Materials Science and Engineering A 498 (2008) 225–230

Contents lists available at ScienceDirect

Materials Science and Engineering A

journal homepage: www.elsevier.com/locate/msea

Microstructure and properties of Cu–1.0Cr–0.2Zr–0.03Fe alloy

H.T. Zhou [a,*], J.W. Zhong [a], X. Zhou [b], Z.K. Zhao [a], Q.B. Li [a]

[a] School of Materials Science and Engineering, Central South University, Changsha 410083, PR China
[b] School of Materials Science and Chemical Engineering, JiangXi University of Science & Technology, Ganzhou 341000, PR China

ARTICLE INFO

Article history:
Received 26 May 2008
Received in revised form 27 July 2008
Accepted 28 July 2008

Keywords:
Cu–1.0Cr–0.2Zr–0.03Fe alloy
Thermo-mechanical
Microstructure
Properties

ABSTRACT

The effects of thermo-mechanical processing on the microstructure and properties of Cu–1.0Cr–0.2Zr-0.03Fe alloy are studied. The results show that the alloy has a strong aging strengthening effect, and cold rolling prior to aging can significantly increase the strength of the alloy. The optimum thermo-mechanical processing is proved to be solution treatment at 960 °C for 2 h followed by 60% cold rolling and aged at 450 °C for 4 h, under which the tensile strength 527 MPa, yield strength 487 MPa and electrical conductivity 82% IACS can be obtained. The high strength of the alloy can be explained by the substructure strengthening due to cold rolling and precipitation strengthening of the α-Fe phase and fine chromium-rich phase as well as coherent $CrCu_2Zr$ particles transformed from the fcc initial precipitates.

1. Introduction

Cu–Cr–Zr alloy and some of its modifications are being used in a number of engineering applications such as trolley wire, lead frames and electrode of resistance welding due to their high strength, high electrical and thermal conductivities as well as outstanding tribological behavior [1–4]. Thermo-mechanical treatment is an effective method for obtaining high strength, high electrical conductivity of Cu–Cr–Zr alloy. Cold working is carried out between the solution treatment and aging to assist in the aging hardening by introducing high density of dislocations. The excellent strength is attributed to precipitation and particle-dispersion strengthening mechanisms, whereas the high electrical conductivity is due to the very low solubility of Cr and Zr in Cu matrix at room temperature.

In order to control the microstructure and improve the properties of Cu–Cr–Zr alloy, it is of great value to optimize the aging process and identify the composition of the precipitates. In recent years, extensive literature is available on the microstructure [5–7], phase precipitations [8–11], physical [12,13] and mechanical [14] properties of the Cu–Cr–Zr alloy. Huang and Ma [15] found the $Cu_{51}Zr_{14}$ existed in the matrix. Tang et al. [5] have identified the precipitates in Cu–Cr–Zr–Mg alloy to be the Cu_4Zr and the $CrCu_2$(Zr,Mg). Liu et al. [16] also found the $CrCu_2$(Zr,Mg) and the Cu_4Zr at the grain boundary in the Cu–Cr–Zr–Mg alloy by rapid solidification. Zeng and Hamalainen [17] showed that three phases Cr, Cu_5Zr and Cu should exist in the system but no Cu_2Zr as postulated in many earlier investigations. Correia et al. [18] concluded that in the Cu–Cr–Zr alloys strengthening was brought about by tiny coherent chromium particles and Cu_5Zr phase caused only a small hardening effect. Mu et al. [19] found chromium-rich phase, zirconium-rich phase and Hesuler phase in the Cu–Cr–Zr–Mg–RE alloy. However, there has been no unanimous agreement on the phase transformation and precipitates of this alloy.

In this work, a Cu–1.0Cr–0.2Zr alloy was investigated in order to obtain an excellent combination of physical and mechanical properties by adding small amount of iron (Fe) and optimizing heat treatment processing. In addition, the early stage of precipitation in aged alloy and the strengthening precipitates of peak aged Cu–Cr–Zr alloy were also studied.

2. Experimental procedure

The Cu–1.0 wt.%Cr–0.2 wt.%Zr–0.03 wt.%Fe alloy was produced in a vacuum induction furnace with electrolytic copper, Cu–Fe master alloy, pure chromium and pure zirconium as charge materials. High purity argon was used as a protective atmosphere in the induction unit. The composition analysis was carried out on the solution-treated specimen. Spark emission spectroscopy (SES) gave the compositions as in Table 1.

The ingot was homogenized and then hot rolled to a thickness of 5 mm, followed by solution treated at 960 °C for 2 h and then water quenched. The quenched plate was cold-rolled to a thickness of 2 mm and cut into small pieces for aging treatment. These pieces were aged from 430 to 530 °C for various periods prior to air cooling.

* Corresponding author. Tel.: +86 731 8830257; fax: +86 731 8830257.
E-mail address: htzhou62@yahoo.com.cn (H.T. Zhou).

0921-5093/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.msea.2008.07.061

Table 1
Alloy compositions analysis

Nominal composition (wt.%)	Designation	Analyzed composition (wt.%)		
		Cr (%)	Zr (%)	Fe (%)
Cu–1.0 wt.%Cr–0.2 wt.%Zr–0.03 wt.%Fe	Cu1.0Cr0.2Zr0.03Fe	0.81	0.23	0.033

Tensile tests were performed on the CSS-44100 tensile machine. The electrical conductivity was determined by measuring the resistance of specimens in 100 mm length using QJ19 Double-Arm Electrical Bridge technique.

The microstructure examination was carried out by a Ploymar-Met optical microscope using standard metallography technique. For HRTEM study, discs of 3 mm in diameter were punched out of aged pieces, ground to about 60–80 μm, and then double jet thinned at room temperature with electrolyte of HNO_3:CH_2OH = 1:3. A JEM 3001-HRTEM equipped with energy dispersive X-ray spectroscopy was used to analyze the precipitates. The accelerating voltage is 300 kV.

3. Results and discussion

3.1. The strength and electrical conductivity

According to previous investigations [5,20], aging temperature has a distinct effect on the strength and conductivity of the Cu–Cr–Zr alloy. Aging at low temperature only results in the formation of Guinier–Preston zones. When the aging treatment was conducted at high temperatures, overaging occurred and the precipitates coarsened and lost coherency with the copper matrix. Fig. 1 shows the effect of aging temperature on the strength and conductivity of the alloy for an aging time of 4 h. It is evident that the value of the strength for the alloy reached the peak after an aging treatment at 450 °C for 4 h and overaging occurred at higher temperatures. Its highest tensile strength is about 527 MPa. On the other hand, with the increase of aging temperature, higher kinetics of precipitating makes the velocity of precipitating greater from the supersaturated matrix, and therefore the electrical conductivity increase. When the aging temperature is over 500 °C, overaging led to the growth of precipitates, which did little harm to the electrical conductivity of the alloy.

Fig. 2 shows the strength and conductivity varying with the aging time of the alloy. It can be observed that the electrical conductivity increases rapidly at the early stage of aging, because the high density of the lattice defects facilitated the precipitating out of the supersaturated matrix. With the increase of the aging time, the velocity of the precipitation becomes slow, and the ratio of the conductivity increase becomes less. The longer time brings about more precipitates. The growth of precipitates reduces the contents of solute atom in matrix and results in a continuous increase in electrical conductivity during the aging. On the other hand, overaging occurs when the aging time longer than 4 h, which reduces the tensile strength of the alloy.

Fig. 3 shows the effect of prior cold rolling on the properties of the alloy. Cold rolling prior to aging is an effective strengthening method with small bad effect on conductivity. The dislocations resulting from cold rolling act as diffusion paths for solute atoms and provide nucleation size for precipitation during aging treatment and finally result in the precipitation hardening effect. In addition, dislocations pinned by precipitates also play role in the strengthening. The electrical conductivity decreases slightly as the reduction of cold rolling increases. This is because the high density of dislocations causes the scattering of the electrons more.

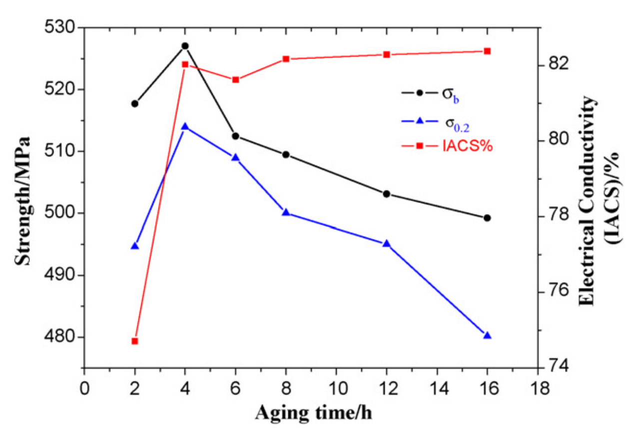

Fig. 2. Variations of strength and electrical conductivity with aging time at 450 °C.

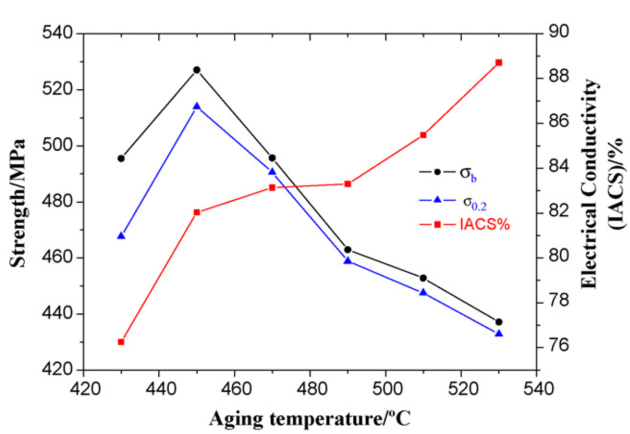

Fig. 1. Variations of strength and electrical conductivity with aging temperature at 4 h.

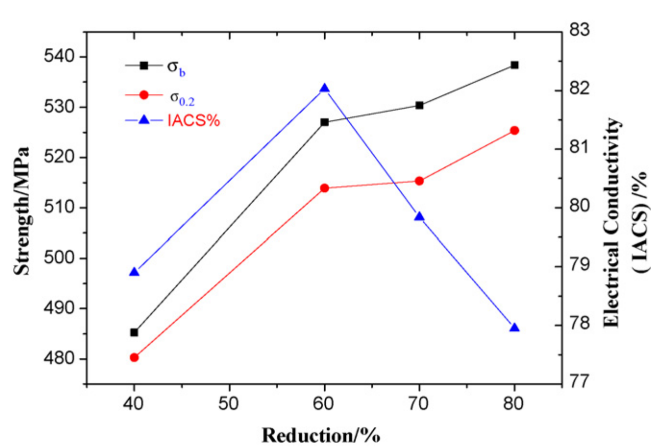

Fig. 3. Effect of prior cold rolling on the properties of the alloy at 450 °C for 4 h.