A Review on Electrical Performances of Nanocrystalline Contact Materials

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Nano technology is one of new areas in material developments, and nanocrystalline contact materials, such as CuCr and AgSnO2, may have different electrical performances from microcrystalline contacts. A review is made in this paper to compare performance differences between nanocrystalline and microcrystalline contact materials, including arcing durations, welding behaviors, chopping currents, breakdown voltages, and breaking capacities.

Keywords: welding, electrical contact, arc duration

1 INTRODUCTION

Contact materials play a dominant role in electrical switching devices such as relays, contactors or circuit breakers. Previous researches indicated that decreasing their grain sizes can improve their performance properties, and nanocrystalline contact materials may show better performances as compared to microcrystalline materials, such as higher voltage withstanding abilities, lower chopping currents and higher welding resistances [1-9]. However, some conclusions on performances of nanocrystalline materials were contrary with each other in different literatures. For example, nanocrystalline materials were reported to show higher breakdown voltages in [7], but it was reversed in [6]. Many papers on fabrication of nanocrystalline contact materials can be found, but only a few can be found on electrical performance comparisons between nano/micro crystalline materials. For example, only 27 papers were found in the electronic resources Engineering Village and IEEE Xplore digital library with combined search words “nanocrystalline”, ”arc” and “contact material”. The 12 papers among these 27 are closely related to electrical performance comparisons of nano/micro crystalline, and they mainly focused on CuCr. Until now researches on nanocrystalline contact materials are not enough and it is not clear if those materials are suitable to be used in real power switching devices. This paper is a review to introduce progresses in this area.

2 WELD OF NANO-MATERIAL

Generally, the smaller grain size of materials is, the less welding force of contact becomes [1-2]. Fig.1 shows welding force characteristics for different grain sizes of Ag in $AgSnO_2$ with 230V and power factor cosφ=0.35 [2], indicating finer Ag grain sizes lead to smaller welding force [2], where Ag powder designated as F(<2μm), M(4-6μm), C(8-10μm) and VC(10-15μm) [2].

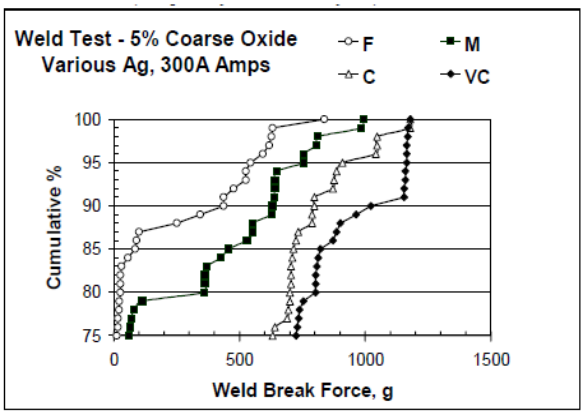

Fig.1: Welding force vs. Ag grain size [2]

Data in Table 1 show welding characteristics of nanocrystalline and microcrtalline contact materials CuCr25 in vacuum at DC42V/10A, where N denotes nanocrystalline (grain size 100--500nm) and M represents microcrystalline (grain size 50--120μm) [3]. The larger operation number before welding leads to a higher welding resistance. It is indicated that nanocrystalline material shows higher welding resistance than microcrystalline material. This results agree well with results in Fig.1

Fig.2 showed phenomena that are contrary to those in Fig.1 and Table 1[2]. Specifically, an unexpected trend of higher weld strength was found in fine SnO2 and fine Ag (F-F) in the low oxides compositions of AgSnO2, where tin oxides with a 50% size of 0.8 μm and 3 μm were defined as F(fine) and C(coarse), respectively[2].

Table 1: The anti-welding characteristics of nano/micro-CuCr25 in vacuum.

Contact pair No.	Operation number before welding	Average operation number
1# N-CuCr25 2# N-CuCr25 3# N-CuCr25	2110 1989 2319	2139
4# M-CuCr25 5# M-CuCr25 6# M-CuCr25	1819 1382 1633	1611

Thus, these experimental results show that contact materials with finer grain sizes will not necessarily provide lower welding forces, and further researches are required to identify whether nanocrystalline contact materials can always exhibit higher welding resistances.

3 ARC DURATION

Table 2 shows the characteristics of breaking arc durations for Nano/Micro CuCr50 at DC24V/10A in vacuum [4], indicating that nano-CuCr50 has longer breaking arc durations than micro-CuCr50. Table 3 shows the characteristics of breaking arc durations Tb of Nano/Micro CuCr25 with DC42V/10A [3], showing good agreement with results in Table 2. The parameters for Nano-CuCr50 are: grain size of Cr 0.1-0.5μm, melting point 1346K, specific heat 3.3 J/(g·K), thermal conductivity 192.3W/(m·K); those for Micro-CuCr50 are 50-120μm, 1349K, 3.0 J/(g·K), 266.6 W/(m·K), respectively.

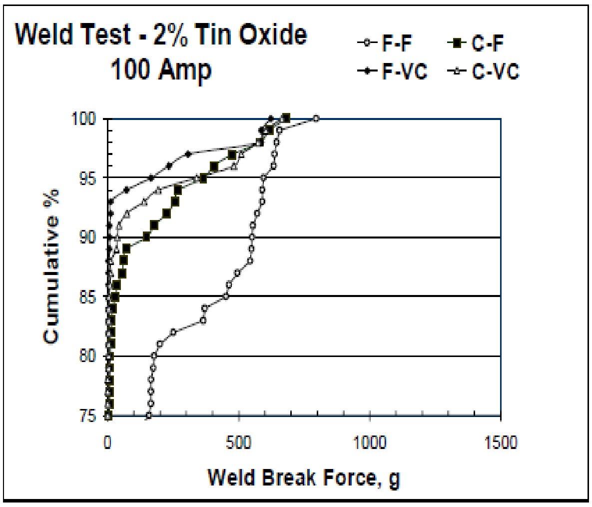

Fig.2: Weld force vs. grain sizes of Ag and SnO2

Table 2: Average breaking arc durations for Nano/Micro CuCr50[4]

Materials	Nano-CuCr50			Micro-CuCr50		
material No.	1#	2#	3#	1#	2#	3#
Average arc duration/ms	4.0	4.3	3.1	2.3	2.8	2.3

Table 3: Break arc durations Tb of nano/micro CuCr25 materials

Materials	Nano-CuCr25			Micro-CuCr25		
material No.	1#	2#	3#	1#	2#	3#
Tb /ms	28.8	22.1	25.0	9.8	11.3	15.3

Fig.3 shows the experimental results in [5] with two different electrode sizes; one pair is with electrode diameter of 12mm, while the size for the other pair is 25mm. Both AC breaking arc voltage and energy of nano-CuCr25 are smaller than those of conventional micro CuCr25 with the same arc current, opening speed and contact diameter [5]. This means that nano-CuCr25 break arcs are less likely to be easily extinguished than micro-CuCr25 break arcs.

In summary, the breaking arc durations of Nano-CuCr are longer than those of Micro-CuCr. The possible reasons are as follows: a lower thermal conductivity of nano-CuCr causes temperature of contact to become higher; and, their fine grain size surface may be easily vaporized.

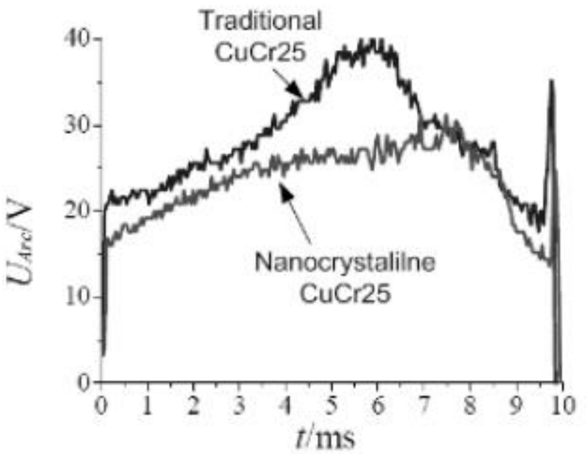

Fig.3: Arc voltage vs. nano/micro material

4 BREAKING CAPACITY

From the experiments in [5], an anode spot that first appeared on the anode surface of nanocrystalline CuCr25 was formed at a peak current of 1.75kA, while that for the micro-CuCr25 material was formed at peak current of 2.5kA. This implies that the nanocrystalline material is less appropriate in breaking capacities since it is more likely to be suffered from anode phenomena than the micro-material [5].

Data in Table 4[6] shows that the breaking capacity of nanocrystalline contact was significantly inferior to that of microcrystalline contact since the 3# and 4# nano-CuCr25 failed to break the T100(24kV/20kA), while the 1# and 2# micro-CuCr25 showed successful results. Liqiong Sun in [9] used a vacuum interrupter with nanocrystalline contact material of CuCr25 to observe anode arc phenomena, indicating that the anode phenomena of the nanocrystalline CuCr25 contact took place at a lower current than the microcrystalline one. Thus, nanocrystalline CuCr showed lower breaking capacities in all published results. The possible reason is that the nano-CuCr has lower thermal conductivity, higher saturated vapor pressure and higher hardness [6].

Table 4: Breaking capacities for nano/micro materials

TVI	Test mode	Test times	Success breaking times
1#M-TVI	T30	3	3
	T60	3	3
	T100	2	2
2#M-TVI	T30	3	3
	T60	3	3
	T100	15	15
3#N-TVI	T30	3	3
	T60	3	3
	T100	2	0
4#N-TVI	T30	3	3
	T60	3	3
	T100	2	0

5 BREAKDOWN VOLTAGE

Table 5 shows the AC breakdown electric fields of contact materials, indicating that the nano-CuCr25 3# and 4#N showed lower breakdown voltages than the microcrystalline 1#M and 2#M[6].

Table 5: Breakdown electric fields for nano/micro materials

material	1#M	2#M	3#N	4#N
Average break electric field (kV/mm)	26.8	26.0	20.9	19.6
Chopping currents (A)	3.8	4.1	2.8	3.2

Yaping Wang reported the experimental results on average breakdown field E(108V/m) of the materials in Table 6[7]. The fixed anode was always pure W, while the movable cathode was made of the test materials. The results indicated the lower voltage withstand for nanocrystalline P-CuCr than the conventional micro C-CuCr50[7]. Although this tendency corresponds to that in Table 5, the materials with nanocrystalline grains (P-CuCr25 and P-CuCr50) showed higher voltage withstand than those with microcrystalline grains (A1-CuCr50, A2-CuCr50) prepared by the same procedures, contrary to Table 5. The same case is also reported in [12]. Thus, nanocrystalline CuCr contact does not always show lower breakdown voltage.

Table 6: Breakdown field E of nano/micro CuCr materials [7]

Material	Grain size	λ (mS/m)	E (10^8V/m)
A1-CuCr50	--	9.2	--
A2-CuCr50	2-3μm	14.2	0.21
P-CuCr25	46nm	16.7	2.25
P-CuCr50	67nm	11.6	1.52
C-CuCr50	<74μm	19	2.57

6 CHOPPING CURRENT

Data in Table 5 showed that nanocrystalline CuCr25 (3#N and 4#N) exhibits lower chopping currents than microcrystalline ones (1#M and 2#M) [6]. The similar conclusions were also found in [8], where nanocystalline CuCr50 has a chopping current of 0.8A, while 3.8A for the microcrystalline material. Thus, nano-material usually shows lower chopping current. The reason is understandable since nanocrystalline materials are likely to have lower breaking capacity that corresponds to lower chopping currents.

7 DISCUSSION AND SUMMARY

Nanocrystalline contact materials may have superior properties than microcrystalline, such as lower chopping currents, higher welding resistances, and even higher breakdown voltages in some cases. However, it also shows inferior performances such as lower breaking capacities, longer arc durations, or lower breakdown electric fields for some materials.

The reason of different performances between nano-/maicro-crystalline contacts has not yet been explained theoretically, but differences in several material properties (such as hardness, specific heat, electrical conductivity) may have important influences [6,10]. Improving thermal and electrical properties of nanocrystalline materials through optimizing fabrication procedures is helpful to improve their electrical performances [10]. Further researches in both experiment and theoretical aspects are needed for nanocrystalline contact materials.

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