CHARACTERISTICS OF FUSE ARCING IN DIFFERENT FILLERS

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NSW 2006 Australia

Abstract:

Aluminum hydro-oxide, boric acid, zinc oxide, titanium oxide and boron trioxide have been investigated here for their prospects as filling media in high-voltage, high breaking capacity fuses. The results of these tests are compared with those on silica sand at high currents. This study demonstrates that silica sand is far superior filler in HBC fuses for heavy current interruption than the compounds tested.

I. INTRODUCTION

The primary purpose of a high breaking capacity (HBC) fuse is to interrupt heavy fault currents effectively in a very short time, even less than quarter of an AC cycle. Silica sand, which is known to possess excellent interrupting capabilities at heavy currents, has been used as filler in HBC fuses for many years. We have investigated the potential of aluminum hydroxide, boric acid, zinc oxide, titanium oxide and boron trioxide as replacement fillers in HBC fuses. Some of these inorganic compounds are considered to be suitable lining materials in expulsion fuses. The purpose of this study was to search for an inorganic compound that may have better interrupting characteristics in HBC fuses than those of sand.

II. EXPERIMENTAL SETUP

We have constructed an experimental version of a high-voltage, high breaking capacity fuse, cylindrical in shape with a length of 240 mm and diameter of 43.7 mm, and with a uniform silver wire of 0.55 mm diameter as fuse element. Different fillers of comparable grain size (10 μm to 100 μm diameter) were poured in the fuse holder under vibration to keep the packing density similar in each case. All materials were tested under the same conditions of supply voltage and prospective currents. The diagram of the circuit used to energise the fuse is shown in Figure 1. The fuse fillers were tested at 6 kV, 50 Hz, 4 kA prospective current [1].

III. EXPERIMENTAL RESULTS

The voltage across the fuse was measured as a function of time by a resistive voltage divider: a Tektronix P6015, 1000:1, 20 kV, 100 MΩ voltage probe (rise time of 5 ns). Current was measured using a 190.8 A/V coaxial current shunt (rise time approximately 60 ns). A Nicolet Pro 42C digital oscilloscope was used to monitor voltage across and the current through the test fuse. From the curves of voltage and current, the energy in the arc was calculated as well as the let-through energy $\int i^2 dt$ in each case. Insulation resistance of the fuse fulgurite was measured one minute after each test. The internal and external diameters of the fulgurite were also measured. In some cases, the fulgurite cross section was highly irregular and an average diameter was taken. Care was taken to extract the full length of the fulgurite to measure its mass. The maximum arc voltage developed across the fuse was also noted. The results of these measurements for a range of fillers are shown in the Table 1.

IV. DISCUSSION

The current was successfully interrupted only with the sand and boric acid fillers. It starts to decrease immediately after the arc ignites for the case of sand, but continues to increase for a few milliseconds for boric acid. There is a clear distinction between the fulgurite of sand with those of the other fillers. In case of sand, the fulgurite is very strong and robust and the internal diameter is the smallest noted so that the arc diameter is the minimum in this case. The fulgurite shape is also regular in case of sand where in almost all other cases the fulgurite was irregular indicating arc instabilities. In many cases simple visual inspection of the fulgurite can enable one to predict whether the fuse has been successful in interruption or not.

Post-arc resistance of the fulgurite for these materials shows interesting results. In case of sand and boron trioxide, the insulation resistance exceeded 100 MΩ in about 20 seconds after the tests indicating their high dielectric strength. The smallest arc $\int i^2 dt$ value was measured for sand, indicating that it is the most suitable HBC fuse filler material. Furthermore, the arc energy is the highest in the case of sand, which shows it can conduct the heat very effectively to its surroundings.

The high arc energy is a result of the high arc voltage developed due to the constriction of arc channel for sand. We believe that the much of the arc energy is not used to fuse the sand and form fulgurite, but that a large fraction of this energy escapes through the interstices present in the sand to the surroundings. The energy expended to form one gram of the fulgurite here is 2.20 kJ which, compares well with our earlier experimental results discussed in reference [2]. Although grain sizes in other fillers were comparable to those of sand, the heat energy appeared to be contained within the fulgurite that consequently formed larger arc channels. The heat conducting capability of the sand enables it to absorb heat from the arc and conduct it to the surroundings [3]. This feature along with the rapid dielectric recovery makes sand the best filler for current limitation and interruption at heavy currents in high breaking capacity fuses. The results shown in Table 1 also contradict the assumption adopted in reference [4] about the linearity of arc energy with the arc $\int i^2dt$. Figures 2–7 show plots of current and voltage for the fillers investigated as a function of time along with the calculated values of $\int i^2dt$ and arc energy.

The behaviour for current interruption is different in expulsion and high breaking capacity fuses. In expulsion fuses, plasma is forced to exit the fuse barrel whereas in case of HBC fuses plasma energy is to be conducted by the fillers to the surroundings. The plasma should remain wholly within the filler of an HBC fuse so that a good liner in an expulsion fuse is not necessarily a good filler in an HBC fuse. The results show that silica sand is superior filler for HBC fuses than the other fillers tested.

Acknowledgements

The authors wish to thank Mr. Gregory J. Toland for his assistance during experimentation.

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Table 1: Results of measurements of arc and fulgurite properties for a range of fillers.

	Sand (SiO_2)	Al $(OH)_3$	TiO_2	B_2O_3	ZnO	Boric acid
Arc energy (kJ)	46.72	42.50	30.13	42.58	28.74	30.18
Arc $\int i^2dt$ ($*10^3$ amp.^{2}-sec)	34.17	70.06	132.22	75.05	135.40	72.01
Weight of the fulgurite (gms)	21.22	12.60	25.00	69.61	20.00	130.00
Internal dia. of fulgurite (mm)	3.70	13.92	23.60	10.00	28.50	18.00
R (after 1 min.)	> 100 MΩ	0.075 MΩ	0.8 MΩ	> 100 MΩ	0.4 MΩ	0.8Ω
Current interruption?	Yes	No	No	No	No	Yes
Max. arc voltage (kV)	9.888	7.752	7.200	7.992	6.136	7.968

0.5 mm approx grain size

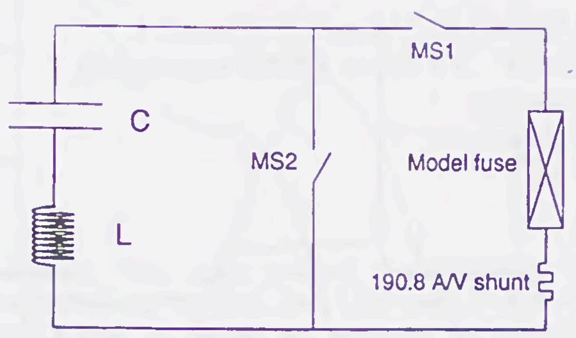

Figure 1: Electrical circuit to energise the test fuse.

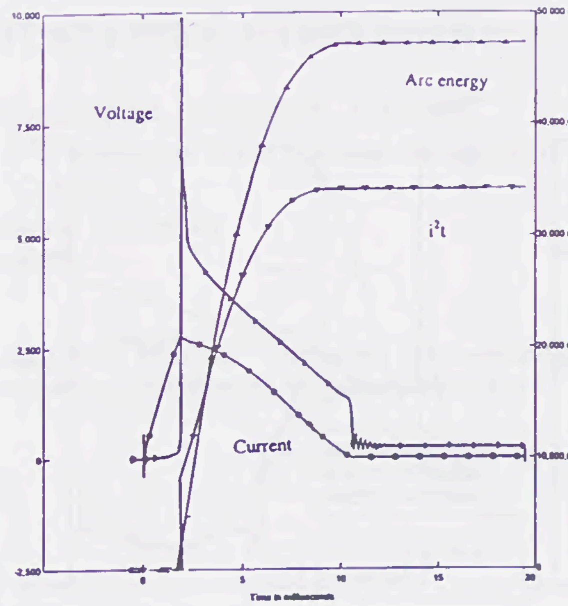

Figure 2: Plots for current and voltage (on left side) and arc energy and arc i^2t (on right side) for silica sand.

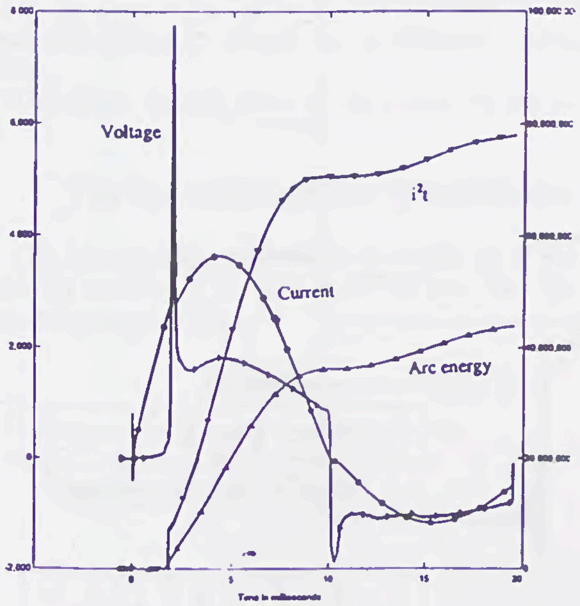

Figure 3: Plots for current and voltage (on left side) and arc energy and arc i^2t (on right side) for Al $(OH)_3$.

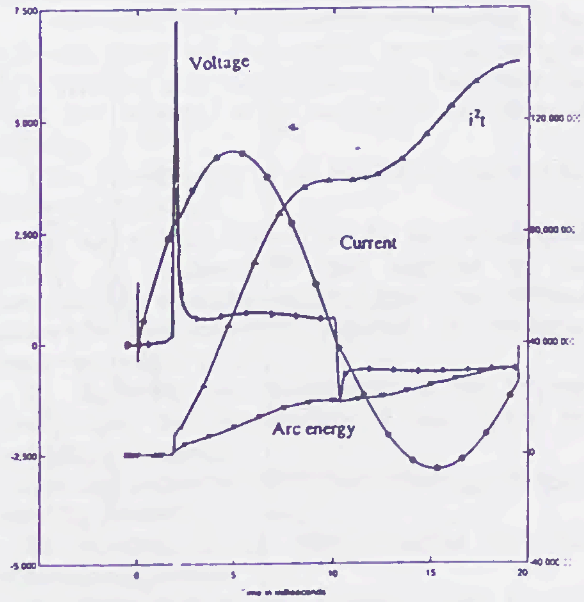

Figure 4: Plots for current and voltage (on left side) and arc energy and arc i^2t (on right side) for TiO_2.

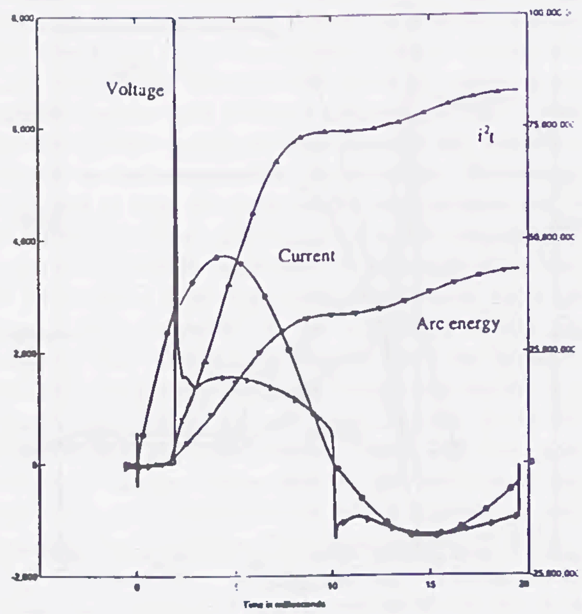

Figure 5: Plots for current and voltage (on left side) and arc energy and arc i^2t (on right side) for B_2O_3.

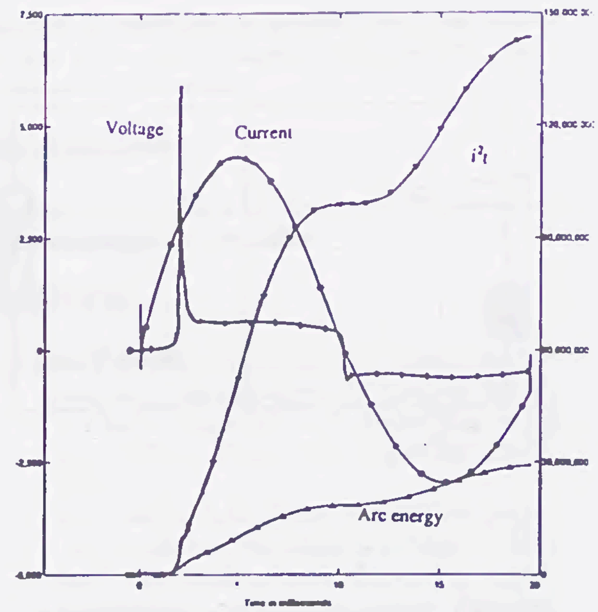

Figure 6: Plots for current and voltage (on left side) and arc energy and arc i^2t (on right side) for ZnO.

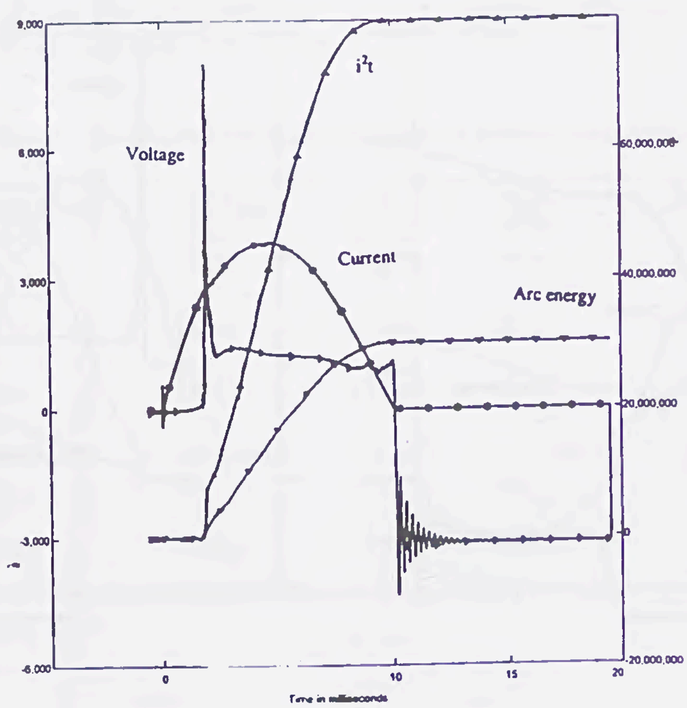

Figure 7: Plots for current and voltage (on left side) and arc energy and arc i^2t (on right side) for boric acid.