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POLYMER NANOCOMPOSITES

Shefali Thakur

Department of Chemical Engineering; Institute of Chemical Technology; Mumbai 400019

Abstract
Polymer nanocomposites are a crucial category of materials used in packaging, sports equipment, the automobile sector, and bioengineering applications due to their unique properties and distinctive design feasibility. They have also been extensively used as sorbents to extract pollutants from environmental waters before their final instrumental analysis. Several materials have been found to exhibit exceptional properties – e.g., strength, stiffness, electrical and thermal conductivity. These can be adapted to a given analytical problem by selecting the polymer/nanomaterial combination adequately. Nanocomposites have become a part of various research ventures owing to their promising potential for various environmental applications and issues and their high versatility. This article intends to scrutinize and briefly describe the essential aspects and developments related to polymer nanocomposites.

Keywords: Polymers, nanocomposites, structures, properties, applications

1. Introduction

One of the most notable and advanced areas for current research and experimentation in nanotechnology is polymer nanocomposites, and the investigation field covers various topics. This would include nanoelectronics, polymeric bionanomaterials, nanocomposite-based drug delivery systems.

In simple terms, Polymer Nanocomposites (PNCs) can be explained as a mixture of two or more components, including the dispersed medium as a polymer matrix and the dispersed phase as nanoparticles of nanofillers. After various research advances and deliberations, it has become well-known that nanocomposite particles possess umpteen advantages, such as being light and biodegradable. Their addition into polymer matrixes can create thermal and mechanical changes and gas properties without affecting manufacturability immensely [23] . In making polymer nanocomposites, the aim is to consider the exceptional properties and impart them into a centralized and standard material. The considerable interference between nanoparticles and macromolecules results in unusual properties. In nanocomposites, significant reinforcement and enhanced properties like decreased flammability and increased conductivity are often obtained at low concentrations of nanoparticles [2] . However, these effects depend entirely on the homogeneous dispensation of the nano additive in the polymer matrix, which is hard to achieve [27]

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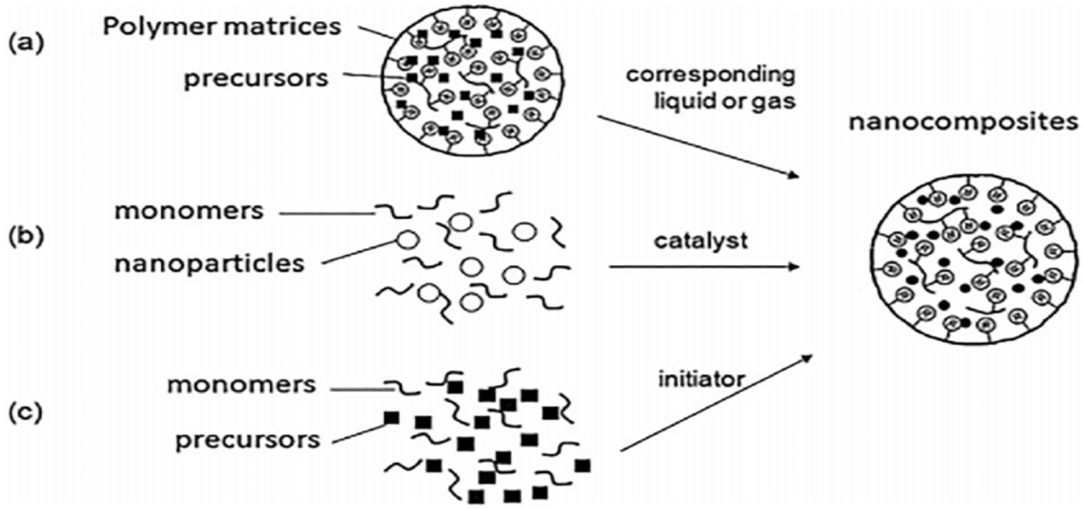

Figure 1

Different methods can be used for the production of the particles. In general, two main strategies are employed: the dispersion of preformed polymers or the polymerization of monomers [12].

Polymeric Nanoparticles	Production Methods
Nanospheres	Solvent evaporation Emulsification/solvent diffusion Nanoprecipitation Emulsification/reverse salting-out
Nanocapsules	Nanoprecipitation

Table 1

The products are usually obtained as aqueous colloidal suspensions regardless of the preparation method employed [33].

1.1 Classification of polymer nanocomposites

Polymer nanocomposites can be categorized into three major types, depending on the dimensions of the dispersed nanoscale fillers[21]. In the first division, the two-dimensional (2D) nanoscale fillers such as layered silicate, graphene in the form of sheets of one to a few nanometers thick and of hundreds to thousands of nanometers long are present in polymeric matrices. The corresponding polymer nanocomposites can be grouped into layered polymer Nanocomposites. In the second division, two dimensions are on the nanometer scale. The third is larger, forming an elongated one-dimensional structure; these nanoscale fillers include nanofibers or nanotubes, e.g., carbon nanofibers and nanotubes or halloysite nanotubes as reinforcing nanofillers to obtain materials with exceptional properties. Last but not least, the third division summarises nanocomposites containing nanoscale fillers of three dimensions of the order in nanometers. These are isodimensional such as nanometric silica beads. Considering various characteristics of polymer nanocomposites, the dimensionality of nanofillers in recent years has become highly interesting [21].

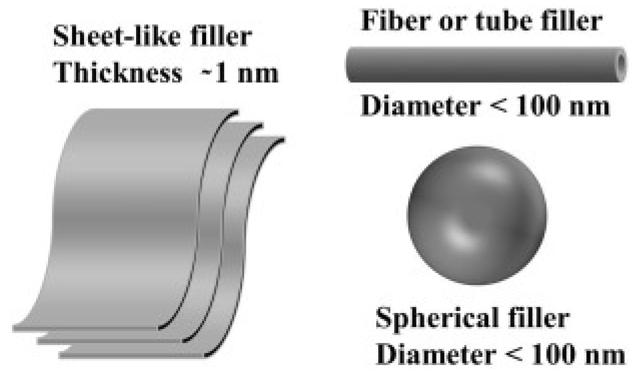

Figure 2

Recent nanotechnology developments afford an unprecedented opportunity for membrane enhancement because it is a permissive technology at the atomic level [46] . Figure 3 shows some collective membrane structures fabricated with nanomaterials. Furthermore, polymer nanocomposites have an essential place in membrane materials because they enhance the transport properties of membranes and offer tremendous stability in an extensive span of operational conditions [4] .

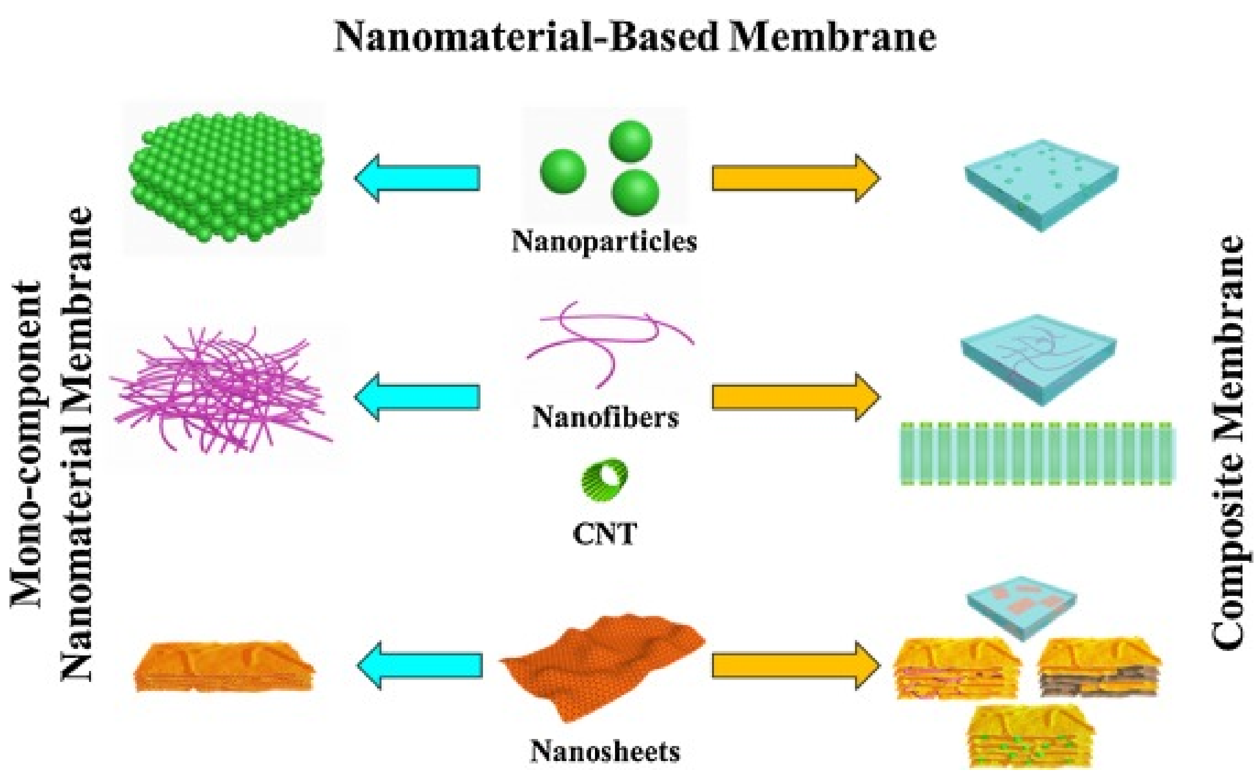

Figure 3

Depending on the degree of segregation of the nanoparticles, three types of nanocomposite morphologies are possible [22] .

1. conventional composites (or micro composites),
2. intercalated nanocomposites: polymer is intercalated between inorganic layers giving rise to nanocomposites containing polymeric chains and changing inorganic layers and,
3. exfoliated nanocomposites.

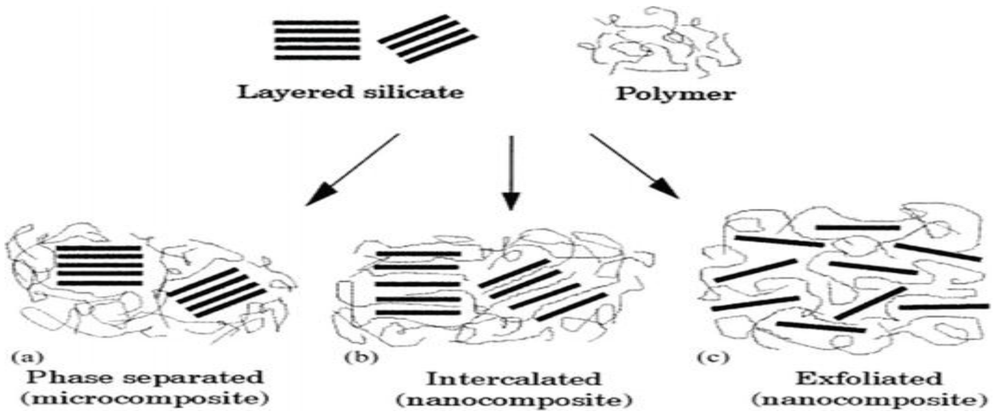

Figure 4

The bonds in exfoliated nanocomposites have high strength and robustness due to extensive surface contact between the polymer matrix and nanoparticles. This can also be considered a significant difference between nanocomposites and conventional nanocomposites.

Composites that exhibit a commute in composition and structure over a nanometre scale have shown remarkable property enhancements relative to conventional composites:[52]

• Increased modulus

• Increased gas barrier

• Increased heat distortion temperature

• Resistance to small molecule permeation

• Improved ablative resistance

• Increase in atomic oxygen resistance

• Retention of impact strength.

This review article emphasizes common types of fillers used in nanocomposites, types of nanocomposites based on various factors, understand how these composites are produced, and discuss the applications and potential of these materials.

2. Preparation of Nanocomposites

A polymeric particle polymer nanocomposite contains a rigid polymer component dispersed within a flexible polymer matrix on a nanoscale level. The tough polymer, with high modulus and high strength, usually has high melting temperature, is insoluble in organic solvents, and combining it with the flexible polymer is thermodynamically unfavorable [12] . Therefore it is tough to prepare a nanocomposite, and phases may undergo segregation during processing and end-use.

Polymer Nanocomposites have a wide range of usages due to their small size and distribution of the small particles over a bulk matrix, giving them different chemical and physical properties because of their large surface to volume ratio [38] . When two or more different constituent materials, each having its unique properties, are combined to create a new substance with exceptional properties and characteristics such as [9]

1. Nanoparticle dispersion
2. Thermal stability
3. Stiffness and stability
4. Chemical structure and surface area
5. Resistance to corrosion

Another aspect that can explain the importance of polymer nanocomposites is the final morphology (surface structure) which does not depend on the process of build-up but on the interactions of nanoparticles, which even leads to the excellent and widespread distribution of nanoparticles in the matrix and also on the procedure of obtaining the nanocomposites.

2.1 Melt intercalation: To fully explore the potential of scientific and potential applications of polymer melt intercalation, various factors such as kinetics, environmental sustainability, and compatibility should be considered [15] .

The most common approaches include polymer annealing at high temperatures, adding the nanofiller, and kneading the composite to achieve uniform distribution. This process can be efficiently utilized and is more economical as well.

This process, however, has a disadvantage because the high temperatures can damage the surface composition of the nanofiller [29] .

2. Prepolymer intercalation, also known as exfoliation adsorption, usually has a polymer or a prepolymer as the soluble solution. For example, layered silicate materials are readily available as well as economical. The electrostatic and Van der Waals forces that hold the layers together are relatively weak. The distance between the layers depends on the degree of hydration. It swells up and gets easily exfoliated by shearing in a solvent mixed with a polymer [37] . Within the dispersed silicate interlayers, the polymer chains then displace the solvent. In due time, the intercalated chains are trapped and adopt a more disordered structure, and the sheets reassemble to form a multi-layered structure. Because of the usage of many solvents, this method is not environment friendly as consorted to melt intercalation. This method mainly uses polymers soluble in water to produce intercalated polymer nanocomposites. Inspired by exfoliation in silicates, exfoliation of graphene intercalated compounds (GIC) is also emerging as another exciting approach [44] . The weak Van der Waals forces and abundant pi-electron clouds between graphite layers lead to intercalation.

Few studies have reported that due to lithium-ion battery charging, organic molecules can also be intercalated by electrochemical methods.

FIGURE 5.

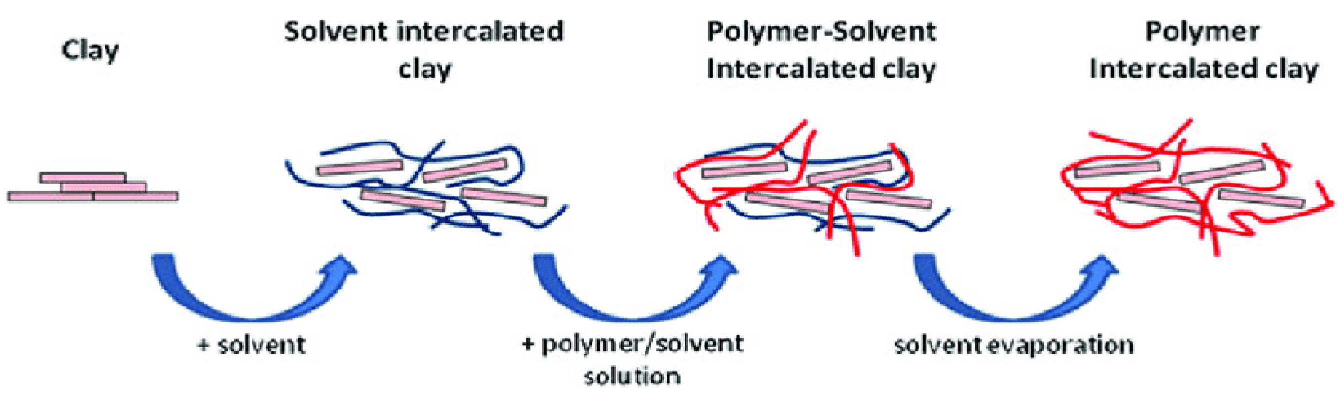

Figure 5

2.3

In situ polymerization processes occur in a solvent-based system (aqueous phase) where the filler in monomer solution swells up. The stage can be a suspension, emulsion, or pure solvent. The

swelling up of the filler takes place because the low molecular weight monomer percolates in between the layers creating a node [34] .
This method can even include a solvent-free (bulk) system. Nylon -6 was first used to create nanocomposites by in situ polymerization. A homogenous mixture formation leads to the addition of an initiator, and then the mixture is exposed to heat and light. Polymers formed in situ results in nanocomposites called thermosets [49] .
Thermosets are extensively and covalently cross-linked that do not allow reshaping. They can be reused by using a filler.

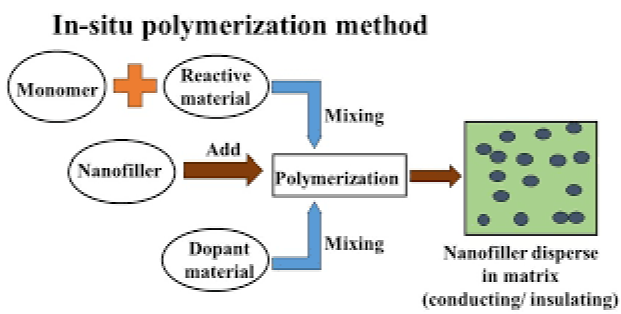

Figure 6

2.4 Template synthesis, also known as sol-gel technology, is based on an opposite principle of previous methods and is a more wet chemical method for forming various nanocomposites. This approach involves the construction of the inorganic colloidal suspension in an aqueous solution or a continuous liquid phase (gel) [9] . The filler acts as building blocks to form a three-dimension structure. The sol-gel process is well adapted for synthesis, where the polymer induces the formation and encourages the growth of the inorganic filler crystals [13] . As those crystals grow, the polymer is trapped within the layers, forming nanocomposite. The high temperature utilized during formation degrades and weakens the polymer and the resulting resistant behavior of the growing inorganic crystals [14] . The above-stated reason led to rejected of this method.

3. Applications of Polymer Nanocomposites

Nanocomposites have various applications in

1. structural
2. bioengineering
3. Electronics
4. Automobiles and aircraft
5. oil pipelines, gas pipeline construction
6. electromagnetic shielding. According to the researchers' results, the inculcation of nanomaterials into polymers substantially enhances their properties, allowing them to widen their application areas.

3.1 Structural applications Polymeric materials are mainly studied and used in structural applications due to their vast domestic and aerospace applications. The same extensive applications are expected from polymer matrix nanocomposites. Inorganic materials are usually used as reinforcement with polymers. Polymeric nanocomposite has exceptional mechanical properties and good electrical conductivity. Hence it is the best choice for structural applications

3.2 Food packaging and safety (barrier materials, antimicrobials, and sensors) Barrier properties result from the plate-like nature of the nanofiller (mostly clays). The high aspect creates a "tortuous path" for materials passing through the composite and tremendously improves the barrier properties of the packaging materials [11] .

3.3 Transportation and safety Weight reduction, high corrosion resistance, and resistance to damage from fatigue are the most significant advantages of composite material usage in decisions regarding its selection [16] . These factors Are crucial in reducing transportation operating costs. These days, it is impossible to imagine the existence of any moving vehicle without the presence of polymer composites.

3.4 Tissue engineering is a part of biomedical engineering to replace and maintain and improve tissues that have been destroyed by sickness, accidents, or other artificial means. This method involves providing a scaffold that supports

structures designed to facilitate cellular growth and proliferation upon implantation into the patient and on which cells are added [40]. The platform should come up with requirements for developing the same.

3.5 Environmental protection: Environmental protection is becoming more problematic in a global society. Generally, some of the critical points that should be considered are removing pollutants (e.g., filtration, absorption by activated carbon), reducing the number of contaminants generated (e.g., using biodegradable polymers, recycling, and electronic pollution control [31].

3.6 UV protection, cosmetics, clothing, and sports Natural sunscreens rely upon physical sunscreen filters such as zinc oxide or titanium dioxide. They do their task by sitting on top of the skin and providing(protection) a barrier against UV rays, driving them away from the skin and preventing any harm [46]. They are used in: glasses, goggles, swimwear, sunglasses, bags, tape, wear, clothing. However, chemical sun filtering agents work by being absorbed into the skin's top layer, deflecting UV rays or absorbing their energy, and changing them into something not harmful [45]. UV protection of polyamide fabrics with polymeric nanoparticles is extensively used. Sun protective textiles are essential for health problems. ZnO, Al2O3, SiO2, and TiO2 nanoparticles, are scattered with different concentrations [25].Nanotechnology has also been wildly applied in cosmetics and sports engineering, such as sports stadiums, field turf, racks, sportswear, equipment, and supplements. This may significantly change the present situation of sports and promote the advance of athletic sports, creating many opportunities to increase the record of athletic sports.

3.7 Solar energy production and storage PNC solar cell is a promising photovoltaic technology. PNC solar cells utilize the high electron mobility inorganic phase to overcome charge transport limitations associated with organic materials [45]. Poly[2-methoxy-5-(2-ethylhexyloxy-p-phenylenevinylene)]/ZnO nanorod PNC solar cells consisting of PbS quantum dots [QDs] prepared by a chemical bath deposition method QDs on the ZnO nanorods enormously improves the performance of the solar cells. Zinc oxide [ZnO] has been considered an extraordinary semiconductor material for solar cells due to its high electron mobility and thermal stability [5]. The undeniable importance of electric energy is related to better storage. Multifunctional polymer nanocomposites could be exploited as structural energy storing devices (batteries etc.), where matrix and filler synergistically undertake the roles of structural support and energy storage [3].

4. DISCUSSIONS

In the sense of hybrid materials with novel properties beyond the realm of unfilled polymers and conventional composites, Nanocomposites bear high promise for enabling new uses and applications of polymer materials. In the most straightforward approach, they can expand the window of a given polymer application. In the best case, they can enable polymer-matrix composites in applications where metal or ceramic materials are currently used. One of the first untapped challenges in the field is to go beyond the simple dispersion of fillers and move towards developing methods to create well-defined 3D morphologies of nanofillers: morphologies that contain highly aligned fillers, house-of-cards structures, edge-connected (star-like) formations, alternating 2D and 1D filters.

Although it currently engages an overwhelming number of research groups, the field desperately needs well-designed scientifically-based studies to explore the fundamentals of these materials. Since the barriers of entering the area are low (no need for special equipment or expensive materials, studies can be published even when reproducing results from previous works or making minor incremental advances), the temptation is high to mix polymers with off-the-shelf nanofillers and report X-ray diffraction and mechanical measurements. However, the real potential of these materials will remain untapped until the nanoscale mechanisms responsible for macroscopic properties are unveiled and further exploited to make radically new materials. New horizons need to be explored, especially outside the "comfort zone" of traditional polymer or materials scientists. Suppose one considers the numerous examples of biological organic/inorganic nanostructures with unparalleled performances and a combination of properties that transcend any synthetic material. In that case, one can only start to imagine the limitless possibilities of this field.

5. CONCLUSION

This article touched upon the basic and essential theories of Polymer Nanocomposites. It acknowledged nanocomposites' classification, preparation, types, and prospects as they have become one of the most prominent and emerging research topics. They receive special recognition, and many kinds of research are conducted to analyze their unique properties, such as less weight, resistance to corrosion, ease of production, and flexibility.

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