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# Electrical Insulators Based on Polymeric Materials: Toward New Cutting-edge Enhancements

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**Abstract** This work reviews the applications of thermoplastic and thermoset polymers. High-voltage applications of polymer micro/nanocomposites are shown. This study focuses on polyesters, which hold a significant position among polymers as engineering materials used in electronics and electro-technology. Polyester is a widely used and important commercial polymer because of its excellent mechanical, electrical, and thermal qualities. These resins are mixed with other materials to be utilized in high-voltage applications. Consequently, they have found useful applications in the insulation industry for the insulation processing of generators, motors, transformers, and other electrical equipment. Employing micro-nano-sized fillers inside polyester composites has been implemented to enhance their dielectric, thermal, mechanical, and electrical properties and to reduce their flammability. Additionally, this research presents recent enhancements in polyester nano composites using different types of nano fillers and the various applications of Polyester resins used as an insulation material predominantly in super-capacitors, fuel cells, electromagnetic shielding, and textiles. Regarding the medical field, polyester-based materials can be used in hard and soft tissue engineering, wound dressings, surgical implants, vascular, reconstructive surgery, and other medical applications.

**Keywords**: Electrical Insulations; Micro/Nano Fillers; Polymeric Materials; Unsaturated Polyester Resins.

## 1 Introduction

In generally, many researchers have developed new types of insulators because of higher voltages. Since the early 1960s, alternative materials, specifically polymers, have evolved and are now widely employed for a range of outdoor insulation applications. The dielectric properties of insulation polymers can be changed over time, due to various aging processes such as exposure to heat, humidity, salinity and mechanical stress [1].

Recently Many utilities favored polymers over porcelain and glass to house high voltage outside materials. Polymer has numerous advantages over ceramic, such as: cheap, light weight, easy handling and installation, quicker manufacturing time, good impact resistance, high mechanical strength, better flexibility in product design, and resistance to vandalism. These advantages have led utility workers to prefer polymer insulators over traditional porcelain or glass insulators. Polymeric materials, particularly polyesters, silicon rubber, and ethylene propylene diene monomer (EPDM) are utilized as insulators for the transmission, distribution, termination of subterranean cables, bushings, and surge arrester housings [2-4].

Subterranean wires, surge arrester housings, and bushings are transmitted, distributed, and terminated using polymer insulators, specifically polyester resins, EPDM, and silicon rubber [5-7].

Polyesters play avital role in polymers. These polymers are greatly employed in a variety of industries, including electrical, electronics, construction, textiles, and packaging. They have outstanding electro-insulating qualities and offer high mechanical strength, thermal resistance, and ease of processing.

One of the issues facing polymeric materials usage is the change in their dielectric properties over time, due to various aging processes such as exposure to heat, humidity, salinity, and mechanical stress [8].

This work covers the latest advancements in electrical insulators made from polymeric materials such as polyesters. It explores the fundamental properties that make these materials suitable for insulation purposes,

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examines recent innovations in polymer composites and nanocomposites, and discusses the potential of novel fabrication techniques to enhance their performance. Additionally, we examine the obstacles and prospects in the subject, hoping to provide a complete review of the most advanced in polymer-based electrical insulators and their potential to change the sector.

## 2 Polymeric Materials

These materials have lengthy chains and enormous molecular weights generated via covalent bonding between several monomers. During polymerization, small company connections can result in different chains of polymers topologies, such as branching, linear, or cross-linked. In other terms, the matrix of polymer can be split into three main groups: thermoplastic, thermoset, and elastomer. They are categorized into these groups based on their various qualities, including as chemical and physical structure, thermal properties, electrical and mechanical performance [1-3]. The following subsections discuss polymer classifications.

### 2.1 Thermoplastic Type

Most of these polymers are branching or linear polymers which melt and flow when heated up, rapidly form into complicated products when melting, and then solidify when cold. The type of thermoplastic has an obvious benefit of allowing rejected or damaged pieces to be re-ground and remolded, as well as the ability to reuse eliminated thermoplastic. Since thermoplastics can't carry electricity, they are employed within several uses for which their insulating qualities are necessary. These types of polymers are utilized as insulators in electric machines [9]. Some of these thermoplastics are shown in **Table 1**.

**Table 1** Thermoplastic utilizations in electric insulations.

| Polymer | Utilizations |
|---|---|
| Polyesters | Business machine parts, films coatings for electrical industries and coffee machines |
| Polyethylene | Wire insulation and cables |
| Polyvinyl chloride | Wire insulation and cables, cable trucking |
| Polyamide | Bearings for food processors and adaptors |
| Polystyrene | TV cabinets and Refrigerator trays/linings |

### 2.2 Thermoset Type

These types of polymers feature a connected structure of networks formed solely from chemical connections. Due to their linkages, thermosets are rigid and fragile substances that can withstand high temperatures and are resistant to acids and other substances [10]. This polymer is frequently employed to isolate electrical wire, while thermosets (heated stable materials) are utilized for circuit breakers, switches, fuse boxes, handles, and electrical components [11].

Unsaturated polyester resins (UPRs) play an essential role in thermoplastic substances because they have an improved easily connected structure, resulting in higher resistance to mechanicals, thermals, and chemicals than other resins. Each of these benefits make these thermosetting polymers suitable for use as matrices for fundamental materials in a variety of industrial applications (electrical insulation, aircraft, automotive, and aircraft sectors, among others) [12].

### 2.3 Elastomers Type

These polymers have significant elongation capabilities exceeding their original length and immediately revert to their initial form without permanent distortion when the stress is released. Their electrical characteristics were identified to obtain a few specialized HV insulators, at minimum for distribution group uses, particularly for mildly contaminated situations.

Presently, Because of their superior performance and lower cost, some of TPEs have emerged as the preferred insulating material [13-15].

## 3 Unsaturated Polyester Resins (UPR)

They are resins that are highly desired for their many properties, flexible processing, and lower cost. These resins are liquid polymers that retain their solid shape after solidification.

In the realm of polymers, polyesters have a significant role as technical materials for electronics and electro technology. polymers implies that polyester are always an appealing class of materials. These polymers exhibit outstanding electro-insulating capabilities while also demonstrating mechanical strength, thermal resistance, and ease of production. They are real dielectric materials with a limited electrical conductivity, polarization in an electrical field, as well as a high sensitivity to the presence of static energy. In the electrical industry, polyester resign is increasingly being utilized in combination with other materials. Because this resin is continuously subjected to a variety of physical and chemical changes, polyesters are always providing new solutions for market and budgetary requirements [16]. They are also utilized in the fabrication of films, coatings for the electronic, membranes, optical waveguides, electrical sectors, and devices that double the frequency of electromagnetic signals [17].

But because UPR is a somewhat brittle material, even the slightest damage or fault might lead it to break and fail. Polyesters also have certain drawbacks, such as considerable shrinkage, poor hardness, and low strength. Because of all of these, UPRs are commonly combined with reinforcing micro- and nanoparticles. To increase their productivity, they should be improved. Nanoparticles can bond to resins very quickly and firmly because of their generally more active surfaces. Furthermore, it is believed that adding inorganic nanoparticles to the polymer will improve its mechanical properties and heat resistance [18].

## 4 Polymer Composites and Fillers

Composites are often made up of two or more materials that have considerably unique chemical and possibly physical characteristics. Nano composites are materials that have at least one component with nano metric properties [19 -20].

Micro and Nano composites materials are widely used and advanced in high-voltage applications therefore, Polymer nano-composites' unique benefits, such as improved dielectrics, high temperature efficiency, designability, and structural characteristics, provide intriguing concepts to possible future studies on these materials to future generations of massive generators, transformers, motors, as well as other electrical appliances, including coil shapes, slot liners, and multipurpose parts.

The following generation utilizing polymer nano composites to achieve high voltage applications as illustrated in **Fig. 1** [21].

Also, polymer nano composites have many applications in energy, electrical, medical, environmental and sensing fields [22]. The composite insulator has strong mechanical properties and is a lightweight insulation material [3].

Fillers play a key function in improving thermal conductivity and electrical characteristics, mechanical properties and tracking and erosion resistance of polymeric Insulators [23]. Ersoy et al. examined several filler materials to enhance the insulator characteristics. Filling materials that can raise the flashover voltage of insulation materials include boric acid ($H_3BO_3$), alumina trihydrate (ATH), and magnesium hydroxide (Mg $(OH)_2$) [24].

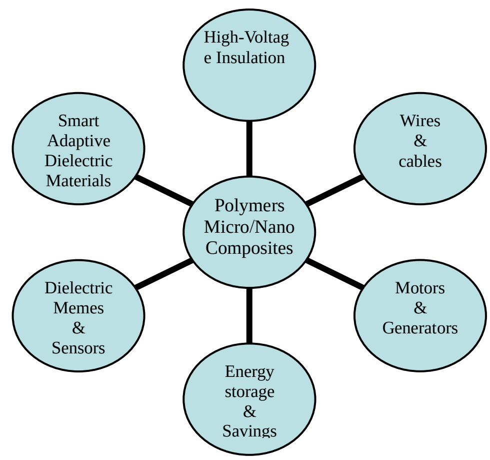


**Fig.1** High-voltage applications of polymer-based micro/nano composites.

Due to nano fillers inclusion, polymer nano composites exhibit exceptional properties when compared to a pristine polymer matrix. The nano fillers are intended to enhance the electrical, magnetic, mechanical, thermal, flame retardancy, and gas barrier properties of the polymers [25].

## 5 Literature Review for Recent Progress in Polyester Nanocomposites

In references [26,27] researchers studied reviews the uses of thermoset and thermoplastic polymers as well as provided a quick overview of each subsystem's operations. Polymeric properties and synthesis route were described. The tensile test, impact behavior, bending test, and relative thermal index are examples of the mechanical characteristics for polymers. The thermal qualities include relative thermal capability, mold stress-relief distortion, relative thermal index, and generic thermal indices. This research also discussed polymer electrical properties, namely dielectric strength. Various methods were discussed to check the suitability of polymers used as electrical insulation, including high current arc resistance to ignition and partial discharge.

Applications of polymeric materials and manufacturing methods to high voltage DC systems (HVDC) were described, along with descriptions of the materials and processes employed for creating cables of various ranges of voltage. The advantages and future developments of polymeric materials for electrical applications were discussed. However, new methods must be created to lower the high cost of filler networks and enhance their technical characteristics. Modern methods, like indentation were utilized with increased force at strained site for overcoming restrictions related to the accuracy of the methods utilized for assessing remaining stresses through polymers.

In Ref. [28] studied a process called calendaring that was used to disperse carbon nano fibers (CNFs) through an UPR. It enables strong dispersion for the nanoparticles and is simple to scale up at the level of industry in comparison to other techniques. To achieve the best dispersion level, calendaring conditions for the processing were designed. Researchers observed that adding extremely small quantities of CNFs to an UPR significantly increases its electrical conductivity. At 0.3% loading of CNFs, electrical conductivity values increased by six orders of magnitude. In contrast, the inclusion of carbon nano fibers does not significantly improve the mechanical characteristics. To confirm if the enhanced electrical qualities come at the cost of workability loss and a significant rise in viscosity. The rheological characterization has been carried out. At some point, a mechanical characterization was completed.

C. Yanen et al. in Ref. [29] focused on investigating physical and thermal characteristics for polyester nano composite created with nanoparticles. Three different nanoparticles were used: Silicon carbide (SiC), fumed Silica (FS), and graphene nano plate (GNP). After the trial findings of the manufactured polyester nano composites were assessed, researchers have concluded that FS nanoparticles are ideal for creating composites with low density, excellent insulation, and good thermal properties, (SiC) nanoparticles can be utilized for creating UPR nano composites have excellent density and toughness, whereas (GNP) nanoparticles may be used for creating UP nano composites have good thermal conductivity.

The researchers of Ref. [30] discussed studies on polyester nano composites containing necessary nano fillers like graphene, fullerene, carbon nanotube, nano diamond, and graphene oxide. The essential polyester resins can be further strengthened by nano fillers to improve the structural and physical properties of the finished nano composite. According to enhanced polyester layout, nano filler performance, and a better matrix-nano filler interaction, excellent performance polyester/nano composites were produced. The most recent advancements in polyester/nano composites technology are also discussed in this article, with a focus on their use in fuel cells, textiles, super capacitors, electromagnetic shielding materials, and biomedical appliances. Future directions in the scientific study of these nano composites are also examined.

In Ref. [31], researchers created several nano composites reinforced with UPR and scattered $TiO_2$ nanoparticles at various filler ratios. They created $TiO_2$-polyester nano-sized resins during the poly-condensation processes. The characteristics of the nano composite samples included hardness, thermal insulation, strength, and morphology. Scanning microscopy with probe indicated that the small particles were virtually evenly dispersed throughout the samples., but certain agglomerations formed when the number of nanoparticles increased. Based on the results of thermal conductivity and hardness, the ideal ratio of 0.2% $TiO_2$ nanoparticles was determined by strength and hardness measurements. When combined with additional chemicals, this 0.2% ratio improves polyester resin samples and is used to manufacture a dental filling containing additional ingredients.

In Ref. [32], researchers highlighted new methods for decreasing UPRs' flammability. UPRs are widely utilized in railroad, construction, and shipbuilding sectors. UPRs generally meet fire safety requirements without modification. These technologies also aim to negative environmental effects of materials and to provide smoke intensity. The present study has examined and applied the process for action of various types of nano FRs, including but not confined to carbon-based, clay-based, layered double hydroxides, transition metal compounds, polyhedral oligomeric silsesquioxanes, and bio-based compounds, to UPRs. Researchers finally reached the conclusion that low loadings of nano FRs may clearly increase thermal stability while simultaneously increasing or somewhat reducing mechanical properties.

## 6 Potential Applications of Polyester

### 6.1 Polyester in Electric Motor Insulation

Generally, polyester resigns have played avital role as insulation materials of electrical machines for many years. Furthermore, because polyester resins can sustain windings electrically and mechanically, they have found useful applications in the impregnation industry. The development of several polyester-based solutions for the Vacuum Pressure Impregnation (VPI) insulated procedure for motors, generators, transformers, as well as other electric equipment has been made possible by their excellent electrical insulation characteristics [33, 34]. Unsaturated polyester imide resins (UPIR) are polyester-based liquids that are better suited for insulating electrical motors [35]. Most resin procedures were chosen specifically since they are described one-component structure, which means that the curing procedure can begin prior to the VPI process without the need for mixing steps with external hardeners. In addition, they have a low viscosity with a thermal class higher than 180°C and lack volatile organic compounds (VOCs).

### 6.2 Polyester in Electromagnetic Interference (EMI) Shielding

Definition of (EMI) shielding is a critical phenomenon that protects electronic devices and humans from pollution caused by electromagnetic radiations [36]. It is a promising usage of polymers and nano materials. To produce materials that are technologically significant, polyester/nano composite EMI shielding efficiency must be increased to 20 dB [30].

Carbon-based nano materials including carbon nanotubes, carbon black, graphene, carbon nano-fiber, and graphite have been employed to improve EMI shielding efficiency (SE) in polymer nano-composites [37]. Seng et al. in Ref. [38] investigated polyester nanocomposites' electrical characteristics and shielding efficiency using multi-walled carbon nanotubes. The range of EMI SE was recorded between (30 MHz and 1.5 GHz) in case of using carbon fibers coated with MWCNT for polyester [30].

Graphene nano platelet-filled polyester Composites are one of the most appealing options for effective and economical EMI shielding; nevertheless, much effort remains to be done to meet all technical requirements. The horizontal dimension of GNPs has a considerable influence on these composites' EMI shielding mechanism. Utilizing the non-aligned smaller-size GNPs, an elevated coefficient of absorption (about 40%) is produced. Using a similar thickness, this absorption efficiency performs better than the earlier bulk polymer composite containing a single filler [39]. For usage within electric devices in the armed forces and additional organizations, new and efficient electromagnetic interference shielding polyester/nano filler combinations are highly sought after.

### 6.3 Polyester in Super-capacitors

Super-capacitors (SCs) can be fabricated by polymer/nano composites with excellent charging and discharging capabilities, cyclic performance, and stability [40]. Such gadgets can be configured for optimal performance, minimal power usage, and recharge-ability [41]. SCs are developed at a rapid pace to achieve lightweight, mechanical flexibility, flexibility, wear comfort, and diverse aesthetics. Moreover, reduced graphene oxide-coated polyester (RGO/PET) yarn is used to generate conductive metal–organic framework (MOF) nano rod arrays, which create a yarn electrode in super capacitor. High specific surface area, strong conductivity, hierarchically structured porosity, and a robust interface are some of the exceptional qualities. Excellent mechanical flexibility and high energy density are achieved by a yarn super capacitor built using this yarn electrode [42].

Functional nano filler and new design modifications for polyester/nano composite based super-capacitors require to be evaluated for improved cycle efficiency and charged-discharged capabilities [30].

### 6.4 Polyester in Textiles

Polyester and materials based on carbonaceous nanofiller are of interest to the textile industry [43,30]. Wu et al created smart e-textiles using a core-shell based on graphene, polyester, and Ag nanowire. The conductivity of the fibers is high (20 ohms/square). Their electronic textile had a high output power of 7 $nW/cm^2$ [44,30].

The fabrics also have a delicate flexibility, are washable, and can be stretched. With carbon nanotubes, graphene, and various nano fillers covered polyester fibers, high-performance smart e-textiles can be produced.

Accordingly, studies on altering thickness of coating can improve textile materials' electric conductivity & usefulness. Wearable technology and garments driven by nanotechnology have a bright future thanks to e-textile composed of polyester and nano filler [30].

### 6.5 Polyester for Medical Applications

Polyester-based materials play an important role in applications related to medicine. Based on their characteristics, they could be a good substitute for different materials made of polymers. They were one of the earliest polymers used for such applications. Rigid and soft tissues engineering, vascular reconstructive surgery, dressings for wounds, dental implants, eye disease, as well as other applications in medicine can all benefit from the usage of polyester-based materials [45]. Polyesters, include PLLA, PLA, PGA, PHA, and PCL are synthetic polymers that are extensively used throughout medical purposes. This is because they can be tailored to a wide variety of specifications are readily available, inexpensive, and easy to process. A large-scale nonwoven manufacturing procedure (spun-bond, carded, and melt-blown) was presented by Tuin et al. as appropriate to manufacture PLA scaffolds for the development of tissue [46].

In the field of biomedicine, polyesters find extensive use in time- and place-specific implants, prostheses, scaffolds to bone healing, and other three-dimensional structures including scaffolds for tissue design and controlled release of drugs methods [45-49]. Additionally, the polyester materials also are be utilized in the prevention of multi-resistant infections, particularly those that occurred through the COVID-19 pandemic, in addition to environmental issues, existing dangers and constraints, and potential future paths.

## 7 Conclusions

This study obviously reviewed the Classifications of polymers and their utilization as insulators in electric machines. Because of their superior material performance such as high strength, toughness, heat resistance, lightweight, as well as high resistance to fatigue and corrosion degradation, composite materials are frequently chosen over traditional materials. Moreover, polyester insulators are increasingly adopted for numerous manufacturing applications, while UPIR have been used for performing the insulation role of electric motors. This study provided a foundation for upcoming research projects in the polyester insulation area. The researchers highlighted the advancement of nano- and micro-composites in improving the electrical, mechanical, and thermal characteristics of polyester insulation materials. Consequently, by adding various nano fillers in varying percentages, such as graphene nano plate (GNP), fumed silica (FS), silicon carbide (SiC), carbon nano fibers (CNFs), and titanium dioxide ($TiO_2$) nanoparticles, hexagonal boron nitride (HBN), and others have been used through a comprehensive review of existing research. Furthermore, this work discussed current technological advancements in polyester/nanocomposites, with applications including electromagnetic interference (EMI) shielding materials, super capacitors, fabrics, materials with shape memory, as well as biomedical products.

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