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# Interface morphology evolvement and microstructure characteristics of hypoeutectic Cu–1.0 wt%Cr alloy during unidirectional solidification

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**Abstract**

Effect of unidirectional solidification rate on microstructure of hypoeutectic Cu–1.0%Cr alloy was investigated. The microstructure evolution of Cu–1.0%Cr alloy was noticed especially during the unidirectional solidification with the different solidification rates. It is shown that eutectic (α+β) and primary α(Cu) phase grew up equably in parallel to direction of solidification. A kind of fibriform microstructure will appear when unidirectional solidification rate is up to some enough high certain values. When temperature gradient was changeless, the interface morphology evolution of the primary α(Cu) phase underwent to a series of changes from plane to cell, coarse dendrite, and fine dendrite grains with increasing the solidification rates. Primary dendrite arm spacing λ1 of α(Cu) phase increases with increasing the solidification rate where the morphology of the solid/liquid (S/L) interface is cellular. However, λ1 decreases with further increasing the solidification rate where the S/L interface morphology is changed from cell to dendrite-type. Its rule might accord with Jackson–Hunt theory model. An experience equation obtained is as follows: $\lambda_1 = -0.0052 + 0.061 G_L^{-1/2} V^{-1/4}$. On the other hand, secondary dendrite spacing λ2 of primary α(Cu) phase will thin gradually with increasing the solidification rate. Moreover, secondary dendrite will become coarse in further solidification. Another experience equation about relationship among secondary dendrite arm spacing ($\lambda_2$), temperature gradient $G_L$ and the velocity of the S/L interface ($V$) is that: $\lambda_2 = -0.0003 + 0.0027 (G_L V)^{-1/3}$. In addition, the volume fraction of eutectic will decrease with the increase of solidification rate.


*Keywords:* Unidirectional solidification; Cu–Cr alloy; Interface morphology

## 1. Introduction

Hypoeutectic Cu–Cr alloy is an important material with high strength and high conductivity, which is generally used to make electrical contactors and electrical leads for power net in high railway system [1]. Hypoeutectic Cu–Cr alloy with unidirectional microstructure is called as a kind of in situ composite material [2]. Due to a high strength of Cr-rich phase, the eutectic part has higher strength than matrix. Eutectic with fiber shape can reinforce the copper matrix in direction parallel to these fibriform microstructures and keep a good conductivity [3]. However, it should be noticed that most of the previous researches mainly focus on the effect of the microstructure of the unidirectional solidified Cu–Cr alloys on conductivity [4,5]. Moreover, some early works thought the fibriform microstructure was Cr whisker in eutectic alloy [6]. But in fact, authors indicated that'Cr whisker' should be 'Cr-rich β phase' in a former work [7]. The certainly orientated microstructure in hypoeutectic alloy is eutectic except for Cr-rich β phase because of effect of primary α phase growth. Orientation of Cr-rich β phase in the unidirectional solidified eutectic-like microstructure of hypoeutectic alloy is also disorder [7]. Authors think that this result is related with evolvement characteristics of interface morphology. In the present work, the effect of unidirectional solidification rate on microstructure and evolvement characteristics of interface morphology of hypoeutectic Cu–1.0 wt%Cr alloy was investigate by LMC method (liquid metal cooling).

## 2. Experiment procedure

The binary Cu–1.0 wt%Cr alloy was smelted from the Cu–25 wt%Cr mid-alloy and electrolytic pure Cu (99.94%) in a middle-frequency vacuum induction furnace with 25 kg capacity by using a high-purity graphite crucible. Then, original sample (ϕ8 mm×100 mm rods) were obtained when Cu–1.0 wt%Cr alloy melt solidified in a die model. These sample rods were treated with unidirectional solidification method in equipment with high temperature gradient [7]. When

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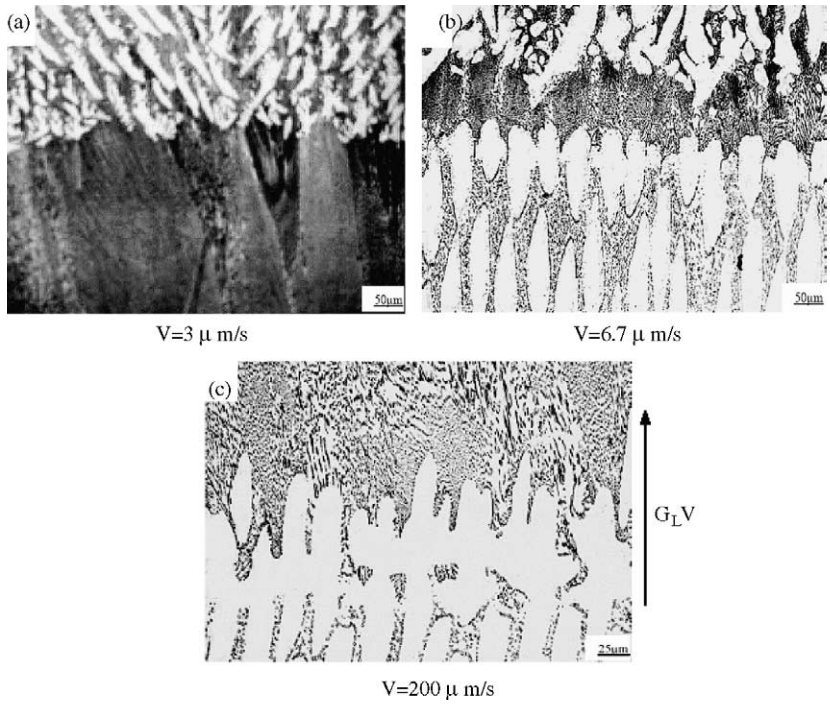


Fig. 1. The longitudinal cross-section of unidirectional solidified and quenched samples showing the S/L interface morphologies of Cu–1.0 wt%Cr alloy under different solidification rate. (a) the planar front; (b) the cell interface; (c) the dendrite interface.

these samples were melted, they were moved downward with several different velocities into a Ga–In alloy pool with water-cooling located below heat region. Some of adiabatic refractory material plates were set at position between heat region and cooling pool in order to make a higher temperature gradient on the S/L interface. By using thermocouples [7], cooling curve of sample can be recorded during solidification process. In this work, the temperature gradient ($G_L$) is about 200 K/cm. Based on the constant temperature gradient, this work adopted a serial of solidification rates ($G_L V$). Where the velocity of the advancing S/L interface ($V$) are about 3.7, 6.7, 12, 30, 60, 100, 200, 400, 600 and 1000 μm/s, in order to investigate the influence of the solidification parameters on the microstructure. The samples were cut along axial direction of samples by line incising technique. The morphology evolution and microstructures were observed with optical microscope and SEM methods.

## 3. Results and discussions

### *3.1. Effect of solidification rate on interface morphology and microstructures characteristics*

Based on having a constant temperature gradient ($G_L =$ 200 K/cm), by changing the velocity of the advancing S/L interface ($V$), an effect of solidification rate on solidification microstructure was investigated in this work. The interface morphologies under different solidification rate are as follows:

As shown in Fig. 1, the S/L interface morphology underwent changes from planar interface to cell and dendrite ones with increasing the solidification rate. In particular, the microstructure of hypoeutectic alloy is not composed of single α phase but primary α phase and eutectic phase. When the advancing unidirectional solidification interface is carried through with a lower velocity, the hypoeutectic alloy will be made up of whole eutectic-type microstructure, where the S/L interface is characterized with planar, intergrowth growth of eutectic and stability growth. The growth of primary α(Cu) phase will be restrained completely [8]. In hypoeutectic alloy, when unidirectional solidification S/L interface is a low velocity planar interface, constitutions of liquid near front edges of intergrowth interface of two phases in eutectic are so obviously different that solute atoms can diffuse easily each other. The solute concentration near S/L interface is further less than one near S/L interface of single-phase alloy. Therefore, whole

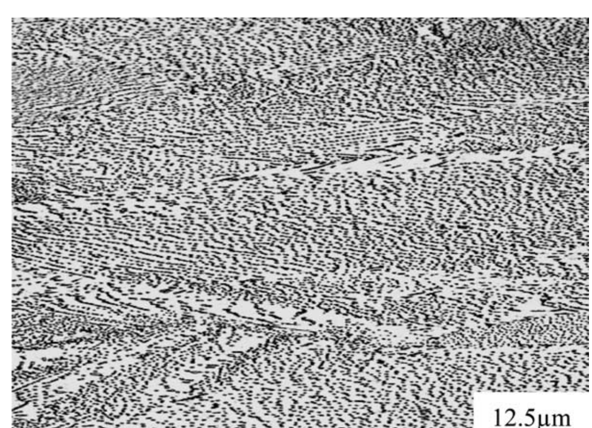


Fig. 2. Microstructure for the planar interface of Cu–1.0%Cr alloy.