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Influence of Some Chemical Elements on SDAS of A357 alloy

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Introduction

Secondary Dendrite Arm Spacing (SDAS) refers to the distance between the center lines of the secondary dendrite arms, as shown in Figure 1. The size of SDAS directly affects the distribution of composition segregation, second phase and formation of solidification micropores. However, the influence of different solute elements on SADS is different. The mathematical model of SADS coarsening coefficient criterion is established to provide a theoretical model for the selection of modifiers and the design of alloy composition.

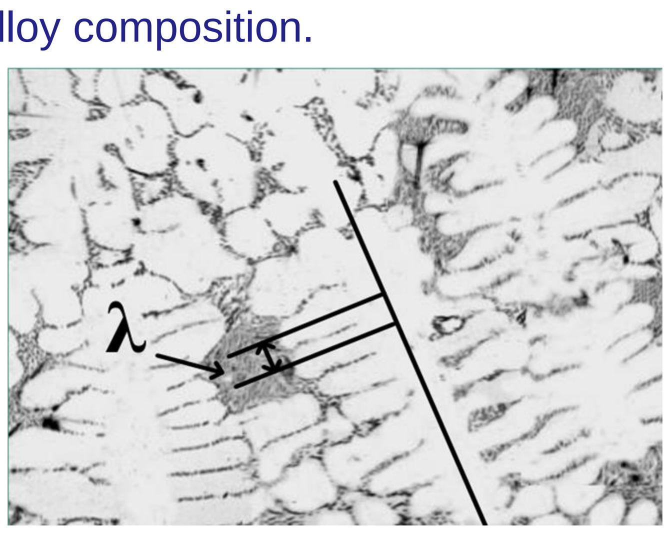

Fig. 1. Schematic of Secondary Dendrite Arm Spacing

Mathematical model of coarsening coefficient

Many scholars who studied solidification theory believe that the distance between the secondary arms increases with the smaller side re-melting of the secondary arm . During the coarsening process of the secondary dendrite arm, the mechanism of coarsening is that the finer secondary arm melts and the coarser branch diameter increases. When a fine secondary dendrite arm is melted, the local SDAS is doubled. The driving force of this coarsening process is the interface energy difference between dendrite arms with different curvature radius. Based on this assumption, the mathematical model was obtained by furer and wunderlin:

$$\lambda_2 = 5.5\left(A \cdot t_f\right)^{\frac{1}{3}} \qquad (1)$$

Where λ_2 is SDAS, t_f is local solidification time and A is coarsening coefficient.

$$A = \frac{-\Gamma D \ln\left(\frac{C_i}{C_0}\right)}{m(1-k)(C_i - C_0)} \qquad (2)$$

Where, Γ is Gibbs Thompson coefficient; D is solute diffusion coefficient in liquid phase; C_i is final liquid concentration; C_0 is original concentration of alloy liquid; m is liquidus slope and k is equilibrium distribution coefficient.

For an alloy with the same matrix, Γ is a fixed value, and the difference of D among solute elements is very small, which can be ignored. When a chemical element is added, the mathematical model of coarsening coefficient A can be expressed to function of C_0 , C_i , m and k:

$$A = f(C_0,\ C_i,\ m,\ k) \qquad (3)$$

The partial derivation of each variable parameter can be obtained as follows:

$$\frac{\partial A}{\partial C_0} = \frac{\Gamma D m(1-k)\left[\frac{C_i - C_0}{C_0} - \ln\left(\frac{C_i}{C_0}\right)\right]}{m^2(1-k)^2(C_i - C_0)^2} \qquad (4)$$

$$\frac{\partial A}{\partial C_i} = \frac{\Gamma D m(1-k)\left[\frac{C_0 - C_i}{C_i} + \ln\left(\frac{C_i}{C_0}\right)\right]}{m^2(1-k)^2(C_i - C_0)^2} \qquad (5)$$

$$\frac{\partial A}{\partial m} = \frac{\Gamma D \ln\left(\frac{C_i}{C_0}\right)}{m^2(1-k)(C_i - C_0)} \qquad (6)$$

$$\frac{\partial A}{\partial k} = \frac{-\Gamma D \ln\left(\frac{C_i}{C_0}\right)}{m(1-k)^2(C_i - C_0)} \qquad (7)$$

Let A' be the criterion factor of the coarsening coefficient of the secondary dendrite arm spacing, which can be obtained by combining (3) - (7):

$$A' = \frac{dA}{df} = \frac{\Gamma D}{m(1-k)C_0 C_i} + \frac{-\Gamma D \ln\left(\frac{C_i}{C_0}\right)(1-k-m)}{m^2(1-k)^2(C_i - C_0)} \qquad (8)$$

It is deduced from (8) that when different solutes of the same concentration are added respectively and the criterion factor A' is less than zero, the element will contribute to refining the SDAS, and the larger the absolute value of A' is, the more obvious the refining effect of the element will be.

Experiment verification

In order to verify the effect of different solute elements on SDAS, 0.2% of Ti, Zr and Cu were added to A357 alloy, respectively. The electric furnace with 10Kg capacity was used to smelt the alloy. The temperature of the melt was maintained at 720 C and was degassed with C2Cl6 , 1% of the furnace charge mass, and skipped of the dross from the melt surface after maintaining the temperature for 10 minus and then the melt was poured into sand mold cavity with the diameter 30 mm at 730 C.

Table. 1. Calculation and SDAS of the specimens

Element	$\lvert A' \rvert$	$SDAS$/μm
Zr	991.1×10^{-7}	33.12
Ti	705.8×10^{-7}	35.04
Cu	483.3×10^{-7}	60.83

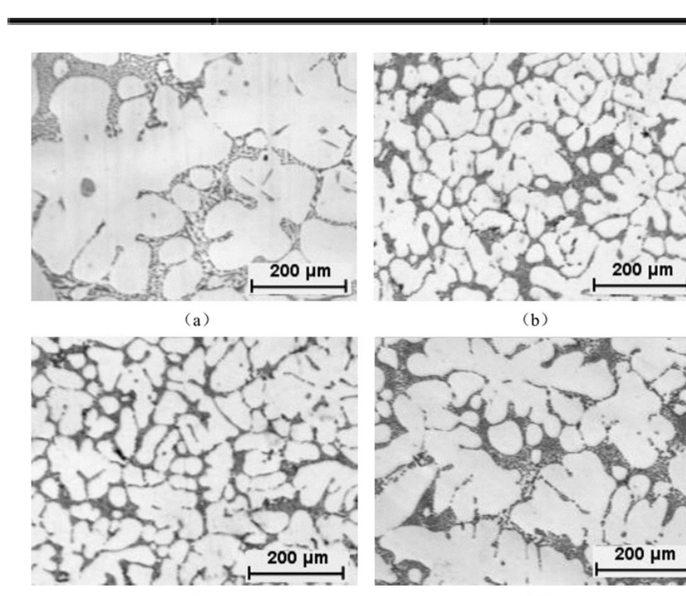

Fig. 2. Microstructure of alloy
a : A357, b : Zr addition, c : Ti addition and d : Cu addition

The specimen was cut from the casting, polished and eroded, and observed with the metallographic microscope with image analyzing software.The calculated A' and SDAS values from experiment are shown in Table 1. The microstructures of the A357 alloy with addition of Zr, Ti and Cu are seen in Figure 2.

Conclusions

A mathematical model is proposed that can be used to evaluate the effect of chemical elements on SDAS of aluminum alloy. In this model, the coarsening coefficient depends on many factors such as m, k, c_o and c_i . As a case study, the model has been applied to A357 Alloy with minor addition of Zr, Ti and Cu. It has been found that Zr has a better refining effect on aluminum alloy than Ti, and Cu has a certain refining effect, but the effect is not as good as Zr and Ti. The model is consistent with the measured results.

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