Silver Tungsten Carbide Contacts for Circuit Breaker Applications

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Abstract—**Silver tungsten carbide (AgWC) contacts are often applied to circuit breaker applications due to their good arcing erosion properties. The low material loss is beneficial for repeatable high interruption capacity. This paper characterizes the influences of contact material microstructure and sintering agents on the switching properties of AgWC40 material.**

A detailed description of the microstructure by quantitative metallurgy methods is a key aspect of this work. Furthermore, the influence of contact material microstructure and composition on the sintering shrinkage are evaluated. Model switches are applied to study the switching performance of AgWC40 materials under defined and reproducible boundary conditions. Performance parameters studied are dynamic sticking tendency at make, arcing erosion and contact resistance after break operation. Cross sections after switching are used as basis for interpretation of achieved test results.

The studies show that effects of sintering agents dominate the resulting contact resistance after arcing, while no differences in erosion can be observed at chosen overload conditions. In addition dynamic sticking tendency could be reduced by finer microstructure and reduced amounts of sintering agents.

contact material; weld break forces; contact erosion; contact resistance; silver tungsten carbide; additive

I. INTRODUCTION

Silver tungsten carbide (AgWC) contact materials are widely used as arcing contacts in circuit breaker applications. An asymmetric combination with silver graphite (AgC) stationary contact is typical for IEC standard devices, while in UL breakers AgWC is often applied symmetric [1] as movable and stationary contact.

For AgWC, as well as for other contact materials, composition, process method and parameters, and microstructure are driving the switching performance. Additives, used as sintering and infiltration agents during manufacturing, are of significant importance as well.

This paper is working out the impact of microstructure and additives of AgWC materials on switching performance and can be used as basis for proper contact material selection.

II. AGWC MATERIALS UNDER TEST

The following tests concentrate on AgWC 60-40 contact materials as a standard representative of AgWC group materials. This composition is often used as arcing contact in IEC standard MCCB or UL type MCB applications. AgWC contact materials under test were manufactured by

- blending and granulation of starting powders
- compaction
- sintering
- infiltration to final composition

AgWC materials are compacted and subsequently sintered under protective atmosphere before infiltration. Possibly existing tungsten oxides on WC surface are reduced during this sintering step. Thermodynamic calculations show that these oxides become unstable against hydrogen at typical sintering temperatures. Details on this reduction behavior have been published in [2] and [3].

During the sintering process a mechanical solidification is taking place between tungsten carbide particles. According to [4] the higher the sinter shrinkage the higher the solidification will be. This sintering effect can be significantly enhanced by using Co and Ni as sintering agents [5, 6, and 7]. The impact of these additives on sintering and possible changes in switching performance have been published in numerous papers, e.g. [8, 9]. Table I is showing the final composition and Vickers hardness of the three AgWC40 types under test.

TABLE I.   AGWC40 MATERIAL VARIANTS UNDER TEST
(FINAL COMPOSITION AFTER INFILTRATION IN WT.-%)

variant/ designation	A	B	C
Ag	60	60	60
WC	remainder	remainder	remainder
Fe	1	1	0
Co	0.7	0.7	0
Ni	0.1	0.1	0.1
hardness (HV 1)	142	177	159
microstructure	medium	coarse	fine

The material shrinkage during sintering process is influencing the porous volume that needs to be infiltrated afterwards. High-level process control is necessary during sintering to achieve the correct final material composition after infiltration.

In a first step all three AgWC powder types have been compacted to a comparable green part density. Then all materials were sintered identically. Diameters of six probes of each AgWC material variant were monitored before and after sintering. Figure 1 is showing the observed sintering shrinkages. The materials differ significantly in their shrinkage behavior. Type A is showing the highest, type C lowest sinter shrinkage.
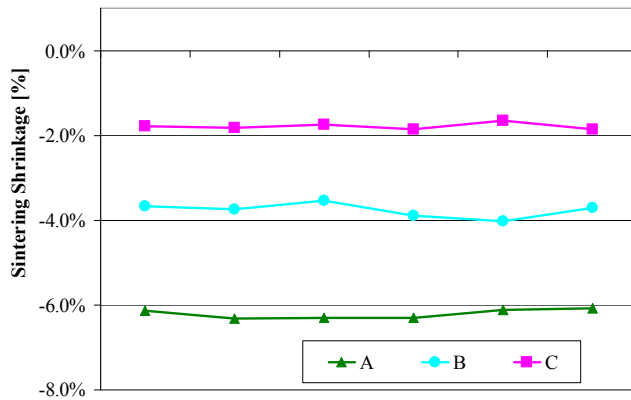

Figure 1.   Sintering shrinkage of AgWC tips before infiltration

The three types of AgWC40 materials differ significantly in their microstructure after infiltration (see Fig. 2 – Fig. 4). Quantitative metallurgy was performed to describe these differences. The certain differentiation between the material phases has high demands on metallographic preparation of the cross section and illumination uniformity [10]. The image analysis was performed by AxioVision rel. 4.8 software from Carl Zeiss GmbH. The differentiation between silver and tungsten-carbide phases is realized by the different grey scale values of these phases in the light optical microscopic pictures of the cross sections. Details on the applied analysis routine have been published in [11].

Figures 2 – 4 are showing pictures of the metallographic cross sections which have been used for the quantitative image analysis. Directly below the same pictures are shown with grey scale differentiation. Detected silver areas are indicated in color, while the tungsten-carbide phase remains grey. All particles with an area smaller than 1 μm² have been filtered out to avoid possible artifacts, as the resolution of the applied technique is limited to 1 μm².
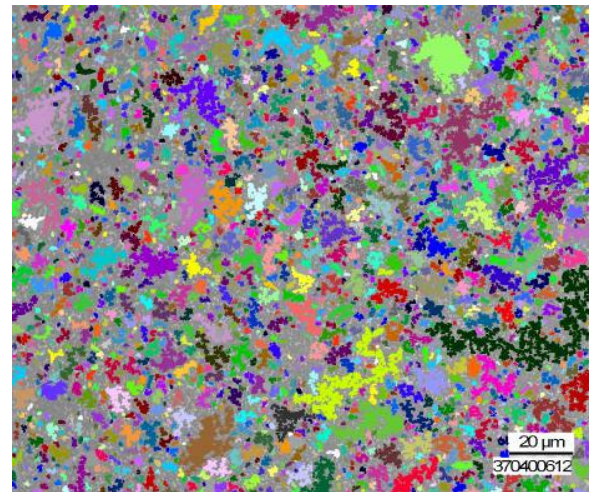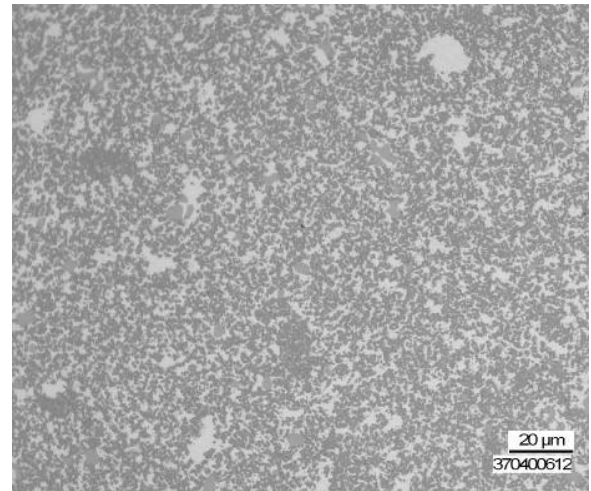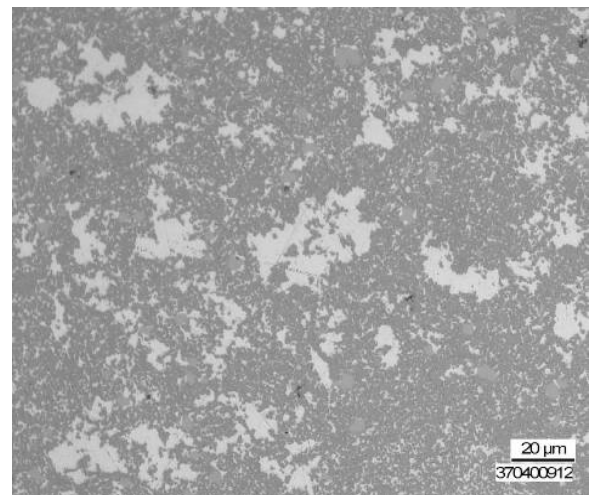

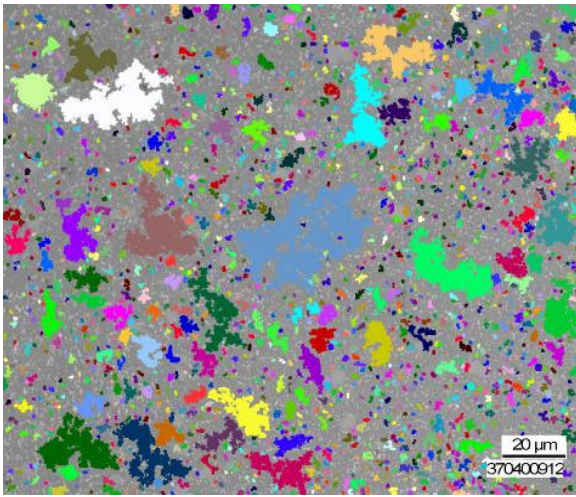Figure 2.   Cross section AgWC40 type A
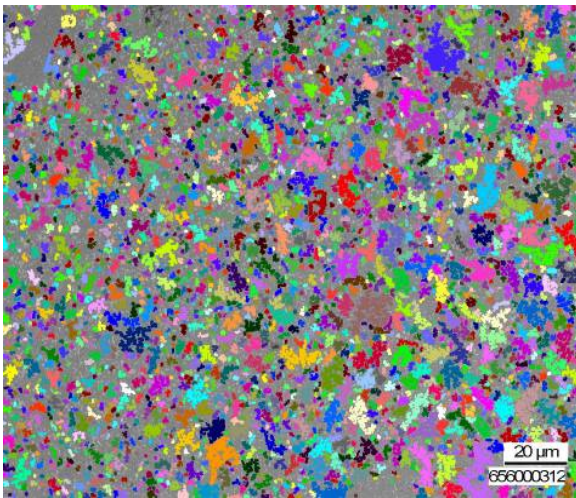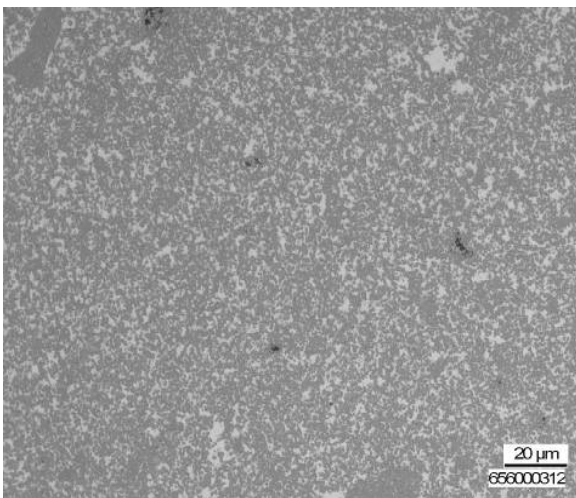
Figure 3. Cross section AgWC40 type B

Figure 4. Cross section AgWC40 type C

The software tool offers various parameters to analyze the material structure once the silver particles are identified. These are amongst others particle length, area, and circumference. In this work the maximum length of silver particles – represented by the maximum Feret diameter – was used to characterize the materials. An illustration of the measurement method is given in Fig. 5.
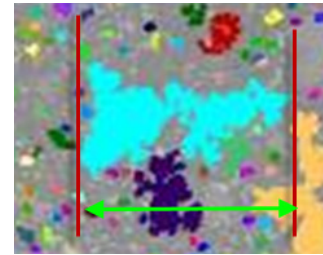

Figure 5. Maximum Feret diameter of Ag particle

The cumulative analysis of area by maximum Feret diameter of silver areas is plotted in Figure 6. The cumulative area is normalized to the total detected area of silver in the cross section. Therefore, the finest microstructure is showing the sharpest increase and is reaching the 100% value first. The 50% quantiles of silver particle size in microstructure can be geometrically derived from the diagram as plotted.
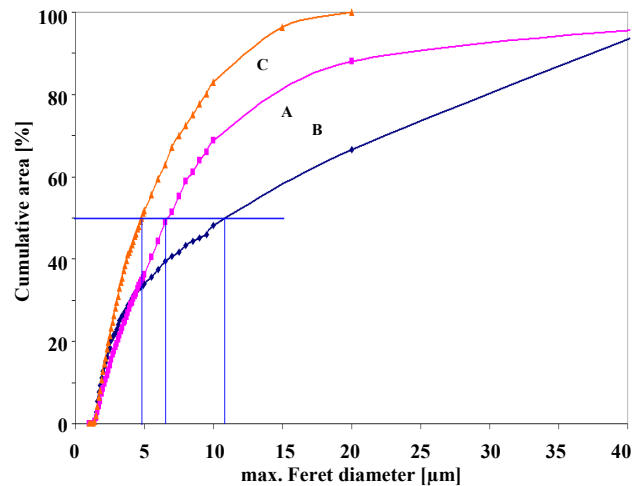

Figure 6. Cumulative area of silver over maximum Feret diameter of detected silver particle

The presented method offers a clear differentiation in microstructure among the three AgWC40 materials under test. But, attention needs to be paid to absolute values (e.g. quantiles) of grain size distribution, as all figures are shifted to higher values. There are two main reasons for this shift. First, all particles smaller than $1\ \mu m^2$ are filtered out by the resolution limit of the applied measurement system. The second reason is based on small and closely spaced particles, which cannot be separated by the measurement technique and are interpret as one single and larger silver particle instead.

AgWC40 type B can clearly be identified as the material providing the coarsest microstructure by applying the quantitative maximum Feret values from Fig. 6, which is obviously in correlation to the optical microscopy cross sections Fig. 2-4. Furthermore, the Feret diameters are showing that material type A is having a slightly larger silver areas within the microstructure compared to type C. Most probably the addition of cobalt and iron is leading to this structural coarsening. Here, quantitative metallurgy is showing its strengths in clarifying those differences in the diagram, which otherwise can hardly be seen in optical micro sections.

Having a closer look on the sintering shrinkage (Fig. 1) a relation between composition, shrinkage, and material structure can be observed. Material type C with lowest content of sintering agents is showing the lowest shrinkage during sintering with about 2%. Composition type B with high dopant contents of iron and cobalt results in 4% shrinkage even though material structure is rather coarse. The highest shrinkage during sintering, approx. 6% can be observed for material type A with high additive content and fine microstructure. In summary sintering agents and fine microstructure within the compacted powder are resulting in increased sinter shrinkage. For the chosen composition and grain sizes the effect of dopants was dominant.

III. INFLUENCE OF MICROSTRUCTURE AND SINTERING AGENTS ON SWITCHING BEHAVIOR

Application orientated tests in model switches have been used to quantify the expected material performance in circuit breaker application under stable, well defined, and reproducible boundary conditions. All switching tests have been performed with symmetrical combination of the AgWC40 types to avoid possible influences from other counter contact materials (e.g. AgC) on the results. Test parameters have been designed to simulate the behavior of a protection device (MCB) under overload conditions and are described in the following sections.

A. Material Erosion by Arcing and Contact Resistance

Break-only model switch tests have been carried out to study the aspects of arcing erosion and contact resistance after arcing. For this test closed contacts are opened in a linear movement and synchronous to natural current zero. The forming switching arc is existing for one current half wave until current zero. After current zero and arc extinguishing the contacts are reclosed without current (no arcing). Then the contact voltage drop between the two closed electrodes is measured by a current of $I = 10$ A DC at extra-low voltage. Afterwards the power supply voltage is applied again, and the model switch control unit triggers the next break operation.

The arc can be moved onto arc runners by a self-induced magnetic field. The influence of the chosen magnetic field strength B on switching performance of AgW materials was published in [12]. Further studies on the influence of the total silver content of AgWC materials have been performed in [13]. These studies were used to define the test parameters for this publication (Table II). The selected break-only test parameters were chosen to simulate the overload break operation of a

circuit breaker in correlation to UL489 Sequence X. Experiments have been performed with alternating polarity to reflect the statistical situation for an AC device and to avoid influences by material migration.

TABLE II.   TEST PARAMETERS BREAK-ONLY MODEL SWITCH

parameter	value
voltage U	230 V
current (peak value) $\hat{\imath}$	1300 A
power factor $cos\varphi$	0.35
magnetic field B	0 mT/kA
opening velocity v	0.4 m/s
number of operations n	50
contact diameter Ø	4.0 mm

The different AgWC40 types have been tested without magnetic field, i.e. without arc commutation, to stress the contact material with a constant and maximum amount of arcing energy W_{break} for every break operation. Break arc energy can be calculated in accordance to Eq. 1 by multiplying the anode-cathode voltage drop U_{AC} with the integral of current $i(t)$ during arcing time t_{arc}.

$$W_{break} = U_{AC} \int_{t_{arc}} i(t) \, dt \qquad (1)$$

For all presented experiments the average break arc energy was determined as $W_{break} = 78$ Ws.

The mass loss was determined by weighing the contacts before and after model switch test. The material erosion per switching cycle for different AgWC types is illustrated in Fig. 7.
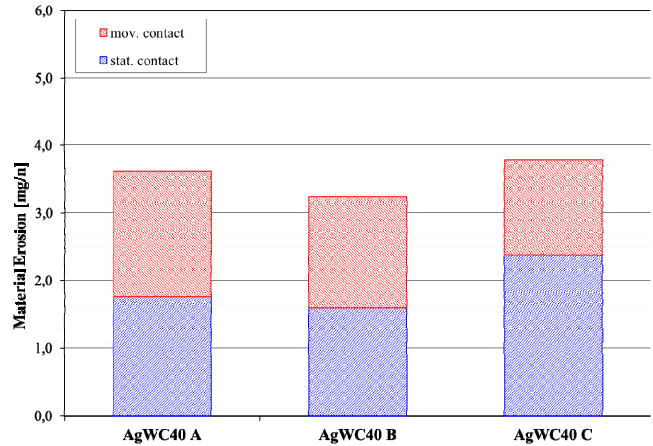

Figure 7.   Contact material erosion of AgWC40 types with different microstructure and sintering agents

The mass loss of all tested AgWC40 materials is on a comparable level, only the stationary contact of type C eroded slightly more. In comparison to other, not presented, tests with different AgWC40 materials, the material erosion values are extremely close. Therefore, no influence of the microstructure and the used sintering agents on material erosion by arcing was observed under the chosen test conditions.

After each break operation the contacts are closed without current flow, and the contact resistance is measured. Figure 8 is showing several quantiles and average values of contact resistance measurements for different AgWC40 types.
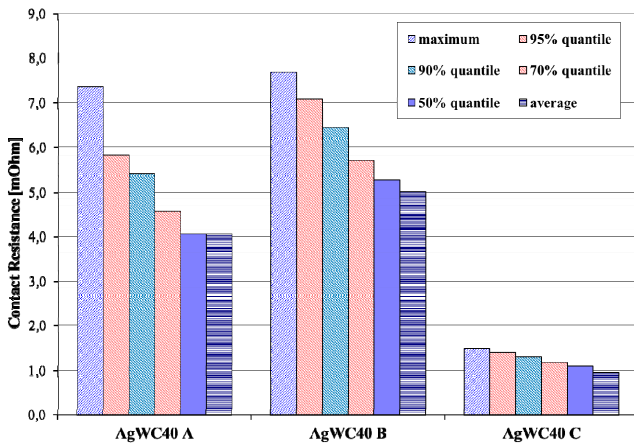

Figure 8. Contact resistance of AgWC40 types with different microstructure and sintering agents

Significant differences between the material types can be observed for their contact resistance behavior, in contrast to the erosion values. Types A and B, representing coarse and fine microstructure at high sintering agent content, are resulting in comparable values for all quantiles. Significantly lower contact resistance values after arcing can be observed for AgWC40 type C, with low content of sintering agents. Cross sections of all materials after test have been prepared for further discussion and analysis of these results and are shown in Fig. 9-11.
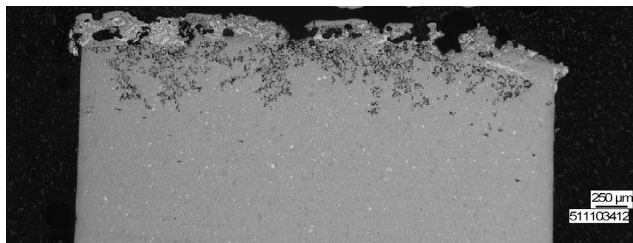

Figure 9. Cross section AgWC40 type A after break-only test
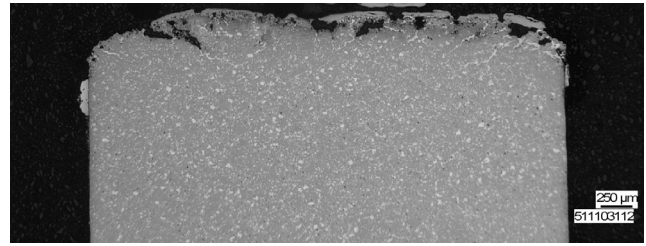

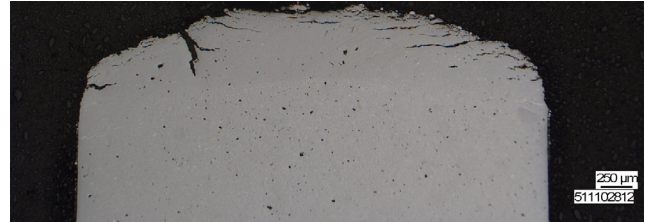Figure 10. Cross section AgWC40 type B after break-only test

Figure 11. Cross section AgWC40 type C after break-only test

Having a closer look on the cross sections significant differences can be seen in the erosion patterns of AgWC type A and B (Fig. 9, 10) compared to type C (Fig. 11). The first two types are eroding homogenous and laminar, while for type C the material loss at contact tip boundary is dominant, resulting in a spherical shape after arcing. In addition, the surface near microstructure of type C is more homogenous, showing less material disruptions at contact surface. Furthermore, tension cracks, parallel to switching surface, can be observed for type C.

Energy dispersive X-ray spectroscopy (EDS) in the cross sections is showing a significant increase of tungsten(-carbide) and sintering additives Fe and Co for types A and B, while silver is depleted in this area. Figures 12 and 13 are showing these results using the example of type A material. This hard and mechanically stable surface layer is providing a poor conductivity and can be seen as root cause for the significant higher contact resistance after arcing in comparison to type C material.
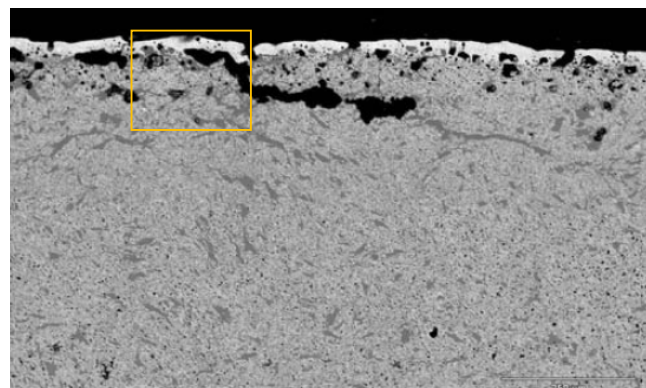

Figure 12. EDS in cross section AgWC40 type A
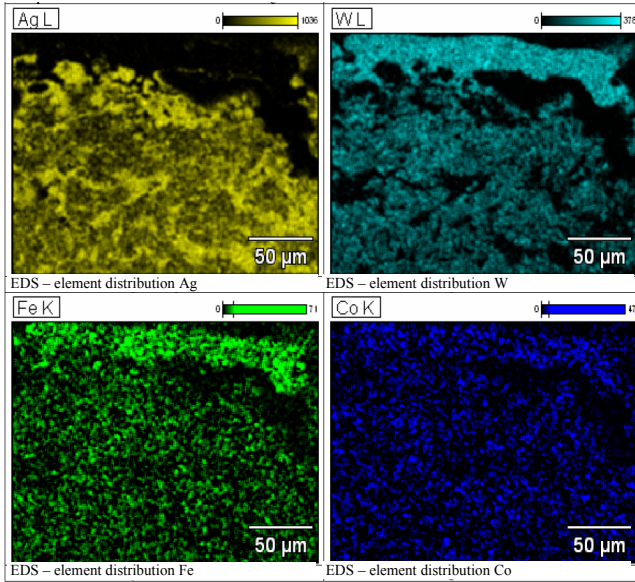(box = area scanned for element analysis in Fig. 13)

Figure 13. EDS element analysis of surface layer in cross section AgWC40 type A

TABLE III.   TEST PARAMETERS MAKE-ONLY MODEL SWITCH

parameter	value
voltage U	230 V
current (peak value) $\hat{\imath}$	700 A
power factor $cos\varphi$	0.35
closing velocity v	1 m/s
contact normal force F	3.5 N
number of operations n	300
contact diameter D	4.0 mm

Separation forces during the linear and currentless opening of the contacts can be measured via a piezoelectric force sensor. Average values and several quantiles of weld break forces, taken from two independent experiments of 300 make operations each, are plotted in Figure 14.
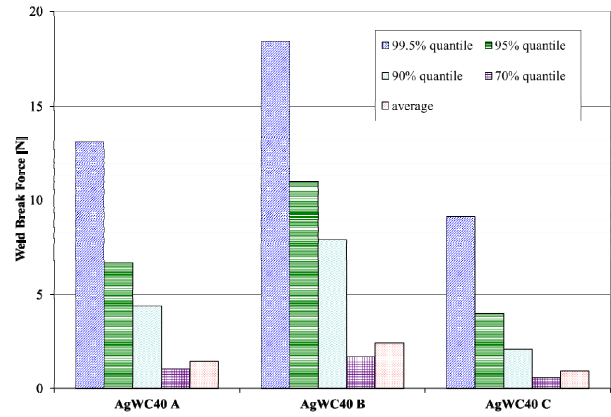

Figure 14. Weld break forces of different AgWC40 variants

The additional influence of refractory metal grain size on contact material erosion is presented in [13] using AgW as a reference material. According to [13] a decrease in average tungsten grain size is resulting in a reduced material erosion during arcing.

B. Weld Break Forces

In a second step, the influence of microstructure and sintering additives on the dynamic sticking behavior of AgWC40 materials was studied via make-only model switch tests. A detailed description of the working principle of these make-only model switch tests is given in [14]. Contacts are closed under voltage and after the initial closing event, a dynamic bouncing of the contacts appears. The mechanism of the model switch realizes a constant mechanical bounce independent of the used contact material combination. The electric arc during bouncing is leading to a dynamic welding of the two contacts. The arcing energy W_{make} that is transferred into the contact material can be estimated by multiplying the measured anode-cathode-voltage U_{AC} drop across the contacts by the integrated current (integration time = bounce time t_{bounce}):

$$W_{make} = U_{AC} \int_{t_{bounce}} i(t)\, dt \qquad (2)$$

The average arcing energy during contact bounce on make operation was observed as $W_{make} = 3.7$ Ws. All other test parameters are summarized in Table III.

Weld break forces of AgWC materials providing a fine microstructure (type A and C) are significantly below those of coarser type B in all quantiles. This result can be explained by the finer distribution of tungsten-carbide particles in type A and C materials, reducing the necessary force to separate the contacts. Comparing the two finegrain materials, lowest separation forces are observed on type C material with a low content of sintering additives and shrinkage. It appears that the weaker matrix of the less sintered WC skeleton can easier be mechanically broken, leading to lowest weld break forces in this test series.

IV. SUMMARY

Experiments on AgWC40 contact materials for circuit breaker application have been performed. Special focus was laid on the influence of contact material microstructure and sintering agents on electrical switching performance under overload conditions. The results can be summarized as follows:

- Quantitative microstructure analysis offers possibilities for detailed description of materials under test and can be used as basis for consolidated comparison.

- Additives like Co, Fe, and Ni are significantly influencing the sintering behavior of AgWC materials. Based on the sintering shrinkage data their influence is stronger than that AgWC microstructure.

- No influence of sintering agents and microstructure on arcing erosion was observed under the chosen test conditions.

- But, the usage of sintering agents is strongly influencing the contact resistance after arcing.

- In addition, a correlation between microstructure and dynamic sticking could be observed. Finer AgWC microstructure is tending to lower weld break forces.

- Lowest separation forces have been observed for AgWC materials with fine microstructure and low amounts of sintering agents.

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