WC / Ag Contact Materials with Improved Homogeneity

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Summary

For low voltage switches and specific medium voltage vacuum bottles (7,1 kV / 4 kA) the contact material of choice is WC/Ag with respect to erosion resistance, chopping current and lifetime. All industrial manufacturing processes, which are established, are based on powder metallurgical manufacturing technologies. Besides the mechanical and physical properties of the contact material, the microstructure and homogeneity are essential for the arcing behaviour of the contacts in service.

For WC/Ag 60/40 contact material different treatment techniques for preparation of powder mixtures (Mixing, ball milling, planetary ball milling) to improve the homogeneity were investigated. For consolidation of samples the press – sinter – infiltration route was used and by use of micrographs an assessment with respect to homogeneity of microstructure was made. With planetary ball milling homogeneity of WC/Ag 60/40 can be improved without disadvantages on WC particle size and handle-ability of powder mixture. The observed differences in microstructure have no influence on the physical properties of the contact material.

Keywords

Contact Material, Tungsten-Carbide Silver, Powder Metallurgy, Microstructure, Homogeneity

1. Introduction

Electrical switchgears are used in the fields of power generation, transmission, distribution, and consumption. Today, vacuum switches (up to 52 kV) are the most important switchgears for power distribution. They have compact construction and are maintenance free.

The microstructures of the contact materials have an important influence on the physical characteristics and the switching performance of the contacts. In general, the requirements for electrical contacts such as high erosion resistance, low welding tendency, good electrical and thermal conductivity, or high hardness can be met by a fine-grained and homogenous microstructure. In this paper, experiments on the improvement of the homogeneity of WC/40Ag contact materials (40 weight percent Ag) are reported. Discussion of the results and conclusions are included.

2. Contact Materials in Vacuum

Depending on the application field, the applied vacuum interrupters and the contact materials used for it, can be divided into three classes: [1]

- Copper chromium (Cu/Cr) for vacuum circuit breaker and recloser vacuum interrupters.
- Tungsten copper (W/Cu) for load break switch vacuum interrupters.
- Tungsten-carbide silver (WC/Ag) for vacuum contactors.

Circuit breakers must be able to interrupt high short-circuit currents, the expected properties of contactors are long lifetime and little chopping currents.

2.1. Requirements for Vacuum Contact Materials

As in all cases of application of electrical contacts the contact materials for vacuum switching devices have to meet a variety of requirements which are:

- dielectric strength
- braking capacity and dielectric recovery
- arc erosion resistance
- service life

- current carrying capacity
- chopping current
- resistance to welding

Depending on the type of application envisaged (e.g. low voltage contactor, medium voltage circuit breaker, etc.) the requirements might be on quite different levels. For a contactor for instance, a service life of 1.000.000 or more operations at rated current may be expected. A circuit breaker for the intermediate voltage range has to stand at least 10.000 operations at rated current, and at least 30 operations in short circuit cases. [2]

2.2 Properties of Vacuum Contact Materials

Technical requirements for electrical switches and contact materials lead to contradictory material properties which can be met successfully by composite materials made by the use of powder metallurgy. They consist of a component with a high melting point, and a component with good electrical and thermal conductivity (composite material). The raw materials are metal powders and also powders of chemical compounds (e.g. refractory metal or their carbides, Ag- and Cu-metal powder).

The steps of the powder metallurgical process are mixing, pressing, sintering (time critical heat treatment below the melting point). To get full density after sintering a re-pressing step or an infiltration step is necessary.

In high and medium voltage switchgears, powder metallurgical contacts based on refractory metals or their carbides are used: WC/Ag, W/Ag, WC/Cu, W/Cu and Cu/Cr. Table 1 lists the properties of the various types of contact materials and their respective manufacturing methods. [3,4]

For application in vacuum contactors W/Cu (with 20 to 30 weight-% Cu) and WC/Ag (with 40 weight-% Ag) are mainly used. Whenever very low chopping currents are required WC/Ag 60/40 is the best material of choice. [2,5]

	Density [g/cm³]	Electrical Cond. [%-IACS]	Vickers Hardness HV	Manufacturing Method
WC/Ag 60/40	> 12,8	> 41	~ 300	Press – Sinter - Infiltration
W/Ag 65/35	> 14,2	> 48	~ 160	Press – Sinter - Infiltration
	> 13,9	> 47	~ 170	Press – Sinter - Repressed
WC/Cu 70/30	> 12,6	> 30	~ 380	Press – Sinter - Infiltration
W/Cu 80/20	> 15,2	> 35	~ 220	Press – Sinter - Infiltration
CuCr 75/25	> 7,9	> 53	~ 80	Press – Sinter – Repressed

Table 1: Properties of powder metallurgical contact materials used for high and medium voltage applications.

3 Experimental Work

3.1 Improvement of Contact Materials

Conventional WC/Ag contact material is composed of a WC skeleton filled with Ag. The arc characteristic is strongly affected by the contact material itself and depends on the homogeneity of the material. The influence of grain size of the high melting WC phase and the content and distribution of the low melting Ag phase on the interruption behaviour, reignition properties, arc erosion, contact resistance and welding behaviour are described in [6 – 10]. From experimental results it is known that with an increase of Ag content an improvement of the electrical properties is possible. With a reduction in grain size for the WC phase an improvement in welding behaviour can be reached. But contrary to these improvements, an increase of erosion rate was found.

In [7] WC/Ag contact materials with different Ag content and WC grain size were investigated. It was found, that the arc concentration and the arc motion is strongly influenced by the Ag content and the WC grain size. With higher Ag content the arc concentration is increased and subsequently the Ag evaporation is elevated. When using very fine WC powder (submicronic powder) it was found that the arc moved more widely over the contact surface as compared with conventional contact material. As mentioned above the use of finer WC powder leads to an increase of interruption ability accompanied, however, with an increase of erosion rate.

Local areas with higher concentration of WC or with increased Ag content (e.g. caused by the presence of WC- or Ag- agglomerates in the original powder mixture) can have the same effect as large single WC grains or contacts with higher Ag content. The presence of these inhomogeneities can disadvantageously affect arc moving behaviour and causes in general a reduction of interruption ability. [7]

Mainly the inhomogeneities of the material are affected by powder processing during mixture preparation. Task of the present study was to improve the homogeneity of the WC/Ag contact material by optimisation of powder processing before consolidation. The homogeneity of a contact material is defined by the degree of uniformity of the two mixed phases, WC and Ag. The homogeneity of contact materials can be influenced by:

- the grain size of the starting powders (WC, Ag)
- the mixing operation used
- the production process used for consolidation

The grain size of the WC powder is mainly given by the customer specification and is optimised with respect to minimisation of erosion rate. Typically WC powder with a grain size in the range of 1 to 5 µm (Fisher Sub Sieve Grain Size) is used [11]. The mixing operation defines the microstructure and respectively the homogeneity of the material. The mixing technique, used for preparation of WC and Ag powder mixture, has a big influence on the homogeneity of the contact material.

The production processes for consolidation and material properties are defined by the ASTM standard B-663 (see Table 2). [12] In ASTM B 663-94 the press – sinter – infiltration and the press – sinter – repress route is described. The press – sinter – infiltration route ensures the best electrical properties for WC/Ag contacts. This process produces the most densified composites, generally 97 % or more of theoretical density, it requires however high thermal energy and this results in a higher price of the contacts. The cheaper process is the press – sinter – repress route but it is difficult to obtain material with as high density as with the infiltration process. This leads to a higher content of residual porosity and gaseous impurities. Furthermore, the material has weak bonding between the WC particles caused by the repressing operation which can lead to a higher erosion rate and lower breakdown strength, respectively, coming from free WC particles on the contact surface. [13]

	Class A	Class B	Class C
Ag content [wt.-%]	38 - 42	48 - 52	63 – 67
Impurities	Total < 1%	Total < 1%	Total < 1%
Pressed - sintered - infiltrated			
Density [g/cm³]	min. 96 % of theor. density	min. 96 % of theor. density	min. 96 % of theor. density
Electrical Cond.[%-IACS]	35 – 40 %	40 – 50 %	50 – 65 %
Hardness HRB	95 - 105	86 - 96	50 - 65
Pressed - sintered - repressed			
Density [g/cm³]	min. 95 % of theor. density	min. 95 % of theor. density	min. 95 % of theor. density
Electrical Cond. [%-IACS]	not specified	not specified	not specified
Hardness HRB	60 - 70	60 - 70	40 - 55

Table 2: Material properties for WC/Ag contact materials (excerpt from ASTM B 663-94). [12]

3.2 Sample Production

For production of sample contacts the press – sinter – infiltration route was used. As starting material, WC powder and Ag powder was used.

To improve the homogeneity of WC/Ag 60/40 contact materials different treatment techniques for preparation of powder mixture – mixing, ball milling and planetary ball milling - were investigated. As parameters the milling time, milling energy and the filling ratio of the milling container were varied.

After preparation of powder mixture the contacts were cold pressed, sintered and finally infiltrated with Ag to get full density. In Figure 1 the applied production route, and variations in powder processing are schematically shown. The consolidated samples were machined to typical dimension of ∅ 25 mm and height of 5 mm.

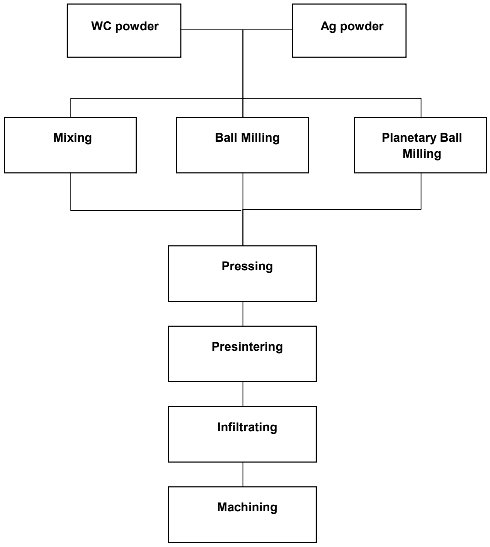

Figure 1: Principal production route for WC/Ag contact material showing the variation of powder treatment techniques (mixing).

4. Results and Discussion

4.1 Sample Contact Investigation

The homogeneity of the contact samples was investigated by microscopic examination and determination of material properties. The homogeneity of the infiltrated contact materials was discussed by inspecting micrographs with the magnification 200:1. In Figure 2 to Figure 4 the microstructure of selected sample contacts are given representing the optimum microstructure for each mixing technique, mixing, ball milling and planetary ball milling, respectively.

For determination of material properties the electrical conductivity and density were measured. For assessment of homogeneity on the micrographs the size of WC agglomerates and Ag cluster were determined. The results are summarized in Table 3. For all sample contacts comparable values for density and electrical conductivity were found. It can be supposed that the different powder processing techniques has no significant influence on the physical properties of the material and all investigated variants are according to the ASTM standard.

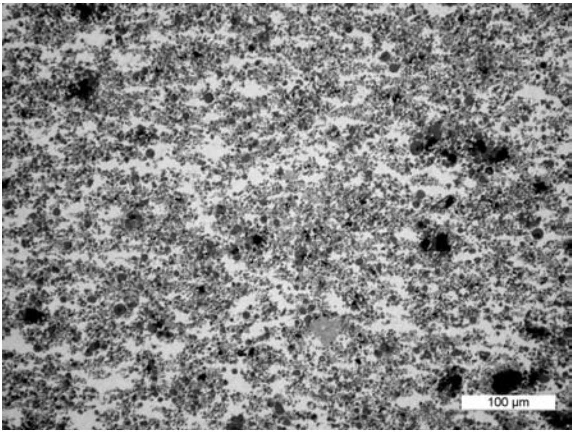

Figure 2: WC/Ag 60/40 contact material prepared by mixing (best result was obtained with short treatment time, the large dark spots are WC agglomerates and no pores)

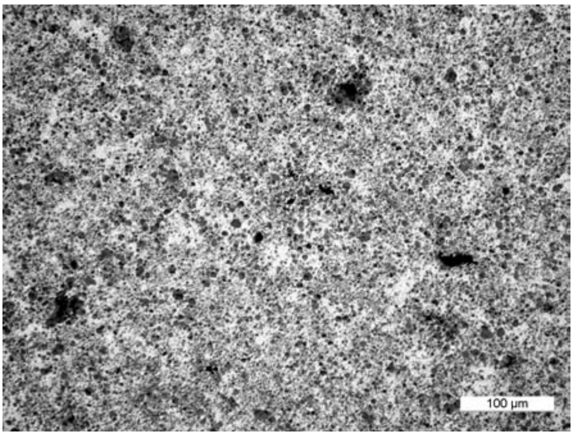

Figure 3: WC/Ag 60/40 contact material prepared by ball milling (best result was obtained with medium treatment time, the large dark spots are WC agglomerates and no pores)

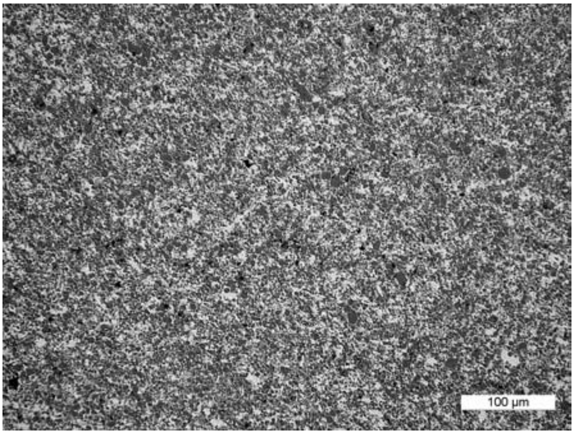

Figure 4: WC/Ag 60/40 contact material prepared by planetary ball milling (best result was obtained with short treatment time)

	Mixing	Ball Milling	Planetary Ball Milling
Density [g/cm³]	13,49	13,08	12,98
Percent of theoretical density	100 %	99,8 %	99,0 %
Electrical Conductivity [%-IACS]	45,2	45,0	43,8
Size of WC agglomerates [µm]	< 100	< 50	< 10
Size of Ag clusters [µm]	< 150 (partly 200)	< 100	< 20

Table 3: Material properties of WC/Ag 60/40 sample contacts and assessment of homogeneity (all values are acc. ASTM standard, see Table 2).

4.2 Mixing

Both raw materials, WC and Ag powder, have a tendency to form agglomerates during processing due to their small grain size. By use of standard mixing operation the energy is too low to destroy these agglomerates. During sintering and infiltration the shape of the WC agglomerates is unaffected which leads to local areas with higher concentration of WC. During sintering the Ag agglomerates melt and the formed cavities are infiltrated by Ag. After consolidation Ag clusters are formed. This material has a very good infiltration behaviour.

With standard mixing treatment the best result was obtained in respect to density after infiltration. Microstructural characterization showed a fully dense material. The contact material in the consolidated state shows an inhomogeneous microstructure with relatively large WC agglomerates and Ag clusters. These inhomogeneities are uniformly distributed over the cross section of the sample contact (Figure 2). The dark spots, visible in the micrograph, have been detected as WC agglomerates using higher magnification (SEM).

4.3 Ball Milling

The energy input during ball milling is high enough to reduce the size of the WC agglomerates. The size of the Ag agglomerates can be homogenized but not really reduced. Also with expansion of milling time no size reduction is possible. The infiltration behaviour is more or less comparable with the mixed samples. The density value is slightly lower as for the mixed powder (Figure 3).

With ball milling the size of the WC agglomerates could be reduced by a factor of 2. The Ag clusters are in the same range as for the mixed sample, but more homogeneous in respect to size and distribution. Therefore, on the micrograph an improved homogeneity can be recognized but according to Table 3 the size of Ag clusters is only insignificant reduced.

4.4 Planetary Ball Milling

With planetary ball milling the WC and Ag agglomerates are destroyed after a very short milling time. On the consolidated samples no inhomogeneities are visible and the WC and Ag phase is very well mixed. From the density measurement it is obvious that no significant difference in comparison to the other samples is detectable (see Table 3). A longer milling time leads to the formation of Ag rich agglomerates and increase of inhomogeneity. The presence of these agglomerates reduces the green strength of the compacts.

With planetary ball milling the size of the WC agglomerates and the Ag cluster is reduced to values of smaller 10 respectively smaller 20 µm, near to the origin grain size of the starting powders. It must be stated that the origin grain size of the WC powder is not influenced by the milling operation.

5 Summary

For WC/Ag 60/40 contact material different treatment techniques for preparation of powder mixtures to improve the homogeneity were investigated. For consolidation of samples the press – sinter – infiltration route was used and by use of micrographs an assessment in respect to homogeneity of microstructure was made.

Milling the powders with the planetary ball mill led to the best results concerning homogeneity. Too long milling times resulted in formation of agglomerates, consisting of WC and Ag, which decrease the homogeneity of microstructure and strength of the green compacts. For the other investigated milling techniques the energy input during processing is to low, therefore it was not possible to destroy the agglomerates which are formed during handling and processing of the powders.

With planetary ball milling, using short milling times, the homogeneity of WC/Ag 60/40 can be improved without disadvantages on WC particle size and handle-ability of powder mixture. The observed differences in microstructure have no significant influence on the physical properties of the contact material.

With regard to development of contact materials for high performance vacuum contactors this specific material property (microstructure), which is not covered by the ASTM standard, will become more and more important in future.

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