Nanocomposites: A New Trend of Structure in Nanotechnology and Material Science

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1. Introduction

Nanocomposites play a very important role in many areas of chemistry, physics, biology, and material science. Nanotechnology deals with particle which is at least one dimension on the nanometer scale. Nanocomposites are materials which are in the purest form that have exceptional fundamental properties. Their high surface area to volume ratio, especially for nanotubes, make them perfect ablative and reinforcement materials. Addition of nanoparticles in polymer matrix may enhance ablative and overall mechanical properties of polymer matrix composites [1,2]. This type of materials is used as thermal protection material for rocket nozzles, space vehicles, and combustion chamber of rocket motors. This material should withstand very high temperature, high thrust, and high impact. The final material should able to form complex shapes and be as light as possible. Nanocomposites have exhibit unique physical and chemical properties due to their limited size and high density of corner or edge surface sites. Since the late 1990s, nanotechnology has been a new frontier of the scientific community. The term "Nanotechnology" can be defined as controlled manipulation of materials with at least one dimension less than 100 nm. This technology attempts to integrate chemistry, physics, material science and biology to develop new materials properties that can be exploited to develop facile process for the development of electronic devices, biomedical products, high performance materials and consumer articles. The commercialization of nanotechnology is expected to boost the wide technological development, improve quality of life and societal benefits around the world. The nanocomposite materials have large variety of systems such as one-dimensional, two-dimensional, three-dimensional and amorphous materials, made of distinctly dissimilar components and mixed at the nanometer scale. Typically, nanocomposites are clay, carbon, or polymer, or combination of these materials with nanoparticle building blocks [3,4]. The general class of nanocomposite is organic/inorganic materials which is now fast growing area of research. The properties of nanocomposite materials are depend not only on the properties of their individual parents but also on their morphology and interfacial characteristics. This type of rapidly expanding field is generating many exciting new materials with novel properties. The others latter can be derive by combining properties from the parent constituents into a single materials. This is also the possibility of new properties which are unknown in the parent constituent materials. Significant amount of industrial and governmental research is being conducted on nanocomposites [5]. The most popular polymers for research and development of nanocomposites are polyamides, polypropylene, polyethylene, styrenics, vinyl, polycarbonates, epoxies, acrylics, polybutylene, teraphthalate, and polyurethane as well as a variety of miscellaneous engineering resins. However, the most common fillers is montmorillonite clay; these are unique because of platy structure with a unit thickness of one nanometer or less and an aspect ratio of 1000:1 range. Usually low loading levels are required for property improvement. Expected benefits from nanocomposites include improvement in modulus, flexural strength, heat distortion temperature, barrier properties and others benefits and unlike typical mineral reinforced systems, they are without the conventional trades off in impact and clarity [6,7].

Nanocomposite is an innovative material having nanofillers dispersed in a matrix. However, the structure is a matrix filler combination, where the fillers like particles, fibers or fragments are surrounded and bound together as discrete unit by matrix. The term nanocomposites has wide range of materials right from three dimensional metal matrix composites to two dimensional lamellar composites and nano wires of single dimensional to zero dimensional core-shell structures representing many variations of mixed layered materials [8]. Nanocomposites has been studied for nearly 50 years, but for few references address the importance of how the organoclay is processed into plastic of choice. Nanocomposite were first referred as early as 1950, and polyamide nanocomposites were reported as early as 1976. However, it was not until Toyota researchers began a detailed examination of polymer/layered silicate clay mineral composites that nanocomposites were become widely studied in both academic and industrial laboratories. From some of the literature survey, it is observed that in the early 1980s that Toyota’s Central Research and Development Laboratories began working with polymer-layered silicate-clay mineral composites and that the period was when the technology began to be studied more widely [9]. The clay mineral is generating the most interest for use in nanocomposites is montmorillonite, generally referred to as clay nanoclay, and sometimes referred to as bentonite. Similarly, it is also observed that the natural clay is the most commonly formed by the in situ alteration of volcanic ash or by hydrothermal alteration of volcanic rocks*. This clay is most widely available and relatively inexpensive, thus becoming the most widely used clay in nanocomposite applications. In some studies, they concluded that the polymer nanocomposites history was in 1990 when Toyota was first used clay/micron-6 nanocomposites

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https://doi.org/10.30799/jnst.315.21070103

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for Toyota car in order to produce timing belt covers. Recently, advances in the ability to characterize, produce and manipulate nanoscale materials have led to their increased use as fillers in new types of nanocomposites [10,11].

2. Classification of Nanocomposites

2.1 Ceramic Matrix Nanocomposites

The potential of ceramic matrix nanocomposites are mainly the Al2O3/SiC systems. Most of the studied reported so far have confirmed the noticeable strengthening of Al2O3 matrix after the addition of low fraction volume of SiC particles of suitable size and hot pressing of the resulting mixture [12]. This toughening mechanism is based on the crack-bridging role of nanosized reinforcements. The incorporation of high strength nanofibers and inorganic nanostructures allows to the preparation of advanced nanocomposites with high toughness and superior failure characteristics compared to the sudden failures of the ceramic materials. Many methods have been used for the preparation of ceramic matrix nanocomposites. The most common methodologies, as used for microcomposites, are conventional powder method, polymer precursor route; spray pyrolysis; vapor techniques (CVD and PVD) and chemical method which include the sol-gel process, colloidal and precipitation approaches and the template synthesis. A large variety of parameters affects the sol-gel process such as type of solvent, timing, pH, precursor, water/metal ratio, etc., allow a versatile control of structural and chemical properties of final oxide materials [13,14].

2.2 Metal Matrix Nanocomposites

It should be consisting of a ductile metal or alloy matrix in which some nanosized reinforcement material is implemented. The metal matrix nanocomposites are suitable for the production of materials with high strength in shear/compression processes and high service temperature capabilities [15]. Both ceramic matrix and metal matrix nanocomposites CNT nanocomposite hold promise, but also pose challenges for real success. The most common techniques for the processing of metal matrix nanocomposites are spray pyrolysis; liquid metal infiltration; rapid solidification; vapour techniques (CVD, PVD); electrodeposition and chemical method which include colloidal and sol gel process [16,17].

2.3 Polymer Matrix Nanocomposites

Polymer materials are widely used in the area of industry due to their ease of production, lightweight and often ductile nature. However, they have some disadvantages, such as low moduli and strength compared to metals and ceramics.

In this context, a very effective approach to improve the mechanical properties is to add fibres, whiskers, platelets or particles as reinforcements to the polymer matrix. For example, the polymers have been filled with several inorganic compounds, either synthetic or natural, in order to increase heat and impact resistance, flame retardancy and mechanical strength. Furthermore, metal and ceramic reinforcements offer striking routes to certain unique magnetic, electronic, optical or catalytic properties coming from inorganic nanoparticles, which add to other polymer properties such as processibility and film forming capability. Another important aspect is that nanoscale reinforcements have an exceptional potential to generate new phenomena, which leads to special properties in these materials. It may be pointed out that the reinforcing efficiency of these composites, even at low volume fractions, is comparable to 40-50% for fibres in microcomposites [18,19]. Addition of reinforcement to a wide variety of polymer resins produces a dramatic improvement in their biodegradability.

There are few methods, which can be explained the preparation of polymer nanocomposites, including layered materials and those containing CNTs.

i) InterCalation of the polymer or pre-polymer from solution
ii) In-situ intercalation polymerization;
iii) Melt intercalation
iv) Direct mixture of polymer and particles
v) Template synthesis
vi) In-situ polymerization
vii) Sol-gel process.

Publications dealing with various methods for the incorporation of nanodispersoids into conducting polymers are also available; the most prominent one is probably the incorporation of inorganic building blocks in organic polymers [20,21].

3. Preparation of Nanocomposites

3.1 Solvent Casting (Exfoliation-Adsorption)

This method is based on the solution system in which the solvent can solve polymer and also disperse the nanomaterial. The solvent can help the mobility of the polymer chains that provide the intercalation of the polymer in nanomaterial layers, or sheets. While the polymer, solvent, and nanomaterial are blended between layers of nanomaterial, polymer, and solvent, and after evaporation of the solvent, the penetrated polymer between nanomaterial layers remains intact which results in nanocomposites. This method can be used for water soluble polymer. However, the disadvantages of these method is the use of large amount of organic solvent, which are expensive and toxic [22]. Exfoliation was carried out by sonication in ethylene glycol and resulted in products that were obtained after heating and vacuuming. After the first composite structure was prepared with the polymer, and final nanocomposite were obtained. We have to synthesize nanocomposites in a water-oil micro emulsion, which is mixed with cellulose acetate-acetone solution. Using phase inversion method, a porous membrane was obtained. The synthesized membrane were used to dechlorinate trichloroethylene in water. Nanocomposite of cellulose acetate were prepared via solvent casting method, which includes dispersion of metallic nanoparticles in ethanol/acetone, mixing with a cellulose acetate/acetone solution, casting and then finally obtained a film, which is used for removal of trichloroethylene from water [23,24].

3.2 Sol-Gel Technology (Template Synthesis)

In sol-gel technology method, inorganic filler is formed in aqueous solution or gel. The polymer behaves as a nucleating agent, which can promote the growth of crystals. After growth of the inorganic advanced filler, polymer intercalates between the nanomaterials and polymer nanocomposites is formed [25]. The template synthesis method is used for the preparation of double layered nanocomposites and is not commonly used for synthesis of PNCs due to high temperature, which degrades polymer and causes aggregation of nanoparticles. Semipermeable/alumina tubular nanocomposite were synthesised with a 200nm diameter pores. The synthesised nanocomposites/ nanocomposites-film using sol-gel technique and investigation of photocatalytic activity of nanocomposites film for the decomposition carried out with various dyes and other various compounds [26,27].

3.3 Electrosprinning

Electrosprinning is the most convenient method for production of nanofibers and nanocomposites. Its advantages include simplicity, cost-effectiveness, higher speed, vast material selection, and versatility. It also provides fiber diameter control. Electrosprinning has three parts as a high-voltage supplier; polymer/composite solution in a capillary tube and a collector [28]. High voltage is applied to obtain an electrically charged jet of composite solution in the needle. Applied voltage provides electrical charge of opposite polarity, and with the formation of electrical field, the surface of the polymer solution droplet is electrified. After that, repulsion occurs, which induces a force that overcomes the surface tension. As a result, a charged jet is ejected from the tip of the needle, and after ejection, the solvent is evaporated, which results in nanofiber/nanocomposite formation on the collector [29]. There are many parameters that can be effective in constructing nanofibers/composites, such as:

- Properties of solution (viscosity, polarity, surface tension, etc.)
- Properties of polymer such as conformation of polymer chains
- Electrical field strength
- Distance between spinneret and collector.

For environmental remediation application, electrosprinning is most widely used method for preparation of Nanocomposites. Obtained composite materials was used as filtration material in removal of particles from water. Also examined filtration ability of nanocomposites, which have a higher flux compared with commercial filtration materials. Furthermore, the obtained membrane has ability to microparticles and bacteria also [30].

3.4 Self-Assembly

Self-assembly is a process in which materials coordinate into specific shapes and functions. Molecule-mediated self-assembly is the most well-known method, which is used for nanocomposite film construction. As environmental applications, synthesized self-assembled nanocomposite membranes for the removal of methanol/methyl tert-butyl ether (MTBE). Self-assembled membranes was synthesized with cross-linked layers of


https://doi.org/10.30799/jnst.315.21070103
polynionic and cationic surfactants. Then, pristine polyelectrolyte surfactant complex membranes were synthesized. Results of the study demonstrated that synthesized self-assembled membranes are potential separation systems for pervaporation separation of polar/nonpolar mixtures [31,32].

4. Properties of Nanocomposites

Nanocomposites are incorporate nanosized particle into a matrix of standard materials. The result of the addition of nanoparticles is a drastic improvement in properties that can include mechanical strength, toughness, electrical or thermal conductivity [33]. Nanocomposites can dramatically improve properties like:

- Mechanical properties including strength, modulus and dimension stability
- Electrical conductivity
- Decreased gas, water and hydrocarbon permeability
- Flame retardancy
- Thermal stability
- Chemical resistance
- Surface appearance
- Optical clarity

Nanoparticles have an extremely high surface to volume ratio, which changes because of their properties. It also changes the way in which the nanoparticles bond with the bulk material. Some nanocomposite materials have been shown to be 1000 times tougher than the bulk component materials [34]. Nanocomposites have been different from conventional composite materials due to the high surface/volume ratio. The area of the interface between the matrix and reinforcement phase is typically an order of magnitude greater than for conventional composite materials. The nanocomposites properties related to local chemistry, degree of thermostet cure, polymer chain mobility, polymer chain conformation, degree of polymer chain ordering or crystallinity can all vary significantly and continuously from the interface with the reinforcement into the bulk of the matrix [35]. The large amount of reinforcement surface area means that a relatively small amount of nanoscale reinforcement can have an observable effect on the macroscale properties of the composite. Other kinds of nanoparticles may result in enhanced optical properties, dielectric properties, heat resistance or mechanical properties such as stiffness, strength and resistance to wear and damage. The number of the nanoparticles introduced very low filler percolation threshold, especially for the most commonly used non-spherical, high aspect ratio fillers [36,37].

5. Benefits and Limitations of Nanocomposites

Nanocomposites have played very important role in manufacturing and in production. The nanocomposites are also used to fabricate different sensors for detection of an unknown material or any hazardous material in environment. There are a few disadvantages associated with using nanocycle before however impact performance. Some research found that by binding two-three nanoparticles together, the hybrid material or nanocomposite has very unique structural and other properties to apply in various sectors. It is very important to see and to implement these nanostuctured nanocomposites in various fields by using their diverse properties. It is observed that there appears to be a reluctance to embrace this new technology due to cost and variability in the quality of some of the products.[1,38,39]. Nanocomposites have been exhibited and proved their various properties like flame resistance, structural properties, thermal properties, electrical properties, optoelectrical properties, chemical-physical properties by different analysis techniques without losing in impact or clarity of the nanocrystals. Because of the nanosized dimensions of the individual atoms/crystals in one direction/two directions exfoliated the transparency in most nanocomposite solutions. However, the surface morphology of nanostructured thin films are multi dimensions with extending to 500nm. Nanocomposites also demonstrate enhanced some different properties like fire resistant properties, hydrophobic properties and chemical binding which are also used in engineering field. In recent research interest of the researchers are to synthesise the hybrid materials by binding different nanoaeroparticles chemically. Nanomaterials are also characterising to optimize and to utilise different properties like these nanomaterials have improved mechanical properties and electrical properties by traditional method. Also increasing in mechanical stability, increase the capabilities of generating energy and improved the photo-physical properties of the nanocomposites also contribute to a reflection on the research. The results of the research show that nanocomposites are the future of the nanoscience by creating various different unknown components, which have unique and diverse properties. Nanocomposites often have a marked reduction in optical clarity by synthesising traditional method, however nanoparticles cause little scattering in the optical spectrum and very little UV scattering. But creating metal-metal oxide nanocomposites or metal-lanthane-oxide composites are an advantageous solution in anicounterfeting technology and in fabricating chemosensors. The high heat resistance and low flammability of some nanocomposites also make them good choices to use as insulators and wire coverings. Another important property of nanocomposites is that they are less porous than regular plastics, making them better to use in the packaging of foods and drinks, vacuum packs and to protect medical instruments and other products from outside contamination [40–42]. In addition, further research will be necessary to, for example, develop a better understanding of formulation or fabrication of nanomaterials to get better routes in improvement of nanotechnology [43].

6. Applications of Nanocomposite

Nanocomposites are promising new applications in many fields such as electronics, medical, packaging, mechanically manufacture components, to fabricate sensors and other systems. Many combinations of nanoparticles have been studied and used in various sectors with the proper choice of compatibilizing chemistries, the nanometer size, chemically interact with different materials/material surface in unique ways. There are few sectors, which are mentioned below [44].

6.1 Electronics

Semiconductor/conductor nanocomposites are capable of generating selfelectric current in their nanostructure. Even metal-metal oxide nanocomposites have been very well used in this sector to conduct the electricity by them self. The structure of these type materials can produce the electrical after binding them together. Metal-metal oxide nanocomposites are easy to synthesise and the process is less time consuming. By binding carbon dots with metal-metal oxide nanocomposites, the nanocomposites have fluorescent properties and electrical/optoelectrical properties to generate selfelectric current. Binding more than two metal-metal oxides together, the nanocomposites have that type of nanstructure which can generate current, so this type of nanocomposites have been used to make electric wires, using it in solar panel and in any electronic gadgets. Recently the research is going on to synthesise lithium-ions and graphene nanocomposites for the battery explosion problem and copper wire leakage problem. By combining this in form of nanocomposites/nanotubes/nanowires with graphene, the nanocomposite was able to reach a milestone of ultra-high conductive properties. By binding these semiconductor nanocomposites, the hybrid material can synthesise for superconductor properties. If it will synthesise than there are lots of free and limitless energy sources will come in the future. Additionally, by modifying the amount of nanoparticles added to the nanocomposites, the electrical conductivity of the nanocomposite could be changed from that of silicon [45,46].

6.2 Films

Nanocomposites have non-porous and chemically a good binder with other material surface, so using the solution of nanocomposites is used to fabricate nanostructured thin film to improve the other material's properties. The presence of nanocomposites on the surface of the material is interacting with the crystals, which have on the surface first layer. Incorporated at nanolevels has also been shown to have significant effects on the transparency and other characteristics of thin films. To improve or to fill the weakness of the material, the nanocomposites thin film can make fined solution to that material. Example the multi-layer of semiconductor nanocomposites on solar panel or transducer can make very vast different comparing to the original source. It can store as much as energy and transfer as much as energy to the other medium. Similarly, nano-modified polymers have been shown, when employed to coat polymeric transparency materials, to enhance both toughness and hardness of these materials without interfering with light transmission characteristics [47].

6.3 Environmental Protection

There are many benefits of nanocomposites to save the environment from the hazardous materials. Metal doped metal oxide nanocomposites have that type of properties, which can detect the hazardous materials in
water and in food beverages. This ability to minimize the extent to which in food beverages/water are absorbed the atoms and detect by quenching study. Researchers found that metal based nanocomposites can be a god option to detect the inorganic or toxic materials because these nanocomposites are easily diluted and chemically easily attached to the atoms of the water and food beverages. Specifically, increasing aspect ratio diminishes substantially the amount of toxic materials absorbed, thus indicating the beneficial effects likely from nanocomposites incorporation compared to microparticle loading [18].

6.4 Food Packaging

In safety of food packaging metal based nanocomposites and fluorescent based nanocomplex are useful to protect the food and duplication of the product. Some nanoparticles have good gaseous barrier property and by binding these nanoparticles, this property can be improved more. Some data provided from various sources which indicate that the less oxygen transmission rates of the polymer nanocomposites. Further data reveals that the polymer nanocomposites with metals or fibers extend the aspect ratio of the filler contributes to overall barrier performance and also improved the quality of food. Development of a combined active/passive oxygen barrier system by adding nanocomposites materials is underway at various laboratories across the world. Passive barrier characteristics are provided by nano clay particles incorporated via melt processing techniques whilst the active contribution comes from an oxygen scavenging ingredient. Oxygen transmission results reveal substantial benefits provided by incorporation in comparison to the base polymer. Increased tortuosity provided by the nanoclay particles essentially slows transmission of oxygen through the composite and drives molecules to the active scavenging species resulting in near zero oxygen transmission for a considerable period of time [48,49].

7. Scope of Nanocomposites

Nanocomposites have been very important in nanoscience because of the inimitable properties, which can be implemented for better future. There are various scopes in different sectors of the nanocomposites [50]:

- Drug delivery systems
- Anti-corrosion barrier coatings
- UV protection gels
- Lubricants and scratch free paints
- New fire retardant materials
- New corrosion resistant materials
- Superior strength fibres and nano thin films
- Self-energy generate materials
- Superhydrophobic materials
- Invisible writing or printing ink for anticounterfeiting polymer applications
- Detect hazardous materials in food beverages
- To fabricate different chemosensors
- Improvment in electro sensor
- Light and strong nanomaterials in automotive filed

Improvements in mechanical properties, electrical properties and chemical properties have resulted in major interest of nanocomposite materials in numerous fields and industrial applications. Today, nanocomposite research is widespread and conducted by various well-known companies and universities across the globe. However, most of these efforts are currently focused on improving the different optical properties, electrical property, electrical property, chemical property and physical property to enhance the use and understand of the concept of nanotechnology [51]. It provides a marked increase in oxygen, carbon dioxide, moisture and odour barrier properties, increased stiffness, strength, heat resistance, maintains thin film on the surface as long. Nanotechnology is revolutionizing the world of materials. It has very high impact in developing a new generation of composites with enhanced functionality and a wide range of applications.

The data on processing characterization and applications helps researchers in understanding and utilizing the special chemical and material principles underlying these cutting-edge polymer/metal/luminescent nanocomposites [52,53]. Although Nanocomposites are realizing many key applications in numerous industrial fields, a number of key technical and economic barriers exist to widespread commercialization. Future trends include the extension of this nanotechnology to additional types of different nanocomposites, where the development of new compatibility strategies would likely be a prerequisite [54,55].

8. Conclusion

Nanotechnology is improving day by day and implementing in every sector. With the help of nanotechnology, the process is cost effective and time consuming. With less human source, the process will complete and conclude with precision and accuracy. Nanomaterials and nanocomposites are an important part or parameter of the nanotechnology. By binding two/three different nanoparticles, nanocomposites are synthesised. Nanocomposites have diverse properties of their related nanoparticles. So with the help of these properties, nanocomposites are useful and having in more demand in every sector. This review article is briefly described the concept of nanocomposites with their related properties and various applications. It also contains the future scope of nanocomposites, so through that conceptual ideas, nanocomposites have been used in various ways to make the future better.

References
