POLYMER NANOCOMPOSITES: RECENT RESEARCH ADVANCES AND ADVANCED APPLICATIONS

Abstract

Materials containing two or more constituents that have distinctly different chemical and physical properties are referred to as composites. When polymers and other organic or inorganic components are mixed at the nanometric scale, they form the heterogeneous hybrid materials known as nanocomposites. The process of developing and polymerizing in situ biopolymers and inorganic matrixes is the one most frequently used to create nanocomposites. Because of their adaptable shape, significant specific surface area, and simplicity of functionalization, polymer nanocomposites are frequently employed. As per their scattered “dispersed phase” and “matrix phase” components, nanocomposites can be categorized. In addition to their many other applications, multi-functional hybrid materials have shown tremendous promise in the fields of optics, sensors, environmental cleanup, electronics, catalysis, soft robotics, storage, energy transformation, mechanics, electromagnetic interface shielding and drug delivery. This study focuses on describing recent advancements in preparation and structure characterized using different techniques, as well as the distinctive characteristics and applications of diverse polymeric nanocomposites.

Keywords: Nanocomposites, Polymer nanocomposties, Electrical properties, Mechanical Properties.

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I. INTRODUCTION

There is a lot of research interest in using nanomaterials in polymer matrices to create heterogeneous materials with distinct characteristics and enhanced performance. Polymer nanocomposites as a concept first emerged in the 20th century and have swiftly evolved alongside developments in nanotechnology and nanoscience [1-3]. Materials that contain two or more elements with noticeably differing chemical and physical properties are known as nanocomposites. While the term "hybrid" typically refers to materials that are molecular or at the nanoscale, nanocomposites include a wider range of component dimensions. For the best performance in a variety of applications, including coatings, sensing, energy harvesting and storage, magnetism, and packaging, they have been designed, synthesized, and customized. Every aspect of our everyday lives has been greatly impacted by the revolution of new composites technology [4]. On the ground of matrix material, composites can be classified as carbon composites, polymer composites metal composites and ceramic composites. The most common types of nanofillers include three-dimensional porous nanofillers, metal nanoparticles and oxides, and carbon-based compounds [5,6]. The most prevalent carbon compounds with "high aspect ratio, thermal conductivity, electrical conductivity and mechanical stability" are graphene (GPE) and carbon nanotubes (CNTs). [7, 8]. Both natural and artificial polymers are available. The polymers that can be produced and used naturally are known as natural polymers. Silk, wool, DNA, cellulose, and proteins are examples of water-based natural polymers [9]. Conversely, synthetic polymers like Teflon, epoxy, polyethylene, nylon, and so forth. When separate components function independently, polymer nanocomposites are unable to achieve their unique synergistic features [10]. In the synthesis of polymer nanocomposites with better properties for a particular application, inorganic nano-fillers such as nano-clays, metaloxide nanoparticles, carbon nanomaterials, and metal nanoparticles can be mixed with a polymer matrix [11,12]. Due to their wide range of uses in environmental rectification and the treatment of many environmental problems, polymer nanocomposites have become more well-known in science [13]. This review's objective is to provide a thorough analysis of the current status of polymeric nanocomposites used as material for water remediation throughout the world. It does this by examining different polymer nanocomposites classifications, cutting-edge synthetic techniques, uses, benefits, drawbacks, and potentials. The review's search terms include "polymeric material," "polymer nanocomposite," "adsorbent," "photocatalyst," "organic pollutant," "heavy metal," "photocatalytic degradation," "adsorption," and "water treatment," and it is based on papers and books that have been published in SCOPUS and Web of Science.

II. COMPOSITES

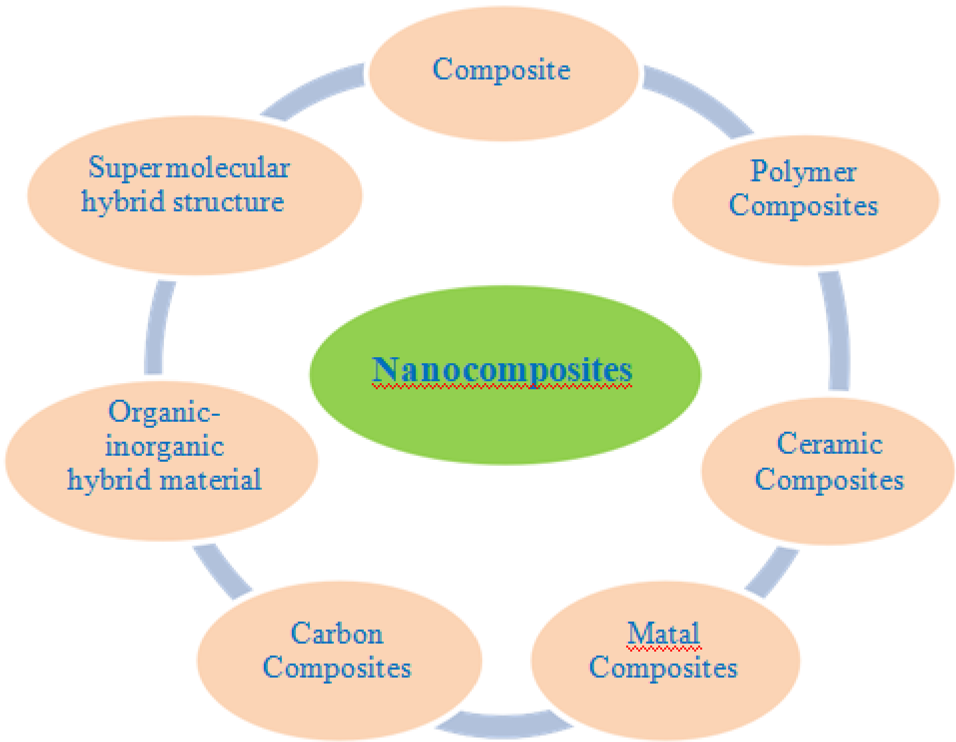
In order to produce a new substance with more properties than the original components in a certain completed structure, two or more distinct member of electorate materials, each with a unique major characteristic (physical or chemical properties), must be combined [14, 15]. Composites are solid materials that are either artificially created or naturally occur. They frequently aim to provide a range of characteristics, some of which include:

- Low coefficient of expansion
- Stiffness and strength

- Resistance to corrosion
- Resistance against fatigue
- Simple structural reconstruction
- Simplicity to create complicated shapes

III. NANOCOMPOSITES

As multiphase materials, nanocomposites must contain at least one phase with dimensions between 10 and 100 nanometers in order to avoid issues with nanoscale morphology like nanotubes, lamellar nanostructures, or nanoparticles. Today, nano-composites have emerged as a means for overcoming the limitations of different engineering materials. These can be categorized according to the dispersed phase composition and dispersed matrix [16]. Modern synthetic approaches have enabled the development of many exciting new materials with novel properties with the help of this rapidly expanding field. Along with the originals' own characteristics, the so-called found's attributes were strongly influenced by the originals' morphological and interfacial characteristics. We obviously cannot rule out the potential that the parent constituent materials may be unaware of the newly created characteristic in the material [17, 18]. Nanocomposite is based on the idea of employing building pieces that have dimensions in the nano-scale range in order to produce new materials with incredible adaptability and an increase in their physical qualities.



IV. TYPES OF NANOCOMPOSITES

The following categories of nanocomposite materials can be produced with respect to whether the composite contains polymeric material. Non-polymer based nanocomposites are those in which the compositions do not include any polymers or components generated from polymers. Inorganic nanocomposites are another name for non-polymer based nanocomposites. Additionally, they can also divided into ceramic based, metal-based and ceramic-ceramic based nanocomposites [19].

1. Polymer Nanocomposites

- **Ceramic Nanocomposites:** Ceramic fillers and an organic polymer matrix, particularly polysiloxanes, make up polymer ceramic materials, which are inorganic-organic composites. The ability of functionalized resins to produce ceramic-like structures upon thermal curing is the basis for the creation of polymer ceramics. Polymer-ceramic composites could be used to build a variety of electro-technical components subject to high thermal loads. The development of connecting materials and foamed materials with excellent thermal stability and effective thermal isolation capabilities could also serve as evidence of the polymer-ceramics' wide range of applications.

- **Inorganic / Organic Polymer**: These substances may contain inorganic elements in side groups that are related to the organic network and have C-atoms in the main chain or network. Additional inorganic cross-linking is also conceivable here. Creamers are made by silylated oligomers or polymers being processed in a sol-gel method after the organic network has already been generated in the precursor.

- **Inorganic / Organic Hybrid:** Inorganic sensors, "organic light-emitting devices (OLEDs), organic field-effective transistors (OFETs), organic phototransistors, and organic photovoltaics (OPVs)" have all been widely researched using organic materials, incorporating all small molecules and polymers. The next generation of commercially produced electronics is expected to be organic electronics due to their high scalability, simple processing capability, flexibility, and low manufacturing cost.

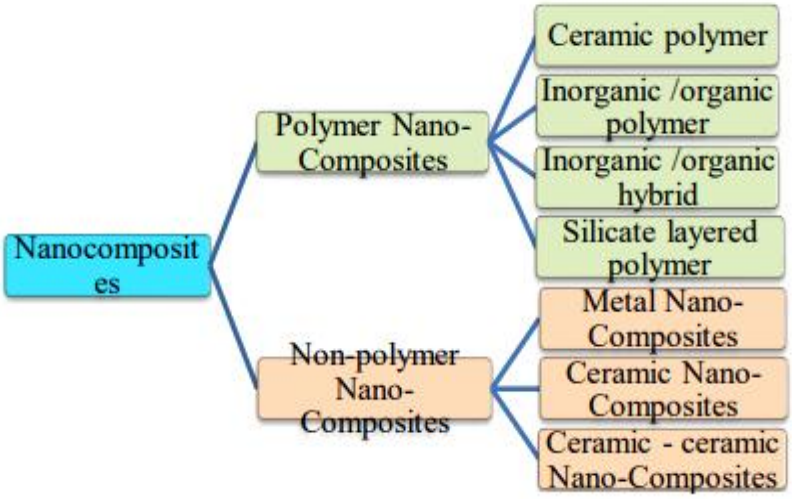
- **Layered silicate Nanocomposites:** Layered silicate minerals are readily available and inexpensive, but it is difficult to incorporate them on the nanoscale into polymer matrices. To produce biologically modified clay or silicates, which are then better suited for use with biological matrices of polymers, it is typically necessary to modify the surfaces of these materials.

2. Non-polymer-based nanocomposites –

- **Metal-based Nanocomposites:** Bimetallic nanoparticles in the type of alloys or core-shell arrangements have been thoroughly investigated because of their enhanced catalytic features and enhancement of transparency associated with particular and distinguished metals. They are distinguishable by:

    - Enhance hardness and strength,
    - Super plasticity,
    - Lower Melting Points(MP),
    - Electrical resistivity enhance,
    - Change Magnetic Properties, etc.

Metal-metal nanocomposites, as like Pt-Ru nanocomposites, are another category for nonpolymer based nano- composites material.



- **Ceramic-based Nanocomposites:** Ceramic composites containing several solid phase particles and the dimension in nano-scale range 50- 100nm of particles are at the minimum of them, are referred to as ceramic-based nanocomposites. For instance, hydroxyapatite/titanium nanocomposites both phases of these composites combine magnetic, chemical, optical, and mechanical capabilities [20–22]. These can be identified by their increased Strength, ductility and hardness.

- **Ceramic-Ceramic-based Nanocomposites:** The ceramic-ceramic nanocomposites can also be categorized as non-polymer-based nanocomposites. They can be employed as synthetic joint transplants for fractured failure and may significantly lower surgical costs while increasing patient mobility. Calcium sulfate-biomimetic quartz is another type of ceramic or ceramic nanocomposites [23]. The application of non-polymer-based nanocomposites or inorganic such as calcium phosphate, hydroxyapatite, and biologically active glass particles, which are metal or ceramics, shows the most potential for both metal-based and ceramic-based nanocomposites. These substances are especially useful for replacing enamel and regenerating alveolar bone. [24].

V. POLYMERIC NANOCOMPOSITES: SYNTHETIC TECHNIQUES AND APPLICATIONS IN REMEDIAL PRACTICE

In manufacture of polymer nano-composite materials, right selection of design, precursors, and synthetic techniques is crucial. To create Poly-Nanocomposites with the desired feature, one must select from a wide range of fillers, monomers, other composite components and synthesis techniques [25]. This highlights how important the design and synthesis processes are in the production of poly-nanocomposites [11]. The most frequently used synthesis techniques include microwave assisted mixing, selective laser sintering, shear mixing, ball milling, roll milling, ultrasonication-assisted mixing, in-situ polymerization, 3D printing and double-screw extrusion [11,26]. Typically, direct compounding and in situ synthesis are the two processes used to create polymer nanocomposites [27]. It has been claimed that problems with nanoparticle aggregation in melt-mixing procedures can be resolved via atomic layer deposition and plasma-assisted mechanochemistry. A comparable role is also played by high frequency sonication in the disaggregation of nanoparticles during mixing processes. The production of thermodynamically stable nanocomposites is possible through in-situ polymerization, and the production of porous objects is effectively accomplished through electrospinning [28]. Nanofillers are increasingly being used in the creation of Poly-Nanocomposites because of their distinctive characteristics and numerous potential applications. Fillers with one dimension less than 100 nanometers are referred to as one- dimensional (1D) nanofillers [11].

They often arrive in sheets, varied in thickness from just a few nanometers to several hundred nanometers. Two examples of one-dimensional nanofillers in order are nanoplatelets of graphene and montmorillonite clay. Polymer nanocomposites produced from various nanofillers and polymers are engrossed in industry as well as academia. Microwave-assisted synthesis is a new technology that is being employed in many areas of chemistry and materials science because of its consistent volumetric heating and the enormous improvement in rate of reaction. Functionalized polymer-based nanoadsorbents have also been produced using microwave-assisted manufacturing [29].

VI. ADVANTAGES OF DESIGNING NOVEL NANOCOMPOSITES

Nanocomposites are composed of a core substrate and one or more nanodimensional phase with distinct properties resulting from structural and chemical variations. The following properties have significantly improved:

1. **Mechanical Characteristics (strength, bulk modules, limit of withstands, etc.):** Jiao et al. [32] created metal oxides/epoxy resin (EP) nanocomposites employing the approach known as sol-gel, and they discovered that the resulting composites displayed improved flexural strength, tensile strength, impact resistance, and lengthening at break. The terms tensile strength, twisting properties, lengthening at break, and impact resistance are all commonly used for describing the mechanical characteristics of materials [30, 31]. The EP is more likely to experience stress concentration when metal oxides are present, which is related to the strengthening process. One way is that when there is a more deformation energy and concentration of stress can be absorbed through the growth of matrix cracks and the toughness of EP increases directly in relation to this.

2. **Thermal Stability:** The breakdown mass fraction as well as temperature of SiO2 in SiO2 / nano-composites polymer have been determined using thermo-gravimetric analysis (TGA), which may be helps in investigation of thermal stability of polymer [33,34]. Saoud et al. [35] examined the impact of SiO2 content on the thermal characteristics of a methacrylate polymer by adding varying amounts of SiO2. The presence of metal oxides in composites reduces the rate of decomposition and boosts resistance for heat as well as thermal stability because decomposition temperature rises of nanocomposites with rises in metal oxide component, however throughout the decomposition process, the point at which the slope of the related curve lowers. The crosslinking network topology restricts the polymer molecular chain's ability to migrate when heated.

3. **Flame Retadency:** Flammable materials Reactive-type flame retardants, as previously mentioned, involve adding a monomer that can improve a polymer's fire resistance, either by creating a polymer that is flame-resistant or through the process of incorporating a

reactant to an existing polymer for chemically coupling a flame-resistant substance at its side or ends chain [36]. In the past, flame retardant compounds had been utilized, but their lack of profitability with polymer-based substances results in losses throughout manufacturing and application. Additionally, the mechanical qualities of the polymers deteriorate when additional flame retardant is added. By converting a portion of the main chain or an attached portion of the polymer into an inflammatory flame- resistant substance, these issues can be fixed and the ability to resist fire can be significantly enhanced [37]. Using reactive flame retardant substances as monomers or polymeric precursor molecules, this technique creates fire-safe polymeric materials. Because there are exist covalent interactions between the flame-retardant constituent and polymers, reactive flame retardant substances are accordingly more effective than additive-type flame retardants in improving the fire effectiveness of polymeric materials. In these scenarios, the flame- resistant substance doesn’t deteriorate or phase-separate. Within the compounds included in this category are those that contain silicon, boron, phosphorus, halogens, nitrogen, and mixtures of phosphorus and silicon. These substances can also used in the synthesis of polymers as co-monomers or chain extenders [38].

4. **Electrical Conductivity:** According to the percolation principle, the amount of filler significantly affects a composite's ability to conduct electricity when the conductive phase is dispersed across an insulating substrate.[39] A preferred filler for creating electrically conducting nanocomposites that is carbon nanotubes (CNTs). Because the mean spacing between each of the fillers elements is larger than the size of the elements when the filler content is inadequate, the electrical conductivity of the composite is very similar with that of a natural insulating material. A "percolation" channel of connected fillers occurs when enough filler is supplied, enabling charge transmission through the sample. The percolation threshold, or critical concentration, is where the conductivity begins to abruptly and quickly rise. The value of the percolation threshold is determined by geometrical factors [40].

5. **Optical Properties:** The most significant optical characteristics of composite materials are the refractive index and to assess a material's transparency, UV-visible spectroscopy is frequently utilized. The PVA matrix contains an increasing proportion of nano-metal oxide, which improves the composite film's capacity for light absorption. The powerful hydrogen interactions that exist among nano-metal oxide and PVA containing hydroxyl groups of PVA, particularly intensified the effect of binding among PVA and metal oxide, may be the cause of the absorbance increasing as metal oxide concentration increases.

VII. CONCLUSION

The research of nano-composites has gained importance in order to develop novel substances for innovative uses. The greatest way to address the rising need for materials with multiple use is through nanocomposites, since they are varied class of materials and they have a better level of amalgamation. The development of thermodynamically stable polymeric nanocomposites is made possible by in-situ polymerization. Porous materials can be created effectively using electrospinning. Additionally, there are clear benefits to selective laser sintering for creating nanocomposites in terms of preventing aggregation.

To create macroscopic designed substances that are created through nanoscale structures, it takes competence in both technological and scientific backgrounds, which makes it a multidisciplinary field. These materials are appropriate for meeting the new demands brought on by technological and scientific advancements. The crucial aspect is that it offers many of our industrial sectors, including those in the biomedical, electrical, chemical, transportation, electronics, and electrical industries, which are endowed with properties like self-healing, self- cleaning, super hydrophobicity, multiple responses, and shape memory, a plausible benefit. Therefore, it is anticipated that these will have a significant impact on keeping the environment cleaner, greener, and safer in the years to come.

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