SOLDERING OF ALUMINUM MATRIX COMPOSITES SIC_P/A356 AND KOVAR ALLOY

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Abstract:

Aluminum matrix composites containing 55% SiC particle reinforcing phase/SiC reinforcement phase particle and Kovar alloy 4J29 were chosen as the base metals. After nickel plating on the surface of SiC_p/Al, two kinds of materials were soldered together by using Zn-Cd-Ag-Cu as the filler metal and $ZnCl_2$ as the flux at the temperature of 420 °C in an argon atmosphere for 5 minutes. The interfacial microstructures and fracture surfaces were investigated with a scanning electron microscope (SEM). The result shows that the electroplating nickel on the surface of SiC_p/Al can improve the weldability of fillers in the composites. There are transition layers not only between the filler and Kovar alloy, but also between the filler metal and nickel layer, which shows that the filler metal, the nickel layer, the composites and Kovar alloy can be joined by the diffusion mechanism. The fracture analysis shows that the fracture is mainly located at the side of composites near the electroplating nickel layer.

1 Introduction

Aluminum metal matrix composites (Al-MMCs) are characterized by low density, a low coefficient of thermal expansion, high specific strength and stiffness, which are proved to be a new promising material in the area of aviation, aerospace electrocommunication and automobile industries [1]. However, its poor weldability is the most serious problem for the application [2]. In order to overcome this problem, researchers did a lot of research including fusion welding, laser welding, electron beam welding, diffusion welding, soldering as well as flash butt welding and so on during the last 20 years [3]. Due to big differences between the base material and reinforced particles, such as the melting point and coefficient of thermal expansion, it is hard to achieve a good joint by conventional fusion welding. Concerning laser welding and electron beam welding, the detrimental interface reaction can not be avoided because of the intensive energy input. With regard to diffusion welding and flash butt welding, the flexibility decreases greatly due to the requirements of these methods, especially in the welding of dissimilar material [4]. Soldering is considered to be the most promising welding method for Al-MMCs due to short heating up time, low temperature welding and flexibility of the weld. There are some general soldering technologies for joining Kovar alloys by which the good joint can be

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achieved [5]. It is necessary to avoid the continuous brittle reaction of products between Al-MMCs and Kovar alloy during soldering of dissimilar materials. Two considerable approaches are to be mentioned in this case [6]:

1) To develop an appropriate soldering filler metal;
2) To use a proper technology. For example, surface modification before soldering, such as plating the metal film. The properties of the joint can be improved greatly due to a decrease in brittleness in the weld. The reason is that metallurgical bonding is formed both between Al-MMCs and the plated metal film, and Kovar alloy and the plated metal film.

The second approach is to plate the nickel film on the surface of Al-MMCs. In this research, the chemical nickel-plating is carried out on the surface of Al-MMCs before soldering.

The Al-MMCs used in this work contain 55 vol.% of SiC particles with the diameter of 50-100 μm. Fig. 1 shows the microstructure of Al-MMCs used in this research. Both Al-MMCs and Kovar alloy were cut with electric spark cutting machine into 50 mm × 10 mm strips, about 4 mm thick for composites and 0.8 mm for Kovar respectively. The nominal composition of A356 is given in Table 1.

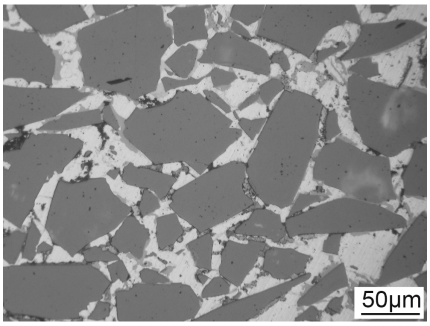


Figure 1. The original structure of Al-MMCs.

Table 1. The nominal chemical composition (wt.%) of A356

Material	Si	Mg	Ti	Al
A356	7	0.4	0.1	Bal.

All samples are ground with/using grit 800 emery paper, and then rinsed in acetone. The Al-MMCs are nickel-plated in a solution containing nickel salt 280 g/L and boric acid 30-40 g/L, with voltage of 15 V and current density of 0.35 A/dm^2. All samples consisting of the composites, Kovar alloy, solder alloy and flux are assembled, and then the soldering process is carried out in a radiation heating furnace filled with pure argon.

After soldering, the microstructure of the joint is investigated by SEM and energy spectrum analysis. The shear strength of the joint is measured with the electronic tensile machine Instron-5569.

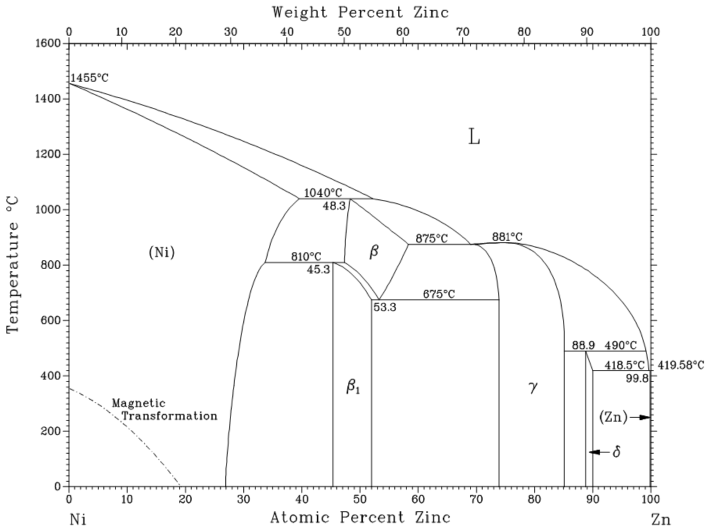
2 Selection of soldering filler metal and soldering flux

In soldering different materials, it is very important to select an appropriate filler metal. Due to the presence of nickel film at the surface of Al-MMCs, the soldering filler metal should exhibit good solderability on both Kovar alloy and the nickel film. Moreover, the liquidus temperature of the soldering filler metal should be at least 30-40 °C lower than the solidus of the base material.

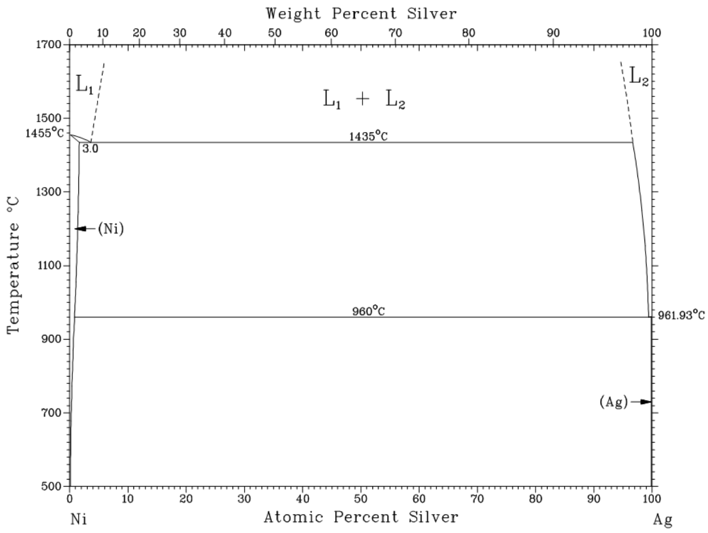
Wettability of the soldering filler metal over the base material is a key characteristic of a good soldering filler metal. Zinc-based filler metal is supposed to solder an appropriate filler metal considering the solidus (577 °C) of Al-MMCs. In many kinds of commercial Zinc-based soldering filler metals, series of Zn-Cd-Ag-Cu are supposed to be the best choice for this research based on the following reasons:

1) For elements Zn and Ni, Ag and Ni, there exists solid solubility which is shown in Fig. 2 (a) and (b), respectively. For elements Cu and Ni, Fig. 2 (c) shows the complete solid solution between them [7]. Consequently, Zn-Cd-Ag-Cu has good wettability for both the nickel film and Kovar alloy.
2) The function of the element Cd in soldering a filler metal into a joint is to decrease the soldering temperature, improve the liquidity of the filler metal, to narrow the melting range and to increase the joint strength.

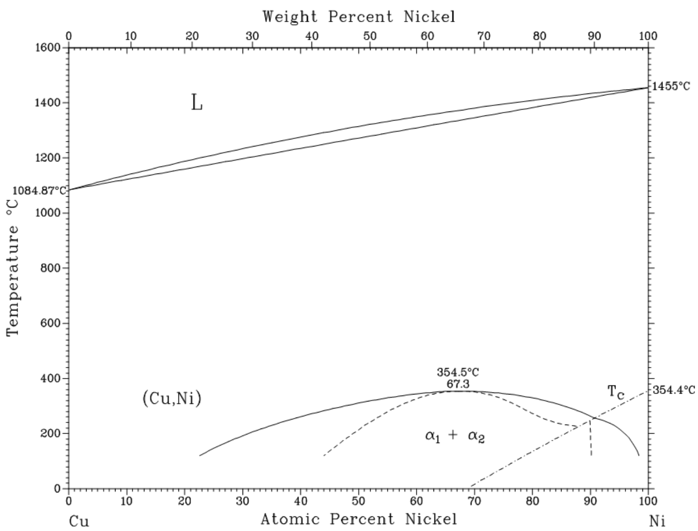
The composition of filler metal is Zn38-Cd58-Ag2-Cu2 and the thickness is 40 μm.



(a)



(b)



(c)

Figure 2. Binary alloy phase diagram (a) Zn-Ni (b) Ag-Ni (c) Cu-Ni.

During the soldering process, the soldering flux of $ZnCl_2$ is utilized. The effect of $ZnCl_2$ can be described as follows [8]:

1) To clean away the oxide and the other impurity on both surfaces of the base material and soldering filler metal.

2) To isolate the joint away from the surrounded air and keep it away from oxidation.

3) To activate the interface between the soldering filler metal and base material, and improve the wetting property of soldering filler metal.

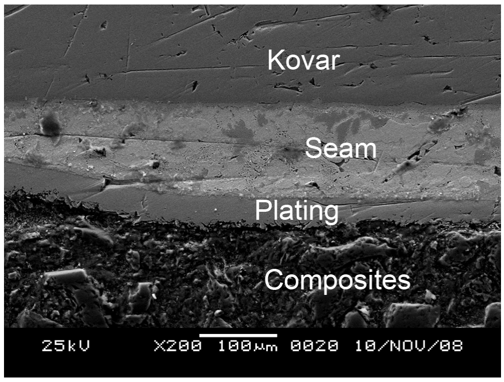
The $ZnCl_2$ flux is brushed on both sides of filler metal. The thickness of the brushed flux is 20 μm. As it is already known, the soldering temperature should be 30-50 °C higher than the liquidus temperature of soldering filler metal. According to the measurement, the liquidus temperature of soldering filler metal is 380 °C. Therefore, the soldering temperature can be fixed at 420 °C and the soaking time is 5 minutes.

3 Results and analysis

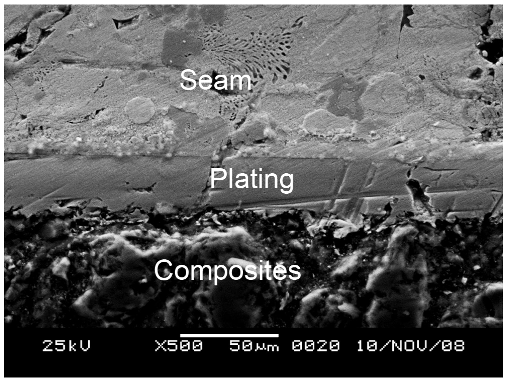
3.1 Microstructure analysis of the joint

Fig. 3 (a) illustrates the microstructure of the soldered joint, with Kovar on top, composites at bottom and electro-plating layer (approximately 40 μm thick) atop composites. The thickness of soldering seam is around 120 μm, which can be seen between the plating layer and Kovar alloy. Wettability of the soldering filler metal over composites is greatly improved due to nickel plating. The magnified scanning interfaces of the soldering seam, the plating layer and composites are shown in Fig. 3 (b). It indicates that the compact joining is formed in the joint probably because of mutual diffusion of Ni element, filler metal and base material during the heat preservation under high temperatures.

Fig. 4 shows the microstructure of the soldered joint observed in back dispersion via SEM. The diffusion layer can be clearly differentiated from the interface structure. The interface includes Kovar alloy (spot A), diffusion zone between Kovar alloy and filler metal (spot B), the structures of filler metal (spot C and D), a diffusion zone between the plating layer and filler metal (spot E), nickel plating layer (spot F) and composites (spot G). For each spot in Fig. 4, EDS analysis was performed.



(a)



(b)

Figure 3. The microstructure of the joint: (a) the whole joint (b) magnified near to the plating material.

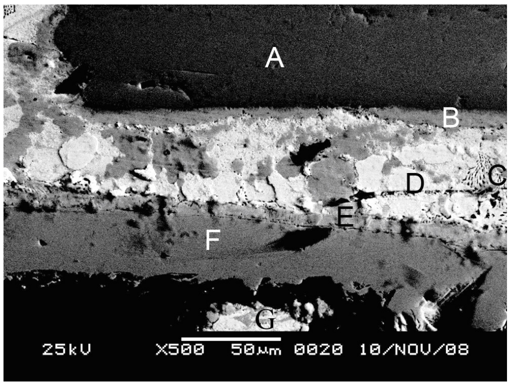


Figure 4. The microstructure of the soldered joint in the soldered seam.

The result of EDS analysis on each spot as shown in Fig. 4 can be seen in Table 2. The grey belt structure (spot B) at the interface between Kovar alloy and filler metal emerges during the soldering process where some elements in Kovar alloy such as Fe, Co, Ni are dissolved into the liquid filler metal.

Table 2. Elements distribution analysis at different spots

Element / Spot	Zn	Cd	Ag	Cu	Al	Si	Fe	Co	Ni
A	-	-	-	-	-	-	58.09	15.32	26.59
B	42.2	20.9	3.7	4.2			10.6	7.9	10.5
C	2.8	95.14	2.00	-	-	-	-	-	-
D	66.44	4.95	25.02	3.59	-	-	-	-	-
E	67.05	1.55	0.36	1.77	-	-	-	-	29.26
F	-	-	-	-	-	-	-	-	100
G	3.18	87.59	2.24	-	5.75	1.24	-	-	-

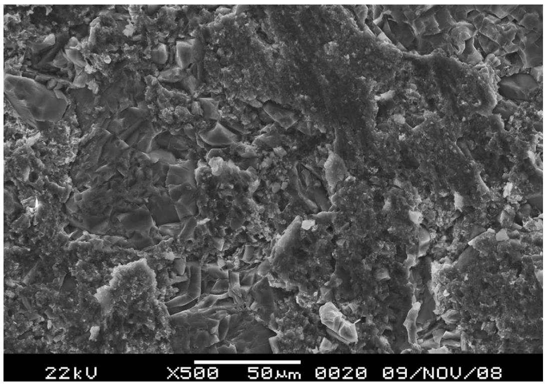
It can also be seen from Fig. 4 that there is a grey structure between the filler metal and plating layer (spot E). In this area, the content of Ni is very high, indicating that remnant Ni is dissolved into the filler metal and further formed into solid solution or compound.

The element Cd diffuses very fast. With a technique of plating a layer of nickel/When plating a layer of nickel, a high content of the element Cd at spot G shows that the filler metal penetrates through the plating layer on the surface of Al-MMCs improving wettability and increasing joint strength through micro-hole filling.

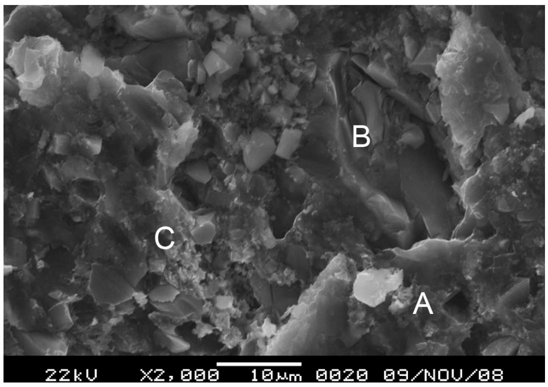
3.2 Fracture appearance analysis of the joint

The tensile strength and yield strength of 55 vol.% SIC_p/A356 is 370 MPa and 255 MPa, respectively. The corresponding value for Kovar alloy is 545 MPa and 418 MPa, respectively. After the soldering process, the shearing test of the joint was carried out with an average shearing strength of 225 MPa. Fracture is found on the composite side near the plating of Ni layer. For further analysis of the formation mechanism of the soldered joint, fracture is observed on the side of the composite via SEM, as shown in Fig. 5. The fracture in Fig. 5 (a) is quasi cleavage. In the magnified picture, as shown in Fig. 5 (b), peeling pit in spot A can be found due to fall-off of SiC particles from the base material and the remaining SiC particles can be seen in spot B. The ductile fracture in the base material as seen in spot C demonstrates that the soldered joint achieves high strength, leading to the fracture on both sides of the composite.

The analysis of another side (on the side of the filler metal) of fracture explains why also the fracture turns out to be a quasi cleavage as shown in Fig. 6. In the high magnified picture as shown in Fig. 6 (b), there is a peeling pit in spot A, where SiC falls off from the base interface, SiC reinforcement phase (spot B) and break-off of the base material (spot C). These findings show that break-off develops/occurs in the composites adjacent to the Ni-plated interface.



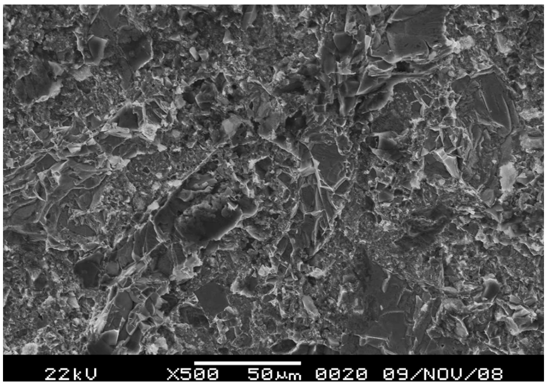
(a)



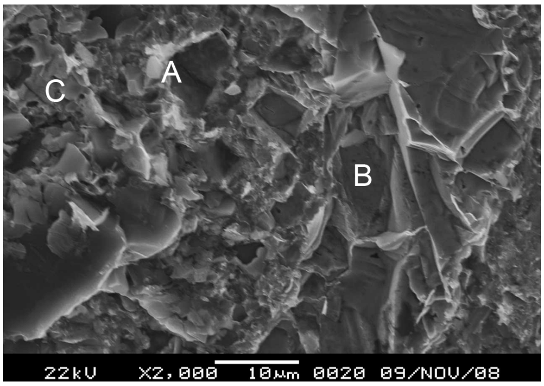
(b)

Figure 5. Fracture appearance on both sides of the composite (a) under low magnification view; (b) under high magnification view.

Considering the traditional soldering method, the main problem is non-wetting between the filler metal and SiC in Al-MMCs. However, after nickel plating, the spreadability of the filler metal is greatly improved and the mutual diffusion of elements takes place much easer between the filler metal and Ni film. Therefore, a strong joint with higher shear strength could be obtained.



(a)



(b)

Figure 6. Fracture appearance on the side of filler metal (a) under low magnification view; (b) under high magnification view.

4 Conclusions

In this research, 55% SiC_p/A356 and Kovar alloy are successfully soldered together. The main achieved results can be summarized as follows:

(1) After Ni-plating on the composites, a good joint can be achieved using Zn38-Cd58-Ag2-Cu2 as the filler metal and $ZnCl_2$ as the flux at the soldering temperature of 420 °C for 5 minutes in an argon atmosphere.

(2) Complex structures are formed in the soldered seam. When plating a layer of Ni, the element Ni diffuses into the filler metal whereas the elements in the filler metal diffuse into composites through the micro-hole. There are two transition layers at both sides of the soldered seam. These processes result in the chemical and metallurgical joining of composites and Kovar alloy.

(3) The shear strength of the joint can be achieved via 225 MPa. Through the analysis of fracture appearance, the break-off develops/occurs inside the joint within the composites near the side of Ni-plating.

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