

INFLUENCE OF STRESSES AND FILLERS ON THE AGING BEHAVIOUR OF POLYMERIC INSULATORS

Abraiz Khattak and Muhammad Amin

COMSATS Institute of Information Technology (CIIT), Wah Cantt, Pakistan

Received: July 06, 2015

Abstract. Polymer composites offer numerous advantages over traditional ceramic materials and occupied place as emerging outdoor insulators. However, due to their organic nature they has affected by multiple stresses which in turn damage the integrity of these materials and reduce their life. To deal with these challenges not only design of these insulators has been improved but different types of fillers were also studied and tested for improvement of their properties. In this review article, stresses responsible for the degradation of properties of composite insulators and different types of fillers used for the improvement of these properties are presented. Furthermore; literature in this field has been used to identify the research gaps. An overview of effort initiated by authors to fill the gaps up to possible extent is also presented at the end.

1. INTRODUCTION

The upper casing of composite insulators is made up of polymer and due to its organic nature it has limitations of aging due to different environmental, electrical, mechanical and thermal stresses [1-10]. Since their development, different composite insulators have been subjected to research in field as well as in laboratory in order to assess their durability [11-14]. Multiple insulation materials are used for insulation purpose and each has different strengths and weaknesses [15-18]. However, any type of neat composite material can be improved by the usage of fillers/additives of different size, concentration and type [19-21]. Moreover, fillers used for best performance need further analysis; which in turn needs comparison among different types of nano composites, hybrid nano-micro composites and neat composite insulators under the same stresses and for uniform duration. The longer is the duration of applied stresses the more accurate are the results [22,23]. In natural environment multiple stresses are present thus to obtain results equiva-

lent to the practical circumstances, insulators need to be evaluated in a multiple stresses environment. These stresses include ultraviolet (UV) light, biological contamination, heat, acid, rain, corona effect etc. Regular applications of these stresses in a systematic order for a long period of time in an environmental chamber are called weather cycles. At the end of each weather cycle, different analysis techniques are used to regularly analyze the integrity of the samples or more accurately saying to check the effects of stresses which may result in tracking, cracking, chalking, treeing, erosion, leakage current and loss of hydrophobicity, etc. [24-31].

1.1. Composites

The composites are materials that are made of two or more components. The composite materials are solid multiphase materials that can be formed by different types of materials having different properties. These properties make them distinguished from other multi component systems including alloys and blends. There are diverse uses of compos-

Corresponding author: Muhammad Amin, e-mail: prof.amin.comsats@gmail.com

ites in construction, transportation and consumer products [32,33].

The constituent composites are the source of diversified properties of composite materials such as hardness, strength, weight, electrical and optical properties that are impossible to achieve separately by individual components. These constituent materials can be organized to obtain particular properties to fulfill special needs. The optimum model and designing process to achieve specific properties for particular engineering usage are very significant.

There are two main phases in a composite, first phase is called the matrix phase which is a continuous phase. Second phase is called the dispersed phase of filler material. The later phase can be further divided into polymeric composites, ceramic composites and metallic composites. Commonly the first phase is fixed deeply in the later phase to construct a composite containing property that cannot be achieved by a single phase.

Polymers mostly have more benefits than other like metals and ceramic polymers [34-36]. Polymers are applied in many technical fields due to their diverse properties that are; ease of production, light weight and ductility. But in contrast to metals and ceramic, their mechanical, modulus and strength properties are less. The increasing demand of polymers requires the enhancement in their properties to attain the peculiar needs. Composite technology is very significant to improve polymers, keeping their light weight and ductile nature intact [37].

2. STRESSES RESPONSIBLE FOR THE DEGRADATION OF COMPOSITE INSULATORS

Broadly mechanical, electrical, environmental and thermal stresses are threats for the reliable role of composite insulators in power systems. Most of these stresses effect take place due to the organic nature of polymer insulators. However mechanical and thermal stresses can be avoided up to certain extent through proper handling, careful during operation and installation. Whereas, electrical and environmental stresses are the main concerns which produce multiple complex effects on insulator's condition and may lead to different unwanted results. Environmental stresses are categorized as heat, moisture, UV light, acid, wind, snow, fog, humidity, rain, biological contamination, and pollution. These stresses cause polymer chain scission and oxidation which is termed as de polymerization and they also cause loss of low molecular weights (LMWs).

Electrical stresses include corona arcing and leakage current which are the main causes of loss of low molecular weights. A corona activity not only produces UV radiation [38] but also ionizes the air which results in generation of certain chemicals which may degrade polymer insulators. As a result of these effects insulators show loss of hydrophobicity, erosion, tracking, loss of flexibility, and reduction of overall mechanical and electrical characteristics. Different types of stresses are listed following which affect performance of composite insulators.

- i. Ultraviolet light
- ii. Ozone gas
- iii. Biological contamination
- iv. Acids
- v. Humidity
- vi. Fog, rain, wind, snow and icing
- vii. Light
- viii. Temperature
- ix. Corona discharge
- x. Leakage current

2.1. Survey of stresses and their effects on composite insulators

In [39], UV radiation was mentioned as one of the main reasons of aging and also carbon and some of additives and UV stabilizers were described as protective measures against UV radiation. A study by Sundararajan et al. on 345 kV EPDM insulator in a coastal environment also showed that only UV absorbers are not enough for UV protection and recommended use of UV stabilizer for long term in service EPDM insulators [40].

In [41], UV effects on SiR were analyzed through several analytical techniques i.e. SEM, ATR-FTIR, and XPS. Depletion of low molecular weights (LMWS) and scissoring were observed, which was accompanied by initial loss of hydrophobicity due to the deposition of surface charge on EPDM and SiR.

T. Imakoma et al. in 1994 extensively studied effects of UV radiation and condensation on SiR through Measurement of Contact Angle, Energy Dispersive Spectroscopy X-Ray (EDX) Analysis, Fourier Transform Infrared (FTIR) Spectroscopy and Scanning Electron Microscope (SEM) observation and found that though SiR is a superior material and maintain its hydrophobicity however under heavy UV radiation cycles its hydrophobicity is also declined. This loss of hydrophobicity occurs because of de polymerization [42]. Amin, Muhammad et al. analyzed combined effect of UV radiation and moisture using FTIR and hydrophobicity classification

method. The sample degraded -7.6% and hydrophobicity remained between HC3 to HC5 [43].

Quanlin Zhao et al. in 2009 studied Ethylene Propylene Diene Monomer (EPDM) in UV radiation/condensation environment and through Raman Spectroscopy and XPS analysis they showed that thermal stability of the sample was not affected at all by UV radiation [44]. However, hydrophobic response of the material for UV radiation was not reported in this study.

Yong Zhu et al. presented effect of UV radiation along with sand blow on high-temperature vulcanized silicone rubber (HTV-SiR) for 2000 h. The sample showed significant decrease in mechanical strength however 100% recovery in hydrophobicity [45] was observed. J. Mergos et al. in 2007 found discoloration in Polyvinylchloride (PVC) and high density polyethylene (HDPE) samples even after just by applying UV/Condensation cycles for few tens of hours [46]. In 2012 Farhadinejad Zeinab et al. used thermo-gravimetric analysis (TGA), leakage current, Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDX) analysis techniques for finding the effects of UVc radiation on thermal, electrical and morphological behavior of silicone rubber insulators and concluded that UVc lowers thermal decomposition temperature, increases leakage current also found that UV radiation alone does not significantly change leakage current. UVc cycles develop erosion near points of fillers and are also cause of loss of hydrophobicity and decomposition of the filler [47]. Similar to UV Aging, biological contamination is an important environmental stress which may damage the integrity of in-service insulators [48]. Biological contamination is the colonizing of living organism on surface of insulators due to organic nature of polymer insulators. These biological organisms may be algae, fungi or lichen [49].

They may decrease hydrophobicity, increase surface conductivity and leakage current; and they may also result in erosion and tracking when other stresses like salt and fog are applied in combination with them [29].

In 2000, Low Density Polyethylene (LDPE) was studied by Matsunaga Masashi et al.; they used water contact angle measurement and FTIR spectroscopy techniques and found that microbiological contamination was slow process which might be accelerated by corona activity. It was also observed that UV light was more serious degradation factor than corona discharge and biological contamination [50].

In [51], it was observed that no polymer material was free from biological contamination attacks, how-

ever with addition of just fungal spores, water and used silicone materials it did not show fungal growth. In some of the formulations after addition of nutrition salt, fungal growth was observed while samples having zinc borate as flame retardant filler did not show fungal growth. This implies that bio-film formation needs other factors for their growth on polymer surfaces and also zinc borate can be used as a growth suppresser rather than Aluminium Tri-hydrate (ATH) [52].

In [53], Laser-Induced Fluorescence Spectroscopy was suggested for analysis of fungi and algae on polymer insulators which is contact free and highly attractive technique for observing biological growth in HV environment. They also showed that how this new technique can be used to measure the degraded hydrophobicity of silicone rubber which showed satisfactory results i.e. concurred with already implemented techniques' results for calculation of hydrophobicity. However, in [54], image analysis technique was suggested to be used in combination with technique used in [53] to determine the severity of growth.

In [49], different methods for detection of biological growth were described but recommended Laser-Induced Fluorescence Spectroscopy for this purpose. In [55] severity of bio-film on polymer surface was analyzed and for which Environmental Scanning Electron Microscopy (ESEM) with X-ray Energy Disperse Spectroscopy (EDS) were suggested. This method is an effective way to find, whether removal of bio-films is possible from insulator at any stage to restore insulator properties or insulator has regained its original condition after cleaning.

In order to avoid or suppress growth, different anti microbiological agents were analyzed in [56], including sodium benzoate (NaB), DCOIT (4,5 Dichloro-2-octyl-2H-isothiazolone-one) and p-amino benzoic acid (PABA). FTIR and contact angle measurement techniques were used for analysis. NaB showed little growth and loss in hydrophobicity and PABA showed no resistant to the growth. Whereas, DCOIT microbiological agent showed highest hydrophobicity after analysis, thus concluded to be the highest growth resistant agent.

Microbiological growth is an important factor and cannot be neglected, therefore preliminary care is required for in service insulators like periodic visit to site and adoption of techniques for checking severity of growth. Flame retardant fillers may also be used for growth suppression while anti microbiological agents help in prevention of growth. Corona activity is an unwanted effect that is not only respon-

sible of power loss in HV transmission lines but also affect the performance of installed in service insulators [8]. Corona generation depends upon different factors like magnitude of applied voltage, moisture, atmosphere and diameter of conductor, etc. Water droplets on surface of insulators increase the effect of corona activity and the effect of the corona during water droplets is called wetting corona activity. In [57], corona discharge was recorded to occur at the tip of water and which is mentioned as cause of loss of hydrophobicity and thus degradation of polymeric insulators.

In [58] and [59], two sources of corona were utilized i.e. corona from water droplet and corona from metal electrodes and their effects were analyzed through periodic visual observation and FTIR. Three samples of 230 and 500 kV polymer insulators i.e. high temperature vulcanized (HTV) silicone rubber; ethylene propylene diene monomer (EPDM) and a blend of EPDM and silicone rubber were tested. Highest corona induced degradation was observed in silicone rubber (SiR), least severe for EPDM and in between for the EPDM and SiR blend.

In [60], hydrophobicity loss and recovery characteristics of Silicone were discussed in detail, properties of polydimethylsiloxane (PDMS) elastomers were reviewed and a thin layer of silica about 10nm at the surface of polydimethylsiloxane (PDMS) elastomers were discussed which were characterized by X-ray photoelectron spectroscopic (XPS), SEM, contact angle, and infra-red spectroscopy. Corona was stated as the physically and chemically degrading factor for composite insulators and cessation of corona treatment cause hydrophobic recovery. Hydrophobic recovery is a superior property of SiR which makes them suitable for outdoor applications.

In [61], resistance to corona and ozone was described as a basic parameter in ranking polymer insulators for outdoor applications. Five different polymeric materials (EP, LSR, HTV, EVA, and EPDM) were tested and very beneficial conclusions were drawn. After 100 h testing surface resistivity decreased of almost all materials and ozone and corona were reported as serious degradation factors for aging of these samples.

The authors of [62] also reported severe cracking, surface roughness and discoloration in which they applied humidity and external mechanical stresses and postulated that degradation increases with the increase of humidity. Humidity was mentioned as severe factor than water droplet corona activity. While in [63] different samples of high temperature vulcanizing (HTV) silicone rubber (SiR) for-

mulations were applied to low corona and high humidity levels in corona cell. Using FTIR technique and visual observations, degradation response was recorded which showed that some of formulations exhibit severe degradation even under low electrical discharges therefore recommended the outdoor insulators to be highly protected from corona discharges.

From [58-63], it can be concluded that corona activity is a damaging factor for composite insulators and resistance to corona activity can be considered for ranking of insulators and also affect of corona may get worse for most of the composite insulators, when other stresses are present in environment like humidity, rain and external mechanical stresses.

In [64], neat SiR was exposed to corona discharge and through physiochemical analysis both physical and chemical damage by plasma was observed. Hydrophilic group OH formation was recorded which causes covering of hydrophobic group and thus loss of hydrophobicity. However after a substantial amount of time recovery in hydrophobicity was seen in [31] for the same material and under the same conditions.

Apart from UV radiation, electrical discharge and biological contamination, other important degradation factors are heat, acid, rain, snow, salt, fog and chemical pollutants. These stresses alone and in combination may degrade the insulator to a limit that it may lead to breakdown [8].

In [26], failed 500 kV composite insulator was analyzed after its 6 years service in field in a chemically polluted environment. The brittle fracture surface was analyzed using X-ray fluorescence spectrum and FTIR spectroscopy. Three chemical functional groups i.e. Nitrate (NO_3^-), nitride (NO_2^{2-}) and sulfide (SO_4^{2-}) were found on brittle fracture surface of composite insulator. The failed insulator was compared with sulfuric acid and nitric acid's laboratory aged insulator which showed that the brittle fracture in the insulator was by coming of nitric acid came through electrical discharge and sulfuric acid came from acid rain.

In [65], HTV-SiR filled with Aluminium Tri-hydrate (ATH) 6 kV outdoor insulator was used as sample. Fog chamber method was observed to investigate surface discharge current which was taken as average of values during wet and dry cycles. Surface hydrophobicity was measured through contact angle measurement method. The results showed that acid rain's most severe damage was erosion while electrical stress played role of a catalyst in degradation process. Overall hydrophobicity decreased and dis-

charge current increased during wet cycle. However, hydrophobicity recovery was observed during dry cycles which might be because of the migration of low molecular weights (LMWs).

In [1], multiple stresses such as UV radiation, corona discharges, acid rain and dry-band arcing were applied to evaluate the degradation of SiR, in which acidic rain was prepared synthetically by keeping pH of 1.9. Techniques SEM, FTIR, and Energy Dispersive Spectroscopy X-Ray (EDX) were used. Oxidation including cross-linking, branching, interchanging and a formation of silanol groups were described as dominant reactions during aging process of SiR. Moreover, presence of LMWs is cause of recovery of hydrophobicity. However, LMWs are stopped from migrating to the surface by silanol groups. Furthermore, it was also postulated that quantitative presence of cyclic silicone oligomers in surface can be used as indication for remaining lifetime of composite insulators.

Another salt fog study was done in [66], in which high temperature vulcanizing silicone rubber (HTV-SiR) was aged through accelerated aging by using artificial acid rain. ATH filler used in SiR dissolved in acid rain. Dry band arcing and discharge heat due to acid rain cause loss of more ATH. Methyl which is a hydrophobic group also degraded in acid rain. Surface roughness, loss of hydrophobicity and increase in surface discharge current was observed. However, like [1] hydrophobicity recovered due to the transfer of LMWs during dry periods. From [63] and [64], it's also clear that silicone rubber recovers hydrophobicity after substantial amount of time.

In [67], standard fog clean method (IEC-507) was used for analysis of 15 kV ethylene propylene di-

ene monomer (EPDM) by applying acid environment at higher altitudes. Flashover voltage analysis and contact angle measurement method were used for analysis. Like other studies, severe degradation in hydrophobicity was seen and also EPDM recovery of hydrophobicity has not been recorded.

These above mentioned stresses play a vital role in the degradation process of composite insulators and result in loss of hydrophobicity and dielectric strength, erosion, tracking, treeing, surface roughness, decrease in surface resistance and increased leakage current etc. These unwanted results not only affect the performance of composite insulator in service but also may cause electrical breakdown after certain period of time.

Aging of composite insulators though is a natural process due to the organic nature of polymer; however its severity depends upon the field where insulators are installed; as well as type of stresses present in the environment. For example, coastal environment, industrial polluted environment, hilly environment and desert environment all have different effects upon the composite insulators. Moreover, one stress may enhance the effect of other like corona discharge increase its degradation effect along with presence of humidity [63].

Table 1 shows the stresses and their overall effects on composite insulators in summarized form.

3. FILLERS

Stresses affect basic thermal, mechanical, electrical properties of composite, which may lead to electrical breakdown. To improve the strength of base materials e.g. SiR, EPDM, epoxy resins etc. differ-

Table 1. Effects of stresses on properties of composite insulators.

Type of stress	Sub-type of stress	Effect on molecular structure	Effects on insulator	Effect on properties of insulator
Environmental stresses	UVR, Acid, Heat, Snow, Salt, wind and ozone	De-polymerization	Loss of elasticity Erosion, roughness, chalking and cracking	Decrease in mechanical strength Decrease in electrical Strength
	Biological contamination	De-polymerization, loss of low molecular weights	Loss of elasticity, cause erosion, Roughness, chalking and cracking	Decrease in mechanical strength and decrease in Electrical Strength
Electrical stresses	Corona Discharge, dry band arcing and leakage current	loss of low molecular weights	Loss of hydrophobicity	Decrease in Electrical strength

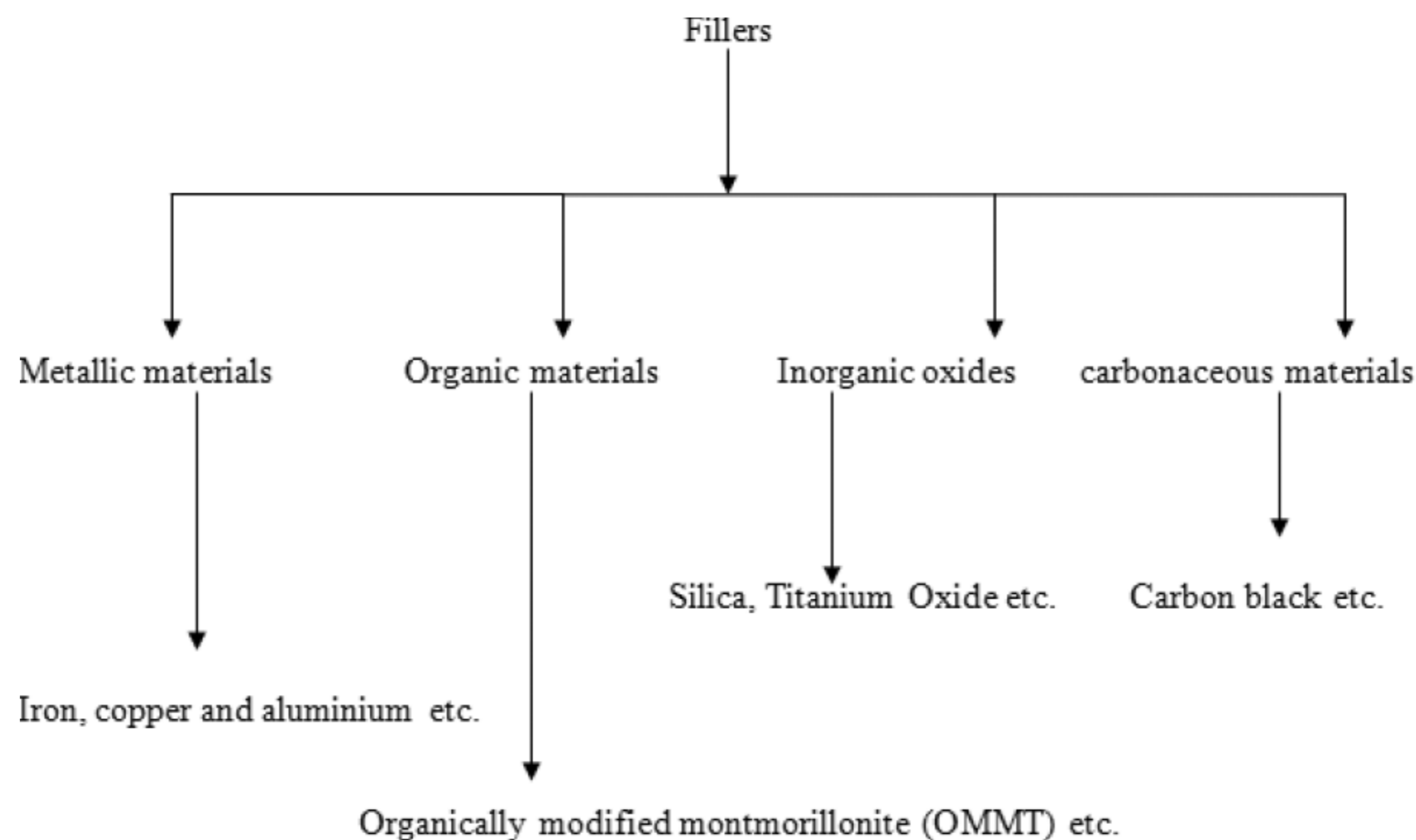


Fig. 1. Types of fillers used in composite insulators

ent types of fillers are used. Fillers not only improve certain properties but also lower the overall cost of composite material. Different types of fillers are used to improve properties of composite materials. Not only type but also concentration and size of filler added to the neat insulator are of great importance. Micro sized fillers have been widely used and tested for the improvement of certain properties e.g. dielectric, mechanical and thermal properties; but due to relatively larger size they exist nearer in bulk matrix. Therefore, they minimize the role of base material and electrical properties are compromised accordingly [68,69]. They also lacked significant properties which were later on offered by nanocomposites [32,70].

3.1. Types of fillers

Materials used as fillers carbonaceous materials, metallic materials, organic materials and inorganic oxides. The following Fig. 1 shows categories and examples of these materials. Metallic materials are iron, copper, zinc, aluminium and nickel. Example of organic materials are Montmorillonite (MMT); and inorganic oxides type fillers are Aluminium trihydrate (ATH), silicon oxide (SiO_2), zinc oxide (ZnO), Calcium carbonate (CaCO_3) Barium titanate (BaTiO_3), and titanium oxide (TiO_2) [71].

3.2. A survey on effect of fillers on properties of composites

In [72], Ye. P. Mamunya et al. studied electrical and thermal properties of nickel (10 μm) and copper (100 μm) filled microcomposites and observed increased thermal and electrical conductivity of both

materials. In [73] almost same results for 0 to 20% zinc filled composite materials were obtained and mechanical properties were also observed to be increased as compared to the neat material.

Guevara-Morales et. al studied dielectric and mechanical properties of epoxy nanocomposites filled with two organo-modified montmorillonite (MMT) clays. Different standard characterization techniques for mechanical and electrical testing were followed in this work. Fracture energy and elasticity were increased while permittivity and loss angle decreased resulting better insulation properties in nanocomposites than neat epoxy resin [74].

In [75], neat poly(ethylene-co-vinyl acetate) and carbon black (CB) filled poly(ethylene-co-vinyl acetate) mixture i.e. (13% VA and 1% CB) samples were aged at 85 °C for 30 weeks in air gap. For chemical changes analysis FTIR spectroscopy while dynamic and isothermal thermo gravimetric studies were performed for the thermal stability analysis. FTIR results for neat poly (ethylene-co-vinyl acetate) showed that oxidation products are formed during aging process while carbon black filled poly (ethylene-co-vinyl acetate) sample did not produce oxidation products during aging. Carbon filled composite material also showed superior thermal stability than neat sample. From carbonaceous materials' group carbon black (CB) was used in composite materials for improvement of properties of different materials. However, after the discovery of carbon nanotubes (CNTs) cathode deposit by Iijima during electrical arc experiment [76], opened doors for scientists to study superior properties of CNTs as compared to other carbonaceous materials.

Young Seok Song et al. not only studied electrical, rheological, thermal and mechanical properties

Table 2. Types of fillers and their effect on properties of composite materials [36,71,73,75,82-88].

Type of filler	Improvement of properties
Silver (Ag)	Mechanical
Aluminium (Al)	Dielectric strength and electrical and thermal conductivities
Zinc (Zn)	Thermal and electrical conductivities and mechanical properties
Nickel (Ni)	Thermal and electrical conductivities
Copper (Cu)	Thermal and electrical conductivities
Iron (Fe)	Thermal and electrical conductivities and mechanical properties
Carbon black (CB)	Electrical and mechanical properties
Single-wall nanotubes	Mechanical properties and thermal conductivity
multiwall nanotubes	Mechanical, dielectric and electrical properties
Expanded graphite	Thermal conductivity, electrical and mechanical properties
Alumina	anti erosion, anti-tracking and thermal conductivity
Zinc oxide	Dielectric strength, and electrical conductivity and mechanical properties
Titanium Oxide	Relative permittivity and thermal strength
Calcium Carbonate	Hydrophobicity and flame retardancy
Silica (SiO ₂)	anti erosion, anti-tracking thermal conductivity and mechanical properties

of carbon nanotubes (CNTs) filled epoxy nanocomposites but also analyzed the influence of dispersion of filler on these properties. Field emission scanning electron microscopy (FESEM) and transmission electron microscopy (TEM) were used for characterization of dispersion. Complex viscosity, loss modulus, and higher storage modulus were observed in poorly dispersed carbon nanotubes (CNTs). Whereas, in well dispersed CNTs not only improvement in thermal conductivity was recorded but electrical conductivity was also increased significantly. An increase in tensile strength and elongation was also recorded in well dispersed CNTs [69]. This work not only shows that CNTs improve the basic properties of materials but also dispersion of filler has an impact on these properties.

Although all fillers' groups discussed above play role in improving physical and chemical properties of composite materials. However, as all fillers do not possess same characteristics, thus do not offer same improvements in composite materials -e.g. inorganic oxide materials include aluminum trihydrate (ATH) and silica are most widely used fillers. Besides the fact, that both are inorganic oxides, but both have different responses in improvement of hydrophobicity, leakage current, permittivity, electrical and thermal conductivity [77-79]. ATH filler is normally used to avoid tracking, increase erosion resistance; and it has flame retardant properties. However, high amount of ATH filler affect the speed of recovery of composite materials [1].

In a review by on inorganic fillers i.e. ATH and silica, Meyer, L.H et al. discussed that as a general

perception about ATH that it provides enhanced erosion resistance than SiO₂ can be misleading and also the electrical conductivity which is measure of the material erosion is also not totally dependent upon the type of filler but concentration, particle size, and dispersion of particles are factors that govern electrical conductivity of the composite materials. Moreover, controlling these factors, either filler can be proved better for improvement of properties of composite materials [80].

In [81], treeing phenomenon in silicone rubber was studied filled with different weight percentages of silica (SiO₂) i.e. 0 to 5 wt%. A digital camera and a microscope system were used for this purpose. Speed of treeing phenomenon was much higher in neat silicone rubber than in nanocomposites. Probability of branch appearance was 90% for neat silicone rubber, 65% for nanocomposites with 1% SiO₂, 77% for nanocomposite with 3% SiO₂ and 100% for nanocomposite 5% SiO₂.

Table 2 shows different metal, carbonaceous, inorganic and organic fillers and properties of composite materials that can be improved by them.

Size of filler is as important as type of filler. Different sizes of fillers of the same material offer different changes in properties of composite materials [85]. In [89], H. Deng et al. studied RTV silicone rubber coating filled with different sizes of ATH. 1.0, 4.5, 13, 17, and 75 μm sized fillers. Salt-fog chamber was used to evaluate the effect of particle size on properties of stated composite material. High resolution roughness tester and Scanning Electron Microscope (SEM) were used for surface roughness

evaluation. It was found that smaller size filled composites are expected to have longer life, than relatively filled with larger sized fillers. Loss of hydrophobicity and leakage current were observed higher in relatively higher size filled composites which resulted poor thermal conduction and higher surface roughness rate.

Since particle size has been an important issue as type and concentration of filler, thus based on the size of filler, microcomposite and nanocomposite materials were extensively studied for their improved properties compared to neat the composite insulating materials.

D. Fabiani et al. studied SiO_2 filled nanocomposite, microcomposite and hybrid nano/microcomposite epoxy resins for DC and AC electrical stresses. Space charge, conductivity, dielectric strength and partial discharge resistance were analyzed for the stated insulating materials. Size of filler showed significant variation in improvement of properties. Microcomposites with larger filler worsen the DC properties and enhanced space charge accumulation. Nanocomposites showed better DC properties as well as better resistance to partial discharges. Hybrid nano/microcomposite epoxy resin though provided best resistance to partial discharges however showed unsatisfactory DC properties [90].

Kailash C. Jajam et al. also studied the influence of size of filler and loading rate effects in composite materials by comparing nano and microcomposites of silica-filled epoxy for quasi-static and dynamic fracture behavior. Although effect of particle size for 3-10% concentration in elastic and physical properties was not seen, however, during quasi-toughness tests nanocomposites showed better fracture toughness and lower dynamic fracture toughness than microcomposites [91]. Sebnem Kemaloglu et al. studied loading effects of micro and nano size BN filler on thermal, mechanical and morphological properties of SiR. Three microcomposites and two nanocomposites were used in study.

In general, addition of fillers decreased the tensile strength, strain and coefficient of thermal expansion while increased hardness, modulus and thermal conductivity. At any loading level nanocomposites were found more effective in tensile properties compared to the microcomposites. Dielectric constant of filled composite was higher than neat composite. With the increase of concentration of filler increased the dielectric constant and beyond a critical limit dielectric constant increased dramatically [92].

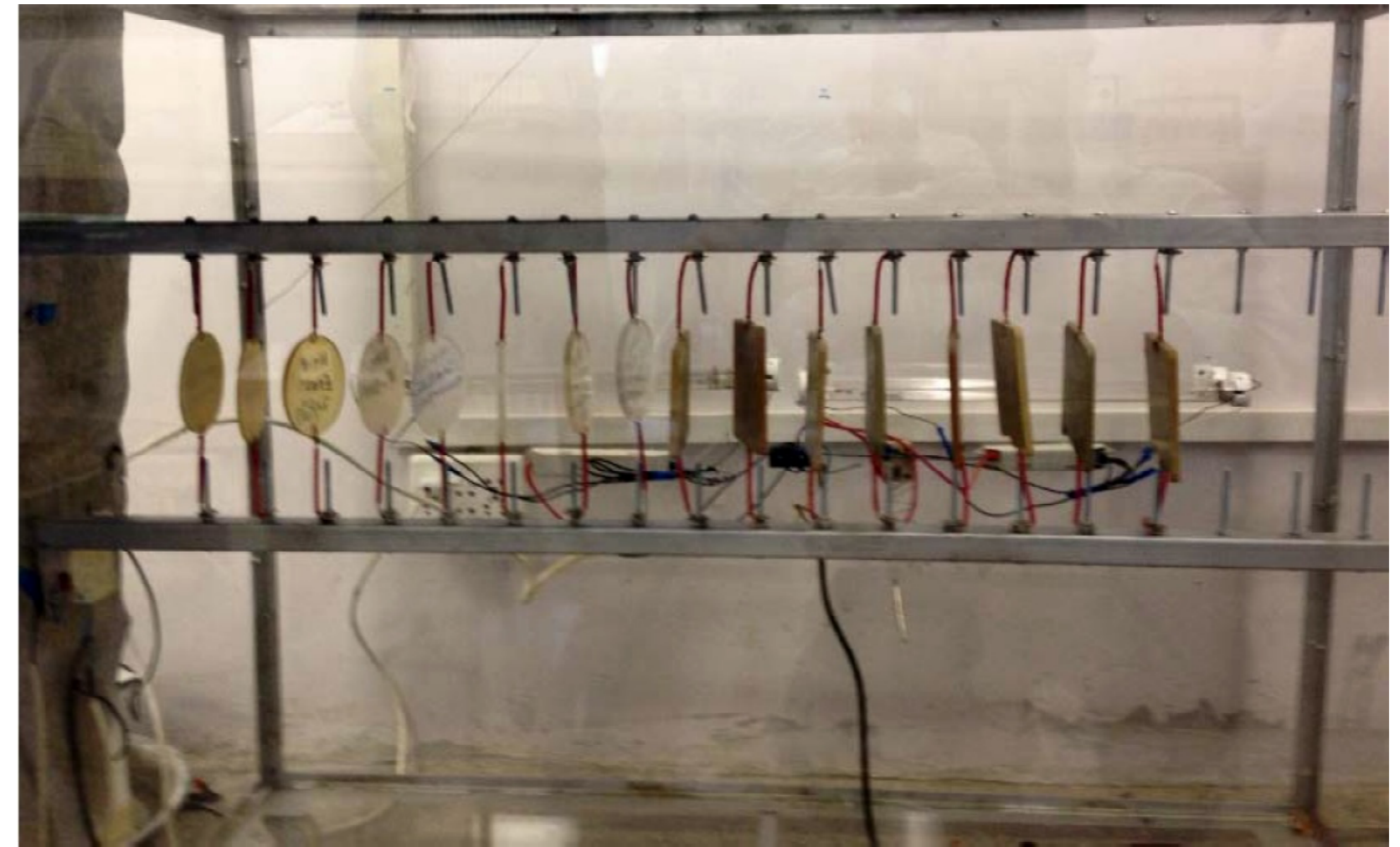


Fig. 2. Accelerated multistress environmental chamber.

C. Putson et al. compared micro and nanocomposites of Non-percolated polyurethane (PU) with different copper filler concentrations (1-4%). Through Scanning Electron Microscopy dispersion of microcomposites was found homogenous while some agglomerates were seen in case of nanocomposites. Increased permittivity was seen in filled composites which was higher in case of nanocomposites. Microcomposites did not show significant improvements in thermal properties while nanocomposites showed better thermal properties than neat PU. This is an evidence of better interaction of nano sized filler with polymer matrix as compared to the micro sized fillers [93].

4. OUR CONTRIBUTION

Composite insulators' properties vary by using different concentrations of the same type of fillers for the same base material. Silica has been used extensively for increasing the strength of composite insulator against multiple environmental and other stresses. However, composites with different concentrations of silica respond differently. There is still need of study and research to recommend optimum amount of filler for the composite insulators. To investigate this problem we have procured different widely used composite materials i.e. EPDM, SiR and epoxy resins and their silica based nano and hybrid nano/micro composites. These materials have been subjected to the major stresses in an environmental chamber for duration of one year using acceleration factor 28 on Islamabad based meteorological data. Further details of the project are explained below.

4.1. Experimental setup

Experimental setup consists of an environmental chamber having dimensions of (3×6×3) cubic feet with accelerated multiple stresses in which several



Fig. 3. . Insulating materials before application of electrical and environmental stresses

insulators can be energized at the same time through 2.5 kV voltage. Thermal stress is applied through a heater of 1500 Watt along with water pot to provide humidity. UV radiation is applied through two lights each of 15 watt. Two weather cycles are followed i.e. summer cycle (47.2 °C) which is 17 days and winter cycle (35.2 °C) is 11 days. After each weather cycle acid rain (pH 4.5) is applied on all the samples uniformly. Fig. 2 shows the accelerated multistress environmental chamber fabricated for this purpose.

4.2. Types of materials

In this work nine types of insulating materials will be analyzed namely neat Silicone Rubber (SiR), Silicone Rubber with 5% Nano Silica (SNC-5n-SiO₂), Silicone Rubber with 2.5% Nano Silica (SNC-2.5n-SiO₂), Silicone Rubber with 10% micro and 2% nano silica (SMNC-10m2n-SiO₂), Neat epoxy, Epoxy with 5% Nano Silica (ENC-5n-Sio2), Neat EPDM, EPDM with 5% Nano silica (EPDM-5n-SiO₂) and EPDM with 20% micro and 5% nano silica (EPDM-20m5n-SiO₂). Neat materials are used as reference in this work. Different materials before energizing and subjecting to stresses are shown in Fig. 3.

4.3. Analysis techniques

Visual observation, Fourier Transform Infrared Spectroscopy (FTIR), Leakage current (LC) measurement, Swedish Transmission Research Institute (STRI) hydrophobicity classification and Scanning Electron Microscopy (SEM) will be used for analysis. This will provide enough data to analyze these insulating materials, and also to find the best nanocomposite material for insulation. At the end, life of these insulators will also be found using the leakage current data.

The purpose of this research is to propose best insulating nanocomposite material to utility companies not only on national level but also at international level the concentration of nano fillers for nanocomposite insulating material will be recommended.

5. CONCLUSIONS

Following points are concluded from this article

- Composite insulators are aged by several environmental and electrical stresses
- UVR, acid, rain heat, snow, salt, wind, ozone and biological contamination are major environmental stresses which damage the integrity of composite insulators.

- Corona discharge, dry band arcing and leakage current are electrical stresses responsible of aging of composite insulators
- These overall stresses cause loss of elasticity, erosion, roughness, chalking, cracking and loss of hydrophobicity in composite insulators
- As a result the insulator decrease mechanical and electrical strength
- Micro and nano sized fillers are commonly used to improve the properties of composite insulators
- In term of longer life nanocomposites are doing well as compared to microcomposites
- Fillers used to improve properties of composite insulators are generally from four groups of materials i.e. carbonaceous materials, metallic materials, organic materials and inorganic oxides.
- Different types of fillers improve different properties of composite insulators e.g. dielectric strength, electrical conductivity, mechanical strength, hydrophobicity flame retardancy, relative permittivity and thermal strength etc.
- Concentration, size, type and dispersion of filler are important parameters in preparation of composites which still need further research.
- A project by authors on long term multistress aging of silica based nano and hybrid nano/micro composites with reference to the neat materials is in progress. The authors are expecting this work; to be helpful for the recommendations of concentration of filler for composite insulators.

REFERENCES

- [1] N. Yoshimura, S. Kumagai and S. Nishimura // *IEEE Trans. Dielectr. Electr. Insul.* **6** (1999) 632.
- [2] N. Bashir, S. Member and H. Ahmad, In: *2nd IEEE International Conference on Power and Energy* (IEEE, 2008) p. 30.
- [3] A. H. El-Hag, A. N. Jahromi and S. Jayaram, // *2007 IEEE Int. Conf. Solid Dielectr.* (IEEE, 2007), p. 172.
- [4] R. Sundararajan, R. Chapman and R. Nowlin, // *2009 Int. Conf. Power Syst.* 2009), p. 1.
- [5] J. Grasaesom, W. Payakcho, B. Marungsri and A. Specimen // *Int. Sci. Index* **5** (2011) 197.
- [6] B. Pinnangudi and R. S. Gorur // *IEEE Trans. Dielectr. Electr. Insul.* **13** (2006) 423.
- [7] I. O. Habiballah, // *World J. Eng.*, 1 (2008) 389
- [8] R. Hackaml // *IEEE Trans. Dielectr. Electr. Insul.* **6** (1999)
- [9] T. Tanaka // *IEEE Trans. Dielectr. Electr. Insul.* **9** (2002) 2
- [10] Y. Xiong, S. Rowland, J. Robertson and R. Day // *IEEE Trans. Dielectr. Electr. Insul.* **15** (2008) 763.
- [11] M. Amin, M. Akbar and M. Khan // *IEEE Electr. Insul. Mag.* **23** (2006) 44.
- [12] M. Martinez, E. Da Silva, J. C. Rodriguez, J. Ramirez, V. De Sartenejas and E. Mirandam, In: *Annual Report Conference on Electrical Insulation and Dielectric Phenomena* (2008), p. 276.
- [13] E. da Silva and S. M. Rowland, In: *Conf. Rec. 2008 IEEE Int. Symp. Electr. Insul.* (IEEE, 2008), p. 530.
- [14] M. Amin and M. Salman // *Rev. Adv. Mater. Sci.* **13** (2006) 93.
- [15] V. Rajini // *Elixir Elec. Engg.* **40** (2011) 5554.
- [16] H. A. Alghamdi, G. Chen and A. S. Vaughan, In: *2012 Annu. Rep. Conf. Electr. Insul. Dielectr. Phenom.* (2012), p. 827.
- [17] K. U. V. Rajini, K. Kanchana and V. Gowdshree, In: *2004 International Conference on Power System Technology* (2004), p. 21.
- [18] A. Chaisaengsukkul, V. Kinares and N. Pattanadech, In: *TENCON 2010 -IEEE Reg. 10 Conf.* (IEEE, 2010), p. 1272.
- [19] F. Su, J. I. A. Zhidong, G. A. O. Haifeng, G. Zhicheng and E. Engineering, In: *Annual Report Conference on Electrical Insulation and Dielectric Phenomena* (2007), p. 300.
- [20] S. S. Vaisakh, M. Hassanzadeh, R. Metz, S. Ramakrishnan, D. Chappelle, J. D. Sudha and S. Ananthakumar // *Polym. Adv. Technol.* **25** (2014) 240.
- [21] T. T. Yuta Okazaki, Masahiro Kozako and Masaya Hikita, In: *International Conference on Solid Dielectrics* ((2010), p. 4.
- [22] H. Homma, T. Takahashi and Y. Miyauchi, In: *Conference Record of the 2006 IEEE International Symposium on Electrical Insulation* (IEEE, 2006), p. 401.
- [23] B. Venkatesulu and M. J. Thomas // *IEEE Trans. Dielectr. Electr. Insul.* **18** (2011) 418.
- [24] S. Chandrasekar, R. Sarathi and M. G. Danikas // *Electr. Eng.* **89** (2007) 489.
- [25] G. C. Silva, F. Piazza and M. Munaro // *IEEE Trans. Power Deliv.* **24** (2009) 1651.
- [26] X. Liang, J. Dai, B. F. Of and A. F. Case // *IEEE Trans. Dielectr. Electr. Insul.* **13** (2006) 870.
- [27] Y. Arief and M. Shafanizam // *Power Energy conference* **2** (2012) 950.

- [28] L. Meyer, S. Jayaram and E. Cherney // *IEEE Trans. Dielectr. Electr. Insul.* **11** (2004) 620.
- [29] S. Kumagai // *IEEE Trans. Dielectr. Electr. Insul.* **14** (2007) 1201.
- [30] I. Ahmadi-Joneidi, A. Majzoobi, A.A. Shayegani-akmal, H. Mohseni and J. Jadidian // *IEEE Trans. Dielectr. Electr. Insul.* **20** (2013) 212.
- [31] Y. Zhu, M. Otsubo, C. Honda and S. Tanaka // *Polym. Degrad. Stab.* **91** (2006) 1448.
- [32] B. E. P. Giannes // *Adv. Mater.* **8** (1996) 29.
- [33] A. A. S. Mohamed, R. Khaled and Zenab M. El-Rashidy // *Mater. Chem. Phys.* **130** (2011) 561.
- [34] T. T. Dietsch // *J. Adv. Mater.* **39** (2007) 3.
- [35] J. Lunt // *Polym. Degrad. Stab.* **59** (1998) 145.
- [36] J. Wu and Yiu-W. Mai // *Polym. Eng. Sci.* **36** (1996) 2275.
- [37] J. Jordan, K.I. Jacob, R. Tannenbaum, M.A. Sharaf and I. Jasiuk // *Mater. Sci. Eng. A* **393** (2005) 1.
- [38] Y. Kim and K. Shong // *IEEE Trans. Power Deliv.* **26** (2011) 1579.
- [39] W. T. Starr // *IEEE Trans. Dielectr. Electr. Insul.* **25** (1990) 125.
- [40] R. Sundararajan, A. Mohammed, N. Chaipanit and T. Karcher // *IEEE Trans. Dielectr. Electr. Insul.* **11** (2004) 348.
- [41] S. Lee, In: *Proceedings of the 6th International Conference on Properties and Applications of Dielectric Materials* (2000), p. 367.
- [42] O. Fujii, I. Nakajima, T. Imakoma and Y. Suzuki, In: *Proc. of the 4th International Conference on Properties and Applications of Dielectric Material* (1994), p. 4.
- [43] M. Amin and M. Ahmed, In: *2007 IEEE International Multitopic Conference* (IEEE, 2007), p. 1.
- [44] Q. Zhao, X. Li and J. Gao // *Polym. Degrad. Stab.* **94** (2009) 339.
- [45] Y. Zhu, B. Ma, X. Liu, B. Song and X. Zhang, In: *2013 Annual Report Conference on Electrical Insulation and Dielectric Phenomena* (2013), p. 426.
- [46] J.A. Mergos, M.D. Athanassopoulou, T.G. Argyropoulos, C.T. Dervos and P. Vassiliou, In: *2010 10th IEEE International Conference on Solid Dielectrics*, (IEEE, 2010), p. 1.
- [47] A.A. S. and H. M. Zeinab Farhadinejad, Morteza Ehsani and Iman Ahmadi-Joneidi // *IEEE Trans. Dielectr. Electr. Insul.* **19** (2012) 1740.
- [48] R. Sundararajan, C. Olave, E. Romero and A.M. Kannan, In: *Annual Report Conference on Electrical Insulation and Dielectric Phenomena* (2007), p. 364.
- [49] S. Gubanski and A. Dernfalk, In: *Proc. 8th IEEE International Conference* (2006) 23.
- [50] M. Matsunaga and P. J. Whitney // *Polym. Degrad. Stab.* **70** (2000) 325.
- [51] S. Wallstrom // *Polym. Degrad. Stab.* **78** (2002) 257.
- [52] S. Wallström, E. Strömberg and S. Karlsson // *Polym. Test.* **24** (2005) 557.
- [53] A. Larsson, A. Roslund, S. Kroll and A. Dernfalk // *IEEE Trans. Dielectr. Electr. Insul.* **9** (2002) 274.
- [54] S. Wallström, A. D. Dernfalk, M. Bengtsson, S. Kröll, S. M. Gubanski and S. Karlsson // *Polym. Degrad. Stab.* **88** (2005) 394.
- [55] S. Wallström and S. Karlsson // *Polym. Degrad. Stab.* **85** (2004) 841.
- [56] S. Atarijabarzadeh, E. Strömberg and S. Karlsson // *Int. Biodeterior. Biodegradation* **65** (2011) 1111.
- [57] M. Anami, C. Honda, Y. Hashimoto and M. Siobara, In: *Proceedings of the 7th International Conference on Properties and Applications of Dielectric Materials* (2003), p. 638.
- [58] V. M. Moreno and R. S. Gorur, In: *Annual Report Conference on Electrical Insulation and Dielectric Phenomena Corona-Induced* (2001), p. 640.
- [59] V. M. Moreno and R. S. Gorur // *IEEE Trans. Dielectr. Electr. Insul.* **10** (2003) 80.
- [60] J. Kim, M. K. Chaudhury and M. J. Owen // *IEEE Trans. Dielectr. Electr. Insul.* **6** (1999) 695.
- [61] B. Ma, J. Andersson and S. Gubanski // *IEEE Trans. Dielectr. Electr. Insul.* **17** (2010) 555.
- [62] V. M. Moreno and R. S. Gorur // *IEEE Trans. Dielectr. Electr. Insul.* **8** (2001) 117.
- [63] V. M. Moreno and S. G. Ravi, In: *Conference on Electrical Insulation and Dielectric Phenomena* (1999), p. 731.
- [64] Y. Zhu, K. Haji, M. Otsubo, C. Honda and A.S. Material // *IEEE Trans. PLASMA Sci.* **34** (2006) 1094.
- [65] X. Wang, In: *Electrical Insulation and Dielectric Phenomena, 1998. Annual Report. Conference 1* (IEEE, 1998), p. 32.

- [66] X. Wang, S. Kumaga, and N. Yoshimura // *IEEE Trans. Dielectr. Electr. Insul.* **5** (1998) 909.
- [67] P.A. Calva, M.G. Mkquez and G.P. Cabrera, In: *Annual Report Conference on Elecmcal Insulation and Dielectric Phenomena* (2003), p. 410.
- [68] P.C. Irwin and K. Younsi // *IEEE Trans. Dielectr. Electr. Insul.* **11** (2004) 797.
- [69] Y. S. Song and J. R. Youn // *Carbon* **43** (2005) 1378.
- [70] B. Venkatesulu and M. Thomas // *IEEE Trans. Dielectr. Electr. Insul.* **17** (2010) 615.
- [71] G. Momen and M. Farzaneh // *Rev. Adv. Mater. Sci.* **27** (2011) 1.
- [72] Y. P. Mamunya, V. V. Davydenko, P. Pissis and E. V. Lebedev // *Eur. Polym. J.* **38** (2002) 1887.
- [73] M. Rusu, N. Sofian and D. Rusu // *Polym. Test.* **20** (2001) 409.
- [74] A. Guevara-Morales and A. C. Taylor // *J. Mater. Sci. Sci.* **49** (2014) 1574.
- [75] M. Çopuroğlu and M. Şen // *Polym. Adv. Technol.* **15** (2004) 393.
- [76] Sumio Iijima // *Nature* **354** (1991) 56
- [77] K. Siderakis, D. Agoris and S. Gubanski // *J. Phys. D. Appl. Phys.* **38** (2005) 3682.
- [78] E. A. Cherney // *IEEE Trans. Dielectr. Electr. Insul.* **12** (2005) 1108.
- [79] A. Syakur and H. Berahim // *Electr. Electron. Eng.* **2** (2012) 284.
- [80] L.H. Meyer, E.A. Cherney and S.H. Jayaram // *IEEE Electr. Insul. Mag* **20** (2004) 13.
- [81] B.X. Du, Z.L. Ma, Y. Gao, T. Han and Y.S. Xia, In: *2011 Annu. Rep. Conf. Electr. Insul. Dielectr. Phenom.* (2011), p. 788.
- [82] K. C. and S. N. Maiti // *J. Appl. Polym. Sci.* **52** (1996) 323.
- [83] A. P. Kumar, D. Depan, N. Singh Tomer and R. P. Singh // *Prog. Polym. Sci.* **34** (2009) 479.
- [84] S. Sarkar and P. K. Das // *Rev. Adv. Mater. Sci.* **37** (2014) 53.
- [85] Mohammad Yousefi, Gholamian Forozan, Davood Ghanbari and Masoud Salavati-Niasari // *Polyhedron* **30** (2011) 1055
- [86] M. Higashikoji, M. Motoyama, S. Ohtsuka, M. Hikita, H. Ikeda, J. Gavillet, G. Ravel, E. Da Silva and M. Frechette, In: *2008 Annu. Rep. Conf. Electr. Insul. Dielectr. Phenom.* (2008), p. 212.
- [87] A. Aman, M. M. Yaacob, M. A. Alsaedi and K. A. Ibrahim // *Int. J. Electr. Power Energy Syst.* **45** (2013) 346.
- [88] Q. Yuan and R. D. K. Misra // *Mater. Sci. Technol.* **22** (2006) 742.
- [89] E. A. C. H. Deng and R. Hackam // *IEEE Trans. Power Deliv.* **10** (1995) 1012.
- [90] D. Fabiani, G.C. Montanari, A. Krivda, L.E. Schmidt and R. Hollertz, In: *2010 10th IEEE Int. Conf. Solid Dielectr.* (IEEE, 2010) 1.
- [91] K. C. Jajam and H. V. Tippur // *Compos. Part B Eng.* **43** (2012) 3467.
- [92] M. Anhalt and B. Weidenfeller // *J. Appl. Polym. Sci.* **119** (2011) 732.
- [93] C. Putson, L. Lebrun, D. Guyomar, N. Muensit, P.-J. Cottinet, L. Seveyrat and B. Guiffard // *J. Appl. Phys.* **109** (2011) 024104.