Journal of Mines, Metals and Fuels, *73(8): 2639-2648; 2025. DOI: 10.18311/jmmf/2025/47375*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.co.in/index.php/jmmf*

The Role of Nano Materials in the Numerous Areas of Manufacturing

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Abstract

The research cycle has been dominated by the shift from fossil fuels to sustainable and renewable energy. Increased population increase, industrialization, depleting oil reserves, and the damaging effects of fossil fuel-based energy generation on the environment are the causes of the change. The new energy producing techniques require functional intelligent and robust materials for energy production and storage. Composite materials made of polymers have been used extensively. The qualities of the composite must be improved in light of the latest demands for material performance. Since the matrix by itself lacks the necessary qualities, reinforcement with fibers and/or nanoparticles can be used to remedy the situation. Numerous

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studies have extensively documented the impact of adding fibers and/or fillers to the polymeric matrix. Recent developments in the creation and utilization of nanocomposites and polymeric composites for energy applications are examined. Improvements to material properties, processing techniques, and enhancing surface adhesion—all of which may occur during material compounding are covered. There are other energy-related applications for these materials that are equally highlighted. Aim: The main goal is to find out the preparation process has an impact on the overall performance of the materials, and some materials can only be prepared using one or more specialised procedures.

Major Findings: *Adding nanoparticles to nano composites alters their properties, broadening the materials' applications. Material science advances have led to the emergence of alternate energy sources sourced from sustainable and renewable resources.The dielectric properties will improve with a gradual increase in the filler materials in the matrix until the dielectric value abruptly changes; this is known as the percolation threshold. Materials' dielectric constants decrease as frequency increases.*

Keywords: *Analysis, Nanocomposites, Nanoparticles, Performance, Preparation*

1.0 Introduction

New technologies and materials for energy generation and storage have been developed as a result of the rise of clean, renewable, and sustainable energy, the ecological effects of greenhouse gases, global warming, human dependence on energy, rising energy consumption, and depletion of fossil fuel reserves[1,2]. Super capacitors, fuel cells, solar cells, lithium batteries, and wind turbines are a few examples of energy systems that are used for generation and storage[3,4]. The material utilized determines how efficient these systems. In other words, material quality has a direct impact on system performance[5,6]. Composite materials have been created recently using elements including metal, ceramic, and polymer matrices. These substances have demonstrated significant promise for energy-related uses[7,8]. The development of energy generation, conversion, and storage has made it necessary to investigate the use of fibers and nanoparticles to reinforce matrices[9,10]. High strength-to-weight ratios, good operating safety, affordability, and environmental friendliness have all been demonstrated for several of these materials[11,12]. Applications such as electronic gadgets, electrical appliances, power grids, industrial, and military devices have made extensive use of nanoparticle-based composites due to these and other characteristics[13,14]. It is possible to customize the inclusion of nanoparticles into polymeric materials to achieve particular energy application features[15,16]. This is accomplished by carefully considering the end-use application while selecting the polymer matrix and the nanoparticle[17,18].

The objectives of research work is to

- To describe Nanoparticle-based composite fillers.
- To demonstrate the various methods of composites based on nanoparticles.
- To illustrate the characteristics and uses of nanocomposites.

2.0 Nanoparticle-based Composites Fillers

Because nanoparticles have greatly improved the performance of composite materials, material scientists and engineers are using them to develop smart and new materials[19,20]. Numerous nanomaterials are available and are chosen according to their intrinsic qualities and the intended outcome. Due to its high surface-to-area ratio and low cost, clay is one of the most popular fillers[21,22]. It may be divided into three primary categories depending on the ratio of alumina to silica. Mineral clay's hydrophilic nature makes it challenging to distribute in polymeric composites because it aggregates and alters the composites' characteristics[23,24]. This behavior is frequently linked to nanoparticles and fillers. Grafting, ultra-sonication, mechanical, physical, or chemical approaches have all been reported as effective ways to distribute the nanoparticles onto the polymer[25,26].

3.0 Making Composites Based on Nanoparticles

The total performance of composite materials is directly impacted by the way they are prepared. A number of

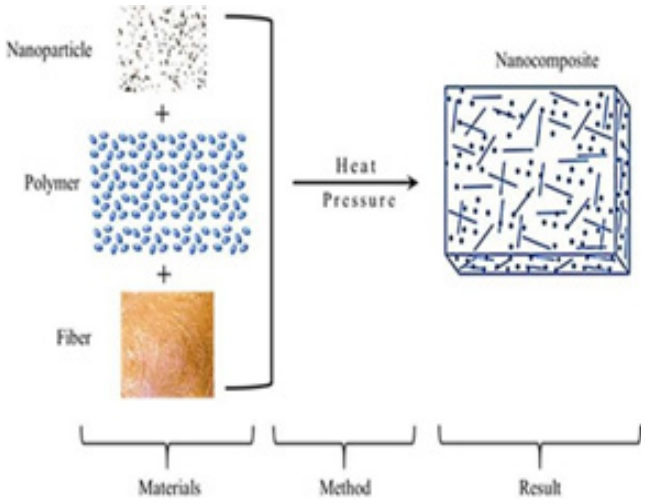


Figure 1. Schematic illustration showing the procedures involved in processing composites from beginning to end.

techniques, such as injection molding, compression molding, extrusion molding, resin transfer molding, and hand lay-up, have been investigated for creating polymer matrices[27,28]. A thorough comprehension of the processing parameters— temperature, velocity/time, and pressure— will improve the composites' qualities. Depending on their nature, the materials used to create polymer matrix composites often need to be preheated in a vacuum oven for a specific amount of time at a specific temperature[29,30]. The entire process of producing nanocomposites is depicted in Figure 1.

4.0 Molding by Compression

One of the earliest techniques for polymer matrix compounding is this one. Unlike injection molding, which works best with short fibers, it can be used to create polymer composites reinforced with both short and long fibers[31]. Two steel plates make up compression molders: one above and one below. The specimen is positioned within the mold cavity a releasing agent is coated inside the mould[32]. This technique can be used to create samples of different sizes, shapes, and intricate material geometries. For laboratory operations, the specimen can be cut to the test sample sizes and shapes, followed by compression molding[33].

5.0 Molding by Extrusion

Either a single or twin screw could be used as the extruder. Temperature, speed, and time are among the parameters that are set based on the characteristics of different compositions. The samples are fed into the hopper and then sent to the screw via the feeder[34]. For external extruders, the mixed samples emerge at the outlet independently based on the extruder's length, whereas for internal extruders, the mixing period is finished before the machine is opened to remove the mixed samples, respectively, employed comparable strategies[35].

6.0 Using Injection Molding

Extrusion and injection molding are comparable processes. By connecting the injection molding machine's outlet to a mold cavity, multiple material sizes and shapes can be produced instantly without the need for an extra machine, such as a compression molder[36]. This is the primary distinction. Various heating zones on the machine are adjusted according to the characteristics of the material. After preheating the machine and setting the necessary settings, such as injection time, pressure, and cooling time, the mold cavity opens, allowing the injected sample to exit[37].

7.0 Hand-lay-up

The initial step involves applying a releasing agent to the mold's surface in layers or sprays to stop the resin (composite) from adhering to the mold cavity. If fiber reinforcement is used, the woven or non-woven fiber ply is positioned inside the mold, and then the resin is poured over the stacked fibers. By evenly distributing the resin with a hand roller, the resin is guaranteed to fully enter the dry layered fibers. Using the hand roller, trapped air bubbles must be eliminated. Property values such as tensile, flexural, and impact strength will decrease as a result of trapped air bubbles. To ascertain the impact of RTM and hand lay-up on the tensile characteristics of epoxy-reinforced carbon fiber composites, employed this technique. Once evenly dispersed, the resin is left to cure at room temperature or a higher temperature in an oven[38].

8.0 Resin Transfer Molding

The first step in the RTM process is to apply a releasing agent to the mold's surface. The planned composite materials' size and shape determine the mold's dimensions. The design incorporates a gating system, also known as a vacuum inlet, that permits liquid resin to enter at one end and exit at the other. Using a pump such as Hypaject, the resin is injected. The presence of the other aperture indicates that the resin has filled the mold cavity and moved throughout. The resin injection is stopped as soon as the resin begins to flow out at the outlet aperture and is given time to cure[39].

9.0 Characteristics and Uses of Nanocomposites

Improved qualities like tensile strength, impact strength, thermal resistance, and moisture absorption have led to the widespread use of composites and nanocomposites. The most sought-after properties are the first three out of a number of others. The aforementioned characteristics, along with others like optical, antireflection, conductivity, and so on, are crucial for materials used in energy applications. While certain polymers need to be modified with other polymers or nanoparticles, others possess conductive characteristics. It has been shown that adding nanoparticles to a polymer matrix provides the appropriate characteristics required for electrical applications[40]. The search for new and innovative materials is an ongoing process due to technological advancements and the rising energy demand. Polymer nanocomposites are a unique material created by combining a polymer continuous phase with a nanoparticle discontinuous phase. Due to the material's remarkable property improvements, it is unique and has garnered a lot of interest worldwide. Thus, the expanding use in fields like electrical and electronic, automotive, aerospace, and medical, to name a few. The intricate interface areas between the polymer matrix and the nanoparticle present a challenge for polymeric nanocomposites, a family of materials with amazing characteristics. The processing techniques address these issues. Therefore, resolving the issue will result in the creation of materials with the required mechanical, electrical, thermal, and optical qualities. The section concentrated on a range of energy-generating and storage applications for nanocomposites[41].

10.0 Supercapacitors

An SC is a type of capacitor with a larger capacitance value than regular capacitors with smaller capacitance values. It is also known as an ultra-capacitor, supercap, or goldcap. The development of SC can help close the gap between electrolytic capacitors and rechargeable batteries. They are primarily utilized in situations requiring rapid charge/discharge since their energy storage capacity is 10–100 times greater per unit volume than that of electrolytic capacitors. SC outperforms rechargeable batteries in terms of charging and discharging cycles. An electric double-layered capacitor is another name for SC. Due to their extended cycle life, increased power density, and greater rate capability, SCs have garnered a lot of attention recently for their exceptional energy storage potential[42]. SC due to its advantages, which include its flexibility, high conductivity, simplicity in synthesis, affordability, and so forth. The several conducting polymers, polyaniline, polypyrrole, and polythiophene that were utilized to create binary and ternary composite electrodes for SC were compiled. Super capacitors used in flexible electronic devices must be mechanically flexible and developed to have high stability, quick charge/discharge times, and acceptable mechanical qualities. The author used graphene and polyaniline to create a composite electrode on a piece of stainless steel fabric. It was found that the flexible all-solid-state SC produced an impressive outcome. The intrinsic properties of polyaniline reinforced with graphene are responsible for the SC's flexibility. The creation of wearable, flexible electronics that are integrated with power devices has recently become feasible. In a similar vein, it reaffirmed the necessity of creating wearable, flexible, and lightweight electronics with energy storage capabilities. According to their paper, two graphene/polymer composite electrodes were integrated with an all-solid- state flexible SC[43].

11.0 The Battery Made of Lithium

Because of its increased safety and capacity to be recharged after losing their charge, lithium batteries have garnered a lot of interest during the past few decades. Lithium

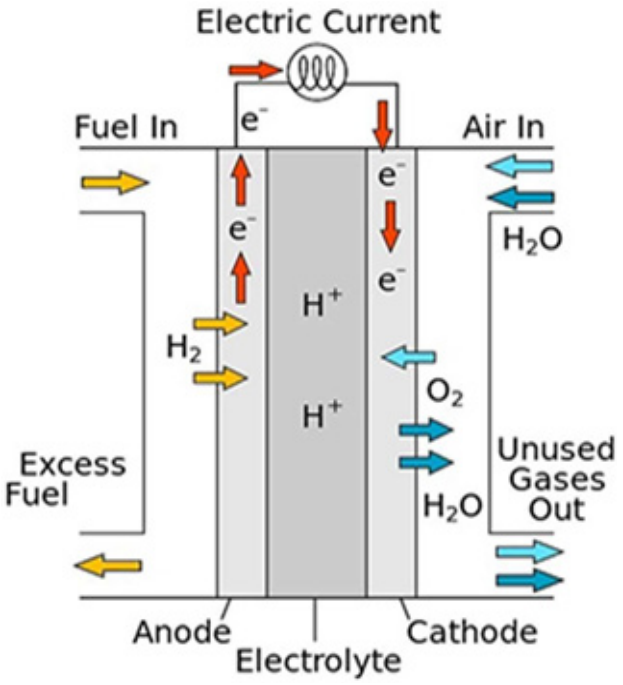


Figure 2. Schematic representation of a fuel cell.

batteries are among the best portable energy storage solutions available for gadgets. Because of their relatively low conductivity, polymers have not been very successful when utilized for polymer-based electrolytes; therefore, nanoparticles must be incorporated. Clay nanoparticles improved the conductivity of clay/polymer nanocomposites used in lithium batteries. It was found that the outcome was superior to that of single-ion synthetic polymer conductors. Polymer nanocomposites are used to make the electrolytes, electrodes, separators, and binders that make up lithium-based batteries because of their architectures and characteristics[44].

12.0 Fuel Cells

A fuel cell is an electrochemical cell or apparatus that uses an electrochemical reaction between hydrogen fuel and oxygen or other oxidizing agents to transform the chemical energy of hydrogen or other fuels into clean power. It is comparable to batteries but differs in that, unlike batteries, which contain the chemical, it needs a steady supply of oxygen and fuel. As illustrated in Figure 2, the cell is separated into three crucial sections: the anode, electrolyte, and cathode. Throughout the process, fuel and air are consumed, which results in the production of carbon dioxide or water and, eventually, an electric current suitable for use in electric equipment[45]. Polymeric materials can be used to create the membrane for this special gadget. The characteristics of the material employed determine how well the electrochemical cell performs. Therefore, for the system to function better, careful material selection is needed. Different composite materials consisting of carbon–carbon, metal– carbon, polymer–carbon, metal–polymer, and polymer–polymer have recently been used to build fuel cells. The materials listed above have been used to construct and test cathode catalysts, anode catalysts, and microbial fuel cell membranes. When compared to traditional materials, the materials have demonstrated improved properties for the system's operating performance. By adding a nanoparticle to the composite, the qualities can be further improved[46].

13.0 Solar Cells

The hunt for new energy sources has been spurred by the growing need for energy and the problems caused by global warming. Alternative energy sources include geothermal, biomass, wind, and solar. Solar energy has garnered a lot of interest and is one of the most significant renewable energy sources. While several solar technologies have been investigated, dye-sensitized solar cell technology is particularly noteworthy for its affordability and environmental friendliness as a means of supplying the world's growing energy needs. The best materials for DSCs are conductive polymers with excellent transport characteristics found in carbon and its derivative composites[47]. All-solid-state polymer-based electrolytes aid in preventing solvent leaks and the chemical instability of volatile liquid electrolytes. Graphene-based polyvinyl butyral composites were created to encapsulate solar cells and improve performance by raising the cells' conversion efficiency. The composites contained varying amounts of graphene nanoparticles; the same authors investigated the impact of graphene content on the encapsulating material for solar cells. A thermogravimetric analyzer and a thermal conductivity meter were used to measure the thermal stability and conductivity, respectively. It is anticipated that the composite material will be used as a potential encapsulation for solar cells and electronic device cooling. The performance of solar cells can be increased simply by

coating the surface with nanocomposite materials. These materials' antireflection, passivity, and required bandgap all contribute to their enormous potential. Several antireflection nanocomposites, including aluminum isopropoxide, zinc sulfide, carbon nanotubes, tetra-ethoxy silane, and a mixture of aluminum isopropoxide and silver nitrate[48].

14.0 Wind Turbine

Diversification into wind energy has the potential to meet the energy demands of nations worldwide. The type of material utilized determines the wind turbine's efficiency; the lighter the blades, the better the machine performs. Composites and nanocomposites based on polymers appear to be a preferred material and have maintained their high level of attention. This is the result of numerous studies that have been published. The kinetic energy of the wind is transformed into electrical power by a wind turbine. For increased strength, light weight, and corrosion resistance, components like turbine blades, gearboxes, hubs, nacelles, and towers are typically composed of carbon and glass fibers. The drawbacks of synthetic- based composites are their high manufacturing costs, environmental health risks, and non- biodegradability. Utilizing natural fibers as a possible substitute for synthetic ones was the focus[49]. They concluded that natural fiber-based composites have better environmental impact qualities, which makes them a viable material for a number of wind turbine components. By adding nanoparticles, the material's qualities can be further enhanced. The nanoparticles will lessen the likelihood of voids forming, which might cause the composite to break or collapse completely. The characteristics of polymeric materials have been improved in a variety of ways. Adding nanoparticles is one of the most promising strategies. Amazing new materials will be produced when the proper ratio of nanoparticles is included. Outlined the key to creating materials with special and desired qualities, particularly for wind turbines. These qualities include High strength to resist the forces of gravity and wind operating on the blade. The blade's high fatigue resistance allows it to endure cyclic loads. High blade stiffness is necessary to guarantee the stability of the ideal shape.To lessen the gravitational forces pushing on the blade, it should be lightweight[50]. The use of carbon nanotubes to reinforce resin allows for this peculiarity. These are allotropes of carbon that can have a nanostructure with an aspect ratio higher than 106. Because of the nature or type of resin, which affects the final properties of the composites, CNT can be utilized to reinforce different resins for varied property requirements. Author proposed CNT-based polymer nanocomposites based on structural uniqueness and transport properties, among other considerations, because wind turbine blades require materials with mechanical, electrical, thermal, fatigue, and barrier qualities. Author described the consequences of increasing wind energy generation for electrical power in a different study. The anticipated issue pertains to the disposal of the turbine blades, which are essentially composites reinforced with glass fiber. The reuse of discarded wind turbine blades for second-generation turbine blades was examined. A hammer mill was used to first grind up the recycled composite material, then it was impregnated with resin and squeezed to the required thickness. Their findings showed that when resin concentration and particle size grew, so did the mechanical qualities. The study demonstrated that it is possible to use recycled wind turbine blades for second-generation wind turbine blades[51,52].

15.0 Dielectric Substances

An electrical insulator that is polarized by an applied electric field is all that a dielectric substance is. In contrast to electrical conductors, such a substance prevents or hinders the flow of electric charges when it is placed in an electric field. All of the electrons in dielectric materials are tightly bonded to their parent molecules and do not have any free charges. Due to their high specific resistance and negative temperature coefficient of resistance, dielectrics are considered nonmetallic materials. The three phases of matter, solid, liquid, and gas, can all contain dielectric materials; a vacuum is an example of a dielectric material[53]. A study by the author claims that one of the least used materials for this purpose is the dielectric property of chitosan nano-metallic oxide composite films. According to their report, this nanocomposite will be useful in applications such as self-regulating heaters, actuators, sensors, capacitors, and fuel cells. Biocompatible, flexible

materials with adjustable dielectric characteristics may one day be used as artificial muscles in medical procedures. It is anticipated that these special qualities would be crucial to the medical industry's development of so-called "smart skin". According to percolation theory, polymer-based dielectric composites' characteristics are best explained. The dielectric value of the composites will rise as the amount of metal oxides in the polymer matrix gradually increases, according to the hypothesis. We refer to the percolation threshold as the point at which the dielectric value changes rapidly. Percolation value is defined as the amount of material that causes the dielectric value to change quickly. The improvement of nanocomposites' dielectric characteristics depends on the different kinds of polarizations included in the composites. Dielectric polarization is brought on by a small departure from the equilibrium position. The dielectric polarization causes negative charges to be displaced in the opposite direction of the field[54-56].

16.0 Conclusion

Significant progress has recently been made in the creation and use of several polymer-based nanocomposites, particularly in industries like electrical and electronic, automotive, aerospace, and medicine. The usage of polymeric composites, preparation techniques, enhancements to composite materials to make them suitable for energy applications, and application areas in the energy sector were all covered in the study. The following conclusions can be drawn from the study: The materials' overall performance is influenced by the preparation process, and some materials can only be prepared using one or more specialized methods. Adding nanoparticles to nanocomposites changes their characteristics, expanding the range of uses for these materials. As a result of advancements in material science, alternative energy sources derived from sustainable and renewable resources have emerged. The dielectric characteristics will grow with a slow increase in the filler materials in the matrix until the dielectric value quickly changes; this is referred to as the percolation threshold. Materials exhibit a drop in dielectric constant as the frequency increases.

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