



Study on bimetallic composites interface of Al/SiC_p-Al matrix composites prepared by liquid-liquid compound casting

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ABSTRACT

Aimed at the preparation of bimetallic composites by using a liquid–liquid compound casting method with a sound interface, this study focused on the interface evolution with an increase in the pouring time interval. The results revealed that the melt mixing occurred when the pouring interval was 3 s. The transition zone appeared at the interface when the pouring interval was 10 s, and a good metallurgical bond was obtained. When the pouring interval was 20 s, a discontinuous oxide layer appeared at the interface. The oxide layer gap formed a channel for the transport of the SiC particles.

1. Introduction

A bimetallic composite is a macroscopic composite material which can optimise the chemical, physical, or mechanical properties of different materials and can effectively improve the comprehensive properties of materials. It has considerable potential and application prospects in aerospace, automobile manufacturing, and other fields [1–3]. Bimetallic composites are primarily fabricated using liquid–solid compound casting method [4,5], by which Liu et al. [6] prepared SiC_p/8009–A356 bimetallic composites with excellent wear resistance, corrosion resistance, and formability.

Because an oxide layer is easy to form on the surface of an aluminium alloy and hinders the bonding of the bimetal interface, the preparation of Al/Al bimetallic composites by using liquid–solid compound casting usually requires a coating on the surface of the solid aluminium alloy. This makes the process more complex, while the plating metal layer used in the plating solution if not appropriately handled causes environmental pollution [7–9]. Moreover, the plated metal is usually introduced as an unwanted element. Feng et al. [10] chose A356 alloy and nickel-plated A6061 alloy to prepare bimetallic composites and found that a coarse cracked Al₃Ni phase generated at the interface became the source of cracks during stretching, leading to a decrease in the interfacial bond strength. Hence, the addition of plating as a heterogeneous element can lead to the formation of brittle intermetallic compounds at the interface, detrimental to the interfacial bonding of the bimetallic composite.

Liquid–liquid compound casting is a method of direct-compounding two liquid alloys through a certain casting process without coating treatment. This technique offers an effective means to simplify the preparation process of bimetallic composites without

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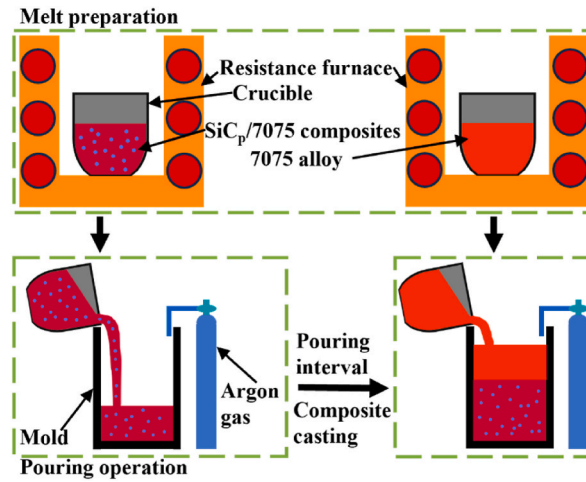


Fig. 1. Schematic representation of the preparation process of bimetallic composites.

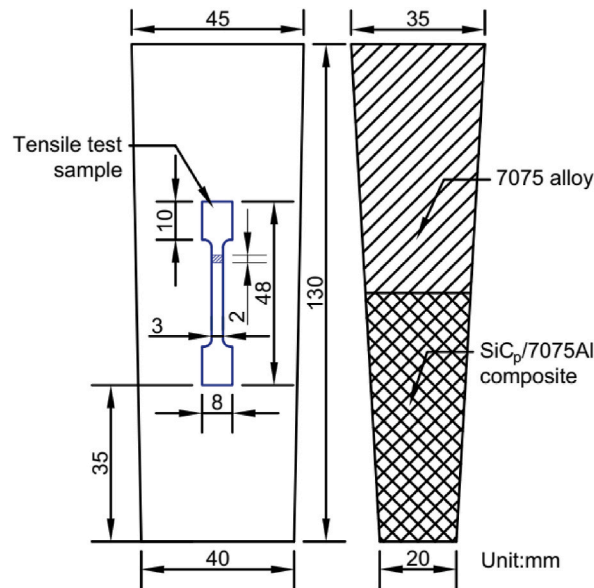


Fig. 2. Schematic dimensions and sampling of the bimetallic composite.

introducing heterogeneous elements [11,12]. Because of the good fluidity of a liquid aluminium alloy, an oxide layer can be very easily formed on its surface. Therefore, the preparation of bimetallic composites by the liquid–liquid compound casting method is difficult, and the evolution of the interface during the forming process still needs to be revealed. In this study, Al/Al bimetal composites were fabricated by combining SiC_p/7075 aluminium matrix composites with the 7075 aluminium alloy through liquid–liquid compound casting, during which the interface evolution was investigated.

2. Experiment

Commercial 7075 alloy (Al–5.67Zn–2.45Mg–1.6Cu) and SiC_p/7075 aluminium matrix composites (Al–5.57Zn–2.33Mg–1.57Cu–3.14Ti–15SiC_p) were used in the present investigation. The bimetallic compound casting process was as follows: The SiC_p/7075 composite and the 7075 alloy were placed in two graphite clay crucibles and melted in two resistance furnaces, respectively. The melt pouring process was protected by argon gas to reduce oxidation. When the melt temperature of the SiC_p/7075 composite reached 750 °C, it was poured into a preheated metal mold maintained at 200 °C. After a certain time interval of 3 s, 10 s, and 20 s, the 7075 alloy with melt temperature of 730 °C was subsequently poured into the same mold. Fig. 1 illustrates the process of preparing a liquid–liquid bimetallic composite.

Metallographic specimens were prepared by mechanical polishing and etching with Keller’s reagent (95-mL H₂O + 2.5-mL HNO₃

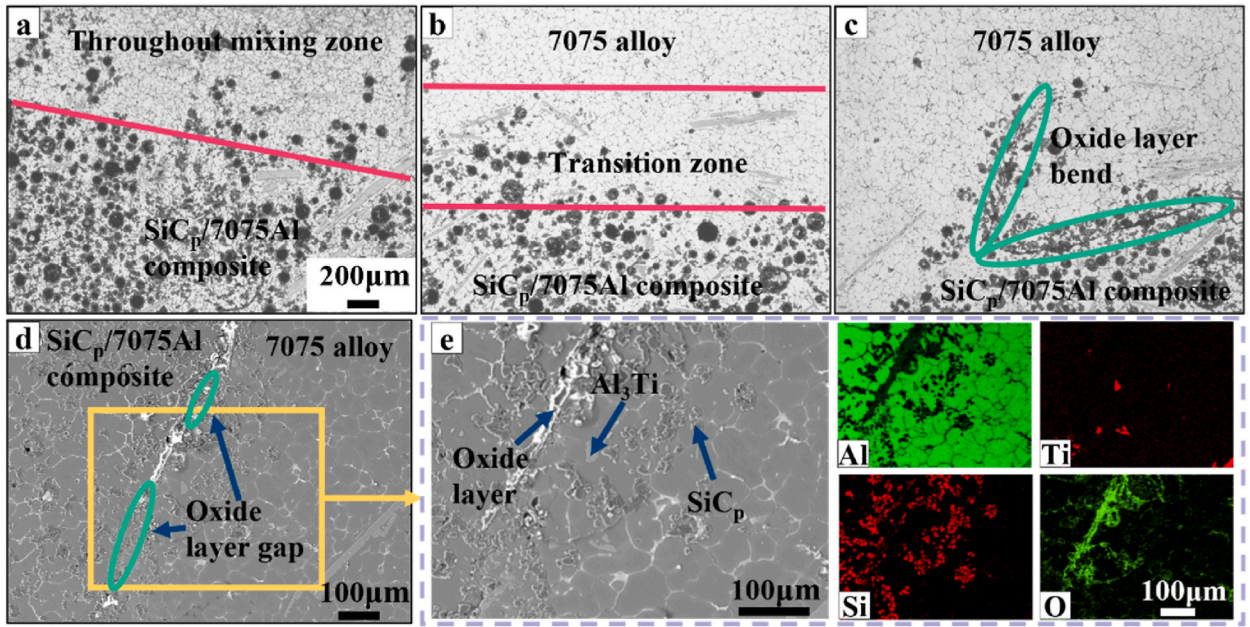


Fig. 3. (a–c) Metallographic micrographs of specimen interfaces at the 3 s, 10 s, and 20 s casting intervals, (d) SEM micrographs of specimen interface with the 20 s pouring interval, and (e) partially enlarged map scan of (d).

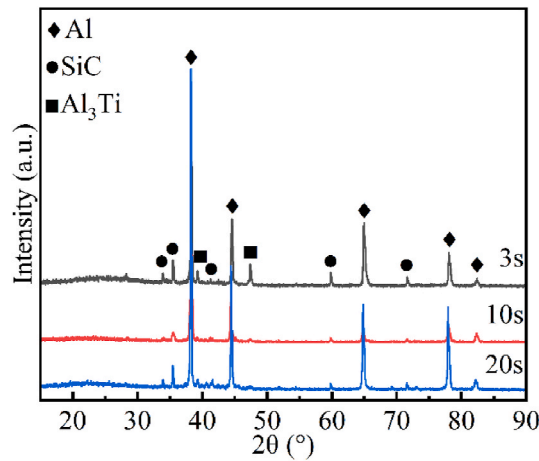


Fig. 4. XRD diffraction pattern of bimetallic composite's interfacial microstructure.

+ 1.5-mL HCl + 1-mL HF). The interfacial microstructure of bimetal composites was characterised using ZEISS metallographic microscope and SUPRA55 scanning electron microscope. The phase composition of the bimetallic composite was determined using a Panaco Empryan X-ray diffractometer with a Cu target. The Instron 3382 electronic universal tensile tester was used to test the interfacial bond strength of bimetallics at the rate of 0.5 mm/min. At least three tensile specimens of each group were determined to obtain the average tensile properties. The specimen dimensions and sampling locations are shown in Fig. 2. Interfacial hardness testing was carried out using a Vickers hardness tester with a load of 0.05 kg and a holding time of 15 s.

3. Results and discussion

Fig. 3 shows the interfacial microstructure of bimetallic composites with different pouring intervals. Fig. 3(a) also shows that when the pouring interval was 3 s, the interfacial microstructure of the bimetallic composites consisted of the SiC_p/7075 aluminium matrix composite zone and mixing zone. The intermixing of the bimetallic composites led to the emergence of gradient regions and the formation of metallurgical bonds, but the slow solidification process and intermixing weakened the metallurgical bonds. With the increase in the pouring time to 10 s (Fig. 3(b)), the mixing zone disappeared and the transition zone appeared. This indicated that a

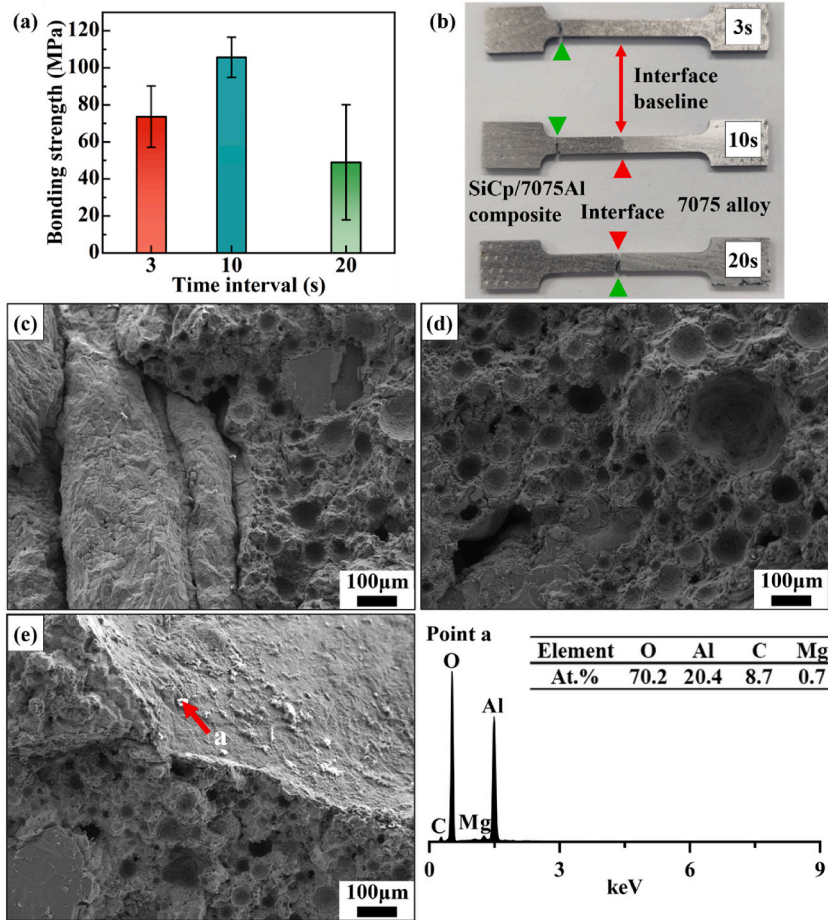


Fig. 5. (a) Fracture strength of bimetallic composites, (b) fracture location of the tensile specimen of bimetallic composites, and (c–e) SEM micrographs of specimen fractures with pouring intervals of 3 s, 10 s, and 20 s.

sound metallurgical bond interface was obtained. When the pouring time continued to increase to 20 s (Fig. 3(c)), the interface appeared with the directional curvature of the suspected oxide layer area wrapped by SiC particles. Fig. 3(d) shows the SEM diagram of the interface with the pouring interval of 20 s. It can be seen that the interface to the oxide layer was not continuous and there were more small gaps. The appearance of the gaps opened the channel for the migration of SiC particles, resulting in both sides of the oxide layer being wrapped by SiC particles. The map-scanned results in the surface shown in Fig. 3(e) revealed that the oxygen elements at the interface were more densely distributed and surrounded by SiC particles. This supported the observation from Fig. 3(c) that the area wrapped by SiC particles with the directional curvature was an oxide layer. The dark grey SiC particles were mainly concentrated in the SiC_p/7075 composite zone, and the light grey Al₃Ti phase was sporadically distributed. The formation of the Al₃Ti phase could be attributed to the intentional addition of Ti to the SiC_p/7075 aluminium matrix composites to increase the wettability between the matrix alloy and the reinforcing particles [13,14].

XRD tests were carried out on the bimetallic composites to determine the phase composition of the interface, as shown in Fig. 4. The bimetallic composite interface consisted of the α-Al phase, SiC particles, and Al₃Ti phase, which was consistent with the energy spectrum results.

Fig. 5 shows the properties and the fracture diagram of the bimetallic composites. The fracture strength of the bimetallic composites with the pouring intervals of 3 s, 10 s, and 20 s was 73 MPa, 105 MPa, and 49 MPa, respectively. Fig. 5(b) shows the fracture location of the bimetallic composite. The samples with pouring intervals of 3 s and 10 s exhibited fractures on the composite side, and their interfacial bond strengths were greater than 73 MPa and 105 MPa, respectively. At the pouring interval of 20 s, the sample experienced a fracture at the interface, with an interface bonding strength of 49 MPa. The transfer of the SiC reinforcing particles to the 7075 alloy side in Fig. 3(a) led to the reduction of the reinforcing particles. Moreover, Fig. 5(c and d) show that the number of dimples in the 10 s sample was more than that of the 3 s sample, resulting in a 43.8% increase in the bonding strength. Oxides indicated by the red arrow in Fig. 5(e), were found on the fracture surface, which was confirmed by the EDS analysis. This was consistent with the observed oxide layer at the interface shown in Fig. 3(d). Hence, it was inferred that the presence of this interfacial oxide layer hindered the achievement of effective metallurgical bonding in the bimetallic composites, consequently leading to a decrease in the interfacial

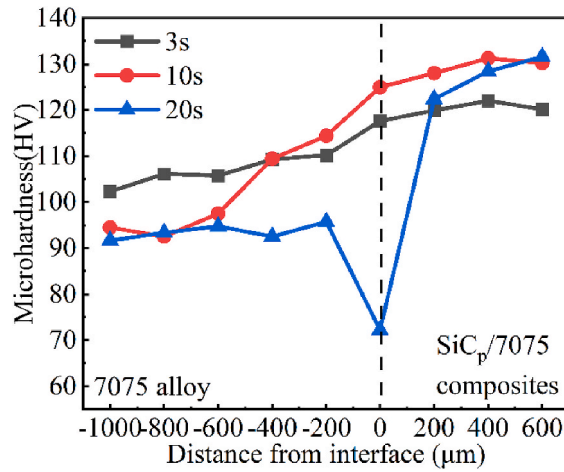


Fig. 6. Vickers hardness distribution at the interface of bimetallic composites.

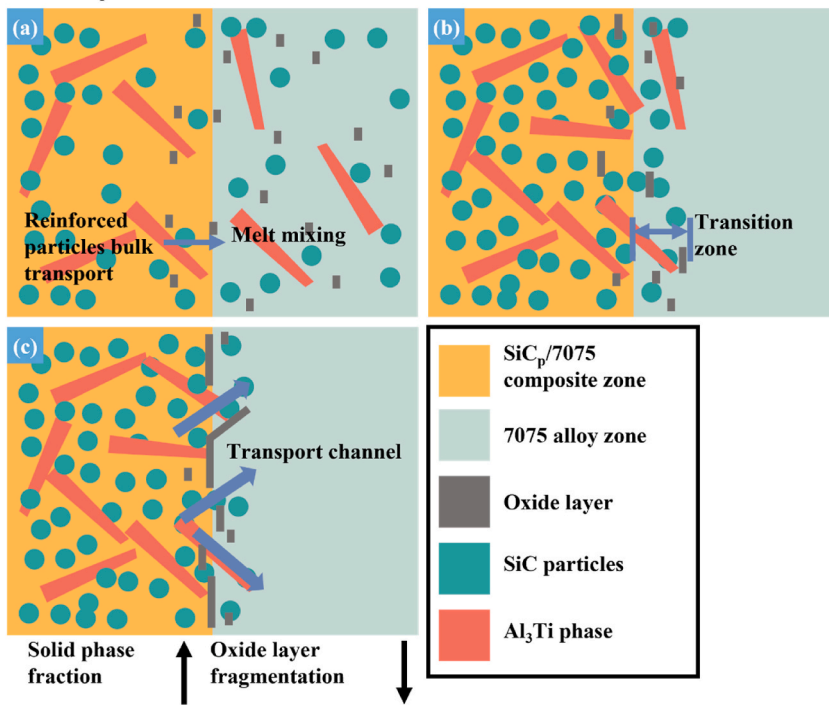


Fig. 7. Schematic representation of the evolution process of the interface in the liquid–liquid bimetal compound casting: (a) intermixing stage, (b) transition zone stage, and (c) oxide layer forming stage.

bonding strength.

Fig. 6 shows the Vickers hardness of the bimetallic composite interface at different pouring intervals. The hardness of the sample was observed to be higher in the 7075 alloy region and lower in the SiC_p/7075 composite region for the 3 s pouring interval. This was attributed to the intermixing phenomenon observed in the interfacial microstructure, which led to the mixing of the SiC particles into the 7075 alloy region to increase the hardness. The loss of SiC particles in the SiC_p/7075 composite region led to a decrease in hardness. The hardness of the sample with a pouring interval of 10 s increased gradually from 90 to 95 HV to 125–130 HV because of the existence of a transition zone. At the pouring interval of 20 s, the hardness of the sample decreased sharply at the interface because of the existence of an oxide layer.

Fig. 7 shows the interface evolution process of liquid–liquid bimetal compound casting. Because of the high affinity of the aluminium alloy melt with atmospheric oxygen, a thin layer of the alumina film with a thickness of 2–4 nm, rapidly formed on the surface [15]. The 3 s pouring interval specimen, because of the short pouring interval, made the solidified layer of the SiC_p/7075

composites thinner, resulting in lower material stiffness. Therefore, when the 7075 alloy was poured in, the unstable solidification layer collapsed and mixed with the 7075 alloy. Chen et al. [16] reported that the oxide film floated to other regions during melt solidification, resulting in the oxide layer movement to both sides of the interface under the melt flushing of the 7075 alloy. Furthermore, the mixing of the two alloys led to the transport of the SiC particles to the 7075 alloy side, resulting in the reduction of SiC particles on the composite side. The decrease in reinforced particles led to the decrease in the material strength and hardness. As shown in Fig. 7(a), the solidified layer on the side of the composite was gradually stabilised with the extension of the pouring interval to 10 s. Therefore, the pouring of the 7075 alloy did not collapse the solidification layer on the surface of the sample. The surface of the composite underwent a remelting process, leading to the formation of a transition zone and the establishment of a strong metallurgical bond. According to Pieczonka [17], the presence of contrasting coefficients of thermal expansion between aluminium ($6.5 \times 10^{-6} \bullet K^{-1}$)– $8.9 \times 10^{-6} \bullet K^{-1}$) and alumina ($25 \times 10^{-6} \bullet K^{-1}$) resulted in tensile stresses between the alumina layer and the SiC_p/7075 composite, induced by the thermal effects generated during the pouring of the molten 7075 alloy. The stress promoted the detachment of the alumina film, causing the alumina film to move away from the interface with the melt after being broken, as shown in Fig. 7(b). When the pouring interval increased to 20 s, the solid fraction of the composite increased significantly, resulting in a simultaneous increase in its stiffness. Moreover, the composite surface temperature decreased, remelting the 7075 alloy poured into only a part of the composite surface and resulting in the discontinuity of the interface oxide layer, as shown in Fig. 7(c). Moreover, the oxide gap formed a channel for the exchange of elements at the bimetallic interface, and the SiC particles were transported from the channel to the other side.

4. Conclusions

In this work, 7075 aluminium alloy/SiC_p-reinforced aluminium matrix alloy bimetallic composites were fabricated using the liquid–liquid compound casting method. The interface was found to be easy to mix when the pouring interval was less than 3 s. When the pouring interval was more than 20 s, the discontinuous oxide layer appeared at the interface. When the pouring interval was between 3 s and 20 s, the interface was the transition zone from the mixing to the discontinuous oxide layer. The interfacial bond strength and the interfacial bond quality were closely related, and the interfacial bond strength appeared to increase first and then decrease. A good metallurgical bond was obtained when the pouring interval was 10 s. The fractures occurred on the side of the SiC_p/7075 composite, exhibiting an interfacial bond strength exceeding 105 MPa.

The interfacial microstructure has an important influence on the properties of bimetallic composites. However, how to regulate the composition, size, and distribution of interfacial phases in bimetallic composites is still a key issue that needs to be addressed. Moreover, it is necessary to investigate the effect of physical fields (ultrasonic/electromagnetic fields) on the microstructure of a bimetallic interface in the future.

Author contribution statement

Yuncong Shang: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Wenda Zhang: Conceived and designed the experiments; Analyzed and interpreted the data.

Heqian Song: Yuxin Li: Analyzed and interpreted the data.

Jinjie Wang: Performed the experiments.

Hong Xu: Contributed reagents, materials, analysis tools or data.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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