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Modification of the composition and technology of the processing of ceramic-polymer insulators

Z. ŚWIERZYNA[1*], G. PAŚCIAK[1], B. MAZUREK[1], J. OLEJNIK[2],

[1]Instytut Elektrotechniki, Oddział Technologii i Materiałoznawstwa Elektrotechnicznego, ul. M. Curie-Skłodowskiej 55–61, 50-369 Wrocław, Poland

[2]NTI-POMIARY Sp. z o. o. ul. Portowa 1, 67-200 Głogów

The nanosized filler influence on the physicochemical and electrical properties of the composite ceramic-polymer (CP) material to be applied in outdoor line HV insulators has been investigated. Also the results of the electrical and mechanical examinations of the CP insulators moulded with the use of the dies made of PET have been presented. As a standard, the moulds for flask – moulding are made of PP material what, because of its high adhesion causes some difficulties during forming of insulator and leads to deteriorating the quality of the insulator surface.

Key words: *electric insulation; composites; polymer materials; testing*

1. Introduction

Polymer concrete composites (ceramic-polymer, CP) were developed in 1960 –1970 in USA and Japan [1]. Since 1980 their insulating power is exploited in both indoor and outdoor high-voltage insulators to which they proved suitable equally to glass and ceramic [1, 2]. They are mounted on power lines in many countries. Up to now ceramic-polymer insulators are made in USA by ABB. In Poland, the original recipe of CP composite was developed and patented in 1996 and applied for processing of post-insulator cores by dust pressing method [3, 4, 5, 8]. The cores were suitable both with housings made of the same PC material and with silicon elastomer housings. In turn, the NTI-Pomiary Sp. z o.o. from Głogów applied this polymer concrete material for processing post- and pull- (line and station class) indoor and outdoor insulators [9] (Figs. 1–3). CP insulators are characterized by good mechanical durability and resistance to mechanical hazard during transportation, mounting and exploitation. The surface of insulator housing is hydrophobic and does not need any covering with glaze and clamps directly bonded to the insulator body. As they provide uniform dielectric on HV terminations at the reduced costs, they can be successfully and safely used to replace the porcelain.

*Corresponding author, e-mail: swierzyna@iel.wroc.pl

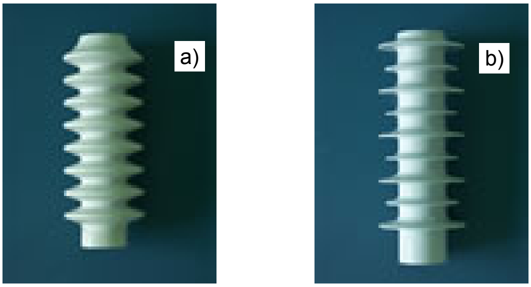

Fig. 1. Ceramic-polymer composite station class post insulators: a) H6-125-II-CP; b) H6-125-II-CP with silicone rubber covering, inner clamps galvanized, M12

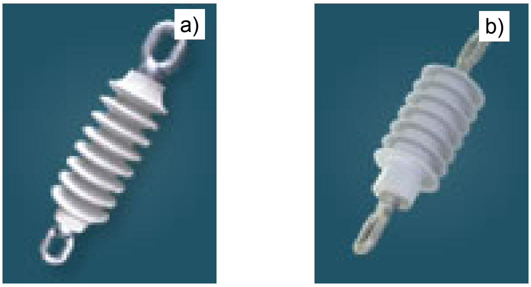

Fig. 2. Ceramic-polymer composite line strain insulators: a) L-CP-60, b) L-CP-60 with silicone rubber covering; inner clamps: steel, twisted-in handle M16

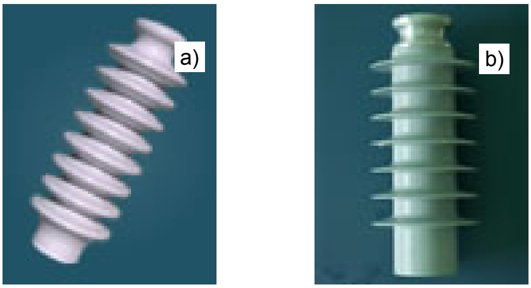

Fig. 3. Ceramic-polymer composite line post insulators: a) LW-CP 8/24, b) LW-CP 12/24; inner clamps: galvanized, M16

2. Ceramic-polymer composite

Ceramic-polymer composite constitute binder (5–30%) and mineral fillers (70–95%). Binder is composed of organic resin (monomeric or polymer), some amount of improves and promoters of resin curing. Typically polyester, polymethacrylate or epoxy resins are used. As a filler, usually quartz powder with strictly selected sizes of grains is applied. Chemical merit of these polymer composites constitute esters of acrylic and methacrylic acids. The key component of these acids is methyl methacrylate. The process of composite curing starts after addition of curing agent which initiates polymerization at room temperature, without the necessity of heating the mixture. The end product has reproducible parameters. Owing to long C–C–C carbon chains formed during resin curing, the composite is resistant to weather and other ageing agents, which makes it attractive alternative to porcelain in application for outdoor insulators [6]. Electrical and mechanical properties of the developed composite were tested. The testing was carried out on both material specimens and products, i.e. on models of insulators.

3. Moulds for ceramic-polymer insulators

Corrosivity of methacrylate compositions, oxygen inhibition and 6% volume shrinkage, all of them are against using traditional metal moulds for moulding composite insulators. That is why those insulators or their cores were fabricated with the use of expendable moulds made of polypropylene (PP) foil (Fig. 4). Insulators made with those moulds have dull, lustreless surface, thus installing them outdoor in hostile, contaminated environment requires covering them with thin silicone films. This work was focused on developing the method of fabrication of CP insulators suitable for installation in hostile environments (II and III contamination zones) without covering with additional protective films. Polyethylene terephthalate (PET) foil was used for fabrication of moulds. Comparing to PP foil, the PET foil is characterized by better wettability and during exothermal process of curing the composite closely contacts with its walls, producing smooth, lustre surface of insulators. IEL OTiME was in position of applied of PET foil for fabricating moulds (Fig. 5) only because its employees managed to master the difficult technology of processing characteristic shapes of insulator shed.

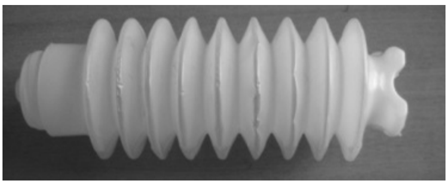

Fig. 4. PP mould for CP insulator

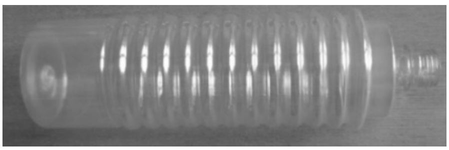

Fig. 5. PET mould for CP insulator

4. Examination of ceramic-polymer composites

4.1. Test specimens

Two polymer-concrete composites based on methacrylate resins were developed to execute specimens and models of insulators (Table 1). The composites differed in mineral filler improving physical properties of insulators. Composite 2 contained a filler with nonosized grains (aerosil 150).

Table 1. Compositions of polymer concretes based on methacrylate resins

No.	Constituent	Composite 1 [g]	Composite 2 [g]
1	binder: methyl methacrylate	500.0	500.0
2	promoters of resin curing	5.0	5.0
3	mineral filler 1– SiO_2	2500.0	2497.0
4	nanofiller – aerosil 150	–	3.0
5	UV stabilizer: TiO_2 and other additives	42.8	42.8
6	adhesive agent	3.5	7.6

4.2. Methacrylate based CP composites resistant to electric arc

Methacrylate based CP composites were tested for resistance to electric arc according to PN-74/E-04441 [10]. The testing was performed on a test stand which enabled one to apply to dielectric, insulating material the 12.5 kV test voltage. The moments ignition and extinction of arc were observed as well as the specimen appearance. The times of arc duration are given in Table 2. The specimens after testing are shown in Fig. 4.

Table 2. Resistance to electric arc of methacrylate-polymer concretes; mean time between the arc ignition and intensive erosion of electrical insulating material of 10-point specimen [s];

Composition with a standard filler	Composition with a nanosized filler
258	260

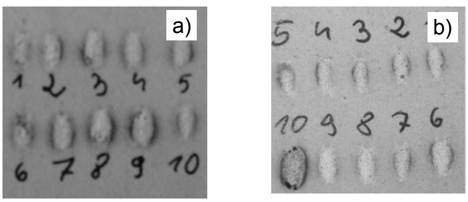

Fig. 6. Methacrylate based CP specimen after testing for resistance to electric arc: a) compound 1, b) compound 2

As can be seen in Fig. 6, the specimen material experienced extensive erosion due to formation of an electric path and increase of electric current in transformer secondary circuit.

4.3. Resistance of methacrylate resin based CP composites to tracking current

For comparison, both methacrylate based CP compositions were subject to testing for resistance to tracking as per PN-89/E-04442 [12]. The test was performed on flat inclined specimen under high voltage as specified in aforementioned standard. According to this standard, the class of material is determined by the highest voltage withstood by specimen for 6 h. To perform the test, the specimen (Fig. 7) was placed in testing chamber and then the highest allowed 6 kV test voltage was applied and maintained constant for 6 h. During testing, the bottom of the specimen was wetted with 0.1% NH_4Cl contaminant (resistivity of 370–400 Ω·cm). The contaminant was fed at a uniform rate of 0.6 cm^3/min. The test results and the mean value of the current flowing in the high voltage circuit are given in Table 3. As during that time no breaks of electric circuit occurred, the composites were evaluated as tested positive for resistance to tracking. The specimens after testing are shown in Figs. 8 and 9.

Fig. 7. Electrodised specimen during testing for resistance to tracking currents

Fig. 8. The methacrylate CP specimen after testing for resistance to tracking at 6 kV

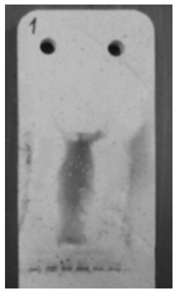

Fig. 9. The specimen of methacrylate CP with nanofiller, after testing for resistance to tracking at 6 kV

Table 3. Resistance of methacrylate CP composites to tracking performed at inclined specimen and high voltage

Material No.	Test voltage [kV]	Test duration [h]	Mean current [A]	Evaluation
1	6	6.0	0.017	positive
2	6	6.0	0.015	positive

4.4. Testing of methacrylate resin based CP composites for water diffusion

Both CP composites were subject to testing for water diffusion as per PN-IEC 61109:1999 [12]. The samples were drawn in groups of six by cutting out 6 specimens from each material. Then they were immersed in a 0.1% NaCl water solution for 100 h. Then the specimens were subject to testing for 12 kV withstand voltage for 1 min. No breakdown or flashover was allowed during the testing and the leakage current was to be lower than 1 mA. Results of testing for water diffusion are presented in Table 4.

Table 4. Results of testing for water diffusion

Tested material	Leakage current [mA]	Evaluation
Composition 1	< 0.1	Positive
Composition 2	< 0.1	Positive

4.5. Testing of methacrylate resin based CP composites for liquid absorption

Both CP composites were subject to testing for liquid absorption as per PN-IEC 383-1:1997 [13]. The fragments of insulator body were immersed in a 1% solution of fuchsine in alcohol. The solution was maintained at the pressure of 15 MPa for 12 h. Then the fragments were taken from the solution, washed in water, dried and broken. No signs of penetration of the dyestuff were visible on freshly fractured surfaces (Fig. 10).

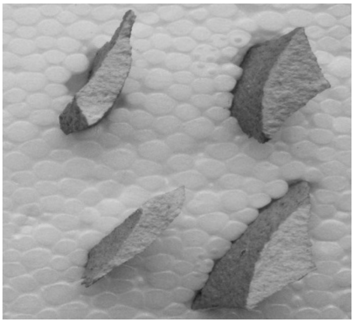

Fig. 10. Fragments of insulator after testing for liquid absorption

5. Testing of ceramic-polymer composite insulator units to PN-EN tests specifications

Methacrylate resin based ceramic-polymer composite composed of filler with ordinary (not nanosized) grains was used to execute insulators with the 500 mm creepage distance (Fig. 1). The insulators were moulded using newly developed PET moulds and subject to mechanical and electrical tests.

5.1. Testing for resistance to tracking and erosion

Insulators being under constant potential at power-frequency adequate to creepage distance of 20 mm/kV [12] were subject to the 1000 h action of salt mist. The rate of salt mist application was 0.4 ± 0.1 l/m^3·h, the size of drops 5–10 μm, salt mist concentration: 10 ± 0.5 kg/m^3. The applied high voltage system was so as under effective current of 250 mA, the drop of voltage in high voltage circuit was lower than 5%. The testing was performed in such a manner that between consecutive applications of voltage the time intervals were sufficient to minimize effects from the previous application. The most intensive discharges occurred during wetting of an insulator, i.e. during the first 2 h of 8 h application of voltage after 16 h time interval. No conducting paths or extensive erosion of electrical insulating material were produced during the test.

5.2. Electrical tests

The insulator units were tested as per PN-EN 60071-1:1999 [15] (wet power-frequency voltage test). The 50 kV [13, 14] alternating voltages were applied to insulators and maintained for 1 min. As no flashovers occurred, the test was evaluated as passed. The examined polymer concrete insulator units passed successfully also the lightning impulse voltage withstand tests as during application of 125 kV high voltage no disruptive discharge occurred.

5.3. Mechanical failing load test

The tested insulators were mounted horizontally to test machine and a mechanical bending load was applied (PN-EN 60168: 1999 P. 5.2.4 [16, 17]). The load which moved perpendicularly to the axis of the examined unit was increased smoothly until fail of insulator. The failing loads of the tested units were in the range of 5.4–5.9 kN and were higher than the nominal flexural strength of that class insulators (4 kN).

6. Test results and discussion

Methacrylate resin based CP compositions both with conventional and nanosize filler proved to have arc and tracking current handling capacities suitable for electroinsulating applications.

Methacrylate resin based CP insulators meet the insulator test specifications for mechanical strength and current handling. Owing to their high electric permittivities and fastness to exposure to hostile, excessive contaminated atmospheres, they can be successfully and safely used in outdoor applications without covering with additional protective film of silicone elastomer.

Mastering the PET foil technology of fabricating moulds for CP insulators will enable replacing the porcelain insulators by CP ones in the most onerous climatic conditions of II and III zones of contamination provided that CP insulators will meet environment test specifications.

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