Properties and Features of Structure Formation CuCr-Contact Alloys in Electron Beam Cladding

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Abstract. The microstructure and properties of the contact CuCr alloy produced by electron-beam cladding have been investigated. The effect of the electron beam cladding parameters and preheating temperature of the base metal on the structure and the properties of the coatings has been determined. The bimodal structure of the cladding coating has been established. The short circuit currents tests have been carried out according to the Weil-Dobke synthetic circuit simulating procedure developed for vacuum circuit breakers (VCB) test in real electric circuits. Test results have shown that the electron beam cladding (EBC) contact material has better breaking capacity than that of commercially fabricated sintered contact material. The application of the technology of electron beam cladding for production of contact material would significantly improve specific characteristics and reliability of vacuum switching equipment.

Keywords: CuCr-contact alloys, electron beam cladding, breaking capacity

INTRODUCTION

CuCr alloys containing 20–50 wt.% of chromium are recognized as contact material and are therefore widely used for a vacuum circuit breakers in a medium voltage class due to their high breaking capacity, resistance to breakdown in vacuum, high electrical and thermal conductivity [1].

Both commercial and technical development of vacuum circuit breakers is aimed at improving their breaking capacity with growth of the working voltage. Increased working voltages require the solution to one of the main problems of the vacuum circuit breaker, namely the breakdown of the electrode gap by a transient recovery voltage (TRV).

Successful quenching of high-current vacuum arc is largely determined by the quality of the contact material of vacuum arc-quenching chamber. The refinement of the chromium grain in the contact alloy allows achieving higher technical characteristics of vacuum circuit breakers [2–5]. To improve the structure of contact material such methods as arc remelting of the sintered electrodes [5], preliminary melting of the contact surface alloy by laser or wide-aperture pulsed electron beam and preburning the vacuum interrupters by contact arc have been used. Processing by these methods is focused on reducing the size of the chromium phases in the thin surface layer.

The most important conditions of functional fitness and reliable operation as the contact material of a vacuum interrupter are its low gas content, the lack of porosity and high interfacial strength. The main advantage of electron beam technology [6] is that the formation of the structure of the cladding contact material occurs under conditions close to those of a vacuum arc discharge melting at short-circuits breaking currents.

EXPERIMENT

Figure 1 shows the process of electron-beam cladding. The electron beam is generated by the electron beam gun with a plasma cathode and then focused on the workpiece surface. Cladding powder is supplied from a special dispenser into the zone of the electron beam, where it is melted.

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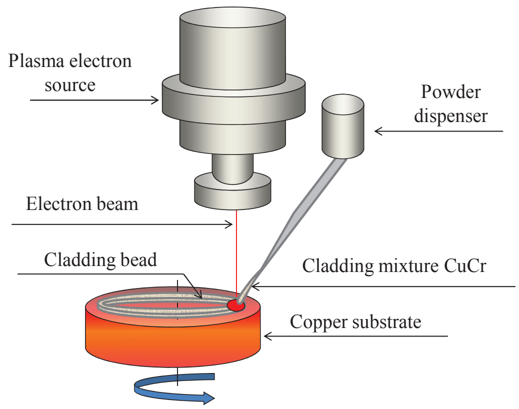


FIGURE 1. Diagram of the electron-beam cladding process

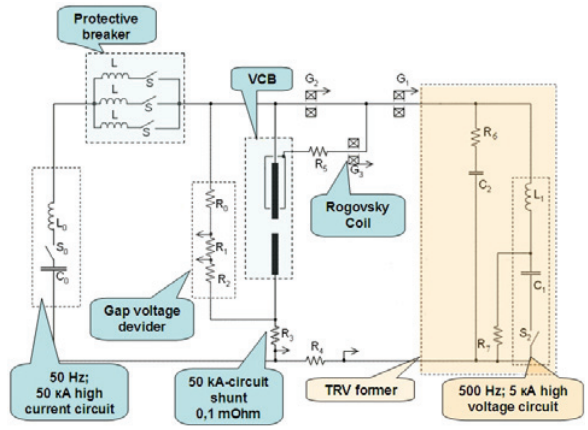


FIGURE 2. Circuit diagram of the experimental set-up

Cladding bead is formed due to crystallization of the cladding material during the movement (rotation) of the sample at a predetermined speed. The thickness of the cladding bead is determined by the speed and amount of cladding material fed per unit time. The temperature of the metal core (substrate) was monitored using a thermocouple inserted in a blind hole located in the center of the disc.

Using optical microscope Olympus GX51 equipped by an image analyzer SIAMS 700 the microstructure of the contacts was investigated. The morphology of Cr grains was examined by means of electron microscope Leo Evo 50 scanning.

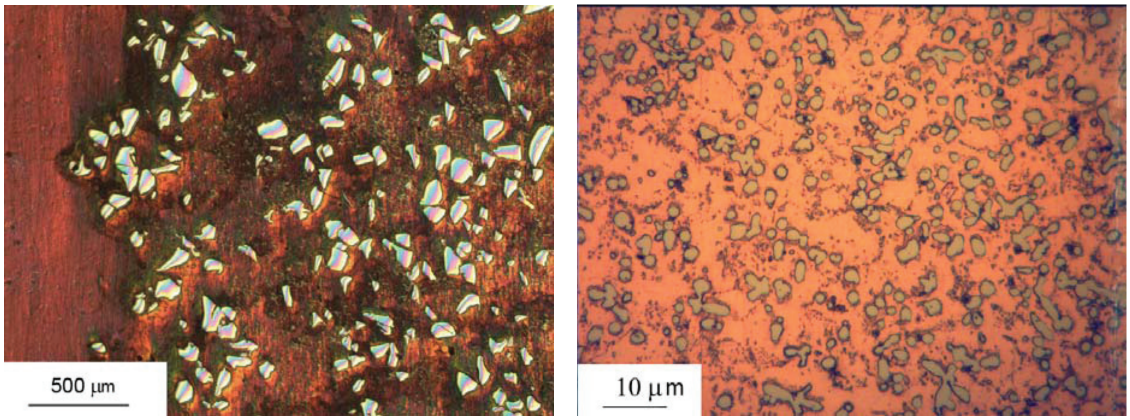
Investigations of the switching characteristics of the contact material were implemented in a vacuum chamber at residual pressure of 10^{-7} mbar at continuous pumping out by the ion pump with a pumping speed of 250 liters/sec. Experimental vacuum circuit breaker consisted of two contacts of Cu75%–Cr25% alloy, one of which is movable and the other is isolated using high-voltage bushing. The speed of movement of the movable contact was 1 m/s, and remained substantially constant during 10 ms.

Experiments were carried out on an experimental set-up, which is based on the Weil-Dobke synthetic circuit (Fig. 2).

RESULTS AND DISCUSSION

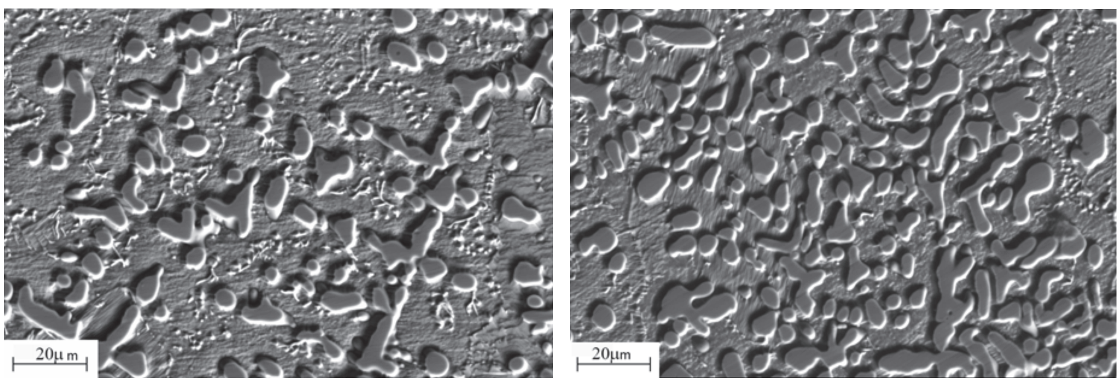
Electron-beam cladding. The major advantage of electron beam cladding as compared with powder metallurgy is the melting of powder components of alloy under vacuum conditions. Therefore, an important point in this paper is to determine the conditions of electron beam cladding and provide the most complete melting of chromium phase. For the most complete melting of chromium particles phase the power density of the electron beam not less than 104 W/cm^2 is required [6]. However, the vapor flow is formed during melting of the copper substrate by the electron beam under vacuum and may blow the cladding powder mixture away. Increasing the temperature of the substrate can reduce the power density of the electron beam and hence to reduce the vapor flow rate. The minimal substrate temperature at which the mixture manages to overcome the vapor blanket is 500°C. The primary chromium particles are completely melted at the substrate temperature not exceeding 600°C. The chromium particles preserve its original shape at the substrate temperature 800°C due to reducing the power density of the electron beam. (Fig. 3(a)).

Detailed analysis of the microstructure of Cu–Cr cladding coating reveals a bimodal structure comprising a chromium primary precipitates (3–5 µm) formed by crystallization of the melt of CuCr and secondary precipitates (0.5 µm) of chromium, which precipitate from a supersaturated solid solution in the copper matrix during dynamic aging (Fig. 3(b)).



(a) (b)

FIGURE 3. The microstructure of electron beam cladding contact material CuCr30 under *T* substrate: 800 (a), 600 °C (b)



(a) (b)

FIGURE 4. The microstructure of the cladding electron beam CuCr alloy with fine precipitates of secondary particles of chromium (SEM backscattered electrons): CuCr20 (a), CuCr50 (b)

The primary precipitations of chromium have dendrite morphology. With the increase of the volume fraction of chromium up to 50%, the morphology of chromium precipitates acquires more spherical (Fig. 4). This is due to the conditions of restricted growth of chromium dendrites.

Testing of CuCr-contacts. The breaking capacity of contacts produced by two different methods such as: vacuum sintering and electron beam cladding under vacuum has been compared. Commercially fabricated sintered contact material was made by JSC "POLEMA". Cladding contacts were made on the experimental setup with the electron-beam cladding.

The vacuum circuit breaker test has been performed according to standard methods [7]. Test conditions are given in Table 1.

TABLE 1. Test conditions

Number of Experiments	Transient Recovery Voltage, kV	Duration of the Half-Wave, ms	Duration arc, ms	β, %
7	21	12.6	11 ±1	50

TABLE 2. The breaking capacity test results for experimental and serial vacuum chambers in a vacuum interrupter

Type of Test	Polarity A	Polarity B	Polarity C	Serial Chamber Average Result
Breaking capacity test for $I_{\text{он}} = 20$ kA, $\beta_{\text{н}} = 50\%$				
Breaking current amplitude, kA	40 ± 1	40 ± 1	40 ± 1	40 ± 1
Number of successful test	7	7	7	6
Number of failed test	0	0	0	1
Endurance testing for $I_{\text{он}}$=20 kA,				
Breaking current amplitude, kA	–	–	28.2	28.2
Number of power cycles	–	–	50	50
Contact wear, mm	–	–	3	3
Breaking capacity test for $I_{\text{он}} = 25$ kA и $\beta_{\text{н}} = 50\%$				
Breaking current amplitude, kA	49.3	–	–	49.3
Number of successful test	5	–	–	1
Number of failed test	0	–	–	4

Tests VCB (Polarity A) on breaking capacity for $I_{\text{он}} = 31.5$ kA, $\beta_{\text{н}} = 50\%$ and maximum breaking capacity								
VCB (+) — successful test (–) — failed test	Breaking current amplitude, kA							
	62.8	64.3	64.3	67.3	67.3	68.0	68.0	68.0
VCB with EBC contacts	(+)	(+)	(+)	(–)	(–)	(+)	(+)	(–)
VCB serial with p/m contacts	(–)	(–)	(–)	(–)	(–)	(–)	(–)	(–)

The test results of vacuum interrupter are shown in Table 2.

The test results show that breaking capacity of chambers with contact materials Cu–Cr, produced by electron-beam cladding is 25% better as compared to that of commercial chambers with contacts made by powder metallurgy. The rest of the chambers parameters such as the chopping current, the contact resistance, and the dielectric strength do not differ substantially except the higher pressure of residual gases in the serial VCB. It should be noted that this increased pressure has a short duration. The restoration of pressure to the original level occurs within a few hours. Such a behavior testifies on the desorption-adsorption processes associated with insufficient cleaning and degassing of contact material made by powder metallurgy.

CONCLUSION

Thus, basing on the studies of the switching characteristics of the contact material it was found that the best breaking capacity had been shown by the experimental cladding contacts as compared to commercial sintered contacts.

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