Effect of Deep Cryogenic Treatment on Electrical Conductivity of Cu-Base Multicomponent Alloy

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Abstract: The electrical conductivity of Cu-base multicomponent alloy before and after deep cryogenic treatment at different situations were measured by conductance instrument, its microstructures were also characterized by optical microscope, and the effect of deep cryogenic treatment on the electrical conductivity of Cu-base multicomponent alloy was studied in this paper. The results show that deep cryogenic treatment can change the electrical conductivity of Cu-base multicomponent alloy, and the electrical conductivity increases with the extension of deep cryogenic treatment time, when deep cryogenic treatment time exceeded 100 min, electrical conductivity increases slightly. However, the higher electrical conductivity can be obtained by aging at 500 °C for 30min after deep cryogenic treatment.

Key words: Cu-base multicomponent alloy, deep cryogenic treatment, electrical conductivity.

1. Introduction

Due to excellent properties in strength, thermal conductivity and electrical conductivity, Cu alloy is widely applied in various fields such as integrated circuit frame, Welding electrodes, and switch contacts of Electrical engineering [1-4]. With the rapid development of technology and modern industry, Cu alloy with higher properties are required. The main methods to improve the performance of Cu alloy are adding alloying elements, improving manufacturing technique, and performing subsequent heat treatment [5-7]. Deep cryogenic treatment, which is a new method applied to metal materials, is helpful to improving properties [8-11]. However, the effects of deep cryogenic treatment on electric conductivity of Cu-base alloy rarely appear to have been researched previously in studies reported in the literature. In this paper, therefore, the influence of deep cryogenic

treatment on the electrical conductivity of a new Cu-base multicomponent alloy was studied, which provides experiment foundation on improving electrical conductivity of the alloy.

2. Experiments

The experimental material was as-cast Cu-base multicomponent alloy, and the composition (mass fraction, %) is 97.89Cu, 0.82Se, 0.71Te, 0.41Al, 0.17Cr. The casting blank were cut into $\Phi 10$ mm $\times$ 5 mm size specimens which were heated to 850 °C in box resistance furnace for 30 min. Then the samples were immersed in liquid nitrogen (-196 °C) immediately, and keep them in liquid nitrogen for 20, 40, 60, 80, 100, 120, 140 and 160 min, respectively. After that, the samples were treated with aging held at different temperature through different time. A WD-Z-type eddy conductance instrument was used to measure the electrical conductivity of the Cu alloy. The microstructure of samples was analyzed by Axiovert200MAT metallographic microscope.

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3. Results and Discussion

3.1 Microstructure

Fig. 1 shows the microstructure of the Cu-base multicomponent alloy before and after deep cryogenic treatment. It can be seen that the microstructure is composed of Cu matrix and irregular particles which were distributed in the Cu matrix, the irregular particles were compounds of Cu and Se(Te). The microstructure of the Cu alloy is slightly refined after deep cryogenic treatment.

3.2 Conductivity

Fig. 2 shows the changing curves between electrical conductivity of the Cu-base multicomponent alloy and the treating time of deep cryogenic treatment. It can be seen that the conductivity reduces from 52.35% IACS before the deep cryogenic treatment to 53.17% IACS held at 850 °C for 20 min and immediately immersed in liquid nitrogen (-196 °C) for 30 min. The conductivity increases with the extension of time, but the conductivity increases slightly when the deep cryogenic treatment was over 100 min.

The deep cryogenic treatment contains two stages, cooling and insulating at a low temperature. Cu alloy is cooled rapidly from 850 °C to liquid nitrogen temperature (-196 °C), which leads to the change of the microstructure. On the one hand, the solid solution atoms in the solidified Cu alloy matrix precipitated too late from Cu solid solution, lattice distortion in Cu solid solution is serious caused, on the other hand, the

Cu lattice contraction due to the rapid changing of temperature, induced a greater internal stress and a large number of dislocations in the material. Besides, deep cryogenic treatment refines the microstructure and increases the number of grain boundaries. This leads to the strong electronic scattering, which result in reducing the conductivity. The solid solubility of solute atoms is low at the low temperature. When the Cu alloy was immersed in liquid nitrogen, the supersaturated atoms precipitated from Cu alloy matrix, and the amount of the precipitates in the matrix increases as time goes on. Although precipitates increases the scattering of free electrons, which lead to decreasing of electrical conductivity, the effect of precipitates on scattering is lower compare with solute atoms in Cu alloy. Furthermore, deep cryogenic treatment for a long time can decrease the density of vacancy defect [12], and reduce the scattering of free electrons induced by vacancy defect. Therefore, the electrical conductivity increases with the time of deep cryogenic treatment extended. It can be seen from the results that the conductivity of alloy after deep cryogenic treatment for 100 min is 58.13% IACS, it has been increased by 8.53% compared with the conductivity of alloy before deep cryogenic treatment.

Fig. 3 shows relation curve between electric conductivity and temperature for the Cu-base multicomponent Alloy by deep cryogenic treatment for 100 min. It can be seen that the alloy electric conductivity increases and then decreases with the aging temperature increasing. The reason is that when

Fig. 1 Microstructure of Cu alloy before and after cryogenic treatment. (a) original and (b) cryogenic treatment (for 100 min).

Fig. 2 Relationship between electrical conductivity of Cu alloy and deep cryogenic treatment time.

Fig. 3 Relationship between electrical conductivity of Cu alloy after cryogenic treatment and aging temperature for 30 min.

the aging temperature is low, atomic diffusivity is weak, and the precipitates rate is slow, when the aging temperature is high, solid solubility of solute atoms in the Cu matrix increase and the saturation reduce, so the amount of the precipitated phase reduces. Thus the best temperature for electric conductivity is 500 °C. Fig. 4 shows the relation curve between electric conductivity and time of Cu-base multicomponent Alloy treated by cryogenic for 100 min. In the early time, the electric conductivity rise quickly with the aging time, when the aging time is 30 min, the alloy electric conductivity rise from 53.17% to 68.42%IACS, increasing by 28.68% than that of the samples without deep cryogenic treatment. After aging over 30 min, the electric conductivity increases a little.

At the early time of aging, the supersaturating is higher, the alloying element precipitate quickly with the form of second phase which making the electric conductivity increase quickly. The precipitated phase increase with the aging process, then the solute concentration of atoms gets balance, and the precipitate rate get slowly, so electric conductivity verge to stable. Noteworthy, the solubility of solute atoms reduce with the temperature decreasing. So after deep cryogenic treatment for a long time, Solute atomic precipitates thoroughly and the electric conductivity rises by a large margin. In fact, the electric conductivity of alloy after deep cryogenic treatment (196 °C) for a long time is less than of the alloy treated by aging at 500 °C after deep cryogenic treatment. The reason is that at lower temperature, solute atoms have low solubility and high super saturation, but the diffusion of the solute atom is very difficult and migration length is short. Thus the precipitated phase become more diffused and the distance of precipitated phase is far less than that of the samples treated by aging at 500 °C after deep cryogenic treatment. The effect of precipitated phase on scattering of free electronic after deep cryogenic treatment is greater than that of aging at 500 °C, which result in the lower electric conductivity of Cu alloy after deep cryogenic treatment than that of the alloy after aging at 500 °C. Moreover, from Ref. [13]:

Se and Te element hardly soluble in Cu, the solubility of Al are greater than its content at room

Fig. 4 Relationship between electrical conductivity of Cu alloy after cryogenic treatment and aging time (at 500 °C).

temperature, the solubility of Cr in the Cu less than 0.03%. We can conclude that Cr is precipitated in Cu alloy during the deep cryogenic treatment process.

4. Conclusions

(1) Deep cryogenic treatment can improve the conductivity of the Cu-base multicomponent alloy, the conductivity increases with the increase of deep cryogenic treatment time. The electrical conductivity of the Cu-base multicomponent alloy treated by aging after deep cryogenic treatment is significantly increased;

(2) The higher electrical conductivity of the Cu-base multicomponent alloy is obtained by aging at 500 °C for 30 min after deep cryogenic treatment. The alloy electric conductivity is 68.42%IACS, increasing by 28.62% than that of the samples before deep cryogenic treatment.

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