Bulk vs thermal sprayed alumina for insulation applications: A comparison of electrical and dielectrical properties

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Motivation:

Testing AM methods (APS) for insulation applications in HV power generator manufacturing. The investigation focuses on the electrical insulation of copper stranded wires in large machine applications.

- Fully automated
- Free form coating process
- Reduced process time

Coating microstructure:

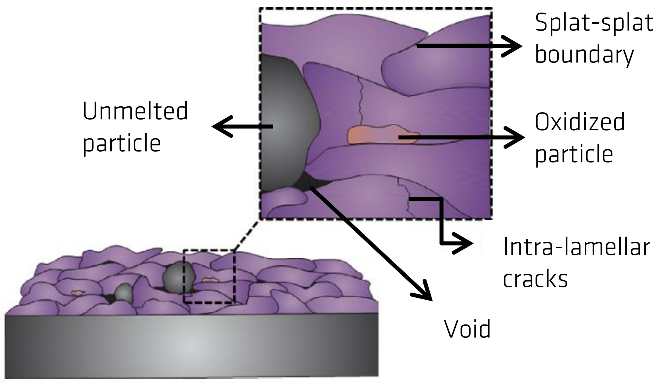

Fig 1: Schematic of microstructual features of coating [1].

Requirements for insulation application:

- High DC bulk resistance R_V
- Low relative permittivity ε_r @ 50 Hz
- Low dissipation factor tan δ @50 Hz
- Dielectric strength E_D @50 Hz > 3.5 kV/mm

Experimentals:

- 99.6 % α-Al_2O_3, D_{50} = 33 µm
- Variation of spray distance (70 - 130 mm)
- Plasma power, gas flow, powder feed kept constant

Results:

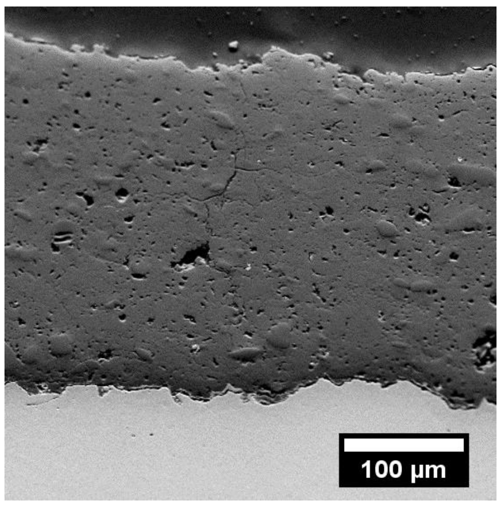

Fig 3: SEM micrograph of cross-section with vertical crack, pores and unmolten particles in 70 mm sample.

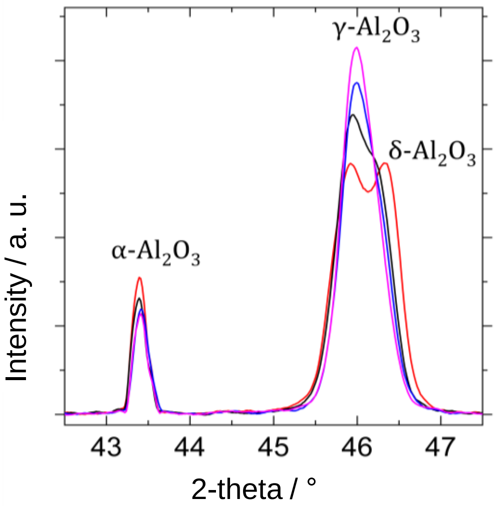

Fig 4: Section from full XRD with phase composition.

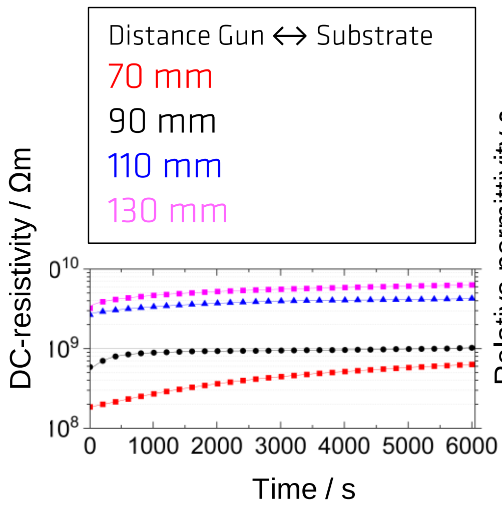

Fig 5: R_V of samples with 4 different coating distances.

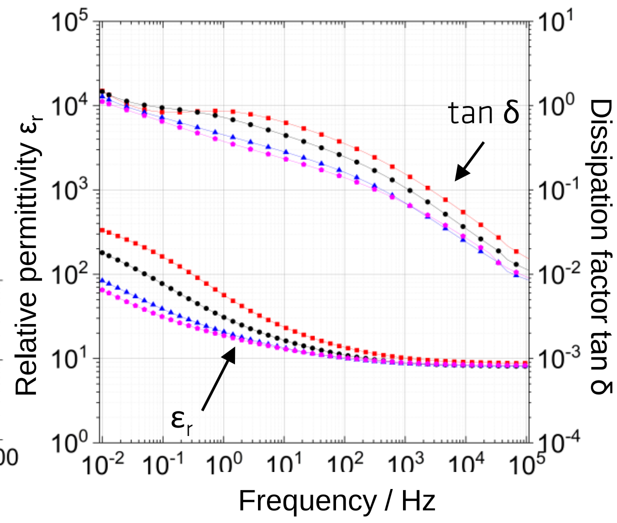

Fig 6: ε_r and tan δ of samples with 4 different coating distances.

Tab:1 Results of coating characterization.

Sample	Thickness / µm	Porosity / %	E_D @ 50 Hz / $kVmm^{-1}$	ε_r @ 50 Hz	tan δ @ 50 Hz	DC-Resistivity / Ωm	Phase
70 mm	217.0 ± 11	5.40 ± 0.8	19 ± 2.6	15.6	0.44	$6 \cdot 10^8$	α, β, γ, δ
90 mm	198.9 ± 17	5.65 ± 0.8	25 ± 1.8	12.2	0.30	$1 \cdot 10^9$	α, β, γ, δ
110 mm	190.7 ± 12	6.44 ± 1.1	25 ± 1.4	10.8	0.20	$4 \cdot 10^9$	α, β, γ
130 mm	183.4 ± 14	6.31 ± 0.9	27 ± 2.6	10.9	0.17	$6 \cdot 10^9$	α, β, γ

- Microstructure corresponds to theoretical expectations
- Phase ratio of γ and δ alumina varies during coating formation
- Ratio is apparently dependent on spraying distance

Discussion & Outlook:

Tab:2: Bulk Alumina data from literature.

α-Al_2O_3 / %	E_D @ 50Hz / $kVmm^{-1}$	ε_r @ 1 MHz	tan δ @ 1 MHz	DC-resistivity / Ωm	Ref
99.5	17	9.8	0.0002	$6 \cdot 10^8$	[2]
99.5	31	10	0.0009	$1 \cdot 10^9$	[3]
99.8	>23	9.6	0.0003	$4 \cdot 10^9$	[4]
99.7	>10	10	0.0002	$6 \cdot 10^9$	[5]

- ε_r: high for low spraying distances, tan δ: 3 magnitudes to high
- E_D and R_V of coatings are similar to bulk alumina and suitable for application
- Spraying distance already has an influence on phase composition and thus on dielectric properties
- Additional APS spraying parameters offer further possibilities to change the layer compositions and thus adjust the dielectric properties (E.g. Slurry Plasma Spraying with nano scale powder or plasma power variation)
- Broader investigation of spray parameters needed to find suitable process window

References
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