Research on the Physical Characteristics of Hot-Pressed Sintering Preparing Self-Fluxing Filler by X-Ray Diffraction

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Abstract. In this paper, Al-12Si self-fluxing filler metal ring was prepared with Al-12Si alloying powders and KAlF4 flux by hot pressed sintering (HPS) method. The microstructure and mechanical properties of the brazing alloy and the brazed 3003 aluminum alloy joint were investigated. The results showed that Al-12Si self-fluxing filler metal ring could be successfully obtained by HPS at 470℃ using a pressure of 300MPa. The prepared filler metal ring was dense and defect-free and the microstructure was mainly composed of Si phase with KAlF4 flux grain uniformly distributed in the Al matrix. The 3003 aluminum alloy joint interface brazed by the prepared filler metal was also well bonded and no pore and defect was found. A quite high joint strength of 75MPa was obtained which is equal to the strength of joint brazed using commercial Al-Si self-fluxing wires prepared by hot extrude method. The results revealed that the filler metal rings fabricated by HPS process had great potentiality in brazing of aluminum alloy especially for the Al-Al pipes joining due to its high joint strength, low cost and the convenience for industrial application.

Keywords: Aluminum alloy, welding, Al-Si filler metal, Microstructure, Mechanical properties.

1. Introduction

Due to its excellent properties such as good specific strength, low density, good surface finish, superior corrosion resistance, and good workability, aluminum and its alloys have been widely used in field of communications and transport [1, 2], architecture [3] and package industries [4-6]. In the past decades, due to the huge lack of copper resources, the use of aluminum alloy is considerably increasing [7-9]. Thus the joining of aluminum alloy to itself or copper alloy is the vital technology to extend the using of aluminum alloy to large fields. Brazing is a particularly simple and cost-effective metal joining technique. Up to now, studies on the preparation of filler metals and properties of the brazed joints had been reported by many researchers [10-13]. Among the many filler metals, Al-12Si (in wt. %) alloy is considered as the most prospective brazing alloy because of its low melting temperature, good formationability and wettability. And now Al-12Si brazing alloy is widely used in form of powder, foil and wire cooperated with flux. However, the use of filler metal and flux during brazing process should be provided separately which is disadvantage for automated industrial application [14, 15]. In addition,
controlling the amount of flux is also particularly difficult. Furthermore, excess use of flux led not only serious corrosion of the brazed component but also pollution of environments. Thus in order to overcome this problem, flux-cored brazing wires was invented [16-19]. In recent years, hot extrusion and extrusion-drawing processes had been developed to produce flux-cored brazing wires [20, 21].

In this paper, Al-12Si self-fluxing filler metal was prepared by hot pressed sintering (HPS) process using Al-12Si alloying powders and KAlF4 flux. Microstructures of the brazing alloy and the brazed 3003 aluminum alloy joint were investigated. Mechanical properties of the brazed 3003 aluminum alloy joint were also evaluated.

2. Experimental procedures
In this experiment, commercial Al-12Si alloying powders (170μm) and KAlF4 flux powders (74μm) were used as raw materials for the fabrication of self-fluxing filler metal. Prior to HPS, the Al-Si powders and flux powders were mixed in the weight ratio of 85:15 and ball-milled for 5 minutes in order to get a homogenous composition. After ball-milling process, the mixed powders were dried in a baking oven for 1 hour at 100℃. Schematic configuration of the mould used for HPS was shown in Fig.1.

![Fig 1. Schematic diagram of hot pressed sintering mould.](image)

The powder mixture was then placed in the impression by feed shoe. The punch reciprocation was made to adjoin the powder mixture together at room temperature, which could degas powder mixtures. It was not stopped until the thickness of the powder mixture up to 3.5 mm. In order to attain a desired density of compacted powder mixture, the HPS process had to be done at 470℃ using a pressure of 300MPa. It was however to be noted that such a high temperature tended to oxidize the component powders to render poor the brazeability of the brazing alloy. This was why the vacuum atmosphere was required during HPS process. After 1 minutes of sintering time, the filler metal ring was ejected by ejecting mechanism of the hot pressed sintering mould.

In order to evaluate the brazing behavior of the Al-12Si self-fluxing filler metal, 3003 aluminum alloy joints were brazed at 610℃ for 10 minutes in an air furnace. 3003 aluminum alloy samples were cut with dimension of 80 mm×20 mm×2 mm. prior to brazing, surfaces of 3003 were slightly polished using SiC sandpaper (400 mesh) and were ultrasonically cleaned in acetone for 15 minutes. Some 3003-3003 joints were cut perpendicular to the interface, mounted and polished. Microstructures and phase composition of the braze and the brazed joints were investigated by scanning electron microscopy (JSM-7500F) equipped with energy dispersive X-ray spectroscopy (EDS) and X-ray diffraction (D8-FOCUS). Tensile test was performed at room temperature on a universal mechanical testing machine with a constant speed of 1 mm/min. At least three samples were tested to obtain the average strength.
3. Result and discussion

3.1. Microstructure characterizations of the filler metal.

Photo of the Al-12Si self-fluxing filler metal rings fabricated by HPS is shown in Fig. 2. As seen in Fig. 2, the filler metal rings exhibited good surface condition and no pores and cracks were detected. In addition, no obvious dimension change of the rings was found.

![Fig 2. Al-12Si self-fluxing filler metal ring.](image)

Fig. 3 shows the microstructure of the Al-12Si self-fluxing filler metal ring. It is noticeable that the interfaces between the Al-Si alloying powders and flux grain were well bonded and free of microvoids and cracks which indicated that full densification was obtained during the HPS process. It can be seen that grain Si phase (as marked An in Fig. 3b) and fine grain flux phase (as marked B in Fig. 3b) distribute uniformly in the Al matrix (as marked C in Fig. 3b), and the size of Si phase and flux phase is about 3μm and 0.5μm, respectively. Thus, a fine structure consisted of Al, Si and KAlF4 is obtained. Furthermore, according to the XRD analysis result as shown in Fig. 4, on other oxide phase besides Al, Si and KAlF4 was detected which indicated that the filler metal ring was avoid any oxidation during the HPS process. This result especially benefits the wetting and spreading of the filler metal on the Al alloy substrate.

![Fig 3. Microstructure of Al-12Si self-fluxing filler metal: (a) OM, (b) SEM.](image)
3.2. Microstructures and Tensile strength of the brazed joint.

Fig. 5 shows sound joints obtained for 3003-3003 aluminum alloy pipe using Al-12Si self-fluxing filler metal rings. The microstructure of the brazed joint using filler metal ring, as shown in Fig. 6, is uniform. The penetration mode of the Al-12Si self-fluxing filler metal ring into the aluminum composite is accepted. It can be seen that the brazed joint was composed of based metal, interface region, and brazing seam. When Si diffuses from the filler metal into the based metal, it seems to be cause melting of the matrix, forming interface region with Al-Si solid solution. Because of the diffusion of Si, the microstructure of brazing seam is different from filler metal. However, a small amount of block primary crystal silicium phase still exists in brazing seam.
According to Fig.6, the microstructure of brazed joint consisted of light gray needle-like phase and gray matrix. For further studying elements percentage of the two different transition regions, constituent in two points A and B were measured (Fig.6) and the results are shown in Table 1. According to Al-Si phase diagram and Table 1, the phase in point A is α-Al solid solution and in point B is eutectic Si.

| area | chemical composition (wt. %) |   |   |
|------|-----------------------------|---|---|
|      | Al  | Si    |   |
| A    | 98.08 | 1.92 |   |
| B    | 85.40 | 14.60 |   |

Tensile strength test results of brazed joints using Al-12Si filler metals with different production technology are shown in Fig. 7. According to Fig.7, the average tensile strength of 3003 aluminum alloy joint using Al-12Si filler metal and KAlF4 was up to 78MPa. And the average tensile strength of 3003 aluminum alloy joint using commercial productions of Al-12Si flux-cored aluminum welding wire was 74MPa, which has been proved to be reliable filler metal to braze aluminum alloys by Weimin. Long [22]. And it is also shown that the average tensile strength of 3003 aluminum alloy joint using Al-12Si self-fluxing filler metal rings was 75MPa, which indicates that the filler metal fabricated by HPS process in this paper is a reliable brazing alloy for the bonding of aluminum alloys.

4. Conclusions

In summary, a new production technology was developed and the brazed joints of 3003 aluminum alloy with Al-12Si self-fluxing filler metal rings were studied, including the microstructure and mechanical properties of the brazed joints. The results can be summarized as follows:

(1) The prepared filler metal ring was dense and defect-free and the microstructure was mainly composed of Si phase with KAlF4 flux grain uniformly distributed in the Al matrix.

(2) The 3003 aluminum alloy joint interface brazed by the prepared filler metal was also well bonded and no pore and defect was found. A quite high joint strength of 75MPa was obtained which is equal to the strength of joint brazed using commercial Al-Si flux-cored aluminum welding wire.

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