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Insulation System in Energy Sector: The Benefits of Polymer Composites

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ABSTRACT

Polymeric composites are used in various engineering applications due to their ability to be adapted for a specific application. As a result, composites could be selected or designed for high performance applications in electrical equipment, such as field grading applications in high voltage technology. Polymer composites with different nano filler and their dielectric performance are characterized. Measurement results and potential applications of the composite systems are presented in this paper.

Key word : HDPE, Polystyrene, dielectric properties, Nanocomposites.

Introduction

Insulation in electrical windings are subjected to heat, moisture, oxygen, strain and vibrations, which eventually cause damage to the winding insulation and can lead to failure of the wire conductor. In most cases these environmental and operational conditions are modest and wiring is used safely for years. In the case of constant usage, extreme operation conditions can cause deterioration of the insulation and may become brittle or fail early. Winding insulation inspections are done visually to find the obvious cracks, damage, and burns. However, visual inspections will not give conclusive information as they are located deep inside the insulation.

The high percentage of electrical equipment failures caused by insulation breakdown clearly illustrates table1, which is derived from Table 36 of the IEEE Gold Book on Electrical Reliability. It reasons that by avoiding insulation breakdown, electrical equipment failure can be reduced severely and in general electrical system consistency will be increased enormously.

Cellulose solid insulation structures have hydroxyl groups having hexagonal structures. Thus making it hygroscopic, moisture will be migrating to the interior of insulation and will be affecting the electrical properties and also causing further degradation. Cellulose solid insulation makes irregular spaces in applications

Table 1-Total failures due to Insulation breakdown

Component	Percentage of Insulation Failure
Transformers	84%
Circuit Breakers	21%
Disconnect Switches	15%
Insulated Switchgear Bus	95%
Bus Duct	90%
Cable	89%
Cable Joints (splices)	91%
Cable Terminations	87%

Dielectric properties have to improve in an insulation system, hence development of hybrid insulation technology for power transformers has evolved over a number of years. The current situation in the power industry together with worldwide economic and environmental situation, have led to a renewed interest in insulation technology. Hybrid insulation technology is growing and expanding. It is playing an increasingly larger role in the changing landscape of the modern power system.

To investigate the concept of insulation evaluation, a series of experiments were conducted like Break down voltage (BDV) test, Tan δ (delta) and tensile strength test (mechanical strength). The results of tests on test specimens viz. High Density Polyethylene HDPE, Polystyrene, in combination with nano composites have suggested the effectiveness and their application to electrical windings. These tests were carried out in order to study the reliability of the winding.

The field of nanotechnology is one of the most popular areas for current research and development essentially in all technical disciplines [2]. The polymer insulation windings were tested in comparision with nano composite insulations to study the different properties of polymers viz. High Density Polyethylene HDPE, Polystyrene and their nano composites. Nano powders, containing a distribution of particles between 50-500nm will fill up the voids, cavities, and gaps in the insulation and makes it compact, which otherwise would have housed moisture or air to make the insulation weak and create partial discharges.

This obviously includes polymer science and technology and even in this field the investigations cover a broad range of topics. Arunkumar etal. gives details about integral aspect of Polymer Nanocomposites [3]. This paper explains the different properties of polymers like High Density Polyethylene (HDPE), Polystyrene and with nano material developed in house using chemical route. Nano material alumina and magnesia were used for the composites as fillers.

This material is added with polymerized material to improve its dielectric, chemical and mechanical properties of the material. In order to find out better insulation for High voltage application, the synthesis of these above samples and tests were carried out at dielectric material division CPRI Bangalore. The mechanical and electrical tests were carried out on the prepared samples.

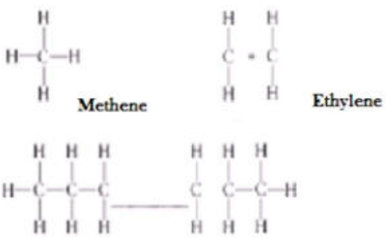
Experimental Work

Polymer nanocomposites represent a new alternative to the material which are conventionally filled with particles of bigger size distribution. Because of their nanometer sizes, filler dispersion nanocomposites exhibit noticeably improved properties when compared to the pure polymers or their traditional composites. These include increased modulus and strength, outstanding barrier properties, improved solvent and heat resistance and decreased flammability. Some of the properties of HDPE and polystyrene are studied and discussed in this paper. Properties of HDPE provide an excellent abrasion resistant product preventing gouging, scuffing and scraping. It has highest impact resistant thermoplastics, maintains excellent machinability and self- lubricating characteristics. Properties are maintained even at extremely low temperatures. HDPE has very good chemical resistance to corrosives as well as stress cracking resistance with the exception of strong oxidizing acids at elevated temperatures.

Moisture and water (including saltwater) have no affect on HDPE. It offers water absorption lesser than 0.01%. It also has a higher tensile strength of four times that of low density polyethylene and it is three times better in compressive strength. HDPE has little branching, giving it stronger intermolecular forces and tensile strength than lower-density polyethylene. It offers tensile strength of 3,100-5,500 (psi). It is also harder and more opaque and can withstand at higher temperatures (120 °C/ 248 °F for short periods, 110 °C /230 °F continuously). Also thermally have good resistant like thermal conductivity of 11.0-12.4 (104 cal-cm/sec-cm), Coefficient of thermal expansion of 6.1-7.2 (105 in./in° F) and deflection temperature of 110-130(°F) at 264 psi and 140-190(°F) at 66 psi.p

Figure 1: HDPE Granules

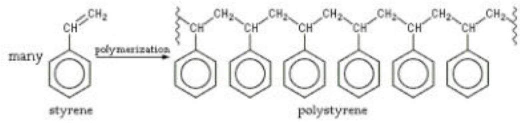
Figure 2: HDPE Molecular chain



The longer the main chain then greater the number of atoms and consequently greater the molecular weight.

The molecular weight, the molecular weight distribution and the amount of branching determines many of the mechanical and chemical properties of the end product. Its dielectric properties are impressive with dielectric strength of 450-500(V/mil), Dielectric constant at 1k Hz is 2.30-2.35, Dissipation factor at 1k Hz is 0.0003, Volume resistivity 1015(ohm-cm) at 73°F, 50% RH

Figure 3: Polystyrene



Polystyrene are an aromatic polymer made from the aromatic monomer styrene, a liquid hydrocarbon that is commercially manufactured from petroleum by the chemical industry. Liang etal has explained about Polystyrene which is one of the most widely used kinds of plastics. Polystyrene is a thermoplastic substance in solid (glassy) state at room temperature and when heated above its glass transition temperature (for molding or extrusion) becomes liquid and becomes solid again when it cools off. Pure solid polystyrene is a colorless, hard plastic with limited flexibility and it can be casted into molds with fine details. Doroudiani.S and Mihai, M [2, 4] explained about Polystyrene, it can be transparent, can be changed to various colors and can be recycled. Polystyrene does not biodegrade and is often abundant as a form of pollution in the outdoor environment, particularly along shores and waterways.

The chemical makeup of polystyrene is a long chain hydrocarbon with every other carbon connected to a phenyl group. Polystyrene's chemical formula is (C8H8) n, it contains the chemical elements carbon and hydrogen shown in figure 3.

Complete oxidation of polystyrene produces only carbon dioxide and water vapor. In addition polymer of styrene results when vinyl benzene styrene monomers (which contain double bonds between carbon atoms) attach to form a polystyrene chain.

Electric properties like Dielectric constant of 2.42.7, Electrical conductivity of 10−16 S/m. thermally also have better stability. Its other characteristics, like thermal conductivity (k) of 0.08 watts per meter Kelvin (W/(m·K)), Glass transition temperature of 95 °C, specific heat (C) of 1.3 kJ/(kg·K) and Melting point of 240 °C. This material has low porosity. The cost is dependent on the selection of the dielectric properties in the material.

Synthesis and Finished Samples: The Synthesis of HDPE with nano alumina, HDPE with nano magnesium oxide, Polystyrene with nano alumina, Polystyrene with nano magnesium oxide samples are shown in fig.7. These were prepared in explanation with schematic formation by blending the granules with nano composites by using the blending machine as shown in fig 5.

Figure 4: Schematic formations of Nanocomposites

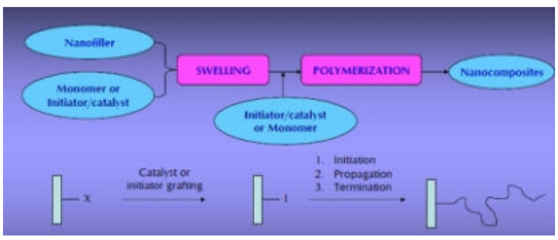


Figure 5: Brebender Plasticorder

Figure 6: Compression Moulding Machine

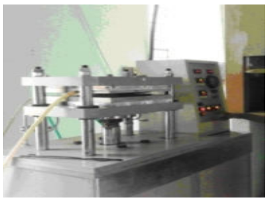


Figure 7: Finished Samples of HDPE and Polystyrene with Nanocomposites

Tests Conducted

For designed polymer HDPE, Polystyrene and HDPE, Polystyrene samples blended with nano filler and the following tests were carried out for comparison of electrical and mechanical properties like

- Break down voltage (BDV)
- Tan δ(delta)
- Tensile strength (mechanical strength)

Breakdown: Breakdown strength of polymer material tested by makes use of the break down tester rated of 0-25KVA. Breakdown voltage tests were conducted are as shown in figure 8.The breakdown voltage tests procedure is carried out by keeping the prepared samples in between the HV and LV electrode. Then it is covered with both the electrodes by insulation tape to avoid flash over in the air. Voltage is applied between the electrodes and then raised till insulation breakdown occurs. Procedure is repeated for 6 breakdowns at different places of the samples and average value to be considered. The values of break down voltages were noted from kV display and procedure is repeated for all the samples.

Figure 8: sample test using HV Source

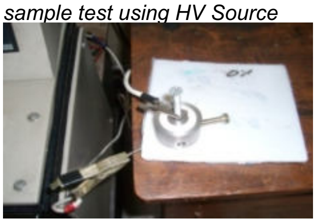


Figure 9: Tan delta and Capacitance tester

Tensile strength: Tensile strength is indicated by the maxima of a stress-strain curve and, in general, indicates when necking will occur. As it is an intensive property, its value does not depend on the size of the test specimen. It is, however, dependent on the preparation of the specimen and the temperature of the test environment and material. The standard way to measure tensile strength is by taking three numbers of each test samples with standard sizes and shapes were prepared as shown in figure. 10. The samples were fixed to the two jaws of the equipment shown in the figure 11. As the load is applied, sample breaks at some point. Load required to break the samples are noted down for three samples and average values are considered in Mpa. In this process the obtained mechanical properties for different specimens were compared.

Figure. 10: Samples prepared

Figure.11: Tensile strength module

Results and discussion

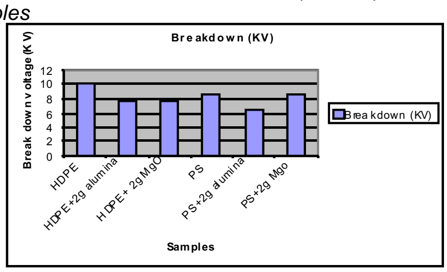
Break down voltage of different all Samples:

Table 2 and graph 1, show variation of BDV with respect to HDPE with nano composites Magnesia and alumina, and Polystyrene with nano composites Magnesia and Alumina.

Table 2: Values of BDV for different samples

Sample	Breakdown (kV)
HDPE	10.021
HDPE+2g Al_2O_3	7.695
HDPE+ 2g MgO	7.743
Polystyrene	8.564
Polystyrene +2g Al_2O_3	8.543
Polystyrene +2g MgO	6.532

Graph 1: Variation of Breakdown(KV/mm) v/s different samples



Results indicate an increase in Break down voltage values indicating usefulness of fillers in improving breakdown voltage values which is actually dependent on cavities and voids in the matrix which will provide path for the electrons to move from one electrode to another.

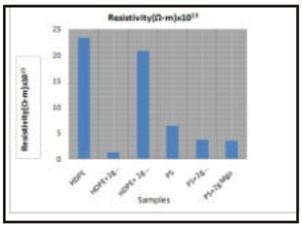
Resistivity of various samples:

The table 3 and graph 2, show variation of Resistivity (Ω-m) with respect to HDPE with nano- composites Magnesia and alumina, and Polystyrene with nano- composites Magnesia and Alumina.

Table 3: Values of Resistivity (Ω-m) for different samples

Sample	Resistivity (Ω m)
HDPE	$2.336x10^{14}$
HDPE (80 g)+2g Al_2O_3	$1.285\ x10^{13}$
HDPE (80 g)+ 2g MgO	$2.084\ x10^{14}$
Poly Styrene (80 g)	$6.365\ x10^{13}$
Poly Styrene (80 g) +2g Al_2O_3	$3.725\ x10^{13}$
Poly Styrene (80 g) +2g MgO	$3.592\ x10^{13}$

Graph 2: Variation of Resistivity v/s different samples

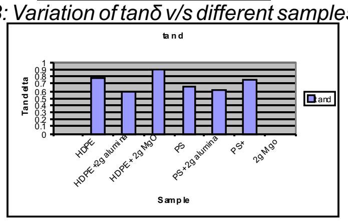


The table 4 and graph 3, show variation of dissipation loss factor tanδ with respect to HDPE with nano- composites Magnesia and alumina, and PS with nano- composites Magnesia and Alumina.

Table 4: Values of dissipation loss factor (tanδ) for different samples

Sample	tanδ
HDPE	0.7847
HDPE (80 g)+2g Al_2O_3	0.805
HDPE (80 g)+ 2g MgO	0.887
Poly Styrene (80 g)	0.653
Poly Styrene (80 g) +2g Al_2O_3	0.655
Poly Styrene (80 g) +2g MgO	0.747

Graph 3: Variation of tanδ v/s different samples



Loss angle is the tangent of the loss angle which is the indication of level of energy dissipation in to the matrix due to its imperfection of insulating material. Lower values of loss angle indicate in the increase in dielectric properties of the samples.

Tensile strength of various samples:

The table 5 and graph 4, show variation of tensile strength of HDPE, Polystyrene and with nano composites viz. Magnesia and alumina.

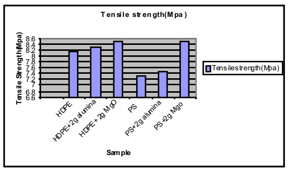
Table 5: Values of Tensile strength (Mpa) for different samples

Sample	Tensile strength (Mpa)
HDPE	8.165
HDPE (80 g)+2g Al_2O_3	8.302
HDPE (80 g)+ 2g MgO	8.461
Poly Styrene (80 g)	7.305
Poly Styrene (80 g) +2g Al_2O_3	7.45
Poly Styrene (80 g) +2g MgO	8.49

A graph explains characterization of polymeric material properties, which is vital part of all investigations dealing with materials. Characterization describes all features of a material that would be sufficient for reproducing the material.

Applications:

Graph 4: Explains variation of tensile strength v/s different samples



HDPE have been under use in high voltage applications. Polymer are resistant to corrosion , chemical attack, Light weight, Chemical resistant piping systems , Fuel tanks for vehicles , Laundry detergent bottles etc.

Polystyrene have the most important properties like excellent thermal performance, High compressive strength, impact absorption, Low weight, 100% recyclable.

In comparison to conventional polymers, nanofiller incorporation has been shown to significantly enhance the physical properties to render their use in high voltage electrical applications.

The Polymeric composites of HDPE and Polystyrene have been shown to be improved in their mechanical properties without affecting their electrical properties. Hence, these composites are having potential to be used as hybrid insulation in place of conventional electrical grade paper.

Conclusion

Polymeric composites with nano fillers have shown consistent increase in tensile strength. The properties like Break down voltage and Tan delta have been decreased marginally. For a limited quantity of fillers (2%) in the polymer matrix.

In case of loss angle (tan delta) the value of specimen is increased from 0.7847 to 0.887 from the plain HDPE to the composite. The variation is not appreciable for the nano filler incorporation.

Increase in tan delta values in case of MgO is consistent, indicating the hygroscopic MgO is adsorbing moisture which is leading to the increased tan delta values.

Similarly, in case of Break down voltage also there is a marginal decrease in the values indicating that the nano fillers are affecting the insulation properties but do not appreciable decrease in values.

The Resistivity is considered as an important property of insulation. Similar, variation as in case of tan delta and break down voltage there is a marginal lowering of the specific resistance from 2.336 E14 Ω-cm and PS 6.365E13 Ω-cm. The advantage of adding nano material is to provide mechanical strength. This is proved by conducting the tensile tests on the samples. Usually the tensile strength of the pure material is low (For Pure polystyrene 7.305Mpa, Pure HDPE 8.165mpa) when compared with the nano composite materials. Tensile strength of the insulating material is increased by adding the nano fillers.

Break down strength of polymer composite is better than cellulose insulation system (80V/mil). Hybrid polymer and nanocomposites can be synthesized by varying by optimizing polymer blended with nanocomposites of relative amount. By improving the electrical properties it can proves that an insulation can have higher dielectric strength.. Nano fillers may also be helping in improving the coefficient of thermal expansion and thermal conductivity of insulation; these aspects are to be further investigated to establish the use of polymeric composites as potential candidates for winding insulation in power transformer construction.

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