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CuCr25W1Ni2 contact material of vacuum interrupter①

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[Abstract] CuCr25W1Ni2 alloy was prepared by means of vacuum induction melting (VIM). A series of Cu/Cr alloys with different compositions (mass fraction, 25% ~ 75%) and Cr grain sizes (up to 150 μm) were investigated for their differences in physical properties and breakdown voltage. The influence of alloy elements and microstructure on the performance of CuCr25W1Ni2 alloy was also discussed. Experimental results show that the chromium phase is strengthened and its size is minimized by the addition of tungsten powder. After electrical breakdown, very fine tungsten particles in the melt layer form the external nuclei in the solidification process. The microstructure of surface melt layer of CuCr25W1Ni2 alloy is much flatter. It can notably improve the dielectric strength. On the other hand, the nickel can enhance the mutual solubility of copper and chromium, and the whole alloy is strengthened.

[Key words] CuCr contact material; vacuum induction melting; dielectric strength
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1 INTRODUCTION

The properties of a vacuum interrupter are mainly determined by the contact material. The properties of the contact material depend not only on chemical composition, structure and impurities, but also on its surface condition which is altered by switching arcs[1,2]. From the nineties of the 20th century, the widely application of CuCr25 alloys has achieved a great progress in the development of contact materials. Experiments have testified that the heat conductivity of CuCr alloys could be heightened when the content of copper is added. As a result, the temperature of contact surfaces decreases and the melt layers are thinner during the operation[3,4].

At present, the application of CuCr50 alloys prepared by the vacuum sintering and infiltrating still takes a great proportion in Chinese electric industry. The main reason is that CuCr25 alloys can not be prepared by the vacuum sintering and infiltrating method. In other countries, there are mainly two methods to prepare CuCr25 alloys, i. e., the mixing powder sintering and the vacuum self-consuming smelting[5]. Westing House corporation prepares CuCr25 alloys through mixing powder sintering. The properties of products are not ideal, for example, the oxygen content is high, density is low and the productivity is small. Siemens corporation prepares CuCr25 alloys through the vacuum self-consuming smelting. The products have excellent properties. But the preparing technology is fairly complicated, and the self-consuming electrodes need to be prepared in advance. So the producing period increases and the cost is much high. Recently, CuCr25 and CuCr25W1Co1 alloys were prepared through the vacuum arc-smelting[6,7]. But the characteristic microstructure is chromium dendrites in both alloys. This is unfavorable for the further improvement of dielectric strength. As for CuCr contact materials, the chromium phase is the dielectric weak phase. Also, researches showed that the microstructure of materials had a great influence on the electrical properties of contacts. For example, the refining of chromium phase size can enhance the dielectric strength, lower chopping currents. At the same time, there is no obvious change in the capability of interrupting and anti-welding[8~10]. To get excellent alloys, high productivity, and lower cost, this paper probes the vacuum induction melting method to prepare CuCr25 alloys. Here the tungsten powder is used as external nuclei to fine and strengthen the chromium phase; and the nickel is used to strengthen both copper and chromium phase by means of solid solution. As a result, the dielectric strength increases notably. The raw chromium material is block instead of powder, and the mass fraction of chromium reduces from 50% to 25%. So the cost is lower. The total producing period is about 2 h, and the productivity is high.

2 EXPERIMENTAL

The CuCr25W1Ni2 alloy was melted by VIM.

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The raw materials were copper preforms, chromium preforms, tungsten powder (size from 0.6 μm to 3 μm), nickel preforms in the mass proportion of 72∶25∶1∶2. The copper, chromium and nickel preforms were put into crucible to melt and the vacuum was kept in a high level (1×10^{-2}~ 3×10^{-2} Pa). When the raw materials being completely melted, the melt temperature reaches 1800~ 1900 ℃. The tungsten powder was put into the crucible when the smelting process was nearly to the end. Then the melt was poured into the copper mold with circulatory water cooling, thus the alloy ingot was acquired. To compare the corresponding properties of the alloy with traditional contact material, the CuCr25 alloy was prepared by the same method.

The densities of alloys were tested on the principle of Archimedes. The conductivities were tested by the FQR-7501 vertex conductometer. Hardness was tested by the Brinell tester. The oxygen and nitrogen content were tested by the LECO infrared gas analyzer.

The alloys acquired above were processed as the specimens with shape of d20 mm × 5 mm. The surfaces of specimens were mechanically polished. Then, they were installed into the simulated vacuum interrupter which was made from the TDR-40A monocrystalline furnace as the cathode and the polished pure tungsten stick as the anode with a radius of 5 mm and an edge radius of 1 mm. To outgas the electrodes in the furnace, the temperature and the vacuum degree were kept at the level of 500 ℃ and 1.5×10^{-3} Pa, respectively, for 30 min. After the cathode cooled to the room temperature in the furnace, a direct current voltage of 8 kV was applied across the electrodes. The cathode was moved towards above anode with a speed of 0.2 mm/min. When the electrical breakdown occurred, the movement was stopped and the distance between two electrodes was noted for calculating the dielectric strength. Then the cathode was moved downwards, preparing for the next test. Every specimen was tested for 100 times, respectively. To eliminate the interference of conditioning[11], the last 60 points were used to calculate the dielectric strength. The microstructure of alloys were observed and photographed by Scanning Electron Microscope (SEM). The compositional distribution was analyzed by Energy Dispersion X-ray (EDX).

3 RESULTS AND DISCUSSION

3.1 Composition and microstructure

The melt of copper, chromium is mixing perfectly under the effect of electromagnetic stirring. The tendency of chromium to gravity segregation during solidification could be lowered through rapid cooling solidification. The compositional distribution of CuCr25W1Ni2 alloy is given in Table 1.

Table 1 Compositional distribution of CuCr25W1Ni2 alloy (%)

Alloying element	Average alloy composition	Rich copper phase	Rich chromium phase
Cu	73.53	96.75	4.51
Cr	23.26	1.91	91.07
W	1.07	0.16	2.62
Ni	2.14	1.18	1.80

Fig. 1 is the characteristic microstructure of CuCr25 alloy prepared by VIM, showing chromium dendrites. It can be concluded that the chromium phase is hard to be refined further only through water cooling solidification. And most of chromium phases exit in dendrites with comparatively big size. It is not favorable for the chromium phase to conduct heat to the copper matrix during the operations of vacuum interrupters, so the dielectric strength would be lowered. In a word, the alloying treatment must be taken to minimize the chromium grains. Fig. 2 shows the

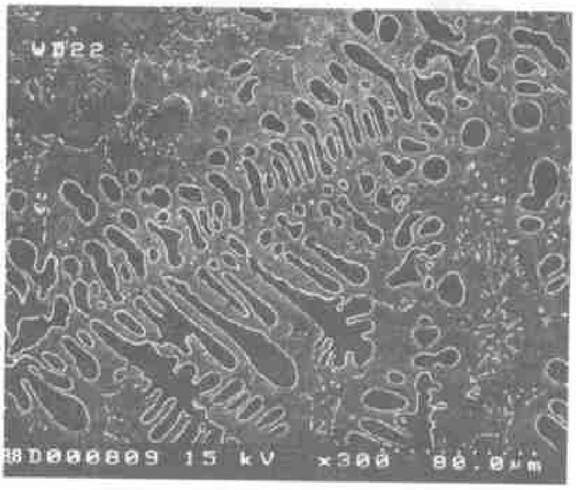

Fig. 1 Microstructure of CuCr25 alloy after chemical etching

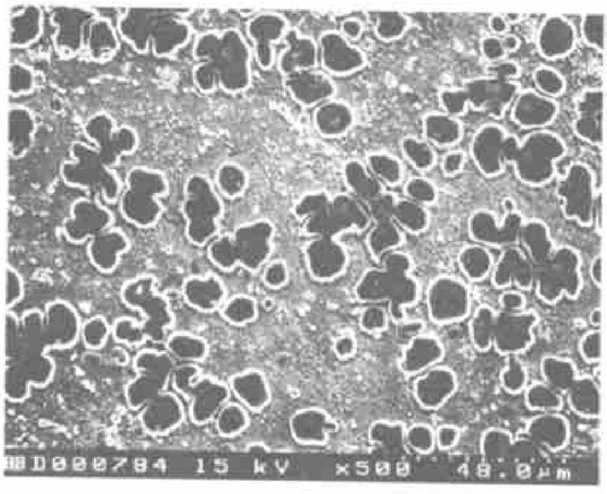

Fig. 2 Microstructure of CuCr25W1Ni2 alloy after chemical etching

chromium morphology of CuCr25W1Ni2 alloy prepared by VIM. The chromium particles have homogeneous distribution in the copper matrix. Because of the function of tungsten powder as external nuclei, the size of chromium grains reaches 5~ 15 μm. Dendritic chromium phase is eliminated. The grey dots in chromium grains are mainly tungsten which can be proved by the analysis of EDX. The border of grey dots is ambiguous, according to the chromium-tungsten phase diagram, it is α solid solution. The tungsten powder has an effective strengthening influence on the chromium phase, selectively.

The characteristic chromium morphology of CuCr25W1Co1 alloy prepared through vacuum arc-smelting is still dendrite[7]. Because thin pieces of tungsten instead of tungsten powder is melted with copper, chromium and cobalt preform from beginning, the thin pieces of tungsten have not the function of external nuclei.

The addition of nickel could lower the electrical conductivity in some extent. But it can strengthen the alloy through solid solution. According to the calculation of thermodynamics, when raw materials were melted, the nickel can enhance the mutual solution of copper and chromium. As a result, there were many particles precipitated from copper matrix in rapid solidification, as shown in Fig. 2. It has a strengthening effect on the whole alloy. Owing to the greater solution of nickel in both copper and chromium phase, the addition of nickel can also enhance the property of infiltrating of copper and chromium phase. It is helpful to reduce the micro porosities in solidification and the density of alloy increases.

3.2 Physical properties and breakdown field

Table 2 is the testing results of alloys prepared through VIM and some other methods. It shows that for CuCr25W1Ni2 alloy, the chromium grains are much finer, the oxygen content is low, conductivity is better and the dielectric strength increases significantly.

Fig. 3 and Fig. 4 are the relationship between dielectric strength and electrical breakdown number of CuCr25W1Ni2 and CuCr25 alloy, respectively. The results show that the process of conditioning is short when the chromium phase is fined. The dielectric strength tends to be stable rapidly. The process of conditioning of CuCr25 increases notably. The CuCr25W1Ni2 alloy prepared by the arc-smelting also has a long conditioning process[7]. For CuCr25W1Ni2 alloy, in addition to chromium phase being hardened by α solution and its homogeneous distribution, nickel contributes to the strengthening of whole alloy. The hardness of CuCr25W1Ni2 is higher than that of CuCr25, resulting that the ability of Cu-

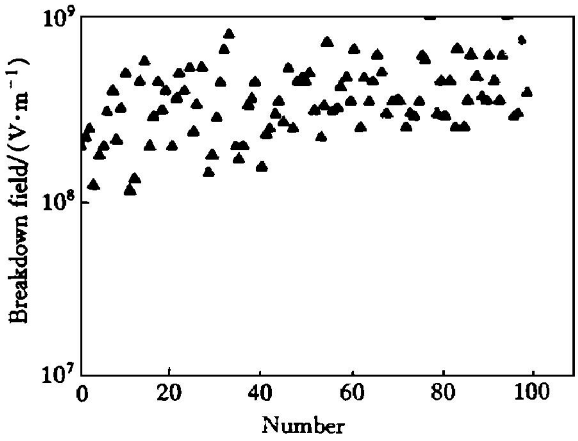

Fig. 3 Relationship between breakdown field and breakdown number of CuCr25W1Ni2 alloy

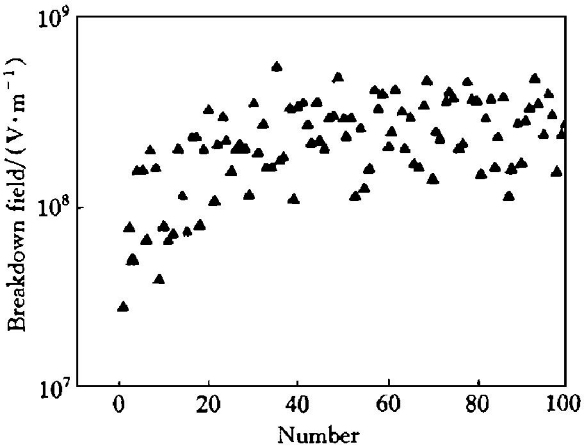

Fig. 4 Relationship between breakdown field and breakdown number of CuCr25 alloy

Table 2 Testing results of properties of CuCr25W1Ni2 alloys

Material	Average grain size of chromium / μm	Relative density / %	Conductivity / (MS·m^{-1})	Oxygen content / 10^{-6}	Nitrogen content / 10^{-6}	Brinell hardness (HB)	Breakdown field / (10^8 V·m^{-1})
CuCr25	20~ 100	99.01	25.0	490	65	80	2.62
CuCr25W1Ni2	5~ 15	99.27	22.3	550	70	91	4.05
CuCr25W1Co1*	20~ 40	98.74	24.9	1040	80	86	3.27
CuCr50**	70~ 150	99.12	18.7	430	60	97	2.53
CuCr25***	20~ 50	> 97.00	20.0~ 29.0	< 3000	< 100	—	—

* —Prepared by vacuum arc-smelting method[7]; ** —Conventional CuCr50 prepared by sintering and infiltrating method; *** —Product requirements of Westing House corporation

Cr25W1Ni2 to resist surface deformation induced by strong electrical field enhances. The decrease of micro salient extent following arc ignition results in the local electrical emission capability lowering. So the dielectric strength in vacuum increases. As for CuCr25 alloy, the dendritic morphology causes greater compositional deviation on the surface. The surface microstructure is not as even as CuCr25W1Ni2 alloy. Vacuum arc can be induced on some dielectric weak zone. It leads to the decrease of dielectric strength of alloy.

It was calculated that the solidification time of chromium phase reduces from several microseconds to tens of nanoseconds by the effect of fine tungsten particles as evenly distributed external nuclei. So the solidification time of CuCr melt solution decreases significantly. The tungsten particles and chromium particles precipitated in the rapid solidification can nail melting alloy liquid induced by the effect of arc, lower the quantity of liquid droplets. So the probability of appearance of particles on the contact surface decreases notably[12, 13]. On the other hand, the nickel can make alloy melt spread easily, so the solidified melt layer is much flat and widely spread. Fig. 5 and Fig. 6 show the microstructures of CuCr25W1Ni2, CuCr25 alloys after 100 times dielectric test, respectively. The fairly flat and widely spreading melt layer can be seen in Fig. 5.

In the CuCr alloys, the chromium phase is the dielectric weak phase. In earlier research[11], during the operation, both copper and chromium phase were heated by the pre-breakdown current. Owing to lower conductance of chromium phase, its temperature increased rapidly, comparatively. It is much easier for the chromium phase to reach the critical point and the breakdown occurs. This phenomenon can be observed also in CuCr25 alloy prepared by VIM, as shown in Fig. 7. As for CuCr25W1Ni2 alloy, owing to the chromium grains having a homogeneous distribution in the copper matrix, it is more favorable for them to conduct heat to the copper matrix. In addition, the chromium phase is strengthened by the tungsten powder, effectively. The breakdown points distributing on the copper matrix are dominant, some on the border between copper and chromium phase (Fig. 8). It can be concluded that the dielectric weak phase, chromium phase, has been strengthened, and

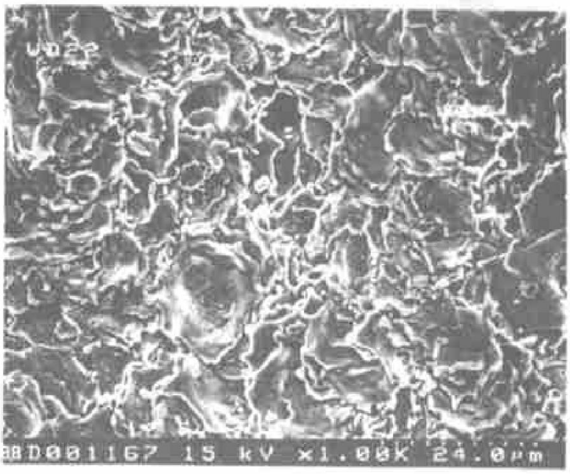

Fig. 6 Microstructure of CuCr25 after 100 times dielectric test

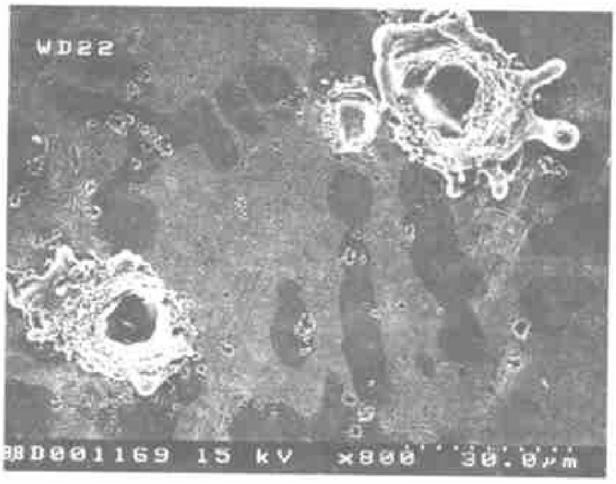

Fig. 7 First-dielectric phase of CuCr25 alloy

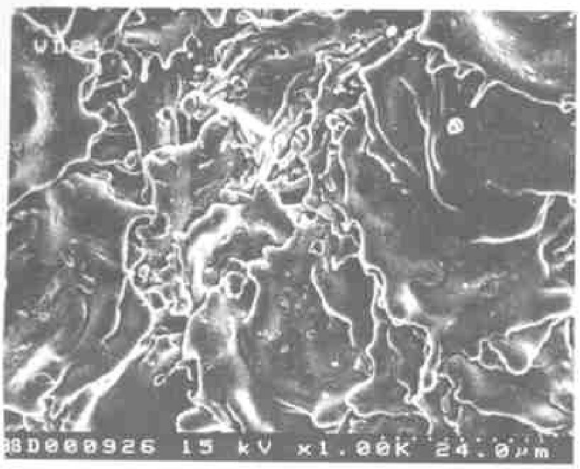

Fig. 5 Microstructure of CuCr25W1Ni2 after 100 times dielectric test

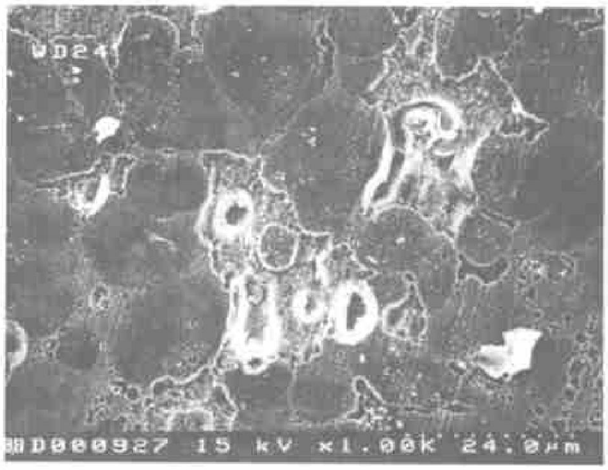

Fig. 8 First-dielectric phase of CuCr25W1Ni2 alloy

the dielectric property of CuCr25W1Ni2 alloy is enhanced significantly as a result.

3.3 Default and its elimination

The segregation of chromium in CuCr25W1Ni2 alloy can be observed sometimes, as shown in Fig. 9. Among the chromium segregation, the bright white particles are tungsten powder by the analysis of EDX. It is obvious that the chromium segregation results from the aggregation of tungsten powder. This segregation zone leads to the breakdown at lower voltage levels easily, resulting in the decrease of dielectric strength.

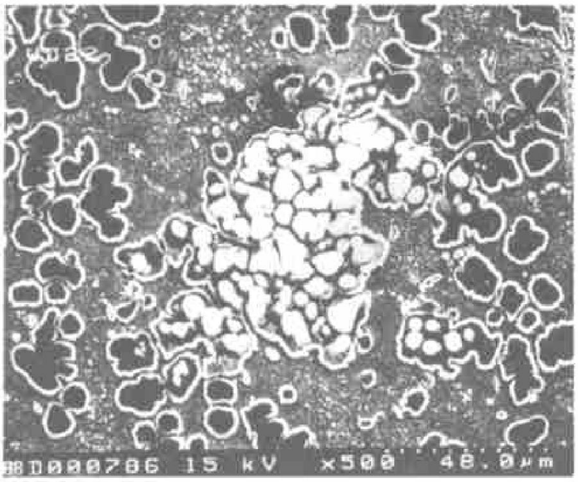

Fig. 9 Segregation of chromium in CuCr25W1Ni2 alloy after chemical etching

To eliminate this segregation, the tungsten powder should be put into the melt at the highest temperature. At the same time, the increase of outputting power can induce an ideal effect of electromagnetic stirring. By this means, the aggregation of tungsten powder can be eliminated, and the quality of alloy can be controlled effectively.

4 CONCLUSIONS

Vacuum induction melting is an effective method to produce CuCr25 contact materials in a grand scale. By choosing appropriate alloying elements and cooling solidification method, the CuCr25W1Ni2 alloy was prepared with excellent physical properties and ideal breakdown voltage. It fulfills the requirements for contact materials in vacuum interrupters with high dielectric strength.

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