

METHODS FOR PREPARATION OF NANO-COMPOSITES FOR OUTDOOR INSULATION APPLICATIONS

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Abstract. Electrical insulation materials are advancing rapidly due to several advantages including light weight, better performance in polluted environment and reduced installation cost. In polymeric micro-composites, enhancing one property of the insulator may affect adversely on the other desired properties. This problem can be addressed practically with the invention of nano-composites. This article provides a comprehensive survey of methods and techniques for the development of nano-composite materials in order to improve its insulation properties as well as its cost and aging properties. These recently evolved nano-composites provide significant improvements in combined electrical, thermal and mechanical properties. This article critically evaluates the methods, their issues and related challenges. In the end, conclusion has been drawn by proposing a set of possible solutions which need to be performed as future work.

1. INTRODUCTION

The Ceramic insulators have been used in the power industry for more than a decade. This material had demonstrated its self-sustaining ability against harsh environmental effects. These are stable structures due to their atoms seal pack configuration and strong ionic bonding between them which help to resist against environmental stresses. Therefore, ceramic housing should not be affected by stresses like Ultra Violet rays, surface electrical activity and humidity etc. Their mechanical strength is due to the stiff nature of material. The housing used for bushing on high voltage equipments provide self-sustaining capability and do not require other materials for strength. The main raw materials of these insulators are clays, feldspar and quartz which are inexpensive and readily accessible.

The seismic acceleration stresses up to 0.5 g can be withstand by these insulators.

Since 1970's, the use of polymeric insulators for outdoor high voltage insulation has increased so dramatically that ceramic insulators are nearly

becoming obsolete in power industry. Electrical companies started using polymeric insulators at distribution voltages, and then gradually, at low voltage transmission, now at 765 kV ac and 500 kV dc [1].

The polymeric insulators have demonstrated best contamination flashover capabilities and therefore are routinely deployed in diverse environments. The reason for the popularity of Polymeric insulation materials are their numerous advantages, like: the density of polymeric materials is lesser than porcelain materials, which makes construction and erection of insulators simpler and quicker. The lighter weight allows the use of less costly structures and fixing arrangements and also results in lower transportation cost.

Creepage distance per unit length is usually higher in polymeric insulators than porcelain insulators. AC wet flashover is avoided by providing alternating diameter weather sheds to polymeric insulators which made their structure more complex.

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The composite insulators revealed a better electrical performance in polluted environment due to their hydrophobic properties. The conductive contamination suspended within the water beads is discontinuous due to formation of water beads on the polymeric surface. This results in lower leakage current and the probability of dry band arcing.

The physical properties of the polymer material dictate that these materials will not smash like porcelain materials. With the instigation of an internal fault, the expected failure method is rupturing leading to an exterior flashover and dissipation of the energy outside of the housing.

The seismic acceleration stresses up to one gram can be withstand without damage by polymeric insulators due to their lighter weight, high damping factor and high strength design uniqueness.

Various studies have shown that micro fillers have improved the performance of composite materials for high voltage insulator performance. The micro fillers have shown significant improvement in the thermal properties of composite material used for outdoor insulators. This feature is very important for protecting insulator against the dry band arc phenomenon. However, further improvement in the micro filled composite material is not possible with the available processing technology. The nano-composite materials were initially developed for commercial application using intercalation method. Since the mechanical properties of these materials were significantly improved, hence the researchers were attracted to consider the resultant materials for outdoor high voltage applications. Later on, significant research was carried out to improve the electrical properties of the nano-composite materials. Large specific surface area of the nano fillers was the focus of researchers to explore its electrical properties for high voltage insulator applications. Nano-particles have diameter of less than 100 nm. They have been made from different sources and include the following types [2]: Aluminum, Gold, Silver, etc. Zinc Oxide, Alumina, Calcium Carbonate, Titania, etc. Silica, Silicon Carbide, Acetylene Black, Polyhedral Oligomeric Silsesquioxanes (POSS).

2. COMPOSITE MATERIALS

For outdoor insulation, two materials are commonly used for the housing: ethylene propylene diene monome rubber and silicone rubber. SiR is preferred due to its characteristic hydrophobicity and its good performance in polluted environments.

3. NANO-COMPOSITES MATERIALS

The conventional polymeric composites can alter certain desired properties of the composite materials (e.g. mechanical and thermal properties); it often comes with the compromise of other properties being negatively affected (e.g. electrical properties). Interestingly, the newly emerging polymer nano-composites provide significant improvements in combined electrical, thermal and mechanical properties [3]. These profound impacts create great benefits specifically to the high voltage insulating industry, especially in electrical properties enhancement. Recently these 'hi-tech' materials with excellent properties have begun to attract researchers in the field of dielectrics and electrical insulation. Since new properties are brought about from the interactions of nanofillers with polymer matrices, macroscopic properties are expected to come out, which would be interesting to both scientists and engineers. Improved characteristics are expected as dielectrics and electrical insulation.

The resistance to arcing is enhanced by adding up of nanofillers and microfillers in a high temperature vulcanizing silicone rubber. S. Rätzke and J. Kindersberger, in their work, found that the best dispersion was obtained for nanosilica; on the other hand, large agglomerates were found to be formed by nanoalumina [4]. The results of the arcing test shows longer time duration with increased filler percentages of SiO_2 and Al_2O_3 . Results are shown in Fig.1.

The authors found that the thermal conductivity rose in an approximately linear fashion with the filler concentration and that the higher thermal conductivity

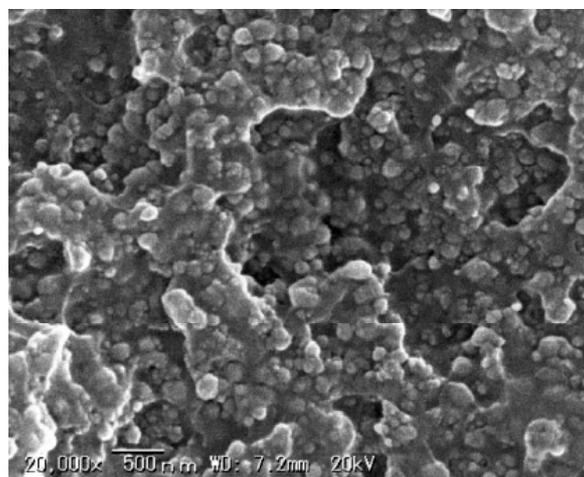


Fig. 1. Synthesis and structure of nanosilica.

improved the resistance to erosion. According to Dengke *et al.* [5,6], the addition of a small amount (2 to 5 wt.%) of inorganic nanofillers to polymers should be sufficient for mechanical and thermal stability and performance improvement. They selected nanosilica because it is a commercial nanoscale material. In other research, Meyer *et al.* [7] showed that RTV SiR filled with nanosilica, when compared with RTV SiR filled with micro silica, demonstrated a higher tracking and erosion resistance, lower roughness, and slightly lower hydrophobicity. The concentrations used in this work were 5% and 10% wt for nano and micro silica, respectively, and nanosilica had higher tracking and erosion resistance than micro silica. Polyamide films tested by Irwin *et al.* [8] displayed significant improvements to elongation, scratch hardness, and strength. Fuse *et al.* [9] studied polyamide with layered silicate nanofillers from 1 to 5 wt.%.

They found that the conduction current decreased with the addition of nanoparticles. Moreover, the dielectric strength was independent of the nanoparticles for impulse, direct current, and alternating current voltages. These researchers did not see an improvement with the use of nanofillers, as they performed these tests.

The epoxy resin with the mixing of nano, micro, and the combination of both nano and micro fillers is demonstrated by Imai *et al.* [10]. It was evident that microfilled epoxy and NMMC maintained a far smaller erosion depth than the base epoxy resin. Imai *et al.* [10] assumed that an increase in particle concentration in nano and micro filler mixtures prevented treeing from propagating efficiently. From these results, it was evident that the nano and micro composites mixture displayed better electrical insulation properties; hence, the formulation with the combination of micro and nano-particles is a good choice. According to Roy *et al.* [11], the voltage endurance behaviour of cross-linked polyethylene (XLPE) was significantly improved with the inclusion of treated nano-particles (aminosilanetreated nanosilica, vinylsilane-treated nanosilica). This difference was attributed to the chemical treatment of the nanosilica. All the nanoscale fillers were characterized by a significantly improved breakdown strength and endurance over the base resin. In this work, nanofillers showed an improvement.

4. POLYMER NANO-COMPOSITES

The specific properties of polymers are typically improved by adding fillers. And the polymer nano-

composites based on silicon rubber have attracted researchers due to their capability to enhance mechanical, thermal and electrical properties. Polymer nano-composites have been demonstrated at lesser [12] or equal concentrations to have properties that are same or enhanced than those of polymer micro-composites [13-14].

The nano-particle's size and high relative surface area to volume ratio causes unusual properties. Due to its larger specific surface area than micro-particles, it interacts additional with its surrounds [15]. The large interfacial interaction between the matrix and the nano-particles yields the physical and thermodynamic stability of the polymer nano-composites [12].

A polymer nano-composite can be defined as a system in which at least one dimension of filler is on a nanometric scale. In the polymer matrix, uniform filler distribution is always desired. The creation of a favorable interaction between the polymer and the nanofiller is mandatory to avoid phase separation and agglomeration. Two potential solutions for improving compatibility of the ingredients are: chemically transform one or more of the components or launch an appropriate compatibilizer [10].

5. NANO-PARTICLES

Nano-particles exist in spherical, tube and platelets and have at least one dimension in nanometers. Like the micro-particles, nano-particles can be manufactured by breaking up a big particle. It is important to avoid agglomeration of the nano-particles and ensure good bond to the matrix irrespective of the preparation methodology. Surface-treatment of the nanosize particles is also possible. A broad range of polar agents, such as silanes and polyalcohols, and non-polar agents, such as stearic acid and fatty acids, are commercially available as surface treatment agents for fillers [9].

5.1 Layered silicates

LS/clay minerals are part of the class of silicate minerals, phyllosilicates. They include natural and synthetic clays such as mica, bentonite, magadiite, laponite, fluorohectorite and so on. LS are the most widely used 2-D nanofillers in various fields. The structure of LS consists of a 2-D layer of two fused silicate tetrahedral sheet with an edge-shared octahedral sheet of metal atoms, such as Al or Mg. The model crystal structure of LS was proposed by Hoffmann *et al.* Fig. 2 [16].

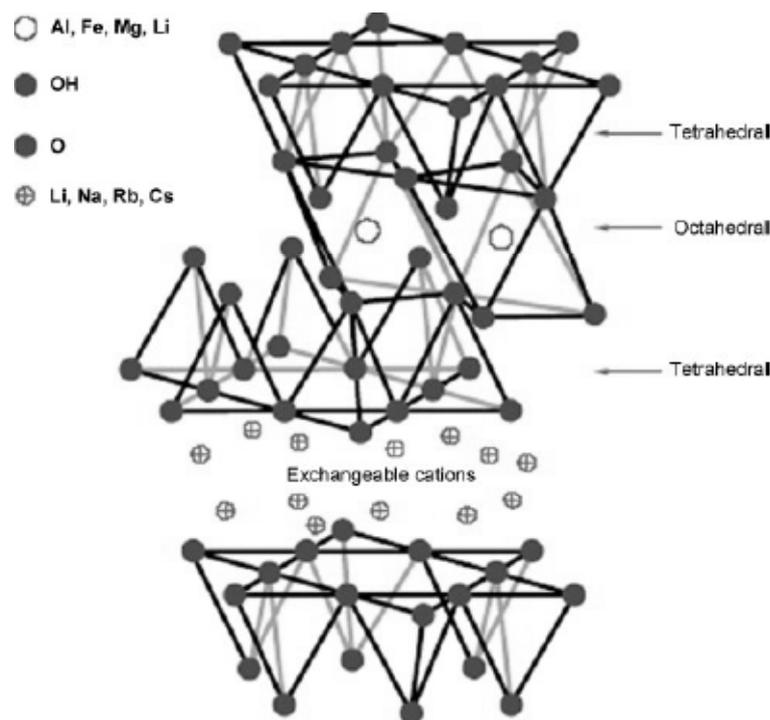


Fig. 2. Schematic structure of Layered Silicate.

These sheet-like nanofillers are ~1 nm thick and 100 s to 1000 s of nanometers long; as a result they possess a high aspect ratio. Therefore, polymer/silicate nano-composites provide an attractive method to improve the polymer properties such as stiffness, strength and barrier properties without any change in processing technique.

5.2. Nanotubes

Among different types of nanotubes, carbon nanotubes are the most widely used and accepted in polymer research field and industry. Carbon nanotubes are allotropes of carbon and belong to the fullerene structural family. In nanotubes the diameters are in the order of a few nanometers; however, they are millimeters or even centimeters long. Therefore, these nanotubes possess a high aspect ratio, thereby imparting high strength to the polymer with a small weight percent. The excellent properties of carbon nanotubes are a consequence of its bonding nature. Carbon nanotube-reinforced composites are of particular interest in the field of material science to develop significantly lightweight strong materials. A major problem in this field is the failure to attain a homogeneous dispersion of nanotubes in the polymer matrix due to the aggregation of these

tubes. Researchers have employed different techniques to attain optimum dispersion of nanotubes in the polymer matrix, including: (i) solution mixing [17,18], (ii) sonication [19], (iii) coagulation [20], (iv) melt compounding [21], (v) in situ emulsion polymerisation [22], (vi) the use of surfactants [23] and (vii) chemical functionalization of nanotubes [24]. Chemical modification of carbon nanotubes is the best technique to get more homogeneous dispersion. This is done through covalent and noncovalent attachments of functional groups in nanotubes with the matrix.

5.3. Spherical particles

Nanofillers with three dimensions in the nanometer regime are the spherical nanofillers generally obtained by a sol-gel process [25]. In sol-gel processes, the organic/inorganic hybrid materials can be formed by the condensation reaction between the functionalized prepolymers and the metal alkoxides, leading to the formation of a chemical bond between the polymer and the inorganic filler. Therefore, the incorporation of filler particles in polymers through the sol-gel process avoids the aggregation of filler.

Silica, TiO_2 , ZnO, CaSO_4 , CaCO_3 , ZnFe_2O_4 , and so on, are the widely used spherical inorganic nanofillers in the polymer field.

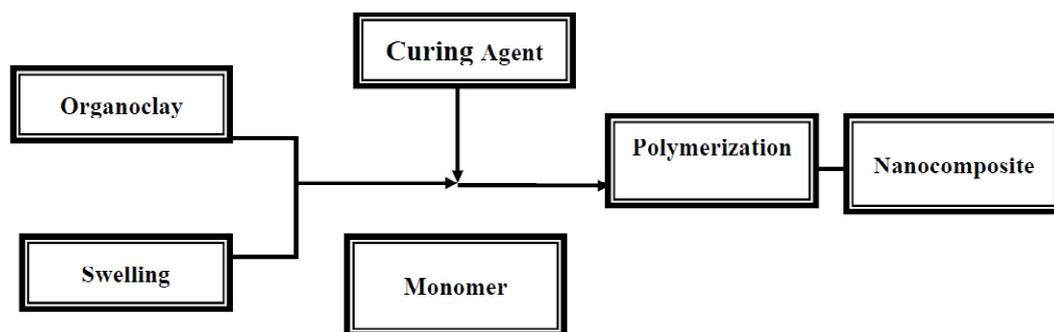


Fig. 3. Block diagram for in-situ polymerization.

6. FUNCTIONALIZED POLYMER WITH NANOPARTICLES

The application area of polymers is generally based on their end properties. The behavior of polymer may drastically affects by a change in its structure. The structure of a polymer can be changed by adding functional groups to the polymer backbone or to the side chains in assorted ways such as grafting [26,27] and using monomers in the polymerization process [28]. However, in these processes unwanted cross-linking and polymer degradation reactions must be avoided by using different techniques. If the interaction between the components is insufficient or chemical treatment of the fillers to be avoided or, a new component named as polymer compatibilizer [29] can be added. The interfacial bonding between the compatibilizer and the nano-particles are dependent on several factors. These factors are the functionality, concentration, and the molecular weight, the molecular weight distribution of the compatibilizer and the mass ratio of the compatibilizer to the nano-particles [30].

7. PREPARATION OF NANO-COMPOSITES

Preparation of polymer Nano-composites can be done by various methods, e.g. they can be prepared by blending or by in situ polymerization. The blending can be done either in two ways either by melting if the ingredients bear the blending temperature above the melting temperature of the polymer [31,32], or by solution, if an appropriate solvent is available [33,34]. A good compatibility between the ingredients is mandatory in order to make a homogenous polymer nano-composite irrespective of preparation method [35].

Compatibility can be enhanced by choosing appropriate blending conditions, e.g. by adjusting the temperature profile and the mixing speed, [36]

or by chemical treatment of the filler or the polymer. Researchers used different methods for preparation of Nano-composites which are briefly described with their inherent advantages and disadvantages.

7.1. In-situ polymerization method

In this method, nanofiller are swollen within the liquid monomer solution so the formation of polymer can occur between and around the intercalated layers. The polymerization can be initiated either by the incorporation of curing agent, initiator or by increasing the temperature, if it is sufficiently reactive. The in-situ polymerization is shown in Fig. 3.

7.2. Solution blending method

This method is based on a solvent system in which the polymer is soluble and the nanofiller layers are swellable. The nanofiller are first swollen in a solvent. When the polymer and nanofiller solutions are mixed, the polymer chains intercalate and displace the solvent within the interlayer of the nanofiller. Upon solvent removal, the intercalated structure remains, resulting in nano-composite. Using this method, intercalation only occurs for certain polymer/solvent pairs. The disadvantages of this method are the use of environmentally unfriendly and economically prohibitive organic solvents. The solution blending method is shown in Fig. 4.

7.3. Melt intercalation method

The melt intercalation technique has become the standard for some polymer/nanofiller nano-composites and is also quite compatible with the industrial techniques. In this method, polymer and modified nanofiller mixture are blended in the molten state under shear. The polymer chains reptate form the molten mass into the filler galleries to form either

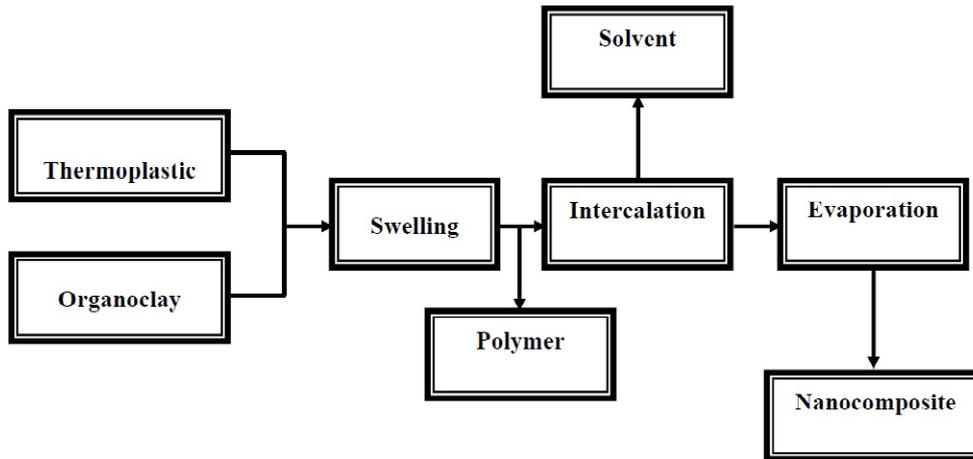


Fig. 4. Block diagram for solution blending method.

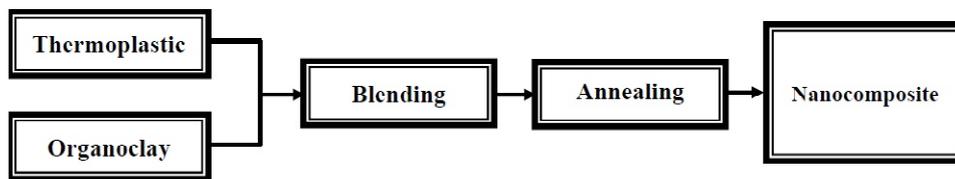


Fig. 5. Block diagram for melt intercalation method.

intercalated or delaminated nano-composites. The melt intercalation method is shown in Fig. 5.

8. DIFFICULTIES IN NANO-COMPOSITES PREPARATION

Researchers faced mainly following problems in nano-composites preparation.

8.1. Dispersion

The physical dispersion methods generally include ultrasonication, ball milling, grinding, and high-speed shearing. The main requirements for effective reinforcement are as under [37]:

- Aspect ratio
- Uniform dispersion
- Placement
- Interfacial stress

For maximum load transfer to the nanotubes, the aspect ratio must be large enough. This is mandatory for the composite's strength and stiffness.

Dispersion is perhaps a basic issue. Dispersion of fillers in a polymer matrix outcome from:

- The use of electrochemical and mechanical forces to make de-agglomeration.
- Complete removal of air bubbles and water,
- Formation of a real uninterrupted inorganic–organic composition [38].

When the nano-sized fillers are uniformly dispersed in the polymer matrix only then the optimal performance of polymer composites can be achieved. Manufacturing such homogeneous mixtures creates considerable challenges.

The kinetic and thermodynamic aspects of the penetration of polymer into the gap between the clay sheets must be considered in order to understand the exfoliation process in polymer–clay nano-composites [39]. Therefore, the efficient dispersion of nano-sized fillers in a polymer matrix is an art than a science.

9. LOW MECHANICAL PROPERTIES

The mechanical properties of Nano-composites can be significantly affected by the interface behavior. The degree of reinforcement is proportional to the filler's interactions and is crucial in optimizing the properties of polymer composites [40].

The other factors contributing to the low mechanical properties include weak interfacial bonding, bad dispersion, and degradation of the nanofiller [41].

10. PROBABLE SOLUTIONS

In the light of thorough survey on the latest research, following solutions address the problems faced during nano-composites preparation:

10.1. Surface modification of nanofillers

Improved dispersion can be achieved through physical or chemical interactions between the filler and the modifier. When nanoparticles are modified by one of these methods, either the character of the surface is changed from hydrophilic to hydrophobic (and vice-versa), or specific groups are chemically bonded on their surface (change in functionality). Fillers are typically hydrophilic and do not disperse easily within most polymeric materials, which are usually hydrophobic. Such modification not only contributes to reinforcement, but also increases the interactions of the particles to impact rheological properties, prevents sedimentation, aids dispersion, or prevents agglomeration. In addition, improved dispersion of the nanoparticles can also be achieved with solvents.

10.2. Physical methods

Surface modification by physical methods is achieved using a low molecular weight surfactant which introduces secondary forces between the nanoparticles and the modifier. A surfactant is a molecule that, when added to a liquid at low concentration, changes the properties of that liquid at a surface or interface [42]. The principle of surfactant treatment is the preferential adsorption, or tendency for a surfactant molecule to collect at the interface, due to polar groups on the surfactant molecules interacting favorably with the high energy surface of the filler. All surfactants consist of at least two parts, one which is soluble in a specific fluid, known as the lyophilic part (or hydrophilic part, in aqueous systems), and one which is insoluble, known as the lyophobic (or hydrophobic) part. Thus, when a surfactant adsorbs from an aqueous solution on a hydrophobic surface, its hydrophobic group usually orients to the surface while its polar group is exposed to water. Since the surface becomes more hydrophilic, the interfacial tension between the surface and water is reduced. Different types of surfactants are in use in the industry [43].

10.3. Chemical methods

A variety of coupling agents including silanes, titanates, and zirconates have been used to enhance the bonding between fillers and polymer matrices. As an example, the hydrophilic properties of silica can be modified by use of silanes. However, uniform surface coverage by coupling agents is hard to attain

with nanoparticles by simple physical and mechanical means. Stearic acid has thus been used with nano CaCO_3 , with the result of virtually no agglomerates of nanoparticles remaining with proper dosage of the dispersing agent [44]. Another non-reactive modifier used by Seon *et al.* [45] to make the filler surface hydrophobic is stearic acid. The presence of adsorbed stearic acid on the surface of the silica nanoparticles reduced the interactions between the silica nanoparticles within agglomerates, which could be broken down more easily.

11. THERMAL TREATMENT OF NANOPARTICLES (CALCINATION)

Storage of Nanofillers under ordinary conditions partially blocked their surface by adsorbed species in the form of moisture. This condition causes a reduced effectiveness of fillers in dispersion. The solution to activate the filler surfaces and to disintegrate the fillers's aggregates during storage is the calcinations [46]. Many of the properties of silica such as adsorption, adhesion, chemical, and catalytic properties depend on the chemistry and geometry of their surface. Dehydration of the silica surface, i.e. the removal of physisorbed (adsorbed) water occurs at temperatures below 473K. The concentration of silanol groups on the surface also drop off monotonically with rising temperature when silica is heated under vacuum [47].

12. MODIFICATION/ENHANCEMENT IN PROPERTIES OF NANOPARTICLES

12.1. Mechanical properties

One of the primary reasons for adding inorganic fillers to polymers is to improve their mechanical performance [48]. The major requirement of polymer nano-composites is to optimize the balance between the strength and the toughness as much as possible [49]. The mechanical properties include tensile strength, elongation at break, tear strength, modulus and hardness etc.

According to Dengke *et al.* [50, 51] the addition of a small amount (2 to 5 wt.%) of inorganic nanofillers to polymers should be sufficient for mechanical stability and performance improvement. Polyamide films tested by Irwin *et al.* [52] displayed significant improvements to elongation, scratch hardness, and strength. Silica nanoparticle-filled PEN composites were melt blended to improve the mechanical properties of PEN [53]. Fig. 6 shows

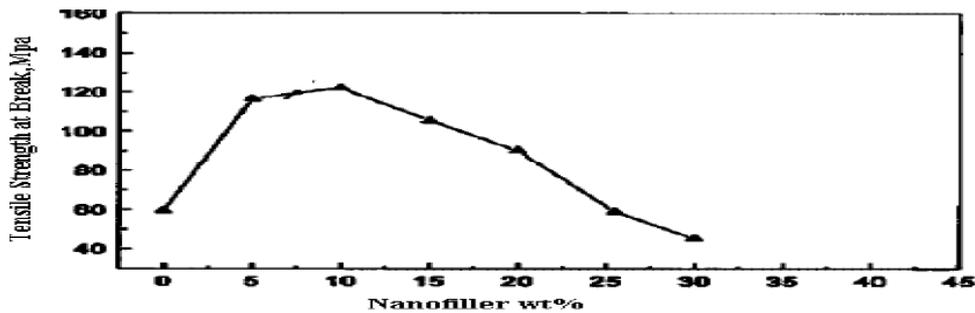


Fig. 6. Mechanical properties of nano-composite samples.

mechanical properties such as tensile strength, and elongation at break of the PA6/modified silica nano-composites also show a tendency to increase and then decrease with increasing silica content and have maximum values at 5% silica content [54].

12.2. Thermal properties

Thermal properties are the properties of materials that change with temperature.

Thermo-gravimetric analysis (TGA) devices are often used to investigate nano-composite thermal stability by monitoring the change in sample weight at high temperatures. It has been found that the addition of nanofillers shifted the thermal decomposition temperature of polymer to higher values, which indicated the enhancement of the nanocomposite thermal stability as compared with the unfilled polymer. The improvement in the thermal stability is probably due to the high surface area of such nano-composites, which prevents the volatile decomposition products from diffusing out during the high temperature degradation process. PI/SiO₂ nano-composite exhibit higher thermal stability than their microcomposite counterpart. The reinforcement of a silicon rubber composite with nanofiller resulted in an improved composite with better thermal properties [55]. Motori et al. [56] found that the temperature index improves considerably with

respect to the base polypropylene, with only 6 wt.% of nanofiller.

13. ELECTRICAL PROPERTIES

13.1. Dielectric breakdown

One of the most important electrical property changes of nano-composites is the enhancement in dielectric breakdown strength which is widely documented in many literatures [57-66].

13.2. Tracking & erosion resistance

Piah et al. [67] investigated the effect of alumina trihydrate fillers on the surface tracking and erosion resistance of natural rubber and found improved surface tracking and erosion resistance of the compounds.

El-Hag et al. [68] studied the tracking and erosion resistance of nanosilica-filled silicone rubber and confirmed that the composites depict significant resistance to erosion as compared with micro-filled silicone rubber composites.

13.3. PD resistance

Researchers have shown that nano materials perform better in term of partial discharge resistance when compared with that of their base materials.

Table 1. Results of corrosion level in polymeric nano materials due to partial discharge.

Polymer composites	Corosion level μ .meter	Comments
Polyamide	14	6kV (AC), 60 Cycles/Sec, 48 hrs
Polyamide /LS Nano Material	2.5	Electrode; IEC (b)
Epoxy	110	60 Hz equivalent TimekV (AC),
Epoxy/ LS Nano Material	50	720 Cycles/Sec,
Epoxy/ Titanate (15nm) Nano Material	32	60 hours/120 hours
Epoxy/ Silica (40 nm) Nano Material	27	Rod-gap-plane Electrode
Epoxy/ Silica (15 nm) Nano Material	19	

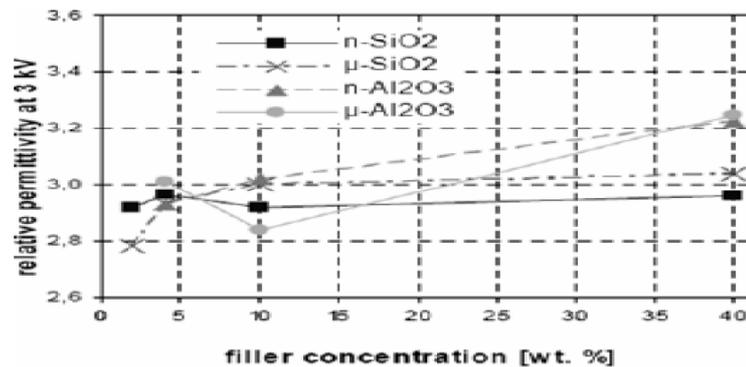


Fig. 7. The graph of permittivity versus filler concentration.

Tanaka et al. investigated the partial discharge resistance of epoxy/layered silicate nano materials and found significant improvement [69]. Kozako et al. also confirmed that only 2 wt.% of nanofiller is sufficient to improve the partial discharge resistance of polyamide/layered silicate nano-composites [70].

Lorenzo et al. conducted internal discharge test upon layered nanosilicates filled epoxy resins and the increment of lifetime was found on those materials [71]. Intensity of erosion in polymer nano-composites produced by partial discharges is shown in Table 1.

13.4. Space charge behavior

The addition of nanofillers also results in space charge reduction as found in epoxy nano-composites [72-74]. There are also claims that charge transport is of utmost importance in improving the dielectric strength and electrical erosion of nano-composites [75,76].

13.5. Permittivity & dissipation factor

The permittivity usually increases with inorganic micro-fillers and tends to decrease with nanofillers, as found in [77,78]. Dissipation factor is also found to be favorable when polymer nano-composites are introduced [79]. The graph of permittivity versus filler concentration is shown in Fig. 7.

13.6 Tangent loss angle

Certain microfillers have high relative permittivity; hence composite materials prepared using such microfillers show higher relative permittivity, because the frequency is increased. However, the behavior of nano-composite material is surprisingly different due to intercalation process. A reduction in tangent loss angle is also observed for epoxy-nanocomposite materials under low frequency and high temperature conditions [80].

14. CONCLUSION

The microfillers technology had reached at its peak as far as the latest instrumentation for their manufacturing is concerned. In polymeric micro-composites, combined properties cannot be enhanced simultaneously. In fact, one property enhancement is achieved at the cost of other. This problem can be addressed practically with the invention of nano-composites. These recently evolved nano-composites provide significant improvements in combined electrical, thermal and mechanical properties.

In polluted environments such as industrial and coastal areas, polymeric insulators are prone to surface degradation, which lead to their breakdown. Micro-fillers are used widely in polymeric insulation materials for outdoor high voltage insulators. Awaiting, only micro-sized fillers have been used as commercial materials. On the other hand, the applications of nano-fillers have unmitigated over the previous few years in research fields and some insulating materials have been manufactured. Considerable endeavor has been exhausted by researchers to discover a successful technique to add in nanofillers into outdoor insulation applications. In this research, SEM analysis technique is used to analyze the quality of prepared nanocomposite. The results suggest that surfactant drastically improve dispersion and hence quality of nanocomposite.

Breakdown voltage is one of the main factors. The samples were tested in two different conditions, without any moisture and with moisture content, according to ASTM D 570 – 95. The samples with moisture content did show a reduction in the breakdown voltage as compared to those of with moisture content.

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