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Quality assessment of the materials with electro technical purposes produced by drop stamping on their microstructure

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It is known that the materials of electrical arc-suppression contacts designed to vacuum circuit breakers in medium and high voltage (10 - 36 kV) and high amperage (20 - 100 kA) set the requirements for mechanical strength, electrical conductivity, an ability to dissipate heat, an ability to prevent the merging of the cathode spots and the establishment of a stationary electric arc when the arc suppression [1]. These requirements are met by composite materials of matrix type metal, where at the role of the electro conductive matrix copper is used, and the strengthening components are solid refractory metals such as chromium, tungsten, molybdenum, etc. It is understood that only material of certain composition with a specific microstructure is able to satisfy these demands which, in turn, depends on the technology of obtaining. Analytical expressions for the optimization of microstructure and, moreover, binding it to a specific technology have not been developed yet. The desired structure is obtained by laborious way of bench experiments and test on the actual unit of the finished contacts as part of the vacuum vessels.

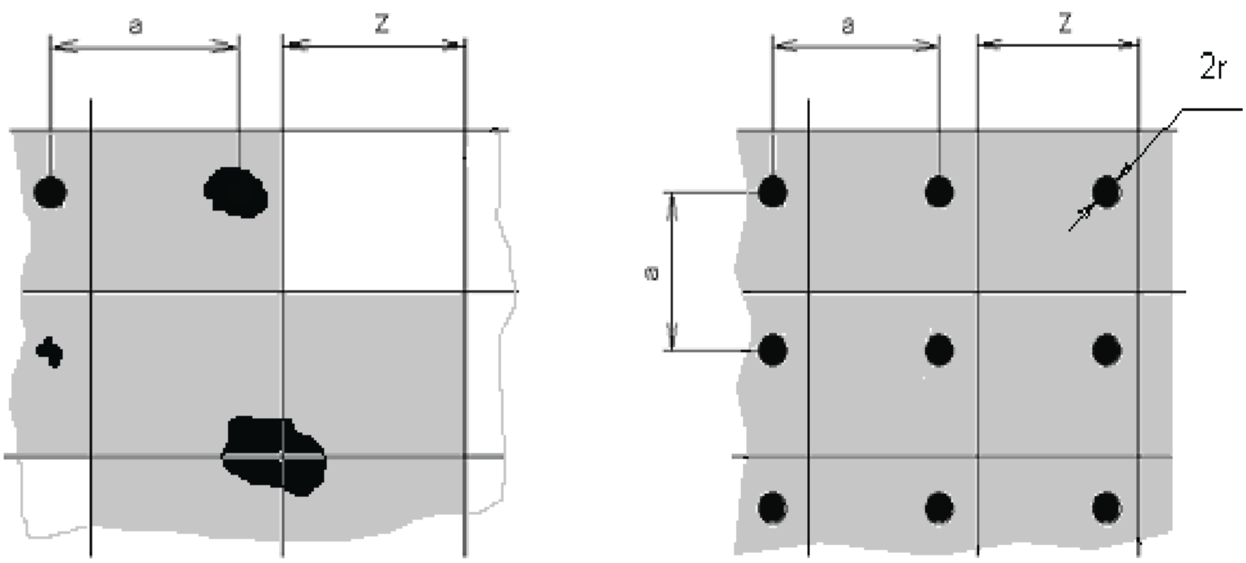
During the study of a similar material system Cr50% mass-Cu, it was found that the material produced by drop stamping technology has certain advantages over material of the same composition, obtained for a conventional for powder metallurgy by method of the previous compression to provide strength and subsequent sintering with the presence of a liquid phase (hereinafter we will refer to this method as a liquid phase sintering) [2]. But quantitative images metallography of the microstructure of these materials found no compelling reason for the existence of such advantages. Indeed, the smaller the particle size of the solid phase gave reason to expect a high mechanical strength, but did not explain the better electrical conductivity. Moreover, materials produced by drop stamping, with almost the same average particle size of a solid phase (13 - 14 microns) had a significant difference in physical properties at various ways of preliminary compact.

The distribution of the particle of the solid phase by size did not explain the difference in the properties, because the vast majority of the materials involved for research had the character close to the log-normal law. The distribution of particles according to Saltykov shape coefficient [3] has shown that in the microstructures of test materials the particles close to spherical and polynuclear forms are dominated.

The question of more objective assessment of the microstructure quality becomes relevant than quantitative metallography gives.

It has been suggested that the physical properties, in particular on the mechanical strength of the materials not only the nature of solid phase particles distribution by their size is influenced on, but also their ability to create a regular frame. This frame not only have a positive influence on the mechanical strength, but also gives electric current a guaranteed way on the matrix with high electrical conductivity, that is provided to the higher conductivity of the material.

To assess the degree of approximation to a regular microstructure for electrical arc-suppression contacts the indicator based on the geometrical characteristics obtained by quantitative metallography was proposed. In this material the real microstructure is compared with an idealized, where solid phase spherical particles with a radius r ,which is equal to half the average feret diameter (average length of the projections on the inclined axis object) corresponding to the actual structure of the particles arranged regularly at the distance a from each other equals the minimum centre-to-centre distance of the real structure particles (Fig. 1).



a)

b)

Figure 1. Calculation of indicator of the real structure approach (a) to the regular idealized structure (b)

The quantitative value of the indicator approach of the structure to the regular (or in short - the regularity indicator) is calculated as follows. Image of the microstructure is covered with conditional orthogonal grid with a cell size $z = a$. If the cell gets at least one particle of a solid phase it is conventionally painted over, for example, in black, if not we leave it unpainted, for example, white. In the particles entering the cell we understand the location of at least one point of the projection image of the particle inside the cell. The ratio of the painted cells to the number of cells in the visual field is found, i.e.

$$K_r = \frac{N_b}{N_b + N_w}, \tag{1}$$

where N_b - a number of sells painted over in black, N_w - a number of sells remained white.

This method of calculating the value of the indicator is very similar to the method of calculating the dimensions of Minkowski "box counting" [4], but the condensation of the grid and calculating the limits of mathematical expressions in this case are not performed, therefore the calculation by formula (1) is quick and easy.

As you can see, the physical meaning of the indicator structure approximation to the regular is the rate (limiting - probability) that a particle of the real structure will get in the space where the particle of idealized structure must be located [5]. It is understood that when covering of the idealized regular structure image with mesh with indicated cell size, each of them gets at least one particle at any location in the initial node of the mesh, i. e. the value of the indicator equals one. The smaller from one is the value, the more real structure is different from the regular.

Of course, other idealized regular structures can also be considered, as it is done in [5], but experience has shown that for each of the reference standard regular structures in most cases the value of the indicator of the regularity differs little or is not different at all, therefore confine ourselves to the considered case.

The proposed indicator has a significant disadvantage because it does not take into account the size of the real structure of the particles and, it is valid only for uniform distribution of their sizes. If the normalized value (1) to an average particle size of the solid phase particles as follows:

$$K_n = K_r \frac{2r}{z}, \tag{2}$$

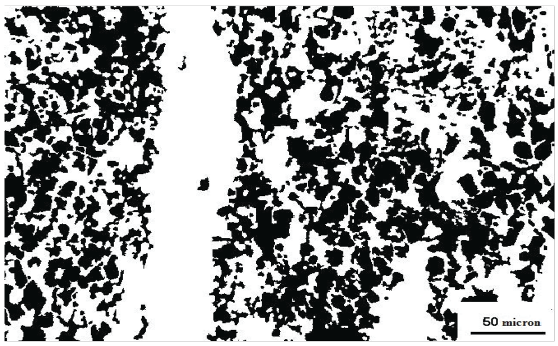
its physical meaning becomes less transparent, but this indicator is sensitive to the physical properties of the material and can be used as a criterion for the quality of the microstructure of at least one class of materials. To check the connection between the proposed indicators and the physical properties of the material, the correlation coefficient was calculated from the known ratio

$$R = \frac{COV(X,Y)}{\sigma_X \sigma_Y}, \tag{3}$$

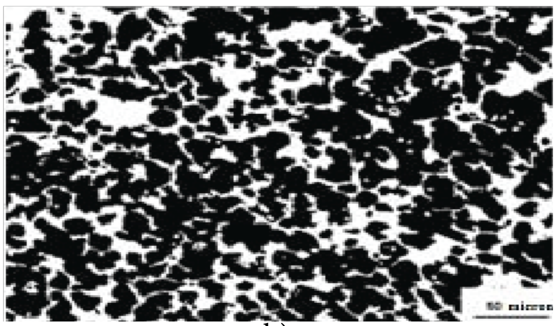
where X - an array of values physical value , Y - an array of geometric characteristics of the microstructure accepted as indicator of its quality.

The objective of the article is the experimental verification of the influence of the microstructure degree of approximation to a regular one on the physical properties of materials for electrical arc-suppression contacts.

For the studies the samples of three lots of powder materials with the composition of 50% Cr mass - Cu have been taken. Samples were obtained as follows: prepared chromium powders PH-1 and copper PMS-1 mixed in the attrition mill then pressed under a pressure of 300 - 400 MPa and agglomerated at 1150-1200 °C in hydrogen and then densified by drop stamping at a temperature of 850 ° C to the relative density 0.97-0.99 from the theoretical, followed by annealing at 650 ° C in argon for stress relief. The division into three lots was made depending on the porosity, at the same time the samples of the third lot prior to the drop stamping were densified under the pressure of 500-700 MPa at room temperature. Each lot consisted of about 15 samples. Made on samples polished sections were photographed with a digital camera, and digital images of microstructures were developed by using AMIC program [6] (Fig. 2), which allowed us to obtain data of quantitative metallography and calculated values of (1), (2) and the fractal dimensions of the microstructures [4] .



a)



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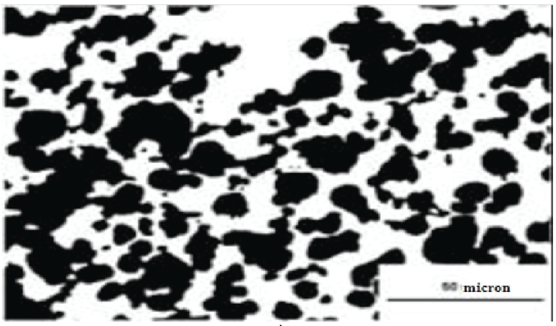

c)

Figure 2. The microstructure of materials after processing program AMIC: a - the first lot, b - the second lot, c – the third lot. The particles of solid phase are black.

Table 1. Physical properties of the materials and the geometrical characteristics of the microstructure of the samples obtained by drop stamping

Lot No	The material properties and geometrical characteristics of the microstructure							
	Density ratio	Specific electrical conductivity, ms m/m	Yield strength, MPa	Resistance to rupture, MPa	Percentage of elongation, %	Regularity indicator	Normalized regularity indicator	Fractal dimension
1	0.983	13.89±0,35	305±17	478±23	7±1	0.67	2.63	1.87
2	0,986	22.22±0,67	346±15	485±24	9.8±1	0.91	4.1	1.94
3	0.970	12.82±0,38	314±16	448±22	3.2±1	0.87	2.72	1.88

Table 2. Correlation between geometrical characteristics of the microstructure and physical properties of materials

Geometrical microstructure characteristics	The correlation coefficient between the geometrical characteristics of the microstructure and physical properties of the material			
	Specific electrical conductivity	Yield strength	Resistance to rupture	Percentage of elongation
Regularity indicator	0.544	0.777	-0.187	0.069
Normalized regularity indicator	0.987	0.988	0.604	0.787
Fractal dimension	0.972	0.998	0.540	0.736

Then in tensile tests the mechanical properties of strength indicators were determined and specific electrical conductivity of the samples was measured. Physical properties of the materials and the geometrical characteristics of the microstructure tabulated in Table.1. Based on the data of Table. 1 the value of correlation coefficient was calculated and summarized in the Table 2.

Table. 2 shows that the regularity indicator calculated by the formula (1) is weakly associated with the physical properties of materials, and cannot be used as a reliable criterion for the quality of the microstructure. Conversely, the normalized regularity indicator calculated by formula (2) and the fractal dimension are strongly associated with both the specific electrical conductivity and yield strength; several weaker with percentage of elongation, i. e. they less characterizes the ductility of the material; and even weaker with the resistance to rupture, but the connection remains visible. It is interesting that well-known Hall - Petch equation [7-9] for single-phase materials describes the growth of yield strength with the grain size decreasing. The answer to the question of whether it is a coincidence, and whether the proposed indicators are sufficiently reliable microstructures quality criteria for other classes of materials obtained by other methods, requires the further researches.

Conclusion

It is shown that the proposed normalized regularity indicator calculated by the formula (2) and the fractal dimension of the microstructure are strongly associated with critical for the materials of the electrical purposes physical properties such as the specific electrical conductivity and mechanical strength at least for the materials of Cr50% mass-Cu, obtained by drop stamping and thus, they can be used as criteria for the microstructure quality. Thus, the calculation normalized quality indicator requires significantly less time and resources, so this indicator has the advantage over the fractal dimension. The issue of the universality of the proposed indicator requires further researches.

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