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Diffusion bonding of copper alloy to stainless steel with Ni and Cu interlayer①

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Abstract: CuAlBe alloy is an attractive shape memory alloy with many important usages in industrial field, in order to spread its range of application it is desirable to be able to join CuAlBe soundly with other metallic materials, for example stainless steel; however the weldability between CuAlBe alloy and stainless steel has never been studied, therefore an experimental investigation of different transition metals was carried out in the diffusion bonding joints of Cu alloys (CuAlBe) to stainless steel (1Cr18Ni9Ti). The microstructure and phase composition of the joint were analyzed by SEM, EPMA and X-ray diffraction. The following conclusions have been drawn: 1) The joint strength with Ni interlayer is higher than that with Cu interlayer when the welding parameters are the same; 2) When Ni interlayer is thinner, Al will interact with Ni and Fe, and the intermetallic compounds such as Fe_3Al are formed in the interface, which decreases the strength of the joints; 3) When the bonding temperature is higher, because the diffusion of Cu in Ni is faster than Ni in Cu, a Kirkendall effect occurs, which also decreases the strength of the joints.

Key words: copper alloys; stainless steel; inter-layer; diffusion bonding **Document code:** A

1 INTRODUCTION

CuAlBe alloy is an attractive shape memory alloy for use in many important industrial components to reduce shock absorption due to its high specific strength, corrosion resistance, damping property as well as good shock absorption and anti-noise properties[1~3]. However, in order to spread its application it is desirable to be able to join CuAlBe soundly with other metallic materials, for example, stainless steel.

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 little work has been carried out on the CuAlBe alloy[4~6]. The weldability of shape memory alloys has been studied principally in Ni-Ti and other Cu-based shape memory alloys[7~9], while the combinations of CuAlBe and stainless steels have never been analyzed. In this paper, diffusion bonding between CuAlBe and 1Cr18Ni9Ti has been undertaken.

2 EXPERIMENTAL

Base materials used in the present work were a Cu-based damping alloy whose chemical composition (mass fraction) is Cu-10%-Al 0.2% Be and stainless steel 1Cr18Ni9Ti. The interlayer materials were pure Ni foil with thicknesses of 0.01, 0.02 and 0.03 mm respectively and pure Cu foil with thickness of 0.03 mm.

Specimens to be bonded were in the form of cylinders 10 mm in diameter and 40 mm in length for CuAlBe and 10 mm in diameter and 70 mm in length for stainless steel. All surfaces of both base materials and interlayer were mechanically polished on SiC emery paper, then the former polished with diamond paste using a cloth. All specimens were washed with acetone in an ultrasonic bath and dried in hot air just before bonding. Diffusion bonding was carried out in a vacuum induction furnace with a vacuum of 6.6×10^{-2} Pa. The bonding temperature in the furnace was program-controlled, and the bonding pressure was 10 MPa.

Metallographic specimens were cut longitudinally from the welded samples and prepared by standard techniques to be examined by optic microscope and scanning electron microsope and fitted for EDS with D/MAX-YA energy dispersive X-ray microanalyser. The elemental distribution was analyzed by EPMA and the tensile fractured surfaces were observed by SEM.

3 RESULTS

3.1 Effect of different interlayer on strength of joints

Fig. 1 shows the relationship between the joint strength and the bonding temperature in joints with a pure 0.03 mm thick Cu and pure Ni foil as interlayer

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respectively in case of the bonding time being 30 min. The joint strength of the joints with Ni foil was higher by 60~ 100 MPa than that with use of pure Cu foil at any bonding temperature, because Ni can completely dissolve the elements Cu and Fe and can also be solution strengthened, while the oxides which can restrict the interdiffusion of elements and brittle intermetallic were produced at the interface when Cu was adopted as an interlayer.

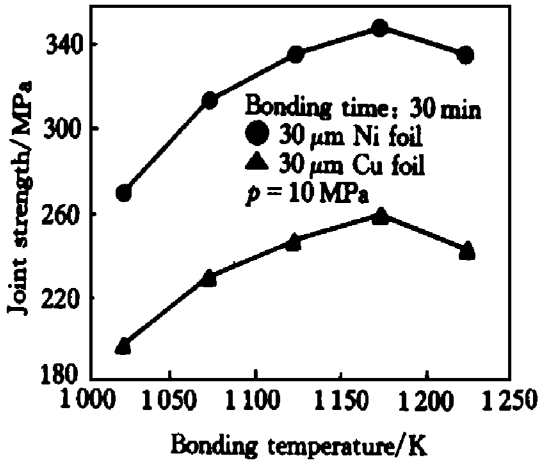

Fig. 1 Effect of bonding temperature on joint strength

3.2 Effect of thickness of interlayer on joints

Fig. 2 shows the relationship between the thickness of Ni interlayer and the joint strength in case of the bonding temperature and bonding time being 1 173 K and 30 min respectively. The thickness of pure Ni foil ranged from 0.01 mm to 0.03 mm. The maximum joint strength was obtained at the thickness of 0.02 mm, the joint strength decreased as the thickness of interlayer increased. Fig. 3 also shows that the joint strength of joints with 0.02 mm thickness Ni interlayer was higher than that of 0.03 mm thick Ni foil at any temperature.

3.3 Effect of bonding temperature on strength of joints

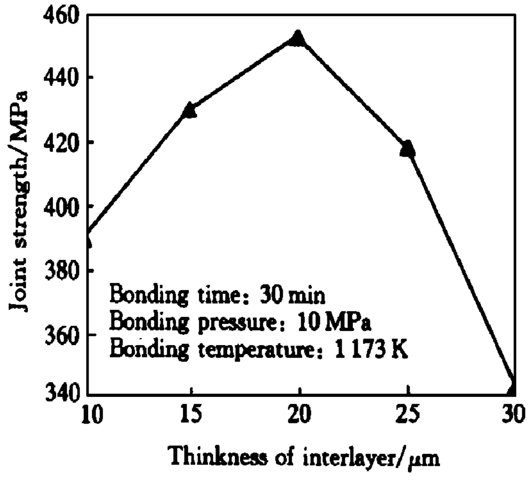

Fig. 2 Effect of thickness of Ni interlayer on joint strength

The bonding temperature influences the yield strength of welded materials and the diffusion of atoms. Fig. 3 shows the effect of bonding temperature on the joint strength. Experimental results revealed that the joint strength was only 270 MPa when the interlayer was 0.03 mm thick Ni foil and the temperature was 1 023 K. The joint was completely fractured in Ni. This may be explained by the reason that the atoms were not completely activated and the welded surfaces had little contact. As the temperature increased, the joint strength also increased and the joints were fractured partially along the interface of Ni and CuAlBe and partially along the interface of Ni and 1Cr18Ni9Ti because the yield strength of materials decreased and the diffusion of atoms was activated. When the temperature was too high, the joint strength also decreased due to the production of brittle intermetallic and the Kirkendall effect at the interface.

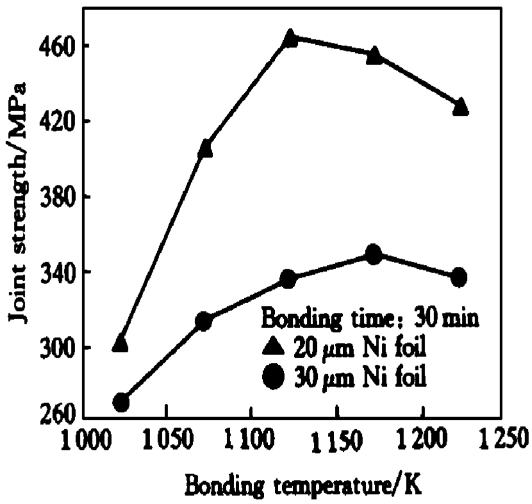

Fig. 3 Effect of bonding temperature on joint strength with different thickness of interlayer

4 DISCUSSION

4.1 Fracture analysis

When the tensile test was performed on the joints with Ni foil as the interlayer, fracture occurred at the bonding interface and was brittle in macroscopic view. Fig. 4 shows the SEM fractographs of bonding joints. The fracture occurring at the bonding interface between CuAlBe and the Ni foil was a plastic one, which was characterized by ductile dimples (Fig. 4(a)), while that between 1Cr18Ni9Ti and Ni interlayer was a cleavage fracture with river ripples (Fig. 4(b)).

On the other hand, the X-ray diffraction of bond joint with 0.01 mm thick Ni interlayer shows that there were many brittle intermetallic compounds formed in the diffusion layer such as AlNi, Fe_3Al and FeCr, which decreased the joint strength, while only AlNi was produced at the interface of joint with 0.03 mm thick Ni foil as interlayer because the restriction

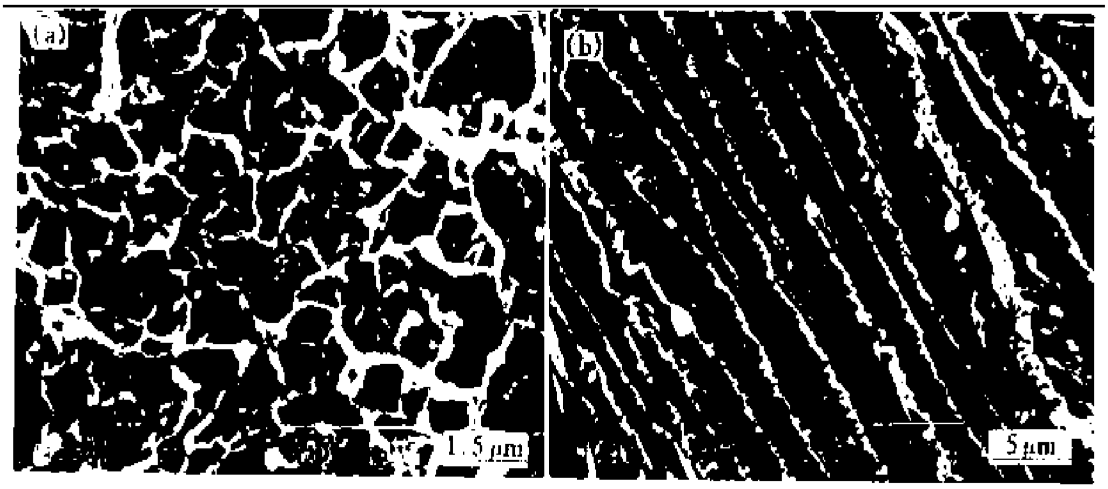

Fig. 4 SEM fractographs of bonding joint of CuAlBe/1Cr18Ni9Ti
(a) —Ductile dimples of fracture surface, δ_{Ni} = 0.02 mm; (b) —River ripples of fracture surface, δ_{Ni} = 0.03 mm

of Ni layer remained at the interface.

4.2 Elemental distribution in joint zone

Fig. 5 shows the bond microstructure and the result of line analysis by EPMA in case of using a 0.03 mm thick Ni foil as the interlayer. The interdiffusion of the different elements from CuAlBe alloy and the stainless steel to Ni interlayer and the Ni from the interlayer to the steel and the Cu alloy is apparent. As seen in Fig. 5(b), about 0.006 mm thick pure Ni layer remained at the interface, which decreased the strength of joints compared with the joints of 0.02 mm thick Ni interlayer. The diffusion of the element Fe and Cr from the stainless steel to CuAlBe was little because the restriction of Ni layer remained at the interface, while the element Al had diffused into the Ni interlayer and formed intermetallic compounds with elements Fe and Ni. This was due to the differences of the atomic radii of the elements. The radius of Ni (1.24 Å) was almost similar to those of elements Fe and Cr in the stainless steel (1.27 Å and 1.25 Å), the interdiffusion of them at the bonded zone did not proceed well. However, the radius of element Al was 1.43 Å which was greatly higher than that of Ni, moreover element Be in CuAlBe alloy promoted elements Cu and Al to diffuse from Cu alloy into Ni interlayer[10]. So the interdiffusion of Ni and CuAlBe was apparent. After long time diffusion at high temperatures, intermetallic compounds were produced, which decreased the strength of the joints.

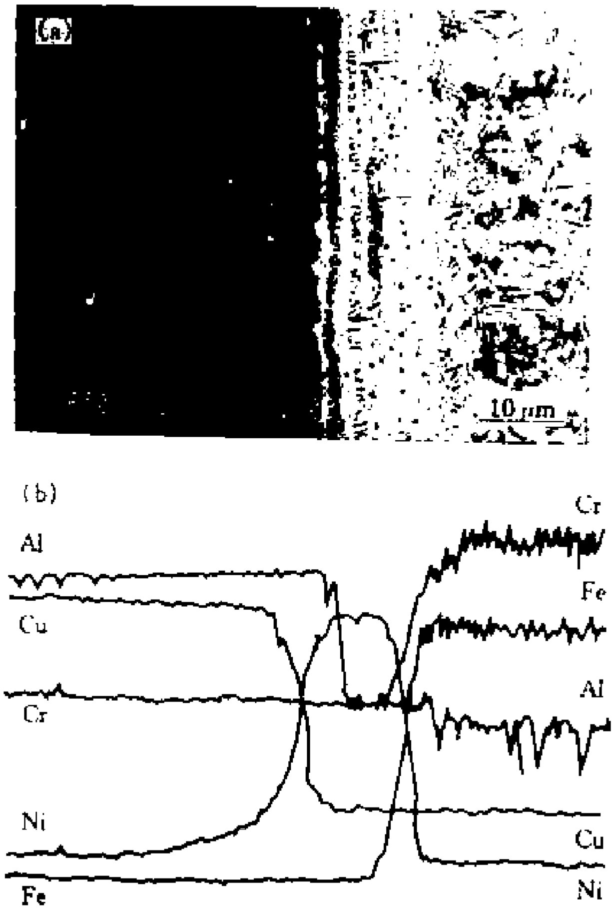

Fig. 5 Microstructure and line analyses of elements in joint zone (δ_{Ni} = 0.03 mm)
(a) —SEM microtructure;
(b) —EPMA line analyses of elements

4.3 Microstructure of joint

Fig. 6 shows the microstructure of the joint

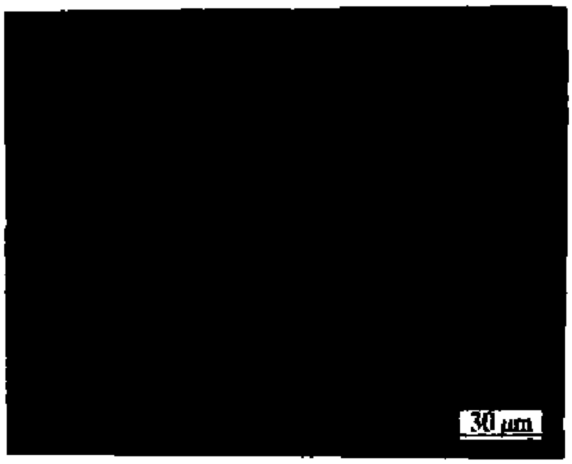

Fig. 6 Microstructure in interface

bonded with Ni interlayer at higher bonding temperatures. A Kirkendall effect was observed at the bond interface of the joint because of differences in the diffusion coefficients of Cu and Ni. According to the metallic theory, the diffusion of Cu in Ni was faster than the diffusion of Ni in Cu. Element Be in CuAlBe, as pointed out above, also promoted element Cu to diffuse into Ni interlayer. These are the reasons that lead to the formation of Kirkendall effect at the bonding interface, while the presence of voids produced by it, to a certain degree, decreases the strength of the joints.

5 CONCLUSIONS

1) Sound diffusion bonded couples can be obtained between Cu alloys (CuAlBe) and stainless steel (1Cr18Ni9Ti) by using interlayer.

2) Bonding temperature, interlayer material and its thickness are very important to the joints. The highest strength of the joints can be obtained only when the optimum bonding conditions are adopted. In this work, pure Ni foil is a better interlayer and its optimum thickness and bonding temperature are 0.02 mm and 1173 K respectively.

3) When the thickness of Ni interlayer is 0.01 mm, intermetallic compounds such as AlNi, Fe_3Al and FeCr form in the interface, decreasing the strength of the joints.

4) Owing to the differences in the diffusion coefficients of Ni and Cu, Kirkendall voids are produced. Their presence also decreases the strength of the joints.

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