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Tensile Properties of Weldments in Alloy GTD 222

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SUMMARY

Alloy GTD 222 is a candidate for gas turbine engine cases having higher temperature capability than Alloy 718. In this work, simple butt welds were made in GTD 222 with two different grain sizes, and between GTD 222 and Alloy 718. Electron beam (EB) and gas tungsten arc (GTA) welds of GTD 222 to itself, and EB welds to Alloy 718, all reached at least the full 1200 °F 0.2 percent YS of coarse grain GTD 222, if at least a post-weld age was applied. GTA welds also achieved the 1200 °F UTS of the coarse grain GTD 222, if a post-weld age, or solution and age, was applied. However, defects in the EB welds limited the ductility and UTS of many specimens. A post-weld solution plus age provided a small improvement in ductility compared to an age alone. GTA welds with Nimonic 263 filler showed a reduction in tensile strength relative to welds with GTD 222 filler for all heat treatment conditions.

INTRODUCTION

The NASA Advanced Subsonics Technology program seeks to aid U.S. manufacturers of engines for commercial aircraft to extend their dominance of the world market into the next century. Engine cycle analysis studies have identified compressors with higher overall pressure ratios in the compressor, about 50:1, as one of the highest payoff technologies. Higher pressure ratios increase the compressor exit gas temperature and thus the temperatures of the components at the back of the compressor: blades, vanes, disks, cases, and seals. This report presents work done at the NASA Lewis Research Center (LeRC) in cooperation with General Electric Aircraft Engine Group, Evandale, Ohio to develop an alloy for compressors with a 100 °F higher temperature capability over Inconel 718. The candidate alloy GTD 222, which was originally developed by G.E. Power Generation as a cast alloy, is a derivative of Alloy 939 with improved creep capability and thermal stability but reduced tensile strength relative to Alloy 718. It was introduced in cast nozzles for land based gas turbines. More recently G.E. Aircraft Engine Group, Evandale has developed the alloy in wrought form for some static structural parts.

NASA LeRC undertook as part of this development program to make and characterize welds in GTD 222, and between GTD 222 and Alloy 718. For most efficient design and manufacture of large compressor cases, it is desirable to be able join smaller case segments without mechanical fasteners, rather than develop the capability to make large single piece case forgings. Also, it is desirable to be able to weld to other alloys which might be used in selected areas of the case. For instance, Alloy 718 might continue to be used for the lower temperature areas of the case.

Electron beam (EB) and gas tungsten arc (GTA) welds were produced joining wrought GTD 222 to itself and to Inconel 718. Two forms of GTD 222 were investigated having grain sizes of ASTM 9-10 and 2-3. The current production process yields an intermediate grain size about ASTM 4. Also, two different filler metals were evaluated in the GTA welding, GTD 222 and Nimonic 263. Nimonic 263 is a similar alloy with somewhat lower strength, but it is widely used and should be available at lower cost. Finally, different weld and post-weld heat treatment sequences were also evaluated for each material/weld type.

MATERIALS AND PROCEDURES

Materials

Alloy GTD 222 was supplied by G.E. as diverse small pieces from two different vendors, in three different forms, and given three different solution heat treatments. These will be described in some detail for completeness, however it will be seen that the weld strengths do not appear to reflect the diversity of material except for grain size, and only two grain sizes were represented, ASTM 9-10 and 2-3.

The two GTD 222 vendors were Teledyne Alvac and Carlton Forge Works/Special Metals. Teledyne Alvac supplied rolled bar with two different cross sections, L-shaped about 1.4 in. high, 0.9 in. along the base, and 0.4 in. thick, and "hat"-shaped which were essentially rectangular, 0.5 by 1.2 in. Carlton Forge supplied a rolled ring about 1.5 in. wide radially and 0.9 in. thick. Rolling procedures were not divulged.

All the materials were solution treated before welding. The Teledyne Alvac GTD 222 was solution treated at either 1800 or 2200 °F for 1 hr, yielding ASTM grain sizes of 9-10 or 2-3, respectively. The Carlton Forge material was solution treated at either 2100 or 2200 °F for 1 hr, but both temperatures yielded an ASTM 2-3 grain size. The particular GTD 222 used for each weld sequence is summarized in table I.

The Alloy 718 used in this study was 1.0 in. thick plate found in stock at NASA LeRC, and is of unknown origin. It was solution treated at 1700 °F for 1 hr before welding. The grain size was ASTM 4.

For each material/weld type, it was desired to evaluate three different weld/heat treatment sequences in duplicate tests using pieces from a single weld were possible. To accomplish this with the GTD 222 available, it was necessary to use a miniature 1.5 in. long tensile specimen. However, this still did not allow pieces to be cut such that the weld plane would be the same with respect to the rolling direction for all three GTD product forms. The material direction perpendicular to the weld planes are indicated in Table I.

Material/Weld/Heat Treatment Variations

Table I indicates the material/weld/heat treatment variations studied. Both EB and GTA welds were made in GTD 222 of the two different grain sizes, also EB welds were made of the coarse grain GTD 222 to Alloy 718. GTA welds in the coarse grain GTD 222 were made with both GTD 222 and Nimonic 263 fillers. For each material/weld type, three weld/heat treatment sequences were evaluated. Again, all materials had first been solution treated. The first two EB weld/heat treatment sequences represent possible production sequences, and the third was simply to show the as-welded properties. The first GTA weld/heat treatment sequence is the normal production sequence. The second two represent possible repair weld sequences applied to a part already solution treated and aged.

For the welds of GTD 222 to itself, the solution and aging treatments used were 2100 °F for 1 hr and 1475 °F for 8 hr, respectively. For the welds of GTD 222 to Alloy 718, the solution and two step aging treatments used were 1700 °F for 1 hr and 1325 °F for 8 hr plus 1150 °F for 8 hr, respectively. All heat treatments were performed in vacuum and the initial cooling rate from the solution treatment was about 50 °F/min.

Electron Beam Welds

Since any weld defects are typically concentrated in the start and stop locations, extra material to be cut away and discarded after welding was tacked onto the butted pieces at both ends of the joint. These were small rectangular blocks cut from scrap GTD 222 having the same thickness as the pieces to be welded. A weld pass was made, then the specimen was then turned with the other side up, and a second weld pass was made. The beam penetration was nearly the full 0.4 in. thickness of the joint. The electron beam current was 14 ma, the accelerating voltage was 111 kV, and the specimen travel speed was 10 in./min.

Gas Tungsten Arc Welds

As shown in table I, the GTA weld of the fine grain GTD 222 had a "double vee" geometry, while those of the coarse grain GTD 222 had a "single vee" geometry. Figure 1 shows the GTA welds schematically with the individual weld passes numbered. For both weld geometries the pieces were first tack welded together at the ends. The root opening space between the 1/16 in. high root faces was about 1/32 in. For the "double vee" welds, the piece was turned over after depositing the first weld pass, and the joint area was ground to remove any unsound material. The second pass was deposited from that side. On the "single vee" welds the final pass was performed in the same manner.

The GTA welds were done manually. No pre- or post-weld heating was used. The weld electrode was 2 percent thoriated tungsten with a 1/16 in. diameter and a 30° angle on the tip. The polarity was straight DC. The argon gas cover had a flow rate of about 25 ft^3/hr. The GTD 222 and Nimonic 263 weld wires had diameters about 0.042 and 0.063 in., respectively.

The welded specimens were inspected radiographically. A few areas were identified which were avoided in cutting tensile specimens. The pieces were then sectioned into thirds for separate heat treatment. The pieces were macroetched and visually inspected before machining, also to avoid any unsound areas in the tensile specimens. It was apparent that in the EB welds of both the coarse grain GTD 222 to itself and to Alloy 718, part of the joint near one surface was not fused. The tensile specimens were placed as far as possible to the other side, but it will be seen that the unfused area was not successfully avoided in all specimens.

Mechanical Testing

Duplicate 1200 °F tensile tests were performed for each material/weld type/heat treatment sequence. The gage length of the test specimen was about 0.113 in. in diameter and 0.56 in. long. The welds were well centered in the gage length. The EB welds were about 0.05 in. wide. However, the GTA welds were much wider, about 0.25 to 0.30 in., and constituted a major portion of the gage length. The widths of the "single vee" welds tended to be slightly bigger than those for the "double vee" welds. Figure 1 shows schematically the difference in the width of the welds in the center of the specimens.

Duplicate 1200 °F tensile tests were also performed on the base materials, except for the fine grain GTD 222. Insufficient material remained beyond that required for the welded specimens.

RESULTS AND DISCUSSION

Base Alloys

Results of the 1200 °F tensile tests for the base alloys, EB welds, and GTA welds are presented in Tables II to IV, respectively. It may be seen in table II that at 1200 °F the large grain GTD 222 has lower 0.2 percent YS but higher ductility than the Alloy 718. Yet, the base Alloy 718 used in this study has lower than typical strength and ductility. More typical values of 0.2 percent YS, UTS, and El for Alloy 718 would be 140 and 160 ksi, and 20 percent.

Electron Beam Welds

Table III shows the EB weld test results. In addition to the basic tensile properties, ratios to the properties for the large grain GTD 222 base alloy are shown for 0.2 percent YS and RA. It is not meaningful to compare elongation, in particular, with the base alloy, since deformation was observed to be very concentrated in the welds. The EB welds were only about 0.05 in. wide, about 10 percent of the gage length of the tensile specimens. Thus, elongation as a percentage of the total gage length is not largely a property of the weld. Because of the surrounding constraint, RA and UTS in the weld are also expected to be less than would be measured in a test volume with normal length/diameter ratio.

Consider first 0.2 percent YS for the self similar EB welded specimens. The values for all reached that measured for coarse grain GTD 222, about 102 ksi, if a post-weld age, or solution and age, was applied. All failures occurred in the welds or at the weld/heat affected zone (HAZ) interface. The welded specimens with the highest yield strength were those from the fine grain GTD 222 given only a post-weld age. Welded specimens from both the fine and coarse grain GTD 222 given a post-weld solution treatment and age were weaker, probably because the cooling rate from the solution treatment in the heat treatment furnace is considerably slower than that which occurs during the welding process itself. The welded specimens from the coarse grain GTD 222 with only a post-weld age were also weaker, but in this case there were flaws in the welds. Two contained cracks and one was a simple failure to hit the joint with the electron beam. One value of 0.2 percent YS for a weld specimen from the fine grain GTD 222 given no post-weld heat treatment was 115 ksi, while the second was only 91 ksi. This appears related to a weld feature we will call "spikes" to be discussed shortly. However, though no defects were observed on the coarse grain GTD welded specimens which also received no post-weld age, their strengths were the lowest, about 78 ksi.

While the 0.2 percent YS was good, in general, many of the GTD self similar EB welded specimens did not display the full UTS or RA of the base coarse grain GTD 222 because of various weld defects. Blued patches on the otherwise gold fracture surfaces were assumed to be preexisting cracks. Cracks were found exclusively in welds of large grain GTD 222 to itself or to 718. In contrast, the welded specimens from the fine grain GTD 222 exhibited the previously mentioned "spikes" on the fracture surfaces. Though the 0.2 percent YS of these welded specimens is generally high, the UTS and ductility appear to decrease in proportion to the fraction of "spikes" on the fracture surface.

Figure 2 shows the fracture surface of one of the fine grain GTD 222 welded specimens. The "spikes" seen there can also be seen in transverse and longitudinal cross sections in figure 3. At the bottom of the electron beam "spike" on the pass from the second side, the liquid/solid interface is left decorated with a second phase and sometimes shrinkage voids. The decorated rings in the transverse section of an untested weld scrap shown in figure 3(b) indicate that the mechanical drive for the workpiece in this particular EB welding machine was not continuous, but rather stuck and skipped leaving a trail of overlapping circles. Voids at the bottom of EB weld "spikes" as shown in figure 3(c) are not unusual, but voids extending up the "spike" circumference were previously unknown to the authors. "Spikes" were observed in polished sections of the other EB welds, but were not related to failure as in the welds of the fine grain GTD 222. The weld shown in figure 3(b) is in the coarse grain GTD 222. Why these "spikes" were the weakest link only in the welds in the fine grain GTD 222 is not understood.

Though in polished sections some voids are observed on the circumference of the weld "spikes" extending up from the tip, there is no suggestion that they cover a large area of the circumference. The long segments of the "spikes" on the fracture surfaces must be revealed by fracture propagation along what appears to be largely bonded interface, perhaps related to the second phase decoration.

The welds to Alloy 718 also reached the yield strength of the coarse grain GTD 222 if at least a post-weld age was applied. Weld cracking was observed on the fracture surfaces of the specimens given the Alloy 718 solution treatment and double age, yet 0.2 percent YS values over 100 ksi were observed. The specimens which were only aged after welding yielded at 116 ksi and failed in the Alloy 718. The joint in one specimen tested as-welded was not completely fused. The other yielded at 70 ksi and failed in the Alloy 718.

Weld cracks limited the ductility and UTS of three of the GTD 222 to Alloy 718 welded specimens. We are reluctant to say that the particular weld/heat treatment sequences exhibiting weld cracks were anything more than at random. The other specimens failed in the Alloy 718.

Gas Tungsten Arc Welds

Tensile properties of the GTA welds are presented in table IV. All failures occurred in the welds or near the weld/HAZ interface. For all the weld sequences using GTD 222 filler, the 0.2 percent YS are about the same as for the EB welds with the same post-weld heat treatment. However, the UTS and ductilities of the GTA welded specimens are consistently higher than those of the EB welded specimens. The UTS approaches that of the large grain GTD 222, 150 ksi. This was probably due partly to the larger weld length/diameter ratio in the tensile specimen gage section, but also to the absence of weld cracking (and absence of incomplete fusion).

Strengths of the fine grain GTD 222 welded specimens were about the same as those of the coarse grain GTD 222 specimens, except for those with the age+weld+age weld/heat treatment sequence which appear to be more than 10 percent higher for the fine grain GTD 222 specimens. Ductilities, however, might appear somewhat higher for welds in the coarse grain GTD 222. The welded specimens with the Nimonic 263 filler had strengths that were 10 to 15 ksi lower than those with GTD 222 filler, but perhaps higher ductilities. This may simply reflect the lower strength of the Nimonic 263.

Differences between the GTA welds in coarse and fine grain GTD 222 are not understood. This is so, in particular, for the age+weld+age weld/heat treatment sequence, since all failures occurred in the weld, not in the base metal or heat affected zone. Also, it is not understood why the age+weld+age sequence produced higher yield strengths than the weld+age sequence. What obvious influence can aging the base alloy before welding have on the properties of the relatively large volume of weld filler laid down subsequently? Yet, even for the weld samples with Nimonic 263 filler, the age+weld+age weld/heat treatment sequence produced higher strength than the weld+age sequence.

CONCLUDING REMARKS

It is somewhat difficult to interpret the results of this study. In some ways they present an optimistic evaluation of the weldability of GTD 222. There is very little physical constraint in the butt welds performed, and sufficient testing was not conducted to reveal variability. Further, it was attempted to locate tensile specimens to avoid areas seen to contain defects.

On the other hand, there were compromises in the experiment which have been cited, variables among the materials and methods, and relative inexperience with EB welding, which might lead to suspicion that some results are too low. However, the defective welds have been identified by failure analysis, and neglecting those results, we see that the properties of good EB or GTA welds in GTD 222 given a post-weld age, or solution and age, do approximate those of coarse grain GTD 222.

SUMMARY OF RESULTS

Simple butt welds were made by both EB and GTA in GTD 222 having two different grain sizes. Both GTD 222 and Nimonic 263 filler were evaluated in GTA welds. EB welds were also made between GTD 222 and Alloy 718. Evaluation of the welds was based on 1200 °F tensile testing, fractography, and metallography. The results are summarized as follows:

1. The EB and GTA welds of GTD 222 to itself and EB welds to Alloy 718 all reached at least the full 0.2 percent YS of coarse grain (ASTM 2-3) wrought GTD 222, if at least a post-weld age was applied and GTD 222 filler was used in the GTA welds.
2. Defects in the EB welds, limited the ductility and UTS of many specimens. This was associated with shrinkage voids and fracture propagation along the surface of the weld "spikes," and other weld cracking not associated with the "spikes".
3. GTA welds achieved both the 0.2 percent YS and UTS of the coarse grain GTD 222, if at least a post-weld age was applied and GTD 222 filler was used. Reduction in area averaged about 75 percent of that for coarse grain GTD 222.
4. Welds with Nimonic 263 filler were about 13 percent weaker than those with GTD 222 filler for all weld/heat treatment sequences.

TABLE I.—DESCRIPTION OF THE MATERIALS, WELD TYPES, AND WELD/HEAT TREATMENT SEQUENCES

Weld type	Alloys joined	GTD 222 vendor	GTD 222 form	GTD 222 grain size, ASTM	Weld configuration (filler metal)	Material orientation of tensile test axis	G.E. GTD 222 code	Weld sequence
EB	222/222	TA	Hat	9-10	Bead on plate (NA)	Rolling direction	WT1	Weld+Soln+Age
								Weld+Age
								Weld
	222/222	TA	L	2-3	Butt (NA)	Transverse	WT6B	Weld+Soln+Age
								Weld+Age
								Weld
	222/718	TA	Hat	2-3	Butt (NA)	Rolling direction/ thickness	WT2	Weld+Soln+Age
								Weld+Age
								Weld
GTA	222/222	TA	L	9-10	Butt double vee (GTD 222)	Transverse	WT5B	Weld+Soln+Age
							WT5A	Age+Weld+Soln+Age
							WT6A	Age+Weld+Age
	222/222	CF	Ring	2-3	Butt single vee (GTD 222)	Radial	WS1	Weld+Soln+Age
								Age+Weld+Soln+Age
								Age+Weld+Age
	222/222	CF	Ring	2-3	Butt single vee (Nimonic 263)	Radial	WS1	Weld+Soln+Age
								Age+Weld+Soln+Age
								Age+Weld+Age

TABLE II.—TENSILE PROPERTIES OF BASE MATERIALS AT 1200 °F

Alloy	Grain size	Material orientation of tensile axis	0.2 percent YS, ksi	UTS, ksi	El, percent	RA, percent
718	3	Rolling direction	132.6	151.2	9.1	15.4
			128.4	147.8	7.6	12.9
GTD 222	2-3	Radial	101.7	150.2	19.9	24.7
			102.8	150.4	20.8	30.8

TABLE III.— TENSILE PROPERTIES OF ELECTRON BEAM WELDS AT 1200 °F

Alloys joined	GTD 222 ASTM G.S.	Weld sequence	0.2 percent YS, ksi	0.2 percent YS, weld ÷ GTD 222	UTS, ksi	El, percent	RA, percent	RA, weld ÷ GTD 222	Failure location
222/222	9-10	Weld+Soln+Age	102.0	1.0	119.7	2.9	7.3	0.3	Weld, 20 percent "spikes"
			104.5	1.0	151.0	9.7	20.1	.7	Weld/HAZ, 2 perecnt "spikes"
		Weld+Age	120.2	1.2	127.0	0.5	8.0	0.3	Weld, 50 perecnt "spikes"
			122.6	1.2	152.5	11.1	8.8	.3	Weld/HAZ, 5 percent "spikes"
		Weld	115.2	1.1	132.7	4.0	28.3	1.0	Weld/HAZ, 1 percent "spikes"
			91.1	.9	96.4	0.9	15.9	.6	Weld, 50 percent "spikes"
222/222	2-3	Weld+Soln+Age	107.5	1.0	142.6	8.2	9.0	0.3	Weld/HAZ, 5 percent cracks
			100.1	1.0	144.9	11.7	13.8	5	HAZ?
		Weld+Age	104.2	1.0	124.4	4.3	7.6	0.3	Weld, 10 percent not fused
			104.1	1.0	152.7	16.1	12.2	.4	Weld, 10 percent cracks
		Weld	78.8	0.8	107.1	13.3	46.1	1.7	Weld/HAZ
			76.7	.8	106.2	13.3	40.8	1.5	Weld
222/718	2-3	Weld+718 Soln+-Age	100.6	1.0	100.6	0.5	9.9	0.4	Weld, 20 percent cracks
			112.7	1.1	119.9	0.8	9.8	.4	Weld, 15 percent cracks
		Weld+718 Age	116.0	1.1	141.6	4.4	8.9	0.3	Alloy 718, far from HAZ
			115.9	1.1	140.8	4.4	7.1	.3	Alloy 718, far from HAZ
		Weld	64.2	0.6	64.2	2.5	8.7	0.3	Weld, 40 percent not fused
			70.4	.7	83.9	4.4	18.2	.6	Alloy 718, far from HAZ

TABLE IV. —TENSILE PROPERTIES OF GAS TUNGSTEN ARC WELDS AT 1200 °F

Alloys joined	GTD 222 ASTM G.S.	Filler	Weld sequence	0.2 percent YS, ksi	0.2 percent YS, weld ÷ GTD 222	UTS, ksi	El, percent	RA, percent	RA, weld ÷ GTD 222	Failure location
222/222	9-10	GTD 222	Age+Weld+Soln+Age	103.7	1.0	148.6	17.7	23.6	0.8	Weld Broke in maching
			Age+Weld+Age	123.8 121.7	1.2 1.2	157.6 154.1	8.0 7.1	11.8 19.0	0.4 .7	Weld Weld
			Weld+Age	101.3	1.0	151.3	16.3	18.7	0.7	Weld No test, big pore
222/222	2-3	GTD 222	Age+Weld+Soln+Age	100.8 101.9	1.0 1.0	148.6 147.5	19.7 10.4	24.3 26.4	0.9 .9	Weld/HAZ Weld/HAZ
			Age+Weld+Age	109.5 107.0	1.1 1.0	150.6 128.6	15.5 4.1	19.5 16.2	0.7 .6	Weld Weld
			Weld+Age	102.8 102.3	1.0 1.0	148.6 150.2	16.5 18.6	23.9 23.1	0.9 .8	Weld/HAZ Weld/HAZ
222/222	2-3	Nimonic 263	Age+Weld+Soln+Age	85.9 86.7	0.8 .8	129.6 124.9	15.2 13.0	30.1 18.2	1.1 .7	Weld Weld
			Age+Weld+Age	97.9 100.1	1.0 1.0	133.9 127.9	12.7 6.8	23.7 18.0	0.9 .6	Weld Weld
			Weld+Age	85.6 88.3	0.8 .9	127.0 132.4	11.2 13.3	20.4 33.1	0.7 1.2	Weld Weld

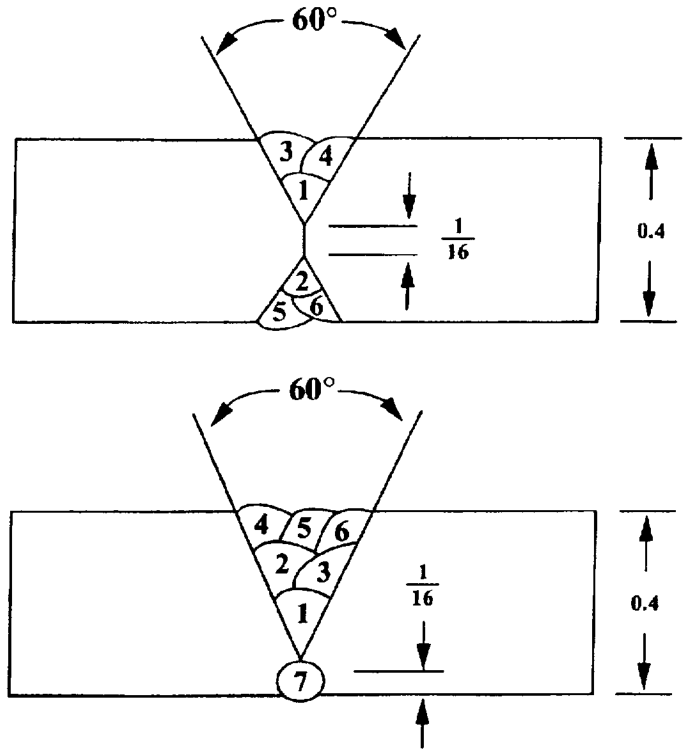

Figure 1.—Sequence of GTA weld passes for single and double vee specimens.

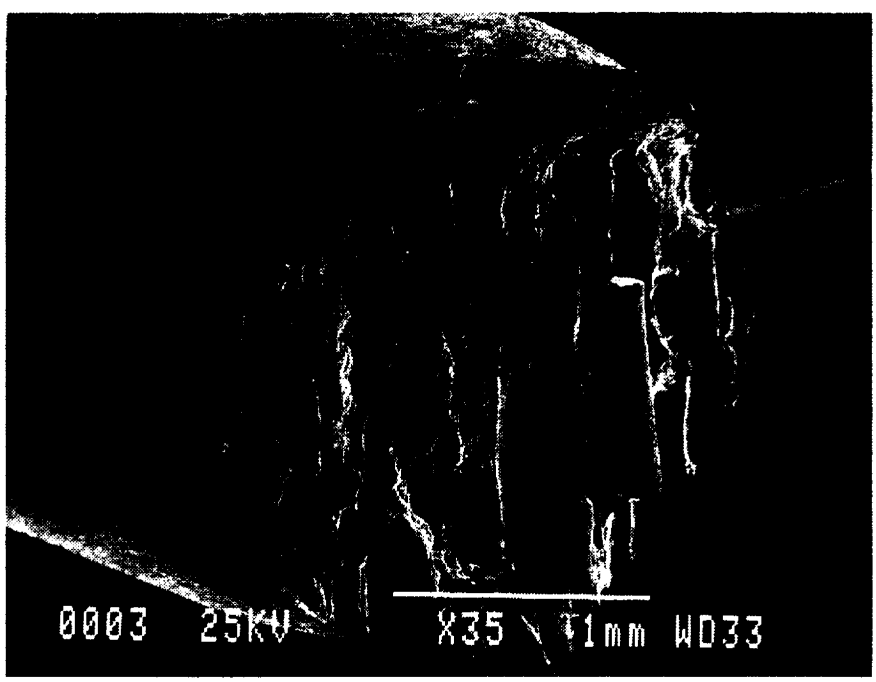

Figure 2.—Fracture surface in an EB weld of the fine grain (ASTM 9-10) GTD 22.

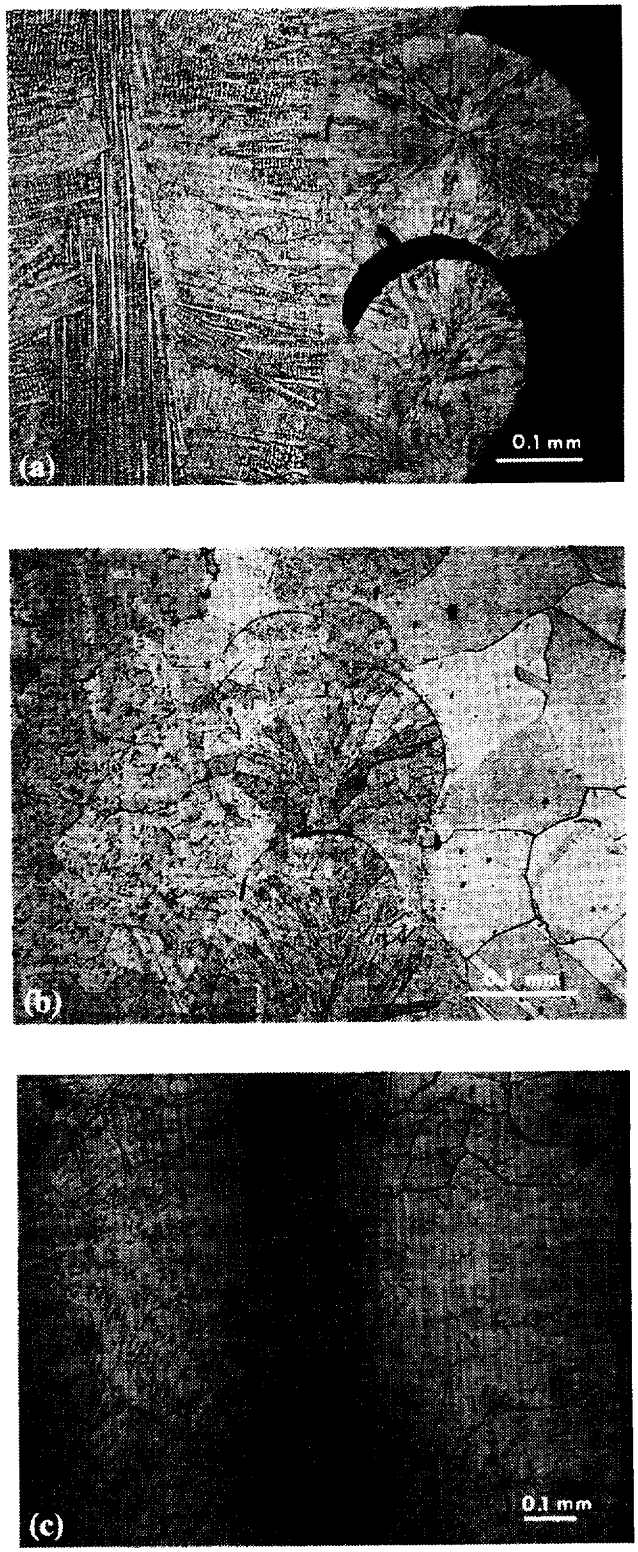

Figure 3.—Cross sections of weld "spikes": (a) Transverse section of "spike" on fracture surface, (b) Transverse section of untested weld piece, and (c) Longitudinal section of untested weld piece.

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