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Effect of Ni addition on the microstructures of melt-spun CuCr ribbons

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The microstructures and resistivities of melt-spun Cu75Cr25 and Cu(75–*x*)Cr25Ni*x* (x = 1 or 3 wt. %) ribbons were studied. The size of the Cr-rich phase from liquid phase separation in the Cu75Cr25 microstructure can be decreased from the micrometer-scale to about 250 nm by using melt spinning. After annealing at 600 °C for 3 h, the resistivity of Cu75Cr25 ribbon can meet the needs of contact. On the melt-spun base, alloying by Ni could further decrease the size of the Cr-rich phase from 250 nm to about 150 nm. However, when the Ni content is higher than or equal to 3%, the resistivity of annealed Cu75–*x*Cr25Ni*x* ($x \geq 3$) ribbons is too high to be used by the medium-voltage vacuum interrupters. For nano-grained CuCr alloys, its lower arc chopping current is advantageous to the use of contact and the circuitry protect, its long arc trace route and high velocity of spot direction motion could mitigate the partial ablate of cathode surface and the lifetime of contact could be prolonged.

Key words: *microstructure; CuCr alloys; contact, melt spinning; resistivity*

1. Introduction

The contact material based on CuCr alloys containing 20–50 wt. % of Cr has been widely investigated because it is a dominating contact material used in medium-voltage vacuum interrupters. To improve its electric properties, refining the Cr-rich phase in its microstructure is an important subject [1–4].

Melt spinning is nowadays the most common method of rapid solidification. It is capable of refining the microstructure, extending the solid solubility limits, forming a metastable phase, etc. A number of studies [5–12] have been undertaken to investigate the microstructures of rapidly solidified metals. However, it has not been well used in the research of refining the microstructure of CuCr alloys containing ca. 20–50

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wt. % of Cr. In these alloys, the liquid phase separation of undercooled CuCr melts will occur in a rapid solidification process. In this paper, the abbreviation Cu*x*Cr*y*Ni*z* will stand for the composition of an alloy containing *x*, *y* and *z* wt. % of Cu, Cr and Ni, respectively. Although the liquid phase separation is disadvantageous to refine the Cr-rich phase, its size can be still decreased to about 300 nm in the microstructure of Cu70Cr30 alloys by melt-spinning with about 10^6 K/s cooling rate [13–16]. Besides rapid solidification, alloying is another general way to refine the microstructure of alloys, so a little work has been done on the influence of Ni addition to the microstructure of melt-spun Cu75Cr25 alloys.

2. Experimental

Pure (> 99.95%) Cu, Cr and Ni were used to prepare CuCrNi alloys by the arc-melting technique. 10 g of the material was inserted into a quartz tube. When the material was heated by high frequency induction to the required temperature, the ribbon was prepared by liquid quenching on a single roller melt spinning under the pressure of 0.5 atm Ar. The velocity of the cooling roller was 33 m/s, the calculated cooling rate of ribbon was about 10^6 K/s. The dimensions of prepared ribbons were about 3 mm wide and 25–40 μm thick. Under this condition, the maximal undercooling of ribbon was about 400–450 K [7, 11].

Some melt-spun ribbons were annealed in a vacuum furnace at 600 °C for 3 h. The microstructures of samples were analyzed by a Hitachi H-800 transmission electron microscope (TEM). The foil specimen for TEM was prepared by a twin-jet thinning device. The resistivity of ribbon was measured by the four point probe method.

3. Results

3.1. The microstructures of melt-spun Cu75Cr25 ribbons

The microstructure of a melt-spun Cu75Cr25 ribbon is shown in Fig. 1a. A spherical particle marked by an arrow is the Cr-rich phase from liquid phase separation [13]. The diameters of the Cr-rich phases in Fig. 1a are about 250 nm. By increasing the cooling rate, the size of the Cr-rich phase from liquid phase separation in the melt-spun Cu75Cr25 microstructure can be refined from the micron-scale to nanoscale [13]. After annealing at 600 °C for 3 h, the Cr-rich phase from liquid phase separation did not obviously grow up; the diameters of the Cr-rich phase in Fig. 1b are still about 250 nm. The result indicates that the Cr-rich phase in the melt-spun Cu75Cr25 microstructure have a good invariance. Even if the material is repeatedly heated by arc in the work process of contact, the melt-spun Cu75Cr25 microstructure would not transform obviously which is advantageous to keep the electric properties of a contact. On the other hand, by contrasting Fig.1a and Fig.1b, the precipitates come forth in the Cu matrix after annealing which mainly causes that the resistivity of Cu75Cr25 ribbons decreases from 16.43 μΩ·cm in the melt-spun state to about 4.53 μΩ·cm in the annealed state (The resistivity of contact should be lower than 5μΩ·cm [3, 4]).

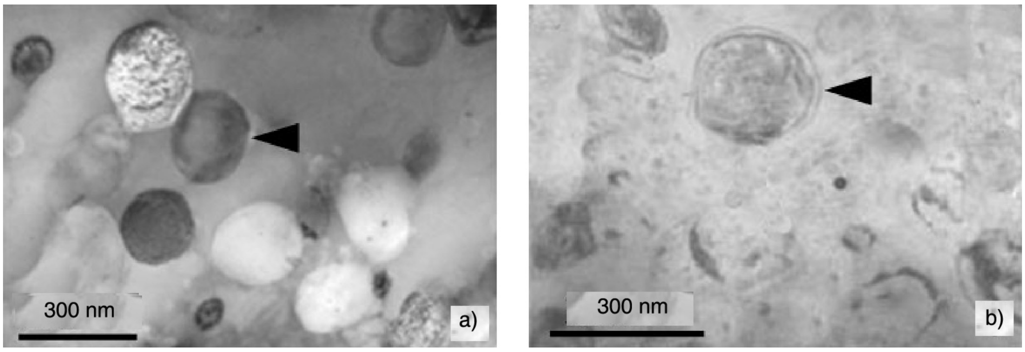

Fig. 1. The microstructure of melt-spun Cu75Cr25; ribbons: a) as-quenched, b) annealed at 600 °C for 3 h. The arrows point to the Cr-rich phase from liquid phase separation

3.2. The microstructures of melt-spun Cu74Cr25Ni1 ribbons

Figure 2a shows the microstructure of a melt-spun Cu74Cr25Ni1 ribbon. The diameter of the Cr-rich phase marked by an arrow is about 200 nm (i.e., is smaller than 250 nm). On the melt-spun base, alloying by 1 wt. % of Ni could further decrease the size of the Cr-rich phase from liquid phase separation. After addition of Ni, the microstructure of Cu75Cr25 alloys is not changed; the diameters of the Cr-rich phase in Fig. 2b are also about 200 nm after annealing at 600 °C for 3 h. Adding 1% of Ni results in that the resistivity of annealed Cu74Cr25Ni1 ribbon is increased to 4.96 μΩ·cm. The reason for the increase of resistivity may be that the concentration of the solute in Cu phase was increased by Ni addition.

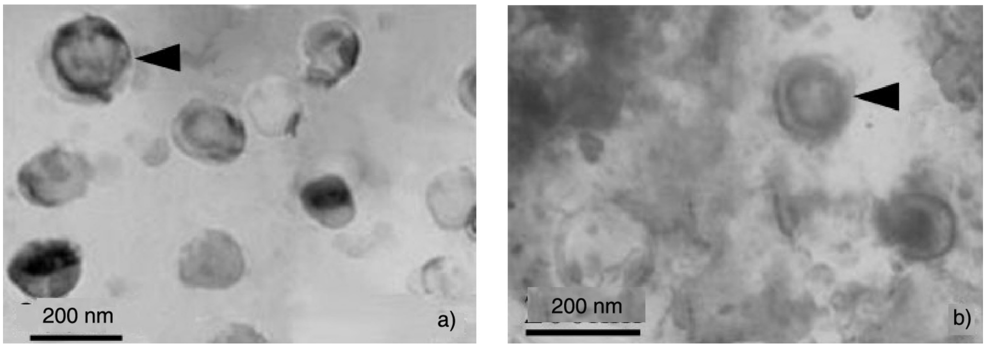

Fig. 2. The microstructure of melt-spun Cu74Cr25Ni1 ribbons: a) as-quenched, b) annealed at 600 °C for 3 h. The arrows show the Cr-rich phase from liquid phase separation

3.3. The microstructures of melt-spun Cu72Cr25Ni3 ribbons

The microstructure of melt-spun Cu72Cr25Ni3 ribbon is shown in Fig. 3a. The Cr-rich phase from liquid phase separation in Fig. 3a is refined to the size smaller than 150 nm. When the ribbon was annealed at 600 °C for 3 h, the Cr-rich phase in Fig. 3b did not grow up much. Upon increase of Ni content in Cu75Cr25 alloys, the alloying effect becomes more remarkable. However, the resistivity of annealed Cu72Cr25Ni3 ribbons is about 13 μΩ·cm, which may be too high to be used by the medium-voltage vacuum interrupters.

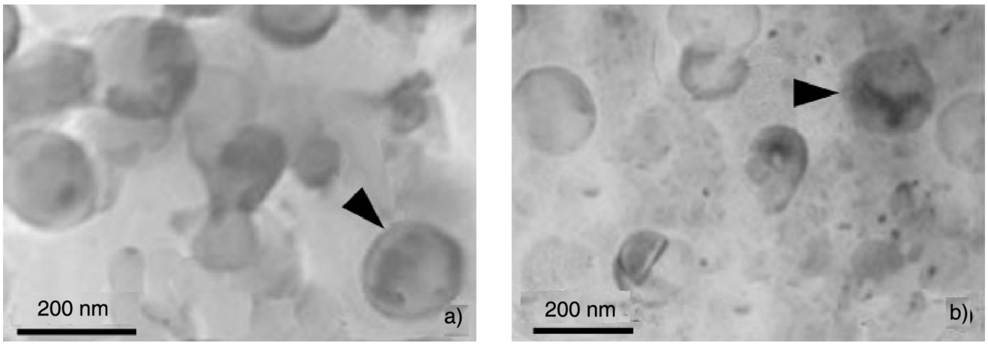

Fig. 3. The microstructure of melt-spun Cu72Cr25Ni3 ribbons: a) as-quenched, b) annealed at 600 °C for 3 h. The arrows show the Cr-rich phase from liquid phase separation

4. Discussion

The arc chopping current of a CuCr contact is an important parameter determining its applicability in service. The arc between electrodes will gradually crush out and the current in a circuit will become smaller and smaller when a breaker is turned off. The current in the circuit is called the arc chopping current when the arc crushes out completely, but the current does not descend to zero. The arc chopping current will arouse an overvoltage by the inductance in a circuit. The overvoltage is very disadvantageous to the electric system. In general, the higher the vapour pressure of contact materials, the lower is the arc chopping current.

The arc chopping currents of melt-spun Cu75Cr25 and Cu74Cr25Ni1 are 1.8 A and 1.6 A, respectively, much lower than that of coarse-grained Cu75Cr25 alloys, 3.6 A. The interfacial energy in nano-grained CuCr alloys is higher than that in coarse-grained CuCr ones, thus the vapour pressure of nano-grained CuCr alloys is also higher than that of coarse-grained CuCr alloys, which results in that the nano-grained CuCr alloys have a lower arc chopping current.

The arc spot stays in a small area with a diameter not exceeding 1 mm on the surface of a coarse-grained Cu75Cr25 cathode. For nano-grained CuCr alloys, the trace of arc spot is in a sub-direction which is different with the random walk pattern of coarse-grained Cu75Cr25 cathode, the arc trace route is about 3 mm long and the velocity of spot direction motion is about 60 m/s [2] which could mitigate partial ablation of the cathode surface and the lifetime of contact may be prolonged. The trace of arc spot and its effects on the contact characteristics have been studied in detail by Yang [2]. In a word, the decrease of sizes of the Cr-rich phase in the microstructure of Cu75Cr25 alloys could improve the electric properties of its contact.

5. Conclusions

By using melt spinning, the size of the Cr-rich phase from liquid phase separation in the Cu75Cr25 microstructure can be decreased from the micron-scale to about 250 nm, which reveals that by increasing the cooling rate of the solidification process, the microstructure of Cu75Cr25 alloy can be markedly refined. After annealing at 600 °C for 3 h, the resistivity of Cu75Cr25 ribbon can meet the technical needs for a contact.

On the melt-spun base, alloying by Ni could further decrease the size of the Cr-rich phase from liquid phase separation, and the higher Ni addition, the smaller becomes the size of the Cr-rich phase. However, when the Ni addition is higher than or equal to 3 wt. %, the resistivity of annealed Cu72Cr25Ni3 ribbons is too high to be used by the medium-voltage vacuum interrupters.

For nano-grained CuCr alloys, its lower arc chopping current is advantageous for the use of contact and the circuitry protect, its long arc trace route and high velocity of spot direction motion could mitigate a partial ablation of the cathode surface and the lifetime of contact could be prolonged.

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Reference

[1] ZHIMAO YANG, QIULI ZHANG, QINGFENG WANG, CHENGYU ZHANG, BINGJUN DING, Vacuum, 81 (2006), 545.
[2] ZHIMAO YANG, QIULI ZHANG, CHENGYU ZHANG, YUE SUN, BINGJUN DING, Phys. Lett. A, 353 (2006), 98.
[3] RIEDER W.F., SCHUSSEK M., GLATZLE W., KNY E., IEEE Trans. CHMT, 12 (1989), 273.
[4] WANG Y., DING B., IEEE Trans. CPMT, 22 (1999), 467.
[5] TENWICK M.J., DAVIES H.A., Mater. Sci. Eng., 98 (1988), 543.
[6] ZHONGHUA ZHANG, XIUFANG BIAN, YAN WANG, XIANGFA LIU, J. Mater. Sci., 37 (2002), 4473.
[7] MASLOV V.V., NOSENKO V.K., J. Mater. Sci., 37 (2002), 4663.
[8] TIANYI CHENG, LÖSER W., LEONHARDT M., J. Mater. Sci., 33 (1998), 4365.
[9] ZHANG LIN, WU YOUSHI, BIAN XIUFANG, XING ZHINA, J. Mater. Sci. Lett., 18 (1999), 1969.
[10] NAGARAJAN R., MANJINI S., CHATTOPADHYAY K., AOKI K., J. Mater. Sci., 32 (1997), 6021.
[11] FENG LIU, GENCANG YANG, XUEFENG GUO, J. Mater. Sci., 36 (2001), 3607.

[12] COOPER K.P., JONES H.N., J. Mater. Sci., 36 (2001), 5315.
[13] YOUHONG WANG, XIAOPING SONG, ZHANBO SUN, XUAN ZHOU, JUAN GUO, Mater. Sci.-Poland, 25 (2007), 199.
[14] YOUHONG WANG, ZHANBO SUN, XUAN ZHOU, SONG XIAOPING, Rare Metal Mater. Eng., 35 (2006), 1289.
[15] SUN ZHANBO, WANG YOUHONG, GUO JUAN, Trans. Nonferrous Metals Soc. China, 16 (2006), 998.
[16] WANG YOUHONG, SUN ZHANBO, SONG XIAOPING, Chinese J. Nonferrous Metals, 15 (2005), 1045.

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