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MICROSTRUCTURAL ANALYSIS OF CRACKS GENERATED DURING WELDING OF 2195 ALUMINUM-LITHIUM ALLOY

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Introduction:

This research paper summarizes a series of studies conducted at Marshall Space Flight Center to characterize the properties of 2195 Al-Li alloy. 2195 Al-Li alloy, developed by Martin Marietta laboratories is designated as a replacement of 2219 Al-Cu alloy for the External Tank (E.T.) of the space shuttle. 2195 Al-Li alloy with its advantage of increased strength per weight over its predecessor 2219 Al-Cu alloy, also challenges current technology. 2195 Al-Li has a greater tendency to crack than its predecessor.

The present study began with the observation of pore formation in 2195 Al-Li alloy in a thermal aging process. In preliminary studies, Talia and Nunes found that most of the two pass welds studied exhibited round and crack-like porosity at the weld roots. Furthermore, the porosity observed was associated with the grain boundaries. The porosity level can be increased by thermal treatment in the air. A solid state reaction proceeding from dendritic boundaries in the weld fusion zone was observed to correlate with the generation of porosity.

These findings led Talia and Nunes to investigate further on the same lines, which resulted in this research. Particular emphasis was placed on the mechanisms of crack formation/propagation generated by VPPA welding process. The micro/macro structures of cracks were characterized by extensive optical and scanning electron microscope (SEM) observations. Differential Thermal Analysis (DTA), Thermal Gravimetric Analysis (TGA), and Energy Dispersive Spectrometry (EDS) investigations of the 2195 Al-Li alloy weldments were carried out in order to identify the nature of the dendritic reaction, porosity, and cracking. At the time of this writing a complete understanding of the nature of pores and cracking tendency of the 2195 Al-Li alloy is lacking. A model, explaining the different facets of the problem in accordance with the observations, is hence proposed.

Experimental Procedure

A series of experiments were performed during the course of this study to explain cracking of VPPA weldments at in 2195 Al-Li alloy. The plate thickness of the test specimens used during the experiments and analysis was 0.2 inches. Welds were performed both with and without filler metal. The welds were carried out in two sequential passes, a root and a cover pass. Samples were prepared for metallographic examination using standard polishing preparation technique and Kellers reagent etch. Optical microscopy observations were performed on a Nixon inverted microscope. One pass autogenous welds samples (no filler material) were selected for further thermal processing, i.e., heat treatment at different temperatures in air, oxygen, nitrogen and helium and vacuum. Extensive SEM fractographic analysis of the repair crack morphology was carried out on a Philips 515 SEM. Some of the cracks were opened in tension mode for analysis of the inner surface. Furthermore, the appearance of tiny surface blisters on weld surface and on the fractured surface indicates an outgassing phenomenon linked to porosity, were also studied. X-ray microanalysis was carried out by EDAX (Energy Dispersive X-Ray System) attached to the Philips 515 SEM. EDAX performs the quantitative X-Ray microanalysis with the help of Super Quant package. This software processes a spectrum to obtain net X-Ray intensities. The subjects of these analyses were of peculiar nature including crack interiors, supposed material "eruptions" from cracks, blisters and their morphology and the presence of magnesium rich "smut"/"snow" and oxides. All counts were taken at of 30 kv. Most of the SEM observations were accompanied by the X-Ray microanalysis.

To learn more about the dendritic or grain boundary reaction observed in the preliminary studies, Differential Thermal Analysis (DTA) and Thermal Gravimetric Analysis (TGA) were carried out. A systematic DTA analysis of the autogenous weld samples and parent metal was performed in air, nitrogen, helium and oxygen atmosphere. The analysis was performed on a DuPont 1090 system. The resulting thermograms were generated by General Analyser VI.0. The furnace and sample block temperature were increased at a linear rate of 10 and 20 ^{O}C/min and the sample weights were from 10 to 20 mg. A comparative TGA study was performed for 2195 Al-Li alloy and Al 2219 as control samples. PERKINS-ELMER 7 Series Thermal Analysis System was used for the analysis where the systems temperature was increased at a linear rate of 20 ^{O}C/min. The sample weight had a range from 70 to 95 mg. All the TGA experiments were performed under a dry nitrogen atmosphere.

Results and Discussion:

Repairs of defective welds sometimes produce new cracks, to be designated as "repair induced cracks." For subsequent SEM observations, repair induced cracks were torn open in a tensile mode. Figure 1(a) presents a view of "repair induced crack" fracture surface, indicating a ductile fracture, where the surface shows a combination of "melting" and "tearing" areas. Figure 1(b) illustrates another portion of the fracture surface, where melting is predominant. EDS microanalysis observations show that the melted areas present less copper and more nitrogen and oxygen than the tearing areas. The above fractographic observations revealed internal porosity with additional evidence of melting and gas pressure.

"Smut" outside the "repair induced crack," is shown in Figure 2. Its presence suggests fluid eruption from inside the crack. A high content of oxygen and nitrogen in the smut suggests a reaction inside the crack between nitrogen/oxygen/air and the crack wall. This reaction may generate gas pressure responsible of the eruption of low melting point smut outside the crack.

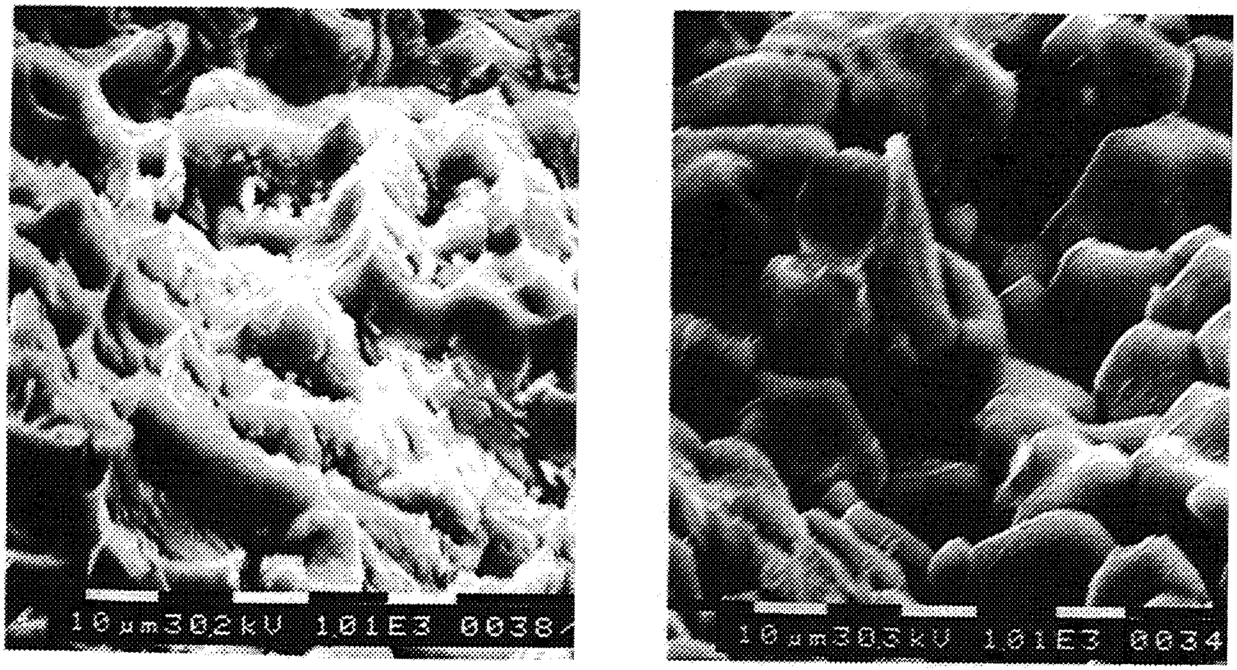
During the course of the study, a few samples of 2195 Al-Li welded specimens accidentally welded without the back shielding were examined. Air-contamination resulted in pore and blister formation. Typical SEM observations of the surface are presented in Figure 3. The root surface exhibits large and small blisters, and evidence of melting. The blisters are surrounded by matter as if matter erupted from inside, similar to the smut observed previously. It is conjectured that presence of a nitrogen/oxygen/air reaction causes melting and generates enough gas pressures in these blisters to cause eruption of melted matter to smut. In the interior of the blister, high nitrogen, magnesium, and oxygen, and decreased copper is measure. An optical micrograph cross section is presented in Figure 4, showing internal blister formation, and evidence of melting or partial melting induced by air contamination. The spherical form of the pore/blister indicates gas pressure acting.

To learn more about the dendritic or grain boundary reaction observed in the preliminary studies, DTA was performed on 2195 welds and parent metal. The analyses were carried out under atmospheres of air, oxygen, helium, and nitrogen.

During the DTA, for the parent metal no reactions were detected below the melting temperature of aluminum. However, all the weld samples exhibited a small endothermic transformation at about 530 ^{o}C, while those heated in nitrogen or air also exhibited exothermic transformations at about 360 ^{o}C. These features may be interpreted as indicating a nitrogen reaction that takes off and then saturates around 360 ^{o}C and, perhaps, partial melting at grain/dendrite boundaries at about 530 ^{o}C. During the TGA experiments in a dry nitrogen atmosphere at constant temperature and constant rate rising temperature, a weight gain of the samples was measured for 2195 Al-Li alloy. Since nitrogen is practically insoluble in the components of the alloy, it is inferred that a chemical reaction took place between the elements of the alloy and nitrogen. The reaction produced a brown film on the surface of the specimen. The film attacked the platinum crucible used to hold the specimen as the temperature moves into the neighborhood of the alloy liquidus. These features are characteristic of Li_3N.

Conclusions:

2195 weld metal exhibits evidence of surface melting on fracture surfaces an endothermic phase transformation at about 530 ^{o}C that would be consonant with grain boundary liquation. Nitrogen reacts with 2195 alloy at temperatures above 360 ^{o}C. Its is speculated that the solid state nitrogen reaction induces grain boundary melting while generating a pressurized gaseous phase that flashes out the melted matter at the free surfaces. In this way internal cracks, porosity, and surface blisters with surrounding exudates are formed.



(a) (b)

Figure 1.- Fractographs of a repair induced crack presenting (a) ductile fracture and (b) evidence of grain boundary melting.

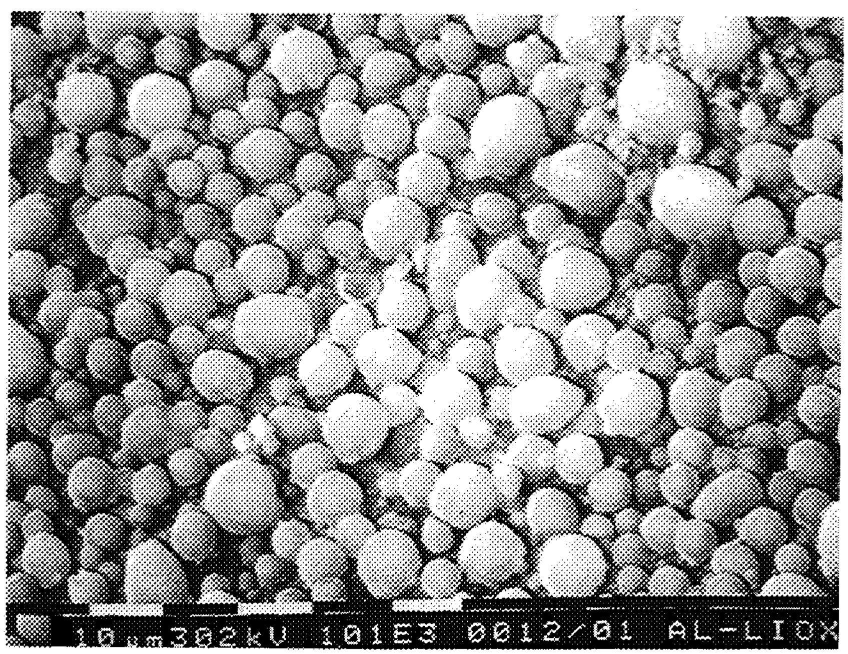


Figure 2.- SEM micrographs showing "smut" observed near the repair crack.

Figure 3.- Blisters on the free surface of a contaminated weld showing evidence of surface melting and gas pressure.

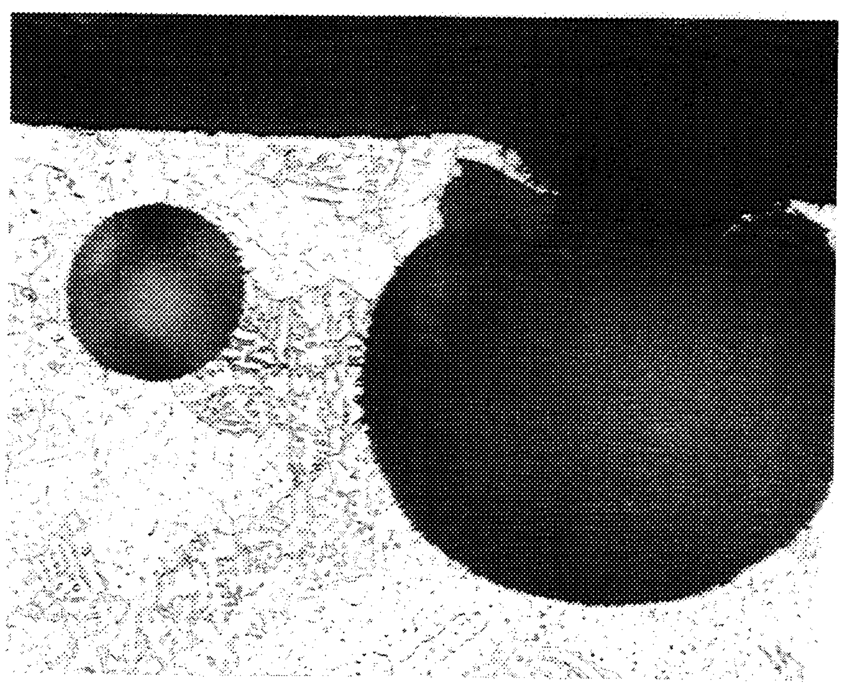


Figure 4.- Internal and external blistering in a 2195 alloy weld bead caused by air contamination.