Development of Contact Material Solutions for Low-Voltage Circuit Breaker Applications (2)

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Abstract— **The focus of the experimental studies was in the influence of contact material composition, production parameters and the contact material - breaker interaction, as the performance of the breaker is a function of breaker design, contact material and especially their interaction.**

Therefore, typical material combinations used for low voltage protection devices were compared by means of their switching behavior and performance. Model-switch tests have been carried out to show this performance under stable and well defined boundary conditions. The chosen test parameters simulate device tests, excluding the influence of switching device kinematics and tolerances.

Focus of the tests was to scrutinize the influence of the material composition on the erosion behavior and contact resistance for AgWC materials. Additionally a comparison on the performance of different silver refractory metals like AgW or AgMo at comparable vol.-% refractory metal was made. Furthermore, the impact of different graphite contents, manufacturing parameters and fiber orientation of AgC materials on weld break forces have been worked out.

This experimental quantification of influences can be seen as a basis for contact material selection during protection device design.

contact material; circuit breaker; silver graphite; silver tungsten; silver refractory metal

I. Introduction

The performance of electrical protection devices like circuit breakers is a function of breaker design, contact materials and most of all the interaction of both. Contact materials for this kind of application should provide excellent anti-welding behavior, low contact resistance, low erosion rates and good arc root mobility. Various solutions applying different or identical contact materials for both moveable and fixed contact are known.

Contact materials made of silver refractory metals are often used as arcing contacts due to their resistance against arc erosion [1]. Typically, the silver content for these materials varies between 30 and 70 weight percent (wt.-%). This group of materials shows relatively high contact resistances after arcing and high weld break forces.

Silver graphite (AgC) is applied as contact material for protection devices, because of its excellent resistance against welding and its low and stable contact resistance. On the other hand the material loss due to arcing is high compared to other contact materials. Typically silver graphite variants with graphite contents from 2 to 6 wt.-% are used.

A suitable contact material compromise has to be found for each breaker design solution, as already pronounced in [2]. This paper continues the experimental work presented in [3] on developing a basis to find suitable solutions by combining breaker design aspects with contact material behavior. Model switch tests have been chosen as a tool to show the behavior of different contact materials under stable boundary conditions, excluding device influences by tolerances and kinematics. Thus, a basis for contact material behavior, selection and main influences regarding protection device application was set.

II. Influences on Weld Break Forces of Silver Graphite Materials

Low weld break forces of contact materials are of significant importance for protection devices, as they must open, break and clear failure conditions in electrical networks and are responsible for personal and installation protection. In the following section the influence of material composition and production parameters on the weld break forces of silver graphite contacts will be scrutinized. Major impacts on arc movement/commutation and contact erosion of AgC contacts have already been worked out in [3]. All AgC variants applied for the following tests have been manufactured by

- powder blending
- compaction
- sintering and
- extrusion.

To study the weld break forces of different AgC variants a make-only model switch was applied. The test current is set by air coils as electrical load. A holding magnet is triggered via a controller, thus realizing a time-controlled make in the range of 0.1 ms synchronous to voltage phase angle. Contacts are closed and current flows through the contacts. A constant bouncing time of approximately 1 ms is realized by the complex mechanical setup. A piezoelectric force sensor will

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measure the weld break force at currentless opening of the contacts. Electrical parameters chosen for the test are summarized in Table I.

TABLE I. TEST PARAMETERS – MAKE-ONLY MODEL SWITCH

Parameter	Value
voltage *U*	230 V
current (peak value) *î*	700 A
power factor *cosφ*	0.35±0.05
contact force *F*	3.5 N
closing velocity *v*	1 m/s
number of operations *n*	300
contact diameter Ø	4.0 mm

The AgC variants have been used as fixed contact, while the movable contacts in all tests were made of Ag/SnO_2 88/12 SPW4 (powder metallurgical silver tin-oxide doped with tungsten-oxide). This material combination is often used for medium sized IEC miniature circuit breakers. The material used for the movable contact has no significant influence on the test results as the weld break force is dominated by the silver graphite variants of the fixed contact.

In a first test the influence of the extrusion ratio on the weld break forces has been studied. Therefore, two versions of AgC 95/5 with perpendicular microstructure (AgC _|_) but different extrusion ratios have been produced. The cross sections of the two materials can be seen in Fig. 1. For the higher extrusion ratio the band type formation of the graphite particles is more distinct. This also leads to a finer microstructure of this material, as the graphite particles are grinded with a higher intensity during the extrusion process, too.

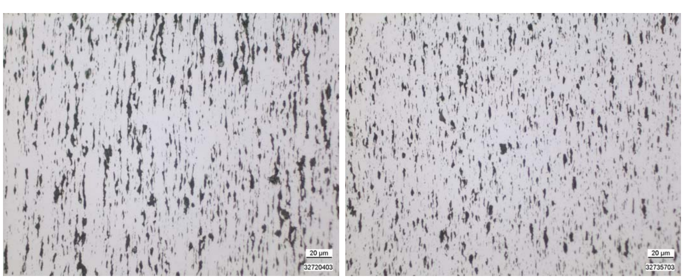

Figure 1. Cross sections of AgC5 _|_ at different extrusion ratios (lower extr. ratio, left; higher extr. ratio, right)

Different quantiles of weld break forces for the two materials are plotted in Fig. 2. The shown data is based on two independent tests with each material.

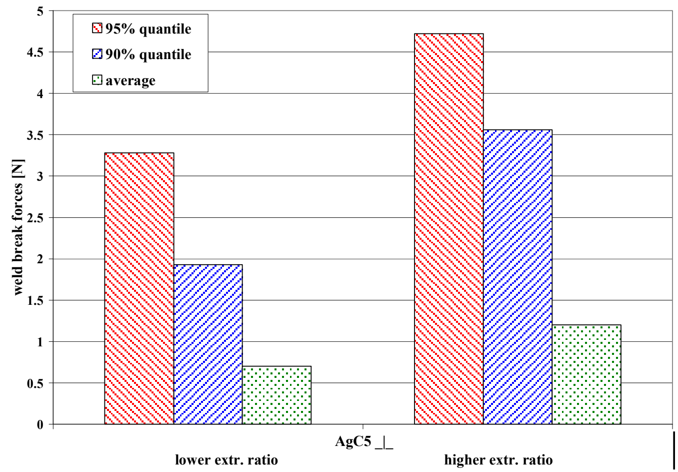

Figure 2. Weld break forces of AgC5 _|_ at different extrusion ratios

Higher weld break forces and therefore stronger welds can be found for the material providing the higher extrusion ratio. This result can be explained by the more intense material compaction during the extrusion process, leading to a stronger material matrix in the final material. The remaining silver matrix has to be broken at contact opening after the graphite is burned during the bouncing arc.

In a next step the extrusion ratio was kept constant on the higher value, but the graphite content was varied between 3 and 6 wt.-%. Densities for the different AgC compositions are shown in Table II.

TABLE II. DENSITIES OF AGC VARIANTS

Contact Material	Density [g/cm³]
AgC3	9.4
AgC4	8.9
AgC5	8.7
AgC6	8.4

The dependency of weld break forces on graphite content (Fig. 3) can be studied by make-only model switch tests. In general decreasing weld break forces with rising graphite contents have been observed with small variations in the specific quantiles of the single experiments, confirming the results presented in [4]. Doubling the graphite content leads to a reduction in weld break forces by a factor of approximately three.

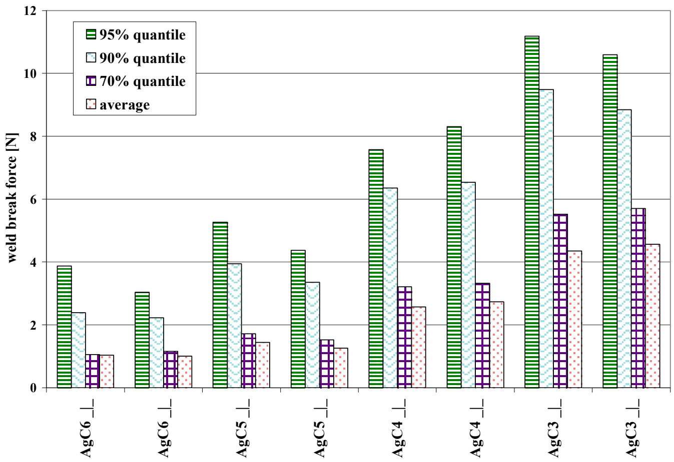

Figure 3. Weld break forces at different graphite contents

The reason for this significant decrease in the welding can be found in the microstructure of the AgC material after arcing. During the bouncing event at make operation the electric arc burns the surface near graphite at the arc root. This reaction leads to a pure silver area, which is very brittle and spongy due to the amount of gas that was entrapped in the liquid phase during the arcing event.

In a last series of make-only model switch tests the influence of the graphite fiber orientation (perpendicular and parallel to switching surface) on weld break forces has been analyzed. Again, the extrusion ratio has been kept as similar as possible. The resulting weld break forces are shown in Fig. 4.

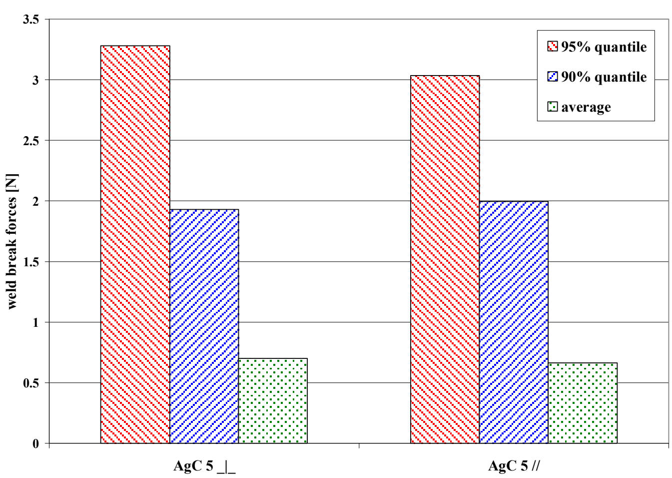

Figure 4. Influence of fibre orientation on weld break force

No significant differences regarding weld break forces have been found for the different material orientations. Slightly lower 95% quantiles for the parallel structure are a result of its flaked microstructure after arcing. Comparable results on weld break forces for switching AgC in air have also been presented in [5].

All performed tests clearly show that there is a severe influence as well of production parameters as material composition on the welding behavior of AgC contact materials. The presented effects have to be taken into consideration for material evaluation in devices and of course for contact material process changes.

III. Comparison on Switching Performance of AgMo, AgW and AgWC

Silver refractory metals (e.g. silver tungsten AgW, silver molybdenum AgMo) and silver tungsten carbide (AgWC) are commonly used as arcing contacts in protection devices. Break-only model switch tests have been performed to study the erosion and contact resistance behavior under overload conditions. All tested contacts used for the tests have been manufactured by

- powder blending
- compaction
- sintering and
- infiltration.

A detailed description of the applied model switch can be found in [3]. The contacts are opened synchronously to the voltage phase angle (at natural current zero) and the current flows for one half-cycle until next current zero. The direction of the current flow is alternated at every switching cycle. The different contact material compositions have been applied to both moveable and fixed contact for the switching test. After current zero the contacts are re-closed without current flow for a short-time contact resistance measurement at 10 A DC. Table III shows the electrical parameters chosen for the break-only model switch tests.

TABLE III. Test Parameters – Break-Only Model Switch

Parameter	Value
voltage U	230 V
current (peak value) $\hat{\imath}$	1,300 A
power factor $\cos\varphi$	0.35±0.05
magnetic field B	0 mT/kA
opening velocity v	0.4 m/s
number of operations n	100
contact diameter Ø	4.0 mm

In a first test series the tungsten carbide content of AgWC contact materials was varied between 40 and 65 wt.-% WC. The arc root stayed on the contact material for the complete current half-cycle for all tested materials as no external magnetic field has been applied. This setup was chosen to convert a similar amount of arc root energy by the anode-cathode voltage drops on all materials (approx. 76 Ws), not influenced by different arc movement and arc root commutation. The average erosion rates of movable and fixed contacts, based on two independent tests for each material composition, can be seen in Fig. 5.

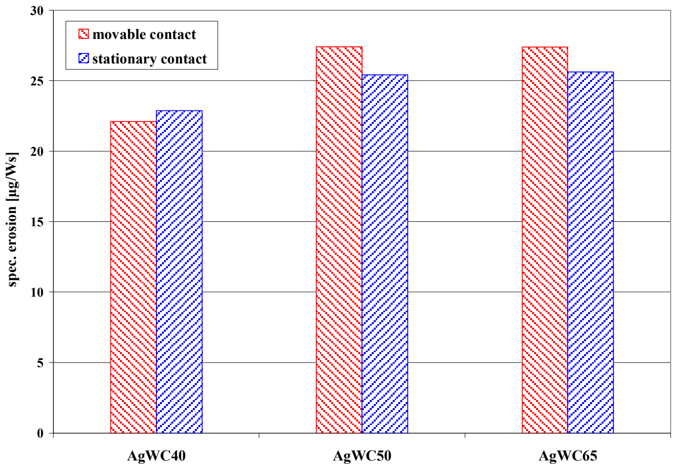

Figure 5. Specific erosion at different WC contents

Lowest material erosion was observed for the AgWC40 material, even though the material contains the lowest amount of high melting/evaporating tungsten carbide. The higher erosion of the contacts comprising the higher WC contents can be explained by the material matrix becoming more brittle, as pointed out in [1, 3], too. Therefore, this higher erosion is a result of mechanical erosion in combination with vaporization and splatter erosion.

Similar erosion rates can be noticed on movable and fixed contact for AgWC40. The slightly higher erosion on movable contacts for AgWC50 and AgWC65 in comparison to the fixed contacts can be interpreted as a result of the movable contact being the upper electrode in the vertical setup of the model switch. Molten contact material will be transferred from the movable to the stationary contact by gravity.

After each break operation the contact resistance has been measured during the test. Figure 6 shows different quantiles for the contact resistance as a function of tungsten carbide content.

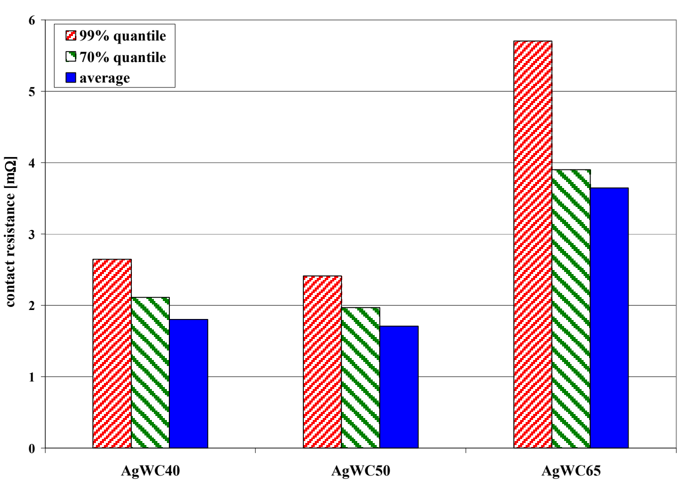

Figure 6. Contact resistance at different WC contents

AgWC40 and AgWC50 show similar values for contact resistance during this type of test. Average and maximum values – represented by the 99% quantile – are on a comparable level. Increasing the tungsten carbide content to 65 wt.-% doubles the values for all contact resistance quantiles. This sharp increase is a result of the contact surface microstructure formed by the electric arc during the break operation (Fig. 7). The break arc root forms on the tungsten carbide and evaporates the silver around. This generates a surface layer consisting mainly of tungsten, tungsten oxide and silver tungstate in all cases, which increases the contact resistance. On the AgWC65 this layer is formed in large agglomerates, as a result of the poor wetting behavior, which built up spacers with low electrical conductivity between the two contacts.

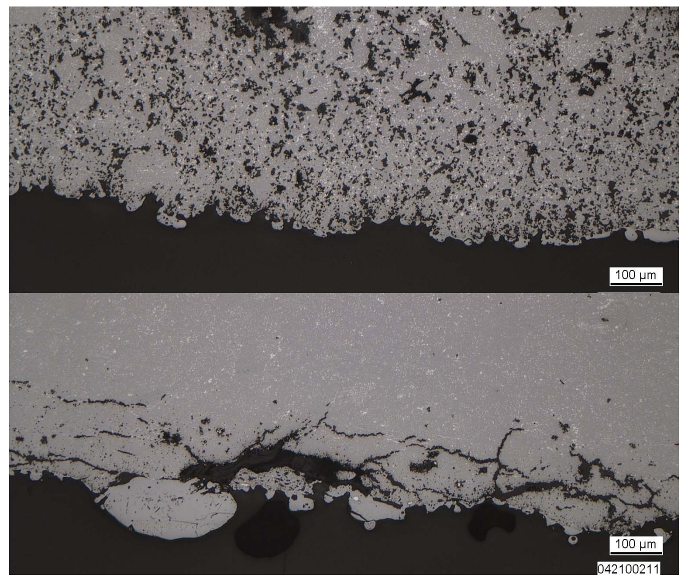

Figure 7. Cross sections of AgWC50 (upper) and AgWC65 (lower) after test

The influence of different refractory metals – tungsten and molybdenum – at constant 40 vol.-% content was also analyzed in addition to the above shown experiments with silver tungsten carbide. The content of 40 vol.-% refractory metal equals an AgWC50, with 50 wt.-% tungsten carbide. Figure 8 is showing the erosion rates of AgW55, AgMo60 and AgWC50.

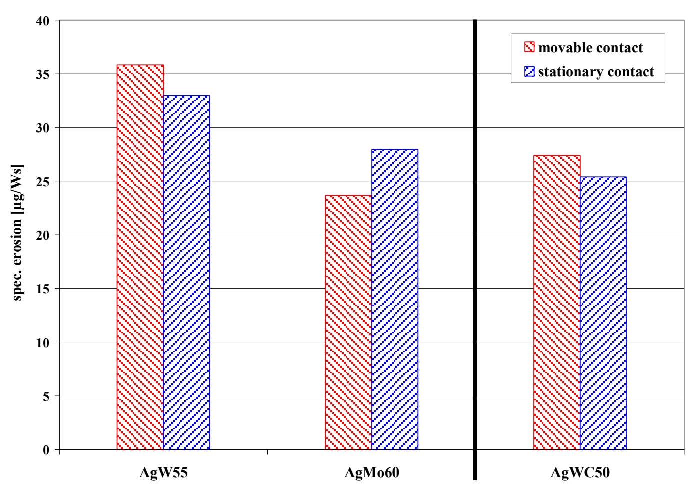

Figure 8. Specific erosion at 60 vol.-% Ag content

The material loss of AgMo60 is on a comparable level to AgWC50, while the erosion of AgW55 is approximately 30% higher. This is a result of the large mechanical cracks that are formed in the material during arcing. These cracks are formed by thermo-mechanical tension caused by the heat shock wave of the electric arc and the vaporization of silver in the heat effected zone. This effect is also explained in [6].

Related contact resistances are shown in Fig. 9. Both, AgW55 and AgMo60 show low contact resistances compared to AgWC50. The high values of single resistance values and therefore switching operations increase all quantiles for the AgMo60 material. Significantly higher contact resistances for AgWC materials in comparison to AgW materials at a peak current of 1,000 A have also been presented in [7]. Different results were found for switching in the rated current range (30 A, 110 V) presented in [8], where contact voltage drop was highest for AgW75 followed by AgMo50 and AgWC60.

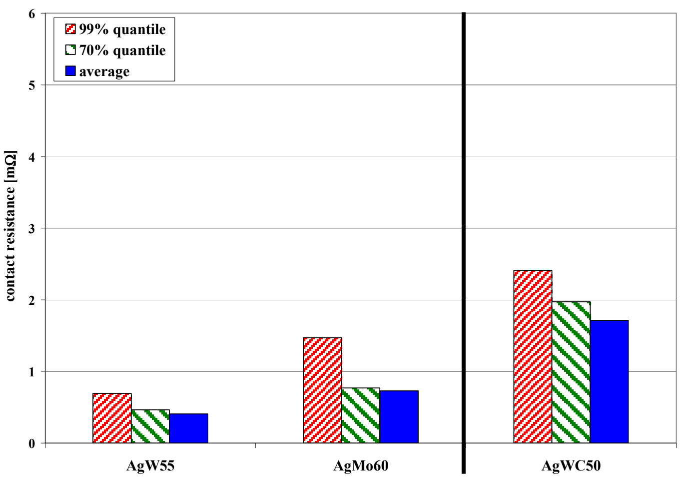

Figure 9. Contact resistance of different silver refractory metals

The low contact resistance of AgW55 can be explained by the high erosion rate. The material loss of the tungsten rich material on the contact surface results in a microstructure that provides enough silver to keep the contact resistance low (Fig. 10). AgMo60 provides a smooth, molybdenum-enriched surface layer, free from agglomerates like they have been found for WC containing materials, due to the different wetting behavior.

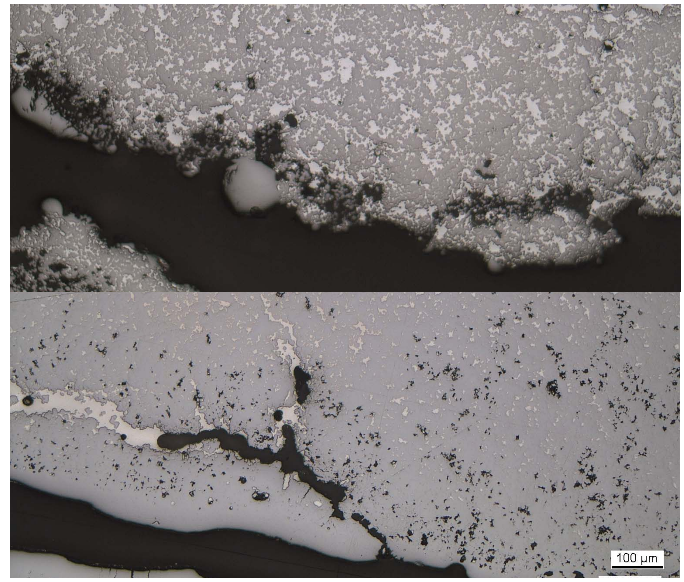

Figure 10. Cross sections of AgW55 (upper) and AgMo60 (lower) after test

AgMo60 shows the best compromise between material erosion and contact resistance compared to AgWC50 and AgW55 under the tested conditions. Further tests showed that there's a tendency towards extremely high contact resistances of AgMo at low current switching or high material losses at high current / short circuit switching [9]. Therefore, all major load and device influences have to be considered for the appropriate contact material selection.

IV. Conclusion

Contact materials and combinations as they are typically applied in low-voltage protection devices have been scrutinized. Continuing the work presented in [3] the experimental studies were focused on the influence of contact material composition and production parameters on the switching behavior. Model switch tests were chosen as a tool to acquire results under stable and well defined boundary conditions.

Graphite content and extrusion ratio have been worked out as main influence factors on weld break forces of extruded AgC materials. Of course kinematics, especially the bouncing pattern, of the switching device and electrical load conditions would affect the absolute values. The graphite orientation, parallel and perpendicular to the switching surface, had a less significant influence under the tested conditions.

Furthermore, the influence of different silver refractory metals (tungsten and molybdenum) and tungsten carbides on material erosion and contact resistance under overload conditions ($\hat{\imath}$ = 1,300 A) was studied. Increasing contact resistances at comparable erosion rates were observed for rising tungsten carbide contents on AgWC materials. AgWC40 showed the best compromise between material loss and contact resistance. Therefore, AgWC40 is one of the most often applied arcing contact materials in modern circuit breaker designs.

AgW showed higher erosion rates than AgWC and AgMo materials due to the intensive formation of mechanical cracks. On the other hand this high materials loss avoided the formation of tungsten-rich surface layers and kept the contact resistance low. AgMo showed single values of high contact resistance as a result of better wetting behavior and therefore closed molybdenum enriched surface layers.

Finally, switching device, load and contact material build a system of interacting components. These single influencing factors have always to be seen in their combination for selecting appropriate contact materials and interpreting switching test results.

REFERENCES

[1] P. Slade, "High Current Contacts: A Review and Tutorial," 21st International Conference on Electrical Contacts (ICEC), Zurich, Switzerland, 2002

[2] C. Lambert , G. Cambon, "The Influence of Manufacturing Conditions and Metallurgical Characteristics on the Electrical Behaviour of Silver-Graphite Contact Materials," 9th International Conference on Electrical Contacts (ICEC), Chicago, IL, USA, 1978

[3] T. Mützel, P. Braumann, R. Niederreuther, "Development of Contact Material Solutions for Low-Voltage Circuit Breaker Applications (1)", 25th International Conference on Electrical Contacts (ICEC) & 56th IEEE Holm Conference on Electrical Contacts, Charleston, SC, USA, 2010

[4] K.-H. Schröder, E.-D. Schulz, "On the Influence of the Production Method on the Erosion and Welding of Contact Materials for Power Engineering," 7th International Conference on Electrical Contacts (ICEC), Paris, France, 1974

[5] E. Vinaricky, "Das Abbrand- und Schweißverhalten verschiedener Silber-Graphit-Kontaktwerkstoffe in unterschiedlichen Atmosphären," Diss., TU Wien, 1994

[6] P. Slade (editor), "Electrical Contacts: Principles and Applications," Taylor & Francis Group, 1999, pp 710-714

[7] M. Lindmayer, M. Roth, "Contact Resistance and Arc Erosion of W/Ag and WC/Ag," IEEE Transactions on Components, Hybrids and Manufacturing Technology, Vol. CHMT-2, No. 1, March 1979

[8] C. Leung, H. Kim, "A comparison of Ag/W, Ag/WC and Ag/Mo electrical contacts," 29th Holm Conference on Electrical Contacts, Chicago, IL, USA, 1983

[9] J. Shea, "High Current AC Break Arc Contact Erosion," 54th IEEE Holm Conference on Electrical Contacts, Orlando, FL, USA 2008

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