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ARTICLE

Effects of Silicon on Microstructures and Properties of Al-40Zn-*x*Si Filler Metal

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Abstract: The effect of Si on the brazability and the microstructures of Al-40Zn-*x*Si filler metals were studied, and the microstructures and the mechanical properties of the joints brazed with Al-40Zn-*x*Si filler metals were investigated. The results indicate that the Al-40Zn-*x*Si filler metal presents the best wettability on 6061 aluminum alloy when Si content is and 4.0 wt%. The microstructure of the filler metal indicates that the primary silicon particles could be found when the silicon content exceeds 4.0 wt%. Al-Si eutectic mixed with Zn-Al eutectoid is located at α-Al interdendritic regions in the brazed seam after cooling with water. Moreover, the Al-40Zn-4Si joint possesses the optimum shear strength of 142.28 MPa. However, the excess of Si would increase the amount of brittle eutectic structure and primary silicon particles in the brazed joints, and thereby the mechanical properties will be deteriorated.

Key words: Al-40Zn-*x*Si filler metal; brazing; microstructure; mechanical property

Aluminum is regarded as one of the most promising lightweight materials for its superior mechanical properties, excellent corrosion resistance and relatively low density. Increasing demands for the joints of aluminum and its alloys have promoted the development of aluminum brazing. So far, a variety of brazing alloys have been researched and developed, such as Al-Si, Al-Si-Cu, and Zn-Al systems. Brazing for the most commercial aluminum alloys with Al-Si eutectic filler metal often becomes difficult because of its high melting point (577 ºC). The relatively high brazing temperature would cause the localized melting of base metal and deteriorate the mechanical properties. In the previous investigations, the ternary Al-Si-Cu alloy was selected as the promising filler metal for aluminum brazing because of its lower melting point [1, 2]. Nevertheless, Cu is easy to react with Al base metal to form Cu-Al compounds. The excessive intermetallic compounds would lessen the mechanical property and reliability of the brazing joint[3, 4].

The brazability of Al-40Zn-4.2Si eutectic alloy was studied by Suzuki et al[5]. The sound joint was obtained at the brazing temperature of 563 ºC. Dai et al[6] studied a series of Al-42Zn-6.5Si-*x*Sr alloys, which indicated that the melting point of Al-42Zn-6.5Si alloy was around 520 ºC and the addition of Sr could enhance the properties of the alloys. However, the effects of silicon on properties of Al-Zn-Si alloy have been rarely reported. In the present paper, the influences of silicon on microstructures and brazability of Al-40Zn-*x*Si filler metals were studied. In addition, the microstructures and mechanical properties of 6061 aluminum alloy brazed joints were investigated.

1 Experiment

A series of Al-40Zn-*x*Si (*x*=2, 3, 4, 5, 6) alloys were prepared in the present work. The chemical compositions of filler metals are listed in Table 1. Pure Zn, Al (99.9% purity) and Al-12Si master alloy were melted in a crucible electrical resistance furnace. A graphite rod was used to stir the liquid brazing alloy every 10 min to ensure composition uniformity. KCl/NaCl eutectic mixture was used over the surface of the liquid alloy to prevent oxidation. All the cast

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ingots were fabricated into wires with 2 mm in diameter for brazing.

The test plates of 6061 alloy used in the present work were processed into specimens with dimensions of 40 mm × 40 mm × 3 mm for spreading test, and 60 mm × 25 mm × 3 mm for shear test, as shown in Fig.1. Before the brazing, all the specimens were degreased in acetone and ground by SiC paper, and then cleaned in alcohol. The spreading test was carried out according to China's National Standard GB 11364-2008[7]. 0.2 g filler metal was placed on the specimen covered with a modified CsF-AlF_3 flux. The heating temperature was 570 ℃, and the holding time was 1 min. The brazing process was performed in an electrical resistance furnace. The specimens with an overlap length of 3 mm were heated at 570 ºC, then retained at the temperature for 10 min, and finally cooled in water.

The melting temperatures of the filler metals were investigated by differential thermal analysis (DTA). The microstructures of Al-40Zn-*x*Si alloys and brazing joints were observed by the scanning electron microscope (SEM) including energy dispersive X-ray (EDS).

2 Results and Discussion

2.1 Brazability of filler metals

The melting points of Al-40Zn-*x*Si filler metals are listed in Table 2. The results show that the solidus and liquidus temperatures of the alloys increase with the increase of Si content. Compared with the Al-40Zn-2Si filler metal, the solidus and liquidus temperatures of Al-40Zn-6Si filler metal are higher by 3.1% and 2.9%, respectively. Nevertheless, the melting points of Al-40Zn-xSi filler metals still gives a remarkably decrease compared to that of Al-12Si filler metal.

Table 1 Chemical compositions of filler metals (wt%)

No.	1	2	3	4	5
Al	Bal.	Bal.	Bal.	Bal.	Bal.
Zn	40	40	40	40	40
Si	2	3	4	5	6

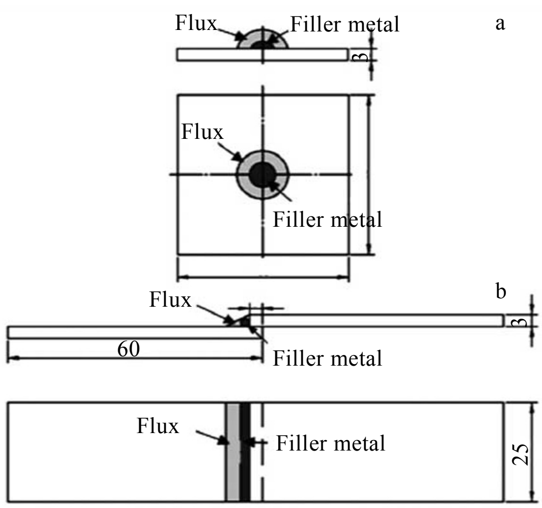

Fig.1 Schematic illustration of the experimental set up: (a) spreading test and (b) lap joint for shear testing

Usually, the wettability is described by the spreading area of a filler metal on the substrate, and as reported, the lager the spreading area, the better the wettability[8]. Fig.2 shows the spreading test results of Al-40Zn-*x*Si alloys. It can be seen that the wettability of Al-40Zn-*x*Si filler metals are improved by adding an appropriate amount of Si. The spreading area of Al-40Zn-4Si filler metal is about 157.19 mm^2, enhanced by 49.69% and 31.74%, respectively, compared to that of Al-Zn-2Si and Al-Zn-3Si filler metals. The spreading area decreases when Si addition increases up to 5.0wt% and 6.0 wt%.

The results presented in Fig.2 suggest that appropriate amount of silicon is beneficial to the spreading performance. According to the Zn-Al binary phase diagram, the solubility of liquid Zn in Al is about 50wt% at 500 ºC. The excessive solubility would go against the spreading performance on the substrate[9-11]. The amount of Al-Si eutectic gradually increases with the increase of Si content, as shown in Fig.3a~3c, which is conducive to enhancing the spreading ability. However, when the content of Si exceeds 4 wt%, the primary Si appears in the filler metal. Meanwhile, the liquidus temperature of the filler metal increases with the increase of addition of silicon, as shown in Table 2. The higher liquidus temperature may lessen the fluidity of the

Table 2 Melting points of the filler metals (ºC)

No.	1	2	3	4	5
Solidus	507.72	510.69	516.26	520.01	523.61
Liquidus	529.21	531.21	538.42	541.39	544.64

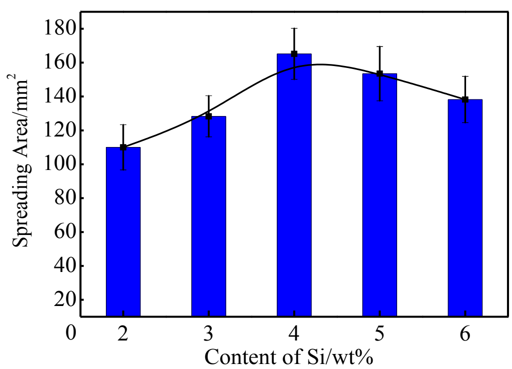

Fig.2 Spreading areas of Al-40Zn-*x*Si on 6061 substrates