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Preparation of CuCr25 alloys through vacuum arc-smelting and their properties^①

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Abstract: CuCr alloys are important contact materials, but all conventional preparing methods have disadvantages and mismatch the requirements for mass production and high-properties. The CuCr25 alloys were prepared by means of arc-smelting in vacuum, and their microstructures, physical properties as well as dielectric strength were investigated. The experimental results show that vacuum arc-smelting is an ideal method to produce CuCr25 contact alloys with fine microstructure, low gas content, high density and dielectric strength. Meanwhile, with the high productivity and low cost, CuCr25 contact materials can be produced with mass production through vacuum arc-smelting method.

Key words: CuCr contact materials; vacuum arc-smelting; dielectric strength

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1 INTRODUCTION

CuCr alloys are important contact materials for vacuum interrupters and are widely used for high voltage applications because of their considerable high interrupting ability and high voltage withstanding stress^[1]. Presently, the main methods of preparing CuCr alloys include vacuum sintering and infiltrating^[2], mixing alloy powder and HIP^[3], and arc-melting^[4], etc, and they all show many disadvantages. For example, although the properties of CuCr alloys prepared by vacuum sintering and infiltrating are excellent, their productivity is poor because of the long production period and high waste rate. The gas content of CuCr alloys through HIP is rather high, which greatly affects their properties. As for arc-melting, the method used by Siemens Corporation, it is not easy to prepare self-consume electrodes in advance because of their high cost and complicate technology. With the development of industry and its more and more requirements for contact materials, it is crucial to probe a new technology which can not only produce CuCr contact materials with high properties, but also meet the need of mass production.

In this paper, CuCr25 alloys were prepared through vacuum arc-smelting method and their microstructures and properties were also investigated. Arc-smelting method here means that Cu and Cr blocks are directly heated to melt by arc without self-consume electrodes. Because of the decrease of Cr content from 50% to 25% and employment of pure Cu and Cr block instead of powder, it is helpful for reducing production costs as well as saving Cr resources. The whole production period is about 2 h, greatly raising the productivity. Experiment results

also show that with the skill of arc-heating and high-speed solidification, the microstructures of CuCr25 alloys are so fine (the size of Cr-gain is only about 30~50 μm) that their comprehensive properties are greatly improved^[5, 6]. These results prove that vacuum arc-smelting is ideal to produce CuCr alloys with high properties and meet the requirement of mass production.

2 EXPERIMENTAL PROCEDURE

Before experiment, pure Cu and Cr ($\geq 99\%$) blocks with a mass ratio of 75: 25 were put in a neutral crucible. The crucible was put in a vacuum arc furnace and heated to 1700 °C in vacuum until the alloys were smelting. Then solidifying the alloys rapidly (about 200 K/s) with circulatory water, CuCr25 alloys were obtained.

The electric conductivity, density and gas content of CuCr25 alloys were measured respectively. Their microstructures were examined by scanning electron microscopy (SEM) and the composition distribution was analyzed by energy dispersive X-ray analysis (EDX).

The prepared CuCr25 alloys were machined to discs with a diameter of 20 mm and a thickness of 5 mm. These were mechanically polished to a mirror finish and put into the electric furnace as cathodes. Above the cathode was a fixed disc anode made of pure tungsten with a radius of 5 mm and an edge radius of 1 mm. The plane of the anode facing the cathode was polished and was parallel to the cathode plane. The cathode and the anode were outgassed in the furnace at 723 K and 1.5×10^{-3} Pa for 30 min. After the cathode cooled to room temperature in the

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furnace, an 8 kV DC voltage was applied across the cathode and anode, and the cathode was driven upwards to the anode at a speed of 0.2 mm/min until breakdown occurred. After every discharge, the cathode was driven downwards, waiting for the next breakdown test. The procedure was repeated 100 times without any cathode transverse movement. The macroscopic breakdown field was then calculated by dividing the applied voltage by the breakdown distance. The microstructure of alloys after the first and 100 times breakdown were analyzed by SEM.

3 RESULTS AND DISCUSSION

3.1 Microstructure and composition

Fig. 1 shows the microstructure of the CuCr25 alloys prepared by vacuum arc-smelting. It can be seen that Cu phase acts as the base of the whole alloys, while Cr dendrites distribute evenly. Owing to high-speed solidification, the size of Cr-grain is fine, only about 30~ 50 μm. From Fig. 1 (b), it can be seen that in addition to Cr dendrites, there are also many tinier Cr particles on the surface of Cu phase. According to Muller's phase diagram for the Cu-Cr system^[1, 7], dendritical Cr phases precipitate from alloy liquid directly, while the tiny Cr particles separate out from Cu phase during the continue cooling process of solid alloys. Because the microstructures of Cr particles are finer, their strengthening effects on the alloys are more prominent.

Table 1 demonstrates the composition distribution of Cu and Cr phases obtained by EDX. It can be found that Cu and Cr phases are all supersaturated solid solution, which is beneficial for improving the comprehensive properties of alloys^[8]. Because of the volatility of CuCr alloys during smelting, there are some deviations in the average composition. In order to inhibit volatilization, argon is filled into the fur-

nace while smelting the alloys.

Table 1 Composition distribution of CuCr25 alloys (mass fraction, %)

Elements	Average	Cu phase	Cr phase
Cu	75.69	98.25	4.32
Cr	24.31	1.75	95.68

3.2 Physical properties

Table 2 presents the main physical properties of CuCr25 alloys prepared by vacuum arc-smelting. The results show that the physical properties of CuCr25 alloys through vacuum arc-smelting have come up to the technological requirement of CuCr25 of the Westinghouse Corporation and nearly exceeded the relative properties of the conventional CuCr50 alloys. These results are due to the effects of arc-heating and high-speed solidification, which lead to sufficient air exhaustion and cooling of alloys during the process from liquid to solid.

Table 2 Testing results of physical properties of CuCr25 alloys

Materials	Grain size / μm	Gas content / 10 ⁻⁶		Electric conductivity / (MS·m ⁻¹)	Relative density / %
		O ₂	N ₂		
CuCr25	30~ 50	< 500	< 20	24.9~ 26.1	> 99
CuCr25*	20~ 50	≤3 000	≤100	20~ 29	≥97
CuCr50**	70~ 150	< 600	< 50	16~ 20	≥99

* Prepared according to the requirements of Westinghouse Co.

** Prepared by conventional method

3.3 Dielectric strength

It is well known that the dielectric strength is one of the most important requirements for the electric properties of contact materials and greatly affects the structure design, interrupting abilities, and delayed discharges of vacuum interrupters^[9]. Table 3 shows the dielectric strength of CuCr alloys prepared

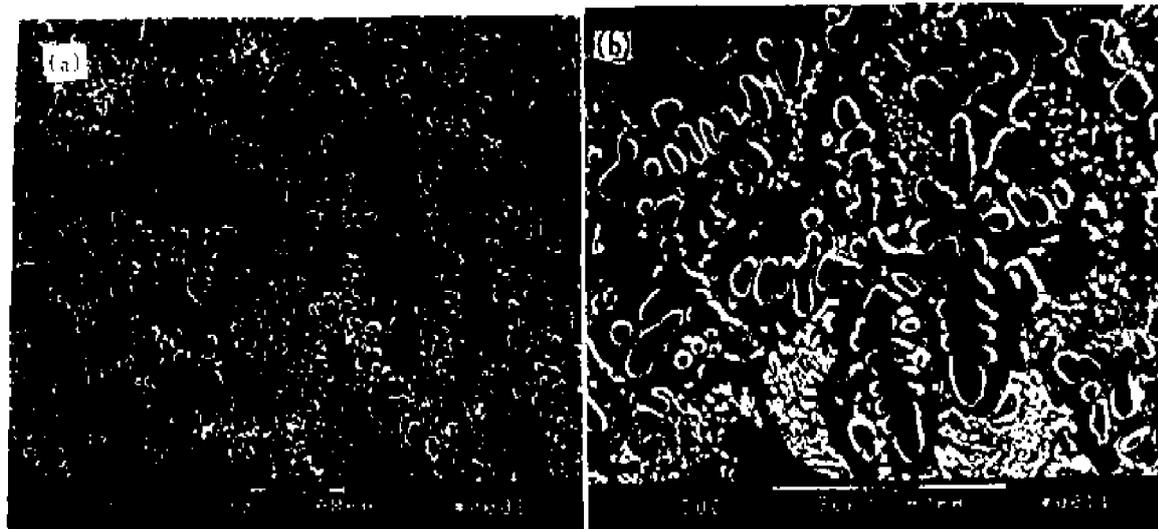


Fig. 1 Microstructures of CuCr25 alloys through vacuum arc-smelting
(a) —Cr dendrites; (b) —Cr particles

Table 3 Comparison of dielectric strength (E_b) of CuCr alloys prepared by different methods

Methods	Vacuum arc-smelting	Arc-melting	Vacuum sintering and infiltrating	Vacuum sintering and infiltrating	Vacuum sintering and infiltrating	HIP
Grain size/ μm	30~ 50	20~ 50	70~ 150	20~ 50	5~ 10	
$E_b / (10^8 \text{ V} \cdot \text{m}^{-1})$	2.14~ 3.69	2.72	2.46	3.00	2.60	2.01

by different methods, and it can be seen that the dielectric strength of CuCr25 prepared by vacuum arc-smelting has reached the level of alloys in other conventional methods as well as in arc-melting of Siemens.

Fig. 2 is a metallograph of CuCr25 after the first discharge, indicating that almost all breakdowns took place on the surface of the Cr phase and a few breakdown pits distributed on the boundaries of Cu and Cr, which is the same as the results^[10, 11] reported previously. This experiment was repeated several times and the results are the same. The Cr phase is still an electrically weak phase in CuCr25 materials, although the dielectric strength of contact gaps has improved because of the fine microstructure and low gas content of the alloys.

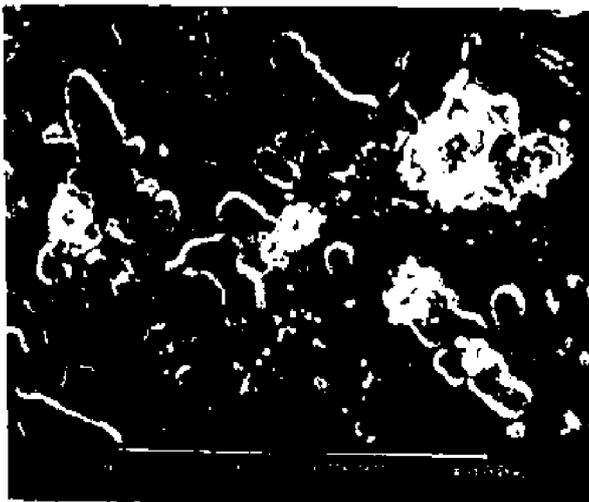


Fig. 2 Morphology of CuCr25 alloys after the first breakdown

4 CONCLUSIONS

In conclusion, vacuum arc-smelting is an ideal method to produce CuCr25 alloys with fine microstructure, low gas content, and high physical and electric properties, because of the effects of arc-heating and high-speed solidification during the smelting

process. With the simplification of technology and saving of Cr resource, the method also meets the requirement for the mass production of CuCr contact materials in industry.

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