Indian Journal of
Advances in Chemical Science

Article

Synthesis, Characterization, Properties, and Applications: A Brief Overview of Polymer Nanocomposites

Fatma Faheem[1]*, Mohd Arsalan[2]

[1]Department of Museology, Aligarh Muslim University, Aligarh, Uttar Pradesh, India, [2]Department of Applied Chemistry, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

ABSTRACT

Polymer nanocomposites (PNC) are made up of a polymer or copolymer with nano particles dispersed throughout the polymer matrix. The polymer nanotechnology group will create techniques that will allow for the patterning of functional surfaces. PNC can be manufactured using one of three methods: *in situ* polymerization, solution, and melt blending processes. The method is chosen based on the type of polymeric matrix, nanofiller, and desired properties for the final products. Because of their promising potential for diverse applications ranging from packaging, remediation, energy storage, electromagnetic absorption, sensing and actuation, transportation and safety, defense systems, thermal flow control, information industry, to novel catalysts, cosmetics, and so on, PNCs have sparked significant research and industrial interest. PNC can also demonstrate novel design possibilities that provide significant advantages in the creation of functional materials with desired properties for specific applications. The ability to use natural resources and the fact that it is environmentally friendly have also opened up new avenues for application. This chapter will review the main topics and recent advances in PNC, such as characterization techniques, manufacturing methods, structures, compatibilization, and applications.

Key words: Environmental friendly, Polymer nanocomposites, Polymeric matrix, Situ polymerization, Specific applications.

1. INTRODUCTION

Polymer nanocomposites (PNC) are simply composites that combine a thermosetting or thermoplastic polymer matrix with a nanomaterial. Due to their promising potential for diverse applications ranging from packaging, remediation, energy storage, electromagnetic (EM) absorption, sensing and actuation, transportation and safety, defense systems, thermal flow control, information industry, to novel catalysts, cosmetics, and so on [1], PNCs have sparked significant research and industrial interest. The polymer composites have excellent mechanical strength and stiffness, as well as corrosion resistance. Fiber-polymer composites are replacing secondary structures with synthetic fibers such as carbon, glass, and kevlar used in polymer composites for aerospace applications. Abstract PNC have piqued the interest of researchers and industry due to their promising potential for a wide range of applications, including packaging, remediation, energy storage, EM absorption, sensing and actuation, transportation and safety, defense systems, thermal flow control, information industry, novel catalysts, cosmetics, and so on. PNC can be made using the following methods [2].

1.1. In Situ Polymerization

In situ polymerization is a very effective method for dispersing carbon-based fillers uniformly in the matrix, resulting in a strong interaction between the matrix and the used filler. It works by combining monomers or pre-polymers with fillers in a good solvent to form a homogeneous mixture, and then polymerization is carried out by adjusting the temperature and time. Material synthesis examples such as carbon black, carbon nano tube, and graphene oxide demonstrate that it is an excellent method for filler dispersion. Because such matrices cannot be dissolved in solvents or fused, this technique is especially important for the preparation of composites with insoluble or thermally unstable polymers as a matrix [3,4].

The *in situ* polymerization process begins with an initiation step and progresses through a series of polymerization steps, resulting in the formation of a hybrid between polymer molecules and nanoparticles. Nanoparticles are first dispersed in a liquid monomer or a precursor with a low molecular weight. Following the formation of a homogeneous mixture, the polymerization reaction is initiated by the addition of an appropriate initiator, which is then exposed to a source of heat, radiation, etc. [5] After the polymerization mechanism is completed, a nanocomposite composed of polymer molecules bound to nanoparticles is formed. Some conditions must be met to perform *in situ* polymerization of precursor polymer molecules to form a polymer nanocomposite, including the use of low viscosity pre-polymers, a short polymerization period, the use of polymers with advantageous mechanical properties, and no formation of side products during the polymerization process [6]. Figure 1 depicts the *in situ* polymerization of nanomaterial synthesis.

1.2. Intercalation of Polymer from Solution

The intercalation method entails the dispersion of nanoplatelets and other types of nanomaterials into the polymer matrix. The nanoplatelets

***Corresponding author:**
Fatma Faheem,
E-mail: fatmafaheem92@gmail.com

ISSN NO: 2320-0898 (p); 2320-0928 (e)
DOI: 10.22607/IJACS.2022.1004009

Received: 15th September 2022;
Revised: 04th December 2022;
Accepted: 06th December 2022

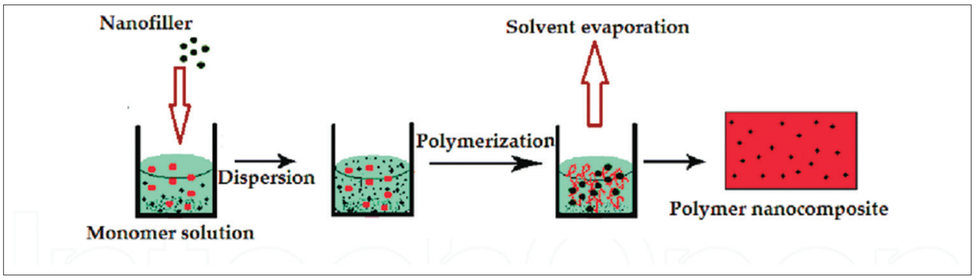

Figure 1: The *in situ* polymerization of nano material synthesis.

swell in monomer solution, and polymer formation takes place between the intercalated sheets through the polymerization method.

The first method used to create polymer clay nanocomposites based on nylon6 [7] was intercalative polymerization. The layered silicate is swollen within the liquid monomer solution in this method, allowing polymer formation between the intercalated sheets. Polymerization can be initiated by heat or radiation, diffusion of a suitable initiator, or an organic initiator or catalyst fixed inside the interlayer prior to swelling. The complete separation of the material's layers is an extreme case of intercalation. Exfoliation is the term for this process. Typically, aggressive conditions involving highly polar solvents and aggressive reagents are required [8]. Figure 2 depicts a schematic representation of the intercalation process.

1.3. Direct Mixing of Polymer and Fillers

A polymer, solvent, and nano-filler are thoroughly mixed by ultrasonication in the direct mixing of polymer and nanoparticulates method, and the solvent is then allowed to evaporate, leaving behind the nanocomposite, which is typically in the form of a thin film. To reduce the cost of polymers, fillers are frequently added. In most cases, such fillers are finely ground inorganic materials like chalk, silica, and clay. The mechanical properties of the material are altered as a result of the presence of filler. As a result, the glass transition temperature of the adsorbed polymer will rise. Solid, liquid, or gas fillers are all possible [9]. They take up space and replace expensive resin with less expensive compounds without affecting other properties. Glass, ceramics, metals, and other materials can be used as fillers in composites. Crystalline silica, silicone dioxide, lithium/barium-aluminum glass, and borosilicate glass containing zinc/strontium/lithium are common glass fillers. Zirconia-silica or zirconium oxide fillers are used in ceramics [10].

Many studies and developments have been conducted on polymer mixing in conjunction with filler (micro and nano) reinforcement. The field is still the subject of research and debate, and innovation is a reflection of its complexity and significance. The treatment received in the mixing process has a significant impact on polymer behavior, affecting downstream operations' productivity, and the service performance of end products. Filler incorporation in polymers consists of three steps: encapsulation, subdivision, and immobilization [11].

1.4. Melt Intercalation

Melt intercalation is the most common method for creating thermo-plastic PNC. It entails annealing the polymer matrix at high temperatures, then adding the filler and kneading the composite to achieve a uniform distribution. The melt mixing process involves mechanically dispersing nanoparticles in the polymer matrix while it is molten. Because it is based on traditional polymer processing methods, this method provides greater ease of preparation [12]. Using a banbury or an extruder, the polymer is typically melted and combined with the desired amount of intercalated clay. Melt blending is done with an

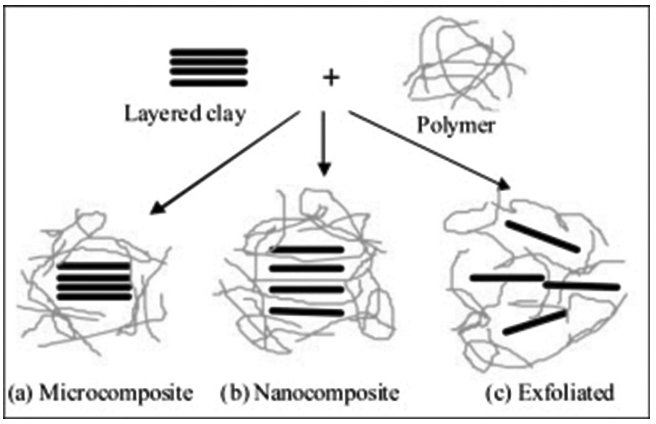

Figure 2: The schematic representation of intercalation process.

inert gas such as argon, nitrogen, or neon present. Alternatively, the polymer and intercalant can be dry mixed before being heated in a mixer and subjected to sufficient shear to form the desired clay PNC. Melt blending outperforms *in situ* intercalative polymerization and polymer solution intercalation. Because organic solvents are not used in melt blending, it is environmentally friendly. Melt blending works with existing industrial processes like extrusion and injection molding. The melt blending process has gained popularity due to its potential in industrial applications [13]. Figure 3: Depicts the melt intercalation process for the preparation of nanocomposite.

1.5. Template Synthesis

A template reaction in chemistry is any of a group of ligand-based reactions that occur between two or more adjacent coordination sites on a metal center. The same organic reactants produce different products in the absence of the metal ion. The term is most commonly found in coordination chemistry. The method of preparing nanofibers within the pores of a microporous membrane or other solid is known as template synthesis. The microporous membrane, also known as a template, is pre-configured to produce the desired nanofiber morphology. A metal oxide (MO) or polymer template with cylindrical pores of uniform diameter is typically used in the synthesis process [14].

The template can be placed directly onto a current collector in one method. The nanoscale cylindrical pores are typically filled with material through a variety of processes such as sol-gel, electrodeposition, or chemical vapor deposition, among others. The template is removed after the nanofibers have formed; leaving the nanofibers adhered to the current collector. Another method is to extrude a polymer solution through the template using applied pressure [15]. When a precursor fiber solution passes through the pores, it comes into contact with a solidifying solution, which causes it to retain a cylindrical structure. It appears to be similar to an extrusion process. Figure 4 depicts the template method of nonmaterial synthesis.

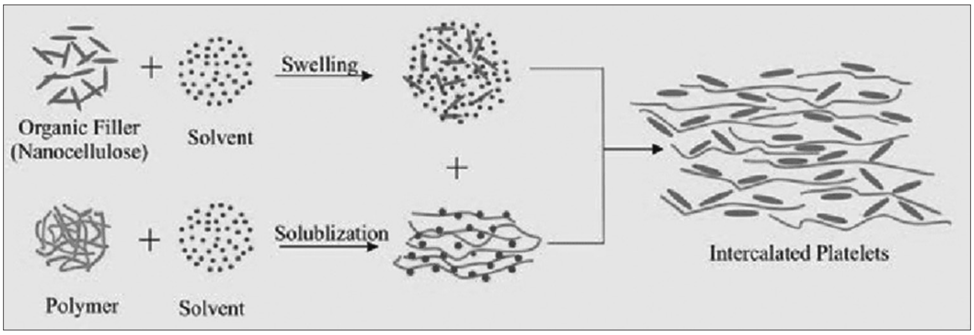

Figure 3: Melt intercalation process for preparation of nanocomposite.

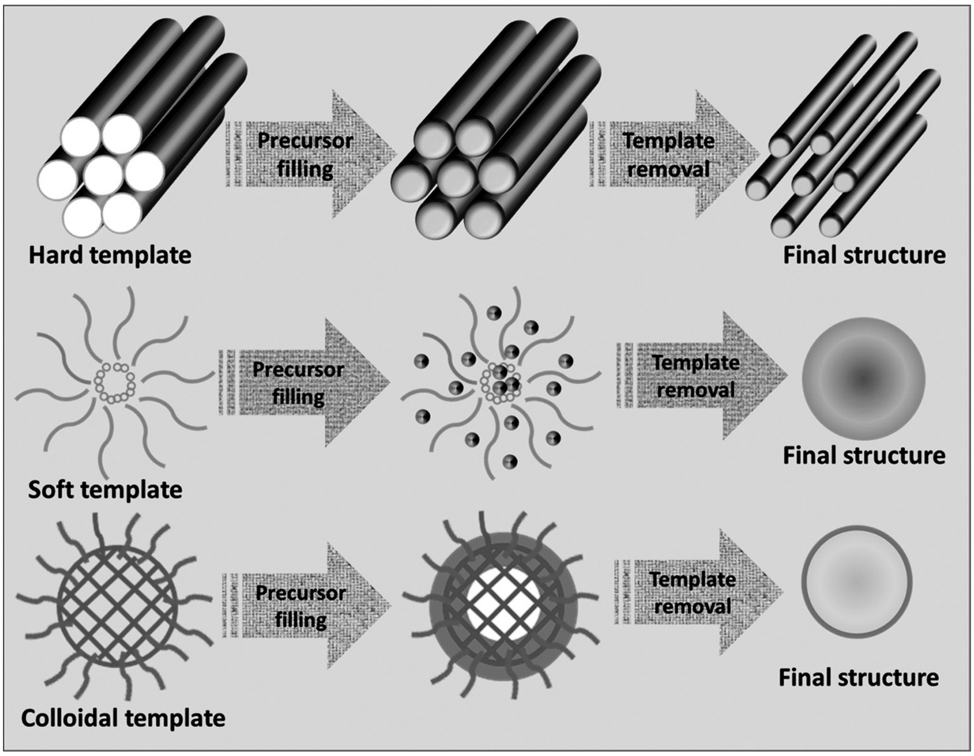

Figure 4: The template method of nonmaterial synthesis.

1.6. Sol-Gel Process

The sol-gel process is a novel approach to the development of new materials. This method allows for greater control over the entire process of solid synthesis. Homogeneous multi-component systems, particularly homogeneous mixed oxides, are easily obtained by mixing the molecular precursor solutions. The sol-gel process is a more chemical (wet chemical) method for producing various nanostructures, particularly MO nanoparticles. In this method, the molecular precursor (usually a metal alkoxide) is dissolved in water or alcohol and then heated and stirred to form a gel through hydrolysis/alcoholysis. In material science, a sol-gel process is a colloidal method for producing porous solid materials (ceramics) from small molecules such as metal alkoxides, nitrides, or sulfides [16,17]. The following Figure 5 depicts the sol-gel process of nanomaterial synthesis.

During this chemical procedure, a "sol" is formed, which gradually evolves into a gel-like diphasic system containing both a liquid phase and a solid phase with morphologies ranging from discrete particles to continuous polymer networks. In the case of the colloid, the particle volume fraction may be so low that a significant amount of fluid must be removed initially in order for the gel-like properties to be recognized. This can be done in a variety of ways. Allowing time for sedimentation and then pouring off the remaining liquid is the simplest method. Centrifugation can also be used to speed up the phase separation process [18].

2. CHARACTERIZATION OF PNC

Various sophisticated techniques were used to characterize the synthesized membranes, revealing the morphology, crystallographic structure, physical properties, presence of groups and bonds in materials, weight loss by materials, and exothermic or endothermic nature of materials, among other things. These are the techniques:

1. Transmission Electron Microscopy (TEM)
2. Scanning Electron Microscopy
3. Fourier Transform Infrared Spectroscopy (FTIR)
4. X-ray Diffraction Analysis
5. Thermo Gravimetric Analysis (TGA)
6. Differential Thermal Analysis (DTA).

2.1. TEM

TEM is a microscopy technique in which a beam of electrons is transmitted through an ultra-thin specimen, interacting with the

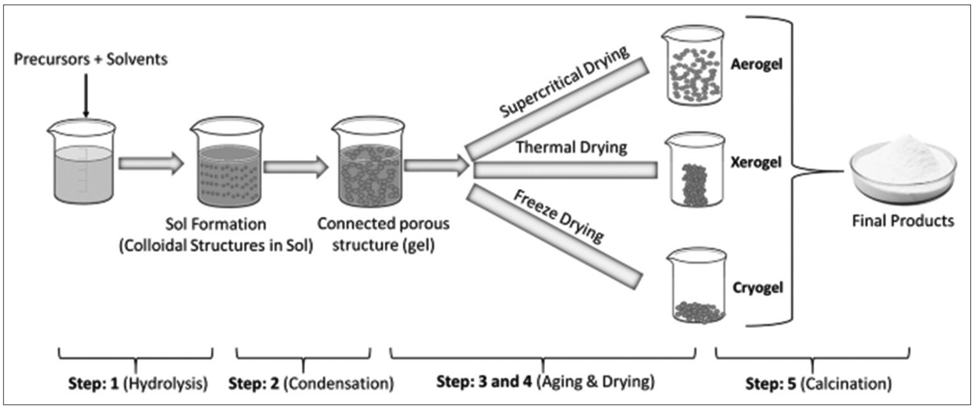

Figure 5: Indicated the sol-gel process of nanomaterial synthesis.

specimen as it passes through. An image is formed from the interaction of the electrons transmitted through the specimen. 1EMs are capable of imaging at a significantly higher resolution than light microscopes. TEM forms a major analysis method in a range of scientific fields, in both physical and biological sciences. TEM analysis was performed with ultra-high resolution optics for characterization which provides maximum performance and productivity for biological and material sciences applications. The first TEM was built by Max Knoll and Ernst Ruska in 1931 [19].

2.2. Scanning Electron Microscopy

SEM is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and contain information about the sample's surface topography and composition. Specimens can be observed in high vacuum, in low vacuum, in wet conditions (in environmental SEM), and at a wide range of cryogenic or elevated temperatures [20]. SEM characterization was performed at an accelerating voltage of 20 kV. The sample was mounted on a copper stub and sputter coated with gold to minimize the charging. This technique is used to identify the morphology, topography, surface defects, inclusions etc. It was Manfred von Ardenne who in 1937 invented a true microscope with high magnification by scanning a very small raster with a demagnified and finely focused electron beam.

2.3. FTIR

FTIR is a technique which is used to obtain an infrared spectrum of absorption, emission, photoconductivity or Raman scattering of a solid, liquid and gas. An FTIR spectrometer simultaneously collects high spectral resolution data over a wide spectral range. The first low cost spectrophotometer capable of recording an infrared spectrum was the Perkin-Elmer Infracord produced in 1957. This instrument covered the wavelength range from 2.5 μm to 15 μm. The sample compartment of a particular model is 200 mm wide, 290 mm deep, and 255 mm high, the entrance and exit beam of sample chamber is sealed with a coated KBr window and there is a hinged cover used to seal it from the external environment [21,22].

2.4. X-Ray Diffraction Analysis

X-ray crystallography is a tool used for identifying the atomic and molecular structure of a crystal, in which the crystalline atoms cause a beam of incident X-rays to diffract into many directions. By measuring the angles and intensities of these diffracted beams, a crystallographer can produce a three-dimensional picture of the density of electrons within the crystal. From this electron density, the mean positions of the atoms in the crystal can be determined, as well as their chemical bonds, their disorder and various other informations also. X-ray crystallography is still the chief method for characterizing the atomic structure of new materials [23].

2.5. TGA

TGA is a method of thermal analysis in which changes in physical and chemical properties of materials are measured as a function of increasing temperature or as a function of time. TOA can provide information about physical phenomena, such as second-order phase transitions, including vaporization, sublimation, absorption, adsorption, and desorption. TOA is commonly used to determine selected characteristics of materials that exhibit either mass loss or gain due to decomposition, oxidation, or loss of volatiles [24].

2.6. DTA

DTA is a thermoanalytical technique, similar to differential scanning calorimetry. In DTA, the material under study and an inert reference are made to undergo identical thermal cycles, while recording any temperature difference between sample and reference. Changes in the sample, either exothermic or endothermic, can be detected relative to the inert reference. Thus, a DTA curve provides data on the transformations that have occurred, such as glass transitions, crystallization, melting and sublimation [25].

3. APPLICATIONS OF PNC

Nanocomposites are composites in which nanofillers have been dispersed in a polymer. For defining nanofillers and nanocomposites, there is no single universally accepted criterion. Composites provide properties and performance characteristics such as increased stiffness, strength, impact resistance, heat resistance, abrasion and wear resistance, and gas barrier that the matrix polymer cannot achieve in the absence of inclusions [22,26]. Depending on the application, a composite may be designed to exhibit such improvements isotropically or anisotropically. Figure 6 depicts some of the most important applications of PNC.

3.1. PNC for Environmental Remediation

Polymer-based nanocomposites could be used as alternative superadsorbents for removing hazardous substances from water and wastewater. In general, most adsorption studies still use a single-component system with a synthetic solution as the wastewater representative. It summarizes recent advances in the development of materials' properties, fabrication methods, and applications for contaminant treatment, pollutant sensing, and detection [23]. It provides critical, actionable guidelines for the design of nanocomposites'

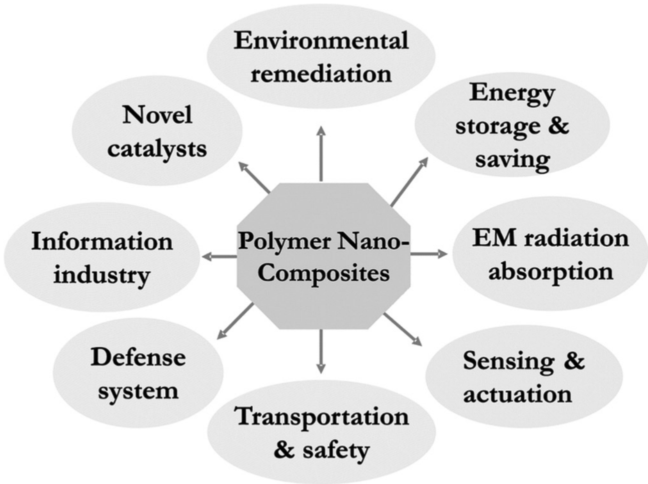

Figure 6: Indicated the some important applications of PNC.

structure and properties in environmental remediation. PNC focuses on bringing technology out of the lab and into the real world by summarizing the most recent developments in PNC and their applications in catalytic degradation, adsorptive removal, and contaminant detection in the environment. Environmentalists and scientists are concerned about organic and inorganic contaminants polluting the world's water resources. As a result, water treatment to remove these contaminants is required. Adsorption decontamination of water has significant advantages over other water treatment methods in this context. Bio-adsorption or sorption techniques based on the use of biologically derived materials, such as a biopolymer, are the most environmentally friendly, and effective solution for heavy metal remediation. Nanocomposites are organic-inorganic hybrid materials that are effective in water adsorptive decontamination. The property enhancement observed in PNC when compared to traditional composites is due to the nano-scale dispersion of some of the components [27].

3.2. Energy Storage and Savings

The utility of polymer-based nanocomposites in energy storage and savings is quite diverse, and they have been proposed for use in a variety of applications. The electronic conductive polymer-based nanocomposite material is an important subclass of PNC. These novel conducting polymer-based composites have sparked a lot of interest and excitement as a material for energy storage applications. Although nanocomposites and polymer materials are being developed for energy storage, inherent limitations in their dielectric properties (e.g., breakdown field and dielectric constant) prevent them from being used for high energy density applications. As a result, composite systems of nanocomposite and polymers have grown in popularity because they have the potential to simultaneously improve the dielectric constant and breakdown field, resulting in significant improvements in energy storage potential [28].

Chemical sensors, electroluminescent devices, electro catalysis, batteries, smart windows, and memory devices all use them. The comfort of processing, configuration adaptability, lightweight, and flexibility according to requirements are important characteristics of these PNC. Fuel cells and supercapacitors are expected to be critical components in updating the prospect of renewable energy schemes for energy storage. The demand for low-cost devices with high energy and power density leads to the development of novel polymer nanocomposite materials for automotive and electric energy storage applications. Energy storage methods necessitate distinct, paramount, and authentic approaches to the storage of electric power by alternate renewable sources to ensure appropriate and dependable devices that can store a sufficient amount of energy and later be used for transportation, electronic devices, electric-powered carriers, and various purposes [29]. Super capacitors, various types of batteries, and fuel cells are examples of electrochemical energy storage operations. Probes, electrolyte media, and a power receiver are typically used in electrochemical storage methods. These ingredients are made up of PNCs, MOs, and conducting substances.

3.3. EM Radiation Absorption

EM pollution causes data loss, signal disruption, system failures, and, most importantly, poses a serious threat to information communication security and human health. Because of the increased use of these EM devices, EM wave radiation has become a serious concern, as these radiations are not only harmful to electronic equipment but also to human health. Human exposure to EM fields is becoming more common and unavoidable as technology advances [30]. EM waves are not deflected by any magnetic or electric field, resulting in serious problems. EM waves cause harm in a variety of ways, including changes in physiological indices, genetic effects, health, and immune functions. The negative effects are becoming more severe over time, necessitating immediate attention.

As a result, the new generation of absorbing materials should have small thickness, light weight, a broad absorption frequency range, and strong EM wave absorption characteristics. Many polymer-based nanomaterials have been shown in recent years to have excellent radiation-absorbing properties. Furthermore, many studies have shown that most nanocomposites have synergistic effects, which will be very beneficial to the materials' absorbing properties [31,32]. PNC is a semi-crystalline material with good piezoelectric properties that has been widely studied and applied as a composite matrix in the field of wave absorption.

3.4. Sensing and Actuation

Sensors are used in a wide range of industries for a variety of purposes. They are used in both every day and more industrial applications. Sensors are used in a wide variety of applications, including motorsport, agriculture, medicine, industrial, aerospace, and agriculture. Sensors can help to improve the world by improving diagnostics in medical applications, the performance of energy sources such as fuel cells, batteries, and solar power, people's health and safety and security, sensors for exploring space, and improved environmental monitoring. Sensors and actuators track different signals, work in different ways, and must collaborate to complete a task. They are also physically separated and frequently used in separate applications. While sensors are in charge of tracking data that enter a machine, actuators take action [33].

Because of the numerous potential applications of conducting polymers, these materials are now being studied all over the world, particularly in the field of sensing. Conducting polymers are extremely sensitive to environmental conditions. Nanostructure conducting polymers and conducting PNC have had a significant impact on sensor research. Because of the high surface-area-to-volume ratio of nanostructure conducting polymers, they outperform bulk conducting polymers. Because of the synergistic effect of size reduction for nanofiller and high electrical conductivity of conducting polymer in nanocomposites, conducting PNC have gained tremendous recognition in the field of sensors to improve sensitivity and selectivity. The electrical conductance of polymer nanocomposite is demonstrated to be governed by conductive filler networks within the polymer matrix. As a result, minor variations in the conductive networks can result in significant variations in the output electric signal of a polymer nanocomposite [34]. In comparison to most commercially available

MO-based gas sensors, polymer-based nanocomposites gas sensors are more sensitive, have a shorter response time at room temperature, and can tune both chemical and physical properties by using different substituents. As a result, it appears that PNCs have a wide range of applications in sensing and actuation.

3.5. Transportation and Safety

Polymer materials are widely used in many aerospace applications due to their many engineering designable advantages such as specific strength properties with weight savings of 20–40%, the ability to meet stringent dimensional stability, lower thermal expansion properties, and excellent fatigue and fracture resistance over other materials such as metals and ceramics. The current global transportation industry expectation is to reduce fuel consumption and thus global warming. It increases the demand for new materials and manufacturing methods in the transportation sector. PNC are a novel class of materials with superior mechanical, thermal, and manufacturing properties. The applications, fabrication routes, and performance of nanocomposites used in the automotive and aerospace fields have received special attention [35]. PNC are widely used in many aerospace applications due to their many engineering designable advantages, such as specific strength properties with weight savings of 20–40%, the ability to meet stringent dimensional stability, lower thermal expansion properties, and excellent. Polymer matrix composites have numerous applications in the automotive, aerospace, and marine industries.

3.6. Automotive Vehicles

Tires and various belts and hoses, as well as polymer matrix composite components in automotive bodies, are examples of polymer matrix composite applications. Carbon fiber reinforced polymer matrix composite is the primary material used in the construction of the body of some very expensive sports cars, such as Bugatti. It is also worth noting that the first polymer matrix nanocomposite used in a commercial product was a timing belt cover for the Toyota Camry in 1993. This breakthrough was followed by other applications such as bumpers, body panels, engine parts, fuel tanks, and mirror housings over the years [36]. By now, the technology has advanced to reduce tyre rolling resistance and to provide ultra-hard protective coatings for paintwork, windscreen glass, and headlamps.

3.7. Aerospace Vehicles

Polymer matrix composites are also used in the manufacture of aircraft tyres and interiors. However, the ability of polymer matrix composites to help satisfy the aerospace industry's relentless drive to improve performance while reducing weight is far more valuable. Most importantly, fiber-reinforced polymer matrix composites can be optimized to combine high strength, stiffness, and toughness with low density, resulting in exceptional strength-to-density and stiffness-to-density ratios as well as superior physical properties, making them a popular structural material for use in aircraft components [37].

3.8. Marine Vehicles

Polymer matrix composites have numerous applications in marine vehicles. Fiberglass boats are among the most well-known examples because fiberglass is a composite made up of a matrix polymer reinforced by glass fibers that can be arranged randomly, as a chopped strand mat, or as a woven fabric. A growing trend in boatbuilding is the use of lighter, stiffer, and stronger carbon fibers instead of glass fibers [38].

3.9. Defense System

PNC have a number of potential benefits, but it appears that this application area is still understudied. Because of their higher hardness combined with improved elastic modulus, PNC have improved scratch and abrasion resistance. Smart materials, harder/lighter platforms, new fuel sources and storage, and novel medical applications are all examples of PNC. Over the last few decades, the field of PNC has become critical for engineering and military industries as it applies to computing, sensors, biomedical microelectronics, hard coating, and many other domains [39]. Polymer nanocomposite materials have recently been developed and now have a wide range of applications due to their outstanding mechanical and thermal properties. PNC for advanced engineering and military applications present recent advances in fabrication methods, properties, and applications of various nano-fillers, including surface-modification methods and chemical functionalization.

3.10. Information Industry

PNC are introduced as a material class with exceptional properties. As a result, analyzing the intercalation process between nanoparticles and polymer bases is critical for achieving desirable mechanical, thermal, optical, and electrical properties. Cell phones emit low frequency magnetic fields measured in milli gauss as well as high frequency microwave radiation. Shielding products for magnetic fields and microwaves for cell phones are available on the market and widely used. Most should be flexible, light, environmentally friendly, and simple to manufacture and chip. PNCs are an excellent material for this application because they can sense the entire requirement [40].

3.11. Novel Catalysts

Nanocomposites are materials that combine nanosized particles with a standard material matrix. The addition of nanoparticles results in a significant improvement in properties such as mechanical strength, toughness, and electrical or thermal conductivity [41]. The use of polymer substrates for the immobilization of active catalyst particles is motivated by a number of advantages, including environmental stability, chemical inertness and resistance to ultraviolet radiations, mechanical stability, low prices, and ease of availability. Furthermore, the use of PNC as photocatalysts allows for easy separation and reuse of the materials, eliminating the need for post-treatment separation processes, and implicitly lowering the procedure's costs [42].

Because polymer-nanoparticle composites are promising photocatalytic candidates, the adaptability of polymers as supports for active photocatalytic nanoparticles has been emphasized, implying that, in addition to the benefits listed above, they could also provide resistance to ultraviolet radiations or other environmental processes, high durability and stability, chemical inertness, and easy availability. Furthermore, the polymers facilitate the adsorption of the target organic molecules on their surfaces, improving the materials' photocatalytic performance. Photocatalysis can be used for a wide range of reactions, from the mineralization of organic pollutants to fine organic processes, with the main advantage being the direct conversion of light energy into chemical energy, which reduces energy consumption or provides a green, low-cost approach to combating environmental pollution. As a result, photocatalysis meets some of the requirements for sustainable chemistry and green organic synthesis. So far, semiconductor materials have been the most widely used in photocatalysis [43].

3.12. Medical Devices

Polymers and composites are critical components in a wide range of medical devices and applications. Some examples of these applications are given below. For a more in-depth discussion, see polymers and composites in the medical device industry. Polymer matrix composites are found in a variety of medical devices, including MRI scanners, C scanners, X-ray couches, mammography plates, tables, surgical target tools, wheelchairs, and prosthetics. Polymer matrix nanocomposites containing carbon nanotubes or TiO_2 nanotubes accelerate bone healing by acting as a “scaffold” that directs the growth of replacement bone [44]. The potential applications of nanocomposites in diagnostics and therapy are being investigated. For example, combining magnetic nanoparticles and fluorescent nanoparticles in nanocomposite particles that are both magnetic and fluorescent appears to make a tumor easier to see during pre-surgery MRI tests and may also help the surgeon see the tumor better during surgery [45].

4. CONCLUSION

The PNC are created from a combination of inorganic nanomaterials and organic polymers, and they have properties that are representative of both components, according to the researchers. They are also referred to as hybrid materials. The interaction of nanoparticles with polymer molecules is truly molecular in nature. These nanocomposites could be made using three different techniques: *in situ* polymerization, solution casting, and melt extrusion. The relationship and route to the polymer-nanoparticle pair determine the best method. Nanocomposites are materials that combine nanosized particles with a standard material matrix. The addition of nanoparticles results in a significant improvement in properties such as mechanical strength, toughness, and electrical or thermal conductivity. Automobiles, aerospace, injection molded products, coatings, adhesives, fire retardants, packaging materials, microelectronic packaging, optical integrated circuits, drug delivery, sensors, membranes, medical devices, consumer goods, and so on. PNC can also demonstrate novel design possibilities that provide significant advantages in the creation of functional materials with desired properties for specific applications. The ability to use natural resources and the fact that it is environmentally friendly have also opened up new avenues for application.

5. ACKNOWLEDGMENT

I extend my sincere thanks to Chairman, Department of Museology, Aligarh Muslim University, for encouraging and supporting me to come forward and explore for the best. I am also thankful to the Department of Applied Chemistry for providing me with the required facility to complete this review study.

6. REFERENCES

1. Y. Lin, A. Boker, J. He, K. Sill, H Xiang, C. Abetz, X. Li, J. Wang, T. Emrick, S. Long, Q. Wang, A. Balazas, T. P. Russel, (2005) Self-directed self-assembly of nanoparticle/copolymer mixtures. *Nature*, **434(7029)**: 55-59.
2. M. Q. Zhnag, G. Yu, H. M. Zeng, H. B. Zhang, Y. H. Hou, (1998) Two step percolation in polymer blends filled with carbon black. ***Macromolecules***, **31:** 6724-6726.
3. M. J. Adams, A. Allan, B. J. Briscoe, P. J. Doyle, D. M. Gorman, S. A. Johnson, (2001) An experimental study of the nano-scratch behaviour of poly (methyl methacrylate). ***Wear***, **251:** 1579-1583.
4. B. P. Costello, R. J. Ewen, N. M. Ratcliffe, M. Richards, (2008) Highly sensitive room temperature sensors based on the UV-LED activation of zinc oxide nanoparticles. ***Sensors Actuators B Chemical***, **134(2)**: 945-952.
5. H. S. Choe, J. Giaccai, M. Alamgir, K. M. Abraham, (1995) Preparation and characterization of poly(vinyl sulfone)-and poly(vinylidene fluoride)-based electrolytes. ***Electrochimica Acta***, **40(13-14)**: 2289-2293.
6. K. Drexler, (1986) ***Eric Engines of Creation: The Coming Era of Nanotechnology***, New York: Doubleday.
7. S. Gullapalli, M. S. Wong, (2011) Nanotechnology: A guide to nano-objects. ***Chemical Engineering Progress***, **107(5)**: 28-32.
8. O. Kamigaito, (1991) What can be improved by nanometer composites. ***Journal of the Japan Society of Powder and Powder Metallurgy***, **38(3)**: 315-321.
9. A. P. Mouritz, A. G. Gibson, (2006) ***Fire Properties of Polymer Composite Materials Pub***, Berlin: Springer.
10. T. R. Hull, B. K. Kandola, (2009) ***Fire Retardancy of Polymers: New Strategies and Mechanisms***, Cambridge, United Kingdom: RSC.
11. M. Baibarac, P. Gomez-Romero, (2006) Nanocomposites based on conducting polymers and carbon nanotubes: From fancy materials to functional applications. ***J Nanosci Nanotechnol***, **6:** 289.
12. N. K. Kothurkar, (2004) ***Solid State, Transparent, Cadmium Sulfide-Polymer Nanocomposite***. Florida: University of Florida.
13. R. Gangopadhyay, A. De, (2000), Conducting polymer nanocomposites: A brief overview. ***Chemistry of Materials***, **12(3)**: 608-622.
14. A. C. Balazs, T. Emrick, T. P. Russell, (2006), Nanoparticle polymer composites: Where two small worlds meet. ***Science***, **314(5802)**: 1107-1110.
15. K. Sanada, Y. Tada, Y. Shindo, (2009) Thermal conductivity of polymer composites with close-packed structure of nano and micro fillers. ***Composites Part A Applied Science and Manufacturing***, **40(6-7)**: 724-730.
16. J. Cho, M. S. Joshi, C. T. Sun, (2006) Effect of inclusion size on mechanical properties of polymeric composites with micro and nano particles. ***Composites Science and Technology***, **66(13)**: 1941-1952.
17. Y. Hong, Y. Li, F. Wang, B. Zuo, X. Wang, L. Zhang, D. Kawaguchi, K. Tanaka, (2018) Enhanced thermal stability of polystyrene by interfacial noncovalent interactions. ***Macromolecules***, **51(15)**: 5620-5627.
18. N. Jiang, J. Shang, X. Di, M. K. Endoh, T. Koga, (2014) Formation mechanism of high-density, flattened polymer nanolayers adsorbed on planar solids. ***Macromolecules***, **47(8)**: 2682-2689.
19. P. Gin, N. Jiang, C. Liang, T. Taniguchi, B. Akgun, S. K. Satija, M. K. Endoh, T. Koga, (2012) Revealed architectures of adsorbed polymer chains at solid-polymer melt interfaces. ***Physical Review Letters***, **109(26)**: 265501.
20. N. Jiang, L. Sendogdular, X. Di, M. Sen, P. Gin, M. K. Endoh, T. Koga, B. Akgun, M. Dimitriou, S. Satija, (2015) Effect of CO2 on a mobility gradient of polymer chains near an impenetrable solid. ***Macromolecules***, **48(6)**: 1795-1803.
21. N. Jiang, J. Wang, X. Di, J. Cheung, W. Zeng, M. K. Endoh, T. Koga, S. K. Satija, (2016) Nanoscale adsorbed structures as a robust approach for tailoring polymer film stability. ***Soft Matter***, **12(6)**: 1801-1809.
22. E. M. Masoud, (2016) Nano lithium aluminate filler incorporating gel lithium triflate polymer composite: Preparation, characterization and application as an electrolyte in lithium ion batteries. ***Polymer Testing***, **56:** 65-73.
23. E. M. Masoud, M. E. Hassan, S. E. Wahdaan, S. R. Elsayed, S. A. Elsayed, (2016) Gel P (VdF/HFP)/PVAc/lithium hexafluorophosphate composite electrolyte containing nano ZnO filler for lithium ion batteries application: Effect of nano filler concentration on structure, thermal stability and transport properties. ***Polymer Testing***, **56:** 277-286.
24. E. M. Masoud, A. A. El-Bellihi, W. A. Bayoumy, E. A. Mohamed, (2018) Polymer composite containing nano magnesium oxide filler and lithiumtriflate salt: An efficient polymer electrolyte for lithium ion batteries application. ***Journal of Molecular Liquids***, **260:** 237-244.

25. E. M. Masoud, (2019) Montmorillonite incorporated polymethylmethacrylate matrix containing lithium trifluoromethanesulphonate (LTF) salt: Thermally stable polymer nanocomposite electrolyte for lithium-ion batteries application. ***Ionics***, **25:** 2645-2656.
26. E. M. Masoud, A. A. El-Bellihi, W. A. Bayoumy, M. A. Mousa, (2013) Effect of LiAlO2 nanoparticle filler concentration on the electrical properties of PEO-$LiClO_4$ composite. ***Materials Research Bulletin***, **48(3)**: 1148-1154.
27. P. Aramwit, (2016) Introduction to biomaterials for wound healing. In: ***Wound Healing Biomaterials***, Netherlands: Elsevier, p3-38.
28. D. Hritcu, M. I. Popa, N. Popa, V. Badescu, V. Balan, (2009) Preparation and characterization of magnetic chitosan nanospheres. ***Turkish Journal of Chemistry***, **33:** 785-796.
29. N. M. Salem, A. M. Awwad, (2013) A novel approach for synthesis magnetite nanoparticles at ambient temperature. ***Nanoscience and Nanotechnology***, **3(3)**: 35-39.
30. A. I. Sherlala, A. A. Raman, M. M. Bello, A. Asghar, (2018) A review of the applications of organo-functionalized magnetic graphene oxide nanocomposites for heavy metal adsorption. ***Chemosphere***, **193:** 1004-1017.
31. K. C. Wu, S. H. Liao, C. H. Liu, B. P. Bastakoti, N. Suzuki, Y. Chang, Y. Yamauchi, F. H. Lin, (2015) Functionalized magnetic iron oxide/alginate core-shell nanoparticles for targeting hyperthermia. ***International Journal of Nanomedicine***, **10:** 3315-3327.
32. L. Yang, J. Tian, J. Meng, R. Zhao, C. Li, J. Ma, T. Jin, (2018), Modification and characterization of Fe3O4 nanoparticles for use in adsorption of alkaloids. ***Molecules***, **23(3)**: 562.
33. C. Li, J. Lu, S. Li, Y. Tong, and B. Ye, (2017) Synthesis of magnetic microspheres with sodium alginate and activated carbon for removal of methylene blue. ***Materials*** **(*Basel*)**, **10(1)**: 1-84.
34. J. A. Lopez, F. González, F. A. Bonilla, G. Zambrano, M. E. Gómez, (2010) Synthesis and characterization of Fe_3O_4 magnetic nano fluid. ***Revista Latinoamericana De Metalurgia y Materiales***, **30(1)**: 60-66.
35. M. Lee, (2016) ***X-ray Diffraction for Materials Research: From Fundamentals to Applications***, New Jersey: Apple Academic Press.
36. M. R. Lasheen, I. Y. El-Sherif, M. E. Tawfik, S. T. El-Wakeel, M. F. El-Shahat, (2016) Preparation and adsorption properties of nano magnetite chitosan films for heavy metal ions from aqueous solution. ***Materials Research Bulletin***, **80**, 344-350.
37. A. Patil, M. S. Ferritto, (2013) Polymers for personal care and cosmetics: Overview. In: ***ACS Symposium Series***, Washington, DC: American Chemical Society.
38. Z. G. Gong, (2013), Nanotechnology application in sports. ***Advanced Materials Research***, **662:** 186-189.
39. R. J. Young, M. Liu, (2016), The microstructure of a graphene-reinforced tennis racquet. ***Journal of Materials Science***, **51:** 3861-3867.
40. A. Seeboth, R. Ruhmann, O. Mühling, (2010) Thermotropic and thermochromic polymer based materials for adaptive solar control. ***Materials*** **(*Basel*)**, **3(12)**: 5143-5168.
41. G. C. Psarras, (2016) Energy materials, the role of polymers. ***Polymer Letters***, **10:** 7-21.
42. E. P. Giannelis, R. Krishnamoorti, E. Manias, (1999) Polymer-silicate nanocomposites: Model systems for confined polymers and polymer brushes. ***Advances in Polymer Science***, **138:** 108-147.
43. L. Wang, D. Zhao, Z. Su, D. Shen, (2012) Hybrid polymer/ZnO solar cells sensitized by PbS quantum dots. ***Nanoscale Research Letters***, **7(1)**: 106.
44. C. A. Stergiou, A. Z. Stimoniaris, C. G. Delides, (2015) Hybrid nanocomposites with organoclay and carbon-based fillers for EMI suppression. ***IEEE Transactions on Electromagnetic Compatibility***, **57(3)**: 470-476.
45. M. Lyu, T. G. Choi, (2015) Research trends in polymer materials for use in lightweight vehicles. ***International Journal of Precision Engineering and Manufacturing***, **16:** 213-220.

***Bibliographical Sketch**

Dr Fatma Faheem has completed Ph.D. from the Department of Museology, Aligarh Muslim University, Aligarh, India. She was actively involved in Research work (Museology and Conservation) from Feb 2014 to the present date. She has several research papers that has been published in reputed journals. She is also an active author in the “Countercurrents” and “Twocircles” newsletters, an Indian writer forum. She has participated in many oral presentations at national and international conferences. She has received the “Best Paper and Oral Presentation Award” for my research papers.