Diffusion Bonding of Magnesium Alloy (AZ31B) to Cu by Using Sn Foil Interlayer

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Abstract. The experimental investigation of diffusion bonding of magnesium alloy (AZ31B) to Cu in vacuum was carried out by using Sn foil as transition metal. The microstructure of the welded joints was studied by SEM, EDS, XRD and the mechanical properties of the samples were tested by tensile experiments. The results show that: the microstructure at interface zone of diffusion brazing joint includes γ-Cu, Mg_2Sn, Mg-Sn-Cu ternary intermetallic compounds, $Mg_{17}(Cu, Al)_{12}$ and (α-Mg+Mg_2Sn) eutectic structure, and the width of diffusion zone increased with the extension of the holding time, the maximum can reach up to 400 μm under the condition of 420 ℃,90 min. The hardness of diffusion welding area was significantly higher than the substrate.

Introduction

In recent years, due to the rapid development of electronic products, especially the high-power LED products, its packaging materials put forward higher requirements on thermal conductivity and heat dissipation. Magnesium alloy has low density, high specific stiffness and strength, good thermal conductivity, especially excellent heat resistance, and copper has good thermal conductivity [1-4]. In order to make full use of their advantages and meet the market demand of high-power electronics cooling products, it is necessary to develop a composite metal material which not only maintain the high thermal conductivity of copper, but using the lightweight and high heat dissipation of magnesium. However, the joining together of these dissimilar alloys still presents a challenge and this can be attributed to the considerable differences in their physical and metallurgical properties[5].

Diffusion bonding is an attractive joining technique which enhance the physical contact of surface to be welded by micro plastic deformation and then achieved combination by mutual diffusion of atom. The heating temperature of diffusion bonding is far below the melting point of base metal and it can heat evenly, which would avoids the bad influence of physical and chemistry characters of base metal caused by conventional welding method. And it is fit for connection situation of large area and high dimensional accuracy [6]. Above all, diffusion welding in vacuum has been concerned in bonding dissimilar materials, but because of the low solubility of magnesium and titanium, it will produce series of brittle metal compounds that worsen the structure and mechanical property of welded joint when welding directly [7]. The research literature [8-10] shows that the suitable interlayer can play a positive role in avoiding forming brittle metal compounds among dissimilar metals, it is an important method to improve the quality of diffusion welding joints. In this study, Sn foil has been used as a method of forming a eutectic with the metals of AZ31B/Cu being joined.

Materials and Experimental

2 mm thickness wrought magnesium alloy AZ31B plate and 2 mm industry pure copper plate were used as the base materials in the experiment. The interlayer employed in diffusion bonding process was Sn foil with the thickness of 20 μm. The chemical composition and thermo-physical properties of AZ31B and pure copper are given in tables1 and 2 .The test materials of AZ31B and pure copper plates were cut by the lining cutting machine with dimension of 60 mm ×40 mm. The

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surfaces of metal to be joined were prepared on SiC paper to a 2000 grift finish and then ultrasonically cleaned with acetone for 5 min. The treated specimens were stacked in a homemade die, and the entire diffusion bonding setup was inserted into a vacuum chamber.

Tab.1 Chemical composition and properties of AZ31B Magnesium alloy

Mg	Al	Zn	Mn	Si	Melting Point/℃	Density/(g cm^{-3})	Shear strength/MPa
Bal	3	1	0.35	0.005	660	1.74	140

Tab. 2 Chemical composition and properties of copper

Cu	Fe	O	Ni	Pb	Melting Point/℃	Density/(g cm^{-3})	Shear strength/MPa
99.9	0.005	0.06	0.006	0.005	1083	8.96	150

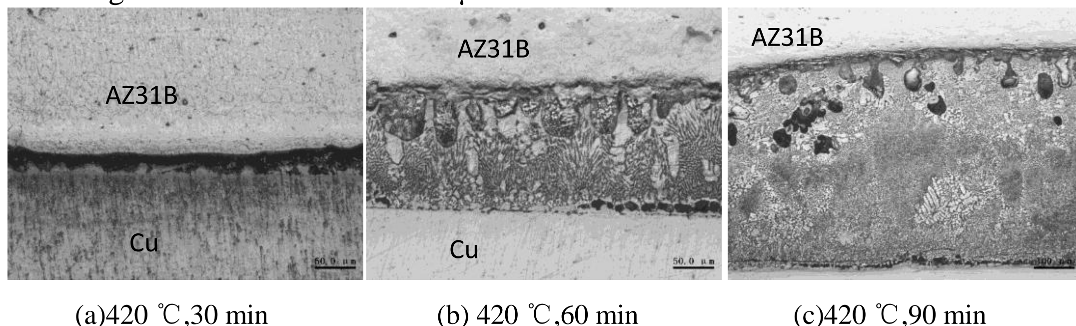
The process of AZ31B/Cu diffusion bonding is as follows: When the degree of vacuum reached 1Pa ~ 4Pa, heated work piece from room temperature to 200 ℃ with the heating rate of 10℃/min and the degree of vacuum maintained at below 10 Pa. When the temperature is higher than 200℃, purged argon to the furnace chamber, with a heating rate of 13℃/ min until the temperature reaches 420 ℃, and then holding time for 60 min. After the incubation, pressure is removed. The bonded samples were allowed to cool down to room temperature inside the bonding chamber and under vacuum atmosphere.

For metallographic examination, the bonded samples were cut transversely through the joint region and polished using diamond suspension down to a 0.5 μm finish. Grounded and polished cross sections were etched in reagents (5% HNO3) for 20 s. Microstructural developments of the joints were examined using scanning electron microscope (S-4800).The chemical compositions of the micro-zones in the joints were analyzed by energy-dispersive X-ray spectroscopy (EDS). Phase structure in the joints were identified using X-ray diffraction (XRD). Microhardness testing of the joints rejoin were conducted using a hardness tester (HVS-50), with a load pressure of 0.25 N and a holding time of 5 s.

Results and Discussions

Bond Formation and Microstructural Analysis

Figure 1 shows optical micrographs of the AZ31B/Sn/Cu bond interfaces after bonding at 420 ℃ for 30, 60 and 90 min. It can be noticed that with the extension of holding time, the width of the diffusion zone gradually increased. In the holding time of 30min, the diffusion region is not obvious. By increasing the bonding time to 60 min, the interlayer and base materials have a fully diffusion resulted in the interlayer Sn foil disappeared at last, the joint interface region contained lamellar eutectic structure, Mg-Sn solid solution and Cu-Sn solid solution compounds. A further increase in the bonding time to 90 min, diffusion of the interlayer and the substrate is more uniform, the width of the diffusion region has reached about 400μm.



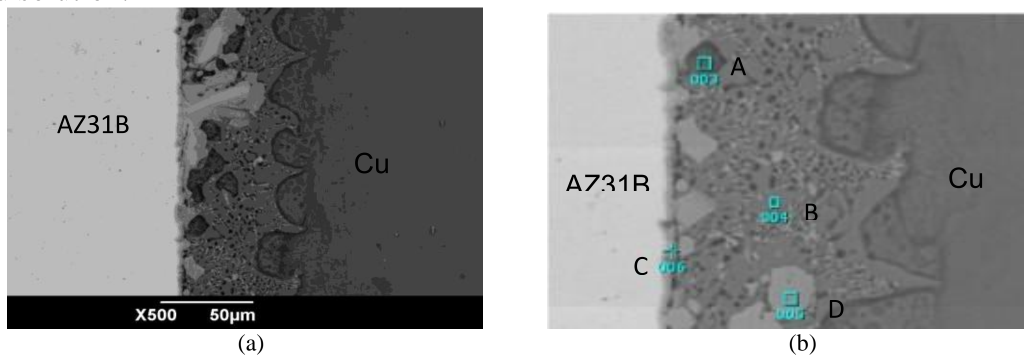
(a)420 ℃,30 min (b) 420 ℃,60 min (c)420 ℃,90 min

Fig.1 Microstructure of diffusion brazed joint at different holding time

According to the Mg–Sn binary phase diagram, it can be suggested that holding time at 420 ℃, atom interdiffusion of Sn and Mg occurred. On one hand, Sn diffuse to the substrate of AZ31B and generated a magnesium-based solid solution towards the surface of AZ31B. The continuous diffusion of Sn changes the composition until it reached the stabled composition of Mg_2Sn (10.7wt %). On the other hand, Mg diffuse to the Sn foil and formed the solid solution on the interlayer surface, it changes to a balanced liquid immediately because of the low solubility of Mg in Sn. It can be noticed from the Mg–Sn binary phase diagram, under the condition of 420 ℃, the solubility of Cu in Sn is extremely small, almost no, but the solubility of Sn in Cu can reach 9%, hence, it mainly occurred the diffusion of Sn to Cu, a new phase of Cu_3Sn formed until the composition reached the stabled (9wt %). With the continuous diffusion, new phase of Cu_6Sn_6 generated until the composition of Sn in copper-based solid solution up to 43.5wt%.

Figure 2 shows scanning electron micrographs of the AZ31B/Sn/Cu bond interfaces after bonding at 420 ℃ for 60 min.Wherein Figure 2(a) is the cross-section overall morphology of the composite plate. It can be seen from the picture, there are three layers of magnesium matrix, a transition zone and the copper substrate. The joint combined well with the absence of interfacial voids, cracks and other defects. A significant diffusion layer formed between the magnesium alloy and copper, its width is about 70 μm, the liquid phase has a better bonding with the magnesium alloy than copper, lamellar eutectic appeared near the magnesium side. Figure (b) is an enlarged zone of the welded zone, different regions of the energy spectrum test results shown in Table 3. The atomic percent ratio of Mg:Sn in A region is about 2:1 which represented Mg_2Sn. According to the component ratio of B, C, D and Mg-Sn, Cu-Sn binary phase diagram, it can be determined the weld area is mainly containedγ -Cu, Mg_2Sn, Mg-Sn-Cu ternary intermetallic compounds, $Mg_{17}(Cu,Al)_{12}$ and (α-Mg+Mg_2Sn) eutectic structure.

Furthermore, formation of the new phases which discussed above can also be explained by XRD analysis across the welded joints. The results show that, on the condition of 420 ℃, 60 min, the microstructure of AZ31B/Sn/Cu joint was Mg_2Sn, Cu_3Sn intermetallic compounds, Cu (Sn) and Mg (Sn) solid solution.



(a) (b)

(a) The cross-section overall morphology of the composite plate (b) an enlarged zone of the welded zone

Fig. 2 Microstructures of interface zone of 420℃, 60min

Tab.3 The test result of different regions of element composition near the weld zone

Element	A(At%)	B(At%)	C(At%)	D(At%)
Mg	61.04	40.51	16.86	39.56
Cu	——	11.66	49.19	13.19
Sn	38.96	47.83	33.95	47.25

Micro-hardness Profile

Structural characteristics of AZ31B/Cu diffusion welding joints determines its mechanical properties. Micro hardness profiles taken across the AZ31B/Sn/Cu joint region are shown in figure 4. It can be seen, copper matrix has a lower micro-hardness value, approximately 80 HV, and magnesium matrix microhardness value is about 57 HV, while a maximum microhardness of 178 HV was achieved in the diffusion zone, which is about two to three times of matrix structure. This

can be attributed to the presentence of high hardness intermetallic compounds. On the interface region appeared microhardness increased, which is due to α-Mg (Cu) solid solution in the magnesium substrate side diffusion layer and precipitation of the second phase, it play an important role in strengthening the interface region, resulting in increased of hardness. Cu-Sn interdiffusion occurred towards the copper matrix, the forming of Cu (Mg) solid solution can strength the joint.

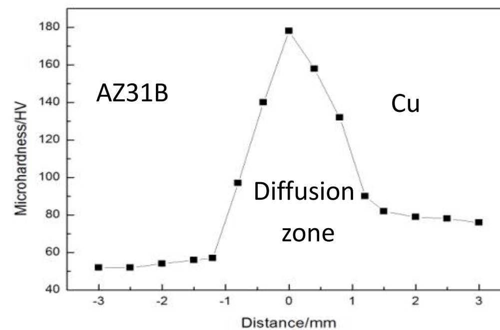


Fig.4 Microhardness distribution of the AZ31B/Sn/Cu welded joint

Conclusion

Diffusion bonding of magnesium alloy (AZ31B) to Cu was successfully achieved using Sn foil interlayers. With the extension of the holding time, the width of the joint diffusion region increases, the maximum can reach up to 400 μm. The interface region of AZ31B/Sn/Cu generated γ-Cu, Mg_2Sn, Mg-Sn-Cu ternary intermetallic compounds, $Mg_{17}(Cu,Al)_{12}$ and (α-Mg+Mg_2Sn) eutectic structures under the condition of 420 ℃,90 min. The hardness of diffusion welding area was significantly higher than the substrate of AZ31B, Cu, and its hardness range from 90 to 178 HV.

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