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Effect of rotating magnetic field on the microstructures and physical properties of Al–Cu–Co ternary eutectic alloy

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ABSTRACT

The solidification microstructures and physical properties of Al–Cu–Co ternary eutectic alloy were studied in a rotating magnetic field (*RMF*). The *RMF*-driven flow was the key factor causing grain refinement and uniformity of solidification microstructures. The temperature distributions during solidification were recorded under the conditions with and without *RMF*. The dependence of the eutectic spacing (λ), the microhardness (*HV*), tensile strength (σ_t) and compressive strength (σ_c) on the RMF were investigated. Electrical resistivity (ρ) measurements of the studied alloy were also performed by using the four-point probe method and the dependence of the resistivity on temperature and *RMF* were determined. Besides, the enthalpy (ΔH) and the specific heat (C_p) values were determined by the differential scanning calorimeter (DSC) analysis. Important changes were found in the microstructure, microhardness, tensile strength, compressive strength and electrical resistivity of the studied alloy with increasing *RMF*.

1. Introduction

Aluminum–based alloys have been widely utilized in many applications such as construction, aerospace, and automotive applications due to their unique combination of mechanical properties. The main exceptional property of these alloys is their light weight, and along with specific strength and toughness, it makes aluminum alloys good candidate materials for many applications [1]. The final properties of a cast aluminum alloy depend on the final microstructure which might be impaired by defects that develop during solidification. Therefore, the effect of the external conditions on the solidification microstructure of Al-based alloys has been widely investigated [2–4].

During the last two decades, some researchers [5–8] have focused on Al–Cu–Co alloys. These alloys are technologically important alloys. Because, In quasicrystals (QC) of Al–Co–Cu alloy, even at about 55% of the melting temperature, large amount of vacancies occurs because, apart from thermal vacancies, there occur structural vacancies, the density of which is significantly greater than those in the crystal alloys [5]. The presence of vacancies may significantly influence the movement of dislocations in quasicrystals. It has been reported that QC phase possess high hardness, low frictional properties, high wear resistance and good bonding properties with a metal substrate [6–8]. Therefore, QC materials appear to be a potential candidate for application as an efficient coating material on a soft substrate.

The adjustment of fine grain morphologies has been approved to be a crucial issue for improving characteristics and properties of aluminum-based alloys. The application of magnetic fields [9–15] in the solidification process is one effective method to improve the microstructure and physical performance of alloys. It is well-known that the flow in a solidifying melt can significantly affect the evolution of the microstructure in metallic alloys and hence the mechanical properties of the material. The control of melt convection is therefore inevitable to achieve high-quality castings. External magnetic fields offer an efficient way for a contactless influence on the melt flow in solidifying melts without contamination. The electromagnetic stirring has various advantages, such

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as refining the solidification structure, improving surface quality of the ingot as well as reducing the macrosegregation during the solidification process of the liquid materials [16–22]. In general, flow control by magnetic fields became an important issue in many applications in the fields of metallurgy, crystal growth or electrochemistry for achieving both a good product quality and efficient production processes [23]. Within this study the convection is driven using a *RMF*. The intensity of the flow can easily be controlled by variations of the magnetic field strength and frequency [18]. Results of previous investigations indicate that the *RMF* has significant effects on the solidification process, such as eliminating gravity induced macrosegregation, refining microstructures and improving material performances [24,25]. These findings show a potential application of the *RMF* in industry [26]. However, the detailed mechanisms of the effect of *RMF*-driven flows during the melt solidification process are still unclear. More experimental and theoretical investigations are necessary.

In this work, the Al—Cu—Co ternary eutectic alloy is chosen to investigate the effect of the *RMF* on solidification microstructures, which show serious macrosegregation under common solidification conditions, and some related physical properties (microhardness, tensile strength, compressive strength and electrical resistivity). This work has been performed in four steps. In the first step, Al—Cu—Co ternary eutectic alloys were directionally solidified under the conditions with and without *RMF*. In the second step, effects of the *RMF* on the eutectic spacings (λ_L, λ_F), microhardness, tensile strength and compressive strength of the studied alloy were characterized by linear regression analysis. In the third step, the temperature dependence of the electrical resistivity of the Al—Cu—Co alloy solidified under different *RMF's* was measured by the d.c. four-point probe method [27]. Finally, the enthalpy of fusion and the specific heat change of the studied alloy were determined from heating curve during the transformation from eutectic solid to eutectic liquid by means of differential scanning calorimeter (DSC).

2. Experimental procedure

2.1. Solidification apparatus and procedure

The Al-%23.9 Cu-%1.2 Co (wt.%) ternary eutectic alloy was prepared with Al (purity is 99.95%), Cu (purity is 99.95%) and Co (purity is 99.99%). The Al—Cu—Co ternary eutectic samples were solidified directionally from the bottom in a cylindrical stainless steel mold using the experimental set-up shown in Fig. 1. The inner wall of the mold was coated with boron nitride (BN). The mold has an internal diameter of 50 mm and a height of 100 mm. The thickness of the mold bottom is 6 mm. Radial heat losses have been minimized by thermal insulation of the side-walls of the mold. Heat losses across the melt-air surface were also found to be negligible. The filling height for each charge was 60 mm. At the top, the mold was closed by a stainless steel lid. The samples were melted inside the steel mold using an electrical furnace. After a holding time of about 1.5 h at a temperature of 640 °C, the mold was taken from the electrical furnace and immediately positioned at a water-cooled copper chill. Water was circulated through this cooling jacket keeping the copper plate during the solidification at a constant temperature of about 20 °C and thus inducing an axial heat transfer from the mold. Special care was taken to achieve a well-defined heat transfer coefficient between the solidifying sample and the cooling system. For that purpose, a thin layer of the eutectic alloy GaInSn was spread on the surface of the copper chill. The use of such a bridging liquid guarantees an optimal heat contact between the copper plate and the stainless steel mold [18]. During the experiment argon gas was flowing through the volume

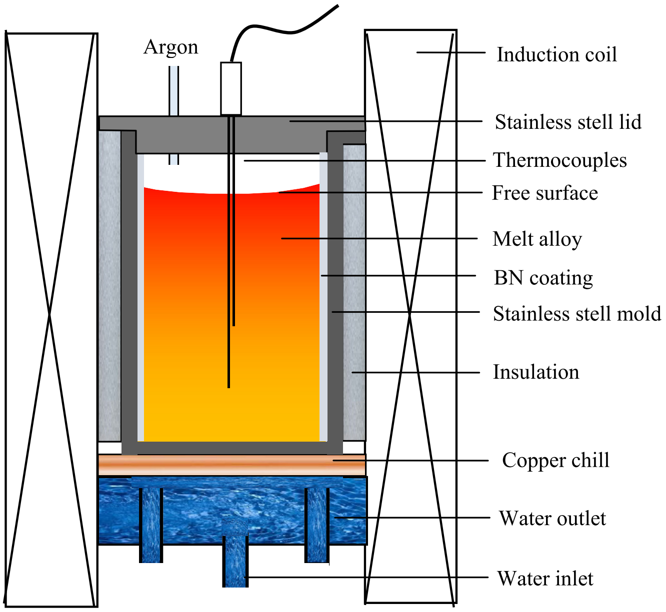

Fig. 1. Schematic illustration of the experimental setup.

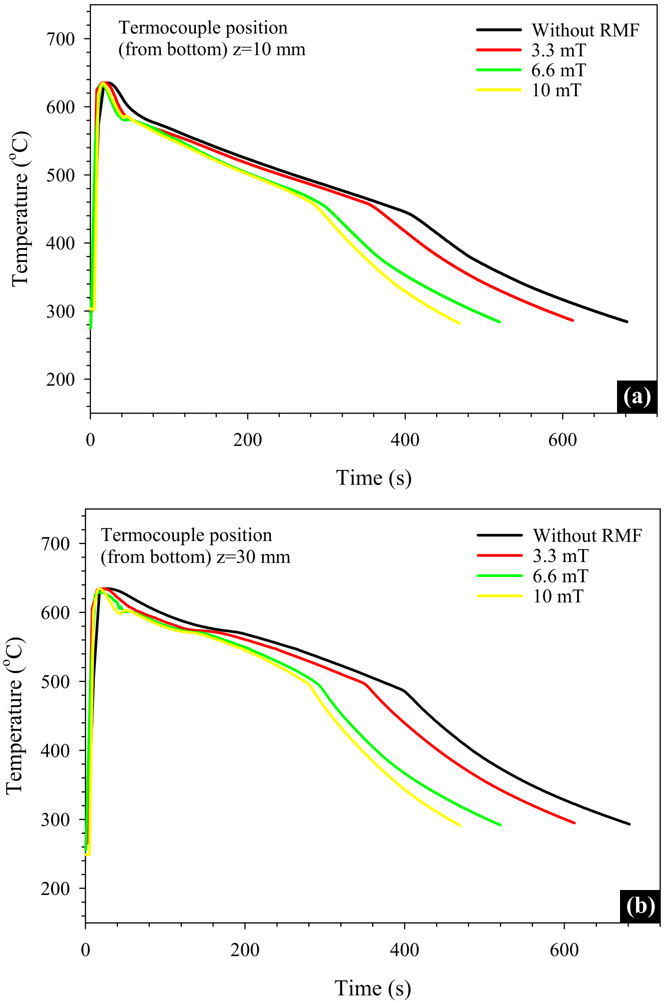

Fig. 2. Cooling curves recorded during solidification at different thermocouple position (a) z = 10 mm (b) z = 30 mm.