

Performance of hydrophobic epoxy insulators under industrial pollution

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Abstract: Cycloaliphatic epoxy resins have been used alongside silicones and ceramics for more than 30 years as insulation materials for outdoor applications. Insulators made of cycloaliphatic epoxies offer many advantages over those made of ceramic or silicones. Standard cycloaliphatic epoxies are construction materials, however, they do not exhibit hydrophobicity as do silicones. A new generation of cycloaliphatic epoxy systems with enhanced hydrophobic properties, hydrophobic cycloaliphatic epoxy try to join the advantages of both cycloaliphatic epoxy resins and silicones. The paper presents the laboratory and field test results of commercially available hydrophobic cycloaliphatic epoxy insulators. These insulators exhibit the hydrophobic properties under clean conditions. Unfortunately, when polluted by industrial dust, the surface become hydrophilic. No hydrophobicity transfer was found even three months after surface contamination. Nevertheless, compared with the standard cycloaliphatic epoxy the hydrophobic cycloaliphatic epoxy offers some advantage under light industrial pollution or sea pollution.

1 INTRODUCTION

Epoxy resins were worked out by P. Castan and S.O. Greenie in 1930s [1]. The first applications for indoor insulation began in 1950s. The cycloaliphatic epoxy resins (CEP) were used for outdoor insulation in 1960s due to their higher resistance to UV radiation and surface discharges.

Approximately over 8 million CEP insulators are in service in the world to date [2]. Most of them are used on medium voltage level. These insulators show positive field experience during more than three decades thanks their advantages over ceramic insulators. Compared to porcelain the density of CEP is smaller, its impact strength is better, the dielectric permittivity is lower, the shape of the piece can be complicated. Cementing of fixing parts will be omitted, metal parts can be cast inside the insulator.

On the other hand, epoxy resins do have certain disadvantages compared to ceramic materials. These include the creeping under continuous mechanical stress especially under elevated temperatures, water absorption and the less resistance to electrical discharges.

Standard CEPs are construction materials, however, they do not exhibit hydrophobicity as do silicones. A new generation of cycloaliphatic epoxy systems with enhanced hydrophobic properties (HCEP, Hydrophobic Cycloaliphatic Epoxy) try to join the advantages of both cycloaliphatic epoxy resins and silicones.

2 SURFACE PROPERTIES OF EPOXY RESINS

The static wetting angle on smooth, new epoxy surface amounts about 110° [3]. Under outdoor conditions the colour of the surface changes gradually and the wetting angle decreases. With the hydrophobicity loss, the leakage current and electrical discharges arise. The resistance to electrical discharges of bisphenol epoxy resin is lower (about 2,5 kV) than that of cycloaliphatic resins. According to IEC587 the CEP based on Araldite CY 184 with alumina trihydrate filler has the class A 4,5 [4]. This material tested after inclined plane method withstands the action of surface discharges for longer than 6 hours under the voltage of 4,5 kV. The pollution layer on the CEP surface absorbs moisture similarly as on a glass surface. These materials do not exhibit the superior properties of silicone rubber. The hydrophilic pollutant on silicone rubber becomes hydrophobic due to diffusion of low molecular weighted chains from the rubber bulk to its surface and through the pollution layer.

There are many epoxy resin modifications. Generally, the addition of silicones increases the hydrophobic properties. The cycloaliphatic epoxy resin CY 5622 was manufactured on the basis of Araldite CY 184 [5] [6]. The efficacy of these modifications seems to be not very clear. There are also suggestion that these new material have the same properties as silicone rubber [7] [8]. Therefore own independent investigation of insulators made from HCEP was started.

3 TEST OBJECTS AND EXPERIMENTAL PROCEDURE

The medium voltage insulators available on the market were selected to the investigations (fig. 1). The insulator dimensions are given in tab. 1. The

rectangular plate of HCEP was additionally used to study the hydrophobic properties on a flat surface.



Fig. 1. The insulator made from HCEP

Tab. 1. Dimension of insulator

Parameter of the Insulator	(cm)
Height	27,5
Leakage distance	60
Shank diameter	5,5
Shed diameter	12,5
Distance between sheds	3

The single insulator was tested according to solid layer method in the cold fog chamber at Cardiff University. The fog chamber was described in [9]. Three test types in the cold fog were carried out: test with the clean insulator and wetting by a very intense fog, test with uniform solid layer and test with non-uniform solid layer. The hydrophobic properties and resistance to electrical discharges were studied. The possible hydrophobicity transfer through the kaolin layer on the insulator and on a flat plate was checked.

Two strings consisted of four and three insulators connected in series were exposed to field test at Glogow Pollution Test Station under the operating voltage of 75 kV. The leakage current was measured by means of LCM monitor manufactured by FGH Mannheim.

4 RESULTS

4.1. Insulator with a clean surface

The cold fog with a conductivity of 250 $\mu\text{S}/\text{cm}$ was produced by two nozzles situated in the opposite corners of the chamber. The water output from the single nozzle amounted 21 ml/min.. It resulted in the total wetting intensity of 2,1 $\text{l}/\text{m}^3\cdot\text{h}$ with the vertical precipitation rate of 0,7 mm/h. The leakage current under the 20 kV increased from 30 μA at dry insulator up to 70 μA after 3 hours of testing. The current did not increase more and no discharges were observed in the darkness. Many separate drops were built on the surface (fig. 2). After three hours the voltage was increased up to 30 kV. The small discharges were observed (water drop corona) under the sheds and on the shank.

The HCEP insulator was also dipped into the tap water having the temperature of 20°C. The insulator surface persisted partly the hydrophobicity even after three months. On the contrary to this, a sample made from the standard CEP became totally hydrophilic after few days of water bath.

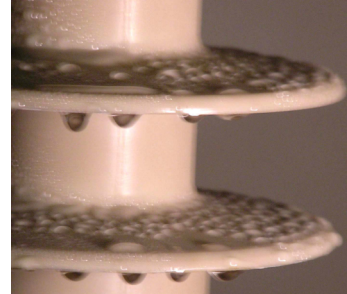


Fig. 2. The droplets formed on the surface after 3 hours of testing

4.2. Tests with uniform kaolin pollution

The pollution produced on the hydrophobic surface by dipping the insulator into the mixture of water and kaolin (40 g/l) is very discontinuous. Therefore the method proposed for contamination of silicone rubber insulators was applied [10]. The kaolin slurry had the conductivity of 160 mS/cm. The pollution layer covered the insulator could be classified as heavy pollution class. Therefore, the lower test voltage of 14 kV and the same wetting as in paragraph 4.1 were used. The leakage current higher than 20 mA was measured during 2 hour of testing. After the second test a very thin black trace was found under a single shed.

The kaolin layer on the HCEP surface absorbs the water drops very well. This means that the contaminated HCEP surface become hydrophilic. After the cleaning and drying the surface exhibit again the hydrophobic properties (the wetting angle of 90°).

4.3. Tests with non-uniform kaolin pollution

In the field the electrical discharges can concentrate on a small part of the leakage distance. These discharges are relative weak (current in the range of 5 mA) and stable (a fixed position). The concentrated discharges can degrade the polymer insulation under a light but long term wetting (drizzle or a dense fog) [11]. It is difficult to maintain long term stable discharges between two sheds. These discharges could be easier generated at the upper flange.

The non-uniform pollution was built in two steps. First the whole insulator was dipped in the kaolin suspension with the conductivity of 0,26 mS/cm. After drying the insulator was partly dipped in the suspension with the conductivity of 5,2 mS/cm, leaving a part between the upper flange and the first shed dry. With

such pollution the discharges burn over the less polluted narrow band even for 4 hours. After the test, a narrow 1 cm wide band was found close to the upper flange. The surface here became mat and rough. It is interesting that the wetting angle on the mat zone is similar to that on the neighboring but not damaged surface (fig. 3). However, the pollution on the HCEP surface is hydrophilic like on a glass surface (fig. 4). The investigated material surface is hydrophobic only in a clean state.

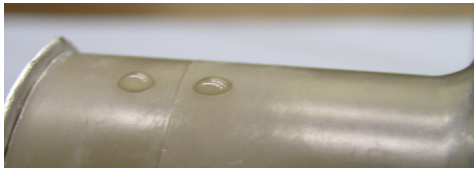


Fig. 3. The mat band formed by stable discharges on the HCEP insulator

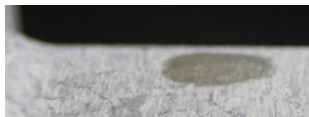


Fig. 4. The water droplet absorbed by kaolin on the HCEP surface

4.4. Investigation carried out on a flat sample

The droplets were observed on the light polluted surface ($DDD = 0,3 \text{ mg/cm}^2$) and on heavily polluted surface ($DDD = 4 \text{ mg/cm}^2$). The droplets were put on the surface 15 days after contamination to allow the hypothetical hydrophobicity transfer from the HCEP through the kaolin layer. The droplet is only partly absorbed on light polluted surface (fig. 5b). The thick pollution layer absorbs totally the droplet (fig. 5c). The contaminated samples were stored for next experiments. The same results were achieved 2 months later. There is no transfer of hydrophobicity from HCEP to the pollutant. This phenomenon is well known for the silicone rubber.

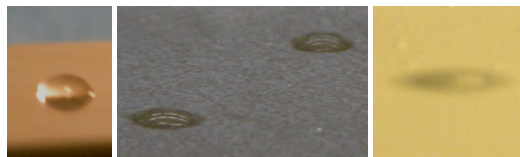


Fig. 5. Water droplet on the flat hydrophobic epoxy surface, a – clean surface, b – light polluted surface, c – heavy polluted surface

4.5. Field test

The string consisted of four insulators is tested at Glogow test station since May 2003. The second string

with only three insulators was hung in July 2005 (fig. 6a). The shorter string has two insulators identical with the insulators of the longer string. The third insulator has the shorter leakage distance of 34 cm. The specific leakage distance of the longer string is 1,9 cm/kV (phase to phase voltage) and suits the light pollution class. The area of the Glogow test station belongs to the light pollution class [12]. The shorter string has the specific leakage distance of 1,2 cm-kV. It is 0,4 cm/kV shorter than that recommended by IEC for pollution class light. The colour of the insulators was changed after 18 months of testing but no erosion was found till today. The surface conductivity of 5 – 25 μS was measured during a longer rainless period. This measurements were carried out by means of a spot probe [13]. The industrial dust absorbs rain droplets and forms a continuous pollution layer on the sheds (fig. 6b). The insulator shank is less contaminated therefore, some droplets are visible there.

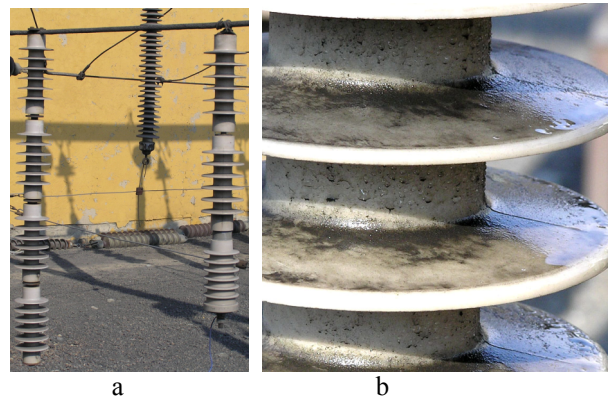


Fig. 6. Insulators tested in the field. a – two strings consisting of 20 kV insulators, b – the polluted insulator surface wetted by rain

The currents on the shorter insulator string measured in April 2006, 9 months after the test beginning are shown in fig. 7. The current of 14 mA was recorded on April, 22. The current reached 4 mA and after 370 seconds increased to 14 mA (fig. 8).

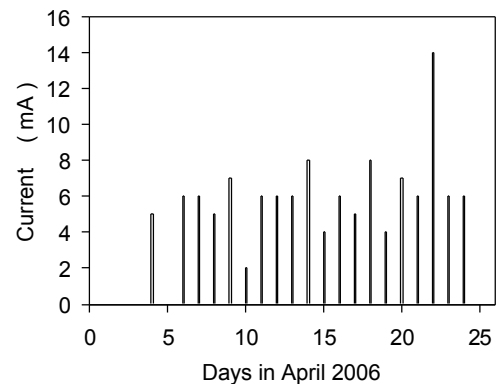


Fig. 7. Maximum current amplitudes in April 2006

The shorter string was sprayed completely (also the surface under sheds) using water with the conductivity of 100 $\mu\text{S}/\text{cm}$ three days later. The current of 51 mA was measured under the voltage of 75 kV. It is nearly four times higher than the current recorded under natural rain. The conductivity of rain water in Poland is now in the range of 20 – 40 $\mu\text{S}/\text{cm}$. Additionally, the natural rain does not completely wet the surface under sheds.

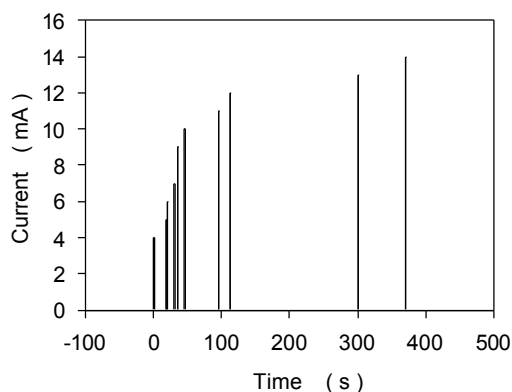


Fig. 8. Current increase on 22.04.2006

5 CONCLUSIONS

The clean surface of HCEP is hydrophobic. However, the artificial or industrial pollution layer on this material preserves its hydrophilic properties. The hydrophobicity transfer does not occur on hydrophobic epoxy even after two months. Nevertheless, the HCEP has better surface properties than the classical cycloaliphatic epoxy.

The HCEP insulator with a very short specific leakage distance of 1,2 cm/kV is tested without flashover and erosion for over 18 months.

Using a non-uniform solid layer the concentrated stable discharges can be modeled in cold fog for few hours. The method reproducing the critical pollution conditions was proposed.

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