High Performance Tungsten Copper Materials Produced by Spark Plasma Sintering For Using as Arcing Contacts in Power Circuit Breakers

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Highlights

- W–Cu 75–25 and W–Cu–Ni 75–24–1 advanced materials were developed efficiently by SPS.
- W–Cu materials yielded superior thermal and electrical properties than W–Cu–Ni materials.
- Functional electrical tests qualified W–Cu materials for using in power circuit breakers.

1. Introduction

The development of high performance tungsten-copper (W–Cu) materials for arcing contacts in HV and MV power electrical apparatuses is a major concern both in industrial and academic media. W–Cu materials are produced by powder metallurgy (PM) techniques due to the lack of mutual solubility between W and Cu on the whole range of compositions or very low solubility (<10^{-3} at.%) and poor wetting of W particles by Cu [1]. Field-Assisted Sintering Technology/Spark Plasma Sintering (FAST/SPS) is a versatile PM method to produce novel advanced materials. It involves low voltage, pulsed (on-off) high DC current and uniaxial pressure assisted sintering to consolidate powder compacts. The sample and the die are heated directly by DC current pulses in cycle times of a few minutes with low energy costs. Accordingly, the sintering activity is improved along with high materials densification and reduced grain growth due to Joule heating, plasma generation, electromigration, a.o. processes that occur on the contact points between the powder particles [2-9]. In this study, SPS process was employed to produce highly dense W–Cu materials with improved properties and their using as arcing contacts in MV minimum oil circuit breakers (MOCBs). The achieved results revealed their potential to be introduced into practical applications in the field of electrical engineering.

2. Methods

The starting composite powders of W–Cu 75–25 and W–Cu–Ni 75–24–1 were prepared in conditions shown by us elsewhere [9]. The powder compact placed inside a graphite die was processed in vacuum in a FCT Systeme GmbH installation of HP D25 type with programmable DC pulse source, using uniaxial pressing force of 140±1 kN at sintering temperature (T_s) of 1050±1°C, dwell time at T_s of 30 min, heating rate of 75°C/min, 12:2 on:off DC pulses and total cycle time of ~1 h. Physical and mechanical properties of resultant disks (Ø x h of 50 mm x 6 mm) were investigated as we detailed in other study [9]. Static (R_s) and dynamic contact resistance (R_d) tests were performed according to the standard IEC 62271-100 using an ISA CBA 1000 circuit breakers analyzer connected with a MOCB of IO 24 kV type (rated voltage of 24 kV) equipped with arcing contacts previously processed in final shape and size from the SPS-ed materials. R_s was determined by measuring the resistance at I_{max} of 200 A after plugging the fixed arcing contact into the tulip contact. For R_d, it was measured the time to reach R_s and the resistance variation on the whole cycle.

3. Results and discussion

Table 1 summarizes mechanical, thermal and electrical properties (mean values) of SPS-ed materials.

Table 1. Properties (H_{IT} – indentation hardness, HV – Vickers hardness, E_{IT} – Young modulus, α – thermal diffusivity, C_p – specific heat, λ – thermal conductivity, R_s – static contact resistance, t/Rd – time/dynamic contact resistance) of SPS-ed materials.

SPS-ed material	**H_{IT} (MPa)**	**HV**	**E_{IT} (GPa)**	**α ($mm^2 \cdot s^{-1}$)**	**C_p ($J \cdot g^{-1} \cdot K^{-1}$)**	**λ ($W \cdot m^{-1} \cdot K^{-1}$)**	**R_s (mΩ)**	**t/R_d (ms/mΩ)**
W–Cu 75–25	3087-3426	291-323	169-184	83-85	0.186-0.188	221-230	0.12	2/0.12
W–Cu–Ni 75–24–1	3332-3753	315-354	180-192	49-50	0.191-0.202	136-145	0.13	3/0.13

The relative densities above 97% were also obtained since the pulsed DC current contributed to surface activation of powders. Under pressure and electric current assisted sintering, localized necks are formed faster around the contact area between the particles due to Joule heating and spark plasma effects [2-9]. Then material densification was obtained in short cycle times. W–Cu–Ni 75–24–1 materials yielded superior hardness but inferior thermal and electrical properties in comparison with W–Cu 75–25 materials. This is due to the addition of 1 wt.% Ni into W–Cu composites that decreased sintering activation energy and improved wetting of W and Cu particles during sintering. Our results agree with other literature studies [7-9]. Figure 1 depicts electrical test results for R_s and R_d determinations for W–Cu 75–25 arcing contacts tested in a MOCB of IO 24 kV type. Similar results were found for W–Cu–Ni 75–24–1 arcing contacts.

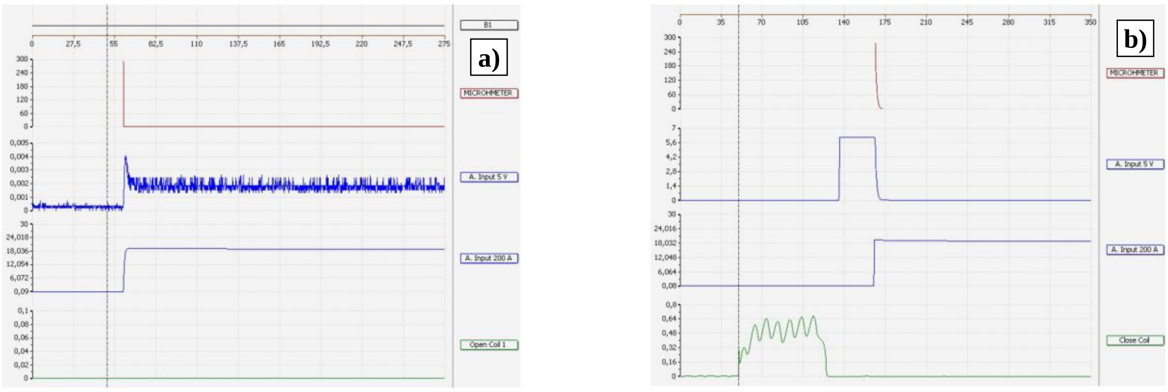

Figure 1. Electrical test results for (a) R_s and (b) R_d for W–Cu 75–25 arcing contacts tested in a MOCB of IO 24 kV type.

W–Cu 75–25 contacts showed better electrical behavior in terms of R_s (R_s of 0.08 mΩ after 150 ms from "Start", constant R_s with current variation) and R_d (R_d of 0.10 mΩ at cycle end, after 150 ms from "Start") without material damage (microcracks, breaks). W–Cu–Ni 75–24–1 contacts had R_s of 0.22 mΩ after 150 ms from "Start", relatively constant R_s with current variation and R_d of 0.22 mΩ at cycle end, after 130 ms from "Start". R_d variation at making contact decreased linearly with high slope of 10 ms for both materials. All arcing contacts exhibited a good behavior at breaking electric arc in mineral oil. The mean R_s values (0.12-0.13 mΩ) obtained for both types of composites are lower than the maximum value (0.2 mΩ) required for the validation of W–Cu materials as arcing contacts in MOCBs or SF_6 CBs.

4. Conclusions

W–Cu 75–25 and W–Cu–Ni 75–24–1 advanced materials were developed successfully by SPS. Properties investigation revealed enhanced properties for all materials. Ni free W–Cu materials had lower hardness and higher thermal conductivity. Static and dynamic contact resistance tests in MOCBs of IO 24 kV type exhibited a good functional behavior of the arcing contacts made from the SPS-ed composite materials.

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Keywords

tungsten-copper composite materials; arcing contacts; spark plasma sintering; static and dynamic contact resistance