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Strength and microstructure of semi-solid stirring brazing of SiC_p/A356 composites and aluminum alloy in air

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ABSTRACT

The semi-solid stirring brazing process of SiC_p/A356 composites and 2024 aluminum alloy was investigated. The two substrates were heated up to the semisolid temperature range of Zn27Al filler metal in the joint region by a resistance heating plate in air. At this point a stirrer was penetrated into the semi-solid weld seam in order to mix filler metal and the two sides of substrates into a single uniform joint. After stirring, specimens were sectioned for analysis of macro- and micro-structures along the weld region. The research shows that SiC_p/A356 composites and aluminum alloy can be successfully joined with semi-solid filler metal by optimizing stirring temperature. It can be found that most of the oxide film on the surface of the base metal was disrupted and removed through the observation by SEM. The metallurgical bonds formed between the filler metal and the base materials. Since the semisolid temperature range of filler metal is narrow, the accurate controlling of weld pool temperature must be considered.

Keywords: Aluminum metal-matrix composites; 2024 aluminum alloy; brazing; stirring; semi-solid.

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Introduction

Aluminum metal matrix composites (Al-MMCs) have been widely applied due to attractive properties, and the associated welding technology is increasing emphasized. Of the many joining processes of Al-MMCs and aluminum alloy, transient liquid phase (TLP) bonding [**1-2**], diffusion bonding [**3-4**] and brazing [**5-6**] are attracting considerable attention because they can avoid the detrimental matrix reinforcement reaction that is associated with fusion welding. However, the bonding processes above are usually conducted in a vacuum condition, which reduces their design flexibility [**1–4**]. If brazing the composite using flux in air, it is difficult for a residual flux to be removed after brazing, and resulting in a corrosion problem [**6**]. To overcome this problem, several reaches on the vacuum-free bonding processes have been performed. Zuruzi AS [**7-8**] et al and Lee CS [**9**] et al have used a surface rotation treatment technique to remove the oxide film during diffusion bonding of Al-MMCs and 6061Al, and have performed successfully vacuum-free bonding. The objective of the present work is to investigate the vacuum-free brazing of SiCp/A356 composites and 2024 aluminum alloy. A mechanical stirring will be used to disrupt and remove the oxide film on the surface of the materials.

Otherwise, the semi-solid joining technology has apparent advantage on joint with absence of dendritic structure and shrinkage porosity [**10-12**]. So, Semi-solid characters of joint were also discussed in papers. It will be a new development for present semi-solid joining technology.

Experimental

The SiC_p/A356 composites used in this work contain 15% volume of SiC particles (diameter 12.6 μm). The A356 aluminum alloy composition was shown in **Table 1**. The composition for 2024 aluminum alloy used in this work was shown in **Table 2**. The filler metal used is Zn-Al alloy. The chemical composition and melting rang of the filler metal are listed in **Table 3.** The specimen is in plate-shape with 2.5 mm×40 mm×50 mm. The filler metal used is in plate shape with a size of 2 mm×3.5 mm×50 mm. The specimens are mounted on moving table, and filler metal is placed between the faying surfaces. The schematic of the stirring brazing equipments is shown in **Fig.1.**

Table 1. Chemical compositions of A356 Al alloy (wt %)

Si	Mg	Ti	Al
6.5-7.5	0.25-0.45	0.08-0.20	Bal

Table 2. Chemical compositions of 2024 Al alloy (wt %)

Cu	Mg	Mn	Fe	Zn	Ni	Ti	Al
3.8~4.9	1.2~1.8	0.3~0.9	0.5	0.3	0.1	0.15	Bal

Table 3. Chemical compositions (wt %), solidus and liquidus of Zn-Al filler metal

Zn	Al	Solidus (°C)	Liquidus (°C)
73	27	440	495

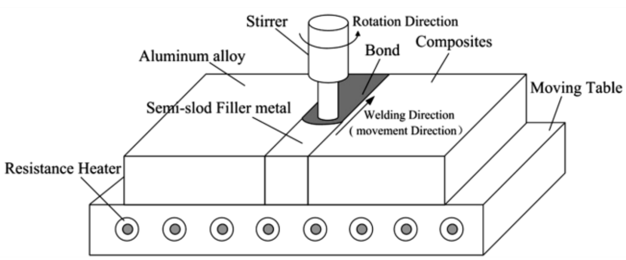

Fig.1. Schematic of semi-solid stir brazing equipments

The whole bonding process subsequence is schematically illustrated in **Fig. 2.** Experimental process is as follows in detail: The two substrates were heated up to the semisolid temperature range of Zn-Al filler metal in the joint region by a resistance heating plate. At this point a stirrer was introduced into the weld seam, and then rotates at approximately 1570 rpm. At this stage, the moving table started to move at a 1.5 cm/min. After the stirring brazing stops, the samples cooled down in air rapidly.

The cross sections of bonded joints were prepared for metallographic analysis by standard polishing techniques. The microstructures of bonded joints were examined by scanning electron microscopy (SEM, JSM-6460LV) equipped with an energy dispersive X-ray spectrometer (EDS). The tensile strength of the bonds was evaluated using a specially designed fixture in an electron tension testing machine (WDW-E200).

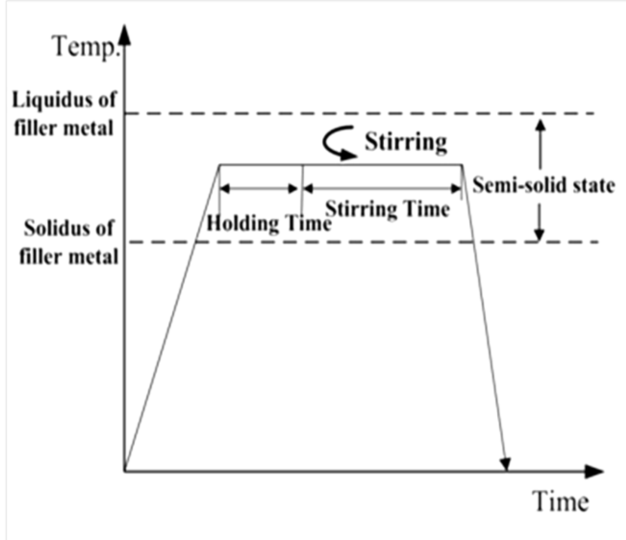

Fig. 2. Schematic of the brazing process subsequence in the experiment

Results and discussion

Here, the temperature and microstructure of semi-solid filler metal are observed and discussed. The relationships among the temperature and solid fraction of Zn27Al filler alloy are shown in **Fig. 3**. Seen from the **Fig. 3**, the semisolid temperature range of filler metal is 440-495 ℃. The relationships among the temperature and microstructure of Zn27Al filler alloy are shown in **Fig. 4**. With increasing of temperature, solid phase grain in filler metal gradually becomes surrounded by intergranular liquid phase. When the temperature becomes higher than 450°C, the solid fraction becomes lower than 86%. In such mushy state, the filler metal become soft and can be easily transformed at aid of additional force.

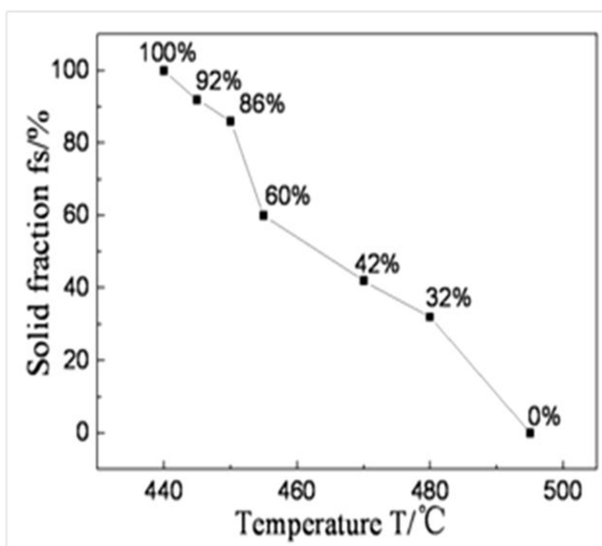

Fig. 3. Relationship between temperature and solid fraction of Zn27Al filler metal.

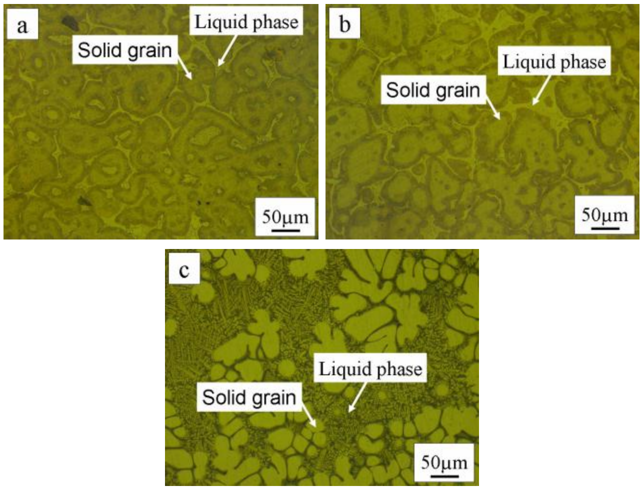

Fig. 4. Microstructures of filler metal at various temperatures: (a) 450 °C; (b) 455 °C; (c) 480 °C.

Fig. 5 showed that the effect of bonded temperature on the macro-appearance of the brazed joints. It was clearly seen that when the bonded temperature was 445 °C, voids with large size formed in bonded gap with the large volume of filler metal being extruded out from the bond region under mechanical stirring. At same time, surface roughing of joint was also founded. However, when the bonded temperature is 455 °C, filler metal can be fully filling up in brazed gap under stirring braing, and surface of joint brazed was smooth and flat at the time. This was because that with solid fraction being 60% at 455 °C, filler metal showed a good fluidity. When temperature was up to 470 °C, filler metal completely was filling up joint gap, and surface of joint brazed was very smooth at the time. There is because that the filler metal having low solid phase fraction owed very good fluidity and was easy to deform like liquid under the function of stirring force. Therefore, curved and smooth surface of joint were observed after stirring brazing.

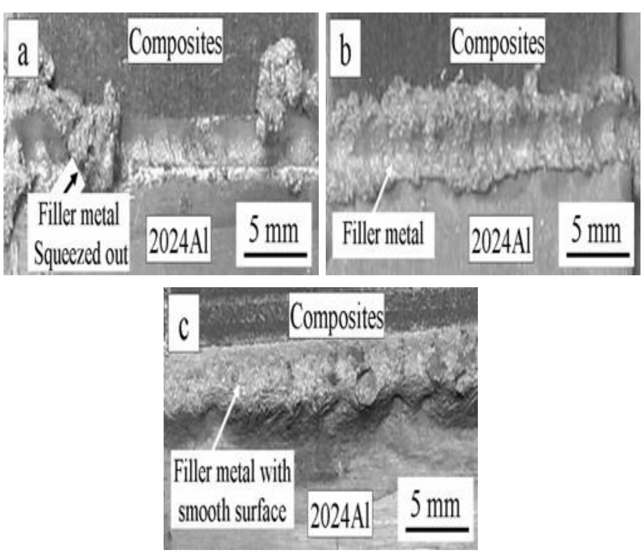

Fig. 5. Macro-appearance of brazed joints assisted by stirring at various temperatures: (a) 445 °C; (b) 455 °C; (c) 480 °C.

Fig. 6, 7, and **8** show the microstructure of joint interface between the Zn-Al alloy/2024 Al and Zn-Al alloy/composites after applying stirring brazing at various temperatures. It can be clearly observed that a metallurgical bonding without the presence of oxide layer was formed between the filler metal and 2024 Al on the interface of joint brazed at 450 °C from Fig.6a. But, there were only some finer inclusions and microcrackings along the joint interface between the Zn-Al alloy and composites in the bond form Fig.6b, which could weaken bonded strength between the bond metal and base material at a degree.

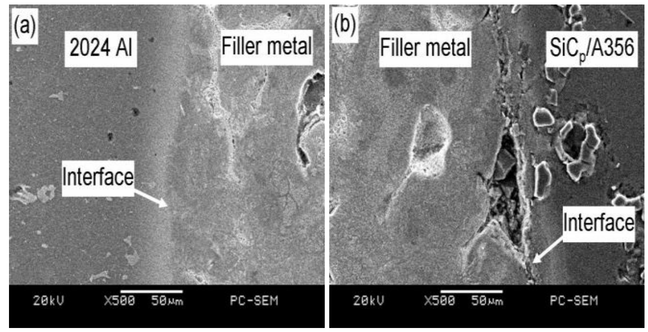

Fig.6. Microstructures of joints interface at 450 °C:(a) interface between filler metal and aluminum alloy; (b) interface between filler metal and SiC_p/A356.

When bonded temperature reached up to 455 °C, the interface between filler metal and two substrates without microvoids and cracks was observed from **Fig. 7**. This is because that there was enough the solid phase grain (α-Al) to disrupt oxide film on the surface of the base composites and 2024 Al during process of interaction between filler metal and base metal by stirring. Moreover, there was amount of liquid to wet the fresh surface. At the time, much amount of Zn diffusion into composites and aluminum alloy led to formation to the apparent diffusion zones in the composites and aluminum alloy found from **Fig. 7a** and **Fig. 7b**, which can promote the metallurgic bond strength on filler metal/composites interface and filler metal/aluminum alloy. It was obvious that desirable bond at the joint interface had be obtained after stirring brazing at 455 °C.

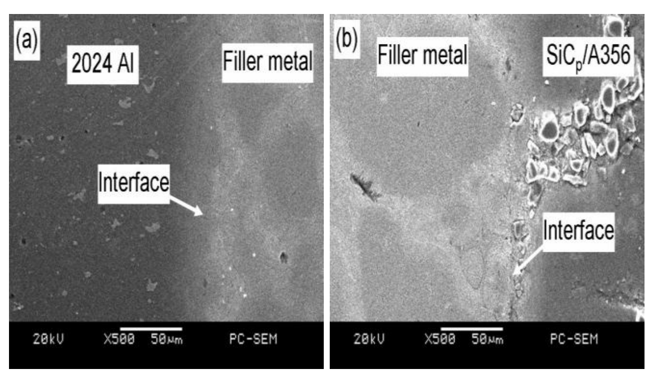

Fig. 7. Microstructures of joints interface at 455 °C: (a) interface between filler metal and aluminum alloy; (b) interface between filler metal and SiC_p/A356.

Fig. 8 showed microstructure of the joint interface at 480 °C. The interface between filler metal and 2024 aluminum alloy without microvoids and cracks was observed, and much amount of Zn diffusion into aluminum alloy led to formation to the apparent diffusion zones in the aluminum alloy found from **Fig. 8a**. But, discontinues crack appeared along interface between filler metal and SiC_p/A356 with presence of oxide layer from **Fig. 8b**. This is mainly because that further decreasing of solid fraction in the filler metal at 480 °C weakened the friction force between semi-solid filler metal and base material, which was the key to disruption of oxide film on the surface of composite. Hence, poor metallurgic bond exited at joint interface at 480 °C.

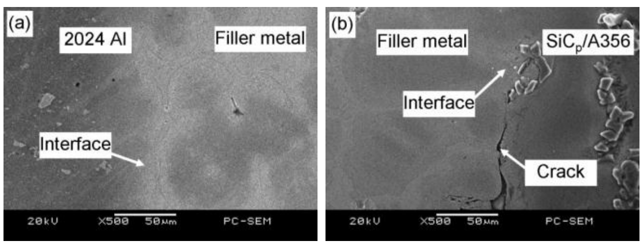

Fig.8. Microstructures of joints interface at 480 °C:(a) interface between filler metal and aluminum alloy; (b) interface between filler metal and SiCp/A356.

Fig. 9 shows the measure method of bonded ratio of interface between filler metal and base material. The relationship between the temperature of filler metal and bonded ratio at various temperatures is shown in **Fig. 10.** The bonded ratio of interface between Zn27Al and 2024 aluminum alloy is higher than interface between Zn27Al and composites at these temperatures. It is shown that a good metallurgical bonding on the interface between the semi-solid filler metal and 2024 aluminum alloy can be easier formed than on the interface between the semi-solid filler metal and composites by stirring brazing. The low bonded ratio could lead to bonded strength weak.

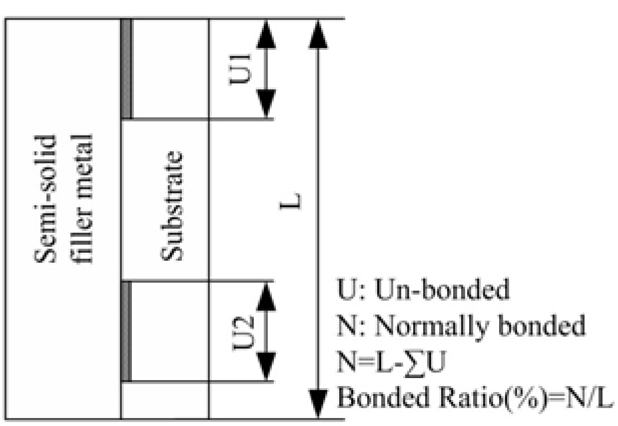

Fig. 9. Specimen of bonded ratio.

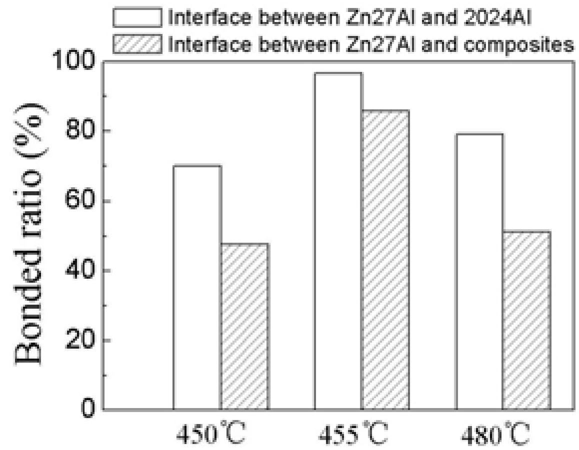

Fig. 10 effect of bonded ratio on different temperatures.

The relationship between the temperature of filler metal and joint strength is shown in **Fig. 11**. The tensile strength of joints bonded by stirring at 450 °C only reaches 38 MPa. This is mainly because the voids in the bond reduced the strength of brazed joints. The tensile strength of joints bonded by stirring at 455 °C is remarkably increased up to 160.2 MPa. The joint interface is free of microvoids and cracks and no large quantities of voids are founded in bond. Therefore, the brazed bonds with such a microstructure are responsible for increasing of the tensile strength. However, the tensile strength of joints bonded by stirring at 470 °C drops to 64 MPa. There is because that discontinues crack appeared along joint interface seriously reduces joint strength. On the base of above analysis, the suitable temperature to attain a desirable strength of joint was 455 °C. In general, the brazed bonds with such a microstructure were responsible for a highest strength of joint.

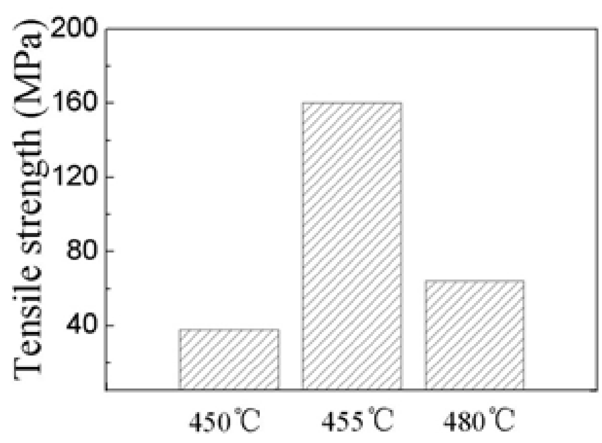

Fig. 11 Relationship between temperature of filler metal and joint strength.

The fractures of joint were all fracture between filler metal and SiCp/A356 by tensile testing machine. The fracture appearance of joint at temperature 455 °C is shown in **Fig. 12**. It can be seen that there are two typical fracture surfaces, the ductile fracture and the brittle fracture surface. This kind of compound fracture mechanism means that the rapture is not completely along the interface. The ductile fracture surface indicates that plastic deformation happened in the composites as shown in **Fig. 12b**. It is indicated that the strength of interface between filler metal and composite is strong than that of composites.

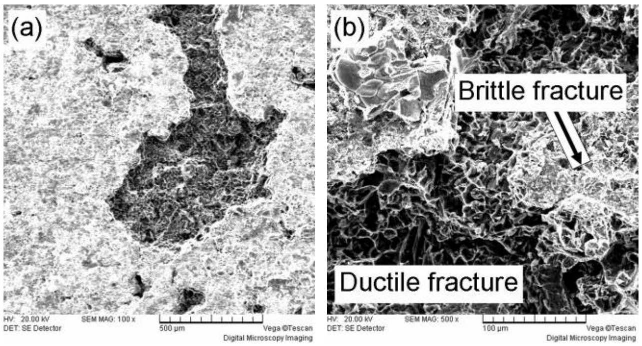

Fig. 12. Fracture surface of the joint when temperature is 455 °C: (a) Fracture surface of joint; (b) local magnification in Fig.12 (a).

Conclusion

The brazing of SiCp/A356 composites and 2024 aluminum alloy had been successfully performed in air by the aid of stirring. With increasing of temperature, solid fraction of filler metal remarkably dropped. The bonded temperature is critical for ideal shape and interface microstructure of joint during stirring brazing. The suitable temperature to obtain a desirable ideal joint was 455 °C.A good metallurgical bonding on the interface between the semi-solid filler metal and 2024 aluminum alloy can be easier formed than on the interface between the semi-solid filler metal and composites by stirring brazing. In general, existence of sufficient solid grains in the filler metal was the key to disruption of oxide film on the surface of composite during stirring brazing.

Acknowledgement

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Reference

1. Sun, D. Q.; Gu, X. Y.; Liu, W. H. *Mater. Sci. Eng A.* **2005**, *391*. 29. **DOI:** 10.1016/j.msea.2004.06.008
2. Huang, J. H.; Wan, Y.; Zhao, H.T.; Cheng, D. H.; Zhang, H. *Mater. Sci. Technol.* **2007**, *23*, 87. **DOI:** 10.1016/j.scriptamat.2004.03.036
3. Liu, L.M.; Zhu, M. L.; Pan, L. X.; Wu, L. *Mater. Sci. Eng. A.* **2001**, *315*, 103. **DOI:** 10.1016/S0921-5093(01)01185-6
4. Zhang, X. P. ; Ye, L. ; Mai, Y. W. *Compos Part A: Appl. Sci. Manuf.* **1999**, *30*,1415. **DOI:** 10.1016/S1359-835X(99)00040-8
5. Zhang, X. P.; Quan, G. F.; Wei, W. *Compos Part A: Appl. Sci. Manuf.* **1999**,*30*,823. **DOI:** 10.1016/S1359-835X(98)00186-9
6. Urena A; Gil L; Escriche E. *Sci. Tech. Weld. Join.* **2001**, *6*, 1. **DOI:** 10.1179/136217101101538479
7. Zuruzi AS; Li H; Dong G. *Mater. Sci. Eng A.* **1999**, *270*, 244. **DOI:** 10.1016/S0921-5093(99)00188-4
8. Zuruzi AS; Li H; Dong G. *Mater. Sci. Eng. A.* **1999**, *259*, 145. **DOI:** 10.1016/S0921-5093(98)01004-1
9. Lee CS; Li H; Chandel RS. *Mater. Proc. Technol.* **1999**, *89-90*, 326. **DOI:** 10.1016/S0924-0136(99)00144-2
10. Yan, J.C.; Xu, H.B.; Shi, L.; Wang, X.H.; Yang, S.Q. *Sci. Technol. Weld. Join.* **2008**, *13(8)*, 760. **DOI:** 10.1179/136217108X333318
11. Shalchi B; Aashuri, H; Kokabi, A; Abbasi, G. M; Molla J. *Solid State Phenomena.* **2006**, *116-117*, 397. **DOI:** 10.4028/www.scientific.net/SSP.116-117.397
12. Narimannezhad, A; Aashuri, H; Kokabi, A; Khosravani, A. J. *Mater. Proc. Technol.* **2009**, *209*, 4112. **DOI:** 10.1016/j.jmatprotec.2008.10.004

