Effect of resin content on electrical and mechanical properties of HV polymer concrete insulators

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Abstract: Insulators are one of the most important parts of the distribution and transmission lines.

We prepared and examined the properties of several Polymer Concretes (PC) with a new formulation and varying resin contents (11, 13.5, 15.5, 17.5% wt) and finally chose the optimized one to produce a 20 kV pin insulator. The initial small samples tests were dielectric strength, tracking & erosion and breakdown voltage. 20 kV pin insulator was made based on best results of initial small samples (i.e.17.5%wt resin). Then electrical, mechanical and thermal tests such as dry lightning impulse withstand voltage, dry and wet power frequency withstand voltage, puncture withstand voltage, cantilever force, tensile strength and temperature cycling, partial discharge and flammability were carried out on insulator to evaluate the developed PC material.

Results showed that increasing resin content improves the performance of PC and also the developed PC can be a very good candidate to produce this type of insulators.

1 INTRODUCTION

A great extent of research has been focused on Polymer Concrete (PC) materials but none of them has been performed such mechanical, electrical and physical tests on PC for electrical purpose.

PC insulators could be suitable alternative pertaining to their high mechanical and dielectric strength, toughness and good weather ability properties. In addition, PC not only has a good formability even in room temperature, but can also be cast integrally with metallic hard wares [1], [2].

There are basically three types of polymer based concrete systems as: Polymer Impregnated Concrete (PIC), Polymer Cement Concrete (PCC) and Polymer Concrete (PC) [1], [3]. Polymer acts as binder for non-polymeric materials in these systems.

Mixing a monomer or resin with aggregates and polymerizing or curing the material after its molding leads to formation of PC. This system is cement free. It also has a large potential for material modification with much more selective control ability on product properties. PC is a mixture of different components in proper ratios, which can be cast into any desired shape. The main ingredients of PC are: Resin, Fillers and Catalyst [4], [5].

Although initially studied for excellent mechanical properties, PC is now widely used in electrical power transmission and other non electrical applications. Some of the major applications as non-electrical are: 1.Lining for pipes and vessels especially for those used for corrosive chemicals. 2. Dams and spillways to prevent excessive erosion. 3. Highways, pavements because of high abrasive resistance. 4. Transmission towers [1], [3]. And electrical applications consist of: 1.Insulators for HV transmission. 2. Bushings. 3. Long rod /Solid core insulation. 4. Casing for transformers (casting) and many others. As already mentioned, PC finds many applications in electrical industry [1], [3].

The first step towards the development of PC as an electrical insulating material was stated in 1974 as a project by I.T.E., USA with North East Utilities, USA. In the same year Westinghouse Research Center started a program under contact from EPRI[1] for development of PC for electrical applications and patented its composition under the trade name Polysil [1]. Although PC has been investigated for more than 30 years and studies in this field have been conducted in many countries [6]-[11], electrical PCs still remain a relatively new class of insulators and the properties of these materials are still being explored. For instance, Pratap has worked on vinyl ester and acrylate based PC for electrical application. He has used high percentage of resin and has gained not good mechanical and electrical properties [3]. Also, Gunasekaran and Becerra in deferent researches have worked on

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vinyl ester and acrylate based PC for electrical application with lower percentage of resin than Pratap but there are no some important mechanical and electrical tests on insulators or samples in these works [1], [2]. A new PC composite material for high voltage outdoor insulation has been developed at Niroo Research Institute (NRI). In this work, we evaluate the effect of resin content on the electrical, physical, mechanical and thermal properties of polymer concrete samples and design and produce 20 kV insulators and finally examine the performance of them. There are no all of these tests and their valuable results in any paper.

2 EXPERIMENTAL

2.1 Materials

PC is the aggregate- resin mixture that is viscose before setting and can be cast into any desired shape and size using suitable casting techniques. The specifications of used materials are given in Table 1. In this work, CoNa (industrial) and silane are used as accelerator and coupling agent respectively.

2.2 Polymer Concrete Preparation

Fillers (silica, hydrated alumina and titanium oxide) were dried at 80°C for 6 hrs to remove moisture. Then they were mixed together for 30 seconds. After that, resin with hardener (Methyl Ethyl Keton Peroxide (MEKP)), accelerator (Cobalt Naphtanate (CoNa)) and coupling agent (3(Trimethoxysilyl)-propyl methacrylate silan) were mixed for 1 minute and then gradually the pre-blended aggregates were added to the resin mixture. Mixing continued for 3 minutes to ensure that the binder adequately wets all the aggregate and filler particles.

2.3 Characterization

We conducted two series of tests: First, sample tests, which were conducted on PC samples to evaluate the effect of resin content on various mechanical and electrical properties. These samples were prepared according to pertaining standard methods. Second, insulator tests which were conducted on the insulator made from the optimum resin content.

2.3.1 Initial small samples tests

-Dielectric strength and break down voltage: The test was carried out on initial small samples according to ASTM D149 (similar to IEC 60243-1) [20].

-Volume resistivity: The test was carried out following the principle of IEC60093.

-Tracking and erosion: The test was carried out following the principle of IEC 60587[21].

Table 1: Specification of used materials in PC

Material	(%Wt)	Trade name	Specification
Vinyl ester resin (Yashm Co.)	17.5	GRP 602	Monomer content: 35% Viscosity: 400 cps Specific gravity: 1.1
MEKP (Iran Peroxide Co.)	0.35	Peroxir KP50	Density: 1.053 g/ml Molecular weight: 210.22
Silica (Hamedan Co.)	69	Silica	Mesh (20-40-60-Flour)
Hydrated Alumina	10.3	$AL(OH)_3$	>99.6% pure
Titanium Dioxide (Panreac (PRS) Co.)	2	Tio_2/Titanium (iv) Oxide	M=79,90
Silane (International Laboratory (USA)) Co.	0.7	3(Trimethoxysyl)-propyl methacrylate (98%)	Density: 1.045 g/ml Molecular weight: 248.35
CoNa	0.15	Industrial Cobalt Naphtanate	Accelerator

2.3.2 Insulator Tests

-Temperature cycling test: The quality was studied by following IEC 383, (between 25 and 95 °C) [22].

-Dry and wet power frequencies withstand: the test was conducted on the insulator at specified test voltages as well as at elevated levels in some cases, by following IEC 383[22].

-Impulse voltages withstand: The test was conducted based on IEC 383 standard [22].

-Punctures withstand: The test was carried out on the insulator by following IEC 383[22].

-Flexural strength and cantilever force: The quantities for this test were measured by following IEC 61952[19].

- Specified tensile load (STL): The test was carried out on the insulator by following IEC 61952 (6-3-2) [19].

- Flammability test: This test was intended to check the insulator material for igniting and self-extinguishing properties with test specimen and procedure according to IEC 60695-11-10.

- Partial Discharge Measurement: The quantities for this test were measured by following IEC 60270 [23].

3 RESULTS AND DISSCUSSION

3.1 Results for initial small samples

3.1.1 Dielectric strength & Breakdown Voltage

When an electrical field is applied to a polymer, the polar groups of polymer molecules, if exist, tend to orient in the direction of the field. If the polar groups are sufficiently flexible to orient in this way, they produce a material with high dielectric constant. If they are not, the material has low dielectric constant [6]. If they have intermediate flexibility constant this permits only a slow partial response. This test was carried out by following principle of ASTM D149 92 [20].

In Table 2 we can observe that when vinyl ester to filler ratio increases the value of dielectric strength and break down voltage increases. It is observed that these two parameters increase with addition of resin steadily. This may be attributed to three-dimensional inert structure of cured resin as binder. Also, with increasing cured resin content orientation of molecules in the electric field becomes more difficult and consequently electrical strength increases.

3.1.2 Volume Resistivity

In Table 2 it is seen that when the ratio of vinyl ester resin to filler increases the changes in the value of volume resistivity is not detectable because of the sensitivity limitation of our experimental device. However this is not important, since the required value for this type of insulating material is about 10^{15} ohm-cm which is still below the measured value for prepared PC [1].

3.1.3 Tracking and Erosion

Tracking is the process that produces tracks as a result of the action of electric discharges on or close to a contaminated surface of an insulating material. Also, erosion is the wearing away of electrical insulating material by the action of electrical discharge. This test evaluates the resistance to tracking and erosion of electrical insulating materials used under severe ambient conditions. This test was carried out by following principle of IEC60587 class IA 4.5 kV that is the most difficult class of this test [21]. The contamination electrolyte used in this study was a 0.1% ammonium chloride solution (NH_4CL) and 0.02% Iso octyl-phenoxy poly ethoxyethanol (a non-ionic wetting agent) in de ionized water. It was 3.95±0.05 Ωm at 23°C. The samples were slab-shaped (12cm×5cm×6cm). In this test, all of four samples survived 6 h at 4.5 kV and passed it successfully and the depth on erosion of samples was less than 2 mm. The samples under Tracking & Erosion test were shown in figure 1.

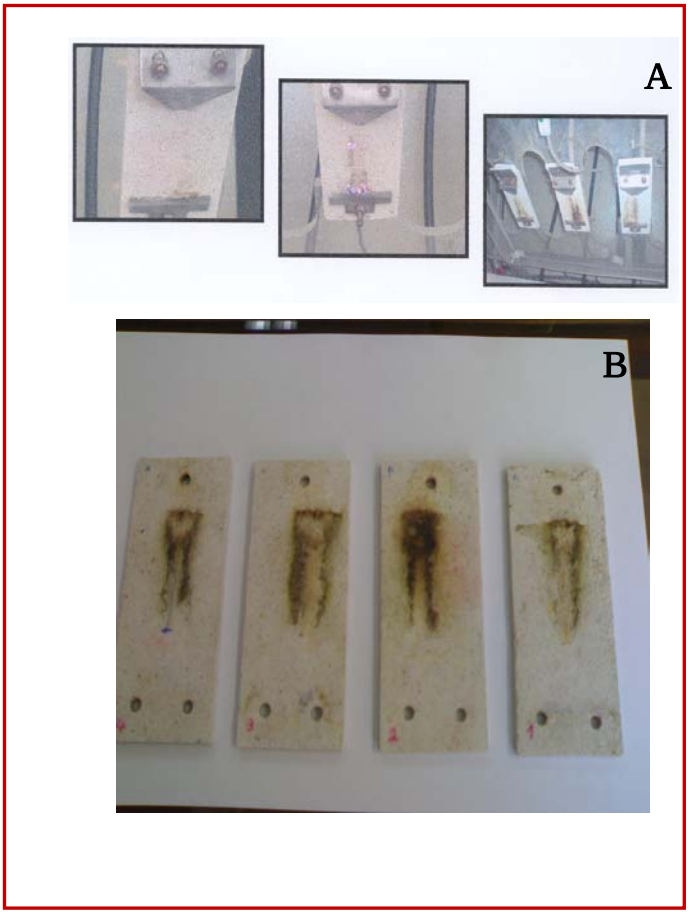
Table 2: Test results for Polymer Concrete samples

Samples (%Wt) Resin	Dielectrical Strength (kV/mm)	Breakdown Voltage (kV)	Volume Resistivity (Ω.cm)
11.0	15.8	40.8	> 2* 10^{16}
13.5	15.2	43.8	> 2* 10^{16}
15.5	16.8	41.7	> 2* 10^{16}
17.5	17.7	45.7	> 2* 10^{16}

3.2 Results for insulator

As it is observed in Table 2, the best results belong to samples containing 17.5% resin and thus we made insulators with this content of resin. 20 kV pin insulators that were made with 17.5 % resin were examined by thermal, mechanical and electrical tests comprising temperature cycling test, dry and wet power frequencies withstand, impulse voltages withstand, punctures withstand and flexural strength and cantilever force, STL, flammability and partial discharge . The results have been shown in Table 3 except temperature cycling, flammability and partial discharge that are quality tests. Beside the results, the standard values of these properties are mentioned for the sake of comparison.

Figure 1: Tracking & Erosion test



As it is shown in table 3 acceptable value based on IEC60076-1 for dry lightning impulse withstand voltage is 125 kV where as this value for our PC insulator is 161 kV. Also, acceptable dry power frequency withstand voltage is 50 kV and this parameter for our PC insulator is 90 kV. In addition, puncture withstand voltage for PC insulator is more than 195 kV that is very higher than standard level that is 120 kV. These results confirm PC insulator electrical design and means electrical design has been performed very well.

3.2.1 Temperature cycling tests result

The insulator was successively immersed in to a hot and cold-water bath respectively with at least 70 º C temperature cycle differences for 15 minutes each time. This temperature cycle was repeated three times. No visual cracks were observed at the end of this test, which indicated resistance of insulator material to a varying harsh environment.

3.2.2. Flammability test result

One of the most important properties of insulators is ability to self-extinguishing for prevention of fire accident in power lines. This insulator passed this test successfully due to presence of high amount of fillers among which ATH was the most effective one to make flame retardant.

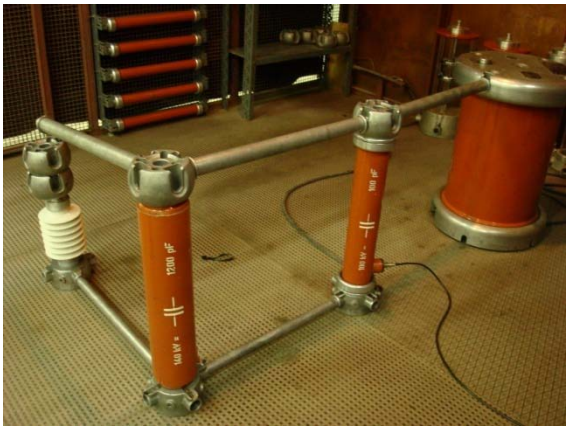
3.2.3. Partial Discharge test result

Partial discharge (PD) is localized electrical discharge that only partially bridges the insulation between conductors and which can or can not occur adjacent to a conductor. In general, it is a consequence of local electrical stress concentrations in the insulation or on the surface of the insulation. To evaluate PD, apparent charge measurement is performed. The apparent charge is usually expressed in Pico coulombs (Pc). The partial discharge test circuit can be observed in figure 2.

Table 3: Test results of polymer concrete 20 kV pin insulators

Tests	Polymer concrete insulator	Acceptable values based on IEC60076-1
Dry lightning impulse withstand voltage (kV)	161	125
Dry power frequency withstand voltage (kV)	90	50
Wet power frequency withstand voltage (kV)	77	-
Punctures withstand (kV)	>195	120
STL (kN)	10	-
Cantilever force (kN)	7.3	-

Figure 2: Partial Discharge test circuit



In this test, two insulators (No1 and 2) with smooth surface and one insulator (No3) with porous surface were chosen to study effect of surface quality on partial discharge phenomena. According to IEC60660, apparent charge for 20 kV insulators in 26 kV test voltage, must not exceed 10 pc. As it is shown in Table 4, the surface quality has not more effective on the value of current rate in low voltages. However the maximum value observed are 2.2 pc for porous surface and 0.6 for smooth surface samples at 28 kV. It is about four times more than a good quality surface. This test is shown effect of surface quality on partial discharge at high voltages situations.

Table 4: Partial Discharge test results of polymer concrete 20 kV pin insulators

NO	Number of sheds	Test voltage(kV)	PD (pc)	Test voltage(kV)	PD (pc)	Test voltage(kV)	PD (pc)	Test voltage(kV)	PD (pc)
1	7*150mm	14	0.1	18	0.3	20	0.4	28	0.5
2	7*150mm	14	0.4	18	0.4	20	0.5	28	0.6
3	7*150mm	14	0.4	18	0.4	20	0.6	28	2.2

4 CONCLUSION

In this research, based on the results gained for initial small samples prepared from new PCs with different polyester resin content, a 20kV PC pin insulator with 17.5wt % resin was made at Niroo Research Institute (NRI). Properties of prepared PCs showed completeness of cure reaction and yield of best results for the one containing 17.5%wt resin. With increasing resin content up to 17.5%wt resin, air intakes and water absorption are decreased which help resistance against tracking, water treeing and electrical breakdown, where as at the same time properties such as compressive and dielectric strength are improved. These insulators passed all required electrical and mechanical tests successfully.

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