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Variations of microhardness with solidification parameters and electrical resistivity with temperature for Al–Cu–Ag eutectic alloy

U. Böyük [a], N. Maraşlı [b,*], E. Çadırlı [c], H. Kaya [a], K. Keşlioğlu [b]

[a] Department of Science Education, Education Faculty, Erciyes University, Kayseri, Turkey
[b] Department of Physics, Faculty Sciences, Erciyes University, Kayseri, Turkey
[c] Department of Physics, Faculty Arts and Sciences, Niğde University, Niğde, Turkey

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ABSTRACT

Al–Cu–Ag eutectic alloy was directionally solidified upwards with different growth rates (1.83–498.25 μm/s) at a constant temperature gradient (8.79 K/mm) and with different temperature gradients (3.99–8.79 K/mm) at a constant growth rate (8.30 μm/s) by using a Bridgman type directional solidification apparatus. The dependence of microhardness (HV) on the growth rate (V), temperature gradient (G) and microstructure parameter (λ) were found to be $HV = k_1 V^{0.10}$, $HV = k_2 G^{0.13}$ and $HV = k_3 \lambda^{-0.22}$, respectively. The electrical resistivity of the Al–Cu–Ag eutectic cast alloy increases linearly with the temperature in the range of 300–780 K. The enthalpy of fusion and specific heat change during melting for same alloy were also determined to be 223.8 J/g, and 0.433 J/g K, respectively by a differential scanning calorimeter from heating curve during the transformation from eutectic solid to eutectic liquid.

1. Introduction

Solidification and melting are transformations between the crystallographic and non-crystallographic states of a metal or alloys. These transformations are basic to such technological applications as ingot and continuous casting, and directionally solidification of composites and single crystals. An understanding of the mechanism of solidification and how it is affected by such parameters as temperature distribution, solidification condition and alloying, are important in the control of the mechanical and electrical properties of cast metals and fusion welds [1]. The metallic materials in industrial's use are usually multicomponent and multiphase alloys. In the case of Cu–Al alloys, the formation of Ag-rich precipitates increases hardness, stress corrosion resistance, and modifies the equilibrium concentration of these alloys [2]. As for Al–Cu–Ag ternary alloy, Ag and Cu present excellent electric conductivity and mechanical ductility, and aluminum is the matrix of lightweight metallic materials. Besides, the Al–Cu–Ag ternary alloy is an important component of industrial aluminum alloys [3,4].

Therefore, purposes of present work were to investigate the dependency of microhardness on the solidification processing parameters (G and V) and microstructure parameter (λ) for directionally solidified Al–Cu–Ag eutectic alloy and the temperature dependence of electrical resistivity (ρ) in the range of 300–780 K for Al–Cu–Ag eutectic cast alloy. The enthalpy of fusion and specific heat change for Al–Cu–Ag eutectic cast alloy were also determined from DSC curve during the transformation from eutectic solid to eutectic liquid.

2. Experimental procedure

2.1. Alloy preparation

In the present work, the composition of the Al–Cu–Ag ternary alloy was chosen to be eutectic composition (Al-17.6wt.% Cu-42.2 wt.%Ag) to growth eutectic three solid phases from ternary liquid. Thus, Al-17.6wt.%Cu-42.2 wt.%Ag alloy was prepared under vacuum atmosphere by using Al (99.999%), Cu (99.9%) and Ag (99.99%). After allowing time for melt homogenization, the molten alloy was poured into 13 graphite crucibles (200 mm in length 4 mm ID and 6.35 mm OD) held in a specially constructed casting furnace (Hot Filling Furnace) at approximately 50 K above the melting point of alloy. The molten alloy was directionally solidified from bottom to top to ensure that the crucible was completely full.

* Corresponding author. Tel.: +90 352 437 4901x33114; fax: +90 352 437 49 33.
E-mail address: marasli@erciyes.edu.tr (N. Maraşlı).

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2.2. Measurement of microhardness of directionally solidified Al–Cu–Ag eutectic alloy

Solidification of Al–Cu–Ag eutectic alloy was carried out with different growth rates (1.83–498.25 μm/s) at a constant temperature gradient (8.79 K/mm) and with different temperature gradients (3.99–8.79 K/mm) at a constant growth rate (8.30 μm/s) by using a Bridgman-type growth apparatus. The temperature of water in the reservoir was kept at 283 K to an accuracy of ±0.01 K using a *Poly Science digital 9102* model heating/refrigerating circulating bath to get a well quenched solid–liquid. The temperature on the sample was also controlled to an accuracy of ±0.1 K degrees with a *Eurotherm 2604* type controller. The details of the apparatus and experimental procedures are given in Refs. [5–7].

The quenched samples were removed from the graphite crucible and cut into lengths of typically 20 mm. After the metallographic process, the microstructures of samples were revealed.

One of the purposes of present study was to obtain the relationships among the solidification processing parameters and eutectic spacings (λ) with microhardness for directionally solidified Al–Cu–Ag eutectic alloy. Microhardness measurements were made with a *Future-Tech FM-700* model hardness measuring test device by using a 500 g load and a dwell time of 10 s giving a typical pyramid indentation. Microhardness is the average of at least 30 measurements on the transverse sections (HVT) and the longitudinal sections (HVL).

2.3. Measurement of electrical and thermal properties of Al–Cu–Ag eutectic alloy

The electrical and thermal properties such as electrical resistivity, enthalpy of fusion and specific heat change for Al–Cu–Ag cast alloy were determined. The temperature dependence of electrical resistivity was measured by the d.c. four-point probe method. The method has proven to be a convenient tool for the resistivity measurement [8]. The specimen thickness and width were measured to an accuracy of 1 μm using a digital micrometer. The resistance data were converted to resistivity values with the measured specimen dimensions. The details of the measuring method have been described elsewhere [9].

Electrical resistivity depends strongly on temperature. In metals, electrical resistivity increases with increasing temperature. The dependence of electrical resistivity on the temperature is often expressed as a slope in the electrical resistivity versus temperature graph and can be given as

$$\alpha = \frac{\rho - \rho_o}{\rho_o (T - T_o)} = \frac{1}{\rho_o}\frac{\Delta\rho}{\Delta T} \quad (1)$$

where ρ is the electrical resistivity at the temperature T, ρ_o is the electrical resistivity at room temperature, $T_o = 300$ K and α is the temperature coefficient of electrical resistivity.

Enthalpy of fusion (ΔH) and specific heat change (ΔC_p) for Al–Cu–Ag eutectic alloy were measured using a DSC (Perkin Elmer Diamond model) in the temperature range of 300–820 K with a heating rate of 10 K/min and under a constant stream of nitrogen at an atmospheric pressure.

3. Results and discussion

3.1. Effect of solidification parameters on microhardness

In previous work [7], the microstructures of directionally solidified samples were characterized using an LEO scanning electron microscopy (SEM) equipped with an energy dispersive X-ray (EDX) spectrometers as well as a computer controlled image system. According to the previous work [7], the black phase, the gray phase, and the white phase were identified as Al solid solution, Ag_2Al and Al_2Cu phases, respectively, and the composition of the quenched liquid phase was the eutectic composition of Al–Cu–Ag system. Typical SEM images of growth morphologies of directionally solidified Al–Cu–Ag eutectic alloys are shown in Fig. 1. According to Ruggiero and Rutter's classification [10], the microstructure of Al–Cu–Ag eutectic alloy seems to be two fibrous and one lamellar structure.

Variations of microhardness with solidification processing parameters and the microstructure parameter are plotted in Figs. 2–4. As can be seen from Figs. 2–4, the dependence of HV on the V, G, and λ can be represented by equations as follows

$$HV = k_1 V^a \quad (2)$$

$$HV = k_2 G^b \quad (3)$$

$$HV = k_3 \lambda^{-c} \quad (4)$$

where k is a constant, a, b, and c are the exponent values relating to the growth rate, temperature gradient, and eutectic spacing, respectively.

Fig. 2 shows the variation of HV with V at a constant G. The value of HV rises with the increasing the value of V. The exponent values relating to the growth rate for both transverse and longitudinal sections were found to be 0.10. The exponent value of 0.10 agrees

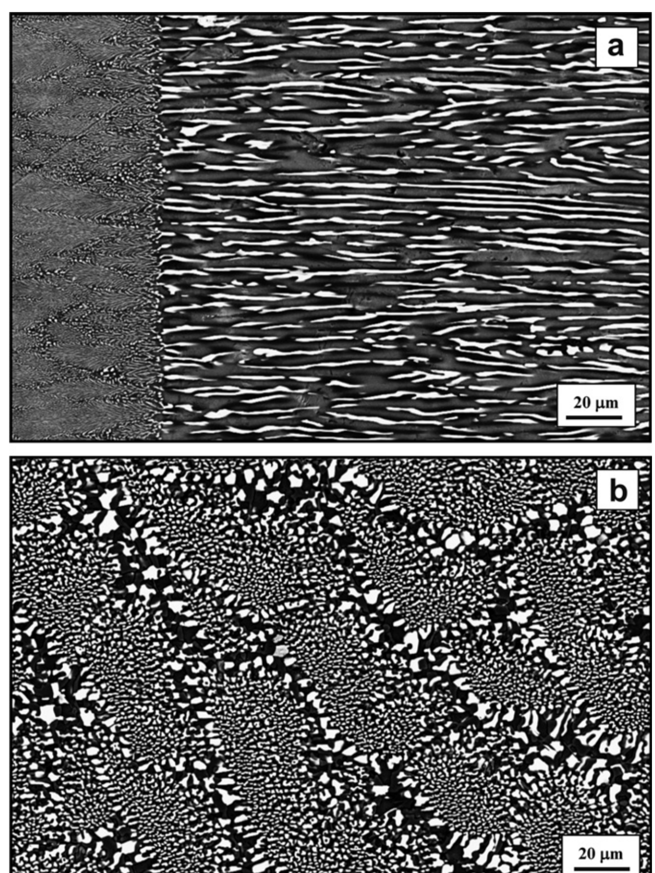

Fig. 1. Typical SEM images of the growth morphologies of directionally solidified Al–Cu–Ag eutectic alloy, (a) Longitudinal section (b) Transverse section (G = 8.79 K/mm, V = 8.30 μm/s).