

# Effects of loading methods on microstructure of diffusion welded joint of AZ31B/Cu with Ni interlayer

S M Du<sup>1,a</sup>, Y Q Zhang<sup>1,b</sup>, C Du<sup>1,c</sup>, J Hu<sup>1,d</sup>

<sup>1</sup>College of Materials Science and Engineering, Xi'an University of Science and Technology, Xi'an 710054, China)

E-mail:<sup>a</sup>shuangmingdu@163.com, <sup>b</sup>18710980374@163.com, <sup>c</sup>980513781@qq.com, <sup>d</sup>dclhujie2009@163.com

**Abstract:** Diffusion brazing was carried out to weld AZ31B magnesium alloy and copper with Ni foil interlayer under different loading methods that are divided into intermittent gradient pressure, gradient pressure and constant pressure. The microstructure and element diffusion of welded joint were analyzed by SEM and EDS. The results show that the AZ31B/Cu can achieve good bonded joint composed of brazing seam zone and magnesium substrate grain boundary penetration zone at 500 °C for 20 min. The loading methods have great influence on the thickness of brazing seam zone, microstructure and  $\alpha$ -Mg grain size of the welded joint. At intermittent gradient pressure, the brazing seam zone reaches the biggest width of 0.18 mm, and the microstructure of brazing seam zone is composed of  $\text{Cu}_{11}\text{Mg}_{10}\text{Ni}_9$ ,  $(\alpha\text{-Mg}+\text{Mg}_2\text{Cu}+\text{Mg}_2\text{Ni})$  eutectic structure and  $\alpha$ -Mg. Under gradient pressure, the width of brazing seam zone reduces, and the microstructure of brazing seam zone is mainly dominated by  $(\alpha\text{-Mg}+\text{Mg}_2\text{Cu}+\text{Mg}_2\text{Ni})$  eutectic structure and  $\text{Cu}_{11}\text{Mg}_{10}\text{Ni}_9$  compounds closed magnesium matrix. When using constant pressure, the microstructure of joint is similar to that under intermittent gradient pressure, the brazing seam zone reaches the smallest width of 0.11 mm, and the size of  $\alpha$ -Mg grains reduces.

## 1 Introduction

Diffusion brazing is a kind of connection method that heats the heterogeneous metals to a temperature below the melting point and then hold for a period of time, low melting liquid phase forms by mutual diffusion between heterogeneous metals, liquid phase dissolves and diffuses with both sides of parent metal, and then a connection joint forms after cooling solidification. This process has the characteristics of brazing and diffusion welding, which filler is not needed and the deformation of workpiece is small after welding, so it is suitable for the connection of dissimilar materials with



poor welding ability or large melting point difference[1,2]. At present, the hot topics in study of diffusion brazing mainly focus on the optimization of process parameters which include heating temperature, holding time, the value of the pressure, and the middle layer[3-5], but research about the effects of pressure methods on joint microstructure and properties is rarely reported. According to the theory of diffusion welding, at constant pressure, the smaller welding pressure is difficult to ensure physical contact between parent metal so that atomic diffusion is influenced, however, larger welding pressure makes the formation of low melting liquid extrusion effect, which leads the welding workpiece serious thinned[6]. Therefore, it is necessary to study the effects of pressure methods on dissimilar metal diffusion brazing behaviors.

Magnesium alloy is the lightest engineering material with the characteristics of high specific strength and stiffness, good thermal conductivity and electrical conductivity, strong vibration damping and electromagnetic shielding performance, easy processing and forming performance, and easy recycling performance of waste, etc, which makes it widely used for aerospace, automobile manufacturing, 3C products and other fields[7]. Copper that has the performance of good conductivity, thermal conductivity, corrosion resistant and wear-resisting is mainly used as the device with conductivity, thermal conductivity and corrosion resistance. Mg-Cu dissimilar metal composite component can fully play the performance advantage of two kinds of parents, so it has a broad application in chemical industry, electronics, Marine, military and other fields[8]. Adopting the traditional welding can't obtain reliable Mg/Cu welded joint because of their poor welding ability and large thermal physical property differences[9].

It is easy to form  $Mg_{17}(Cu/Al)_{12}$  and  $Cu_2Mg$  intermetallic compounds that affect the joint properties if Mg/Cu are welded directly[10], in order to improve this situation, appropriate interlayer is used for welding materials to form a gradient bonded joint, which reduces the thermal stress and hard brittle phase of joint[11]. It can be seen from phase diagram that copper and nickel can form continuous solid solution, Mg-Ni-Cu can form ternary eutectic reaction at 480 °C, which is beneficial to improve the performance of the joint. Therefore, this paper choose Ni foil as the interlayer to weld AZ31B magnesium alloy and Cu under different pressure condition, and then analyze the effects of loading methods on the microstructure and element diffusion of welded joint.

## 2 Experimental materials and methods

The size of experimental materials for AZ31B magnesium alloy and industrial pure copper T2 is 10 mm×10 mm×2 mm and Ni foil is 10 mm×10 mm×0.02 mm, the chemical composition of parent metal is shown in Tables 1 and 2.

Table 1 Chemical compositions of AZ31B Mg alloy(wt, %)

Al	Zn	Mn	Si	Mg
2.5-3.5	0.5-1.5	0.2-0.5	≤0.1	Bal

Table 2 Chemical compositions of T2 Pure Copper(wt, %)

Fe	Ti	Ni	Cu
0.005	0.006	0.005	Bal

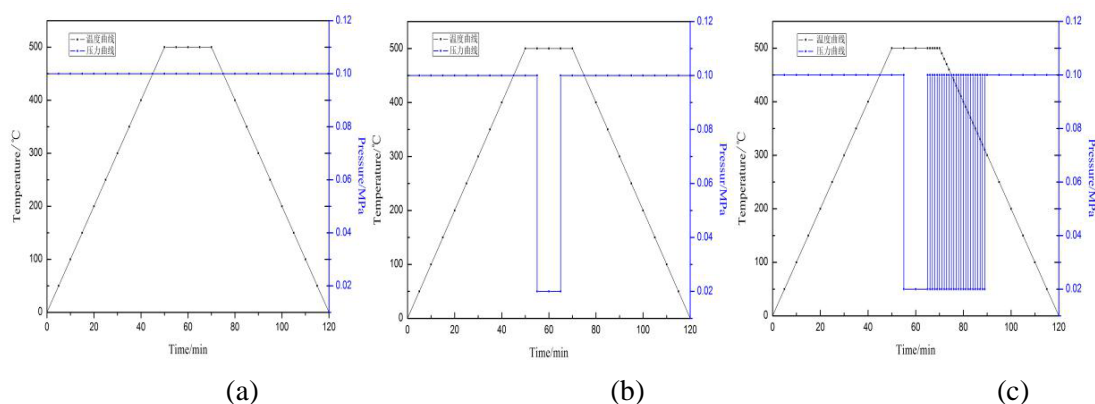


Fig.1 Technological parameters curve of diffusion brazing under different loading methods

(a) Constant pressure (b) Gradient pressure (c) Intermittent gradient pressure

Before welding, the intended bonding surface of specimens were ground using SiC papers until the contact surface was smooth, and then put them in acetone solution to clean 3-5 min by ultrasonic cleaner and dry, at last, specimens were then assembled in the vacuum furnace. Adopting the bonding parameters of temperature is 500 °C and the bonding time is 20min. The technological parameters curve of diffusion brazing under different loading methods that are divided into constant pressure, gradient pressure, intermittent gradient pressure are shown in Figure.1, the gradient pressure means the pressure reduces to 0.02 MPa in the middle of bonding time for 10 min and in the rest of the stage is 0.1 MPa; intermittent gradient pressure means the pressure is 0.02 MPa in the middle of the bonding time for 10min, changes with a frequency of 0.1 MPa to 0.02 MPa per minute during the last 5 minutes bonding time and the stage of cooling phase of 500-300 °C, and in the rest of the stage is 0.1 MPa. After welding, the joint samples were grounded and polished and then the microstructure of welded joint was analyzed by modern analysis methods.

### 3 Results and discussions

#### 3.1 The microstructure of welded joint under intermittent gradient pressure

Fig.2(a) and Fig.2(b) show the microstructure and the elemental line scan of diffusion brazing joint under intermittent gradient pressure. Fig.2(c) and Fig.2(d) are respectively the enlarged drawings of the diffusion region closed to copper substrate(A area) and magnesium matrix diffusion region(B area) in Fig.2(a).

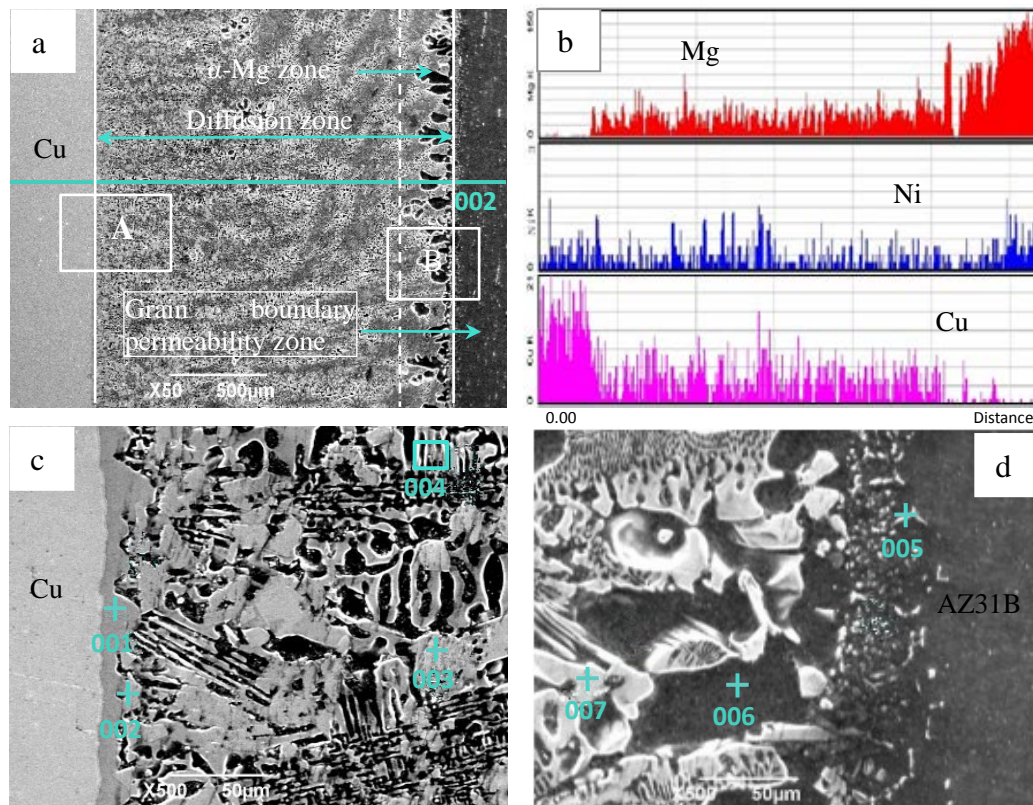


Figure.2 Microstructure and element line scan of AZ31B/Cu under intermittent gradient pressure

- (a) Overall microstructure of the joint interface
- (b) element line scan (c) enlarged view of the interface near copper side
- (d) enlarged view of the interface near magnesium side

Fig.2(a) shows that the interlayer of nickel foil has already dissolved and the bonded joint achieves good metallurgical combination. The joint is mainly dominated by the uniform diffusion brazing seam of 1.8 mm width and magnesium based grain boundary permeable zone. The microstructure of brazing seam is dense, and found no pores, cracks, welding defects. The brazing seam is mainly composed of the copper substrate diffusion zone, eutectic zone and the magnesium matrix diffusion zone. The large black columnar crystals and dendrites growing to brazing seam zone appear at the interface between brazing seam zone and magnesium matrix permeable zone, the formation of this grain shape is due to the part of solid/liquid interface growth protruding to the front of the eutectic liquid region, a greater undercooling increases the growth rate of the protruding part and then makes it further extend to the depths of the liquid, in this condition, the solid/liquid interface is not likely to remain planar but forms many branches extending to the liquid, and these branches eventually form columnar crystals and dendrites. The decrease of the pressure in the holding stage makes more liquid fill weld zone, more atoms are activated and the diffusion reaction is more intense in the cooling stage using intermittent gradient pressure, so the width of the brazing seam is larger. It can be seen from Fig.2(c) that a small amount of lumped compounds are mainly distributed near the copper side. From Fig.2(d), it can be seen that the lamellar eutectic structure is the main structure near the magnesium substrate. The aggregation of a small amount of compounds at the copper side is mainly because the

shock effect by the pressure in the cooling stages is more significant to the magnesium side atoms. In order to determine the phase of each layer, EDS is used to analyze the feature points, the results are shown in Table 3.

Table 3 The test result in different regions of the elemental composition near the weld zone(At %)

Measured point	Mg	Ni	Cu
001	3.12	1.18	95.7
002	31.46	0.93	67.61
003	33.68	29.7	36.62
004	79.43	1.32	19.25
005	96.72	1.74	1.54
006	98.24	0.23	1.53
007	50.56	2.14	47.3

It can be seen from Table 3, the gray transition layer near the Cu matrix (Fig. 2(c) 001 point) is  $\gamma$ -Cu. The atomic ratio of Cu/Mg of the block structure(002 point) distributed at the gray transition layer is closed to 2:1, it can be deduced as  $\text{Cu}_2\text{Mg}$ . The block structure (003 point) at central area has a chemical composition of 52.68% magnesium, 8.7% nickel and 38.62% copper, so the compound is considered as a ternary compound of  $\text{Cu}_{11}\text{Mg}_{10}\text{Ni}_9$  based on shape appearance figure. According to the atomic ratio, the lamellar eutectic structure (004 point) in the central region of the joint interface is ( $\alpha$ -Mg+ $\text{Mg}_2\text{Cu}$ + $\text{Mg}_2\text{Ni}$ ) eutectic structure. Fig.2(d) shows the diffusion layer structure closed to magnesium substrate, the color of black columnar crystals and dendrites (006 point) is similar to magnesium matrix, according to the atomic content, the layer is considered as magnesium based solid solution layer ( $\alpha$ -Mg zone).The bright white block compound (007 point) at the edge of  $\alpha$ -Mg grain region has a chemical composition of 50.56% Mg, 2.14%Ni and 47.3%Cu, the atomic ratio of Mg/Cu is closed to 1:1, which is considered as a mixture of  $\text{Mg}_2\text{Cu}$  and  $\text{Cu}_2\text{Mg}$ . The white grain boundary precipitation stripe (005 point) near the magnesium matrix is controlled by the interdiffusion among the elements. Under the condition of heating and loading, the atoms are activated in turn, due to the high initial concentration gradient between heterogeneous atoms, then atoms diffuse mutually, grain boundary has more defects and lower energy, so it is easy to precipitate  $\alpha$ -Mg. With the increase of holding time, magnesium, copper and nickel will produce ternary eutectic reaction when reaching the appropriate condition.

From above analysis, it can be concluded that the microstructure of bonded joint under intermittent gradient pressure are  $\gamma$ -Cu,  $\text{Cu}_2\text{Mg}$ ,  $\text{Cu}_{11}\text{Mg}_{10}\text{Ni}_9$ , ( $\text{Mg}_2\text{Ni}$ + $\alpha$ -Mg+ $\text{CuMg}_2$ ) eutectic structure and  $\alpha$ -Mg.

### 3.2 The microstructure of welded joint under gradient pressure

The microstructure and EDS line scan of welded joint under gradient pressure are shown in Fig.3, Similar to bonded joint under intermittent pressure gradient, the interface diffusion zone of bonded joint under gradient pressure is composed of diffusion brazing seam zone and magnesium substrate grain boundary permeability zone. Differently, the brazing seam width is reduced to 1.3 mm and no obvious  $\alpha$ -Mg zone appears. The EDS line scan shows the middle reaction layer elements diffuse relatively uniform, so the main microstructure are eutectic structure and a little block compounds, the position of the block compounds has been changed, which is mainly distributed in the diffusion



reaction layer near the magnesium matrix. Magnesium, nickel and copper elements appear peaks at the diffusion reaction layer near the magnesium matrix, so the existence of Mg-Ni-Cu ternary compounds is further confirmed.

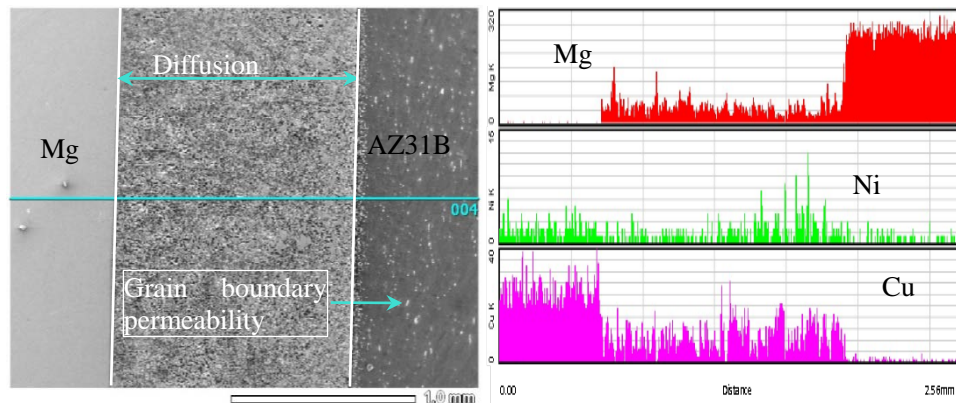


Fig.3 Microstructure and element line scan of AZ31B/Cu with Ni interlayer under gradient pressure

### 3.3 The microstructure of welded joint under constant pressure

The microstructure and EDS line scan of welded joint under constant pressure are shown in Fig.4.

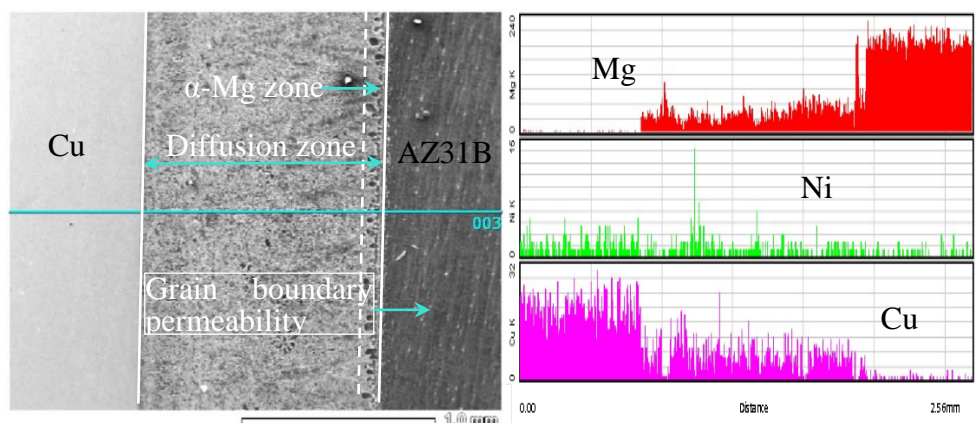


Fig.4 Microstructure and element line scan of AZ31B/Cu with Ni interlayer under constant pressure

Compared with Fig.2 and Fig.3, the microstructure of welded joint is extremely similar to that under intermittent gradient pressure, but the brazing seam zone width significantly reduces to 1.1 mm. The grain size of  $\alpha$ -Mg presenting columnar crystals and cellular crystals decreases; At constant pressure, constant high pressure makes a large amount of eutectic liquid phase extrude, the atomic diffusion rate in liquid is greater than that in solid, the reduction of eutectic liquid phase will slow atomic diffusion velocity, which leads to the decrease of diffusion layer width. A small amount of liquid phase makes the temperature gradient on the front edge of the solid/liquid interface more uniform, compared with the vast liquid phase under intermittent gradient pressure, the cooling rate decreases and a limited amount of liquid phase will also prevent the growth of crystal nucleus, therefore, all these factors have contributed to the decrease of  $\alpha$ -Mg size.

## 4 Conclusions

(1) AZ31B/Cu with Ni interlayer under different pressure methods can achieve metallurgical

bonding joints composed of brazing seam zone crystals and magnesium substrate grain boundary penetration zone, and the loading methods have great influence on the thickness of brazing seam zone, microstructure and  $\alpha$ -Mg grain size of the welded joint.

(2) At intermittent gradient pressure, the width of brazing seam zone is 0.18 mm, and the microstructure of brazing seam zone is composed of  $\text{Cu}_{11}\text{Mg}_{10}\text{Ni}_9$ ,  $(\alpha\text{-Mg}+\text{Mg}_2\text{Cu}+\text{Mg}_2\text{Ni})$  eutectic structure and  $\alpha$ -Mg. Under gradient pressure, the width of brazing seam zone reduces to 0.13 mm, and the microstructure of brazing seam zone is mainly dominated by  $(\alpha\text{-Mg}+\text{Mg}_2\text{Cu}+\text{Mg}_2\text{Ni})$  eutectic structure and  $\text{Cu}_{11}\text{Mg}_{10}\text{Ni}_9$  compounds closed magnesium matrix. When using constant pressure, the microstructure of bonded joint is similar with that under intermittent gradient pressure, but the brazing seam zone width is minimal, which is only 0.11 mm, and the size of  $\alpha$ -Mg reduces.

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