Rolling-Cladding Technology for Cu-Al Thin Sheet

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Abstract. In order to meet the demand of electronic and heat-radiating devices for Cu-Al composite the rolling-cladding technology for Cu-Al thin sheet was developed. The corresponding roll-cladding technology was optimized by the experiments. The varying regularity of thickness ratio in the rolling process of Cu-Al thin sheet was studied. The change in the Cu-Al interface was investigated by adopting different annealing technologies. The results show that the critical rolling reduction rate for Al-Cu cladding decreases with increasing the thickness proportion of Cu. The reduction rate of Al and Cu is proportional to total reduction rate. With the increase of the rolling reduction rate of Al and Cu, the reduction rate of Cu and Al also increases. Annealing can enhance the bending performance of the thin sheet. However, when the annealing temperature is too high, the hard and brittle intermetallic compounds form at the interface of Cu and Al, which will deteriorate the bonding strength of Cu-Al cladding sheet.

1. Introduction
Cu-Al composite thin sheet have attracted much attention in recent years due to their high conductivity, high thermal conductivity, low contact resistance and light weight and corrosion resistance of aluminum [1, 2]. It is widely used in aviation, aerospace, machinery, medical treatment, food, civil and other fields [3]. At present, there are many forming methods of Cu-Al composite plate, including solid-solid method, liquid-solid method and liquid-liquid method [4]. Among them, the diffusion welding method has the advantages of low pressure, no macroscopic plastic deformation, low bonding strength and suitable for precision parts that are no longer processed after welding. The explosion compounding method is noisy, dangerous and inefficient, which is not good for precise control. The casting and rolling method has high temperature, easy to oxidize, and the melting point of bimetal is different. Extrusion drawing method has poor continuity, which is suitable for metal composite pipes, rods and wires. Based on the above shortcomings, rolling compounding has become a general trend [5].

Heat treatment can improve the interface bonding and mechanical properties of Cu-Al composite plates [6]. Diffusion heat treatment changes the mechanical bonding mode of the composite interface into metallurgical bonding mode to improve the composite strength and the bending of the plate. However, the structure of the composite interface layer formed by diffusion heat treatment has an important effect on the bonding strength and electrical and mechanical properties of the plate. In this
work, the effects of different annealing processes on the microstructure and properties of copper-aluminum rolled composite plate were studied by orthogonal experiment.

2. Experiment and methods
Pure copper (T2) and aluminum (1060) were used in the experiment and the chemical compositions are listed in Table 1. The thickness of Cu-Al composite plate is 2 mm after hot-rolling cladding. Diffusion annealing process, which is studied by more systematic orthogonal experiment, is adopted. Orthogonal experiment of annealing temperature and time is shown in Table 2. The metallurgical bonding behavior and microstructure of Cu/Al composite interface layer were studied by X-ray diffraction (XRD) and scanning electron microscope with energy dispersion spectrum (SEM/EDS). After annealing treatment, the mechanical properties of Cu-Al composite sheet are measured according to the standard test.

| Tab. 1 Chemical compositions of Cu-Al composite plate (Atom %) |
|-----------|------------|---|---|---|---|---|
| Elements  | Cu         | Pb | S  | Cd | P  | Fe |
| T2        | 99.9900    | 0.0003 | 0.0016 | 0.0002 | 0.0013 | 0.0009 |
| Elements  | Fe         | Mn | Mg | Si | Zn | Ti | Cu | Al |
| 1060      | 0.35       | 0.03 | 0.03 | 0.25 | 0.05 | 0.03 | 0.05 | 99.21 |

| Tab. 2 Orthogonal experiment of annealing temperature and time of Cu-Al composite plate |
|-----------|------------------|
| Number    | Annealing temperature T / °C | Annealing time / h |
| 1#        | 380              | 8               |
| 2#        | 380              | 10              |
| 3#        | 400              | 8               |
| 4#        | 400              | 10              |

3. Results and discussion

3.1. Effect of annealing heat treatment on the interface of composite plate
In rolling-cladding, copper and aluminum bimetal interface mainly depends on the plastic rheology of the contact point to form physical bond or the surface of uneven interposition to form mechanical meshing, and shown in Fig.1 a. Metallurgical bonding occurs during annealing and given in Fig.1 b. At high temperature, dissimilar metal atoms of copper and aluminum diffuse to each other through the bonding interface into the adjacent metal matrix, inducing migration of grain boundary, resulting in more bonds and new arrangement of atoms on both sides of the bonding surface, and migration of grain boundary at the same time. These atomic movements will promote the formation of more overlapping lattice positions or common grain boundaries of the bonding surface, and eventually form the copper-aluminum interface layer, which will transfer the bonding surface from the physical bonding state to the metallurgical bonding state. When the annealing temperature is increased or the annealing time is prolonged, the copper and aluminum metal atoms continue to diffuse into the adjacent metal matrix at the bonding interface and crystallize. As shown in Fig. 1c, the copper and aluminum interface layer are thickened and there are hard and brittle metal compounds are formed.

![Fig. 1 Cu-Al interface under different heat treatment states](a) (b) (c)
Fig. 2 illustrates variety in interface composition of Cu-Al roll-cladding sheet. As can be seen from Fig. 2a-d, as the annealing temperature increases, the composition of the copper-aluminum interface changes in steps, indicating that brittle intermetallic compounds are formed at the copper-aluminum interface. In Fig. 2a, the element composition without ladder at the interface, and it is difficult to diffuse between copper and aluminum at low temperature. Brittle compounds are not easy to form at the composite interface, and mesophase is not easy to form. Fig. 2d shows the morphology of the composite interface via annealing at 400 °C for 10 h. It is obvious that intermetallic compounds are formed at the composite interface, such as Cu₉Al₄, Cu₄Al, Cu₃Al₂ and CuAl₂ (as shown in Fig. 3 below). This hard and brittle intermetallic compound destroys the original composite interface and reduces the composite effect of the interface. When the annealing temperature is less than 380 °C, it can be seen from the morphology diagram of the composite interface via annealing at 380 °C for 8h that no obvious intermediate layer is formed in the composite interface. As the heat treatment temperature increases to 400 °C, the diffusion depth at the bonding interface of Cu/Al composite plates increases continuously, forming intermediate layer compounds, which are not obvious, as shown in Fig. 2c. Subsequently, when the annealing time is increased (see Fig. 2b) or the annealing temperature is increased (see figure 2c,d), the diffusion of copper and aluminum atoms is increased, forming an obvious diffusion layer and forming brittle intermetallic compounds, which influences the composite effect of the interface.

Fig. 2 Variety in interface composition of Cu-Al roll-cladding sheet (a) 380°C×8h, (b) 380°C×10h, (c) 400°C×8h and (d) 400°C×10h
Fig. 3 XRD image of the Cu-Al roll-cladding sheet (a) Al side and (b) Cu side

3.2. Effect of annealing heat treatment on properties of composite plate

Table 3 shows the influence on bending properties and hardness of copper-aluminum composite sheet. As can be seen from Table 3, when the annealing temperature exceeds 380°C, the interface of copper and aluminum cracks at the second bending, and the interface bonding strength decreases. According to the interface analysis, brittle intermetallic compounds (Cu_9Al_4, Cu_4Al, Cu_3Al_2 and CuAl_2) are generated at the copper-aluminum interface, which reduces the interface bonding strength of copper-aluminum composite plate, resulting in interface cracking in bending test. It can be seen from Fig. 2 and Table 3 that in the annealing process, when the annealing temperature is more than 380°C, intermetallic compounds are produced, which is unfavorable to interface bonding. As can be seen from Fig. 2d, a thick intermetallic compound formed at the interface, which was hard and brittle. In the bending experiment, the interface of copper and aluminum was cracked, and the original composite interface was damaged as a whole. In annealing treatment, metal compounds generated at the interface of copper and aluminum seriously reduce the bonding strength of composite plates, so the annealing of copper and aluminum bimetal composites is generally selected at 380°C for 10h.

Table 3 Effect of annealing temperature on bending properties and hardness of Cu-Al cladding sheet.

| Annealing temperature and time | Hardness /HB | Bending number | Bending properties |
|-------------------------------|--------------|----------------|--------------------|
| 380°C×8h                      | Cu 8         | Cu 8           | 25                 | Aluminium fracture |
| 380°C×10h                     | Cu 10        | Cu 10          | 25                 | Aluminium fracture |
| 400°C×8h                      | Cu 8         | Cu 8           | 2                  | Interface crack    |
| 400°C×10h                     | Cu 10        | Cu 10          | 2                  | Interface crack    |

4. Conclusion

The best annealing process of Cu-Al rolling-cladding is 380°C for 10h and it can improve the plasticity (bending performance). After annealing treatment, intermetallic compounds formed at the diffusion layer, such as Cu_9Al_4, Cu_4Al, Cu_3Al_2 and CuAl_2 and a small amount of CuAl, and Al lateral enrichment CuAl_2, Cu side enrichment Cu_9Al_4. The formation of Cu_9Al_4 can alleviate the interface weakening caused by CuAl_2, and the bending properties and hardness of Cu-Al cladding sheet was improved.
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