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ROLE OF THE MICRO/MACRO STRUCTURE OF WELDS IN CRACK NUCLEATION AND PROPAGATION IN AEROSPACE ALUMINUM-LITHIUM ALLOY

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Introduction

Al-Li alloys offer the benefits of increased strength, elastic modulus and lower densities as compared to conventional aluminum alloys. Martin Marietta Laboratories has developed an Al-Li alloy designated 2195 which is designated for use in the cryogenic tanks of the space shuttle. The Variable Polarity Plasma Arc (VPPA) welding process is currently being used to produce these welds [1]. VPPA welding utilizes high temperature ionized gas (plasma) to transfer heat to the workpiece. An inert gas, such as Helium, is used to shield the active welding zone to prevent contamination of the molten base metal with surrounding reactive atmospheric gases. [1] In the Space Shuttle application, two passes of the arc are used to complete a butt-type weld. The pressure of the plasma stream is increased during the first pass to force the arc entirely through the material, a practice commonly referred to as keyholing. Molten metal forms on either side of the arc and surface tension draws this liquid together as the arc passes. 2319 Al alloy filler material may also be fed into the weld zone during this pass. During the second pass, the plasma stream pressure is reduced such that only partial penetration of the base material is obtained. Al 2319 filler material is added during this pass to yield a uniform, fully filled welded joint. This additional pass also acts to alter the grain structure of the weld zone to yield a higher strength joint.

Examinations of butt welds produced at the Marshall Space Flight Center in Al-Li 2195 has revealed cases of crack-like porosity in the weld fusion zone. Butt welds in 2195 Al-Li alloy with 2319 filler wire performed at Vanderbilt University under a range of welding conditions [20] exhibited secondary cracking along interdendritic boundaries in the fusion zone of fractured specimens in nearly all cases. Similar cracks were reported in the run-out portion of remaining unfractured samples. Two Vanderbilt samples displayed .06" interdendritic tears in the center of the fusion zone which were not involved in the fracture. Talia and Nunes found porosity in the first pass fusion zone in two pass weldments in the identical alloy. [3]

Cast aluminum alloys are particularly susceptible to interdendritic hot cracking due to their high coefficient of thermal expansion and high solidification shrinkage (approximately 6%). Chemical composition strongly influences the susceptibility to hot cracking among aluminum alloys. For example, a binary Al-Li alloy showed maximum susceptibility at 2.6 w/o Li, while binary Al-Mg alloys show maximum susceptibility at 1.4 w/o Mg. [4]

The present study focussed on the crack structures as potential flaws responsible for the premature fracture of cast fusion zone of 2195 Al-Li alloys, which would otherwise exhibit much grater strength.

Experimental Procedures

2195 Al-Li alloy plates were produced by the Reynolds Metals Company, two passes (root pass and cover pass) welds were performed at the Marshall Space Flight Center by Lockheed Martin -Manned Space Systems and Lockheed Martin Astronautics. Tensile samples were milled to obtain uniform cross-sections. Tensile tests at room temperature were employed to study the initiation and propagation of cracks and microcracks in the welding zone. Most of the tests were interrupted and transverse and longitudinal sections of the welds were examined by optical micrographic techniques.

Each metallographic sample was prepared for examination using standard polishing preparation techniques and etched with Keller's reagent. Observations were performed using a Nixon inverted microscope. Additional observations were performed using an scanning electron microscope.

Results and Discussion

The initial optical metallographic observations of the single pass weld revealed a well formed grain structure with a small amount of porosity. This porosity appear to compare with the initial porosity of the parent metal. However, Scanning Electron Micrographs revealed large porosity specially around the Cu-rich second phase (see Figure 1) and some of the pores take a crack-like shape as shown in Figure 2. The grain boundary integrity is by the porosity and the crack-like shape of the G.B. could reduce the fracture strength of the material.

Figure 3 exhibits sings of the influence of grain structure on the tensile behavior of a high-strength **2195 Al-Cu-Li** alloy. Crack nucleation can occur at slip-band grain boundary intersections and subsequent propagation can then occur along the slip bands or along grain boundaries. The welded zone has a central dendritic structure. Most of the long cracks seen in the microscope appear related to such dendritic structure and they are formed by a series of two to four narrow subcracks (see Figure 4). The number of subcracks increase as the deformation increases. A combined mechanism of G.B. cracking and metal yielding seems to govern the deformation.

Tensile tests at room temperature were employed to characterized the mechanical properties of the different alloys and to observe changes in the microstructure, especially in the welding zone. For comparison, 2219 samples were also tested. Additional tensile tests were performed to evaluate the welding zone strength after solution treatment (1 hr. at 485 degrees C) and aging (7 days at room temperature). Table 1 present a summary of the tensile data of the alloys. It is noteworthy that when cracking occurred corresponding serrations were observed in the stress-strain curves for both 2219 and 2195.

Table 1 - Tensile Data

	Y.S. (psi)	UTS (psi)	Max Def.*	Fracture Strength** (psi)	Max. True Strain*
2219 As Welded	13,342	42,692	31.2 %	55,618	0.27
2195 As Welded	30,864	43,866	5.8 %	46,410	0.06
2195 Thermal Treat.	27,120	51,112	22.8 %	61,508	0.20

* Assuming an strain gauge of 0.25 " - **Force divided by the fracture area

In general 2195 is a stronger material than 2219. The yield strength (Y.S.) of 2195 is much larger than the one presented for 2219. The UTS of both materials are similar but surprisingly, the fracture strength of 2219 is 20 % larger than of 2195. A possible explanation for the lower fracture strength may be the greater porosity of the G.B. of the 2195 as observed in Figure 1. Figure 5 illustrate the crack structure of 2195 as welded near the yielding (31,000 psi) at almost no deformation. A very well defined crack is observed. For 2219 cracks appear at larger deformation. Figure 6 presents the initial of crack arrangement for a deformation of 13.2 % under true stresses of near 51,000 psi. Note the heavier deformation texture of 2219.

The thermally treated 2195 alloy increased in fracture strength from 20 % bellow to 10 % above that of 2219. Due to the thermal treatment, the G.B. segregation was eliminated (see Figure 7). Apparently, 2195 become much stronger if the interdendritic material is redissolved into the grains.

Conclusions and Recommendations

Initial results have led to the following tentative conclusions:

a) The fracture strength of 2195 alloy welds is limited by the grain boundary integrity. G.B. porosity has a negative effect upon G.B. Integrity in 2195 alloy.

b) The pattern of aligned dendrites at the center of both 2219 and 2195 welds is a source of initial cracks leading to fracture.

c) Cracking produced serration in the stress-strain curve for both 2219 and 2195 alloys.

d) In situ SEM observation of tensile tests at room temperature should be employed to characterize the structural features associated with the progressive phases of deformation.

e) Hot tensile tests should be performed to evaluate the effect of the temperature variation on the integrity of the weldments.

Acknowledgments

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References

1) Nunes, A.C. "The Variable Polarity Plasma Arc Welding Process: It's Application to the Space Shuttle External Tank - First Interim Report", NASA Technical Memorandum TM-82532, June 1983.

2) Materials Science and Engineering Department - Vanderbilt University, "Analysis of the 2195 Aluminum-Lithium Alloy Weld Microstructure and Properties", Prepared for Martin Marietta Manned Space Systems, September 30, 1992.

3) Talia, G.E., Nunes, A.C., "Microstructural Analysis of the 2195 Aluminum-Lithium Alloy Welds", Prepared for the Marshall Space Flight Center, 1993.

4) Cross, C.E., Olson, D.L., Edwards, G.R., Capes, J.F., " Weldability of Aluminum - Lithium Alloys", Proceedings: Second International Aluminum-Lithium Conference, 1983

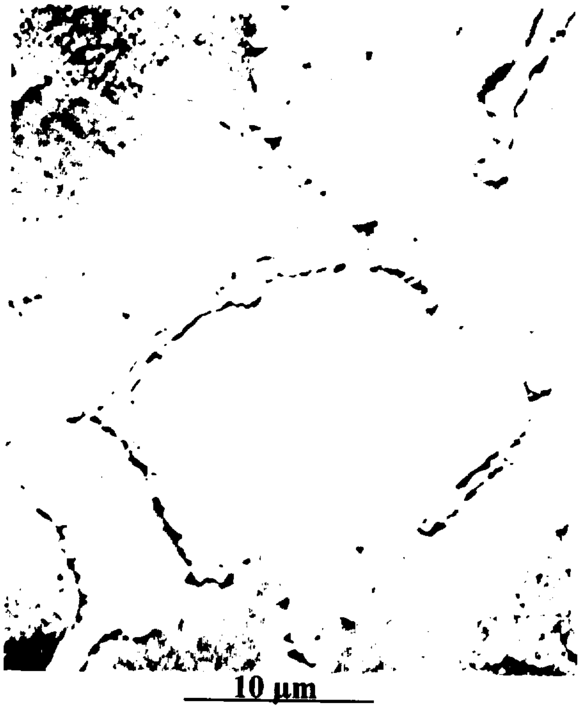

Figure 1.- Scanning Electron Micrograph presenting porosity special around the Cu-rich phase.

Figure 3.- Photograph presenting crack nucleation at slip band-grain boundary intersections.

Figure 2.- SEM micrographs showing G.B. with a crack-like shape.

Figure 4.- Optical micrographs of 2195 Al-Li alloy subjected to deformation.

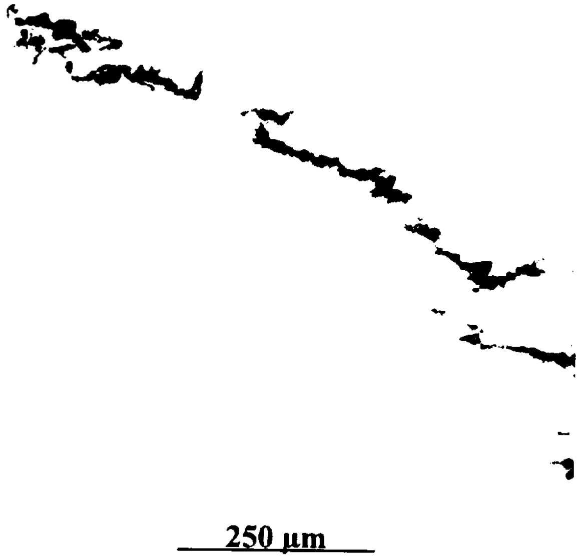

Figure 5.- Crack structure of 2195 at almost no deformation.

Figure 6.- Crack initiation in 2219 at deformation of 13 %.

Figure 7.- Micrographs showing the effect of the thermal treatment on the G.B. structure.