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Transient liquid phase diffusion bonding of copper alloy to stainless steel using CuMn alloys as interlayer①

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Abstract: With CuMn alloy as interlayer, the transient liquid phase (TLP) diffusion bonding of Cu alloys (CuAlBe) to stainless steel (1Cr18Ni9Ti) was studied. The results show that the bonding pressure, time and temperature and the content of Mn in CuMn alloy have great effects on the strength of bonding interface; when they are 1 MPa, 40 min, 1 223 K and 30 % respectively, the maximum joint strength of 487 MPa is attained. The fracture occurring at the bonding interface is a plastic one and the effect of Mn has been analyzed.

Key words: copper alloys; stainless steels; diffusion bonding; CuMn alloys **Document code:** A

1 INTRODUCTION

CuAlBe alloy is an attractive shape memory alloy used in many important industrial components due to its high specific strength, corrosion resistance and damping property as well as good shock absorption and anti-noise properties[1~3]. In order to spread its application it is desirable for CuAlBe to be soundly joined with other metallic materials. Presently, the study on such materials is mainly about the relationship between the chemical composition, structure and mechanical properties of CuZnAl and CuAlNi alloy, while research on the CuAlBe alloy has scarcely been carried out[4~8]. The weldability of these alloys has been studied in Ni-Ti and other Cu-based shape memory alloys[9~11], while the combinations of CuAlBe and stainless steels have never been analyzed.

Transient liquid phase diffusion bonding is commonly used in such materials as Ni-based alloys[12], titanium alloys, aluminum-based composites[13] and ceramics; in this study, it is used in the bonding of CuAlBe and 1Cr18Ni9Ti. Because of the difference of the physical and chemical properties between these materials being bonded and especially the presence of Al in CuAlBe (about 10 %), which may easily interact with the elements in stainless steel and form intermetallic compounds, resulting in the decrease of the joints strength, so CuMn alloys interlayer is employed as the interlayer in the present work.

2 EXPERIMENTAL

Base materials used in this study were a Cu-based damping alloy of CuAlBe and 1Cr18Ni9Ti stainless steel. The chemical compositions and mechanical properties of these materials are shown in Table 1. The interlayer materials were Cu15Mn, Cu20Mn, Cu30Mn, Cu40Mn and Cu50Mn alloys respectively.

The specimens used were in the form of cylinders with diameter of 15 mm and length of 80 mm. All surfaces of both base materials and interlayer were mechanically polished on SiC emery paper, the former polished with diamond paste. All specimens were washed with acetone in an ultrasonic bath for 5 min and dried in hot air. Diffusion bonding was carried out in a vacuum induction furnace.

In the present work, the bonding temperatures were 1 163, 1 193, 1 223 and 1 253 K respectively, the bonding times were 5, 10, 15, 20, 25, 30, 40, 60 and 120 min respectively, and the pressures were 0.5, 1, 2, 4 and 5 MPa respectively.

3 RESULTS AND DISCUSSION

3.1 Effect of bonding pressure on strength of joints

Fig.1 shows the relationship between bonding pressure and the strength of joints. When the bonding pressure is low, the higher the bonding pressure is, the higher the joint strength becomes. This is caused by the reason that the liquid insert metal can lead to good contact and wetting of the welded surfaces. The maximum joint strength was 1 MPa, the joint strength decreased as the bonding pressure increased because much of filler metal was forced out.

3.2 Effect of bonding time and temperature on joints strength

Bonding temperature and time are very important to transient liquid phase bonding. Provided that the bonding time is relatively short and/or the bonding temperature is low , the wetting of CuMn

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Table 1 Properties and composition of CuAlBe alloy and 1Cr18Ni9Ti stainless steel

	Element content/ %					Mechanical properties	
CuAlBe alloy	Al	Be	B	Cu		σ_b/ MPa	δ_5/ %
	9.0 ~ 13.5	0.10 ~ 0.6	0.02 ~ 0.1	Bal.		600 ~ 640	6 ~ 8.60
	Element content/ %					Mechanical properties	
1Cr18Ni9Ti stainless steel	C	Mn	Si	Cr	Ni	σ_b/ MPa	δ_5/ %
	≤0.12	≤2.0	≤1.0	17.0 ~ 19.0	8 ~ 14.0	530 ~ 560	40

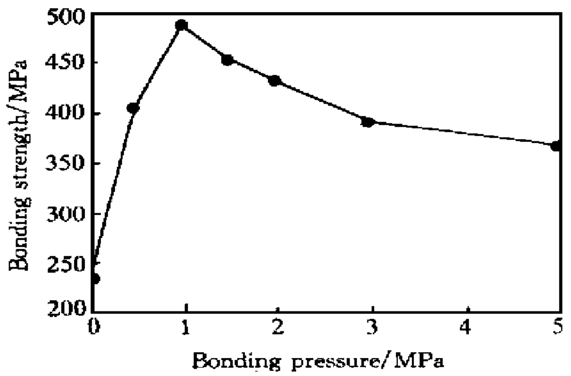

Fig.1 Effect of bonding pressure on joint strength (Interlayer: Cu30Mn)

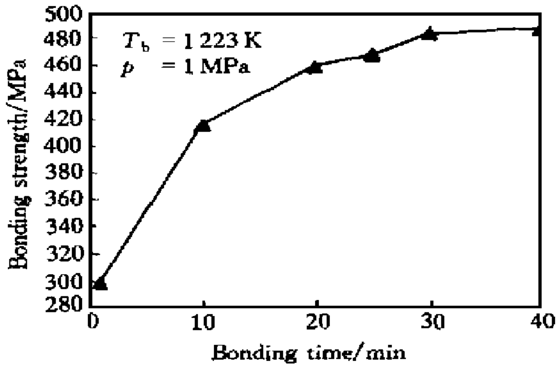

Fig.2 Effect of bonding time on joint strength (Interlayer: Cu30Mn)

interlayer to base materials will not occur completely, which decreases the joint strength. While longer bonding time and higher temperature also will not increase the bond strength because the brittle intermetallic compounds are produced, caused by the diffusion from CuMn interlayer to the welded materials and the interdiffusion of element Al from CuAlBe alloys and Ni and Fe from 1Cr18Ni9Ti. The relationship between the joint strength and bonding time and effect of bonding temperature on joint strength are shown in Fig.2 and Fig.3. The results show that when using Cu30Mn as the interlayer, the temperature of 1 223 K, bonding time of 40 min and bonding pressure of 1 MPa are the optimum parameters.

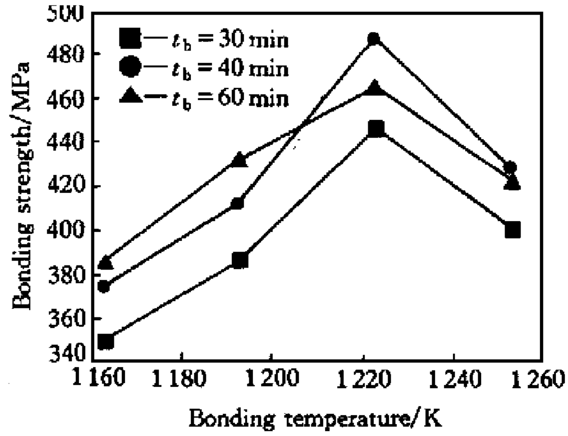

Fig.3 Effect of bonding temperature on joint strength (Interlayer: Cu30Mn, p = 1 MPa)

3.3 Effect of element Mn in interlayer on strength of joints

To improve the plasticity of intermetallic compounds, the replacement of covalence with metallic bond may do good. Therefore, a CuMn interlayer was employed in the present work to give rise to the strength of joints. Because the element Mn can replace Al firstly, the covalence of Ni-Al is also replaced by the metallic bond of Ni-Mn, which improves the plasticity of intermetallic compounds by reducing the resistance to the motion of dislocation.

Fig.4 shows the relationship between the content of Mn and the strength of the joint. In case of using Cu15Mn as an interlayer, according to the Cu-Mn phase diagram, the temperature of liquidus and solidus are 1 223 K and 1 193 K respectively. At the bonding temperature of 1 223 K, the welded surface can be wetted by melting Cu15Mn interlayer. However, at the bonding temperature of 1 193 K the interlayer does not completely melt, which greatly restricts the diffusion of Mn. Using Cu30Mn as an insert metal, because the eutectic temperature was

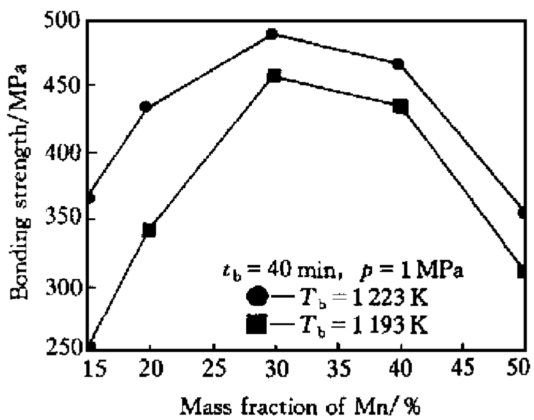

Fig.4 Effect of content of Mn on joint strength

871 ℃, at the bonding temperature of 1 223 K and 1 193 K respectively, the superheated Cu30Mn interlayer has good wettability to the base materials. When using Cu50Mn as an interlayer, the temperature of liquidus and solidus are 1 223 K and 1 179 K respectively. At the bonding temperature of 1 223 K, the welded surface can be more effectively wetted by the liquid filler metal than at the bonding temperature of 1 193 K.

3.4 Microscopic analysis

3.4.1 Microstructure of joint

At 1 223 K and 1 MPa, Fig.5 shows the microstructures of the joint about the effect of bonding time on the diffusion of liquid insert metal. When the bonding time is 10 min, the liquid metal diffuses along the grain boundary and justly corrodes the grain boundary, which leads to lower joint strength, as shown in Fig.5(a). When the bonding time is 40 min, liquid metal diffuses into 1Cr18Ni9Ti and greatly corrodes the grain boundary, thus increaseing the strength of joint, as shown in Fig.5(b). At the bonding time of 120 min, liquid filler metal deeply diffuses into stainless steel and the rich Fe particles

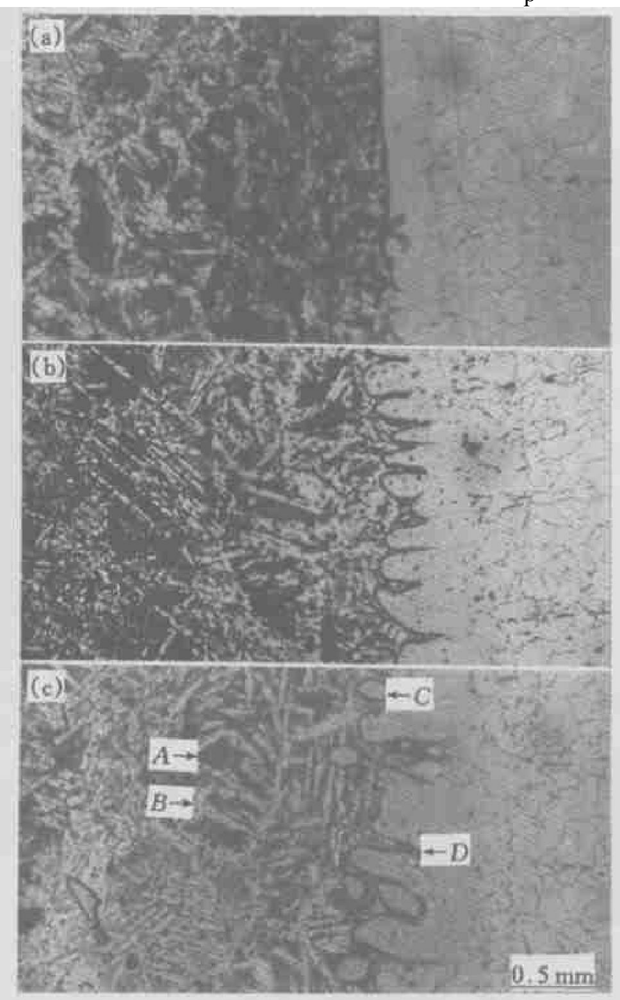

Fig.5 Microstructures of joints bonding with different times
(a) — t_b = 10 min; (b) — t_b = 40 min; (c) — t_b = 120 min

are formed at the bond interface, which decreases the joint strength, as shown in Fig.5(c). Fig.6 shows the schematic diagram of diffusion at the interface.

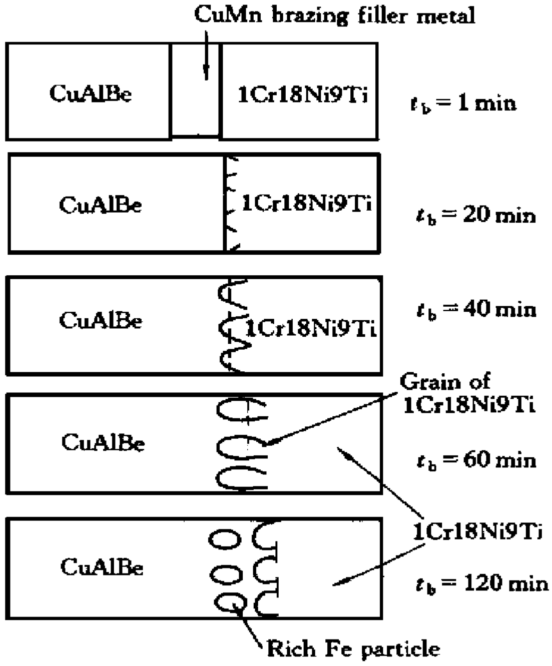

Fig.6 Schematic diagram of effect of bonding time on diffusion of liquid metal along grain boundary

Table 2 shows the result of EDX analysis of the bond joints corresponding to Fig.5(c). Complex compounds are formed on the bond interface between the stainless steel and the CuAlBe alloy. The content of Mn at the interface ranges from 4.8 to 7% (mass fraction) because of the evaporation in a vacuum condition and dilution by the CuAlBe alloy.

Table 2 Results of EDX analysis

Position	Content of element/ %					
	Fe	Mn	Cu	Al	Ni	Cr
Black phase (*A*)	2.5	5.9	75.1	11.8	2.1	2.6
White phase (*B*)	3.4	6.7	72.1	9.3	4.7	3.8
Fe particles (*C*)	62.6	6.5	4.9	6.3	5.2	14.5
1Cr18Ni9Ti next to interface (*D*)	63.1	4.8	4.4	6.5	6.2	15.0

3.4.2 Fracture analysis of joint

Fig.7 shows the photographs of tensile fractured surface of the joint. As shown in Fig.7(a), at the bonding temperature of 1 193 K and the bonding time of 15 min, because the Cu15Mn interlayer does not completely melt, the fracture is composed of block materials in which the content of Mn is 13.2%, mainly with Cu15Mn alloy, and the content of Mn in the ductile dimple is 6.1%. At the bonding temperature of 1 223 K and the time of 40 min with Cu30Mn as an insert metal, the fracture occurred at the bonding interface is a plastic one which is characterized by ductile dimple of 6.7% as shown in Fig.7(b), and

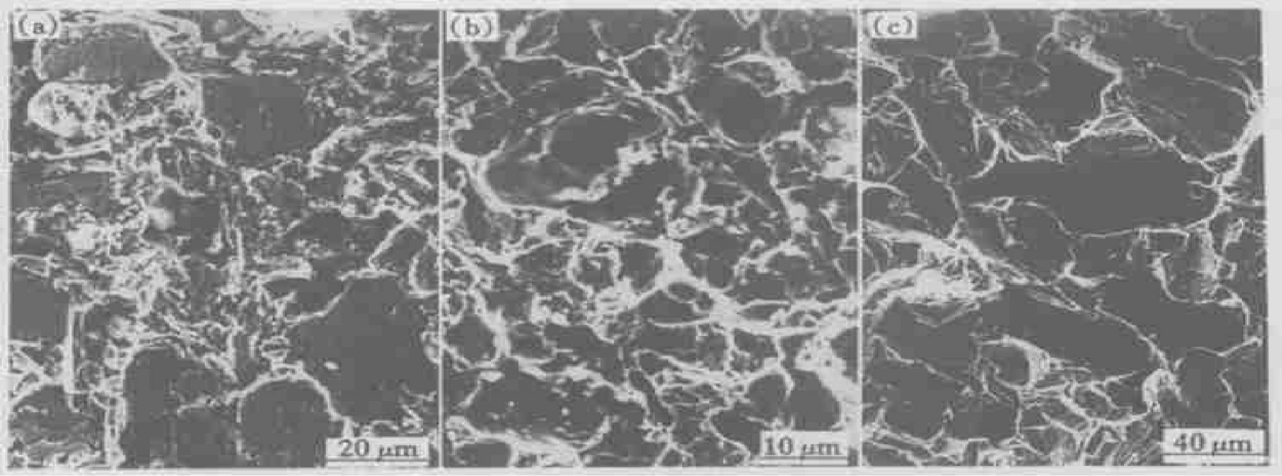

Fig.7 Tensile fracture surfaces of CuAlBe and 1Cr18Ni9Ti with different interlayer at different welding parameters

(a) —Cu15Mn, 1193 K + 15 min; (b) —Cu30Mn, 1223 K + 40 min; (c) —Cu30Mn, 1223 K + 120 min

the intermetallic AlNi is not produced at the interface according to XRD analysis. However, when the bonding time is 120 min with Cu30Mn as the interlayer at the bonding temperature of 1223 K, the fracture is cleavage with river ripples, in which the content of Mn is 0.7 %, as shown in Fig.7(c). This is due to the depression of malleability brought by Mn. As the bonding time increases, the melting CuMn interlayer deeply corrodes the grain boundary and rich Fe particles are produced at the interface of 1Cr18Ni9Ti with CuMn interlayer, and the content of Mn is almost exhausted.

4 CONCLUSIONS

1) Using Cu30Mn as an insert metal, the maximum joint strength of 487 MPa is obtained at the bonding temperature of 1223 K, time of 40 min and pressure of 1 MPa. And the welded surface of the insert metal is well wetted by the liquid braze, in which the fracture is plastic with ductile dimples. When using Cu15Mn as an insert metal, at 1193 K, 1 MPa for 15 min, the interlayer does not completely melt and the block materials of Cu15Mn alloy lie at the interface, which reduces the joint strength. When using Cu30Mn as an insert metal, at 1223 K, 1 MPa for 120 min, rich Fe particles are produced at the interface and the fracture is cleavage with river ripples.

2) The covalent of Ni-Al and Fe-Al is replaced by Ni-Mn at the grain boundary due to the replacement of Al by Mn firstly, which improves the plasticity of intermetallic compounds by reducing the resistance to motion of dislocation. Only when the content of Mn is higher than 6.7 % at the interface can the plastic of joints be improved effectively.

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