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Cladding of stainless steel on aluminum and carbon steel by interlayer diffusion bonding

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An Al–Cu–Mg interlayer alloy is used in cladding the sheets of 304L stainless steel/L2Y2 aluminum alloy and 304L stainless steel/Q235A carbon steel. Effects of cladding temperature and time on the interfacial bonding of the two sheets are studied. Experimental results show that the Interfacial cohesion of the substrates and the clad stainless steel is closely related to the thickness of the diffusion layers in the substrates and the clad, and controlled by diffusion layer thickness in 304L side.

Keywords: Clad; Aluminum alloys; Interface diffusion; Iron aluminide

Bimetallic sheets which consist of dissimilar metal components have been widely used in many industrial fields due to their excellent mechanical and functional properties [1,2]. Several methods such as explosion [3], rolling [4], weld overlay [5], inversion casting [6] and laser cladding [7] have been developed for producing bimetallic sheets. Generally, the commonly used bilayer sheets are stainless steel and aluminum or carbon steel, and they are produced by cladding two metallic materials directly, which has some drawbacks either in engineering or economics [8–10]. Due to the fact that mechanical properties and deformation and fracture behavior of bi-material plate are mainly dependent on their interfacial bonding of the cladding materials, the selection of processing variables affecting interfacial structure, diffusion distance and compound formation and morphology are critical [11].

In order to improve the bonding of stainless steel on aluminum and carbon steel, an Al–Cu–Mg interlayer material is developed by the current authors. The advantage of using the interlayer is that the Al–Cu–Mg alloy in semisolid state at processing temperature can promote metallurgical bonding between the two cladding materials. This paper presents the effects of cladding temperature and time on the interfacial bonding of the stainless steel/aluminum and stainless steel/carbon steel through the Al–Cu–Mg interlayer.

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A low carbon ferritic–pearlitic steel containing 0.1% C (Q235A) and a commercial aluminum plate (L2Y2) as substrate (2 mm), and an austenitic stainless steel (304L) as clad (0.85 mm) are used through this study. Chemical compositions of the materials are given in Table 1. An aluminum alloy with Cu and Mg additions is used as an interlayer material (2 mm), and its amount of liquid phase present between solidus and liquidus is listed in Table 2.

The specimens of the substrate, clad and interlayer are in the form of 25 mm × 25 mm plates, and their surfaces are ground to give a uniform finish with #800 emery paper and cleaned before being clamped together with a molybdenum fixture assembly. Then, the sample is put into a vacuum furnace and heated at a temperature between 600 °C and 640 °C for different time, and cooled inside the furnace to room temperature, with the total thickness of the clad sheet being about 4.5 mm.

Microstructure characterization was carried out by optical microscopy (OM), scanning electron microscopy (SEM), and X-ray diffraction. The metallographic samples of the clad sheet were mounted in a cold setting resin, ground and polished and etched with Keller's etchant (150 ml H_2O, 3 ml HNO_3, 6 ml HCl and 6 ml HF). The thickness of the diffusion layers was measured at least ten times at different locations on the section. X-ray diffraction, using Cu Kα radiation in 2θ range from 20° to 80° was performed to identify the phase presented at the interfaces in the clad sheets.

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Table 1. Chemical composition of the substrate and the clad materials

Material	Element (wt.%)									
	C	Si	Mn	S	P	Cr	Ni	Fe	Cu	Al
L2Y2	–	0.22	0.15	–	–	–	–	0.25	0.01	Balance
Q235A	0.09	0.41	0.98	0.003	0.003	–	–	Balance	–	–
304L	0.03	0.51	0.83	0.002	0.022	18.7	9.8	Balance	–	–

Table 2. Amount of liquid present between solidus and liquidus of the Al–Cu–Mg alloy

Temperature (°C)	559	600	620	630	640	648
Liquid (vol.%)	0	10	20	33	50	100

Interfacial bonding of the clad sheets was evaluated by shear stress measured by a universal test machine according to the test standard of GB/T 6396 [12]. Microhardness of the interfaces was measured with a FM-700 Vickers microhardometer, and the hardness tests are performed under an indentation load of 25 g for 20 s. Analysis points were spaced so as to eliminate the effect of neighboring indentations. The microhardness was evaluated by taking five indentations, and only the three middle values were averaged.

Figure 1 shows the microstructures of a well-clad specimen of the 304L/Al–Cu–Mg/L2Y2. It can be seen that a wide diffusion zone lies between the 304L steel and the Al–Cu–Mg interlayer material, while no distinct diffusion layer is observed in the Al–Cu–Mg/L2Y2 interface due to the homology of the two alloys. In the case of 304L/Al–Cu–Mg/Q235 clad as shown in Figure 2, a diffusion layer appears also at the interface of the Al–Cu–Mg interlayer and Q235A steel, although it is much thinner than that at the 304L/Al–Cu–Mg interface.

Actually, the cladding of the stainless steel on the carbon steel with Al–Cu–Mg interlayer involves a diffusion process which is essentially the same as hot-dip aluminizing [13] with the exception of less liquid aluminum occurrence. Through X-ray diffraction, the analysis of the diffusion layers in the Q235A and the 304L steels, as shown in Figure 3, reveals that the intermetallic phase Al_5Fe_2 is dominant in the diffusion layer in the Q235A, while the diffusion layer in 304L steel is composed of $Al_{13}Cr_2$ and Al_5Fe_2 with a little Al_3Ni_2 formation.

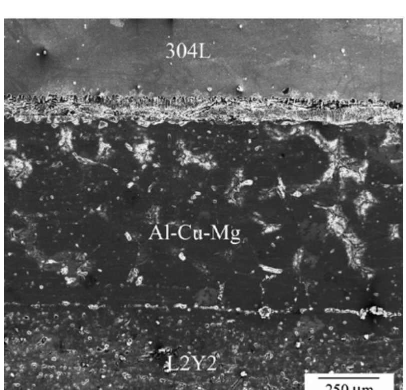

Figure 1. Microstructure of the 304L/Al–Cu–Mg/L2Y2 cladding at 630 °C for 40 min.

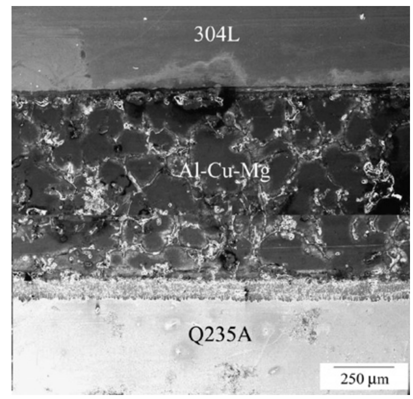

Figure 2. Microstructure of the 304L/Al–Cu–Mg/Q235A sample cladding at 640 °C for 20 min.

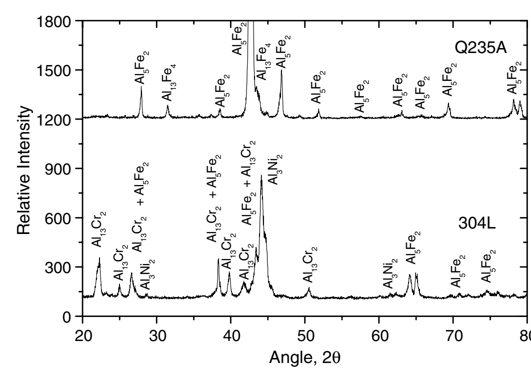

Figure 3. X-ray diffraction pattern of the diffusion layers of the Q235A and 304L.

Figure 4 shows the effects of cladding temperature and time on the thickness of diffusion layer in the 304L and the Q235A steels. Obviously, the thickness of the diffusion layers in the Q235A and 304L steels is increased with increasing cladding temperature and time, and the Q235A steel acquires much thicker diffusion layer than 304L does at the same cladding conditions.

For the cladding of 304L/L2Y2 sheet, a good cohesion between the L2Y2 aluminum substrate and the aluminum alloy interlayer occurs at the temperature above 600 °C for 10 min, and it is improved with increasing temperature at more liquid phase presence as indicated in Table 2. However, the bonding quality of the 304L/L2Y2 clad is controlled by the joint of 304L and the Al–Cu–Mg interlayer. Although the addition of Cu and Mg in the interlayer material does enhance cohesion