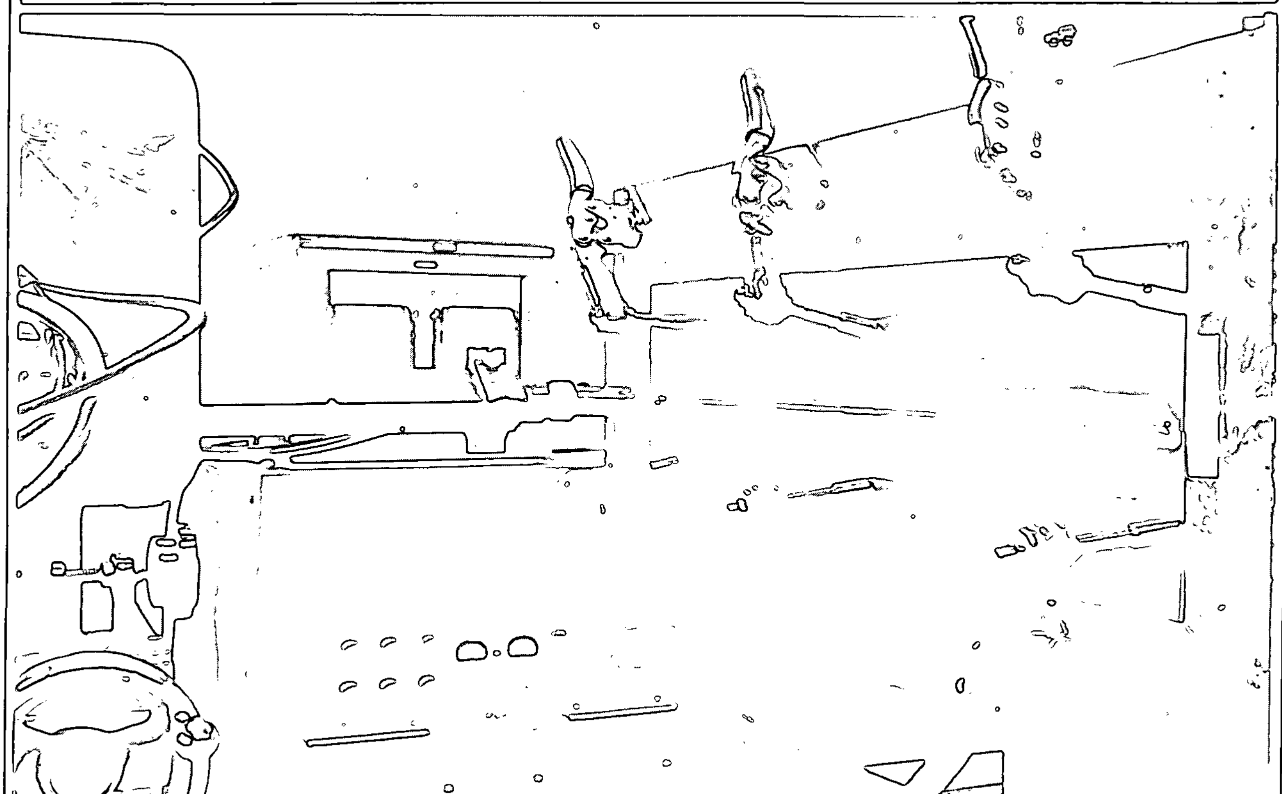


FIGURE 2 - HORIZONTAL WELD POSITION SETUP

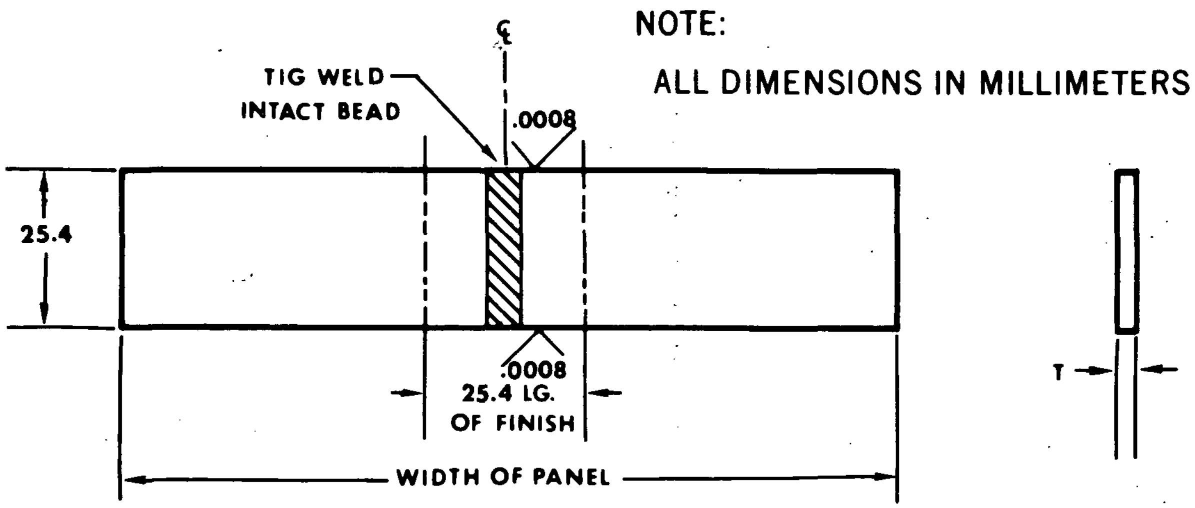


FIGURE 3 - TRANSVERSE WELD TENSILE SPECIMEN FOR AMBIENT TEMPERATURES

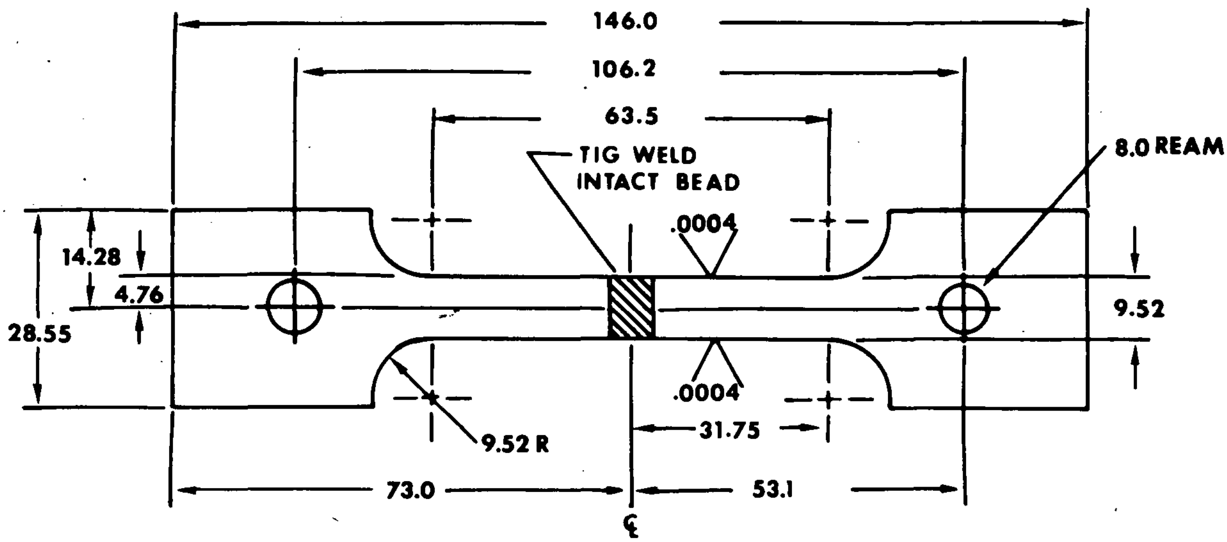


FIGURE 4 - TRANSVERSE WELD TENSILE SPECIMEN FOR CRYOGENIC TEMPERATURES

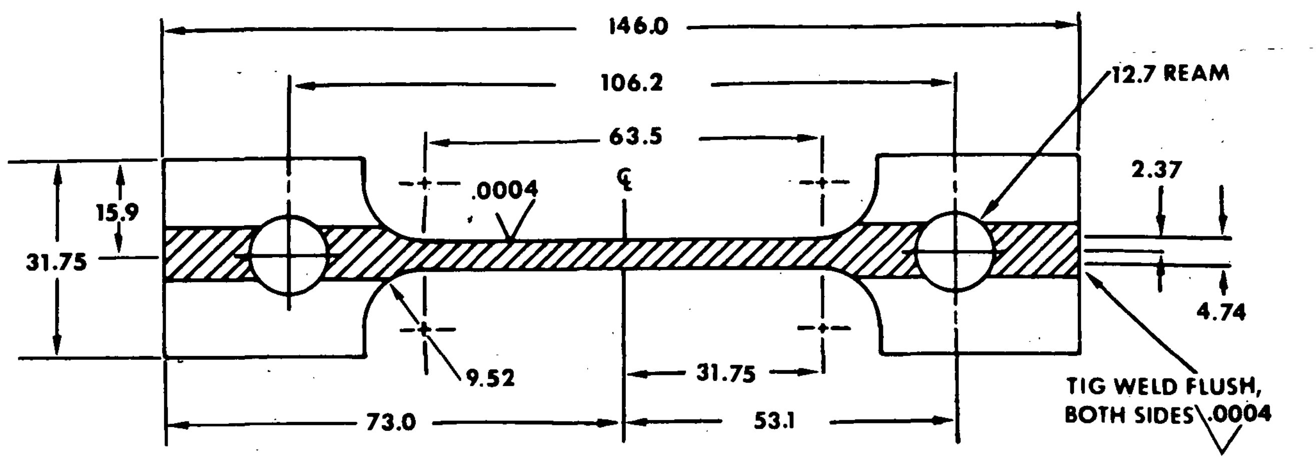


FIGURE 5 - ALL WELD METAL TENSILE SPECIMEN CONFIGURATION

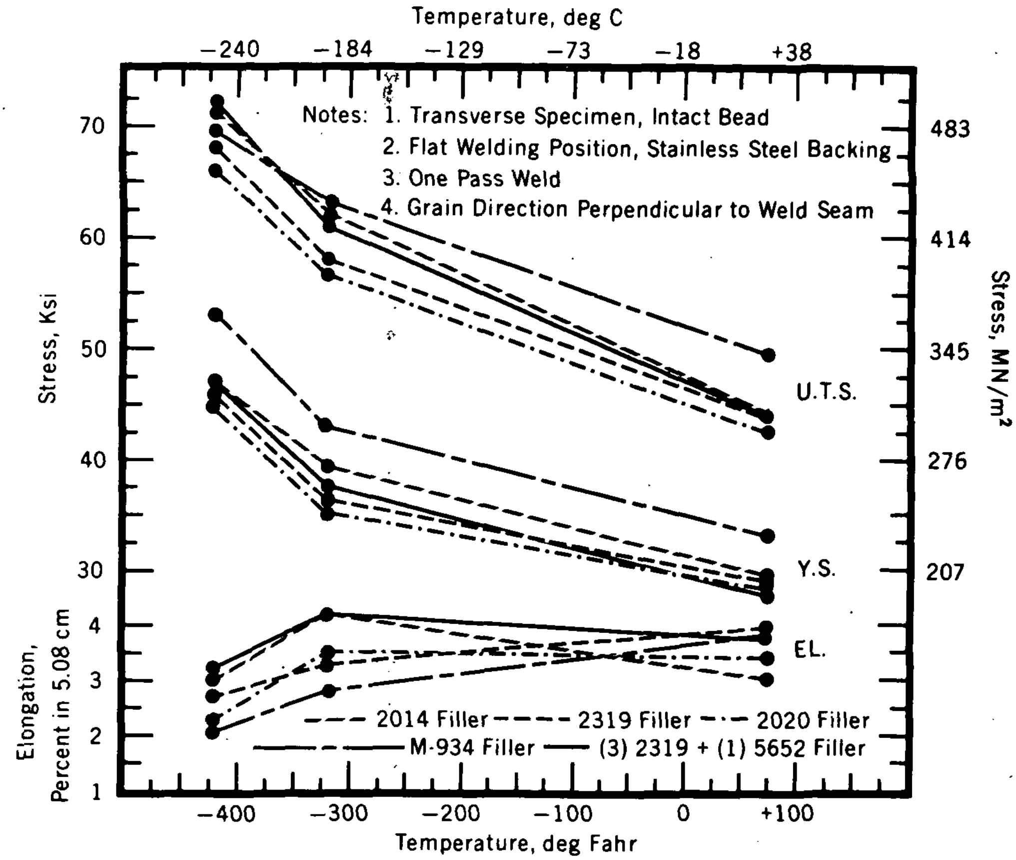


FIGURE 6 - LOW TEMPERATURE MECHANICAL PROPERTIES OF TIG WELDMENTS IN ALLOY 2219-T87 (6.35 mm THICK PLATE)

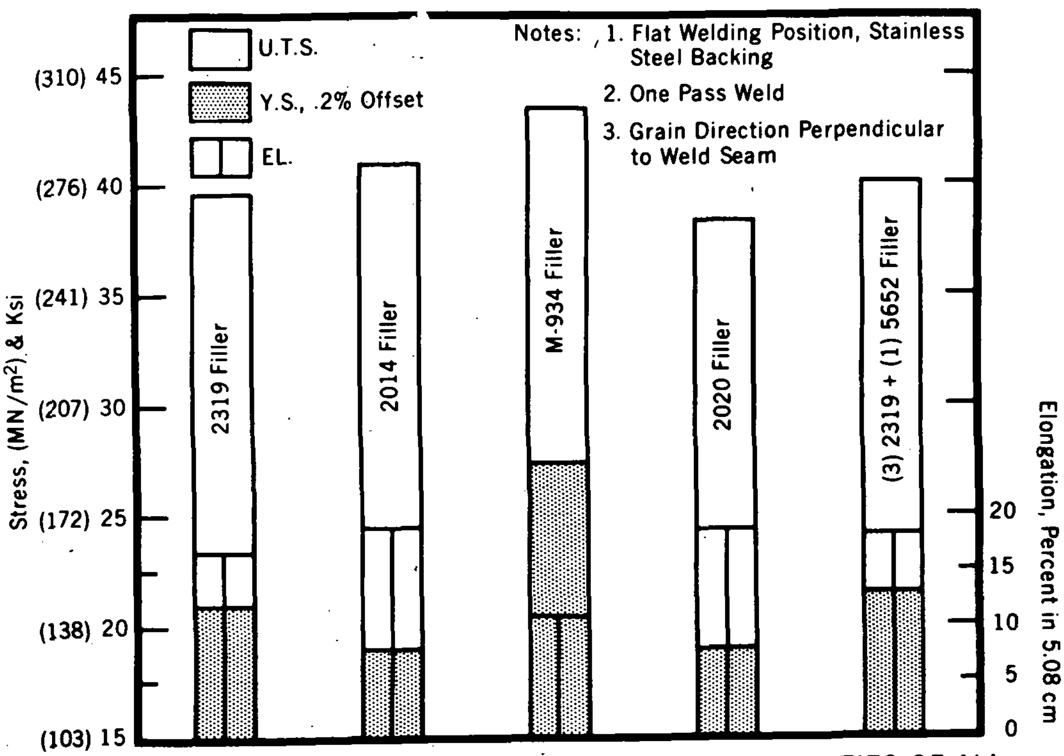


FIGURE 7 - ROOM TEMPERATURE MECHANICAL PROPERTIES OF ALL WELD METAL FROM TIG WELDMENTS IN ALLOY 2219-T87 (6.35 mm THICK PLATE)

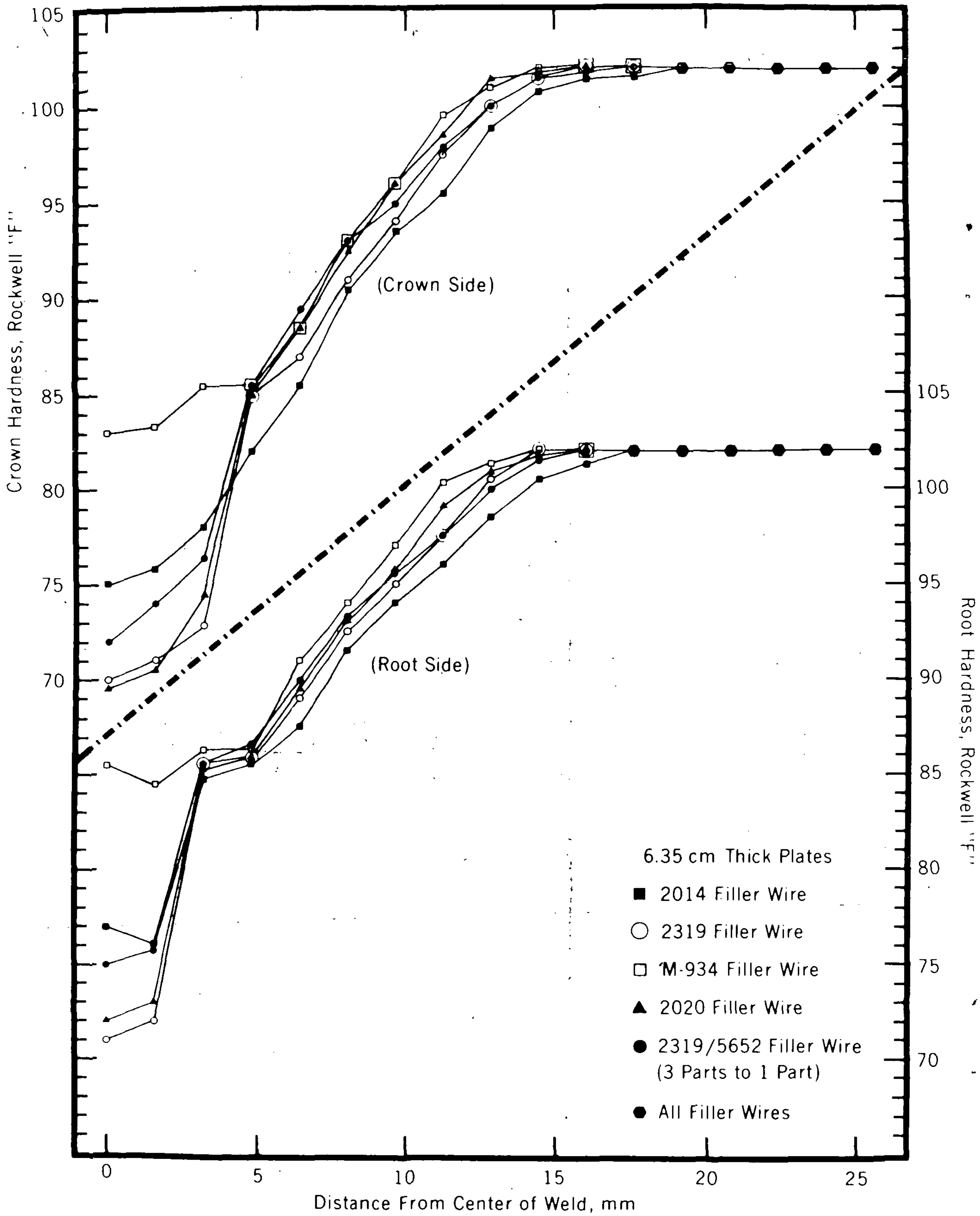
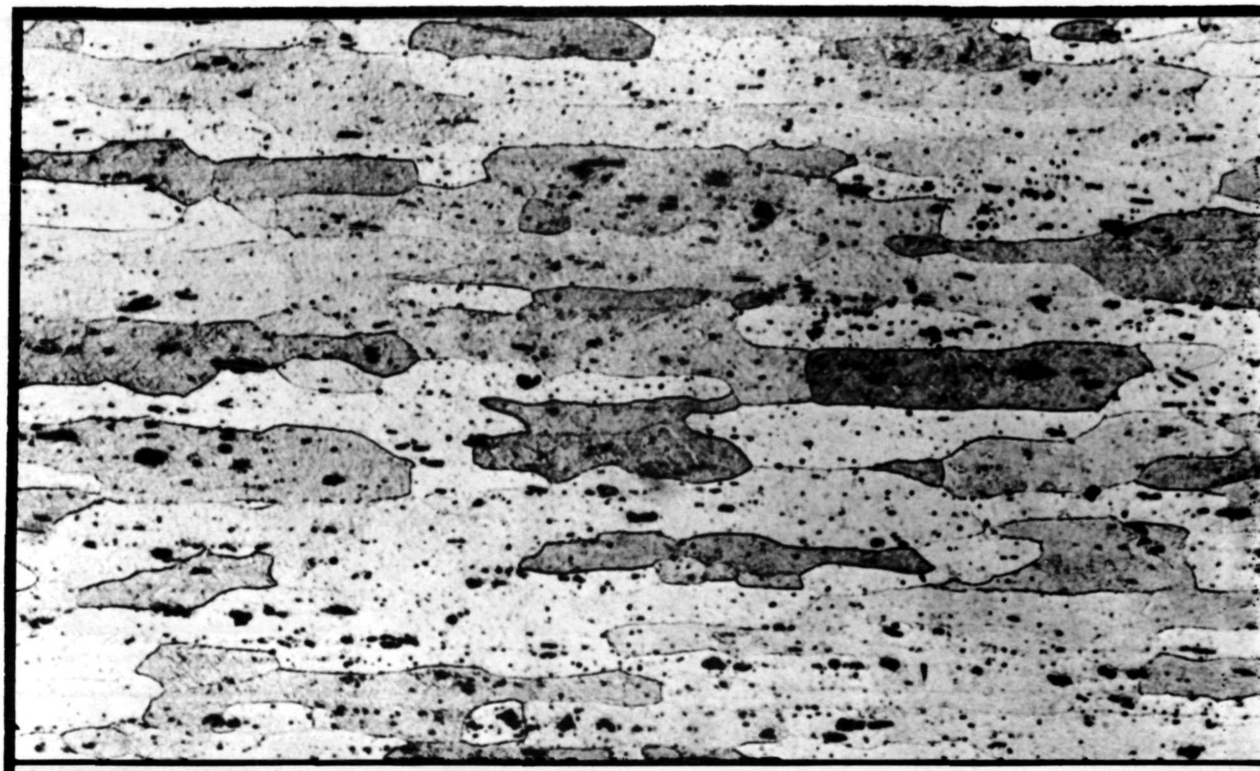
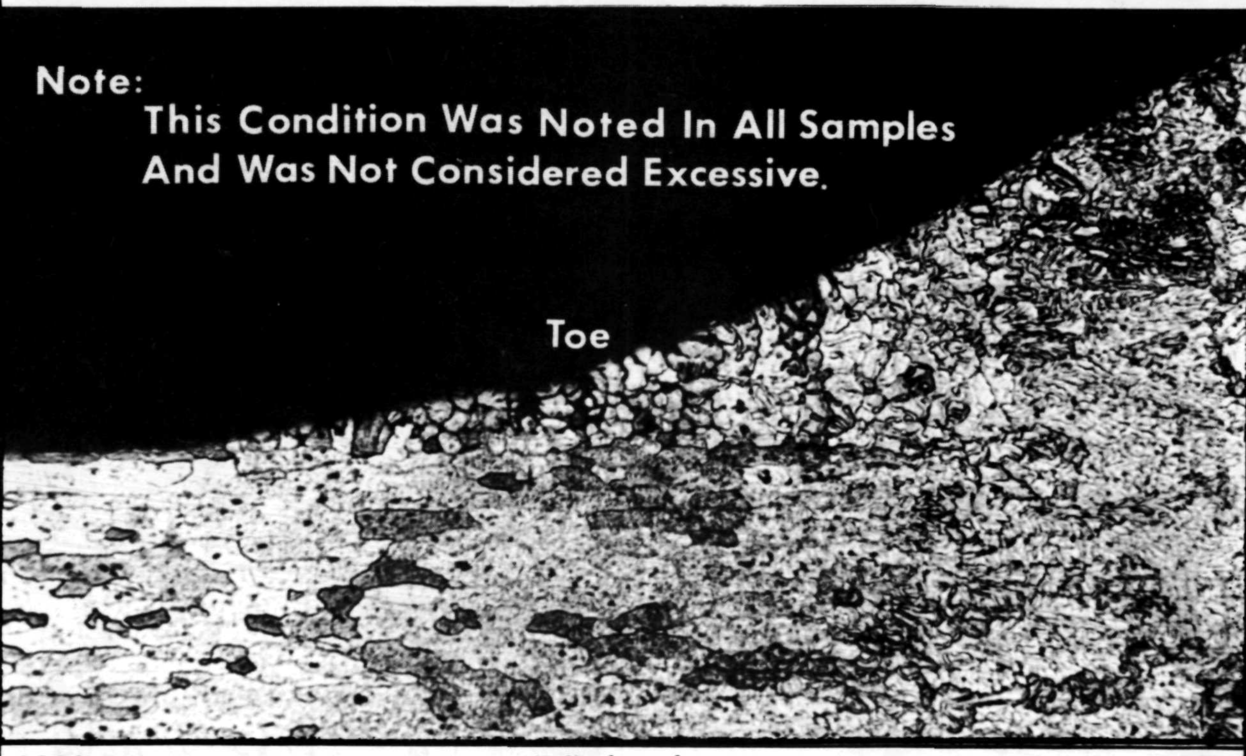


FIGURE 8 - HARDNESS SURVEYS ACROSS TIG WELDMENTS OF ALUMINUM ALLOY 2219-T87



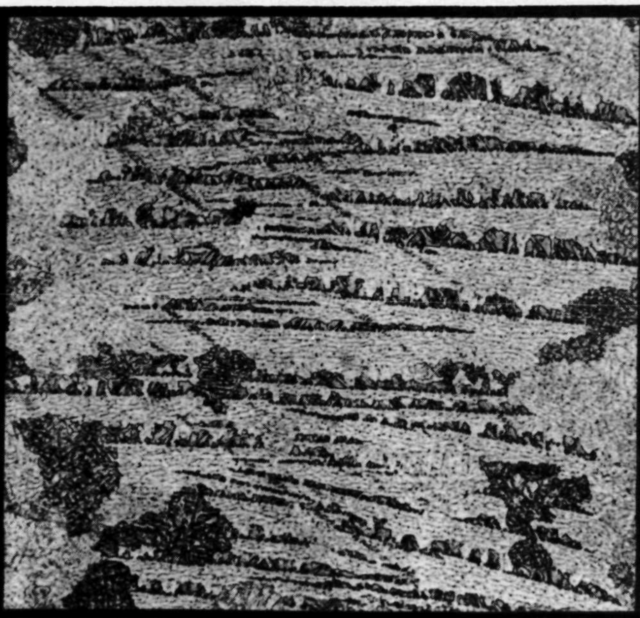
Parent Metal | Keller's Etch | Mag. 300X

FIGURE 9 - TYPICAL STRUCTURE OF A 6.35 mm THICK 2219-T87 PLATE



2020 Filler | Keller's Etch | Mag. 150X

FIGURE 10 - PRECIPITATE AT TOE OF 6.35 mm THICK 2219-T87 WELD



(A) 2020 Filler Mag. 100X

(B) 2319/5652 Filler (3 to 1) Mag. 100X

FIGURE 11 - TWINNING IN 6.35 mm THICK 2219-T87 WELD

Keller's Etch

2020 Filler Mag. 100X

FIGURE 12 - MICRO-POROSITY IN 6.35 mm THICK 2219-T87 WELD

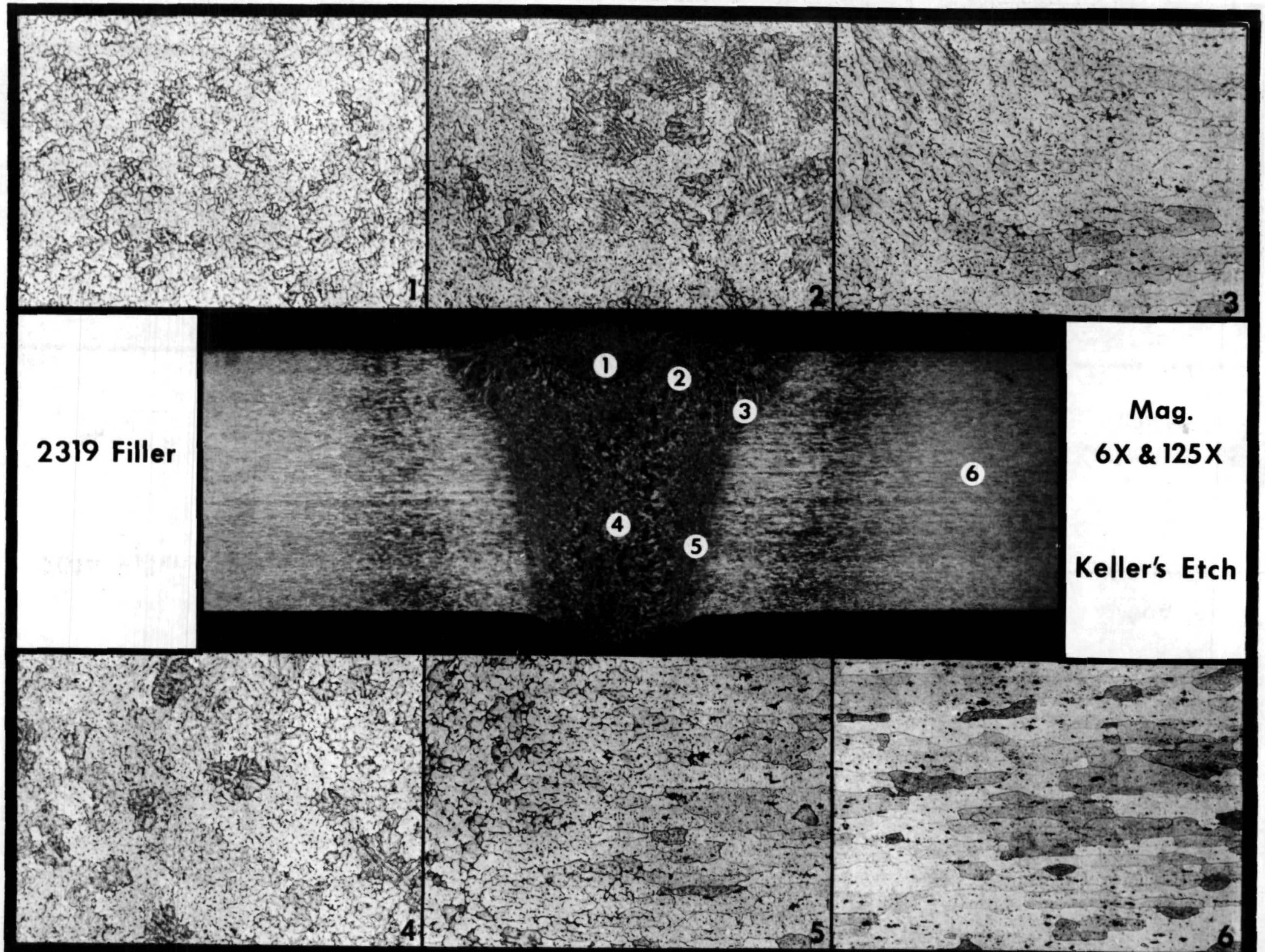


FIGURE 13 - CROSS-SECTION OF A WELDMENT IN 6.35 mm THICK 2219-T87 PLATE

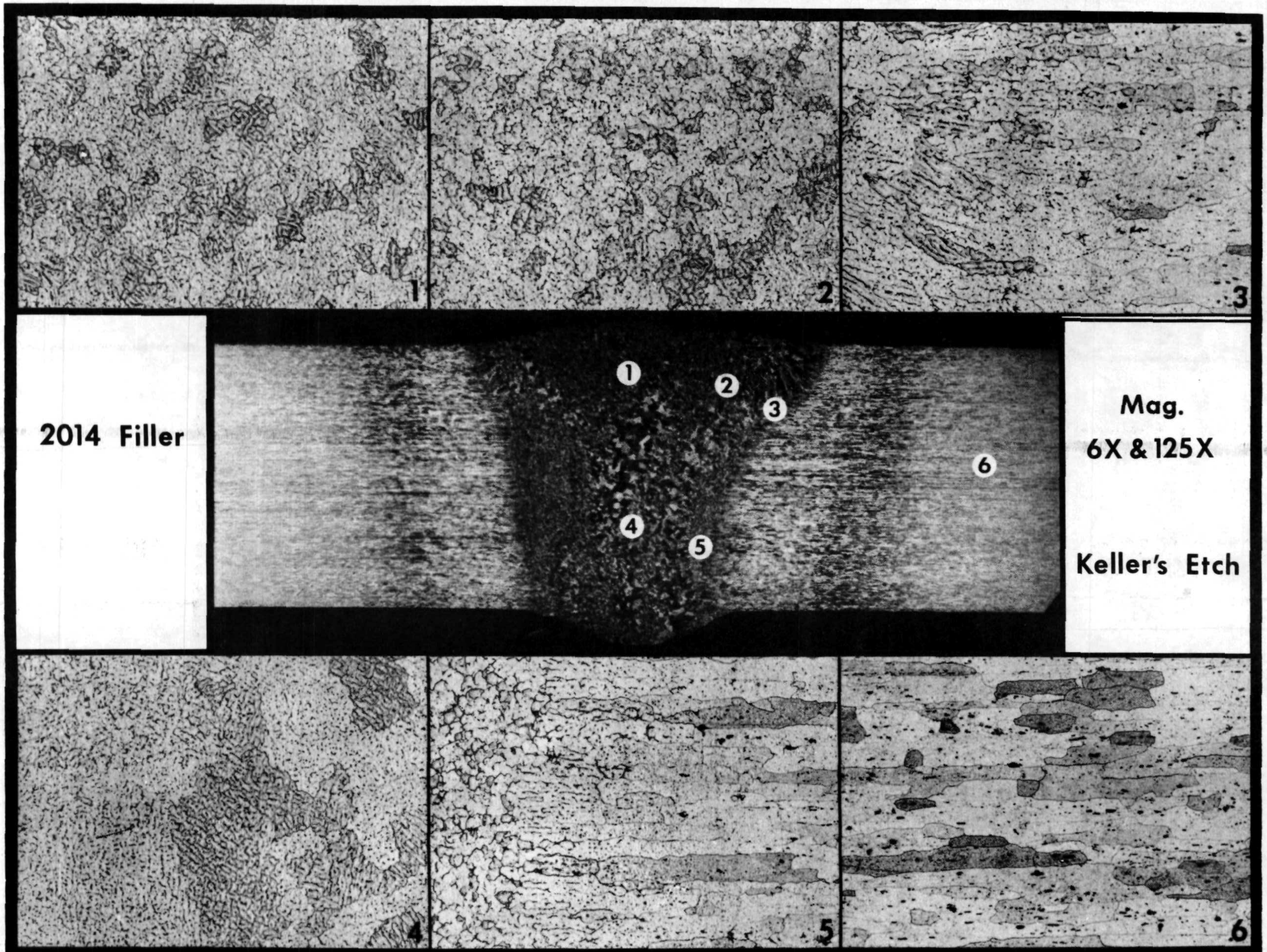


FIGURE 14 - CROSS-SECTION OF A WELDMENT IN 6.35 mm THICK 2219-T87 PLATE

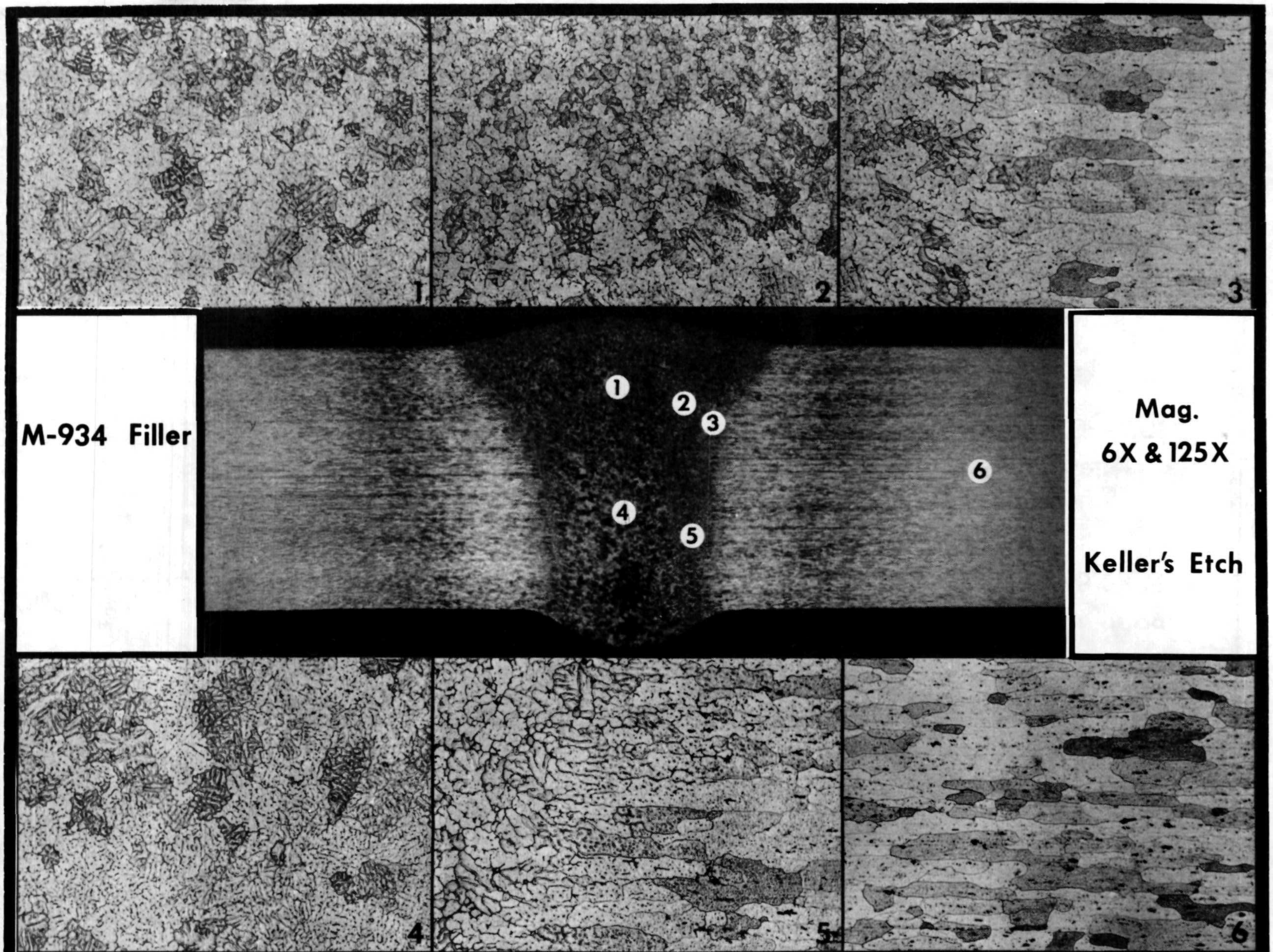


FIGURE 15 - CROSS-SECTION OF A WELDMENT IN 6.35 mm THICK 2219-T87 PLATE

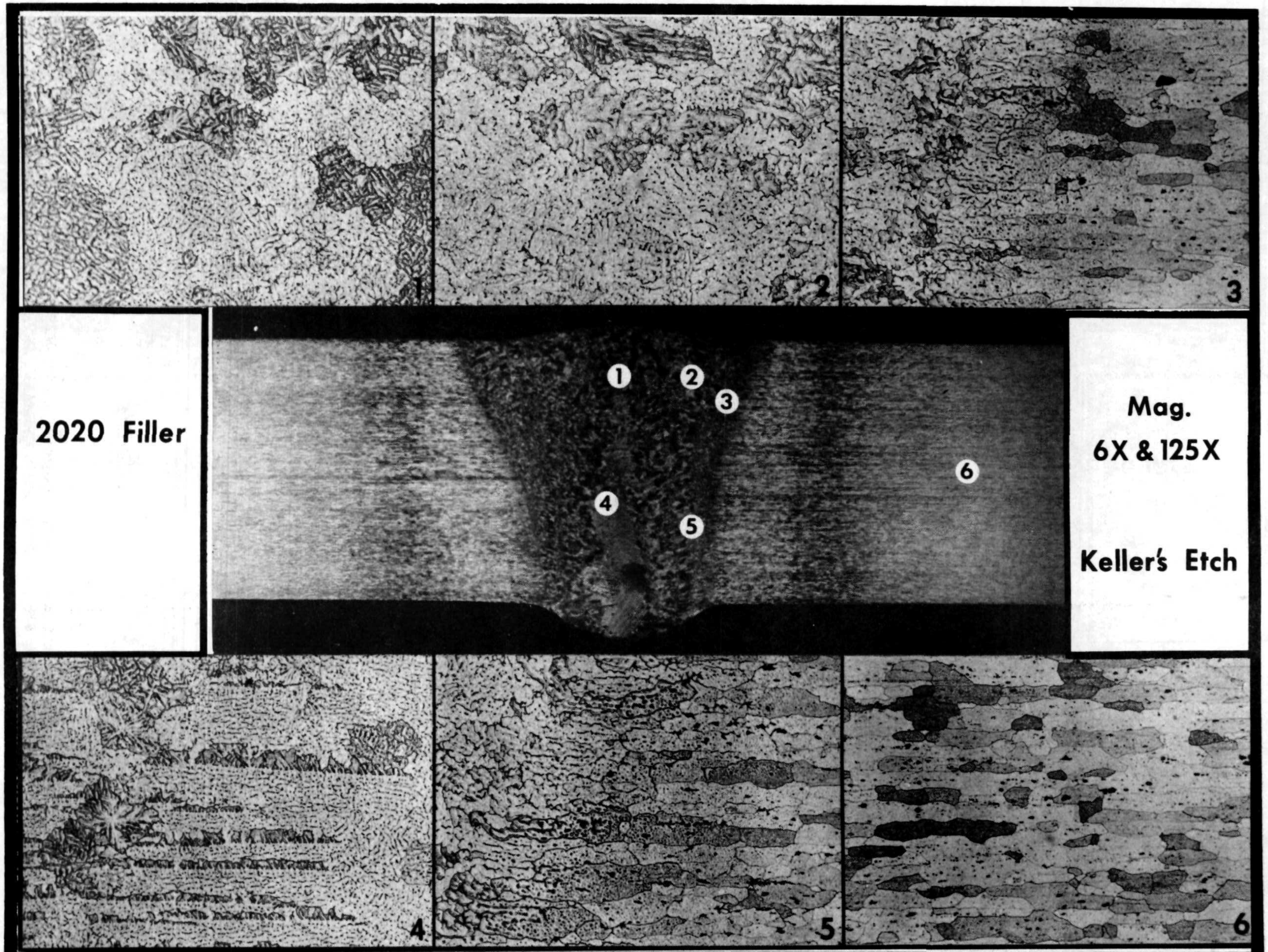


FIGURE 16 - CROSS-SECTION OF A WELDMENT IN 6.35 mm THICK 2219-T87 PLATE

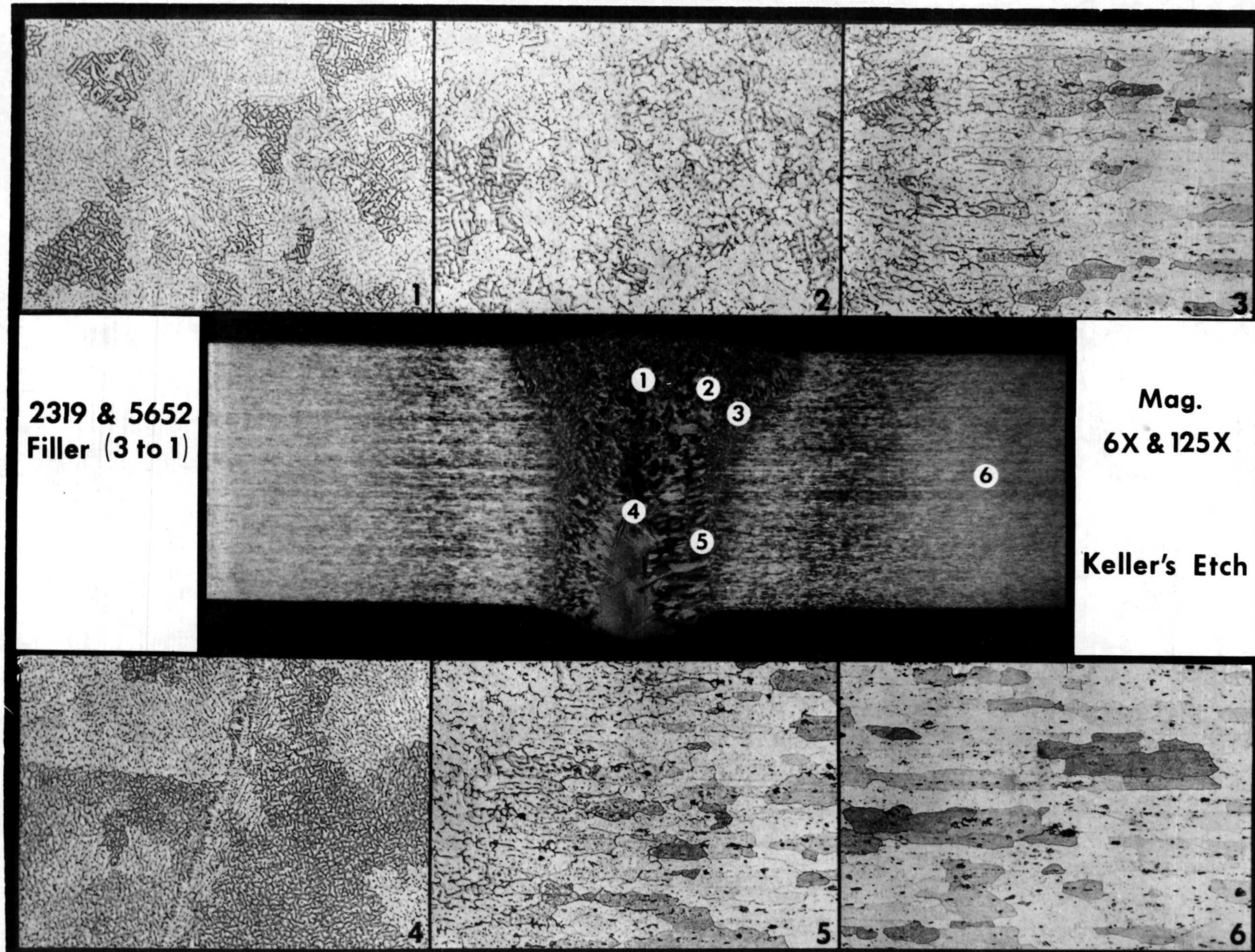


FIGURE 17 - CROSS-SECTION OF A WELDMENT IN 6.35 mm THICK 2219-T87 PLATE

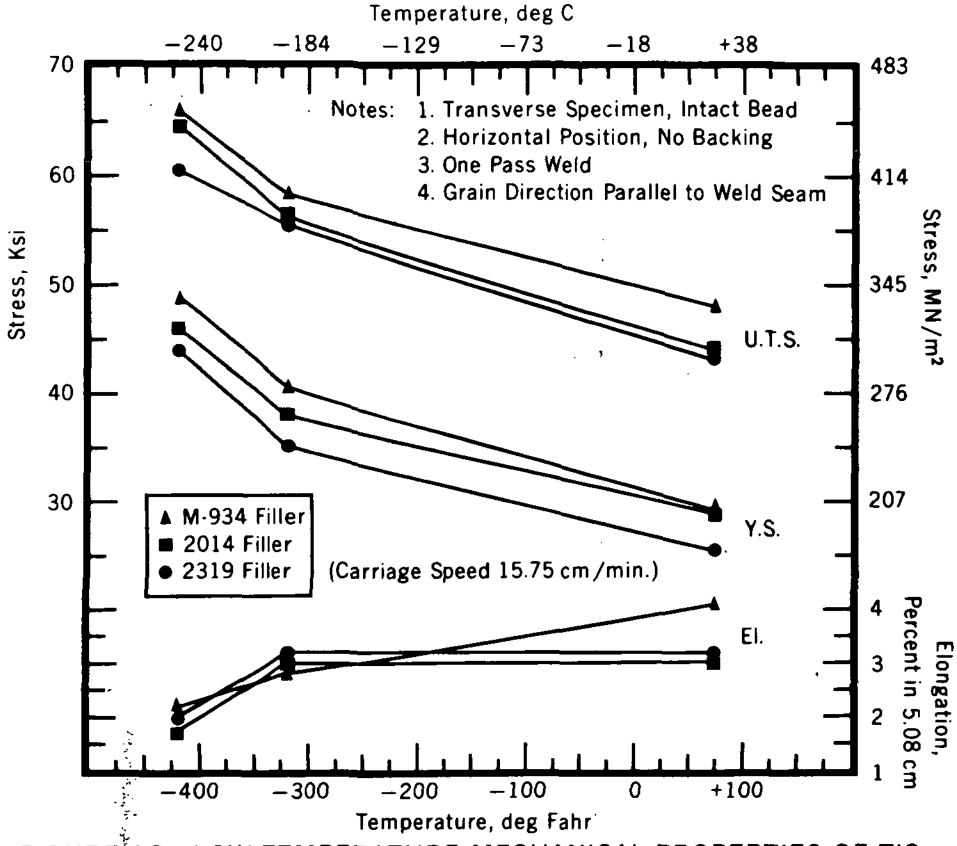


FIGURE 18 - LOW TEMPERATURE MECHANICAL PROPERTIES OF TIG WELDMENTS IN ALLOY 2219-T87, 6.35 mm THICK PLATE

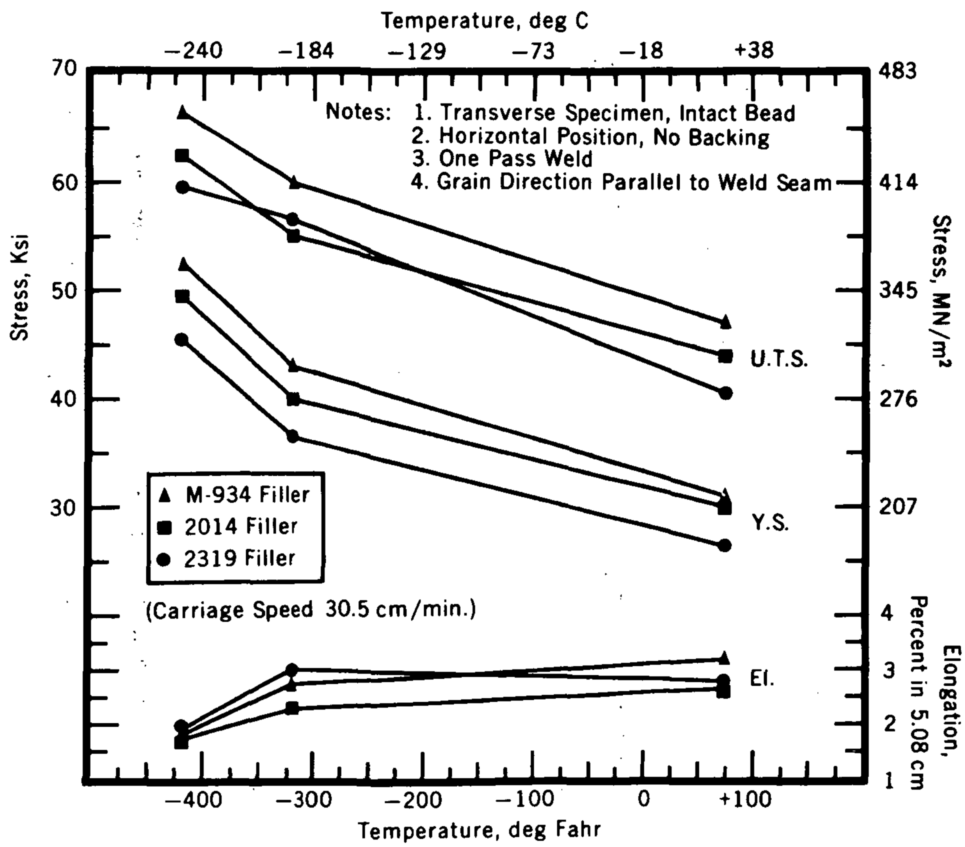


FIGURE 19 - LOW TEMPERATURE MECHANICAL PROPERTIES OF TIG WELDMENTS IN ALLOY 2219-T87, 6.35 mm THICK PLATE

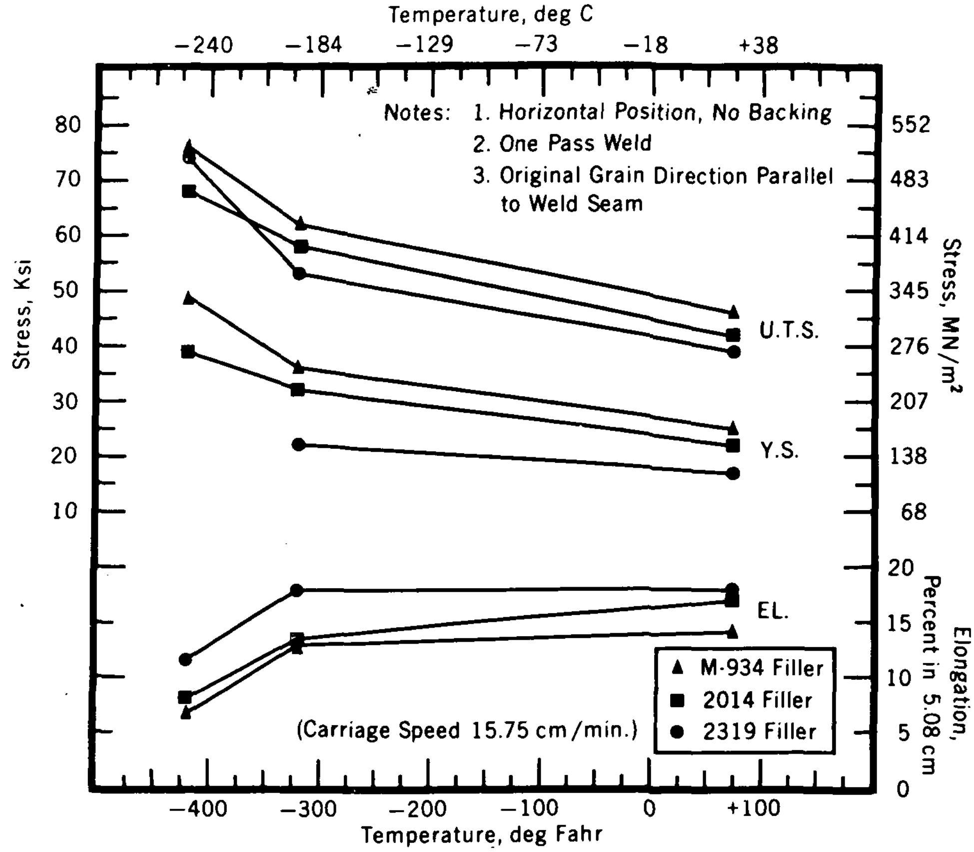


FIGURE 20 - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALL WELD METAL FROM TIG WELDMENTS IN ALLOY 2219-T87, 6.35 mm THICK PLATE

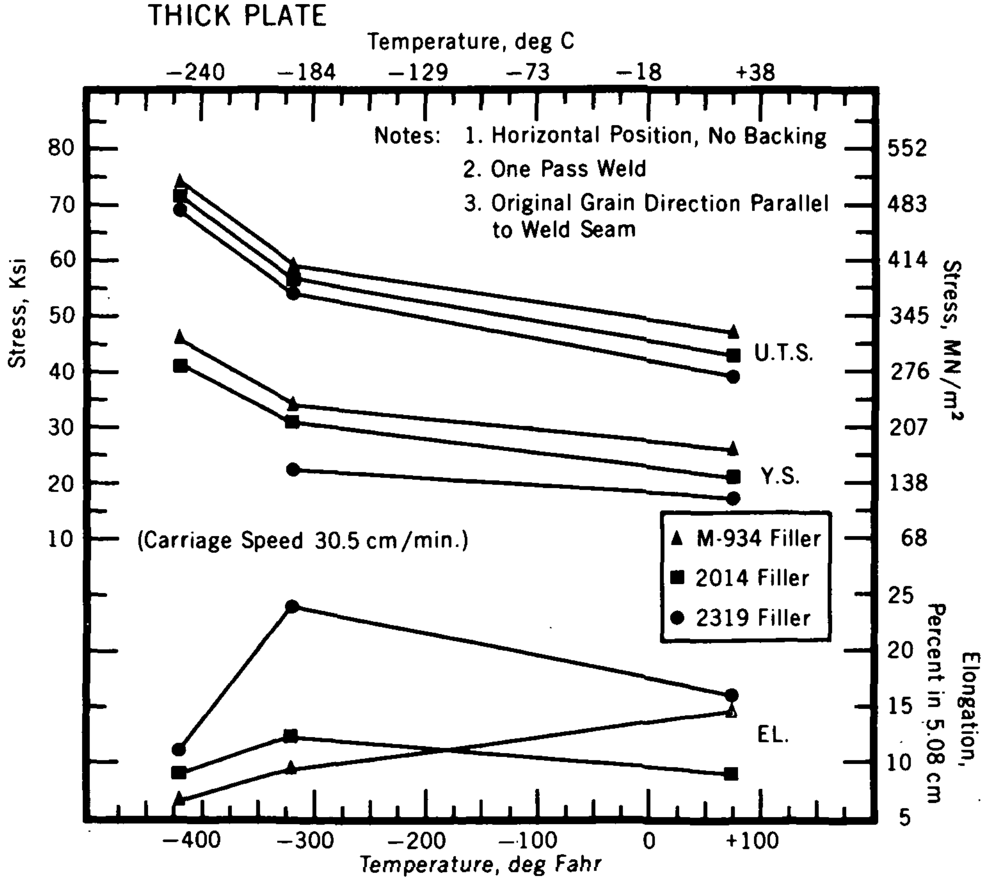


FIGURE 21 - LOW TEMPERATURE MECHANICAL PROPERTIES OF ALL WELD METAL FROM TIG WELDMENTS IN ALLOY 2219-T87, 6.35 mm THICK PLATE

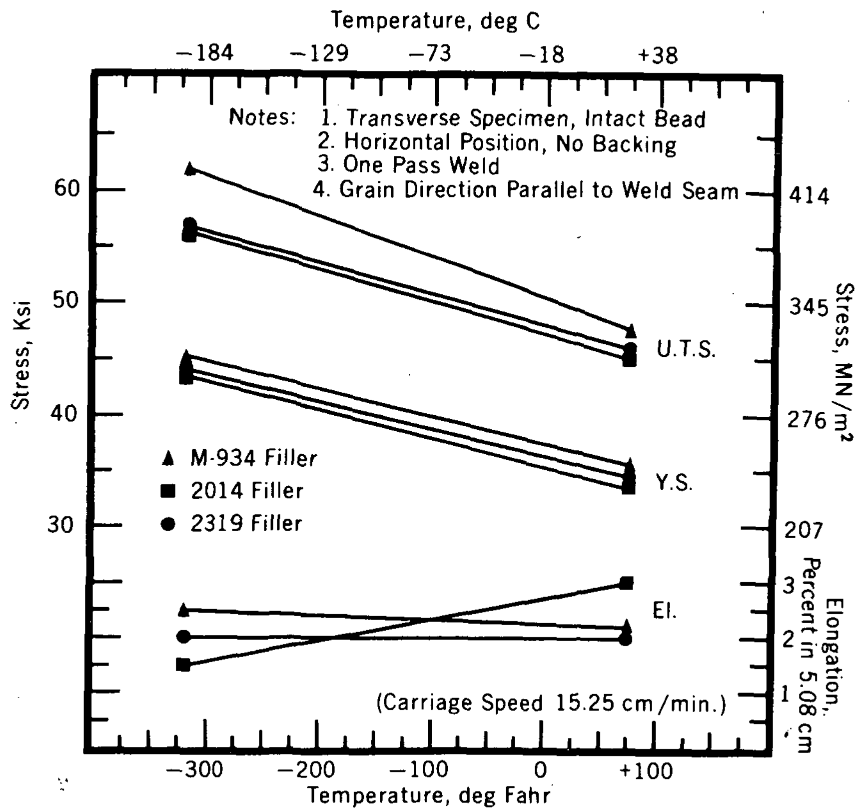


FIGURE 22 - LOW TEMPERATURE MECHANICAL PROPERTIES OF TIG WELDMENTS IN ALLOY 2219-T87, 6.35 mm THICK PLATE, AFTER THERMAL EXPOSURE OF 350°F (177°C) FOR 100 HOURS

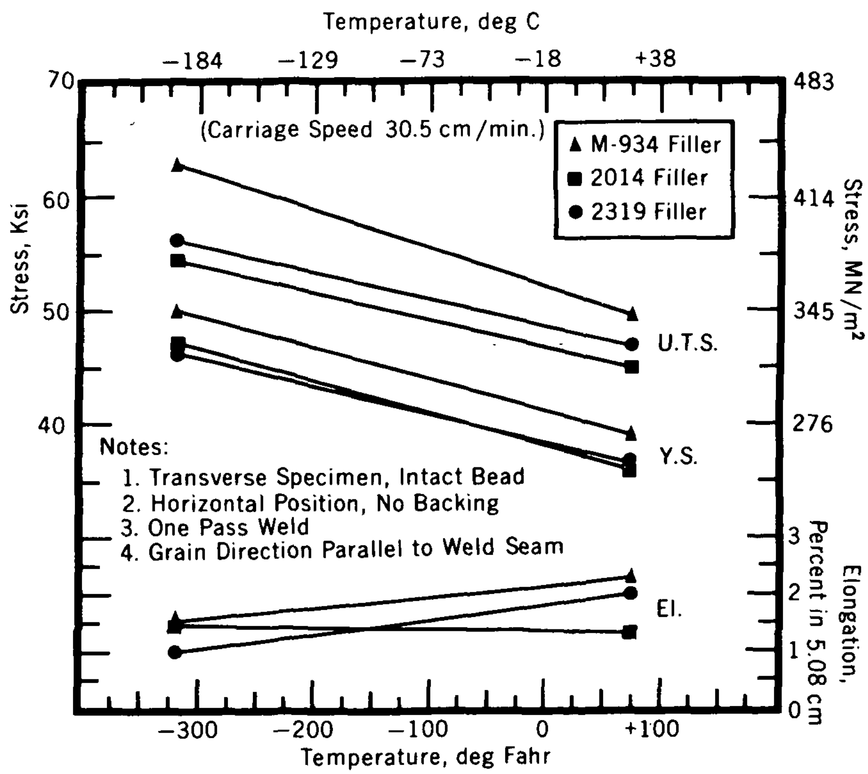


FIGURE 23 - LOW TEMPERATURE MECHANICAL PROPERTIES OF TIG WELDMENTS IN ALLOY 2219-T87, 6.35 mm THICK PLATE, AFTER THERMAL EXPOSURE OF 350°F (177°C) FOR 100 HOURS

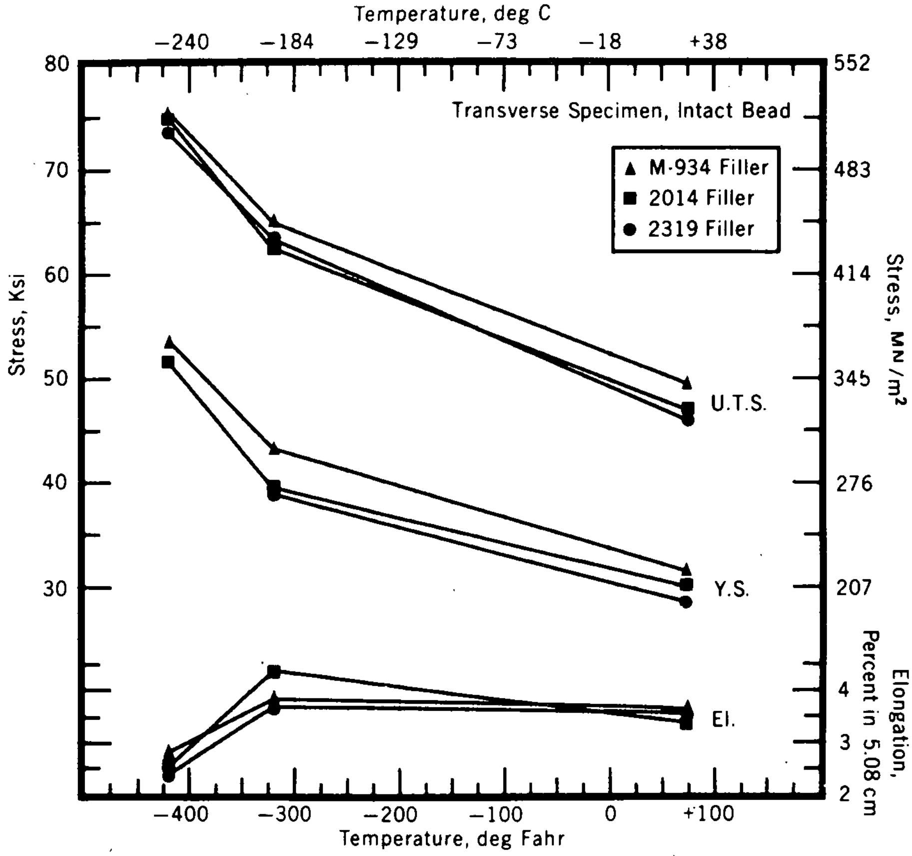


FIGURE 24 - LOW TEMPERATURE MECHANICAL PROPERTIES OF TIG WELDMENTS IN ALLOY 2219-T87, 3.18 mm THICK SHEET

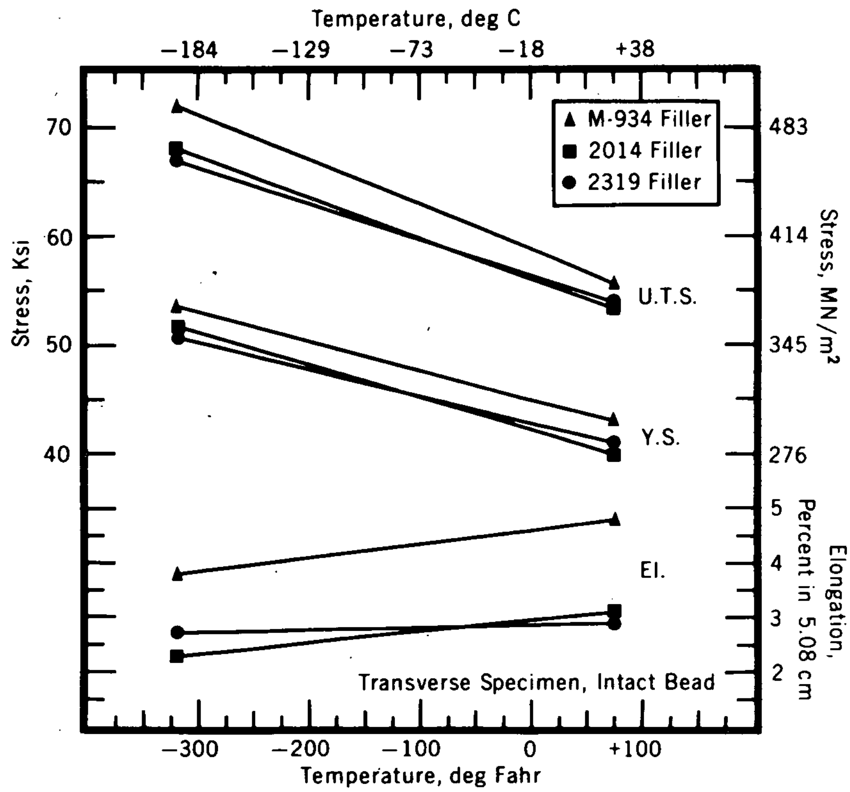


FIGURE 25 - MECHANICAL PROPERTIES OF TIG WELDMENTS IN ALLOY 2219-T87, 3.18 mm THICK SHEET, AFTER THERMAL EXPOSURE OF 300°F (149°C) FOR 100 HOURS

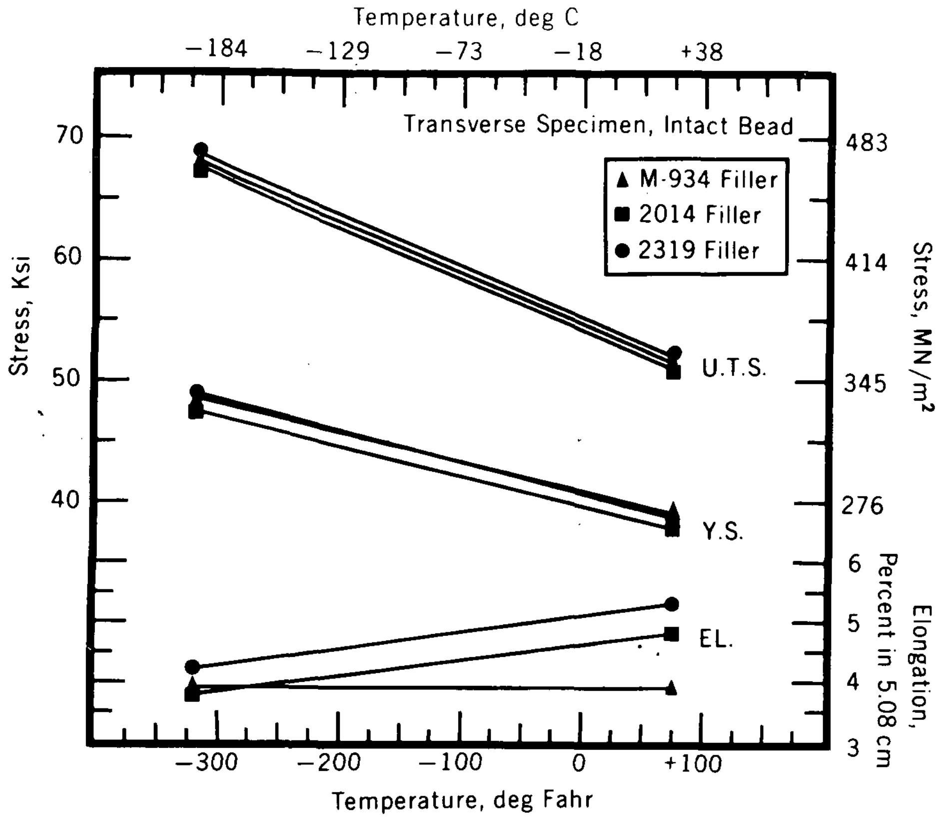


FIGURE 26 - MECHANICAL PROPERTIES OF TIG WELDMENTS IN ALLOY 2219-T87, 3.18 mm THICK SHEET, AFTER THERMAL EXPOSURE OF 350°F (177°C) FOR 100 HOURS

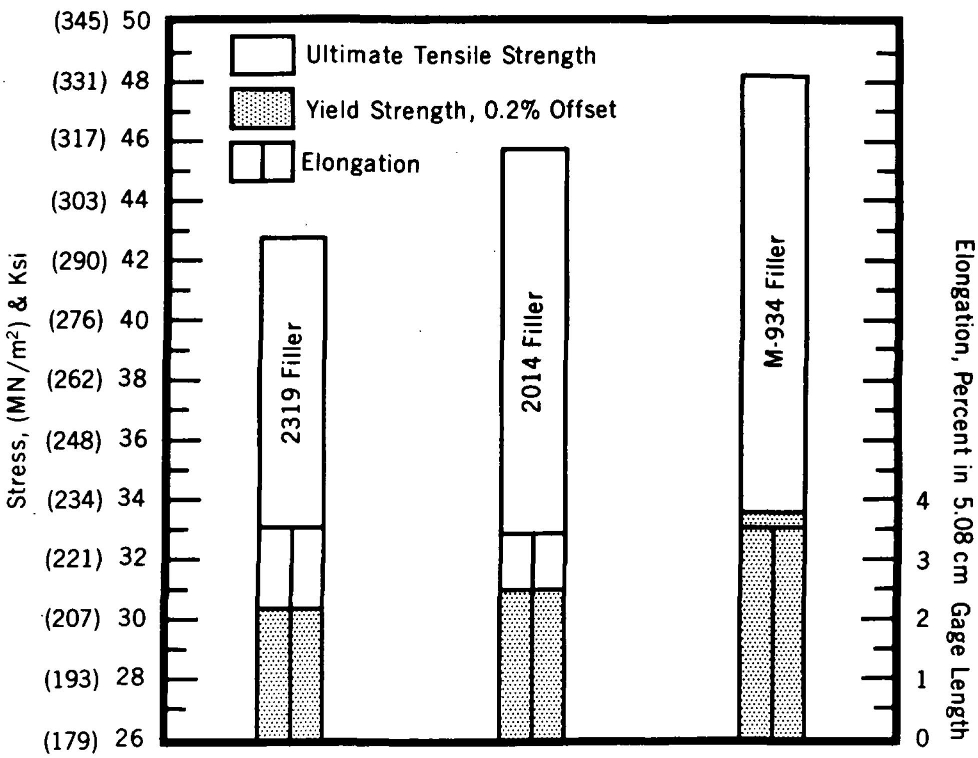


FIGURE 27 - MECHANICAL PROPERTIES OF ALLOY 2219-T87 TRANSVERSE TIG WELDMENT (INTACT BEAD) IN 12.7 mm THICK PLATE WELDED IN THE HORIZONTAL POSITION

APPROVAL

IMPROVED TIG WELD JOINT STRENGTH IN ALUMINUM ALLOY
2219-T87 BY FILLER METAL SUBSTITUTION

By

R. M. Poorman and C. V. Lovoy

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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