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Microstructure and properties of CuCr contact materials with different Cr content

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Abstract: In order to study effect of Cr content on microstructure and properties of CuCr contact material, three different Cr content contact materials, named CuCr25, CuCr30 and CuCr40, were manufactured by vacuum casting process. The microstructure, physical properties and breaking current properties were studied. The results show that both the consistency of the microstructure and the tensile strength increase, while the Cr particle size, the electrical conductivity and the density all decrease with increasing Cr content. The interrupting property of CuCr25 and CuCr30 is almost the same, whereas that of CuCr40 is the worst.

Key words: CuCr contact material; microstructure; interrupting property

1 Introduction

As a new type of switch with excellent performance, vacuum switch has been developed rapidly since its first application in power system in 1960s [1]. Now it has been widely applied in medium voltage field and begins to occupy the high voltage field. As one of the key factors which decide the breaking capability of vacuum interrupter [2], the contact material plays an important role in vacuum switch.

At present, the contact materials have been applied in different specifications. Vacuum switch can be generally classified into three kinds [3]: 1) semi-refractory metal together with good conductor, typically like CuCr alloy; 2) refractory metal together with good conductor, typically like CuW alloy; and 3) Cu alloy, like CuBi alloy. Table 1 [4] lists the qualitative comparison of these three kinds of materials. Through the contrast, it is known that CuCr contact material is a machinery-mixed composite material, and it keeps the intrinsic physical properties of the two different kinds of metal. Since the high withstand voltage, large breaking capacity and long life are the advantages of CuCr alloy, it has been taken for the best contact material for vacuum interrupter [5].

Further research on the contact materials of vacuum interrupter aims at improving the properties of CuCr contact materials, especially at the aspects of enhancing the resistance to weld, increasing voltage withstand property and strengthening the interrupting capacity [6]. Currently, there are two main methods to achieve these goals, one is to add some other elements into the CuCr alloy, and the other is to improve the manufacturing technique and change the Cr content in the alloy [7]. In this study, the vacuum casting was used to manufacture three different Cr content contact

Table 1 Qualitative comparison of contact materials for vacuum interrupter

Material	Gas content	Melting point	Vapor pressure	Work function
CuCr	+	+	+	++
CuW	+	+	+	−
CuBi	++	+	+	++

Material	Ionization energy	Electrical conductivity	Inspiratory capacity	Smoothness on contact surface
CuCr	+	++	++	++
CuW	+	+	+	++
CuBi	+	++	+	−

−: Unacceptable; +: Acceptable; ++: Best

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materials, and the microstructure and properties were studied.

2 Materials

The process of vacuum casting was heating, melting and solidifying raw material in vacuum induction furnace [8]. The whole process included loading, melting, refining, alloying and pouring. Because the melting and pouring were carried out under the condition of vacuum, the gas content of material decreased greatly and the purity of the alloy increased and the operation was simple.

The operating principle of medium-frequency vacuum induction furnace was [9]: when the medium-frequency current flew through the spiral induction coil, the electromotive force (EMF) generated. The magnetic field flux in internal coil was the maximum, so the heated metal was put in the coil to induct EMF and cause circumfluent medium-frequency current. The induction current was concentrated on the metal surface because of the action of its own magnetic field. Meanwhile, it formed a current sheet, which was similar to the current in the coin with contract directions. In terms of the Kelvin effect of medium-frequency current, the current sheet on metal surface had high current density. Therefore, the heating effect was centralized and strong, which heated the metal until it melted [10].

The raw materials were prepared by melting Cu block and Cr block with mass ratio of 75:25, 70:30 and 60:40, respectively. The Cu block and Cr block were put into the furnace under high vacuum (0.01−0.03 Pa) to melt. After the materials were totally melted and held for a period of heat preservation, the melted solution was poured into water-cooled copper mould and solidified quickly. Then the alloy ingot was obtained.

3 Microstructure

The microstructures of vacuum cast CuCr25, CuCr30 and CuCr40 contact materials were observed by optical microscopy, and the images are shown in Figs. 1(a)−(c).

The microstructures of these three CuCr contact materials are all typical casting configurations. Cr dendrites are distributed uniformly around Cu matrix phase. The dimension of Cr phase is small by using high-speed solidification. Besides Cr dendrites in the alloy, there are still lots of Cr grains with smaller dimension distributed around Cu phase. Cr dendrites are separated from liquid alloy directly in the process of solidification, but Cr grains are separated from Cu phase secondly in the process of continuing cooling. The invigoration effect of Cr grains on the whole alloy is more obvious, because its dimension is small [11].

Since the components of CuCr alloy cannot dissolve each other, CuCr alloy is machinery-mixed composite material. But in the alloy, a few elements are in the solid solution of other phase, so that the performance of the alloy is affected. With Cr content increasing in the alloy, the consistency of microstructure increases and Cr particle size decreases. All the changes are beneficial to improve withstand voltage. The Cr content in the solid solution of Cu matrix increases with the increase of Cr content. Since the solid solubility of Cr in Cu matrix has a great effect on the conductivity of Cu phase in the alloy, the conductivity of the alloy decreases with increasing Cr content.

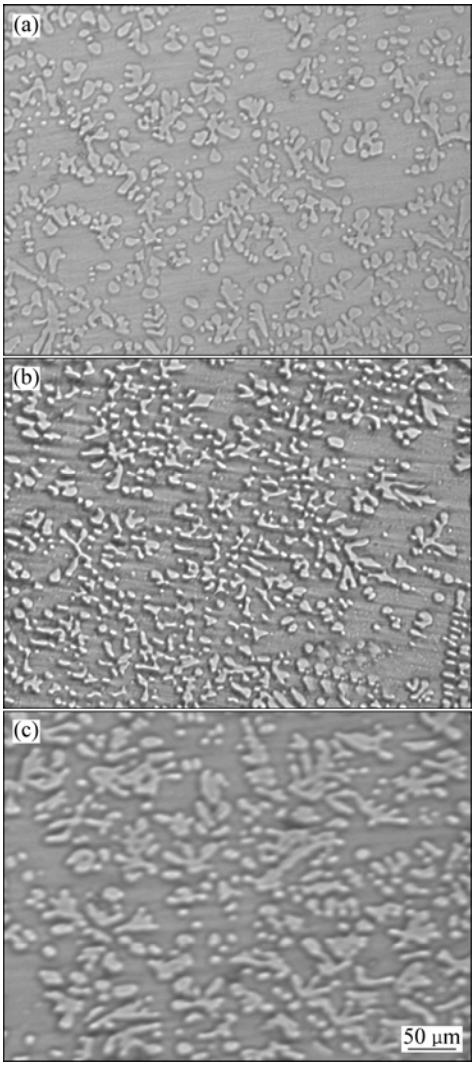

Fig. 1 OM images of vacuum cast alloys: (a) CuCr25 alloy; (b) CuCr30 alloy; (c) CuCr40 alloy

4 Physical properties and mechanical properties

The physical and mechanical properties of vacuum cast CuCr contact materials are listed in Table 2. With increasing the Cr content, the electrical conductivity and the density decrease a little, while the hardness increases and the tensile strength basically increases linearly.

Table 2 Physical and mechanical properties of CuCr alloys

Material	Electrical conductivity/ $(MS\cdot m^{-1})$	Density/ $(g\cdot cm^{-3})$	Hardness/ $(N\cdot mm^{-2})$	Tensile strength/ MPa
CuCr25	30.6	8.41	83.9	319
CuCr30	28.0	8.27	89.7	327
CuCr40	23.8	8.16	97.2	342

Owing to the high electrical conductivity of Cu, the electrical conductivity of CuCr alloy decreases when the Cr content increases and the Cu content decreases correspondingly. Generally, if the alloy has good electrical conductivity, its temperature conductivity exhibits well. It can be seen from the following formula as:

$$\rho\lambda=LT \tag{1}$$

where ρ is the electrical resistivity, λ is the temperature conductivity, L is the Lorentz constant and T is the thermodynamic temperature [12−13].

The consistency of material is the ratio of the measured density and the theoretical density, which is the premise of well breaking property. Low consistency means high residual porosity which can make the breaking property of contact material bad [14].

Since Cr is the strengthening phase, the hardness increases with the increase Cr content. The solid solubility of Cr in Cu phase of CuCr alloy increases with increasing Cr content, which is beneficial to increase the hardness and strength. The hardness of material has a certain relationship with breakdown voltage. Generally, the material with a high hardness has a high withstand voltage.

The anti-welded property of contact material has a direct relationship with its tensile strength. Usually, the tensile strength of contact material matrix is used to assess the anti-welded property. The anti-welded property improves with decreasing tensile strength. So the anti-welded property decreases with increasing Cr content [15−16].

5 Breaking current capacity

In order to compare the breaking current capacity of CuCr contact material with different Cr content, the same vacuum interrupters are manufactured by using vacuum cast CuCr25, CuCr30 and CuCr40 alloys. Contact structures are all cup-type axial magnetic field. Figures 2 and 3 show the shape of vacuum interrupter and contact structure, respectively. The breaking current tests of three vacuum interrupters are carried on a Weil Synthetic Circuit with arc-igniting branch under the same conditions. The breaking current increases until the vacuum interrupter fails to break.

Fig. 2 Shape of vacuum interrupter

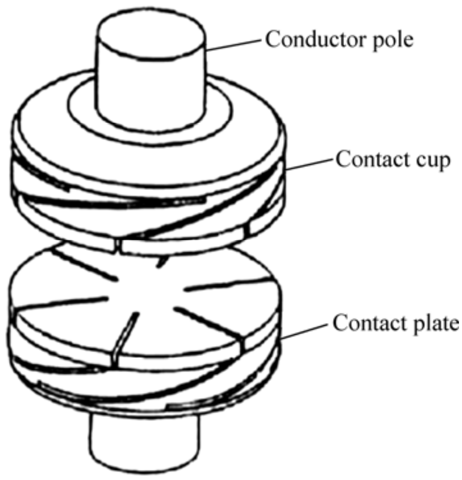

Fig. 3 Cup-type AMF structure

The limiting breaking current of CuCr25 contact material is 23.9 kA, while these of CuCr30 and CuCr40 alloys are 23.0 kA and 21.3 kA, respectively. It is recognized that the breaking current capacity of CuCr25 alloy is higher than that of CuCr30 alloy, and that of CuCr40 alloy is the lowest.

Figure 4 shows the breaking current and arc voltage of vacuum interrupters with CuCr25, CuCr30 and CuCr40 contact materials when the current is at peak. The arc voltage of vacuum interrupters with CuCr25 and CuCr30 contact materials are lower. So the arcing energy is lower, which is conducive to break current.

The photos of three contacts surface after breaking are shown in Fig.5. According to the effect of metal

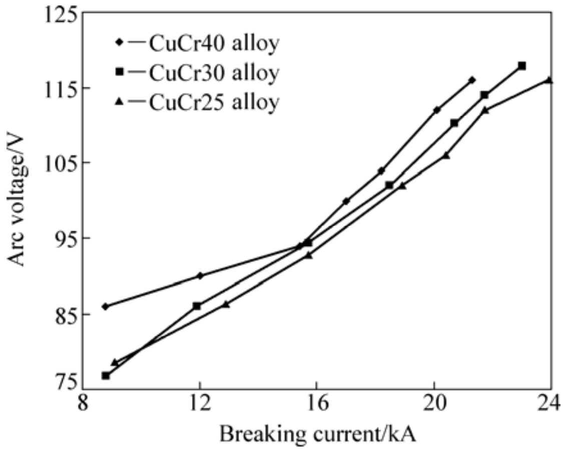

Fig. 4 Breaking current and arc voltage at current peak

gasification on the anode surface of contact, a new criterion which can predict the breaking current capacity of contact materials is given. As shown below, with the decrease of ND, the breaking current capacity increases correspondingly [17].

$$\mathrm{ND}=\frac{\phi_{a2}}{C_{\Delta 2}m_{a2}}\cdot\frac{\rho_{d1}\phi_{i1}}{C_{\Delta 1}m_{a1}\phi_{e1}}\cdot\left(\frac{m_{\Delta 2}}{\rho_{m2}}\right)^{2/3} \tag{2}$$

where $C_{\Delta}=C_p\theta_b+C_{\Delta m}+C_{\Delta b}$; $m_{\Delta 2}=m_{a2}\times 1.66\times 10^{-24}$; θ_b is the boiling point; $C_{\Delta m}$ and $C_{\Delta b}$ are the latent heat of fusion and evaporation, respectively; Φ_{a2} is the electron work function of cathode material; ρ_{m2} is the density of anode material; Φ_{i1} is the ionization energy; ρ_{d1} is the electrical resistivity of cathode material.

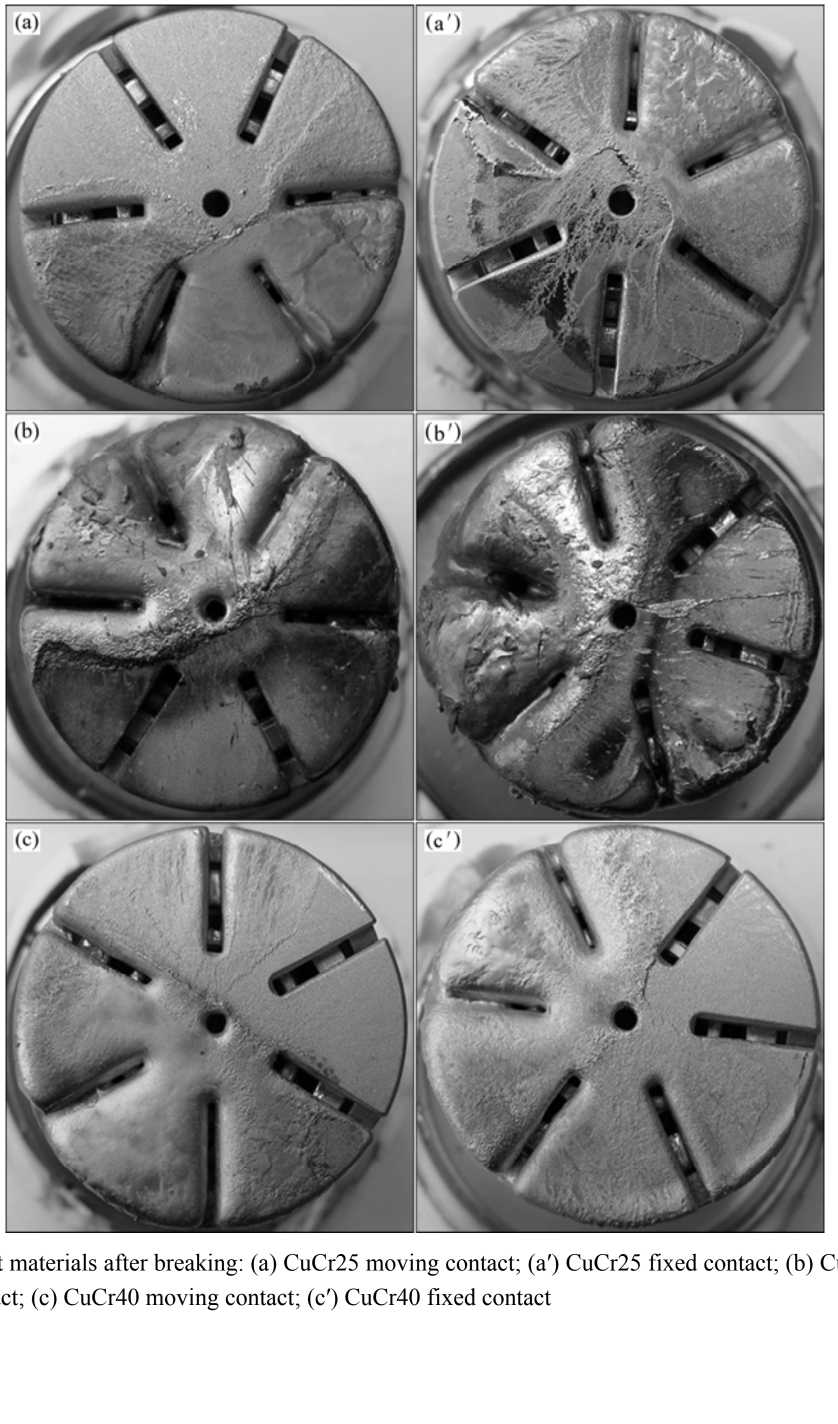

Fig. 5 Photos of contact materials after breaking: (a) CuCr25 moving contact; (a′) CuCr25 fixed contact; (b) CuCr30 moving contact; (b′) CuCr30 fixed contact; (c) CuCr40 moving contact; (c′) CuCr40 fixed contact

Based on the atomicity percentage of each element and the linear superposition principle of $X=AX_a+BX_b$, the related parameters of CuCr25, CuCr30 and CuCr40 contact materials are computed. The parameters are substituted in the criterion formula to calculate ND values. The results are listed in Table 3. The theoretical predicting result agrees basically with the test result.

Table 3 Computation results of ND

Material	ND
CuCr25	1.18×10^{-25}
CuCr30	1.34×10^{-25}
CuCr40	1.61×10^{-25}

6 Conclusions

1) The consistency of the microstructure increases and the dimension of Cr particles decreases with increasing Cr content dissolved in Cu matrix.

2) Both the electrical conductivity and the density decrease, while the hardness increases; the tensile strength increases linearly with increasing of Cr content.

3) The breaking current capacity of CuCr25 and CuCr30 alloys is almost the same, whereas that of CuCr40 alloy is the lowest.

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不同Cr含量CuCr触头材料的组织与性能对比

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摘 要：为研究Cr含量对CuCr触头材料组织和性能的影响，采用真空熔铸法制备三种(CuCr25、CuCr30、CuCr40)不同Cr含量的触头材料，并对这3种材料的显微组织、物理性能及电流开断性能进行对比研究。结果表明：随着Cr含量的增加，CuCr材料微观组织的致密度提高，Cr颗粒得到细化，但是Cu基体中固溶的Cr含量增加；材料的电导率和密度均降低，硬度增加，抗拉强度呈线性增加；CuCr25和CuCr30的电流开断能力相当，CuCr40较低。

关键词：CuCr触头材料；组织结构；开断特性

(Edited by FANG Jing-hua)