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Solidification process and microstructure of transition layer of Cu−Al composite cast prepared by method of pouring molten aluminum

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Abstract: The Cu−Al composite casts were prepared by the method of pouring molten aluminum. The solidification process and the microstructure of the transition layer were investigated during the recombination process of the liquid Al and the solid Cu. The results reveal that the microstructure of the transition layer in the Cu−Al composite cast consists of α(Al)+α(Al)−$CuAl_2$ eutectic, α(Al)−$CuAl_2$ eutectic, $CuAl_2$+α(Al)−$CuAl_2$ eutectic and Cu_9Al_4. Additionally, the pouring temperature, cooling mode of the Cu plate surface and start time of the forced cooling after pouring have no effect on the microstructure species. But the proportion of the various microstructures in the transition layer changes with the process parameters. The pure Al at the top of the transition layer starts to solidify first and then the α(Al) phase grows in a dendritic way, while the $CuAl_2$ phase exhibits plane or cellular crystal growth from the two sides of the transition layer towards its interior. The stronger the cooling intensity of the Cu plate outer surface, the more developed the dendrite, and the easier it is for the $CuAl_2$ phase to grow into a plane crystal.

Key words: copper cladding aluminum; pouring aluminum method; transition layer; solidification process; solidification microstructure

1 Introduction

The copper resources are scarce, and the high price limits its wide application in the communications and electric conduction industries. Copper cladding aluminum (CCA) composite as a perfect substitution for pure copper has attracted broad attention. Firstly, it was used as conductor material in Germany. Subsequently, Europe and America and other developed countries, and China began to study and apply the CCA composite one after another [1,2]. The available evidence shows that the microstructure and thickness of the transition layer play a decisive role in the bonding strength. Accordingly, the formation of the transition layer, the microstructure constitution in the layer and the mechanical properties of the transition layer has been investigated [3−7]. In particular, the influence rules of temperature, time, cooling ways, heat treatment and high magnetic field on the transition layer have been evaluated when different types of the methods to prepare copper cladding aluminum composites are used [8−13].

The metallurgical bonding between copper and aluminum is the key technology in preparation process of copper cladding aluminum composite [14]. At present, all the preparation methods can be divided into two types according to the metallurgical bonding achieved before or after plastic processing. Achieving metallurgical bonding after plastic processing is that the copper is wrapped on the surface of the aluminum to realize the mechanical bonding and then the metallurgical bonding between the copper and aluminum is achieved by the atomic diffusion of copper and aluminum during the heat treatment. The rolling compound and tube-weld cladding technique belong to this type, and its disadvantage is that the heat treatment time is too long, the equipment is huge, the energy consuming is high and the bonding strength cannot be guaranteed [15,16]. Achieving metallurgical bonding before plastic processing is that the Cu−Al alloy or Al−Cu alloy is formed between the solid Cu and liquid Al after the contact of liquid Al with solid Cu, and the metallurgical bonding between Cu and Al is achieved after the solidification. The methods used are the continuous core-filling casting, horizontal core-filling continuous casting and pouring aluminum method [17,18]. The more advanced method to get the CCA profiles of high bonding strength and short technological process is the horizontal continuous

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casting [19]. But the disadvantages of the method of horizontal continuous casting are that the quality of the inner and outer surface of the copper tube billet (especially the outer surface) is not easy to guarantee, the process is complex, the equipment investment is large and the transition layer of Cu−Al composite is not even easily. The pouring aluminum method becomes the more practical method of preparing Cu−Al composite ingot for the easy processing and convenient operation. But the influences of the solidification process of the transition layer and technology parameters on the composite quality are not clear, which cause the difficult control of the composite quality. It is important to clarify the solidification process of the transition layer for controlling the tissue of the transition layer easily and improving the composite quality. So, the solidification process and the effects of related technological parameters on the composite quality are studied in this work when preparing the Cu−Al composite ingot by pouring aluminum method.

2 Experimental

The pure Al and pure Cu with 99.90% purity were chosen as the experimental materials. The Al ingot was placed into the clay graphite crucible, and the crucible was heated in the resistance furnace. Subsequently, the liquid Al was degassed and refined with C_2Cl_6 after the temperature of the liquid Al reached the set temperature (20 °C higher than the pouring temperature) and held for 20 min. When the temperature of the liquid Al dropped to 780 °C or 830 °C, the crucible containing the liquid Al was taken out and then poured into the experimental device shown in Fig. 1. Before pouring the liquid Al, the surface of the Cu plate with the dimensions of 80 mm × 80 mm × 6 mm was polished with sandpaper to remove the oxide skin. Next, the Cu plate was placed on the cooling device shown in Fig. 1. After that the sand mold with the cavity dimensions of 60 mm × 60 mm × 80 mm was placed on the Cu plate and sealed with the silicate bonded sand, and then argon was introduced into the casting mold to protect the internal surface of the Cu plate to prevent oxidation. The temperature of the liquid Al was maintained by spreading the insulation covering agent on the surface of the liquid after pouring. Then, the outside surface of the Cu plate was cooled by jet air, spraying or water injection, the average cooling rate of the internal interface of the Cu plate were 0.6, 1.8, and 4.2 °C/s, respectively (temperature range: 500−780 °C). The time from pouring to the beginning of forced cooling was 40, 60 or 110 s. The thermocouples were fixed to the longitudinal axis of the cavity, and their distances to the Cu plate were 0, 5, 10 and 20 mm, respectively. The nickel−chromium/nickel−silicon thermocouple wire with the diameter of 0.5 mm was used, and the error of calibrated thermocouple is 0.75%t, t is the measured temperature. The recording of the temperature−time curves for the four locations was performed by using a DMR2100 paperless recorder, as shown in Fig. 1. The metallographic samples were intercepted in the area of copper and aluminum composite, and they were etched with a solution containing 2.5 mL HNO_3, 1.5 mL HCl, 1 mL HF, and 95 mL H_2O after shining and polishing. The microstructure was observed with an Axiovert 200 MAT metallographic microscope and the energy spectrum analysis was proceeded by an SN−300 electron microscope.

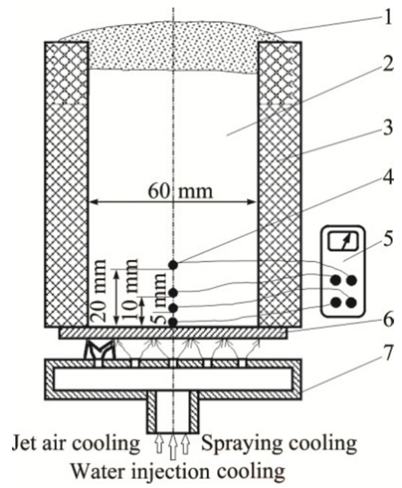

Fig. 1 Schematic plan of preparing Cu−Al composite cast using method of pouring molten aluminum (1—Covering agent for thermal retardation; 2—Liquid aluminum; 3—Sand mold; 4—Thermal couple; 5—DMR2100 paperless recorder; 6—Copper plate; 7—Cooler)

3 Results and discussion

3.1 Casting quality of Cu−Al composite cast

The photographs of the vertical section of the Cu−Al composite casts under different technological parameters are shown in Fig. 2. The pictures reveal that shrinkage cavities clearly appeared at the junction of the Cu and Al when the outside surface of the Cu plate was cooled by a air jet, and the longer the holding time, the more serious the phenomenon of shrinkage cavity formation. The Cu and Al metallurgical bonding was well achieved when the pouring temperature was 780 °C and the holding time was 40 s under spraying cooling and water injection cooling. The transition layer was present at the junction of the Cu and Al. Basically, the higher the temperature during pouring, the longer the holding time, the weaker the cooling intensity of the Cu plate outside surface, thus the thicker the transition layer.

3.2 Microstructures of transition layer

The samples were intercepted at the junction of the Cu−Al composite cast. The microstructures of the transition layers are shown in Figs. 3 and 4. Three kinds