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Cracking in Be/Al Nd: YAG laser weld

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Abstract An investigation was conducted to determine the cause of weld cracking in laser Be/Al weldments. In agreement with earlier studies, features consistent with hot shortness cracking on the fracture surfaces were observed. Closer examinations of the fusion zone crack regions reveal that the cracking was a result of thermal stress, shape of weld roots and impurities segregation. The defects are related to the weld parameters. The cracks easily nucleate at conduction mode weld and blowholes easily appear at keyhole mode weld.

Introduction

Beryllium is widely used in the nuclear, aeronautical, and astronautical industries, due to the excellent characteristic of low density, high specific strength, and high specific heat. It is also a constituent element in the recently developed bulk metallic glasses because it is the smallest atom among the metallic elements [1, 2]. However, it is difficult to weld with other metals because of its brittleness and low ductility. It has been established that the cause of cracking in Be welds is associated with the presence of low-melting-point impurities, e.g. Al [3–12].

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Passmore [3] has demonstrated that impurities such as Al, Fe and Si segregate to the weld centerline in autogenous weldments. These elements were also found to be concentrated at fusion zone edges. In another study, Hauser and Monroe found high levels of Al, Si, Ti, and Cr in second phases associated with fusion zone cracks. The second phase particles were found by transmission electron microscopy (TEM) of specimens removed from the fusion zone. These were identified as $AlFeBe_4$ and in areas where there was insufficient Al to form $FeBe_{11}$ phase. The authors proposed that the cracking was a result of Al-rich hot-short regions that combined with thermal stresses, produced intergranular cracks [4].

The purpose of this work is to characterize the fracture mechanisms of solidification cracks in Nd:YAG lasers Be/Al welds and to identify the impurities associated with the fracture. This is the key to the processing controls necessary to understand and minimize fusion zone cracking in Nd:YAG lasers Be/Al welds.

Experimental procedure

Modern Nd:YAG lasers have the ability to shape the temporal power profile of each pulse at pulse repetition rates of up to several KHz. This flexibility gives control of the thermal input with a precision not previously available. It allows the control of penetration, melt pool shape and size and the onset of boiling, keyhole formation and explosion ejection [8]. Conduction mode welds and keyhole mode welds were used to produce specimens. The main parameters are depicted

Table 1 Main weld parameters

	Average peak power density (W/cm^2)	Travel speed mm/min	Absorptivity %
Conduction mode	1200	700	10
Keyhole mode	2200	1200	70

in Table 1. SEM and EDX were conduced to analyze both heat effected zone and weld fusion zone.

Results and discussion

Fusion zone microstructure

In Fig. 1, scanning electron micrographs show the microstructure of the fusion zone by conduction mode weld. The figures show a very fine microstructure of weld fusion zone. The center (b) is equiaxed grain and gradually converts into columnar grain at weld edges (b and c), following the heat flow direction. The eutectic structure has the good characteristic of little segregation, low fluidity and little constriction. Dendritic segregation is expected to occur, both to the interdendritic regions within individual grains and to the boundaries between the columnar grains. Since beryllium is almost immiscible in aluminum, the alloy is virtually a composite material with beryllium phase embedded in the aluminum matrix. The interaction of the two phases in response to an external stress plays a key role in controlling the plastic properties of the composites.

Crack in weldments

Conduction mode welds and keyhole mode welds were utilized to produce specimens. Figs. 2 and 3. displays the morphologies of conduction mode and keyhole

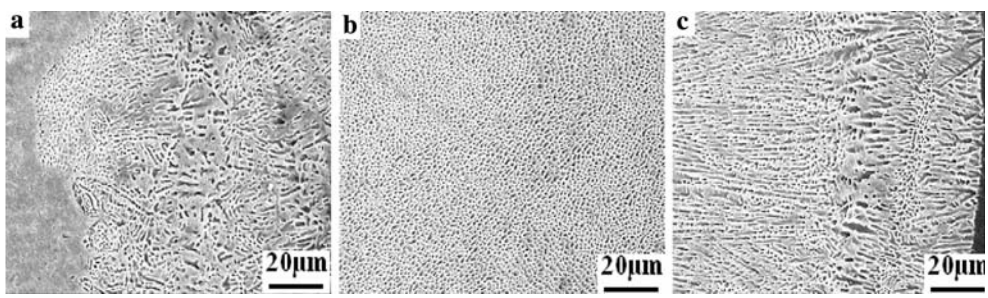


Fig. 1 SEM micrograph showing microstructure of fusion zone, (**a**) at Al 1 mm from center of the weldment,(**b**) center of the weldment, (**c**) at Be 1 mm from weld region

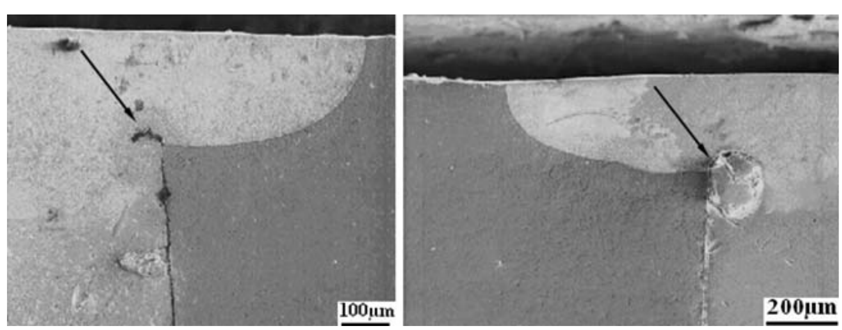


Fig. 2 Low magnification SEM micrographs of conduction mode weldments, the cracks are shown by arrows

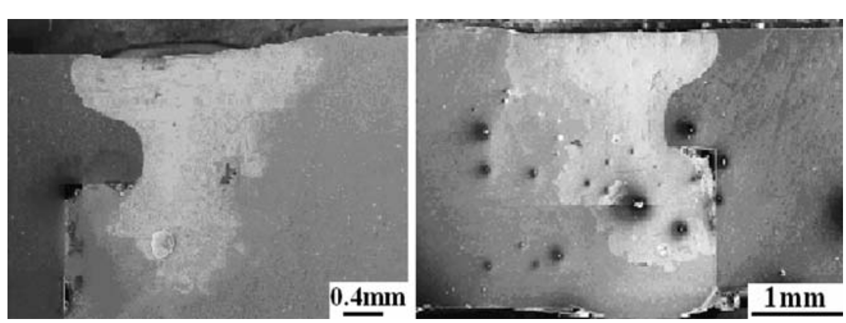
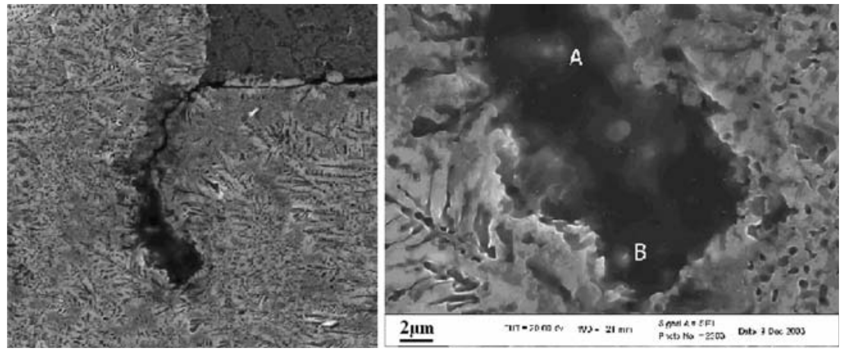


Fig. 3 Low magnification SEM micrographs of keyhole mode weldments

Fig. 4 Sketch map of selecting dots at crack



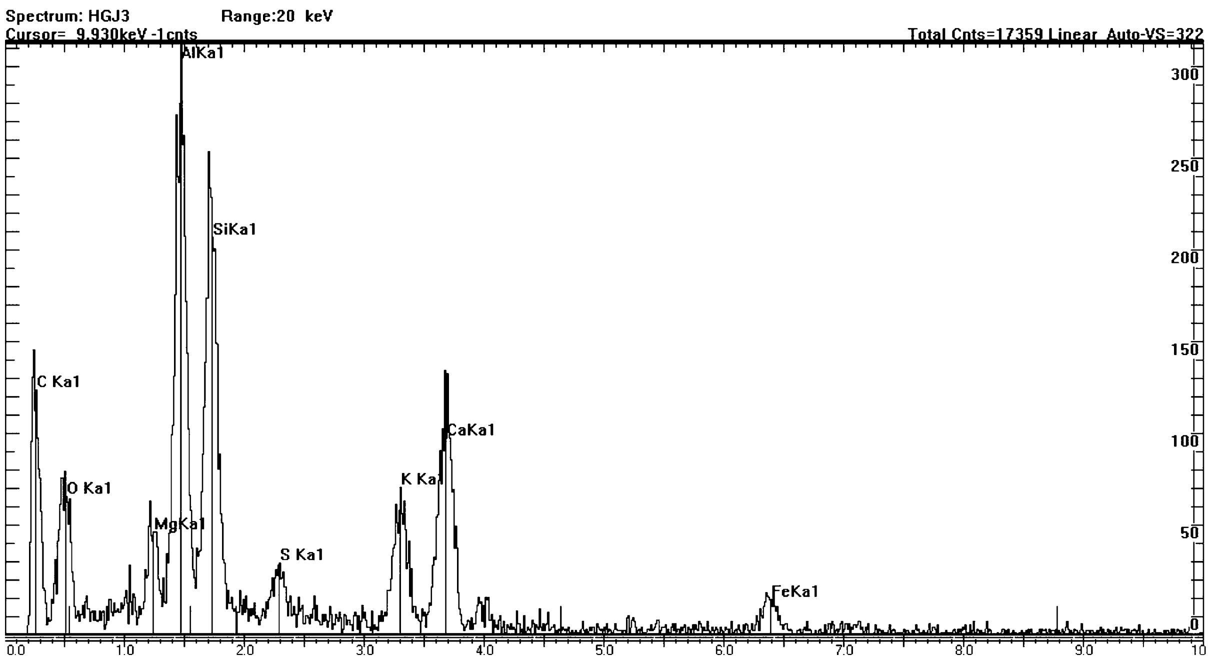


Fig. 5 EDS spectra from weld crack at **A** point

mode weldments, respectively. In Fig. 2, it is clear that the welding cracks easily nucleate at root of welds as shown by arrows. The element Al will give rise to a low-melting-point constituent, forming a binary eutectic with Be at 644 °C. This represents a reduction in melting temperature compared to Al. The large difference of the melting temperatures of Al and Be, enlarges solidification temperature region of fusion zone, and brings great thermal stress, especially at the root of welds. Thermal stress easily concentrates at welds root [12], and lead to the crack nucleates. The examination of the fusion zone crack regions revealed the cracking was a result of thermal stress, shape of welds root and impurities segregation. The SEM/EDS analysis of the crack is shown in Fig. 4–6.

The EDX analysis near such crack of a conduction mode weld sample shows that the principle impurities present (not considering Be), are C, Si, S, Ca, Fe. These elements are expected to segregate to the final liquid to freeze during solidification. Although the solidification reaction of interest involves an uncharacterized multicomponent system, precluding a definitive analysis in terms of the phase diagram, some information can be gleaned from the available binary and ternary diagrams. With the exception of Al and Si, these impurities are likely present as beryllide compounds. Of these elements, only Fe exhibits any measurable solubility at lower temperatures, approximately 0.04 at pct at 600 °C [7]. Impurity elements with equilibrium partition coefficients less than unity are pushed ahead of the advancing Be solid/liquid interface during solidification. This is characterized by a negative liquidus slope. According to the EDX analysis, the impurities are not being found in the fusion zone except for the crack at the root of weld. These impurities are expected to segregate to the root of

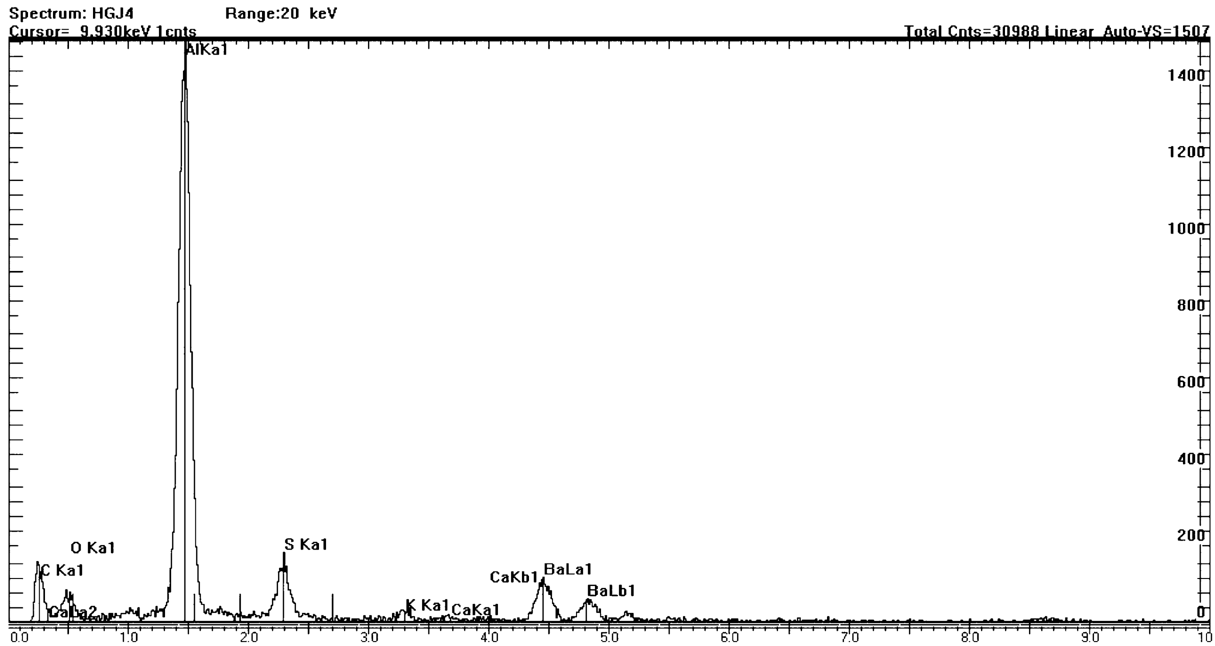
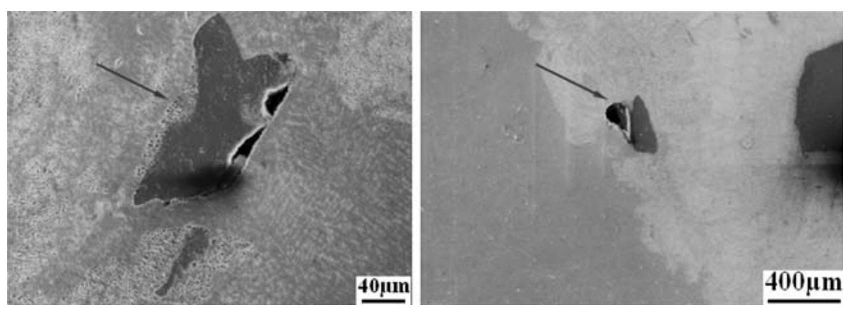


Fig. 6 EDS spectra from welds crack at **B** point

Fig. 7 Excursion beryllium and gas hole in the fusion zone by keyhole mode weld, the arrows show the excursion beryllium



weld. The segregation will reduce the ductility of the materials and augments the tendency of crack nucleate.

Some specimens were produced by keyhole mode weld. The appearance of the joint is shown in Fig. 3. The examination revealed that the main limitations are blowholes. While some other defects maybe made in the keyhole mode, which are some excursions of beryllium in the fusion of Be-Al eutectic, excursions of beryllium usually coexist with some blowholes, as shown in Fig. 7, the arrows indicate the excursions of beryllium. The defects, such as blowholes and excursions, of the keyhole mode are due to the characteristics of high average peak power density and a deep melt pool. Thus to obtain a good weldment, an optimized peak power density should be selected in the keyhole mode weld.

Conclusions

An investigation of weld defects in Be/Al Nd:YAG laser welds has revealed that the defects easily nucleate at the root of the weld. Closer examination of the fusion zone crack regions revealed the cracking was a result of thermal stress, shape of weld roots and impurities segregation. The defects are related to the weld parameters, the crack easily nucleate at conduction mode weld and blowholes easily appear at keyhole mode weld.

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