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Transient liquid phase diffusion bonding of 6061-15 wt% SiCp in argon environment

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ABSTRACT

Extruded 6061-15 wt% SiCp composite was joined by transient liquid phase diffusion (TLPD) bonding process in argon environment using 50-μm thick copper foil interlayer. The bonding was carried out at 560 °C with two different applied pressures (0.1 and 0.2 MPa) and five different holding times (20 min, 1, 2, 3 and 6 h). Kinetics of the bonding process was significantly accelerated in the presence of reinforcement (SiC). This acceleration is attributed to the increased solute diffusivity through defect-rich SiC particle/matrix interface and porosity. Adequate bond strength (90% of the original composite strength) was achieved for bonding at 0.2 MPa pressure with 6 h of holding. This is very close to the reported highest bond strength achieved (92% of the original composite strength) for joining aluminium-based metal matrix composite by TLPD process in vacuum followed by isostatic pressing. The rejection of oxide at periphery on completion of isothermal solidification, and elimination of void at bond interface through solid state diffusion at higher pressure (0.2 MPa) were the main reasons of achieving high bond strength.

1. Introduction

A major problem in widespread industrial application of aluminium-based metal matrix composite (AlMMC) is the difficulty encountered in joining (Ellis, 1997). Mechanical fastening (bolting or riveting), fusion welding and solid state diffusion bonding of such composites involve several difficulties such as damage of reinforcement (for mechanical fastening); formation of brittle phase (Al_4C_3), HAZ cracking and weld porosity (for fusion welding); and excessive plastic deformation under high applied pressure (for solid-state diffusion bonding) (Bushby and Scott, 1995; Devletian, 1987; Field, 1989; Gittos and Threadgill, 1991; Hall and Manrique, 1995; Luhman et al., 1983; Shirzadi and Wallach, 1997). The transient liquid phase diffusion (TLPD) bonding process which employs an 'interlayer' (often a pure metal) for the formation of low melting point composition (e.g. eutectic), has the advantage of lower bonding temperature, lower bonding pressure and less surface finish requirement than solid-state diffusion bonding. However, completion of the TLPD bonding process requires a long time mainly due to isothermal solidification stage (Natsume et al., 2003). Commercial application of this technique requires adequate bond strength development with regard

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to understanding the microstructural variation and process kinetics.

Although a number of investigations have been carried out on TLPD bonding of different monolithic metals and alloys, reports on the TLPD bonding of AlMMCs are limited. Among different interlayer used in TLPD bonding of monolithic aluminium-based alloys, the use of copper interlayer has proved to be successful for joining conventional aluminium alloys, and bond strength comparable to that of the parent material has been reported (Dray, 1985). Again, the published literature on TLPD bonding of AlMMCs mainly dealt with the development of bonding conditions using different thickness of copper interlayer in order to achieve adequate bond strength. While studying TLPD bonding of SiC fiber reinforced AlMMC with 10-μm thick copper interlayer at 550 °C in air environment, it has been reported by Bushby and Scott (1993) that higher bonding pressure (20 MPa) was necessary in order to limit oxidation of copper and maximize the bonded area to 80%. On the other hand, bond strength of 92% of the parent material strength was achieved by Shirzadi and Wallach (1997) for joining AlMMC by TLPD process at 560 °C, 0.1–0.2 MPa pressure, using a 7-μm thick copper interlayer with 20 min bonding time in vacuum followed by isostatic pressing. In other investigation, using mixed powder interlayer (Al–Si–SiC–Ti), bond strength of 50 MPa was achieved by Huang et al. (2007) for joining 6063–SiCp composite by TLPD process in vacuum at 595 °C, 0.003 MPa, with a bonding time of 90 min. Whereas in argon environment, bond strength of 68 MPa was achieved by one of the present authors (Pal, 2005) for joining extruded 6061-15 wt% SiCp using copper powder interlayer at 560 °C, 2 MPa, with a bonding time of 20 min. In most of these studies of TLPD bonding using copper interlayer, bonding temperature was kept at 550–560 °C, which is slightly above the eutectic temperature of Al–Cu system (548 °C) and below the solidus temperature of AlMMC. However, different pressures were used for bonding performed under different conditions. TLPD bonding in air environment requires very high-pressure application (20 MPa) in order to achieve metal-to-metal contact at bond interface (Bushby and Scott, 1993). The high pressure causes excessive plastic deformation of AlMMC, which is not desired. Therefore, conventional TLPD bonding is performed at lower pressure (0.1–0.2 MPa) in vacuum or inert environment in order to achieve adequate bond strength without plastic deformation. Again, for low pressure conventional TLPD bonding in vacuum with lower bonding time (20 min), presence of void at bond interface has been identified by Shirzadi and Wallach (1997). These voids were responsible for lowering down the bond strength to a certain extent. The low pressure bonding with lower time of holding (20 min) was followed by isostatic pressing to achieve high bond strength. However, the low pressure TLPD bonding with higher bonding time (say, 6 h) has not been studied for AlMMC. Moreover, in all these investigations of TLPD bonding of AlMMC, no explicit correlation was made between bond microstructure and different stages of the process. Also, bonding time was kept low (maximum 2 h) without any correlation with the completion of isothermal solidification or homogenization of bond region, and no comparison of process kinetics was made with monolithic system. Present investigation aims at developing adequate bond strength for extruded 6061-15 wt% SiCp composite, by TLPD process in argon environment, with regard to process mechanism and microstructural evaluation, for different bonding times up to 6 h.

Table 1 – Chemical composition of 6061 alloy (wt%)

Mg	1.0
Si	0.6
Cu	0.3
Cr	0.2
Al	Rest

2. Materials and methods

2.1. Material

As-received material was an extruded rod of AlMMC consisting of 6061 matrix alloy and 15 wt% (12.93 vol%) silicon carbide (SiC) particulate reinforcement of 23 μm average size. The nominal composition of 6061 alloy (Anon., 1990) is given in Table 1. In addition it contains some iron (0.6 wt%) as an impurity which was confirmed by chemical analysis in optical emission spectrometer (UNISPEC: 4L/0096). The density of as-received AlMMC was also measured by water displacement method.

2.2. Specimen preparation for bonding

The extruded rod was machined to produce discs of 15 mm diameter and 10 mm height. As a result the faying surfaces of discs became perpendicular to the extrusion direction. The faying surfaces of discs were polished to 1 μm finish. Pure copper (99.97 wt%) foil of 50 μm thickness was used as interlayer. The interlayer was punched out to a diameter of 15 mm for bonding. The interlayer and polished faying surfaces of discs were finally rinsed in acetone and dried by a hot air blast just before bonding.

2.3. TLPD bonding

The interlayer was placed between the polished faying surfaces of the two AlMMC discs. This assembly was then set by an adhesive tape and inserted inside the diffusion bonding unit. The bonding was carried out in a programmable electric furnace keeping bond centerline horizontal. A thermocouple inserted into the drilled hole in one of each pair of discs was used to monitor bonding temperature. The argon gas (99.99% Ar, 3–5 ppm O_2, 3 ppm H_2O, 2 ppm H_2, 1 ppm CO_2, 1 ppm CO) was flown into the bonding chamber at a rate 5 l/min to maintain inert atmosphere. The bonding temperature was kept at 560 °C which is above the eutectic temperature (548 °C) of Al–Cu system (Anon., 1992) and below the solidus temperature (582 °C) of 6061 matrix alloy (Anon., 1990). The specimens were heated to the bonding temperature (560 °C) at a rate of 6 °C/min, held at that temperature for five different lengths of time (bonding time), viz. 20 min, 1, 2, 3 and 6 h, and cooled down to 540 °C at a rate of 5 °C/min inside the furnace. Then the specimens were taken out of the furnace and cooled in still air to the room temperature. Two different pressures, 0.1 and 0.2 MPa, were applied for bonding.