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Microstructure and crystal growth direction of Al−Cu alloy

Ti-jun CHEN, Xiang-wei LI, Hai-yang GUO, Yuan HAO

State Key Laboratory of Advanced Processing and Recycling of Nonferrous Metals,
Lanzhou University of Technology, Lanzhou 730050, China

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Abstract: The microstructures and crystal growth directions of permanent mould casting (PMC) and directionally solidified (DS) Al−Cu alloys with different contents of Cu were investigated. Simultaneously, the effects of pouring temperature on the microstructure and crystal growth direction of permanent mould casting pure Al were also discussed. The results indicate that the *α*(Al) crystals in the pure Al do not always keep common columnar grains, but change from the columnar grains to columnar dendrites with developed arms as the pouring temperature rises. The growth direction also varies with the change of pouring temperature. Cu element has similar effects on the microstructures of the PMC and DS casting Al−Cu alloys and the *α*(Al) crystals gradually change from columnar crystals in turn to columnar dendrites and developed equiaxed dendrites as the Cu content increases. The crystal growth direction in the PMC alloys gradually approaches ⟨110⟩ orientation with increasing Cu content. But the resulting crystals with growth direction of ⟨110⟩ do not belong to feathery grains. There are also no feathery grains to form in all of the DS Al−Cu alloys.

Key words: Al−Cu alloy; directional solidification; crystal growth direction; permanent mould casting; microstructure

1 Introduction

Compared with ZA27 alloy, the melting point of 10% Si (volume fraction) particle reinforced ZA27 in situ composite (Si_p/ZA27 composite) is significantly raised from 497 °C to 625 °C [1]. Its pouring temperature thereby is raised correspondingly. However, the pouring temperature rise leads to the primary *α*(Al) dendrites to change from original small equiaxed dendrites to very developed columnar dendrites, even to feathery grains with large anisotropic morphology as the temperature is raised to 750 °C [2]. Feathery grain is a kind of specific columnar dendrite that is often found in Al alloys [3]. Due to its strong anisotropy and nonuniform aspect, this kind of microstructure is highly undesirable in Al manufacturing. The investigation indicates that the mechanical properties of the Si_p/ZA27 composite are obviously impaired due to this microstructure [1]. To avoid the feathery grains, it is of importance to verify their formation conditions.

In fact, the primary metal phase in the Si_p/ZA27 composite is identical to that of Al alloys and both of them belong to *α*(Al) phase. So, it can be considered that the formation of feathery grains in the composite is similar to that of Al alloys. The existing investigations on Al alloys indicated that high temperature gradient and growth rate, the presence of fluid flow, the absence of nucleation agents and a given amount of certain solute elements with specific crystal structure can accelerate the formation of feathery grains [4−6]. That is to say, the composition of an alloy has large effects on the formation of feathery grains. The reason is that the solutes change the anisotropy of the solid−liquid interface and the adsorption kinetics of atoms, thus resulting in the formation of twins and the change of growth direction [3,7−9]. But a recent study has shown that the formation of feathery grains was not concerned with solute kind, but with its amount [10]. The investigation demonstrated that the formation actually depended on Zn content for Al−Zn alloy and ⟨110⟩ orientated feathery grains were clearly found above 60% Zn [11].

In order to verify the formation of feathery grains in the Si_p/ZA27 composite, it is necessary to clarify the effects of all kinds of solutes. Cu is a main alloying

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Corresponding author: Ti-jun CHEN; Tel: +86-931-2976573; Fax: +86-931-2976578; E-mail: chentj1971@126.com; chentj@lut.cn
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element for the composite [12]. But the existing investigations have not involved the effect of Cu element on the microstructure, especially on the formation of feathery grains. The proposed structure of feathery grains is made of thin lamellar dendrites in the center of their trunk by a coherent (111) twin plane [3,7]. Twinned dendrite trunks always grow along ⟨110⟩ direction and have a highly complex branch morphology of ⟨110⟩ secondary arms [3,4]. The formation of the very anisotropic morphology is essentially attributed to the change of α(Al) growth direction from the isotropic growth along ⟨100⟩ to the anisotropic growth along ⟨110⟩. The present work indicates that the growth direction of the α(Al) in Al−Cu alloy can change to ⟨110⟩ orientation under given Cu content and solidification conditions, but the resulting morphology is not so anisotropic.

Therefore, the study on the effect of Cu element on the microstructure of Al−Cu alloy is significant not only for verifying the microstructure of the Si_p/ZA27 composite, but also for understanding the formation and structure of feathery grains in Al alloys. In the present work the effects of Cu content and directional solidification on the microstructure and crystal growth direction of Al−Cu alloy were mainly investigated. For comparison, the cases of permanent mould casting pure Al, especially the effects of pouring temperature were discussed.

2 Experimental

The raw materials used in this work are pure Al and Al−50Cu master alloy. According to the compositions of target alloys, the raw materials were melted in a resistance furnace at 790 °C, then degassed using C_2Cl_6 and poured into a permanent mould with a cavity of *d*16 mm × 130 mm at 740 °C. The mould temperature was at room temperature prior to pouring. The Cu content in the ZA27 alloy is always limited within 2%−2.5%, but to verify the effects of Cu content on the microstructures and growth directions of primary α(Al) crystals (including those in the ZA27 alloy and Cu-containing Al alloys), the range of Cu content should be chosen as wide as possible. So, the employed Cu content was selected within the range from 0 to 23%. The investigation indicated that feathery grains could form in the ZA27 alloy when pouring temperature was elevated to 650 °C or above [13]. So, the pouring temperature of 740 °C was employed in this work. A given amount of pure Al was also remelted and poured into the same mould at different temperatures ranging from 680 °C to 830 °C to investigate the effect of pouring temperature on the microstructure and crystal growth direction. A specimen with dimensions of *d*16 mm×10 mm was cut from the bottom end of each casting rod away for 50 mm. Then, each specimen was sectioned into two small specimens along axial direction. The cross-section of one of them was finished and polished. For the Al−Cu specimens, the cross-sections were etched by 1% HF aqueous solution and for the pure Al specimens, they were etched by 15% NaOH aqueous solution at 70−80 °C. They were observed with an optical microscope (OM) and analyzed by energy dispersive spectrometer (EDS) on a scanning electron microscope (SEM). Finally, some typical specimens were finished and polished again, and then vibrating-polished and analyzed on the SEM by electronic back scattered diffraction (EBSD).

To investigate the effect of Cu content on the microstructure and growth direction of the Al−Cu alloy under directional solidification conditions, casting Al−Cu rods with a diameter of 10 mm and with the same compositions (0−23% Cu) to those of the alloys employed in the above experiments were first prepared. Then each of the rods was put into a quartz tube with a diameter of 10.5 mm, remelted and directionally solidified on a zone-melted directional solidification device. The employed solidification rate was 30 μm/s. All of the solidified rods were cut into two parts along their axis direction. One of them was used for metallographic observation and analysis. The preparation processes of metallographic specimens and EBSD specimens, and the observation and analysis methods are same as those of the above permanent mould casting specimens.

3 Results and discussion

3.1 Effects of pouring temperature on microstructure and crystal growth direction of permanent mould casting pure Al

Figure 1 gives the microstructures of the pure Al poured at different temperatures. It can be found that the primary grains are in columnar form at 680 °C (Fig. 1(a)). Then, the columnar crystals generate branches (Fig. 1(b)) and the branches gradually evolve into dendritic arms as temperature rises (Fig. 1(c)). The crystals thereby become into columnar dendrites at 740 °C (Fig. 1(c)). The dendritic arms become more and more developed and the crystals change into the developed columnar dendrites when the temperature is further elevated (Fig. 1(d)). Simultaneously, both the length of the columnar crystals or columnar dendrite region and the primary dendritic arm spacing (PDAS) increase as the temperature rises, which can be more clearly seen from the quantitative results shown in Fig. 2. In addition, the columnar crystals, especially the columnar dendrites are refined as they grow towards the casting rod center and thus the primary trunk spacing decreases (Fig. 1). In view of the variation of the primary