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Evaluation of interface bonding strength of aluminum/silicon carbide

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Abstract The quality of interface bonding between matrix and reinforcement is important in composite strengthening. Interface bonding strength of particulate reinforced metal matrix composites were investigated by joining process. The aluminum/silicon carbide specimens were prepared by different processing temperature with constant holding time. The structural morphologies have been evaluated by using scanning electron microscope and interfacial products were identified by using energy dispersive spectroscopy. The interface strength has been evaluated by tensile test and microhardness test.

Keywords Interface bonding strength · Metal matrix composites · SEM · EDS

1 Introduction

Metal matrix composites (MMCs) are known to have high strength, light weight, and high temperature stability. In MMCs, interface and interface region plays a crucial role to determine the mechanical properties, such as strength, ductility, and toughness, etc. [1]. The strengthening of composites is owing to the effective bonding at the interface of matrix and reinforcement. It is believed that strong interface bond permits and distribute load from the matrix to reinforcement which resulting in increase in elastic modulus and strength [2]. The nature of interface bonding depends on the several factors that can influence on the interfacial behavior of the composites. These factors are fabrication method, reaction products in the interface, surface of reinforcement, and composition of matrix alloys [3].

There are number of studies that have been conducted in developing and understanding the various techniques for the fabrication of Al/SiC_p composites and correlating the interface structure and mechanical behavior of MMCs. Liquid state processing is done above the melting temperature of the matrix alloy to get enough viscosity for the casting process. Hence, the high temperature also causes various defects such as porosity, oxide film, and formation of reaction products at the interface [4]. The chemical reaction product forms at the interface of liquid aluminum and SiC during high temperature processing. This product reduces the strength of the composites. The chemical reaction product formed either continuous layer or as discrete precipitates around the SiC particles according to following equation [5]: $4Al_{(l)} + 3SiC_{(s)} \rightarrow Al_4C_3 + 3Si$, and it degrades properties of MMCs owing to interface product behaves as brittle manner and it increases corrosion. The rate of chemical reaction between liquid aluminum and SiC increases with increase in temperature [6]. Al_4C_3 reaction rate also depend upon the prolonged contact between liquid aluminum and SiC_p. A sufficient amount of bond is possible only when good wetting of the reinforcement by matrix alloy is obtained, and this is very much dependent on the surface properties of reinforcement, composition of matrix, and viscosity of matrix at the processing temperature. The passive oxidation method of the reinforcement has been successful to the extent both for preventing the detrimental interfacial reaction and enhancing the wetting characteristics [7]. The certain levels of Si and Mg are required to improve the wetting behavior [8]. In the present study, the interface bonding strength of 6061 Al/SiC composites were investigated.

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Table 1 Nominal compositions of aluminum

Cu	Si	Mg	Mn	Fe	Ni	Zn	Sn	Pb	Ti	Al
1.83	0.68	0.102	0.221	0.762	0.064	0.786	0.006	0.081	0.036	Balance

The specimens were prepared through melt joining process. The prepolished silicon carbide sections have been made to have contact with molten aluminum and then the couple was allowed to cool as a single unit to preserve the interface for subsequent microstructural evolution. The interface bonding strength of Al/SiC was evaluated by tensile test and hardness test.

2 Experimental procedure

A monolithic, alpha silicon carbide plates were prepared by sintering process. Hot pressing was conducted at a temperature of 1,900°C and pressure of 3,000 psi for 2 h. The samples were fully dense SiC particles with a density of about 3.2 g/cm^3 and elastic modulus is 410 GPa. The silicon carbide plates were cut from the sintered bars by using diamond coated saw cutter. The joining faces were grounded and polished to have flatness. The silicon carbide plate was kept in steel mold and clay graphite crucible was kept over the mold which contains liquid Al. A commercial casting grade of aluminum alloy has been used for the work. The chemical composition of this alloy is given in Table 1. The whole setup was kept in furnace. The experiments were conducted at different temperatures such as 700°C, 750°C, and 800°C and constant holding time of 30 min. The heating rates in the furnace varied from 8°C to 15°C. During the holding time, the liquid aluminum has developed a contact with SiC plate without any force (natural contact).The mold pattern was taken out and cooled in a room temperature. The casting specimen is shown in Fig. 1. The bonded Al/SiC samples were cut from the casting specimen using a low speed diamond cutter. A section through each bond region was metallographically prepared using a standard method. The bond region was examined by optical microscope and scanning electron microscopy (SEM). The intermetallic composition of interface region was analyzed by using energy dispersive spectroscopy (EDS). The tensile strength of the bonded samples were evaluated by FIE tensile machine. The microhardness was measured in the interface region using Wilson Wolpert hardness tester with 500 g load at different location across the interface region.

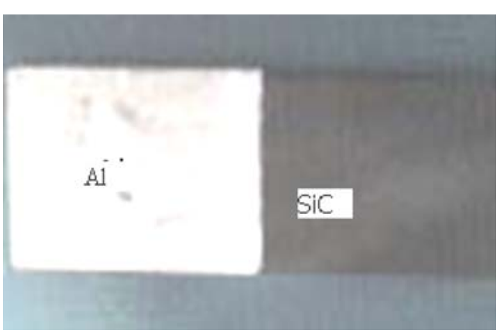

Fig. 1 Bonded aluminum–silicon carbide specimen

3 Results and discussions

3.1 Interface structure analysis of Al/SiC

The bright field and dark field images of the interfacial microstructure of Al/SiC composites are shown in Fig. 2. These images are showing different interface structures. It was observed from the Fig. 2a that no penetration of liquid aluminum in the SiC plate. The other images show the matrix penetrating into solid SiC plate. When the liquid aluminum has contact with solid surface of SiC, the Si atoms are released from the SiC due to chemical reaction between aluminum and SiC. The content of Si was slowly dissolved in liquid matrix due to the following reaction [9]: SiC → Si + C.

The vacancy created in the SiC due to mentioned reaction, the liquid aluminum accumulates in the local zone. The presence of carbon ions then left from the interface and migrates to liquid matrix by diffusion process. This carbon reacts with aluminum to form Al_4C_3 at elevated temperature. This reaction may be suppressed, when enough concentration of element Si in the liquid matrix. The silicon dissolved faster than compared to carbon. The overall silicon content is desirable to enhance wetting between matrix and reinforcement [10] and it also eliminates unwanted chemical reactions. Hence, the presence of Si is controlling the reaction between carbon and aluminum alloy due to low solubility of carbon in the liquid aluminum which contains enough Si. The EDS analysis was conducted at the interface and interface compound was identified. The interface compound consists of Si, C, Mg, and Al in the composite. The quantitative results of interface compounds are given in the Table 2. The Fig. 3 shows the EDS analysis at the interface of Al/SiC processed at 700°C.

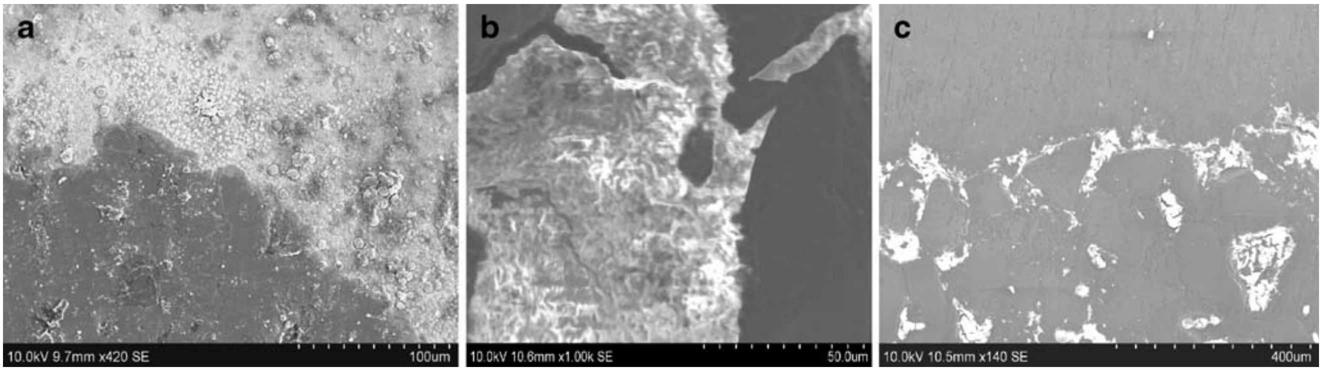

Fig. 2 **a** SEM showing the interface bond between Al/SiC at 700°C. **b** SEM showing the interface bond between Al/SiC at 750°C. **c** SEM showing the interface bond between Al/SiC at 800°C

Table 2 Quantitative results from EDS for Al/SiC interface processed at different processing temperature at 10-min holding time

Temperature °C	Weight % of Elements				
	C	Mg	Al	Si	others
700	19.33	0.12	75.8	4.79	–
750	26.55	0.9	62.5	9.18	–
800	33.71	0.81	52.09	12.42	–

Table 3 Tensile strength of Al/SiC specimen

Materials	Temperature (°C)	Tensile strength (MPa)
6061 Al/SiC	700	0.241
6061 Al/SiC	750	0.352
6061 Al/SiC	800	0.41

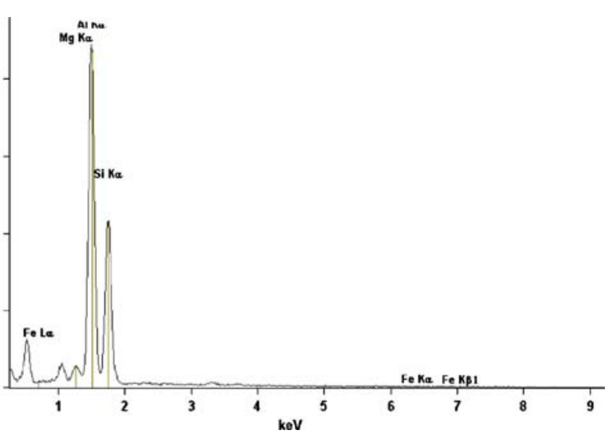

Fig. 3 EDS analysis of interfacial compounds in 6061 Al/SiC at 700°C

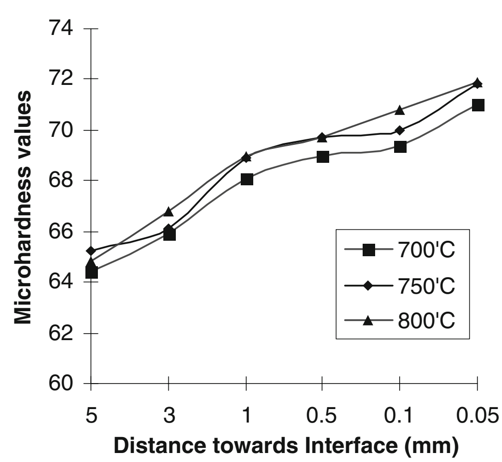

Fig. 4 Microhardness values recorded away from the interface in Al/SiC

3.2 Interface bonding strength of Al/SiC

3.2.1 Tensile strength

The tensile strength of Al/SiC specimens was examined according to ASTM E-338 and test results were tabulated in Table 3. The results revealed that the strength of bond increased gradually with increasing processing temperature due to formation of interface reaction product. It is clear evident that diffusion of Si and carbon content of material react with aluminum and behaves as a brittle manner.

3.2.2 Hardness at the interface

The interface microhardness measurements were made for the present study on the surface region of composites. Figure 4 shows the microhardness distribution in the bond region for the samples processed with different holding temperatures. The hardness measurements have been taken from base (matrix) materials into near the interface. The hardness curves show the hardening strength increased toward interface owing to partially dissolved and dispersion of elements near the interface. The matrix material is a soft material and dispersion of elements materials being contribute to improve composite strengthening near the interface region [11, 12]. There is a similar effect being observed for the all the specimen. The weak interface bond in a composite is enhanced by higher hardness near the interface region. This higher hardness may be caused by a high Si and Al_4C_3 content at the interface region. The EDS analysis shows that the Si and C content are high at the interface region. It is clearly understood that when holding temperature is increased, the Si content is also increased which reduces formation of Al_4C_3 at the interface region of composites.

4 Conclusion

From this study, the following conclusions could be drawn:

- The structural morphologies of interface in the MMCs may be altered by the presence of interfacial compounds at the interface region.
- The higher hardness value associated with near interface region and interface, caused by extensive weak interface bond, thereby reducing ductility of composites.
- The interface bond strength was altered by the partially dissolved and dispersion of elements such as Si, C, and Mg.
- The interface bond strength increases with increase in processing temperature due to increase in concentration of Si at the interface which minimizes to formation of Al_4C_3 the SiC surface.
- The weak interface bonding is attributed by higher hardness at the interface. The hardness of matrix is increased at the interface region due to presence of dissolved silicon and carbon which promotes Al_4C_3 formation.

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