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Mechanical Tests for Materials used for Achievement of Breaking Electric Contact for High Currents

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Abstract:
Breaking electric contact has been made for closing the circuits, respectively for taking over the temporary current conduction or for the long time conduction also for re-opening the closed electric circuit, putting out the current in this way.
Although the contacts are the small parts of equipment volume in which they were mounted, there are complex exigencies and obviously different from case to case.
For meeting these requirements, the electric contact must have the following properties:

- -high thermal and electrical conduction;
- -resistance to corrosion and material transfer due to electric arc between the contacts when opening and especially closing the circuit;
- -wearing resistance;
- -low and constant value of elasticity all time of operating.

There is no material complying entirely with the main requirements of electric contacts for switchgear, that's why the choosing of adequate contact material for each application imposes a compromise between the wished properties and the limit properties of materials.
Keywords: Sintering, soldering, traction, resiliency, bending.

1. Introduction

The wide diversity of the working conditions under which the electric contacts operate imposes combining by diverse technologies the electrical and thermal conductive properties of some materials like: Ag., Cu etc with the properties of mechanical strength and resistance to electric arc of other materials, either metallic ones like W, Ni etc. or non-metallic ones like graphite, metallic oxides (CdO, ZnO etc.)

The concomitant manifestation of these two contradictory properties in the contact material could be got by carrying out of two parts the electric contacts:

- active part of the electric contact (contact pellet) made of the pseudo-alloy W-Cu-Ni by means of powder metallurgy, assuring the arc resistance
- contact-support made of Cu-Ni-Si, giving a high and constant elasticity to the electric contact for the entire time of operation

In this paper, the physical-chemical tests (hardness, density, chemical composition) performed in the country on contact pellets are presented. The test results are compared to the values guaranteed for the same material executed by the company DODUCO Germany.

There are also presented the mechanical tests (tension, resiliency, static bending) on a CuNiSi alloy used as contact support. The results are compared to Cu CrZn alloy from import and CuCr alloy made at LAROMET Bucharest.

2. Materials for achieving the active part of the contact

The choice of the compound material WCu/80.20 for the active part of the contacts of SF6 high voltage circuit breakers is justified by combining in this material the wolfram refractoriness, which confers it high wearing resistance in electric arc, with especially good electrical and thermal conductivity of copper, which assures low resistivity and high heat dissipation capacity for the material.

WCu/80.20 can be produced only by processes specific to powder metallurgy, due to the high melting point of W.

For a given composition of the compound material - WCu/80.20, its performances are determined by the material microstructure, which in its turn is conditioned by the chosen technological variant and by the characteristics of the raw powders. These ones should provide a homogenous and compact structure. From here it clearly results the necessity of assuring the constancy of the raw material quality and rigorous control of the technological operation parameters.

The microstructure of the compound materials from the system W-Cu can be of two types: embedment or interpenetration.

In the first case, one of the system elements is dispersed into the matrix of the second one; in the second case, firstly a continuous lattice, with interconnected porosity, homogenous, is formed by the more refractory element and subsequently it is filled with the melted, less refractory element; it results a body formed of two interpenetrated lattices.

The second variant of microstructure provides better physical-mechanical characteristics than the first one, but is compositionally limited by the content of the more refractory element, which should be higher than 50% volume.

Because the compound material WCu/80.20 has a wolfram content more than 50% volume, it can be carried out in the variant of interpenetrating microstructure. With this end in view, the technology is chosen so as to get firstly a sintered, porous body made of wolfram, with sufficiently high mechanical strength for not disaggregating at the subsequent infiltration with melted copper. The porosity of the wolfram body should correspond to the copper volume content, provided by the composition. At the same time, it is important that the porosity to be entirely interconnected, for assuring as uniform as possible infiltration of the melted copper, in the whole mass of wolfram.

3. Quality control for the active part of the contact

The technical procedure of soldering by means of induction heating and keeping the initial characteristics of the contact support in the bending area is highly automated, due to the joining of the two temperature measuring devices within the heating equipment, and for that reason it provides the result repeatability if the technological itinerary, once established, is strictly followed. For correctly setting the technological parameters (clearance between components, shape of the joint, heating temperature, time for maintaining at constant temperature, solder, remover, pressing force etc.) and the equipment parameters (installed power, specific power, frequency, cos φ etc), there were necessary experiments followed by a rigorous destructive control for determining the composition, apparent density, hardness and porosity. The destructive control of the active part of the contact was done on experimental models achieved at Technical University – Cluj, according to STAS 4203/74 – *Faults* and STAS 10952/1-77 – *Metallographic analysis of welded joints.*

The test results are presented in Table 2. If we compare the data from Table 2 with the data from Table1, where the values guaranteed by DODUCO Company – Germany are written, we find that all the four models are within the imposed limits, model C, having the hardness 322 HV10 and density 15.905 Kg/dm^3 above the higher limit imposed by DODUCO Company. The fact that the chemical composition is within the imposed limits means that the powders of W, Cu, Ni, all from import, have been well dosed and the technological parameters (temperature, maintaining time) have been well chosen.

Table 1. Characteristics of the compound material WCu/80.20 (values guaranteed by DODUCO Company – Germany)

Chemical composition - wolfram content - nickel content - copper content	 80 ±3% ≤0.5% rest
Apparent density: (WCu)	15.6 ±0.3 g/cm^3
Hardness HV 10: (WCu)	240±40
Porosity: (WCu)	≤3 %
Average dimension of wolfram grains	10 - 15/ max 60 um
Thickness of the copper plated layer:	$1.5_0^{+0.5}$ mm
Electric conductivity: (WCu)	20 ±4 m/Ωmm^2

Table 2. Table of measurements, analyses and tests. Half-finished articles for contact pellets made of compound material WCu/80.20, Cu-plated

Part type	**Part no.**	**Average outer diameter (mm)**	**Average inner diameter (mm)**	**Height (mm)**		**Compound material WCu**				
				Total	**Of which: $h_{Cu(cca)}$**	**Chemical comp. %**		**Apparentdensity g/cm^3**	**Hardness HV10**	**Porosity %**
						W+Ni	**Cu**			
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
A	1	32.84	16.58	56.20	1.7	77.90	rest	15.421	221-236	1.50
B	1	42.34	23.18	40.26	2.8	81.26	rest	15.848	309-322	0.50
C	1	29.07	7.14	41.46	2.0	81.55	rest	15.905	285-322	0.60
	2	29.28	7.08	40.26	1.4	80.14	rest	15.631	285-297	0.87
	3	29.10	7.10	41.30	2.1	80.51	rest	15.702	297-309	0.80
D	1	35.36	16.59	29.58	1.4	79.32	rest	15.572	245-254	0.90
	2	35.91	16.65	29.00	1.7	78.02	rest	15.480	264-274	0.70
	3	35.25	16.54	28.40	1.8	78.28	rest	15.504	274-285	0.85

4. Cu-based alloys intended to achieve the contact support

The alloys intended to achieve the contact support should have a good electrical conductivity and high elasticity.

DODUCO Company –Germany uses the alloy CuCrZrF44 for achieving the contact support; this alloy has the following properties:

- hardness: 135 - 175 HV10
- conductivity: > 43 m/Ωmm^2
- softening temperature: 475^0 C.

For achieving the contact support, two alloys were used:

- alloy CuCr, STAS 11532-87 produced by LAROMET Bucharest;
- alloy CuNiSi produced by ICEM Bucharest.

According to STAS 11532-87, the alloy CuCr has the following properties:

- chemical composition: Cr (0.5 – 1.2) %, with rest;
- hardness: minimum 120 HV30 or minimum 110 Hb/2.5/62.5/30;
- conductivity: minimum 80 m/Ωmm^2 (min. 70 % of copper electrical conductivity);
- tensile breaking strength : minimum 370 N/mm^2;
- yield strength: minimum 270 N/mm^2;
- elongation: A_5 = 18 %;
- softening temperature: 475^0 C.

The material is delivered as extruded bars with diameter (Φ10 - Φ50) mm and plates with thickness (16 - 50) mm.

For getting the hardness, the material is thermally treated as follows:

- heating for putting into the solution at temperatures 1000 -1030^0 C, for 1.5 - 2h
- sudden cooling in cold water.

The time from taking it out of furnace until putting it into cold water should not exceed 7 seconds.

If the bars are deformed after hardening, they should be manually deformed before the tempering operation, because after tempering it is difficult to straighten them.

- ageing at temperatures of 450 - 475 ^{0} C, for 4.5 -5 h, followed by free cooling in air.

The alloy CuNiSi was produced by ICEM Bucharest, with a view to using it in achieving the pressure welding wires.

The mechanical properties of this material have been determined in the Laboratory for Material Strength, Faculty of Mechanics -University from Craiova.

In order to determine the mechanical characteristics of the alloy CuNiSi in the half-finished article Φ35x65, samples were taken by longitudinal cutting; they are necessary to the following tests:

- Tensile;
- Bending by single shock (resiliency);
- Static bending (deflection).

5. Testing of materials intended for carrying out the contact support

5.1. Tensile tests

The testing method was set according to STAS 200-87, and for carrying out the test, the 20 tf multi-purpose testing machine with hydraulic drive, type EDZ 20, was used within the Laboratory for Material Strength, Faculty of Mechanics -University from Craiova.

The used specimen was carried out with threaded clamps with a view to using the extending rods, necessary for fixing it in the clamping dies of the testing machine.
The initial data referring to the testing sample according to the used norm are:

d_0 = 4 mm
S_0 =12.56 mm^2
L_0 =20 mm

After performing the test:

D_n = 2.7 mm
S_n = 5.72 mm^2
L_n = 22.7 mm
F_{max} =695 kgf

Where:
- 0 index represents the initial condition of the specimen;
- n index represents the final condition of the specimen;
- F_{max} = maximum force at which the breaking of the specimen occurred.

Thus, the mechanical characteristics of the tested material result:

$$R_m = \frac{F_{max}}{S_0} = \frac{695}{12.56}[\frac{kgf}{mm^2}] = 542.8\ N/mm^2$$

$$A_5 = (L_n - L_0) \text{ x } 100\ [\%] = \frac{12.56 - 5.72}{20} \times 100[\%] = 13.5\ \%$$

$$Z = \frac{S_n - S_0}{S_0} \times 100[\%] = 54.45\ \%$$

The significance of the calculated quantities is the following:

R_m –maximum tensile load of the material;
A_5 –specific rupture elongation for $n=L_0/d_0$ =20/4=5, for short specimens;
Z – specific rupture constriction.

The quantities calculated above could be compared to a stainless steel, e.g. X10CrNiTi18,9, containing both chromium and nickel as alloying elements.
So, from the literature, it results that for the mentioned alloyed steel, the mechanical characteristics are:

R_m =550 N/mm^2
A_5 =56 %
Z =75 %

By analyzing the results, it could be seen that the maximum tensile loads are almost equal, and the specific rupture elongation and constriction for the alloy CuNiSi are lower than those for alloyed steel. However, during the tests, an aspect which should be emphasized was noticed: when the force got near F_{max}, the specimen elongation reached the value Δl=5 mm, leading to a specific deformation:

$$E = \Delta l/L_0 x100 = 5/20x100 = 25\%$$

After rupture, it was noticed that the specific elongation was 13.5% only; this shows that the material has a high degree of elasticity, with the trend to returning to the initial condition.

5.2. Single shock bending test

For determining the breaking tenacity characterized by the resiliency value, the U notch was carried out by a specimen according to STAS 1400-71, type ISO.

The test was carried out on a 30 kgfm Charpy hammer, and the rupture energy was W=5.5 Kgfm.

The resiliency was calculated to be:

$$KCU_{15/2/10} = \frac{W_{\max}}{S_0} = \frac{5.5\times 9.81}{0,8} = 67.4\ [J/cm^2]$$

which is a satisfactory value.

By visualizing the breaking section, it can be expressed as rough breaking section S_r =0.6 cm^2, as grained breaking section S_b=0.2 cm^2, respectively.
It results:

$$C_r = \frac{S_1}{S_0}\times 100 = \frac{0.60}{0.80}\times 100 = 75\ \%$$

$$F_b = \frac{S_b}{S_0}\times 100 = \frac{0.20}{0.80}\times 100 = 25\ \%$$

The conclusion which can be drawn from the two characteristics - the crystal one C_r and the grain one F_b - is that the material has preponderantly a fragile rupture resulting from the crystal characteristic C_r.

5.3. Static bending test (deflection)

By the bending, the aspect of the outer surface of the tested sample was followed and the stress resulted at a maximal imposed load was determined.

The sample resulted from the studied half-finished article has the cross section 10x8.

The moment of inertia is I_J = 426.6 mm^4, and the moment of resistance is W_Y = 106.66 mm^3.
The bending (deflection) test was performed up to a maximum force F_{max} = 1950 tf, and the distance between the propping rolls is l=50 mm.

The maximum stress bending moment will be:

$$M_{i,max} = \frac{F_{\max} xl}{4} = \frac{1950 \times 9.815}{4} = 239.12x10^3 \, [Nmm]$$

The maximum pressure in the moment when the maximum stress force is reached will be:

$$\sigma_{max} = \frac{M_{i,\max}}{W_Y} = \frac{239.12 \times 10^3}{106.66} = 2.243 \; N/mm^2$$

Until the moment of interrupting the bending at which the pressure σ_{max}=2,243 MPA was generated, no crack starting was noticed on the outer surface of the sample, showing that material breaking would be produced at a pressure higher than that one calculated above.

The sag measured during the test when reaching the maximum force was 5.5 mm.

The alloy corresponds to the stresses in the contact construction and has higher hardness than the alloy Cu-Cr, whose hardness is about 110daN/mm^2.

- chemical composition: Ni 7 %, Si 3 %, cu rest;
- hardness: min 190 HB 2,5/62,5/30;
- softening temperature: 475^0 C.

6. Conclusions

The hardness of the alloy CuNiSi is higher than that of the other two alloys. At the maximum tensile load, the alloy CuNiSi has 25 % elongation, and after breaking the elongation decreases to 13%, indicating the capacity of this material to return to its initial form. This property is essential from the point of view of the electric contact quality and reliability, because after opening the circuit, the inner diameter of the tulip assembly does not change. Otherwise, when the inner diameter of the tulip assembly increases (it returns no more to the initial form), the contact surface between the tulip assembly and arc contact decreases, the current density increases and implicitly the temperature increases too, up to values which could cause the solder melting, the destruction of the electric contacts and even the destruction of the switchgear. If during the soldering process, the temperature in the area of assembly flexure exceeds the softening temperature, 475^0 C, the support hardness decreases to values of 60 - 65 HB2.5/62.5/30 (electrotechnical copper hardness).

Two are the processes which assure the fulfillment of these two conditions:

- high vacuum electron beam welding technology, under 1.33 x 10^{-3} N/m^2;
- electric contact soldering technology by induction current heating and keeping of initial characteristics of the contact support.

Both technologies have been experimented with very good results, and the second process assures the achievement of electric contacts at a high quality level and for a low cost price.

Because the elasticity of the alloy CuNiSi is higher than that of CuCr, but the cost price is higher, the experiments have been performed with contact supports made of CuCr.

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