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Characterization of friction stir welded boron carbide particulate reinforced AA6061 aluminum alloy stir cast composite

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ABSTRACT

Development of welding procedures to join aluminum matrix composite (AMCs) holds the key to replace conventional aluminum alloys in many applications. In this research work, AA6061/B_4C AMC was produced using stir casting route with the aid of K_2TiF_6 flux. Plates of 6 mm thickness were prepared from the castings and successfully butt joined using friction stir welding (FSW). The FSW was carried out using a tool rotational speed of 1000 rpm, welding speed of 80 mm/min and axial force of 10 kN. A tool made of high carbon high chromium steel with square pin profile was used. The microstructure of the welded joint was characterized using optical and scanning electron microscopy. The welded joint showed the presence of four zones typically observed in FSW of aluminum alloys. The weld zone showed fine grains and homogeneous distribution of B_4C particles. A joint efficiency of 93.4% was realized under the experimental conditions. But, FSW reduced the ductility of the composite.

1. Introduction

Aluminum matrix composites (AMCs) have captured the attention of the materials community to a large extent. AMCs combine the advantages of aluminum alloys and the special properties of ceramic particles [1]. AMCs possess high specific stiffness, high strength to weight ratio at room or elevated temperatures, excellent fatigue properties, high formability and improved wear resistance [2,3]. AMCs have become a major focus in aircraft, automotive and marine industries due to those excellent properties. But, the replacement of conventional aluminum alloys with AMCs in many applications in the above said industries demands the development of secondary processes such as machining and joining of AMCs [4].

Welding of AMCs using conventional fusion methods degrades the joint properties due to solidification induced structure and chemical reactions [5]. The difference in densities between the matrix and reinforcement materials results in particle segregation. It is difficult to retain the distribution of ceramic particles in the weld zone compared to that of parent composite. The high viscosity of the composite material inhibits material flow which creates a nonuniform distribution of weld stress reducing the joint strength. The heat input during fusion welding often initiates reactions between aluminum matrix and ceramic particles which forms brittle intermetallic compounds in the weld zone. The fusion welded joint is further susceptible to porosity [6–9]. Therefore it is suggested to use solid state welding methods to join AMCs to eliminate those defects. Friction stir welding (FSW) has emerged as a preferred solid state welding method to join AMCs [10].

FSW was invented at The Welding Institute (TWI), UK in 1991. A nonconsumable rotating tool harder than the base material is plunged into the abutting edges of the plates to be joined under sufficient axial force and advanced along the line of the joint. The tool consists of two parts namely shoulder and pin. The material around the tool pin is softened by the frictional heat generated by the tool rotation. Advancement of the tool pushes plastically deformed material from front to back of the tool and forges to complete the joining process [11,12]. Since FSW is a solid state process, a solidification induced structure is absent in the weld zone. Therefore, all the defects related to fusion welding methods are overcome [13].

Some studies on FSW of AMCs reinforced with various ceramic particulates were reported in literatures in recent years [14–23]. Chen et al. [14] studied the microstructure of friction stir welded AA6063/(6, 10.5 vol.%) B_4C and observed substantial grain refinement of aluminum matrix in the weld zone. Vijay and Murugan [15] estimated the effect of various tool pin profiles on microstructural evaluation of friction stir welded AA6061/10 wt.% TiB_2 and reported that the square pin profile yielded higher tensile strength and finer grains in the weld zone. Nami et al. [16] assessed the

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Table 1
The chemical composition of AA6061-T6 alloy.

Element	Mg	Si	Fe	Mn	Cu	Cr	Zn	Ni	Ti	Aluminum
wt.%	0.95	0.54	0.22	0.13	0.17	0.09	0.08	0.02	0.01	Balance

effect of tool rotational speed on microstructure of friction stir welded AA6061/15 wt.% Mg_2Si and noticed defects in the weld zone at higher tool rotational speeds. Gopalakrishnan and Murugan [17] developed a mathematical model to predict the tensile strength friction stir welded AA6061/(3–7 wt.%) TiC. Guo et al. [18] applied electron back scattered diffraction technique to precisely reveal the grain size of friction stir welded AA1100/16 vol.% B_4C. Bozkurt et al. [19] evaluated the microstructure of friction stir welded AA2124/25 vol.% SiC in detail and observed cracking of SiC particles and traces of SiO_2 phase in the weld zone. Dinaharan and Murugan [20] analyzed the effect of FSW on microstructure and other properties of AA6061/(0–10 wt.%) ZrB_2 and recorded that FSW shattered the cluster of particles in the parent composite into fine particles of different sizes. Guo et al. [21] noted breakage and fragmentation of particles in friction stir welded AA1100/(16 and 30 vol.%) B_4C. Periyasamy et al. [22] investigated the effect of heat input on microstructure and mechanical properties of friction stir welded AA6061/10 vol.% SiC. Wang et al. [23] obtained enhanced distribution of SiC particles in the weld zone of friction stir welded AA2009/15 vol.% SiC.

The objective of this work is to study the effect of FSW on microstructure and mechanical properties of AA6061/12 wt.% B_4C AMC. The microstructure and properties of as-cast AA6061 are compared with the prepared AMC to comprehend the effect of B_4C particle and FSW. B_4C is a potential reinforcement which has excellent chemical and thermal stability, high hardness and low density and is used for manufacturing of armor tank, neutron shielding material, etc. [24].

2. Experimental procedure

AA6061 rods were melted in an electrical furnace using a coated graphite crucible. The chemical composition and optical photomicrograph of aluminum alloy AA6061-T6 are respectively presented in Table 1 and Fig. 1. The melt was agitated with the help of a mechanical stirrer to form a fine vortex. The mixtures of preheated B_4C particles with an equivalent amount of K_2TiF_6 flux (with 0.1Ti/B_4C ratio) were added at a constant feed rate into the vortex. Argon gas was supplied into the melt during the operation to provide an inert atmosphere. After stirring the molten mixture, it was poured down into the preheated permanent mold. The temperature of the melt was maintained at 860 °C. Castings were taken with various weight percentages (0 and 12 wt.%) of B_4C particles. A detailed fabrication procedure is available elsewhere [25,26].

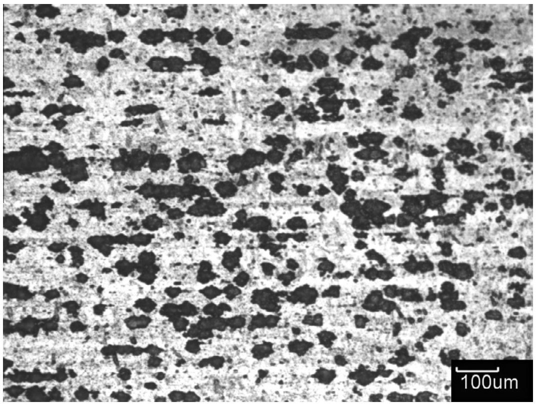

Fig. 1. Optical photomicrograph of as received AA6061-T6 extruded rod.

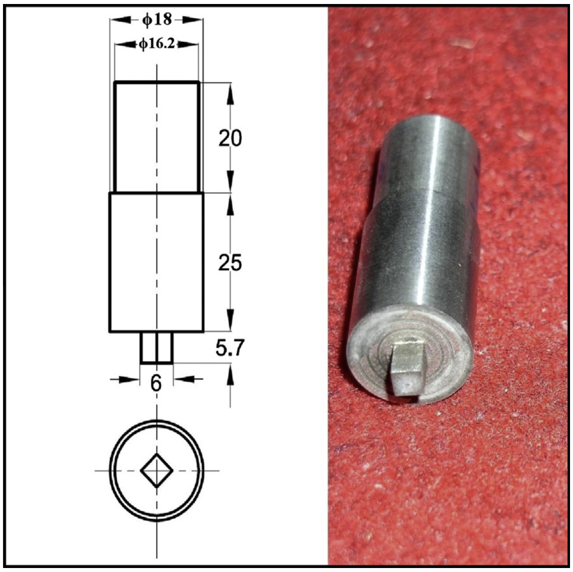

Fig. 2. Dimensions and fabricated friction stir welding tool.

Plates of size 100 × 50 × 6 mm were prepared from each casting. The butt welding of AA6061/B_4C composites was carried out semi automatically on an indigenously built FSW machine (M/s RV Machine Tools, Coimbatore, INDIA). A tool made of high carbon high chromium steel oil hardened to 62 HRC with square pin profile was used [15]. The dimensions and fabricated tool are shown in Fig. 2. The joints were fabricated at a tool rotational speed of 1000 rpm, welding speed of 80 mm/min and axial force of 10 kN. The parameters were chosen based on several trail runs to produce a defect free weld. Typical FSW defects such as tunnel, pin hole, void, worm hole and piping as shown in Fig. 3 were observed on the trail welded plates.

Specimens were cut from the welded plates to carry out microstructural and mechanical characterization. The specimens were prepared as per standard metallographic procedure and etched with Keller's reagent. The digital image of the macrostructure of the etched specimen was captured using a digital optical scanner. The microstructure was observed using an optical microscope (OLYMPUS-BX51 M) and a scanning electron microscope (JEOL-JSM-6390). X-ray diffraction patterns (XRD) were recorded using Panalytical X-ray diffractometer. The microhardness was measured using a microhardness tester (MITUTOYO-MVK-H1) at 500 g load applied for 15 s. The tensile specimens were prepared as per ASTM: E8M-13a standard having a gauge length of 40 mm, a gauge width of 7 mm and a thickness of 6 mm. The ultimate tensile strength (UTS) was estimated using a computerized universal testing machine (HITECH TUE-C-1000).

3. Results and discussion

3.1. Macrostructure and microstructure of the welded joint

AA6061/B_4C AMC plates of 6 mm thickness were successfully butt welded by FSW. A typical welded plate is shown in Fig. 4.