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Method of assessment of varnishes modified with nanofillers

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The method of analysis and assessment of the results of investigations of nanofilled varnishes used for electrical insulation have been presented. The proposed method enabled consideration of an effect of the coating thickness. The investigation indicated that improving of the bond strength depends on loading and the size of nanoparticles. The method of fabrication of composites with nanoparticles has an influence on their properties. Composites with fumed silica showed improved dielectric properties. Absorption of water of all formulated varnishes with nanofillers decreases provided that some additives were incorporated.

Key words: *impregnating varnish; nanofiller; bond strength; pulse resistance; electrical strength; water absorption*

1. Introduction

Incorporation of a small quantities of nanoparticles into a polymer dielectric changes its properties. If the size of particles of the incorporated filler approaches that of the polymer chain length, the particle stop to behave like foreign inclusion; space charge densities are very small and the Maxwell–Wagner interfacial polarization is negligible [1–6].

The impregnating varnishes used for electrical insulation modified due to improving their properties with various kinds of nanofillers were investigated. When analysing the properties of varnishes modified with nanofillers it should be considered many affecting factors, e.g.: a stage of curing (if nanofilled varnishes which showed higher thermal endurance need to be cured in higher temperatures), an obtained thickness of coating (how adding of a nanofiller influences the thickness of coating and other properties connected with the thickness), methods of fabrication of nanoparticles and loading, methods of dispersing in varnish.

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2. Experimental

Two kinds of impregnating electroinsulating varnishes based on polyester (PE) and polyesterimide (PES) resins were modified by incorporating 1–3% of two kinds of nanosilica – fumed nanosilica with average grain size 7 nm and nanospheres of silica with diameter ca 400 nm, zinc oxide, titanium dioxide, and montmoryllonite. The composites were formed utilizing various methods of dispersing. The properties of pure and nanoparticle filled varnishes were compared.

Three types of samples were used: steel panels coated by varnish (acc. to EN 60455-2) for determination dielectric properties, helical coils (according to EN 61033) for measurements of bond strength of impregnating varnish to an enamelled wire substrate and the cast pieces of varnish (according to EN 60455-2) for water absorption testing.

3. Results

3.1. Loading of the nanofillers

The bond strength at higher temperatures of base varnish PES and 1 to 1.5% fumed nanosilica loaded composite is shown in Fig. 1. Improving of its bond strength at higher temperatures is up to ca. 20% and 30%, respectively.

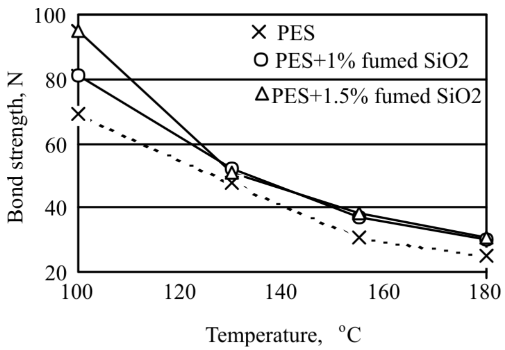

Fig. 1. Temperature dependence of the bond strengths in pure PES and PES filled with 1.0% and 1.5% of fumed nanosilica

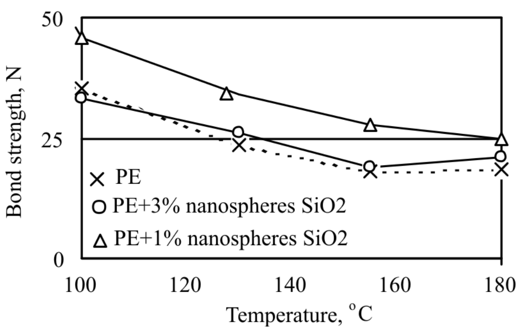

Fig. 2. Temperature dependence of the bond strengths in pure PE and PE filled with 1% and 3% of silica nanospheres

At 1% loading of nanospheres of nanosilica, the bond strength of nanofilled PE varnish is almost not changed while at 3% loading improving of this properties is significant, i.e. above 40% (Fig. 2). Thus the larger particles need higher loading (3%) to improve their properties.

3.2. Thickness of coating

Some of the properties of electroinsulating varnishes, e.g. a breakdown voltage, electrical strength or resistance to impulse voltage, strongly depend on the obtained thickness of coating. Therefore exceptions from these proportionalities could be considered as change of a feature of the material. An example of dependence of the time of life under pulse voltage on the insulation thickness for series of various composites of PE varnish with nanofillers is presented in Fig. 3. The same dependence for series of nanofilled PES varnishes but after rejecting of three composites with abnormal high endurance is shown in Fig. 4. These rejected composites, two with nanosilica and one with zinc oxide demonstrated improved impulse voltage endurance. For the three composites the "barrier effect" for partial discharges erosion was obtained and the pulse voltage endurance were from 10 to 100 times higher than those for a standard composite.

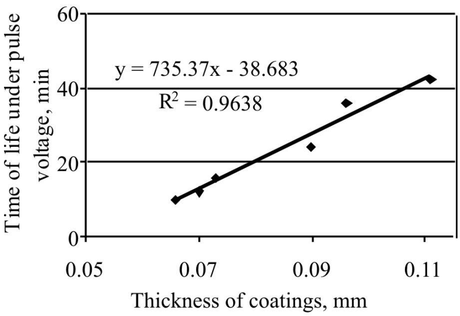

Fig. 3. Dependence of the time of life under pulse voltage on the thickness of coating for various nanofilled PE varnishes

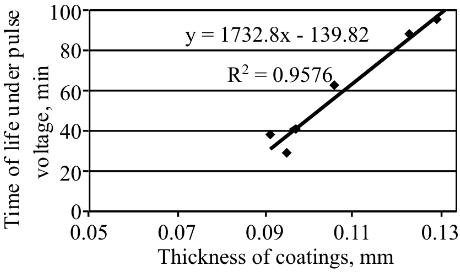

Fig. 4. Dependence of the time of life under pulse voltage on the thickness of coating for various nanofilled PES varnishes after excluding of 3 compositions

Due to difference thickness effect from nanofiller effect a similar analysing of the electrical strength was conducted. Linear coefficients of correlation between electrical strength and thickness of insulation have been calculated. The results of testing PE based varnishes with and without nanofillers are presented in Table 1.

Table 1. The results of testing of electrical strength
of pure (No. 1) and nanofilled PE varnish

No.	Thickness of coating [mm]	Dielectric strength [kV/mm]		
		23 °C	155 °C	180 °C
4	0.054	109.4	78.8	69.6
11	0.057	103.7	99.5	93.1
1	0.061	104.3	90.9	67.1
5	0.062	96.2	68.5	65.3
12	0.064	105.3	70.3	67.5
7	0.066	104.1	96.3	75.3
3	0.066	108.9	71.9	64.0
2	0.077	89.9	66.9	64.7
14	0.083	92.2	35.5	23.9
13	0.094	84.8	44.5	30.9
Coefficient of correlation between dielectric strength and thickness	all composites	–0.86	–0.80	–0.84
	all except No. 5	–0.92	–0.82	–0.84
	all except No. 7	–0.87	–0.84	–0.85
	all except Nos. 5 and 7	–0.92	–0.86	–0.85

Table 2. The results of testing of electrical strength
of pure and nanofilled PES varnish

No.	Thickness of coating [mm]	Dielectric strength [kV/mm]		
		23 °C	130 °C	180 °C
1	0.084	78.4	82.6	70.2
5	0.091	96.2	78.4	77.6
2	0.092	76.7	61.0	50.2
7	0.096	86.6	72.7	66.1
3	0.101	80.3	67.7	60.7
4	0.101	81.5	65.3	60.7
8	0.170	66.7	44.5	42.2
6	0.178	67.0	41.8	38.8
Coefficient of correlation between dielectric strength and thickness	all composites	–0.77	–0.92	–0.84
	all except No. 5	–0.87	–0.92	–0.87
	all except No. 2	–0.83	–0.97	–0.95
	all except No. 5 and 2	–0.91	–0.97	–0.99

In the presented results, sample No. 5 (with TiO_2nanoparticles) showed abnormal low electrical strength while sample No. 7 (one from the samples with fumed SiO_2) showed improving of this property. The same calculation for series of PES varnish is presented in Table 2. After excluding samples No. 2 (with ZnO nanoparticles) and

No. 7 (one from the samples with fumed SiO_2), the coefficient of correlation considerably increases.

3.3. Absorption of water

Incorporation of nanofillers to varnish should diminish its liquid and gas permeability due to the barrier effect. Our examination of water absorption of nanofilled electroinsulating varnishes demonstrated that the method of fabrication of a composite influences its properties. The composites were prepared using various methods of nanoparticle dispersing – with an ultrasonic homogeniser (h) and a disperser (d). In some experiments, the nanoparticles were prearranged by milling (m) as well some additives were added, an air releaser (b) among others. The composites containing the air releaser (b) showed lowered water absorption (Figs. 5 and 6).

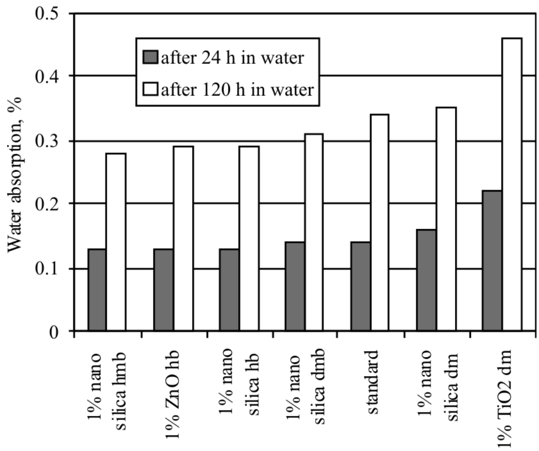

Fig. 5. Absorption of water for PE varnish with nanofillers

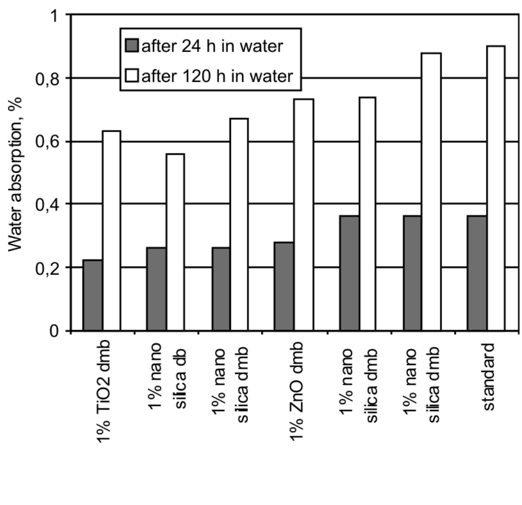

Fig. 6. Absorption of water for PES varnish with nanofillers

4. Conclusions

Impregnating electroinsulating varnishes based on polyester (PE) and polyesterimide (PES) resins have been invrestigated with various nanofillers (nanosilica, metal oxides and montmoryllonite), formed utilizing various methods of dispersing. Improving the bond strength depends on the size of nanoparticles and their contents; larger particles need higher loading. The method of analysis of the results enabled consideration of the thickness of the coating effect. Some composites with nanosilica showed much better resistance to pulse voltage and slight increasing in electric strength, especially at raised temperatures. The nanocomposites containing the air releaser showed lowered water absorption.

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