



# A novel method to improve the hardness and electrical conductivity of Cu–Cr–Al alloy



Yuhui Wang<sup>a, b, \*</sup>, Pengda Xing<sup>b</sup>, Peng Wang<sup>a</sup>, Jianhua Liu<sup>a</sup>

<sup>a</sup> State Key Laboratory of Metastable Materials Science and Technology, Yanshan University, Qinhuangdao 066004, China

<sup>b</sup> National Engineering Research Center for Equipment and Technology of Cold Strip Rolling, College of Mechanical Engineering, Yanshan University, Qinhuangdao 066004, China

## ARTICLE INFO

### Article history:

Received 16 August 2015

Received in revised form

2 October 2015

Accepted 3 October 2015

Available online 8 October 2015

### Keywords:

Cu–Cr–Al alloy

High pressure aging treatment

Microhardness

Microstructure

Electrical conductivity

Precipitation strengthen

## ABSTRACT

As a novel method, high pressure aging treatment dramatically improves the hardness and electrical conductivity of Cu<sub>51.76</sub>Cr<sub>47.03</sub>Al<sub>1.21</sub> alloy with regards to the corresponding values obtained by annealing the sample under a pressure of 1 bar.

© 2015 Elsevier B.V. All rights reserved.

## 1. Introduction

The Cu–Cr alloys are used as resistance welding electrode and vacuum switch contact for their high voltage withstanding stress, good electrical conductivity and resistance to surface welding [1–3]. However, their poor compactness affects alloy performance which is a common problem [4]. Plastic deformation combined with solid solution treatment and aging is one of the effective methods to improve the performance of Cu–Cr alloy [5]. High pressure during heat treatment was reported to further optimize the microstructure and in turn the mechanical and electrical properties [6–9]. According to the Ma's investigation [8], high pressure of 4 GPa during heat treat increases the hardness and the compressive yield strength and reduces the electrical conductivity of CuCrAl alloy. The enhancement of lattice distortion and the dislocation density benefits for the precipitation of Cr particles during aging [8]. On the other hand, high pressure will slow down the element diffusion, which may alter the precipitation process

and in turn influence the final performance. It is thus expected that high pressure during aging may lead to better improvement of electrical and mechanical property than high pressure heat treatment followed by aging at normal pressure. This is thus the purpose of the present investigation, aiming to study on the influence of high pressure aging on the mechanical property and the electric conductivity of a Cu<sub>51.76</sub>Cr<sub>47.03</sub>Al<sub>1.21</sub> (wt.%) alloy. It has been turned out that high pressure aging can be a novel method to fabricate high performance metallic materials.

## 2. Experiment

Ingots with the composition of Cu<sub>51.76</sub>Cr<sub>47.03</sub>Al<sub>1.21</sub> were prepared using infiltration method. Oxygen-free copper powder (average particle diameter of 50 μm, 99.97% purity) of 5 wt% were firstly mixed with 95 wt% chromium powder (average particle diameter of 75 μm, 99.9% purity). Then the mixture was sintered at 1090 °C in a vacuum hot extrusion furnace in order to get a Cr skeleton ingot with a small percentage of copper acting as binder. The ingot was subsequently immersed into molten Cu and Al (97.4 wt% Cu and 2.6 wt% Al) at 1200 °C for 2 h, to allow the diffusion of copper and Al into Cr skeleton. The final product contains 51.76 wt% Cu, 47.03 wt% Cr and 1.21 wt%Al, i.e.

\* Corresponding author. National Engineering Research Center for Equipment and Technology of Cold Strip Rolling, College of Mechanical Engineering, Yanshan University, Qinhuangdao 066004, China.

E-mail address: [yhwang@ysu.edu.cn](mailto:yhwang@ysu.edu.cn) (Y. Wang).

Cu51.76Cr47.03Al1.21 alloy. Thereafter, the ingot was put into a KLX-12B box-type resistance furnace and solution-treated at 930 °C for 30 min. After solid solution treatment, the cylindrical samples with  $\Phi 10 \text{ mm} \times 10 \text{ mm}$  dimension were aged at 400–550 °C for 30–180 min under high (4 GPa) and atmospheric pressure, respectively. In order to protect the samples against oxidation during high pressure aging, the Cu–Cr–Al alloy samples were sealed in graphite sleeve which is isolated from the samples by BN powder. The graphite sleeve together with samples was then embedded in pyrophyllite mould. High pressure aging treatment was carried out in a CS-IB type six-anvil high-pressure equipment with a pyrophyllite used as pressure transmitting medium. Then, the samples were cooled down to room temperature. It is worth mentioning that high pressure aging was performed in CS-IB type six-anvil high-pressure equipment while the atmospheric aging was done in the KL-12D box type electric resistance furnace. THV-5 Vickers hardness tester and WD-Z eddy current conductivity meter were used to determine hardness and electrical conductivity of the samples. The microstructures of the studied alloy were observed using S-3400N scanning electron microscope (SEM) and JEOL-2010 transmission electron microscope (TEM).

### 3. Experimental results and discussion

#### 3.1. Hardness

Fig. 1a shows the change of hardness with respect to aging temperature (400–550 °C) for 60 min. It is evident that the hardness of the investigated alloy under high-pressure aging treatment is found to be higher than the sample aged in atmosphere. In

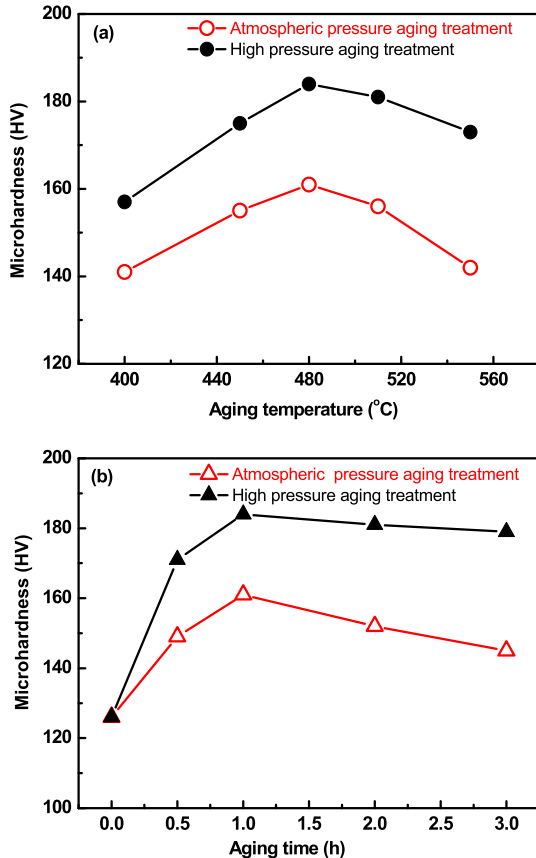


Fig. 1. Hardness curves of the investigated alloy varying with aging temperature and time. (a) aging temperature; (b) aging time.

addition, the hardness value of both cases, high pressure aging and atmospheric aging, rise up to a certain value and then starts to decrease with increasing the aging temperature. It should be noted that the peak hardness was obtained at 480 °C. Fig. 1b shows the variation of hardness with respect to aging time at aging temperature of 480 °C. Similar to aging temperature effect, hardness of the studied alloy increases up to certain aging time (60 min) and then decreases. It is worth mentioning that hardness of the sample aged under high pressure drops slowly than the sample aged in atmosphere. Further, the hardness value of the sample processed at high pressure aging treatment is found to be 184 HV at 480 °C for 60 min that shows an increment of 53.33% and 14.29% than that of the cast alloy (120 HV) and that of the alloy after atmospheric aging treatment (161 HV), respectively.

Back-scattered electron (BSE) images of the investigated alloy after high pressure aging treatment represents that micro holes in Cu matrix are clearly reduced than as-cast condition/its counterpart (after atmospheric aging), thus the matrix compactness increases (Fig. 2a and 2c). On the other hand, TEM observation shows that the size of dispersedly distributed Cr granules is found to be smaller (1.7 nm) after aging at high pressure than the sample aged in atmosphere (2.3 nm) (Fig. 2b and d). Due to the high pressure, internal micro-porosities form bridges resulting in reduction the number of micro-holes and increase in alloy compactness. In addition, high pressure is responsible for generating high internal strain in the studied alloy.

The aging effect is mainly affected by the size and distribution of precipitation. Precipitation strengthening can be explained from the following equation [12]:

$$\tau = 2Gb/\lambda \quad (1)$$

where,  $\tau$  indicates the shear stress,  $G$  is the shear modulus,  $b$  is for Burger vector and  $\lambda$  is the spacing for the intra crystalline particles. As  $G$  and  $b$  are constant for a material, thus shear stress ( $\tau$ ) would be inversely proportional to particles spacing ( $\lambda$ ). It means the smaller the particle spacing is, the greater the shear stress will be. In our case, as discussed the number of dispersed Cr particles would be more in high pressure aging resulting in smaller inter-particles spacing. As there is smaller spacing among Cr particles, the shear stress increases and dislocations move around the second phase particles. Hence, significantly higher strengthening effect is obtained. Moreover, density of the samples processed under high pressure aging treatment increased which effectively improve the compressive deformation ability and increases hardness. Therefore, the hardness value of the investigated alloy processed under high pressure aging treatment appears to be higher than the alloy processed under atmospheric aging treatment. It should be noted that the precipitated Cr particles grew up when the aging temperature was higher than 480 °C or aging time was more than 60 min. However, it destroys the coherency between the Cr particles and matrix. In addition, the solubility of Cr in Cu matrix is increased with increasing aging temperature. Thus, some of the precipitated Cr particles dissolve into the matrix resulting in the less strengthening effect and the hardness is decreased. However, hardness of the samples processed at high pressure aging treatment is decreased more slowly than its counterpart. This may be due to the growth difficulties of the Cr precipitation at high pressure (4 GPa).

#### 3.2. Electrical conductivity

Fig. 3a shows the electrical conductivity of the investigated alloy at different aging temperatures aged for 60 min. It can be seen that electrical conductivity of the alloy rises at the beginning and then goes down with increasing the temperature for both processing

Download English Version:

<https://daneshyari.com/en/article/1607706>

Download Persian Version:

<https://daneshyari.com/article/1607706>

[Daneshyari.com](https://daneshyari.com)