

Microstructural Observations of Arc Welded Boron-Aluminum Composites

Investigation indicates it may be possible to join B/Al composites by arc welding

BY J. R. KENNEDY

ABSTRACT. Welding studies were conducted on boron-aluminum (B/Al) composites to observe the effects of gas tungsten-arc welding on the boron reinforcing filaments and aluminum matrix. The objective of this investigation was to determine the basic potential of arc welding B/Al composites for possible structural applications. Microstructural observations after welding revealed matrix fusion without apparent boron filament damage. Analysis of weld metal regions indicated that aluminum filler metal additions intermixed with the matrix and altered its chemical composition. It is concluded that arc welding of B/Al composites may be possible by control of welding energy input.

Introduction

Exposure of boron filaments to molten aluminum raises the question of chemical reactivity and its effect on filament properties. Boron-aluminum interactions are time-temperature dependent and may be sluggish in the solid state, or very rapid in the presence of a superheated liquid aluminum matrix. Thermal treatments

such as diffusion welding, casting, and arc welding may induce various interfacial reactions detrimental to filament strength and composite structural efficiency. For example, it has been found that amorphous boron dissolves noticeably in molten aluminum at 1000 C.¹ In other work on cast boron-aluminum composites, several minutes of exposure to molten aluminum at about 740 C caused considerable interaction leading to partial dissolution and edge scalloping of the boron-filaments.² It was also determined² that exposures up to three minutes at 740 C resulted in minimal observable reaction effects.

In a study of the interaction between boron and aluminum,³ boron

filaments were placed in molten aluminum at 680 C. After exposure times of 1 min and 15 min, interaction layers were measured at 2-3 μ m and 5 μ m, respectively. In a study of B/Al solid state reactions,⁴ it was found that a time-temperature dependent incubation period exists, after which a loss of strength occurs. In some cases, tensile strength increased during this period, suggesting some beneficial effects of the interfacial reaction. Studies of B/Al interactions during fusion welding have been generally quite limited. It is reported that gas tungsten-arc, electron beam, and plasma welding usually result in severe weld embrittlement and filament degradation.^{5,6} Typical effects on the boron included fil-

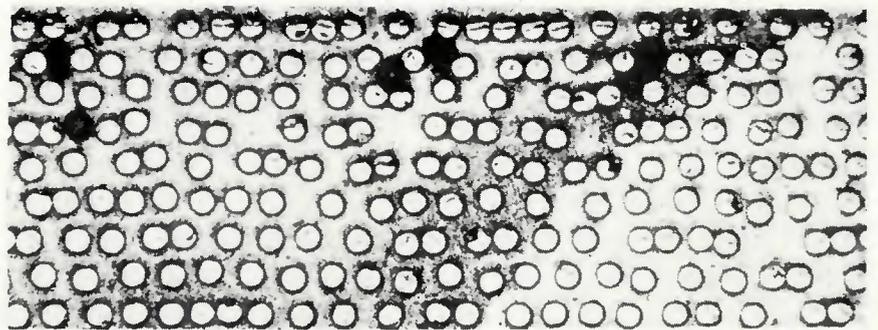


Fig. 1 — Transverse section of arc weld in B/Al, made with 4043 filler wire at 6435 joules. X30, not reduced

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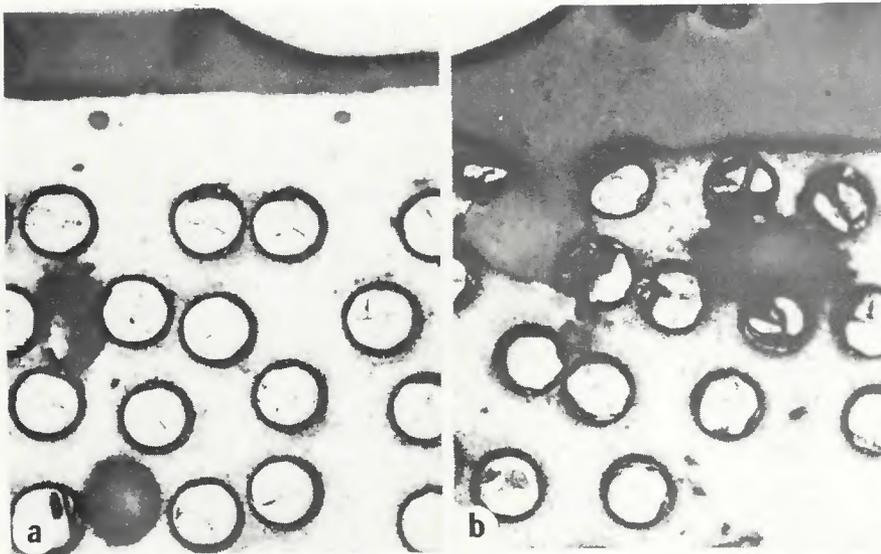


Fig. 2 — Comparison of arc welds made at 6435 joules: (a) 4043 Al filler addition; (b) no filler metal addition, X150, reduced 29%

ament cracking, break-up, misorientation, and partial or complete dissolution. In the worst cases, reductions in composite strength at the weld joint have been as high as 90 percent. On

the other hand, resistance-spot welding of boron-aluminum, which also requires matrix fusion, has shown more promise in minimizing adverse thermal effects on the boron filaments.^{5,8}

The most significant qualitative difference between resistance welding and the other fusion processes is the relatively lower thermal energy input of the former. The influence of welding energy input on interfacial reactions has also been demonstrated in welding studies on titanium-tungsten and titanium-graphite composites.⁹ As welding energy input was increased, tungsten dissolution became greater and titanium carbide formation around the graphite filaments grew thicker. It was concluded that thermal energy delivered to the composite during welding is a significant factor in controlling the nature of filament-matrix reaction products. High welding heats can increase dissolution between components, producing extensive diffusion zones and larger quantities of additional phases. Quantitative evaluation of these effects and their contributions to composite efficiency will be necessary for practical utilization in future applications.

It is clear that the specific effects of short time, high thermal energy exposure on boron-aluminum composites have not been completely characterized. This program was undertaken

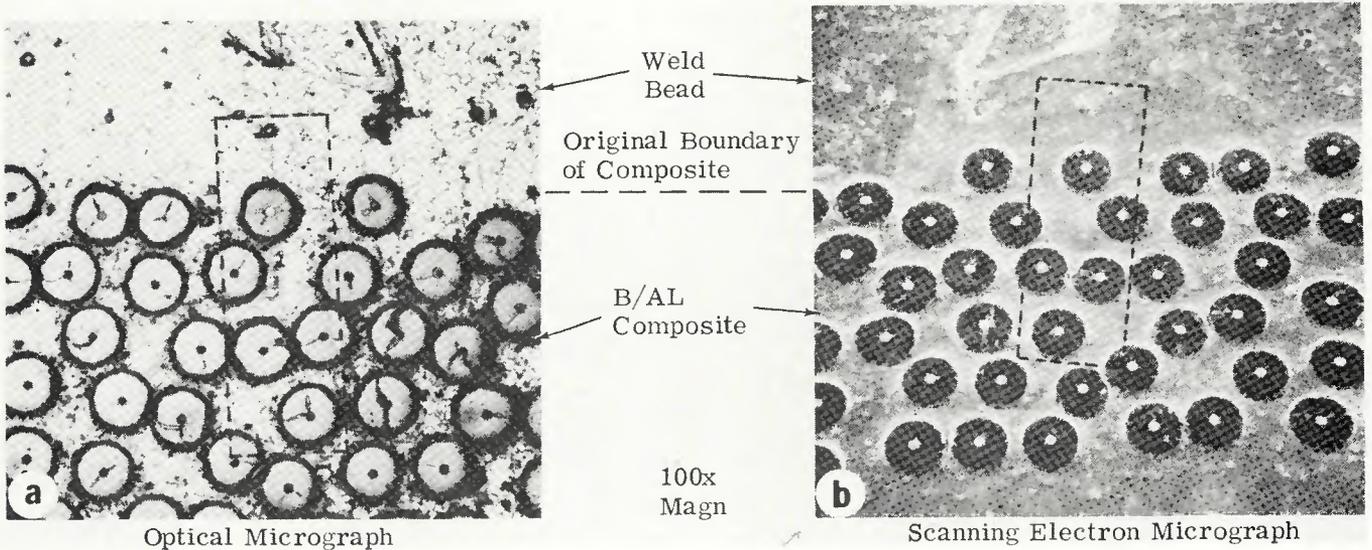
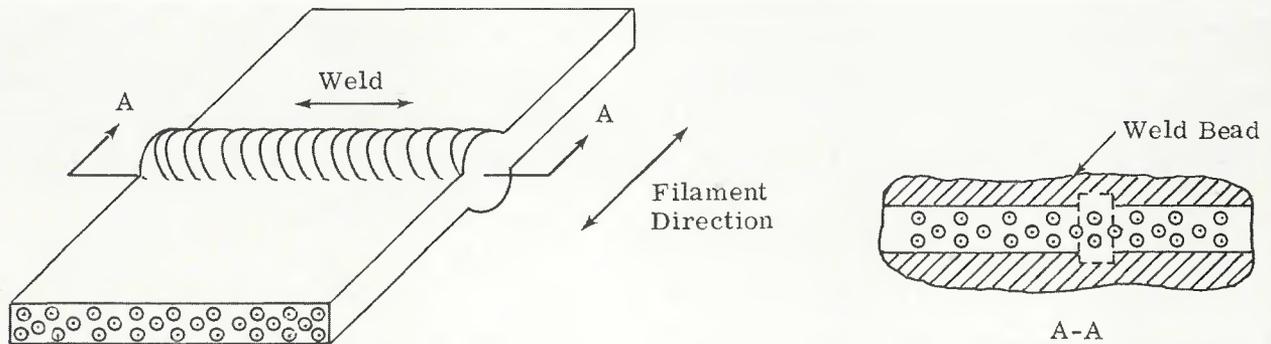


Fig. 3 — B/Al weld region selected for examination: (a) optical micrograph; (b) scanning electron micrograph. X100, reduced 21%

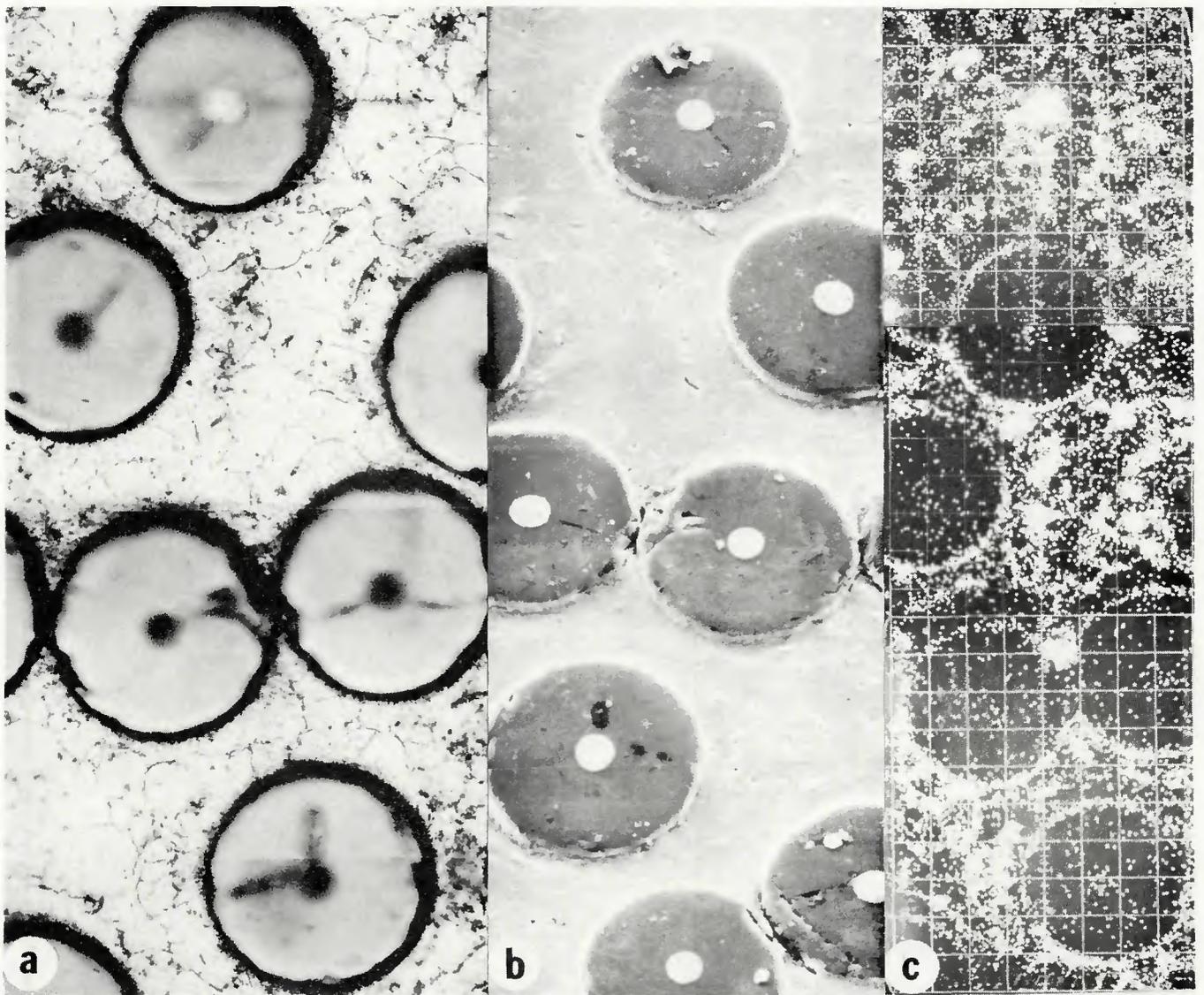


Fig. 4 — Comparison of selected region on arc welded B/Al composite: (a) light micrograph (X500); (b) scanning electron micrograph (X500); (c) silicon distribution electron microprobe (X400). Entire group reduced 35%

to obtain more insight into arc welding of B/Al composites. The present work describes an initial study to observe and to assess qualitatively the condition of boron filaments and aluminum matrix after exposure to gas tungsten-arc welding.

Experimental Procedure

Tests were conducted on 0.025-in. (50%-6 ply) and 0.050-in. (40%-9 ply) thick B/Al composite sheets, made from unidirectionally aligned 0.004-in. diam boron filaments and 6061 aluminum. The composites were fabricated by hot pressing. Arc welding was performed using a standard 300 A ac/dc welding power supply with a manual gas tungsten-arc welding torch. An 0.040 in. diam thoriated tungsten electrode, alternating current, and argon gas shielding were employed during welding. All specimens were bead-on-sheet welds;

when filler metal was added during welding, 1/16-in. diam 4043 aluminum wire was employed.

Immediately prior to welding, the B/Al specimens were degreased by cloth wiping with isopropyl alcohol, followed by a light surface milling in the intended fusion region with a hand draw file. The specimens were clamped in a copper welding fixture with a 1/4-in. space between the hold-down bars. A copper backing bar with a 1/4-in. wide x 1/16-in. deep groove was also used.

Specimens were metallographically prepared by minimizing final polishing time, first with diamond to $1\mu\text{m}$, and then with alumina to $0.05\mu\text{m}$. Boron filaments were also extracted for examination by leaching the aluminum matrix with dilute hydrochloric acid.

In addition to optical microscope observation of composite microstructures, scanning electron microscopy

(SEM) was performed with a Cambridge Stereo-Scan instrument, and electron microprobe analysis was conducted with a Philips AMR-3 analyzer.



Fig. 5 — B/Al interface in weld region

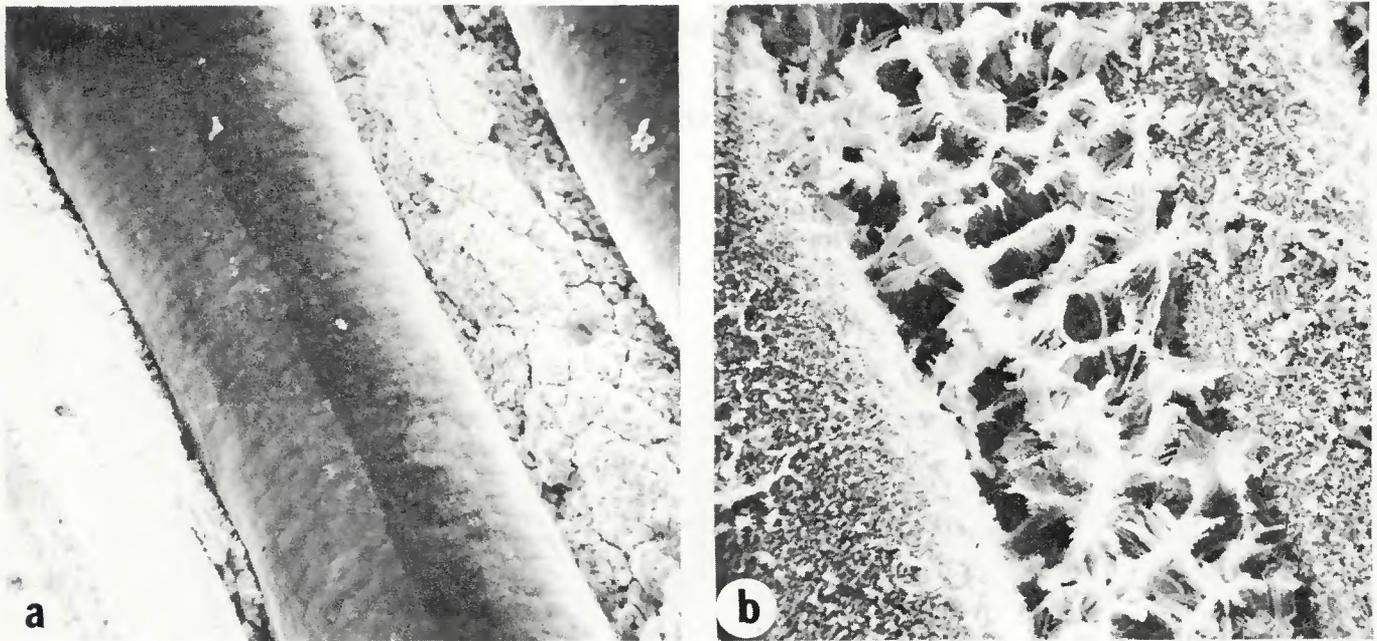


Fig. 6 — Scanning electron micrographs of exposed boron filaments: (a) as received; (b) as welded. Both X400, reduced 5%

Results and Discussion

The effect of increases in welding energy input on 0.050-in. thick B/Al composite was studied. The specimens used for this study were 1/4-in. wide and 2-in. long; they were clamped and welded from one side only under a stationary arc, essentially producing a localized arc spot weld. Under these conditions, the energy input (joules) is the product of arc power and fusion time ($A \times V \times sec$).

Welding With and Without Filler Metal

A transverse section of a weld made with 4043 Al filler addition at 6435 joules (26 A, 16.5 V, 15 sec) is shown in Fig. 1. Large pores were formed in the weld metal interior, as contrasted to fine pores in the weld crown. Matrix melting has caused some shifting of the boron filaments in the fusion zone. A comparison of two welds made at 6435 joules with and without filler metal is shown in Fig. 2. These results generally typify the entire group of specimens made in this study that were welded up to energy levels of 18,000 joules. When filler metal was not added, the upper boron filaments were subjected to intense arc heating that caused severe filament fragmentation and dissolution. In addition, the difficulty in maintaining a stable weld puddle increased, usually resulting in the aluminum's being drawn away from the puddle center to its edges, indicative of poor wetting between boron and aluminum.

On the other hand, these problems were largely eliminated when filler metal was present. Apparently, the additional Si-enriched filler metal helps to shield the top layers of boron and promotes metal flow into the matrix, as evidenced by the penetration observed in Fig. 1. Due to the limited scope of this initial work, a full spectrum of fusion effects have not been determined. This includes the effects of higher energy inputs, the welding of thicker sheet, and the effect of longer passes. However, it is known qualitatively that excessive energy inputs will cause significant filament damage and displacement regardless of filler metal additions.

It should be noted that a certain percentage of filament damage, such as radial cracking and contact fragmentation, as shown in Figs. 2 and 4, is considered "normal" and also exists to varying degrees in as-received and welded B/Al composite sheet. This damage is believed to occur during primary fabrication of the composite.

Microstructural Examination

An analysis was made of the microstructure from an arc welded bead-on-sheet specimen of 0.025-in. thick B/Al, shown schematically in Fig. 3. This specimen was welded from both sides (not simultaneously) using 4043 Al filler addition, at an energy level of about 4950 joules/in. (20 A, 16.5 V, 4 ipm). A weld region was randomly selected from this specimen for subsequent examination by various techniques, as shown in Fig. 4. Our interest was to observe particular effects on the boron and the matrix

resulting from this exposure. In Figs. 3 and 4, the SEM region shows the filaments intact within an apparently sound matrix.

The distinct grain boundaries in the matrix are clearly evident in the light microscopy photograph of Fig. 4. The presence of Si in this region is confirmed by the microprobe analysis that shows a definite correlation between the grain boundaries and Si-rich regions. It can also be noted that the Si distribution is relatively uniform through the specimen thickness. The average Si concentration after welding was calculated to be about 4.7%; the Si concentration in unwelded as-received composites was 0.58%. The nominal Si distribution in 4043 Al filler metal is 5% and in 6061 Al about 0.5%.

The matrix appears to have been completely melted and fairly uniformly enriched with filler metal, while the filaments remained apparently undamaged. This microstructure appears to be typical of a Si-rich condition in aluminum welds and castings,^{10,11} where relative insolubility of Si in Al causes dispersion of small areas of Al-Si eutectic in the Al matrix and grain boundary enrichment. A Si layer or ring is also seen immediately adjacent to each filament (in some cases, a double Si ring is apparent). It is likely that as freezing progressed in the matrix, a solidification front rich in Si advanced to the filament periphery where the Si then segregated as along a grain boundary.

After being polished and etched, the boron usually stands slightly in

relief above the matrix, making sharp planar focusing of both B and Al difficult with the optical microscope; this results in the characteristic shadowing around each filament.

Examination of the B/Al interfacial region at higher SEM magnifications revealed a portion of the interface configuration to be in the form of a small concave fillet between the filament and matrix, as shown in Fig. 5. A somewhat rough or jagged texture was also discernible in the transition zone vicinity of various filaments.

Further SEM observation of B/Al interactions was made on welded specimens in which the matrix was leached to expose boron filaments. Figure 6 is a comparison between as-received and as-welded B/Al composite. In the welded specimen, to which 4043 Al filler was added, the variable mottled surface texture of the boron filaments is evident. The filigreed matrix between the filaments, resulting from a differential etching rate, probably represents a skeletal grain boundary network, enriched in Si as a result of welding.

Subsequent electron microprobe analysis showed these areas to be Si rich relative to the as-received composite. Microprobe scans over the filaments in the welded specimen also showed significant concentrations of Al and Si. The work by Klein⁴ on solid state reactions in B/Al composites showed that the interaction

phase has an uneven, acicular appearance with the needlelike protrusions into the matrix. The interaction product in that work has been tentatively identified as AlB_2 . The reaction product in the welded condition has not yet been identified, but the presence of a combination of complex intermetallic compounds is not unlikely.

Conclusions

It has been shown that thin-sheet B/Al composites can be subjected to certain arc welding thermal conditions without severely damaging the boron filaments. It is possible to add and to intermix filler metal through the matrix to alter its chemical composition significantly. These results indicate that arc welding of B/Al may be possible by control of welding energy input. Identification of the subsequent fusion reaction products, and the effects of those products on composite mechanical properties, has not yet been determined but is planned in continuing studies. In addition, knowledge of reaction growth rate kinetics and the means to control the reaction products during welding would increase the potential of B/Al for consideration as welded structures.

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"Microstructure-Property Control with Postweld Heat Treatment of Ti-6Al-5V-2Sn" by R. P. Simpson, Air Force Materials Laboratory, and K. C. Wu, Northrop Corp.

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