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Microstructure of interaction interface between Al-Si, Zn-Al alloys and Al_2O_{3p}/6061Al composite①

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Abstract: Interaction behaviors between Al-Si, Zn-Al alloys and Al_2O_{3p}/6061Al composite at different heating temperatures were investigated. It is found that Al_2O_{3p}/6061Al composite can be wetted well by AlSi-1, AlSi-4 and Zn-Al alloys and an interaction layer forms between the alloy and composite during interaction. Little Al-Si alloys remain on the surface when they fully wet the composite and Si element in Al-Si alloy diffuses into composite entirely and assembles in the composite near the interface of Al-Si alloy/composite to form a Si-rich zone. The microstructure in interaction layer with Si penetration is still dense. Much more residual Zn-Al alloy exists on the surface of composite when it wets the composite, and porosities appear at the interface of Zn-Al alloy/composite. The penetration of elements Zn, Cu of Zn-Al alloy into composite leads to the generation of shrinkage cavities in the interaction layer and makes the microstructure of Al_2O_{3p}/6061Al composite loose.

Key words: Al_2O_{3p}/6061Al composite; Zn-Al alloy; Al-Si alloy; interaction interface; wettability
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1 INTRODUCTION

The discontinuously reinforced metal matrix composite is one of the new structure materials, and has many excellent properties and wide application. With the rapid development in material research and the great potential needs in application, researchers have paid more and more attention to the secondary process for the material such as joining technology, machining technology[1-4]. In many joining processes, brazing[5], diffusion[6-8] and transient liquid phase(TLP) bonding[9-14] attract considerable attention, and many research results on interaction behavior between the interlayer material and the composite matrix have been obtained. ZHANG et al[5] found that the low joint strength could be improved by using Al-Si-Mg interlayer. Klehn et al[9] concluded that increasing the aluminum content in the interlayer would reduce the meltback of the matrix material and form a joint with less reinforcement segregation in weld zone. It was found that Ni interlayer could avoid the production of reinforcement rich zone in the joint, which was attributed to its high diffuse coefficient[10]. Thus, it is important to research the mechanism of the interaction between the interlayer alloy and the composite to be welded due to the key role of an interlayer in welding aluminum MMCs.

Moshier et al[15] detected that after the penetration of Si, Zn into SiC_w/6061Al, the distribution of SiC_w in the composites would be disarranged and SiC_w rich zone formed when studying the interaction between Al-Si, Zn-Al eutectic alloys and SiC_w/6061Al composite. Little research concerned about the interaction between Al_2O_{3p}/6061Al composite and Al-Si or Zn-Al alloys. Therefore, in the present paper the interactions that occur between Al_2O_{3p}/6061Al composite and BAlSi-1, BAlSi-4 and Zn-Al alloys are discussed, with the aim to lay a foundation for bonding Al_2O_{3p}/6061Al composite.

2 EXPERIMENTAL

The materials used were BAlSi-1, BAlSi-4, Zn-Al alloys with the mass of 0.2 g, and Al_2O_{3p}/6061Al composite made by squeeze casting, which contain 30% Al_2O_3(volume fraction) particles with an average diameter of 0.4 μm. The chemical compositions of the matrix alloy(6061-T6 alloy) and BAlSi-1, BAlSi-4, Zn-Al alloys are listed in Table 1 and 2, respectively. All samples with dimension of 25 mm × 30 mm × 2 mm were mechanically polished and then ultrasonically degreased in acetone before heating. The interaction experiments of BAlSi-1, BAlSi-4 and Zn-Al alloys with Al_2O_{3p}/6061Al composite were conducted in an vacuum furnace(5×10^{-3} Pa). The Al-Si alloy samples were heated to 580－630 ℃, and held for 1－10 min. The Zn-Al alloy samples were heated to 400－600 ℃, and held for 1－5 min. All samples were cooled under vacuum.

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Table 1 Chemical compositions of 6061Al alloy (mass fraction, %)

Mg	Si	Cu	Fe	Mn	Zn	Ti	Ni	Al
1.03	0.75	0.43	0.36	0.22	< 0.05	< 0.05	< 0.05	Bal.

Table 2 Chemical compositions and melting point of alloys

Alloy	Chemical composition (mass fraction)/%							Melting point/ ℃
	Si	Cu	Zn	Fe	Mn	Mg	Al	
BAlSi-1	4.5 - 6.0	< 0.30	< 0.20	< 0.80			Bal.	577 - 629
BAlSi-4	11.0 - 13.0	< 0.30	< 0.20	< 0.80			Bal.	577 - 582
Zn-Al	0.81	3.22	89.3	0.01	0.91	0.82	4.20	382 - 399

To observe the wetting effect of alloys on the composite, the samples were cut along cross-section, then were polished and etched in a solution of 2 mL HF+ 3 mL HCl+ 5 mL HNO_3+ 250 mL distilled water. The microstructure of the interface between the two materials was examined by scanning electron microscopy(SEM). The element diffusion in the interaction layer was tested by electron probe micro-analysis(EPMA). The chemical composition of the interaction layer was determined by energy dispersive X-ray spectroscopy(EDX). X-ray diffractometry(XRD) was used to analyze the phase construction of the interaction layer.

3 RESULTS AND DISCUSSION

3.1 Al-Si alloy

The temperature is one of the key parameters in the wettability experiments of brazing. At the temperature below 600 ℃, it can be found that both BAlSi-1 and BAlSi-4 alloys could hardly wet Al_2O_{3p}/6061Al composite in any holding time. When the temperature rises to 600 ℃, it can be seen that BAlSi-4 alloy could wet the composite, but quite an amount of non-melted BAlSi-4 alloy still remains on the surface of the composite. However, BAlSi-1 alloy could not wet the composite at 600 ℃ for any holding duration. When increasing the heating temperature up to (615 ±5) ℃, BAlSi-4 alloy fully wets the composite for any holding duration; BAlSi-1 alloy partially wets the composite when the holding time is less than 5 min, and all BAlSi-1 alloy melts wet the composite when the holding time is beyond 8 min. When the heating temperature exceeds (630 ± 5) ℃, Al_2O_{3p}/6061Al composite can be excellently wetted by BAlSi-1 alloy for any holding duration.

Fig. 1 shows the microstructure of interaction interface between Al-Si alloy and composite. It can be found that little Al-Si alloy remains on the surface of Al_2O_{3p}/6061Al composite when Al-Si alloy fully wets the composite. Meanwhile, Al-Si alloy penetrates into Al_2O_{3p}/6061Al composite to a certain depth. It can be also found that the penetration of BAlSi-4 alloy is deeper than that of BAlSi-1 alloy under the same condition. For example, When the temperature is up to 610 ℃ and the holding time is 5 min, the penetration of BAlSi-4 alloy reaches 1 mm in depth (the largest depth here), while that of BAlSi-1 alloy is only 700 μm.

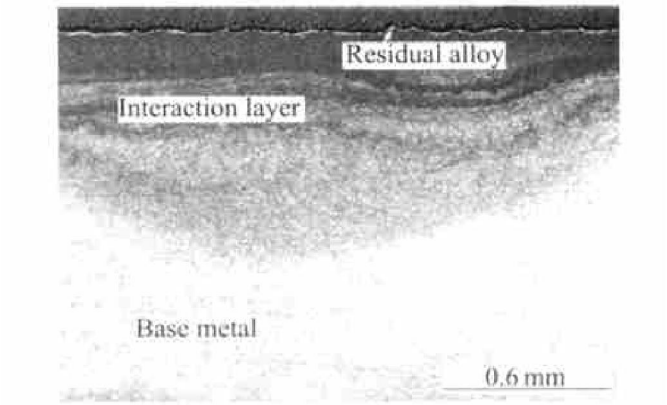

Fig. 1 Morphology of cross-section of interaction interface of Al-Si alloy/composite

Fig. 2 shows the microstructure of interaction interface between Al-Si alloy and Al_2O_{3p}/6061Al composite. It can be observed that the microstructure of interaction layer keeps compact after the interaction between Al-Si alloy and Al_2O_{3p}/6061Al composite in comparison with that of the base metal, and there is no crack or void at the bondline of Al-Si alloy/composite. Some shrinkage voids appear in the residual Al-Si alloy on the surface of composites when short holding time is used(Fig. 2(a)). This may result from the fact that there is not enough melted alloy to supplement the shrinking position due to the poor fluidity of the melted alloy when the residual Al-Si alloy solidifies. When the holding time is extended, shrinkage voids disappear(Fig. 2(b)).

Figs. 3(a) and (b) show the backscattered electron images of interaction interface between Al-Si alloy and composite, and Figs. 3(c) and (d) show the Si distribution images corresponding to the position in Fig. 3(a) and (b). It should be noted that almost all Si elements in Al-Si alloy diffuse into the

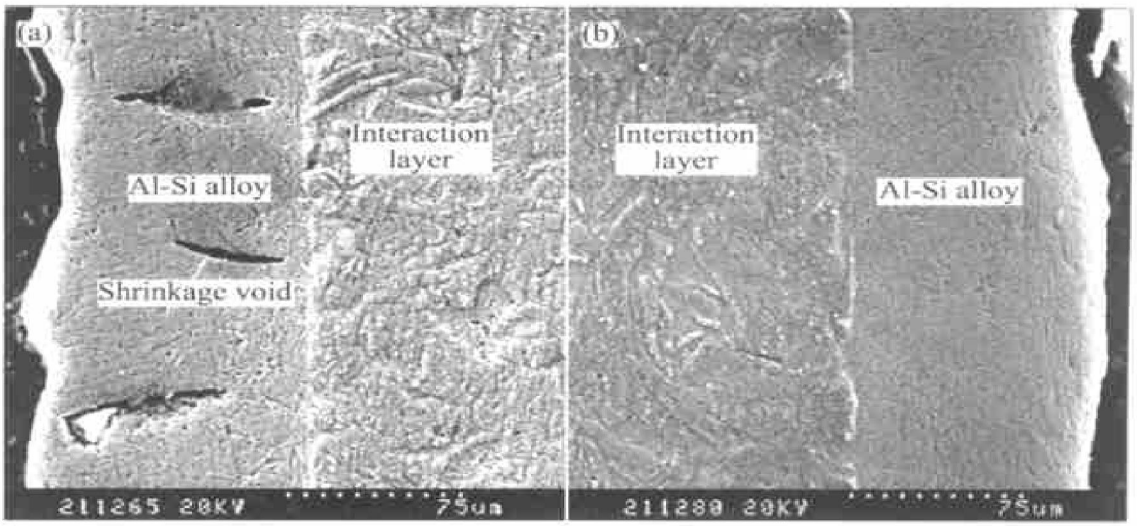

Fig. 2 Microstructures of interaction interface between Al-Si alloy and Al_2O_{3p}/6061Al composite
(a) —Holding for 2 min; (b) —Holding for 7 min

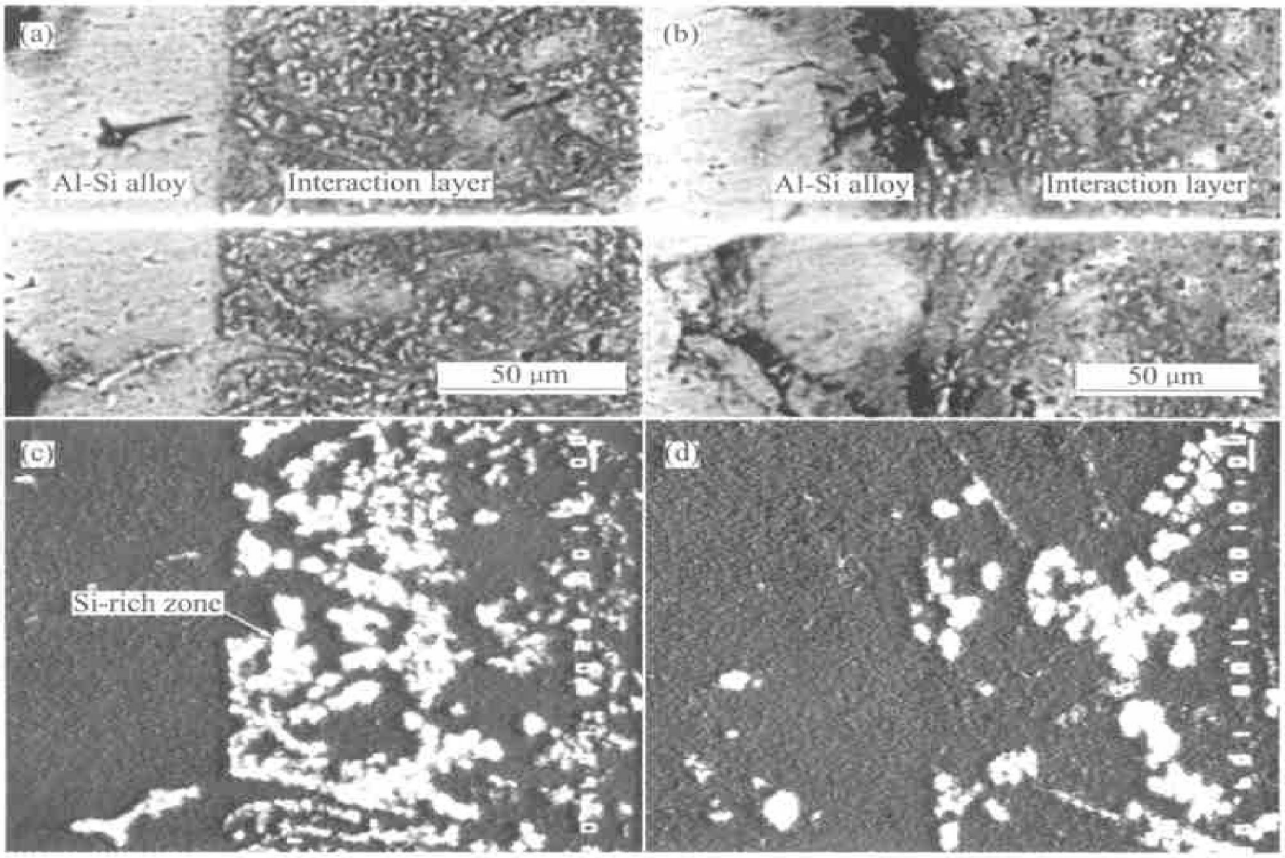

Fig. 3 Back scattered electron images((a) and (b)) and corresponding element distributions((c) and (d)) of interaction interface of Al-Si alloy/composite

composite after the interaction between Al-Si alloy and composite. And the majority of the element Si assembles in the composite near the interface of Al-Si alloy/composite to form a Si-rich zone during diffusion (Fig. 3(c)). If prolonging diffusion, the element Si in the composites will penetrate further into the composite, and the Si-rich zone will disappear(Fig. 3(d)).

3.2 Zn-Al alloy

When the heating temperature is higher than 430 ℃, Al_2O_{3p}/6061Al composite can be wetted well by Zn-Al alloy. The wetting area increases with increasing the temperature. The microstructure of cross-section of Zn-Al alloy/composite is presented in Fig. 4. Fig. 4(a) showed the cross section of Zn-Al/composite is divided into three layers: residual Zn-Al alloy layer, interaction layer and untouched base metal layer. Compared with Al-Si samples, more Zn-Al alloys remain on the surface of the composite. There exists a lot of dendrites in the residual Zn-Al alloy,

and porosities appear in the residual alloy close to the interface of Zn-Al alloy/composite(Fig. 4(a)). More and larger shrinkage cavities appear in the residual alloy close to the interface of Zn-Al alloy/composite at the temperature beyond 550 ℃, which results in extreme loosening of Zn-Al residual alloy(Fig. 4(b)).

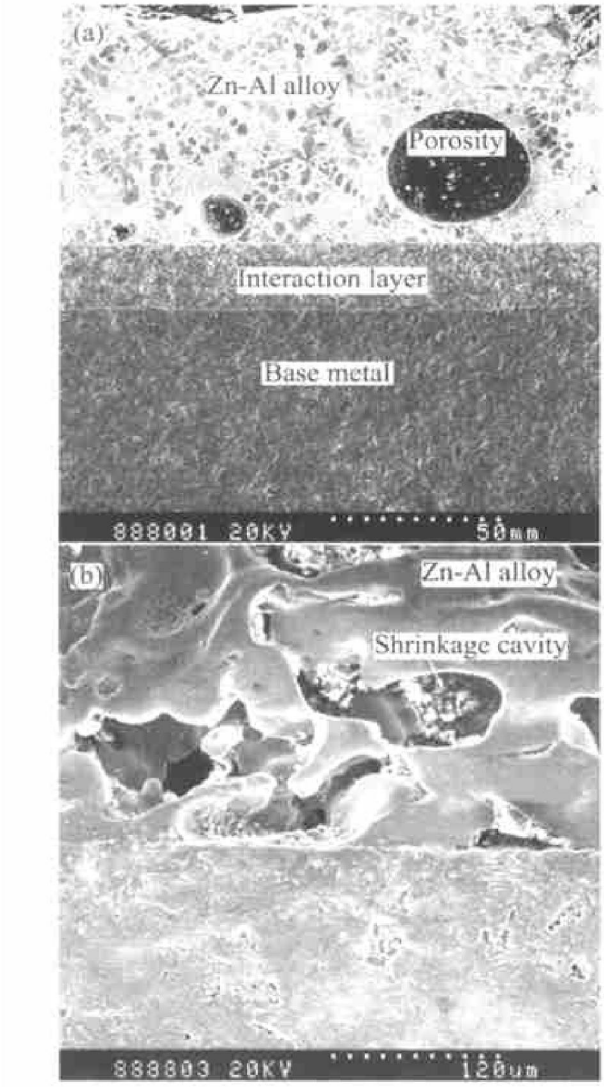

Fig. 4 Microstructures of cross-section of Zn-Al alloy/composite at different heating temperatures
(a) —460 ℃; (b) —600 ℃

Fig. 5 illustrates the microstructure of interaction interface between Zn-Al alloy and Al_2O_{3p}/6061Al composite. The interaction layer of Zn-Al alloy/composite is more uniform than that of Al-Si alloy/composite. Experimental results show that the depth of interaction layer increases with increasing temperature, and is about 100 μm at 430 ℃ and 500 μm at 600 ℃.

Fig. 6 shows the backscattered electron images and element distributions of interaction interface of Zn-Al alloy/composite. Line scanning results of Zn element in Figs. 6(c) and (d) reveal that Zn penetrates deeply into the composite with a great decline in content at the interface of Zn-Al alloy/ composite

Fig. 5 Microstructure of interaction interface between Zn-Al alloy and Al_2O_{3p}/6061Al composite

and an increase up to a certain value at a penetration depth of 50 μm. From interaction layer to base metal, Zn content increases and keeps invariable in the base metal(Fig. 6(d)). Line scanning results of Cu element are similar to those of Zn. Al content rises greatly at the interface of both Zn-Al alloy/composite and interaction layer/base metal, and obtains the highest in the base metal. Line scanning results in Fig. 6 show that the Al-rich phase and Zn(Cu)-rich phase alternatively occur in the residual Zn-Al alloy which accords to the alternative presence of Al and Zn (Cu) content peak value. It should be noted that the diffusion of elements of Zn-Al alloy into composite could not change the uniform distribution of Al_2O_3 particles in the interaction layer and no Al_2O_3 particle segregation is observed in composite(Figs. 6(a) and (b)). Zn(Cu)-rich phase appears in some regions in the interaction layer similar to those in the residual Zn-Al alloy where the element Zn and Cu distributions appear in high peak value, while Al in low peak value(Fig. 6(c)). This phase is testified to be $CuZn_5$ by XRD analysis. EDX results show that the contents of Zn and Cu in the interlayer are in the range of 38.04%–62.24% and 2.71%–10.07%, respectively.

As shown in Fig. 5 and Fig. 6, it can be found that quite a number of shrinkage cavities exist in the interaction layer, while the microstructure of Al_2O_{3p}/6061Al composite without interaction keeps dense. The appearance of shrinkage cavities is tied up with the penetration of Zn-Al alloy to Al_2O_{3p}/6061Al composite, and they make the microstructure of the interaction layer(it forms on basis of elements Al, Zn, Cu that diffuse from Zn-Al alloy) loose. Evidently, if such a microstructure is produced during joining of Al_2O_{3p}/6061Al composite with alloys, it would weak

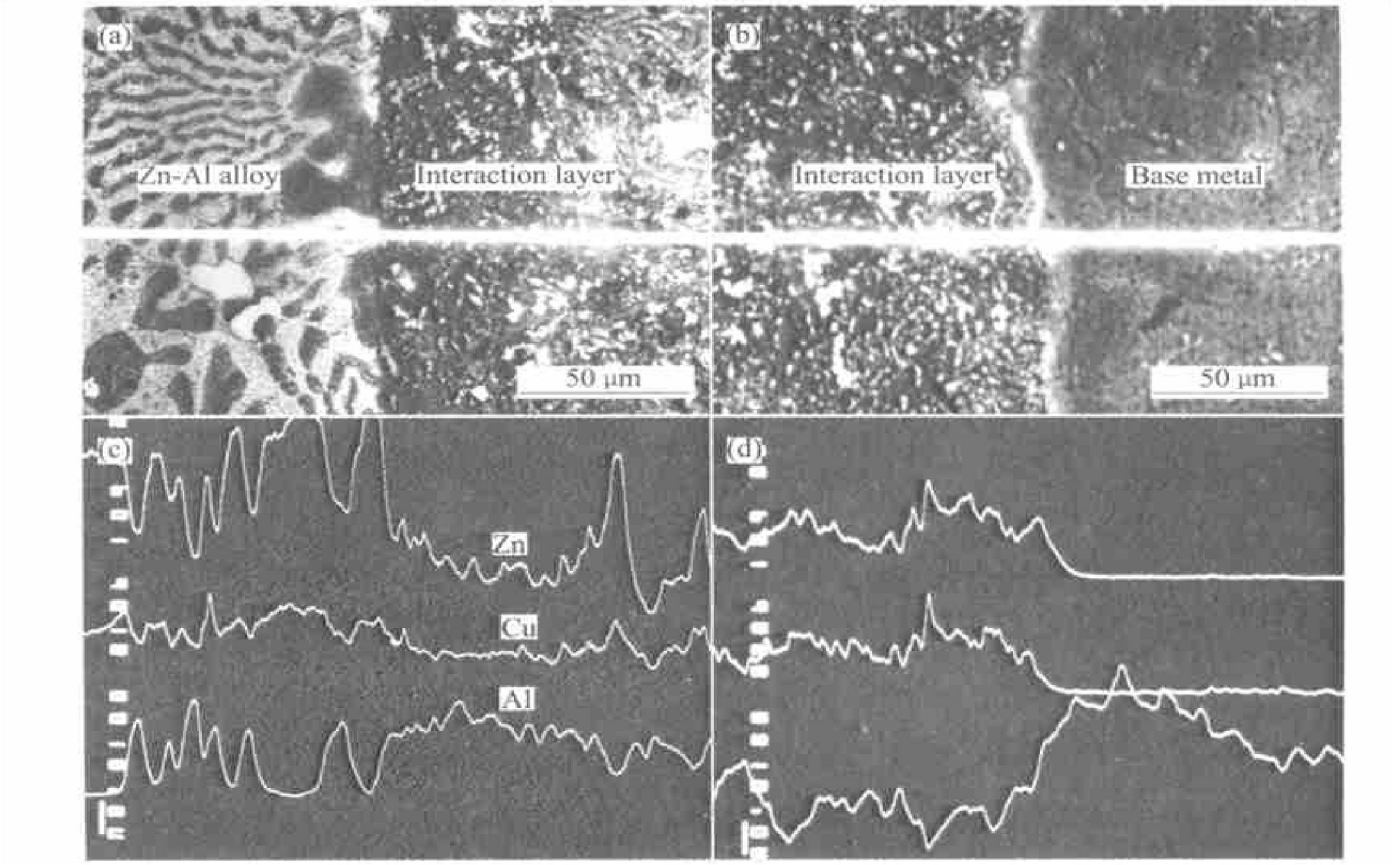

Fig. 6 Back scattered electron images((a) and (b)) and corresponding element distributions((c) and (d)) of interaction interface of Zn-Al alloy/composite

the ultimate strength of bonded joints. So it is necessary to decrease heating temperature in order to limit the penetration of elements Zn, Cu into the composite.

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