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Effect of silicon content on microstructure, mechanical and electrical properties of the directionally solidified Al–based quaternary alloys

Emin Çadırlı [a, *], Uğur Büyük [b], Sevda Engin [c], Hasan Kaya [b]

[a] Omer Halisdemir University, Faculty of Arts and Sciences, Department of Physics, Niğde, Turkey
[b] Erciyes University, Faculty of Education, Department of Science Education, Kayseri, Turkey
[c] Dumlupınar University, Faculty of Technology, Department of Energy Systems Engineering, Kütahya, Turkey

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ABSTRACT

Effect of silicon content on the microstructure (lamellar and flake), mechanical (microhardness, ultimate tensile strength) and electrical resistivity properties of Al–Cu–Fe–Si quaternary alloys has been investigated. Al–26Cu–0.5Fe–xSi (x = 6.5, 8, 10, 12 and 14 wt %) were prepared using metals of 99.99% high purity in the vacuum atmosphere. These alloys were directionally solidified under constant temperature gradient (8.50 K/mm) and growth rate (8.25 μm/s) by using a Bridgman–type directional solidification furnace. Eutectic spacing, microhardness, ultimate tensile strength and electrical resistivity were expressed as functions of composition. The dependency of the eutectic spacing, microhardness, tensile strength and electrical resistivity on the composition (Si content) were determined. According to experimental results, the microhardness, ultimate tensile strength and electrical resistivity of the solidified samples increase with increasing the Si content, but decrease eutectic spacing. Variation of electrical resistivity with the temperature in the range of 300–650 K for studied alloys was also measured by using a standard d.c. four–point probe technique.

1. Introduction

Al–Cu–Si–Mg and Al–Cu–Fe–Si alloys are the most widely used cast aluminium alloys for a wide range of applications, especially in the transport field, due to their excellent castabiliy, good corrosion resistance, high strength-to-weight ratio. In particular, the automotive industry has taken a giant step forward in reducing the weight of cars by replacing cast and malleable iron automotive components with aluminium casting (for example for cylinders heads, engines blocks, pistons, brake calipers), providing affordable improvements in fuel efficiency. However, the mechanical properties of aluminium alloy cast components are strongly dependent on the local microstructure, which is directly related to the chemical composition and the solidification conditions imposed by the casting system (mould, cores, cooling circuit, coolers, etc.) [1–3].

Multiphase solidification in multicomponent alloys is pertinent to many commercial materials and industrial processes, while it is also possible to raise challenging questions from a fundamental point of view. Within the past few years, research activities dedicated to multiphase solidification of ternary and multicomponent alloys have experienced considerable amplification [4–6]. Multiphase solidification of multicomponent materials attracts pronounced academic interest as well. The study of the solidification behavior of multicomponent and multiphase systems is an important question in understanding the different properties of these materials.

The aim of the present work was experimentally investigate effect of Si content (C_o) on the microstructure (lamellar spacing λ_L, flake spacing λ_F) microhardness (HV), ultimate tensile strength (σ_t) and electrical resistivity (ρ) of the directionally solidified Al–26Cu–0.5Fe–xSi alloys and also find out the influence of temperature on the electrical resistivity.

2. Experimental procedure

2.1. Sample preparation and directional solidification

Using the vacuum melting and hot filling furnaces [7], Al–26Cu–0.5Fe–xSi (x = 6.5, 8, 10, 12 and 14 wt %) alloys have been prepared under vacuum atmosphere by using 99.99% purity metals. After allowing time for melt homogenization, the molten alloy was

* Corresponding author.
E-mail address: ecadirli@gmail.com (E. Çadırlı).

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poured into graphite crucibles (20 cm in length 0.4 cm inner diameter and 0.63 cm outer diameter) 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.

Then, each sample was positioned in a Bridgman–type furnace in a graphite cylinder (30 cm in length 1 cm inner diameter and 4 cm outer diameter). The block diagram of the experimental setup and details of the Bridgman–type directional solidification furnace are shown in Fig. 1. In the experimental technique, the sample was heated about 100 K above the melting temperature and solidification of the samples was carried out with different compositions at constant temperature gradient (8.50 K/mm) and growth rate (8.25 μm/s) in the Bridgman–type growth apparatus. After 10–12 cm steady state growth, the samples were quenched by rapidly pulling it down into the water reservoir.

The temperature of water in the reservoir was kept at 283 K with accuracy of ±0.1 K by using a digital heating/refrigerating circulating bath (model 9102; Poly Science) to obtain a well quenched solid–liquid interface in the present work. The sample temperature was also controlled to accuracy of ±0.1 K using a *Eurotherm 2604* type controller. In order to see the effect Si content on the λ, *HV*, σ_t and ρ, directional solidification experiments were repeated for each compositions of Al–26Cu–0.5Fe–xSi alloy (x = 6.5, 8, 10, 12 and 14 wt %).

2.2. Measurement of temperature gradient and growth rate

The temperatures in the sample were measured by three K-type 0.25 mm in diameter insulated thermocouples which were fixed within the sample with spacing of 10 mm. In this study, a 1.2 mm OD × 0.8 mm ID alumina tube was used to insulate the thermocouples from the melt. All the thermocouple's ends were then connected the measurement unit consists of data-logger and computer. The cooling rates were recorded with a data-logger via computer during the growth. When the solid/liquid interface was at the second thermocouple, the temperature difference between the first and second thermocouples (ΔT) was read from data-logger record. The temperature gradient ($G = \Delta T/\Delta X$) in the liquid phase for each sample was determined by using the measured value of ΔT and ΔX.

The growth rate (V) was calculated with two different methods. In the first method, the values of growth rate were calculated from the measurements of the time taken for the solid–liquid interface to pass the thermocouples separated by a known distance. In the second method, the total solidification time and solidification distance (on the longitudinal section of the polished sample) were measured. The ratios of the distances to the times were measured to obtain the growth rates and these were similar for both methods.

2.3. Metallographic examination

The quenched sample was removed from the graphite crucible and 1 cm in lengths from the top and bottom were cropped off and discarded. The rest of the sample ground to observe the quenched solid-liquid interface (longitudinal section) was separated from the sample. This part was ground, polished and etched to reveal the quenched interface. Then, the longitudinal and transverse sections of sample were mounted in a cold-setting epoxy-resin. The longitudinal and transverse sections were wet ground down to grit 4000 and mechanically polished using 6, 3, 1 and 1/4 μm diamond paste (ASTM Standard E3). After the polishing process, the microstructure was revealed by chemical etching process (5 mL nitric acid, 3 mL hydrochloric acid, 2 mL hydrofluoric acid and 190 mL H_2O for a 5 s at the room temperature). The micrographs of the samples were taken with a *Nikon Eclipse MA 100 optical microscope* using different objectives. The eutectic spacings (λ_L and λ_F) were measured with

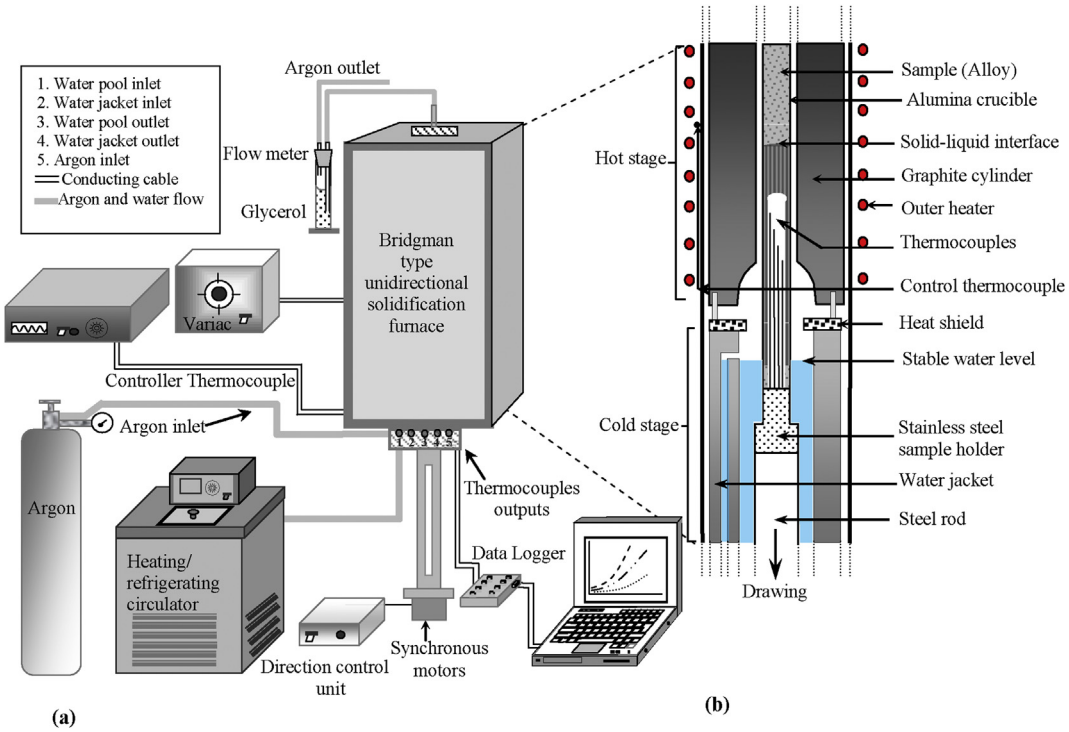

Fig. 1. (a) Block diagram of the experimental setup, (b) The details of the Bridgman type directional solidification furnace.