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Influence of thermomechanical treatment on microstructure and properties of electroslag remelted Cu–Cr–Zr alloy

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ABSTRACT

Effect of thermomechanical treatment (TMT) on aging behavior of electroslag remelted Cu–Cr–Zr alloy was investigated. The relationship between microstructure, mechanical and electrical properties was clarified using hardness, tensile and electrical conductivity testing methods and optical and scanning electron microscopy techniques. The results showed that an appropriate processing and aging treatment may improve the properties of the alloy due to the formation of fine, dispersive and coherent precipitates within the matrix. Indeed, the optimum condition for electrical conductivity and mechanical properties was obtained after cold working of 40% followed by aging at 500 °C for 150 min.

1. Introduction

Different types of high electrical conductivity alloys have been developed in research centers for a variety of applications. Ehsanian et al. [1] reported Cu–Cr–Zr alloys as an excellent candidate for getting fine combination of mechanical properties and electrical conductivity. As demonstrated by Li et al. [2], these properties made this alloy a good choice to be applied in lead frame, bullet train, long-distance wire, heat sink material for International Thermonuclear Experimental Reactor (ITER), etc.

Eich et al. [3] concluded smelting and casting in controlled atmospheres like vacuum or a protective high purity noble gas as common methods for producing these alloys. Electroslag remelting (hereinafter, this may be referred to as ESR process) is an attractive process which has been used for producing ingots of metals with high reaction activity, as described by Kelkar et al. [4]. Ahmadi et al. [5] evaluated this process for a stainless steel and concluded that the ingots and materials manufactured this way could possess structures with uniform density and a high degree of homogeneity, no segregation or shrinkage cavities and no undesired impurities or oxide inclusions. Prasad and Rao [6] worked on recycling light scrap of oxygen free high conductivity copper using ESR technique and stated that the same process was used for producing certain copper alloys like Cu–Cr, Cu–P and Cu–Ti from copper scrap. However, less is known about the effect of this process on Cu–Cr–Zr alloys. Jovanovic and Rajkovic [7] stated that the chemical composition and especially processing technology of Cu–Cr–Zr alloys were protected by patents or classified documents.

Durashevich et al. [8] reported that appropriate thermomechanical treatment can raise strength and hardness and electrical conductivity of these alloys produced by induction vacuum method. Li et al. [2] concluded that due to very low solubility of Cr and Zr in Cu at room temperature, Cu–Cr–Zr alloys possessed high conductivity after proper aging treatment. Moreover, they claimed that the strengthening mechanism was related to the combined effect of precipitation hardening (Cr and intermetallic compounds of Cu and Zr precipitates), work hardening and texture strengthening. Liu et al. [9] revealed the way solidification rate could affect the initial microstructure and subsequently aging behavior of the alloy.

In the present work, ESR technique was conducted on an ingot of Cu–Cr–Zr alloy prepared using an induction furnace and effects of this process on microstructure and precipitation behavior of the alloy was studied. The purpose of this paper was to design ESR method to produce Cu–Cr–Zr alloy in a large scale and obtain the proposed mechanical and electrical properties according to the standard [10] through casting and subsequent deformation and aging processes.

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2. Experimental procedure

Oxygen free high conductivity copper (OFHC), Cu–4.8%Cr and Cu–32%Zr (KBM AFFLIPS) master alloys were used for alloy preparation in an induction furnace (AEG, medium frequency, capacity 120 kg). Oxygen free copper was produced using scrap copper, coal and CaB_6 (Dalian Co.) as deoxidizer in an induction furnace. Cu–4.8%Cr master alloy was produced using oxygen free copper and electrolytic chromium in a similar process. Surface of melt was covered with coal and small amounts of magnesium (200 g) to avoid oxygen absorption from the air. Then, the melt at 1300 °C was poured into a cast mold with graphite liner. Diameter and height of the mold were 110 and 750 mm, respectively. The solidified ingot weighting about 85 kg was refined by ESR method using a water-cooling mold and slag with composition of 40%CaF_2–30%NaF–20%Na_3AlF_6–6.7%ZrO_2–3.3%SiO_2 to eliminate casting defects and unwanted elements like P, S and Mg [11]. Schematic of ESR furnace used in this research is given in Fig. 1. The furnace was operated at 40 V and 4500 A whereas the melt temperature was about 1600 °C. Cu–0.65Cr–0.147Zr alloy was obtained as a result of melting and refining process.

The produced ingot (610 mm length, 130 mm diameter) was extruded at 950 °C with the reduction of about 400% using a 1250 ton machine, solution annealed at the same temperature in an electrical furnace (Azar furnace 1250) and water quenched [12]. The samples of this alloy were then 20%, 40% and 60% cold rolled. Afterward, the cold rolled samples were aged at 500 °C for 60, 90, 120, 150 and 180 min in the same furnace [7–9,13,14].

For optical microscopy studies, the selected samples of the produced alloy before and after aging were polished and etched in a solution of HCl, $FeCl_3$ and alcohol. Scanning electron microscopy (SEM) investigations, as well as energy dispersive X-ray spectroscopy (EDS) studies were done using a MIRA//TESCAN scanning electron microscope operating at 15 kV.

Hardness of the samples was tested in an Instron Wolpert GmbH testing unit using the HB10 (HBW 2.5/62.5) method (according to ASTM: E10-12 standard test) after being grounded and polished. The selected samples of the alloy were cold worked, aged and then machined to a diameter of about 6 mm and gage length of about 30 mm (according to the standard test method [15]) and employed for the uniaxial tensile test using an HEKERT machine.

In order to find the best aging condition, electrical conductivity of the samples was measured and expressed in %IACS (International Annealed Copper Standard) using SIGMASCOPE® SMP10 Fischer conductomer after polishing. In both mechanical tests as well as electrical test three measurements were done for each sample and the average was reported.

3. Experimental results

Macro and microstructure of the alloy after ESR process are shown in Fig. 2a and b. As seen in these figures, the microstructure mostly consisted of fine and columnar grains with few amounts of small precipitates in the matrix and at the grain boundaries. This microstructure was the result of higher solidification rate in ESR technique.

Fig. 3a–d illustrates X-ray maps of the microstructure of the produced alloy. It can be observed that Zr dispersed rather uniformly throughout the matrix while Cr concentrated on special locations and formed fine metallic precipitates. The high temperature of the molten slag could be the reason for this behavior.

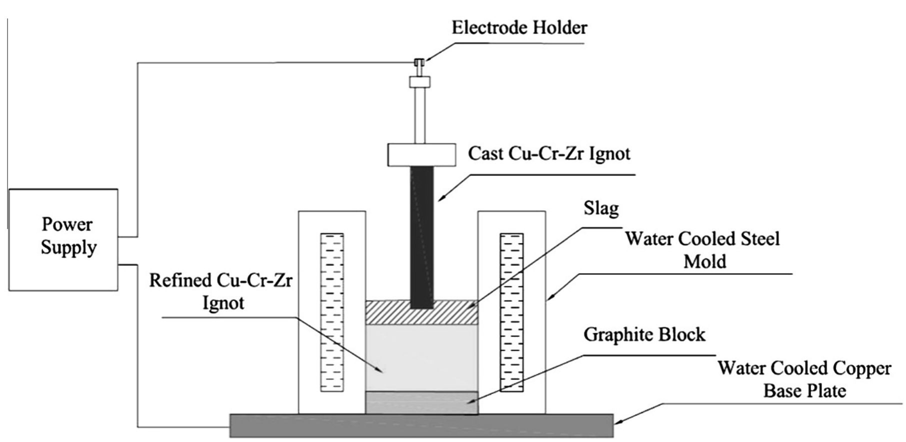

Fig. 1. Schematic of ESR furnace used in this research.

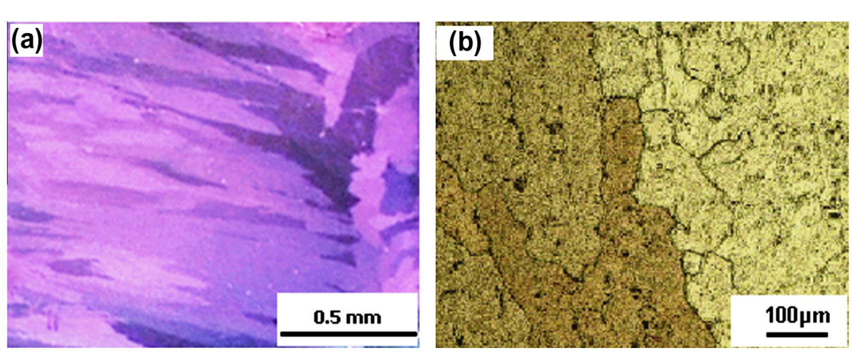

Fig. 2. (a) Macrostructure and (b) microstructure of the alloy after ESR process.