Conductive tape influence on composite dielectric spectra

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***Abstract*—Partial discharges suppression in slot part of rotating machines is an issue to be solved using the different attempts. Since decades the conductive layers of main wall slot insulation are used. Besides their resistivity / conductivity which allows proper contact with stator core and partial discharges / vibrational sparking reduction, their dielectric properties shouldn't affect the losses in stator insulation. Thus, the dielectric properties of composites used as main wall insulation of rotating machines are presented and discussed. The comparison of final dielectric properties of a composite concerning three different types of conductive tapes are presented. One type of epoxy resin was used as matrix and influence of conductive tapes based on a) PET-non-woven with additional polyester threads, b) polyester / glass fibres and c) electrically conducting glass fabric on whole composite dielectric spectra were investigated. The methodology of investigation is based on broadband dielectric measurement in frequency spectra. The test results show significant differences of composite dielectric behaviour dependent on tape type used as filler.**

***Keywords*— composites, rotating machines, dielectric**

I. INTRODUCTION

The problem of partial discharges in slot and at end winding is an issue for decades in rotating machines. The suppression based on geometry and material of stress grading system is solved strongly [1]–[4]. If focusing on slot discharges the issue of slot discharges or vibrational sparking [5], [6], [7] occurs. This topic is a material issue, resp. the resistivity of contact between a slot bar and stator core. Failures in stator winding insulation occurs according to [1] due to poorly made electrical connections between stator bars, loose bars in the stator slot, vibration sparking, poorly designed corona suppression coatings and inadequate spacing of the stator bars in the end-windings.

The suppression of vibration sparking, and slot discharges is strongly dependent on layer surface resistivity [8]. Vibration sparking (VS) occurs due to the bars' movement within the stator slots and if the outer corona layer's resistance is **too low**. The authors of [5] propose the corona layer resistance per square should be chosen above 5 kΩ to prevent electrical arcs developing. The chosen resistance of the corona layer should not be above 25 kΩ per square otherwise slot discharges may occur. As [5] mentioned, ensuring reliable earthing and a suitable corona layer resistance will prevent both slot discharges and vibration sparking. However, the experience worldwide by producers variety, there is a wide range (not only the strict values as in [5]) regarding the recommended resistance range of the OCP. There is a wide range for recommended OCP resistance which seems to be technical acceptable like given in the international standard IEEE 1434 [9].

It should be noted that the aim of surface resistivity [8] to avoid described issues should not affect the whole composite dielectric behaviour in key parameters as breakdown voltage, permittivity, and loss factor [10], [11], [12]. Based on this note, the experiment comparing dielectric behaviour of several conductive tapes cured with one specific resin has been prepared. The focus of the investigation was on the frequency spectra of permittivity and loss factor in temperature range 20 °C – 100 °C.

II. EXPERIMENT

The verification of dielectric spectra of investigated materials was based on the measurement of surface resistivity of uncured conductive tapes and on broadband dielectric spectroscopy (BDS) of cured pure resin and cured composites.

A. Polyester resin

One polyester resin was used for all specimen preparations. The FTIR spectra of cured pure resin and cured composites is shown in Fig. 1.

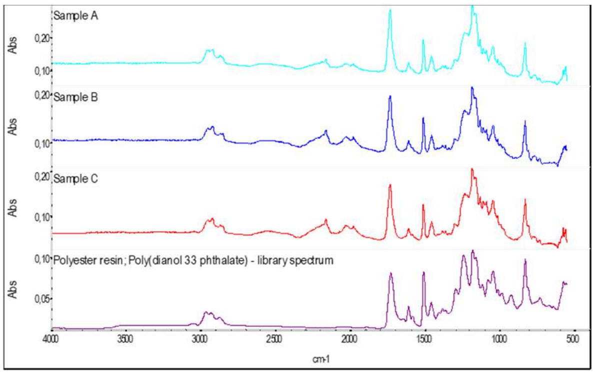


Fig. 1 FTIR spectra of cured pure resin and cured composites

B. Material A

A conductive non-woven tape with a given resistance of 1000 Ω/□, is referred in this chapter as Material A. This tape is described as **PET-non-woven with additional polyester threads** inserted in machine direction impregnated with a cured carbon-filled resin. This tape contains a small amount of zinc-naphthenate as an accelerator. According to IEC 60085, this tape is in thermal class F. More of its properties can be seen in Table I.

TABLE I. MATERIAL A PROPERTIES

Properties	Units	Values	Test method
Thickness	mm	0,05	DIN EN 29073-2
Area weight	g/m2	45	DIN EN 29073-2
Area weight of backing material	g/m2	30	DIN EN 29073-2
Tensile strength	N/50mm	≥ 60	DIN EN 29073-2
Surface resistance (without accelerator)	Ω/□	1000	DIN VDE 0303-3

C. Material B

A conductive non-woven tape with a given resistance of 1000 Ω/□ is labelled as Material B in this experiment. The tape **consists of polyester fibres** in the warp direction and **glass fibres** in the weft direction. It is impregnated with an electrically conducting binding agent, which is fully cured. As in previous material, zinc-naphthenate is used as an accelerator and is in the same thermal class (Class F) according to IEC 60085. More of its properties can be seen in Table II.

TABLE II. MATERIAL B PROPERTIES

Properties	Units	Values	Test Method
Thickness	mm	0,08	DIN EN 29073-2
Area weight	g/m2	65	DIN EN 29073-2
Area weight of backing material	g/m2	45	DIN EN 29073-2
Tensile strength	N/50mm	≥ 200	DIN EN 29073-2
Surface resistance (without accelerator)	Ω/□	1000	DIN VDE 0303-3
Elongation at break	%	≥ 20	DIN EN 29073-2

D. Material C

A conductive tape with a given resistance of 1000 Ω/□ is labelled as Material C. This tape is an **electrically conducting glass fabric**. Material C is also impregnated with zinc-naphthenate as an accelerator and falls into the same thermal class F according to IEC 60085. In Table III, more of its properties can be seen.

TABLE III. MATERIAL C PROPERTIES

Properties	Units	Values	Test method
Thickness	mm	0,09	DIN EN 29073-2
Area weight	g/m2	125	DIN EN 29073-2
Area weight of base material	g/m2	105	DIN EN 29073-2
Tensile strength (without accelerator)	N/50mm	≥ 300	DIN EN 29073-2
Surface resistance (without accelerator)	Ω/□	1000	DIN VDE 0303-3
Elongation at break	%	≥ 1,5	DIN EN 29073-2

Fig. 2 Experimental tapes

E. Composite preparation

For the experiment, three different composite materials were created from the already mentioned conductive tapes and one resin. Tapes with width of two centimetres were used. Samples were made with half overlap and two layers. On each layer were applied about 15 ml of resin (Fig. 3). No spacers were used for the curing. Samples were compressed by pressure 610 Pa (Fig. 4) and the edges were secured against leakage of resin. Each sample were cured in oven with circulating hot air at a temperature 145 °C for 10 hours.

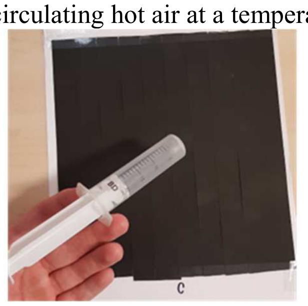


Fig. 3 Application of resin

Fig. 4 Prepared sample for curing

III. TEST RESULTS

A. Resistivity measurement

Firstly the verification measurement of surface resistance was done using special electrode system (Fig. 5) with HIOKI RM3548 RESISTANCE METER (Fig. 6). The values of surface resistivity $R_{\square}$ for material A, B C including accelerator is given in Table IV.

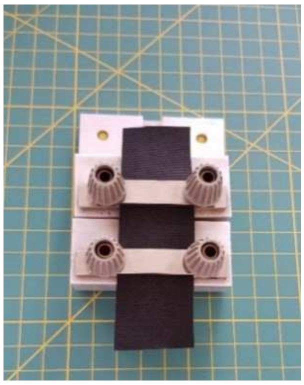


Fig. 5 Electrode system for uncured tapes - surface resistivity measurement

Fig. 6 Measurement with HIOKI RM3548

TABLE IV. SURFACE RESISTANCE - INCLUDING ACCELERATOR

	Sample A	Sample B	Sample C
	Surface resistivity R□ [kΩ]	Surface resistivity R□ [kΩ]	Surface resistivity R□ [kΩ]
Average	**1,247**	**1,393**	**1,444**
St.dev	0,0768	0,14841	0,21911
Variation	6%	11%	15%

B. Dielectric spectra measurement

Broadband dielectric spectrometer (BDS) was used for dielectric frequency spectra measurement. The aim is to demonstrate the effect of material composition on the dielectric properties of the composite. The BDS analyser measures complex impedance spectrum Z*(ω) and subsequently evaluates and obtains required data using algorithms. Cured samples (see chapter E.) were reduced to 4×4 cm and inserted into electrode system of used analyser. Measuring was performed during constant temperatures from 20 °C to 100 °C with increment 5 °C, measured frequency was setup in range of $1 \cdot 10^{-1}$ to $1 \cdot 10^{7}$ Hz and constant AC voltage 1V.

There is to be seen in Fig. 7 the dominant conductivity part of the loss factor spectra. It is due to the fact, the resin has not been cured with accelerator, because it is present only in conductive tapes. The curing conversion is not fully provided and the ionic conductivity remains in the resin chains. The statement is supported with data of simultaneous thermic analysis (STA) which are shown in Fig. 8. Here can be seen the STA measurement of pure resin as cured in the oven (1st curing 1) and STA analysis of the same sample after BDS (20-100 °C) measuring program (2nd curing). Only small post curing occurs according to data in Fig. 8. The comparison of thermal STA analysis of fully cured samples A, B, C is shown in Fig. 9 and no big differences among the three materials are evident based on structural behaviour (0 – 160 °C).

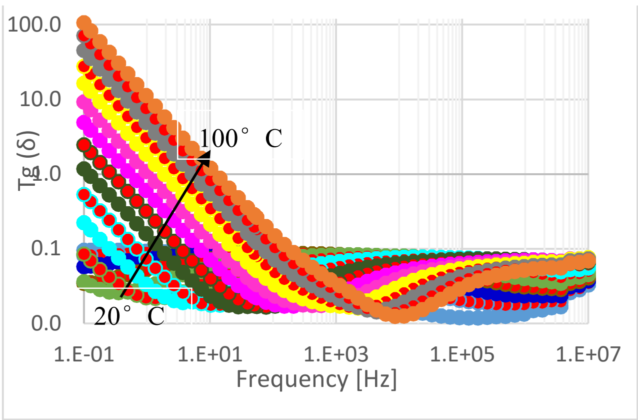
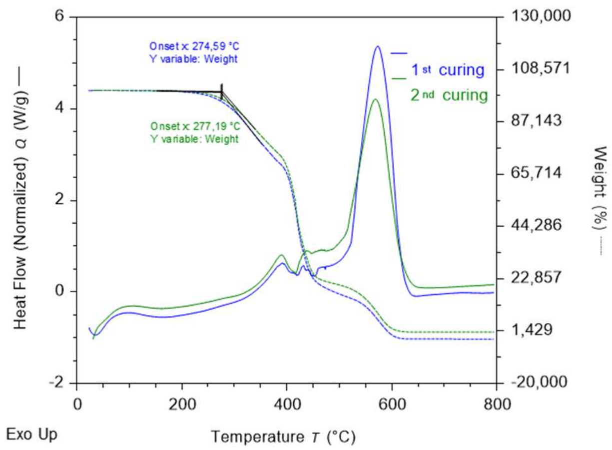


Fig. 7 Loss factor of pure resin



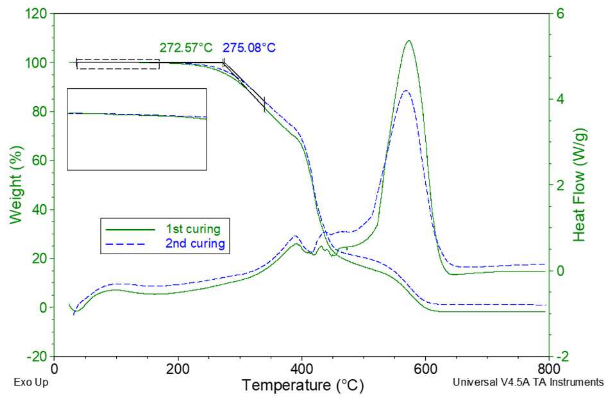


Fig. 8 STA analysis of pure resin

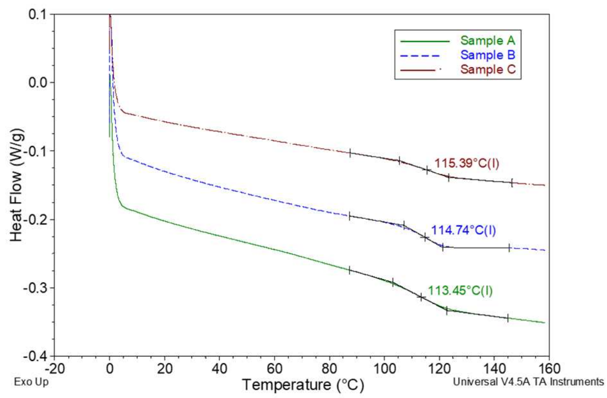


Fig. 9 DSC analysis of cured composites

The data from BDS analysis presenting the loss factor behaviour in wide frequency spectra (0,1 – 10^{7} Hz) and temperatures (20 – 100 °C) is shown in Fig. 10. Here is evident the influence of conductive tape type. The relaxations differ for samples A, B and C. Quite big conductivity for **material A** occurs, but not such a polarization at higher frequencies. (The tan d peaks at 85-100 °C and 10 -50 Hz are probably due to the migration polarization effects as composite sample delaminates at these temperatures.)

Material B is smooth with low loss factor at low frequencies, only strong polarization at 6-7 MHz region occurs.

Material C has a wide temperature dispersion of the loss factor in low frequencies and not only conductivity, but some polarization effects are evident in 0,5 – 3 Hz (example for 100

°C). The part of polarization at higher frequencies is evident at 1 MHz.

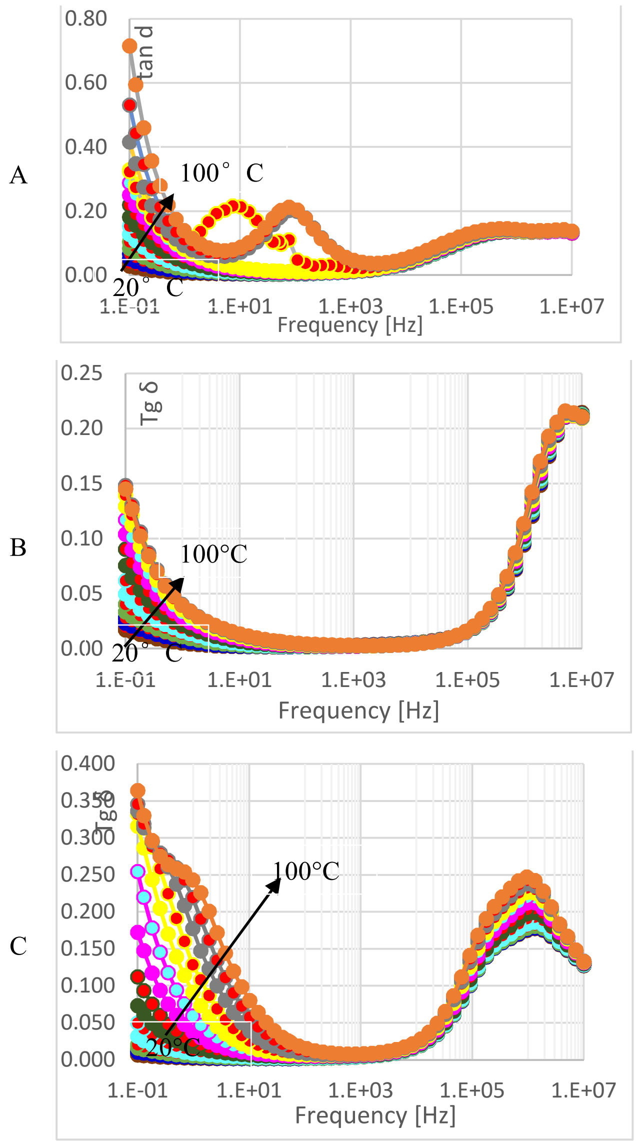
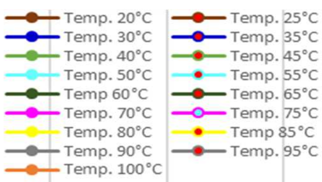


Fig. 10 Loss factor of composite with A, B, C layer for



IV. CONCLUSIONS

The differences in polarization spectra of three composites were shown in the paper. The effect of conductive type to dielectiric spectra differ on tape basic material when **PET-non-woven with additional polyester threads (A)** has strong conductivity effects in low frequencies region.
Polyester / glass fibres (B) is smooth with low loss factor at low frequencies, only strong polarization at 6-7 MHz region occurs and **Electrically conductive glass fabric (C) has a** polarization at 1 MHz

The loss factor at 50 Hz, which is the operating frequency, is as low as expected and requested.

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