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Polymer Nanocomposites: Synthesis and Characterization

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Abstract: The properties of polymer nanocomposites take after their microstructures, which are significantly impacted by control of nanoparticle scattering to achieve the ideal properties of the materials. By coordinating the nano-polymers, the attributes of the singular polymers, like warm, optical, mechanical and gas properties, are effectively upgraded. Polymer nanocomposite materials of are utilized in the support of underlying parts as a result of their high solidarity to length proportion and high opposition. Due to their primary properties, they are additionally significant in clinical applications utilized for the support of biodegradable polymeric nanocomposites during the time spent bone tissue re-designing. The level of crystallinity, just as the pace of crystallization, can without much of a stretch be impacted. Utilizing determined conditions, spherulitic development is controlled in the restricted space with the goal that the principal cores are missing from the heterogeneous crystallization, including homogeneous nucleation prompting the side-effects. Also, the carbon nanotube has mechanical, warm, and electrical properties, makes it appropriate for use in the development of support materials. The advancement of multifunctional polymer nanocomposites of the primary properties make them considerably more grounded than steel yet lighter than aluminum, and they have electrical conductivity more noteworthy than copper.

Keywords: Nanocomposites.Nanotechnology. Reinforcement. Polymer.Carbon nanotubes.

1. Introduction

Polymer nanocomposite (PNC) contains polymers or copolymers with attributes of nano-filler and nanoparticles. They also come in varied shapes, such as fibers, platelets as well as spheroids, consisting of a dimension that must be at least in the range of 1- 50 nm**.** Current research in all technical disciplines is majorly centered on the field of nanotechnology. One topic which is attracting a lot of attention is the area of polymer science and technology, which is broadly diverse. Practical applications of the polymer composites are well known since most of the techniques are used for enhancing the advantages of the polymers [1]. Most of the applications of polymer nanocomposites are included in the reinforcing materials, such as the short fibers commonly fused with thermoplastic polymers to improve both their thermal and mechanical properties.

By integrating the nano-polymers, the characteristics of the individual polymers, such as thermal, optical, mechanical and gas properties, are easily enhanced. Most of the properties of polymer nanocomposites resemble their microstructures, which are greatly influenced by control of nanoparticle dispersion to attain the desired properties of the materials [2].

1.1 Advantages of Polymer Nanocomposites

Polymer nanocomposite materials are very useful in separate applications because of their numerous benefits and properties. These materials are used in the reinforcement of structural components because of their high strength to length ratio and high resistance. Because of their structural properties, they are also valuable in medical applications used for the reinforcement of biodegradable polymeric nanocomposites in the process of bone tissue re-engineering. Polymer nanocomposite materials have a higher resistance to the compressive as well as flexural properties [1].

Another advantage of using polymer nanocomposite materials is high thermal resistance and electrical conductivity. The nanoparticles can withstand a higher thermal conductivity than other materials without melting. Their thermal conductivity also offers resistance to flame or fire because of their tendency to withstand high temperatures without breaking the bonds between their particles [1].

2. Method-Nanocomposite Synthesis

2.1. Considerations for Developing Nanocomposites

There has been a growing interest in the field of nanotechnology. More specifically, the polymer matrix based nanocompositesand the growing attention to their applications in research and other areas. These gained much attention and recognition following the exfoliation of the clay capable of producing substantial benefitsin mechanical properties, along with the alteration of the polymer system [1]. Initially, the achievement of these results was not anticipated: Nano effects that improved their properties on top of the predicted continuum mechanical prediction. A lot of studies have concluded, despite having unique andfascinating property profiles, that the nanocomposite of the clay-based ((montmorillonite) contains platelets with an octahedral sheet layer of aluminum oxide between two tetrahedral layers of silicate)regularly conforms to the continuum mechanical prediction [3].The structure of clay-based nanocomposite can be given with the following figure:

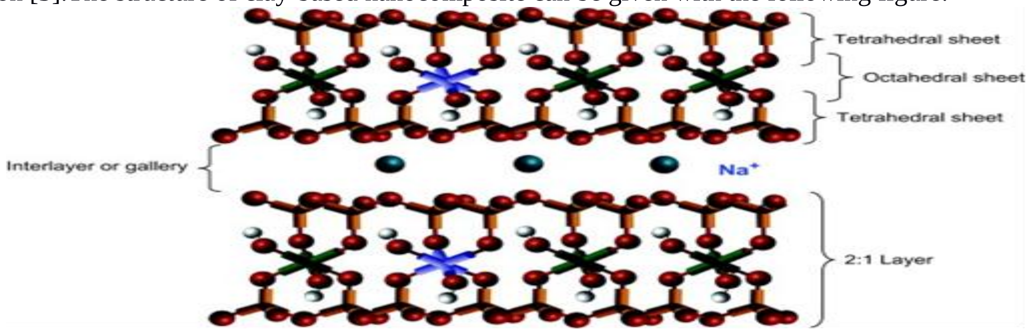

Figure 1: Illustration of the sodium montmorillonite structure of clay-based nanocomposite.

Additionally, under a confined space, the degree of crystallinity, as well as the rate of crystallization, can easily be influenced. Using specified conditions, spherulitic growth is controlled in the confined space so that the first nuclei are absent from the heterogeneous crystallization, including homogeneous nucleation leading to the byproducts [4].The spherulitic size is attainable when the nanoparticles incorporate nucleation effects, as well as the disruption in the polymer matrix.

Crystallization via nucleation is capable of taking place with the inorganic particles as well as nanoparticle inclusion. Nano-particles can substitute for lacking primary nuclei at nano dimensional scales. The crystallization process is a convoluted, as well as, competing process that is influenced by many factors, such as the chain diffusion rate that causes minimized crystallization kinetics [4].

Another important consideration in the development of polymer nanocomposites is the change in the glass transition temperature (T_g)of the polymer matrix characterized by increasing nano-particles. The interaction between the particles and the matrix will influence both decreases and increases of T_g. The nano effects which are achieved when the amorphous polymer is added with small particles causes the $T_g$tochange. This does not follow the predictions of continuum mechanics [1].

When the changein the glass transition temperature (T_g) is within several nanometers, the transition of the glass polymer will be influenced by the environment. It can also be referred to as the confinement effect. In Table 1 below, the decreases and increases in (T_g)will be influenced by the specified interaction (see section 2.2)between the particles and the matrix to help predict the model of the polymer [1].

Table 1: The change in glass transition with the incorporation of nanofiller

Polymer	Nanofiller	T_g change (°C)
Polystyrene	SWCNT	3
Polycarbonate	SiC (0.5–1.5 wt%) (20–60 nm particles)	No change
Poly(vinyl chloride)	Exfoliated clay (MMT) (<10 wt%)	−1 to −3
Poly(dimethyl siloxane)	Silica (2–3 nm)	10
Poly(propylene carbonate)	Nanoclay (4 wt%)	13
Poly(methyl methacrylate)	Nanoclay (2.5–15.1 wt%)	4–13
Polyimide	MWCNT (0.25–6.98 wt%)	−4 to 8
Polystyrene	Nanoclay (5 wt%)	6.7
Natural rubber	Nanoclay (5 wt%)	3
Poly(butylene terephthalate)	Mica (3 wt%)	6
Polylactide	Nanoclay (3 wt%)	−1 to −4

2.2. Interfacial Interaction between Filler and Polymers

The particulate properties that are filled with the polymers are influenced by the interfacial interaction. The strength of the interaction, as well as the interface area/size, will influence the adhesion between the polymer matrix and the particles too. By using a surface treatment, the strength of the interaction can be impacted, while the specific surface area of the filler will influence the former quantity [5].

The interfacial interaction between the fillers and the polymer improves the properties of the composite material, especially if amino functionalized silanes are used; this increases the interaction significantly. It can be observed when the polypropylene composite is made using a different amount of the filler treated with the eight functional tri-alkoxy silane combination agents. This helps the mechanical properties of the material, which is an interfacial interaction between filler and polymer [5].

2.3. Nanocomposite Processing

There are numerous techniques that can be used for the processing of nanocomposite materials. The technique of nanocomposite processing is greatly influenced by the type of nanoparticles and the polymer matrix used for the application process [3]. The synthesis methods are greatly influenced by the environment of the reaction processes, including the interfacial interaction between the fillers and the polymers. Some of the processing techniques include:

2.4. a. Polymer latexes

This technique is characterized with the preservation of the varied state of the nanoparticle obtained from the colloidal dispersion in water. It is normally used in the processing of polysaccharide nanocrystal reinforced polymer nanocomposites. The processing of the aqueous suspension is normally achieved with sulphuric acid rather than hydrochloric acid because of its ability to form stable aqueous suspensions [6]. The structure of the polymer latex is shown below

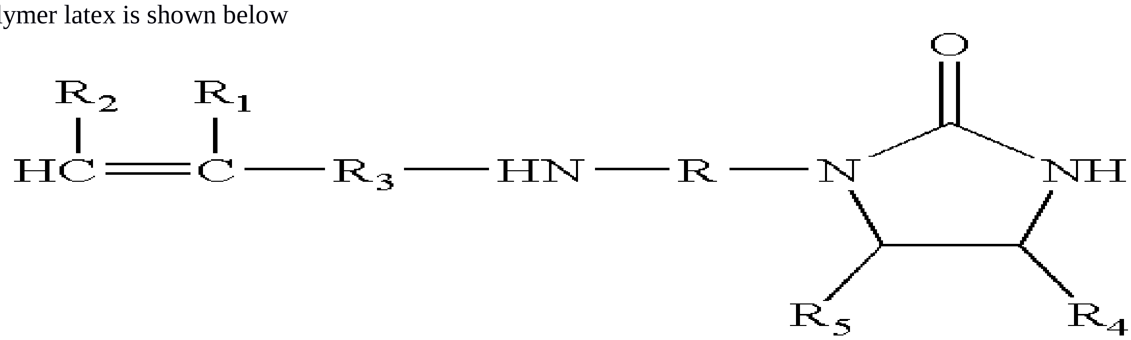

Figure 2: Structure of the Polymer

2.3. b. Long chain grafting

The main aim of this processing technique for nanoparticles is to improve their apolar synthesis yield [7]. Long chain grafting involves merging long chain unsaturated complex molecules in special mixers to attain a characteristic and specific compound. For instance, proposed the grafting of long chain unsaturated carboxylic acids onto polypropylene using the HaakeRheocord RC mixer [8]. According to the study, the long grafting process was enhanced by the use of mixed initiators. There is a rapid increase in the initial phase due to the monomer concentration while addition of styrene reduces the rate of reaction and the overall degree of grafting. The long chain grafting aims to provide a reinforcement effect on the resultant polymer, which provides biodegradable polymeric nanocomposites with desirable mechanical qualities.

Goffin, et.al. poly-grafted cellulose nanowhiskers, which involved the synthesis of the lactone through a ring-opening polymerization process [9]. The study was used to establish that covalent grafting on cellulose nanowhiskers (CNWr) surfaces enhanced its thermo-mechanical properties. Through atomic microscopy, the study established that the cellulose nanowhiskers were dispersed in an excellent manner within the PCL (poly caprolactone) matrix. Consequently, the resultant composite exhibited an excellent interfacial compatibility between the PCL matrix and the nanofiller [6]. Designing and utilizing the aforementioned nano biodegradable materials by modifying their mechanical resilience and flexibility facilitated the development of the ideal nanocomposite material. In essence, the scientists established that they could design and fabricate a wide range of nanocomposites, which would be used to generate a wide range of biomedical tissues.

Properties of Nanocomposites

Nanoparticles are essential tools in scientific technology and are gaining a lot of attention and interest in pharmacology and biotechnology, including pure technological applications. Most of the material of the molecular or atomic structure consist of a unique structure that is useful in achieving the properties of the nanocomposite materials [2]. However, the properties of the polymer matrix are significantly dissimilar to nanoscale fillers.

Nanocomposite materials are stronger, and particles such as molybdenum disulfide, graphene, carbon nanotubes, and tungsten disulfide are frequently used for reinforcement of the biodegradable, polymeric nanocomposites in medical applications, such as the process of bone tissue reengineering [10]. Polymer nanocomposite materials have a higher resistance to compressive as well as flexural properties.

Nanocomposite materials have good electrical conductivity and currents are applied in numerous technological applications. A multi-walled carbon nanotube has been constructed using polymer nanocomposite that has higher electrical conductivity [10]. Moreover, the structural properties of the polymer nanocomposite are used as resistance material to flame obstruction [11].

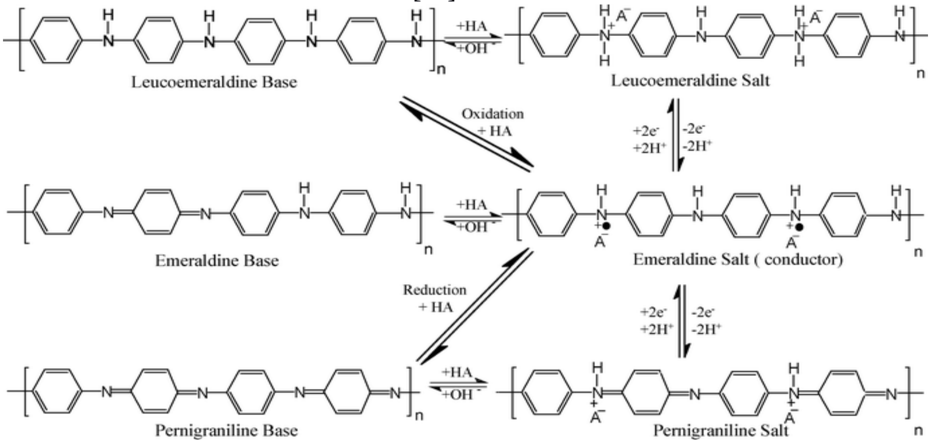

Figure 3: Structural property of chiral conducting polymer

3. Results and discussion

a. Characterization techniques

There are varied means of identifying the features of these materials by using their structures, composition, and other properties, such as the magnetic, electrical, and physical properties among others. The particle sizes of nanocomposite materials are normally measured in nanometers (nm) [2]. The particles come in varied shapes such as irregular, tubular, and spherical which can also be aggregated, fused or agglomerated forms.

The properties of the altered fillers and the polymer nanocomposite materials are in fluenced by their thermal performance. Thermal characterization influences their application in high-temperature processing, which in turn influences the compounding process of the material. This also influences the modified surface of the fillers, which is useful for maintaining the weight of the materials during the surface modification.

The surface of the material used for flame retardancy in the polymer composite has a nano additive property(new method to enhancing coating performance) which is separated by the nanoscale dimensions. These materials are usually nano-clay as well as nano-graphene platelets, carbon nanotubes (CNTs), halloysite nanotubes (HNTs), and the carbon nanofibers (CNFS).

4. Various types of Polymer Nanocomposite

4.1. CNT-Polymer Nanocomposite

Carbon nanotubes (CNTs) resemble hexagons in which the carbon atoms are shaped into rolled tubes, i.e. carbon with a characteristic cylindrical nanostructure. Carbon nanotubes have a length to diameter ratio of 132,000,000:1, which makes them among the largest nanocomposites.The chemical equation for the carbon nanotube (CNT) is represented below, as well as it's spherical characteristics.

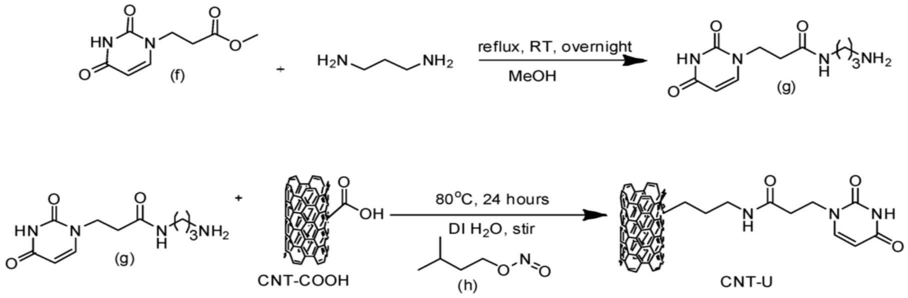

Figure 4: Chemical equation for the carbon nanotube (CNT) and the characterization property (tube).

The unique composition of the carbon nanotube (CNT), as well as its mechanical, thermal, and electrical properties, makes it suitable for use in the construction of reinforcement materials, including the development of multifunctional polymer nanocomposites. The structural properties make them even stronger than steel yet lighter than aluminum, and they have electrical conductivity greater than copper [12].

4.2 Magnetic Polymer

Magnetic nanocomposites consist of magnetic nanoparticle materials scattered into a solid matrix. Usually, the polymers which are less than 30nm can be fabricated using different methods such as thermal decomposition, co-precipitation, emulsion methods, laser ablation in liquids, hydrothermal synthesis, co-sputtering, and co-evaporation.

From the above examples, the carbon nanotubes, which can be produced with a diverse array of ferromagnetic NPs, have different structures. More importantly, the ferromagnetic materials in the CNT are covered with carbon shells which inhibit oxidations as well as provide antiferromagnetic contributions. In addition to that, it has higher temperature stability [2].

4.3 QD- Polymer Nanocomposite

There are numerous applications of polymers that are highly desirable and can be used for wave guiding in combination with optical devices. These are especially suitable for conducting operating wavelengths since they have a high transparency that exceeds 400nm, in addition to being easily constructed and possessing low propagation losses. The application uses a nanocrystalline material that is attached to a semiconductor using colloidal chemistry. The nanocrystals used in the semiconductor are normally referred to as quantum dots (QDs) because they are confined to the 3D carries i.e. three dimensional (3D) charge carrier confinement the energy levels are quantized in all spatial directions and the energy levels are discrete.

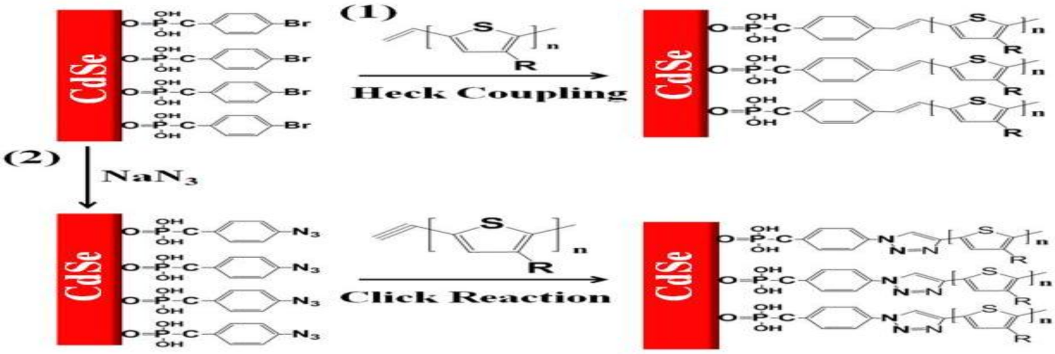

Figure 5: illustrates the coupling polymers and QD has advantage over one that is lacking.

Therefore, the application of QDs in polymers is a suitable approach for use in photonic devices as the core to wave-guiding. Applying the right concentration of QD in the matrix offers a suitable mechanism for guiding wavelengths of varied colors. Different types of QDs are attached to the polymers [13].

5. Conclusion

Polymer nanocomposite materials are gaining the spotlight because of their structural properties and numerous advantages that can be used for varies applications in different fields, such as medical applications, fuel cells, and manufacturing processes. A different modification of the nanocomposite material improves the properties of the matrix as well as its reinforcement properties. Various properties of polymer nanocomposites can be used to improve or optimize materials by nano-level construction, which can yield superhydrophobic character as well as adhesion.

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