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Evolution of bonding interface in solid−liquid cast-rolling bonding of Cu/Al clad strip

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Abstract: Cu/Al clad strips are prepared using solid−liquid cast-rolling bonding (SLCRB) technique with a *d*160 mm × 150 mm twin-roll experimental caster. The extent of interfacial reactions, composition of the reaction products, and their micro-morphology evolution in the SLCRB process are investigated with scanning electron microscope (SEM), energy dispersive spectrometer (EDS), and X-ray diffraction (XRD). In the casting pool, initial aluminized coating is first generated on the copper strip surface, with the diffusion layer mainly consisting of α(Al)+$CuAl_2$ and growing at high temperatures, with the maximum thickness of 10 μm. After sequent rolling below the kiss point, the diffusion layer is broken by severe elongation, which leads to an additional crack bond process with a fresh interface of virgin base metal. The average thickness is reduced from 10 to 5 μm. The reaction products, $CuAl_2$, CuAl, and Cu_9Al_4, are dispersed along the rolling direction. Peeling and bending test results indicate that the fracture occurs in the aluminum substrate, and the morphology is a dimple pattern. No crack or separation is found at the bonding interface after 90°−180° bending. The presented method provides an economical way to fabricate Cu/Al clad strip directly.

Key words: Cu/Al clad strip; solid−liquid cast-rolling bonding; bonding interface; reaction diffusion; peeling test

1 Introduction

The Cu/Al clad strip has many advanced properties, such as high conductivity, light weight, and low price compared with pure copper or copper alloys. Accordingly, it has been widely used as power connectors, tapes, and other electric and heat conductive elements in electrical engineering and heat exchange field [1−3]. At present, several methods are used to produce clad strips, but roll bonding is always one of the effective and efficient processes because of its low cost and high productivity [4,5]. Significant efforts have been spent on improving bonding strength by optimizing the rolling and diffusion annealing heat treatment technology parameters [6−10]. However, time-consuming preparation is necessary for the strip components prior to the roll bonding process, and the total rolling reduction is always no less than 60%.

In recent years, combining the rapid solidification with roll bonding technology has enabled the application of a new short flow process based on twin-roll casting in bimetallic clad strip fabrication [11]. Cladding of Mg alloy with Al has been conducted with twin-roll casting process using melted Mg and solid Al strip by BAE et al [12]. The formability of the Al−Mg−Al cladded sheet could be improved by annealing and secondary rolling to reduce the thickness of the reaction zone. An experiment on twin-roll casting of aluminum−steel clad strips was conducted by GRYDIN et al [13], in which melted Al and solid steel strip were used. Results of deep-drawing and adhesive strength tests for the clad strips have proven the applicability of the strips for further plastic deformation processing. Moreover, with the 1050 aluminum alloy as matrix and mild steel wire as reinforcement element, the wire-inserted composite strip was fabricated using a twin-roll caster [14].

Brittle reactive products, such as $CuAl_2$, are easily generated at the solid−liquid bonding interface between Cu and Al [15,16]. The thickness of the reactive diffusion layer even reaches 50−100 μm under high temperature for a long time [17], which easily weakens the bonding strength. Existing works mostly focus on the diffusion process without deformation or after

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deformation. The present work deals with a new solid−liquid cast-rolling bonding (SLCRB) technique. A concurrence of solid−liquid and solid−solid hot-roll bonding in SLCRB process exists, which uses solid copper strip and molten aluminum to fabricate Cu/Al clad strip directly with twin-roll caster. A study is also conducted on the bonding mechanism and micro-morphology evolution in the bonding interface.

2 Experimental

As shown in Fig. 1, the solid copper strip and molten aluminum are fed into the roll bite of the twin-roll caster simultaneously. Then, Cu/Al clad strip is fabricated by combining the rapid solidification with hot-roll bonding. The tension of the copper strip and contact angle θ can be controlled using a decoiler. The ladle, tundish, and delivery device ensure the continuity and stability of the feeding molten aluminum into the casting pool. The experiments are conducted on a d160 mm × 150 mm twin-roll experimental caster at National Engineering Research Center for Equipment and Technology of Cold Strip Rolling, Yanshan University, China. Table 1 lists the experimental parameters. The total thickness of Cu/Al clad strip is 2.0 mm, of which 0.5 mm for Cu and 1.5 mm for Al.

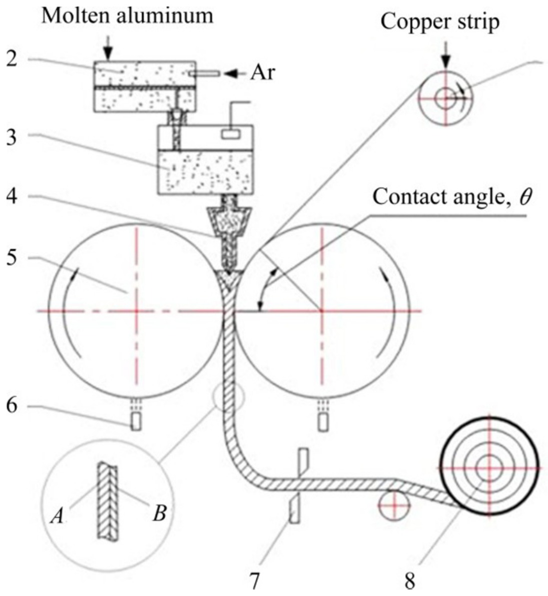

Fig. 1 Schematic diagram for SLCRB of Cu/Al clad strip: 1—Decoiler; 2—Ladle; 3—Tundish; 4—Delivery device; 5—Twin-roll caster; 6—Spray system; 7—Shearing machine; 8—Coiler

The bonding strength of prepared Cu/Al strip was measured by conducting a peeling test using an Instron 5848 tensile tester according to ASTM−D903−93. The test is carried out at room temperature with a peeling speed of 30 mm/min. And the SEM and XRD were applied to observing the micro-morphology evolution of the bonding interface along the rolling direction.

Table 1 Experimental parameters

Parameter	Value
Thickness of Cu/Al clad strip/mm	2
Width of Cu/Al clad strip/mm	80
Rolling velocity/(m·min^{-1})	2
Casting temperature of molten Al/°C	700
Initial temperature of casting roller/°C	25

3 Results and discussion

3.1 Overview of cast-rolling bonding area

As shown in Fig. 2, the sliced samples of the workpiece in the cast-rolling bonding area are acquired through emergency stop and quick cooling, among which, a large hole caused by the discontinuity in molten aluminum feeding can be found in Sample 1. Some as-cast defects exist, such as small voids, in the casting pool of Samples 2, 3, and 4. Fortunately, these defects have been eliminated by the sequent rolling entirely below the kiss point, and the compactness of aluminum component is accordingly improved in the final clad strips.

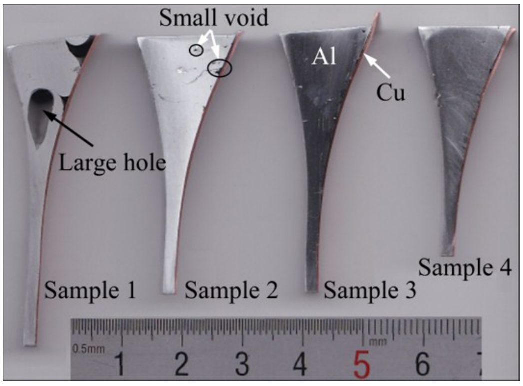

Fig. 2 Sliced samples of workpiece in cast-rolling bonding area

Figure 3 presents the macro-morphology evolution of the bonding interface along the cast-rolling area. In the casting pool, the molten aluminum contacts with copper strip without pressure and a gap can be found between the aluminum and cooper strip (Zone I). Below the kiss point of the cast-rolling area, hot-roll bonding is applied on the solid aluminum and copper strip, and the macro-morphology of bonding interface is obviously improved by severe deformation (Zones II, III and IV). At the exit of the caster, the thickness of copper strip is reduced to some extent (Zone IV).