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Review Article

# Nanocomposites: A Newer Technology in Drug Delivery Systems

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## ABSTRACT

Nanotechnology, the study of controlling matter on an atomic and molecular level deals with structures and components with size between 1 to 100 nanometers in at least one dimension, and involves creating or modifying materials or devices within that length scale. One of the fundamental aspects of nanotechnology is the creation of new materials having one of the dimensions at nanoscale. These materials, known as nanomaterials, are engineered at nanoscale and have entirely different properties than their "bulk" counterpart. Nanocomposites involve use of nanofillers that improve properties of the polymer matrix. It makes the nanocomposites much lighter in weight with enhanced thermal, chemical, mechanical, optical, magnetic and electrical properties to a much greater extent than that of the conventional composites. Nanocomposites are being explored in site-specific drug delivery systems and have proved to be safe and biocompatible with targeted effect achieved much faster than the conventional composites.

**Keywords:** Nanocomposites, polymer matrix nanocomposites, intercalation.

## INTRODUCTION

According to Drexler, Nanotechnology is the principle of manipulation of the structure of matter at the molecular level. It entails the ability to build molecular systems with atom-by-atom precision, yielding a variety of nanomachines. The basic attribute of nanotechnology is the size that makes it feasible to be used in many different fields. The nano size of the materials provides advantages such as high surface area and low surface defects in the material thereby improving material properties.

Nanomaterials may be found in human hip joints, Organic Light Emitting Diodes (OLEDs) for displays, ear implants, pacemaker and water splitting. The commonly used engineered nanomaterials in consumer products are nanosilver, carbon nanotubes, metal oxides at nanosized (ferrous oxides, titanium dioxide and zinc oxide), silica and gold. Other engineered nanomaterials used in consumer, medical and industrial products are nanocarbon, cerium oxide, nickel, aluminium oxide and the nanoclays copper oxide, iron oxide and quantum dots.

## 1. COMPOSITION OF NANOCOMPOSITES

Nanocomposites are composite materials having one of the phases with dimension in the nanometer range. Nanocomposites are possible alternatives to microcomposites and monolithics due to their outstanding properties. Nanocomposites are composed of two or more distinct constituents or phases having different physical and chemical properties and are separated by a distinct interface.

The constituent that is generally present in greater quantity is called the matrix. The constituent that is embedded into the matrix material in order to improve the mechanical properties of nanocomposites is called reinforcement (or nanomaterials). Reinforcement is generally in the form of nanosized filler materials. Generally, nanocomposites show anisotropy (properties are directionally dependent) because of the distinct properties of constituents and inhomogeneous distribution of the reinforcement.[1,7]

**Advantages of nanocomposites are as below:**[1]

1. Improvement in properties of matrix material in nanocomposites can be achieved by the addition of small amount of nanofiller materials compared to conventional composites that require high concentration of micro particle to improve properties.

2. Due to the addition of small percentage of nanofiller materials, nanocomposites are much lighter in weight compared to conventional composites.

3. Nanomaterials having size dependent properties with enhanced thermal, chemical, mechanical, optical, magnetic and electrical properties to a much greater extent than conventional composites.

Nanocomposites differ from conventional composites due to high surface area to volume ratio of the reinforcing nanoparticles and their exceptionally high aspect ratio. The reinforcing material can be made up of particles (e.g. minerals, metallic nanoparticles, Carbon nanotubes), sheets (e.g. exfoliated clay stacks, graphene) or fibers (e.g. Electro spun nanofibers).

The area of the interface between the matrix and nano-reinforcement is typically an order of magnitude higher than the conventional composites. Clays are a group of nanofiller materials which have been extensively used for preparation of polymer matrix nanocomposites. Polymer/clay nanocomposites have been receiving tremendous attention recently in academics and in industries due to their improved properties compared to conventional composites.

Properties of nanosized material such as conductivity, mechanical, and optical properties are different than bulk material although composition of material is same. Synthetic polymers are prepared from petrochemicals take very long time to degrade and hence toxic. This drawback can be overcome using biodegradable polymer. Biodegradable polymers may be natural or synthetic. Natural biopolymers include chitosan collagen, silk, and protein. Synthetic biopolymers are polylactic acid (PLA), polyglycolic acid, poly-lactic acid and poly e-caprolactone.

Recently, use of biopolymers such as polysaccharides, proteins, lipids and their blends has been increased as packaging materials because of their biodegradability, sustainability and availability. Biopolymer provides transparent film and coating as oxygen barrier along with improved mechanical properties.[8-11]

However the biopolymer possesses some disadvantages in comparison to synthetic polymer in terms of mechanical stiffness, transparency and thermal stability. These limitations can be overcome by combining nanosize fillers in the biopolymer matrix to prepare nanocomposites. Biodegradability of nanocomposite increases after making composite with nanosized clays.[9,15]

Inorganic materials such as clays, hydroxyapatite, silica and carbon nanotube are mostly used in the preparation of composites. Synergistic effect and strong interfacial interaction of biopolymer and inorganic material could improve the swelling properties, mechanical properties, drug loading capacity and controlled rate of activity.[12-15] Nanocomposites can be prepared with polysaccharides such as hyaluronan and methylcellulose nanocomposites with poly (D, L-lactic-co-glycolic acid) (PLGA). However, in nanocomposite, the interaction between filler-matrix and between filler-filler molecules is important for successful preparation.[16-19]

## 2. BENEFITS OF NANOCOMPOSITES

Key property of nanocomposite is large surface area due to nanosized polymer which results in improved interaction between filler and matrix. It was found that tensile strength of composite increases as concentration of nanofiller increases up to some extent and then remains constant such as addition of nanocrystalline cellulose (up to 5% w/w), in the chitosan matrix increases the tensile strength of composite, beyond this concentration, tensile strength of composite remains constant.[20,21]

Nanoparticles prepared by polysaccharides nanocrystals showed strong interactions in the form of hydrogen bonding between them. It leads to agglomerates of nanoparticles. In nanocomposite, these interactions are beneficial to create filler network within the matrix.

Magnetic nanoparticles are sensitive to external alternating magnetic field. It is used frequently in nanocomposite to control drug release.

Nanocomposite hydrogel has problem of undesired dehydration during its use in drug delivery. However, the study showed that addition of montmorillonite (MMT) nanoclay in the polyvinyl alcohol (PVA) hydrogel increases its water retention property.

Nanocomposites of PLGA-MMT with paclitaxel drug showed enhanced cellular uptake of paclitaxel in cancerous cell and better interaction of nanoparticles with the gastrointestinal tract (GIT). Chitosan/silk fibroin nanocomposite blend film showed improved tensile strength and enhanced water/moisture sensitivity.[22-24]

Poly (ester-amide) functionalized ZnO nanocomposite showed enhanced thermal stability. PLGA alone showed inflammatory response in the spinal cord, but nanocomposite of PLGA with hyaluronan and methylcellulose showed much reduced inflammatory response.

PLA possesses limitations such as low cell adhesion and inflammatory reaction. This can be overcome by making composites with calcium phosphate. PLA/hydroxyapatite composite showed decreased degradation rate compared to PLA alone.[25,26]

Celecoxib is used as adjuvant for treatment of colon cancer. Hemocompatibility studies showed that free celecoxib revealed haemolysis but nanocomposite of hydroxyapatite-chitosan loaded with celecoxib showed decreased haemolytic activity. This is due to the rigid structure of composite which did not attach to the red blood cell membrane. Biodegradability and biocompatibility are principle properties of nanocomposites which allow their use in various types of drug delivery systems.[27,28]

## 3. TYPES OF NANOCOMPOSITES

Nanocomposites are classified according to the types of reinforcement materials and matrix materials used in their construction. According to the type of matrix material, nanocomposites are generally classified into following three classes:

*1. Ceramic Matrix Nanocomposites*

*2. Metal Matrix Nanocomposites*

*3. Polymer Matrix Nanocomposites*

### *Ceramic Matrix Nanocomposites*[1,28,29]

Ceramic matrix nanocomposites with at least one phase having nano dimension are a new generation of engineering materials, having a wide range of applications in industrial sector. Ceramics can be described as solid materials that exhibit very strong ionic bonding in general and in few cases covalent bonding. High melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength, render ceramic-based matrix materials a favourite for applications requiring a structural material that doesnot give way at temperatures above $1500^0C$. Naturally, ceramic matrices are the obvious choice for high temperature applications.

High modulus of elasticity and low tensile strain which most ceramics possess, have combined to cause the failure of attempts to add reinforcements to obtain strength improvement. This is because at the stress levels when ceramics rupture, there is insufficient elongation of the matrix which keeps composite from transferring an effective quantum of load to the reinforcement and the composite may fail unless the percentage of fiber volume is high enough. A material is reinforcement to utilize higher tensile strength of the fiber, to produce an increase in the load bearing capacity of the matrix.

Many methods have been reported in the literature for preparation of ceramic matrix nanocomposites. Generally, the common methods used in microcomposites fabrications are conventional powder method, polymer precursor route, spray pyrolysis, and chemical methods such as sol-gel process, colloidal and precipitation approaches and template synthesis. Some common ceramic matrix nanocomposites include $Al_2O_3/SiO_2$, $SiO_2/Ni$, $Al_2O_3/TiO_2$ and $Al_2O_3/SiC$. After the discovery of carbon nanotubes (CNT), they have been widely used in nanocomposite fabrications. Some common examples of CNT based ceramic matrix nanocomposite include $Al_2O_3$/CNT, $MgAl_2O_4$/ CNT and MgO/CNT.

### *Metal Matrix Nanocomposites*[1,29]

Metal matrix nanocomposites are materials reinforced by nanoparticles and consisting of ductile metal or alloy matrix in which nanoparticles reinforcement is implanted. These composites consist of metal/alloy matrix filled with nanoparticles and display physical, chemical and mechanical properties entirely different from those of matrix material. High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts.

They can withstand elevated temperature in corrosive environment than polymer composites. Most metals and alloys could be used as matrices and they require reinforcement materials which need to remain stable and nonreactive over a range of temperature. Light metals form the matrix for temperature application and the reinforcements in addition to the aforementioned reasons are characterized by high moduli.

Most metals and alloys make good matrices. However, practically, the choices for low temperature applications are not many. Only light metals are responsive, with their low density proving an advantage. Nanoparticles are generally used to improve wear resistance, mechanical properties and damping characteristics. Metal matrix nanocomposites are being investigated by researchers recently, owing to their superior properties due to nanoparticle embedment, thus finding wide range of applications in structural components.

At nano-level the interaction of particles with dislocation becomes important and results in remarkable improvement of mechanical properties. The nanoparticles act as a barrier in dislocation movement and thereby improve the mechanical properties.

The common techniques used for the processing of metal matrix nanocomposites are spray pyrolysis, liquid metal infiltration, vapour techniques, rapid solidification, electrode position and chemical methods, which include colloidal and sol-gel methods. Some common metal matrix nanocomposites include Fe-Cr/$Al_2O_3$, Ni/$Al_2O_3$, Fe/MgO, Al/CNT and Mg/CNT.

### *Polymer Matrix Nanocomposites*[1,30-32]

Polymer matrix nanocomposites are materials that have polymer as a matrix material and nanoadditives are used as reinforcement material. The additives can be one-dimensional (nanotubes and fibers), two-dimensional (layered materials like clay) or three-dimensional (spherical particles). Polymer matrix nanocomposites have been gaining considerable attention both in academia and in industries, due to their outstanding mechanical properties such as high elastic stiffness and strength with a small concentration of nanoadditives. The other excellent properties of polymer nanocomposites are barrier resistance, flame retardancy, wear resistance, magnetic, electrical and optical properties.

A typical polymer matrix composite is a combination of polymer and filler reinforcement. Polyamide is a thermoplastic polymer, and carbon and glass fiber are generally used as reinforcement materials.

The polymer matrix and fillers are generally bonded by weak intermolecular forces, however, in some cases chemical bonding is employed, as well. If the filler material in composite is dispersed on an atomic or molecular level (nanometer level) and chemical bonding with the matrix material is created, then remarkably improvements in the mechanical properties of the composite material and some new and unexpected or exotic properties can be achieved. To achieve high strength, clay minerals (montmorillonite, saponite, hectorite etc.) are being used as filler materials.

Polymers have outstanding properties such as lightweight, high durability, easy processing, corrosion resistance, ductility and low cost. Compared to ceramics and metals, polymers have relatively poor mechanical, thermal and electrical properties. Polymers also have poor gas barrier properties, heat resistance and fire performance properties.

Polymers are less dense than ceramics and metals, they have a low coordination number and lightweight atoms of carbon and hydrogen as a backbone, which makes them find applications as structural components and construction materials in lightweight applications such as automobile, defense, aerospace and electronics.

The inclusion of nanoparticles with high surface area, high surface energy and often with anisotropic geometry in the polymer matrix decreases the interparticle distance and increases polymer matrix interaction strength. Therefore, polymer nanocomposites with completely new set of properties are suitable for new applications and also expand the performance space of traditionally filled polymers.

They use polystyrene (PS), styrene–acrylonitrile copolymer (SAN), polycarbonate (PC) and polypropylene (PP) with alumina beads having 35nm and 400nm dimension as filler materials. The average volume fraction of filler particles is maintained at 25%. Sample preparation consists of polymer solution in a polar solvent and mixing in the beads for several hours on a magnetic stirrer. The mixture is then poured over a large surface container to allow the solvent to evaporate and then subsequently dried under vacuum at $100^0$C.

Pure polymer is then added to the samples to achieve the desired particle volume fractions. In literature, many processes have been described for preparation of polymer nanocomposites including layered materials and those that contain carbon nanotubes. The common ones are 1) *In situ* polymerization; 2) Intercalation of polymer from solution; 3) Direct mixing of polymer and fillers; 4) Melt intercalation; 5) Template synthesis; and 6) Sol-gel process.

Melt blending is a relatively new process of nanocomposite fabrication. This process involves melting of polymer to form a viscous liquid. The nanoparticles are dispersed into polymer matrix by means of high shear rate along with diffusion at high temperature. The nanocomposites are then fabricated by either compression molding or injection molding.

### *Properties of Polymer Matrix Nanocomposites:*[1,32,33]

Properties of nanocomposites depend not only on properties of individual components but also on following important parameters:

- Process used in nanocomposite fabrication
- Degree of mixing of two phases
- Type of adhesion at the matrix interface
- Volume fraction of nanoparticles
- Nanoparticle characteristics
- Nature of the interphase developed at matrix interface
- Size and shape of nanofiller materials
- Morphology of the system

In order to achieve enhanced properties of nanocomposites, the nanosized particles should be dispersed and distributed in the matrix material properly, to prevent agglomeration of particles and deterioration. Aggregates limit the property enhancement of nanocomposites. To achieve maximum property enhancement, the nanoparticles should be homogeneously dispersed in the matrix. Fig. 1 shows distribution pattern of nanoparticles within the matrix material. Other important factor that affects nanocomposite property is the nature of interface between matrix and filler material. The most common feature of polymer matrix nanocomposite is the existence of phase border between the matrix and filler material and hence the development of interface layer between the two. The properties, composition and microstructure at the interface vary across the interface region.[1,34]

If interface region has good bonding between the matrix and filler material, overall properties of nanocomposite will be much profound. Most of the interphase properties depend on the bound surface and therefore the nanocomposite properties can be tailored by optimizing interfacial bond between nanofiller and polymer matrix. The interaction between interconnecting phases depends on the ratio of surface energy of filler and matrix. Nanosized particles have high surface area and the total surface area of a nanoparticle determines the extent of interface phenomenon contributing to the properties of nanocomposites.[35,36]

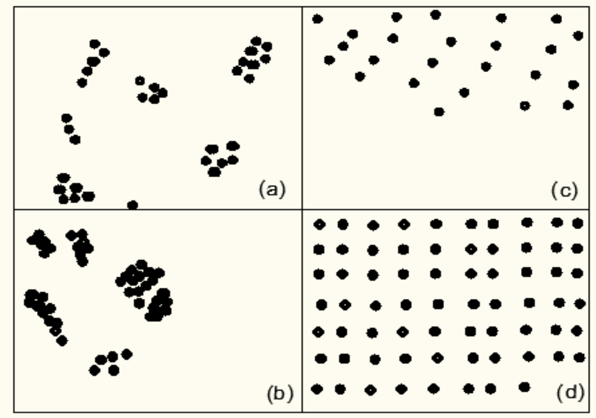

**Figure 1:** Distribution and dispersion of nanoparticles in the matrix

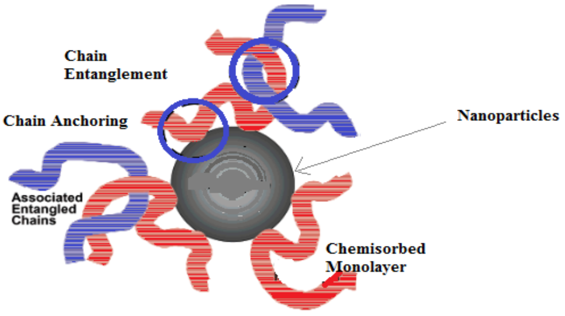

**Figure 2:** Interphase region between nanofiller and polymer matrix

As can be seen in Fig. 2, structure of the region between filler and polymer matrix consists of flexible polymer chains, typically in sequence of adsorbed and unadsorbed segments. Adsorbed segments have point of contact with nanoparticle surface in the form of anchors/ trains while unadsorbed segments have no surface contact and exist as loops and tails entangled with other polymer chains in their vicinity.[1,34] The thickness of the interphase region depends on many factors such as flexibility, energy of adsorption and extent of polymer chain entanglement. The interface structure determines the stress or load transfer from matrix to filler. The host polymer needs to have very good interaction with the nanofiller material surface either chemically or physically in order to have good polymer properties. Good adhesion at the interface improves interlaminar shear strength, corrosion resistance, fatigue, dielectric properties, thermal stability and flame retardancy at low filler-volume fraction.[1, 35-39]

Morphological characteristic nature of the composite system describes structure property relationship of polymer nanoplatelet type of nanocomposite. A good dispersion of nanomaterial is hard to achieve, especially in non-polar polymer, however, uniform dispersion of nanoplatelets ensure good quality of nanocomposites.

Nanocomposites containing layered reinforcements, depending on processing techniques, nature of the components (layered silicate, organic cation and polymer matrix), dispersion techniques, and the interaction between polymer matrix and layered nanomaterial, the microstructure of nanocomposites can be classified as exfoliated, intercalated and phase separated (aggregated).

When the polymer cannot be intercalated between the silicate layers, a phase separated (aggregated) composite is formed, whose properties are almost the same as that of conventional microcomposites. In the intercalated nanocomposites, the polymer chains intercalate into the silicate layers in a crystallographically regular order, regardless of the clay to polymer ratio.

A well-ordered multilayer microstructure is formed with alternating polymeric and clay layers. In an exfoliated nanocomposite, the clay layers are completely and uniformly dispersed in the polymer matrix. The clay layers are separated in the polymer matrix by an average distance that generally depends on clay loading. Generally, the clay layer content in an exfoliated nanocomposite is lower than that of an intercalated nanocomposite.[40,41]

### *Types of Polymer Matrix Nanocomposites*

The major component in polymer matrix nanocomposite is the polymer itself. The choice of polymer matrix material for preparing polymer matrix nanocomposites for a specific application is generally guided by their mechanical, electrical, magnetic, optical, biocompatibility, chemical stability and functionality. Thermoset based nanocomposites are generally most common nanocomposites and have wide applications. Recently thermoplastic-based nanocomposites have attracted much of research interest both in industry and academia. Properties of polymers mainly depend on polymer structure, which in turn depends on chemical composition, surface morphology and processing parameters. The difference between thermoplastics and thermosets is that they respond entirely in a different way to the heat and this is mainly due to the differences in their molecular structures.[1,41]

### *Thermoplastics*

Thermoplastics soften when heated and become more fluid as heating is continued. The curing process of thermoplastics is completely reversible as no cross linking takes place. Thermoplastics soften on heating and harden on cooling. This property allows thermoplastics to be remolded and recycled without affecting the properties.

### *Thermosets*

Thermosets contain polymers that cross-link together during curing process and form an irreversible chemical bond. These polymers do not soft or melt on heating but breakdown chemically at high temperatures. Thermosets have improved mechanical properties, high chemical and heat resistance properties.

## 4. METHODS FOR PREPARATION OF NANOCOMPOSITES

Nanocomposites can be fabricated either by chemical or mechanical process. Uniform and homogeneous dispersion of nanoparticles in polymer matrix is one of the major problems encountered in polymer nanocomposite fabrication. Nanofillers have a tendency to aggregate and form micron size filler cluster, which limits the dispersion of nanoparticles into the polymer matrix thereby deteriorating the properties of nanocomposites. Researchers have made many attempts to disperse nanofillers uniformly and homogeneously in the polymer matrix by chemical reactions, polymerization reactions and surface modifications of filler materials. Mostly nanocomposites are fabricated by the following four methods: [1,42-44]

*Intercalation Method*

*In situ Polymerization*

*Sol - Gel method*

*Direct Mixing Method of polymer and nanofillers*

### *Intercalation Method*

Intercalation method generally involves dispersion of nanoplatelets type of nanomaterials into the polymer matrix. It is well-known that incorporation of clays (nanomaterial) into polymer matrices improves bulk properties such as stiffness, shrinkage and flammability. Intercalation is a top down approach and requires surface modification of nanoplatelets for homogeneous dispersion of plate-like nanofillers in the polymer matrix. Intercalated morphology occurs when polymer chains diffuse into the gallery spacing of layered structure.[1]

**The nanoplatelets can be homogeneously dispersed by the following two techniques:**

*Chemical Technique:* This technique involves *in situ* polymerization method in which nanoparticles are dispersed in the monomer and then polymerization reaction takes place. In this method, nanoplatelets are dispersed into polymer followed by additional polymerization process. The nanoplatelets swell in the monomer solution and polymer formation occurs between the intercalated sheets.

*Mechanical Technique:* In this method, direct intercalation of polymer with nanoplatelets takes place through solution mixing. The polymer is dissolved in a cosolvent and nanoplatelet sheets swell in this solvent. These two solutions when mixed together, the polymer chains in the solution intercalate into nanoplatelet layers and displace the solvent.

### *Melt Intercalation Method*[45,46]

Melt intercalation is a promising method extensively used in the industry. This method involves mixing nanofillers (clays) into the polymer matrix at molten temperature. In this method, mixture of polymer and nanofibers are annealed either statically or under shear as shown in Fig. 3. This method is compatible with current industrial processes, such as extrusion and molding and it allows the use of polymers, which are not suitable for *in situ* polymerization or solution intercalation. Melt blending is a similar process and involves melting of polymer powder or pellets to form a viscous solution and nanofillers are added into this polymer solution by high shear rate combined with high temperature diffusion. The final shape of components can be fabricated by compression molding, injection molding or fiber production technique.

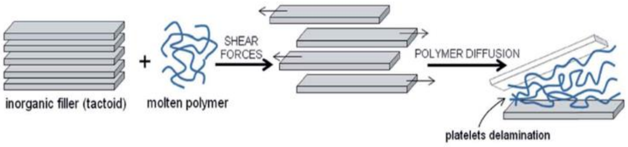

**Figure 3:** Melt Intercalation Method

### *In Situ Polymerization Method*[1,44, 47]

*In situ* polymerization involves swelling of nanofillers in monomer solution since the low-molecular weight monomer solution easily seeps in between the layers causing swelling as shown in Fig. 4. The resulting mixture is polymerized either using radiation, heat, initiator diffusion or by organic initiator. The monomer is then polymerized between interlayers thus forming exfoliated or intercalated nanocomposites as shown in Fig. 4.

*In situ* template synthesis is a similar method where the clay layers are synthesized in the presence of polymer chains. Both polymer matrix and clay layers are dissolved in an aqueous solution and gel is refluxed at high temperature. The polymer chains get trapped inside the clay layers and nucleation along with growth of clay layers take place on the polymer chains at high temperature. The only drawback of this process is that high temperature synthesis causes decomposition of polymer.

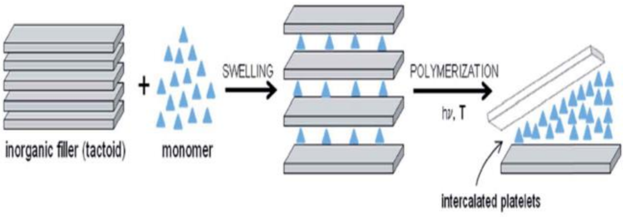

**Figure 4:** *In situ* polymerization

### *Sol - Gel Method*[1,44,48]

Sol- gel method is a bottom up approach and it is based on an opposite principle than all the previous methods. Sol is a colloidal suspension of solid nanoparticles in a monomer solution and gel is the 3D interconnecting network formed between the phases.

In this method, solid nanoparticles are dispersed in the monomer solution forming a colloidal suspension of solid nanopartices (sol). They form interconnecting network between phases (gel) by polymerization reaction followed by hydrolysis. The polymer nanoparticle 3D network extends throughout the liquid as shown in Fig. 5. The polymer serves as a nucleating agent and promotes growth of layered crystals. As the crystals grow, the polymer is seeped between layers and thus nanocomposite is formed.

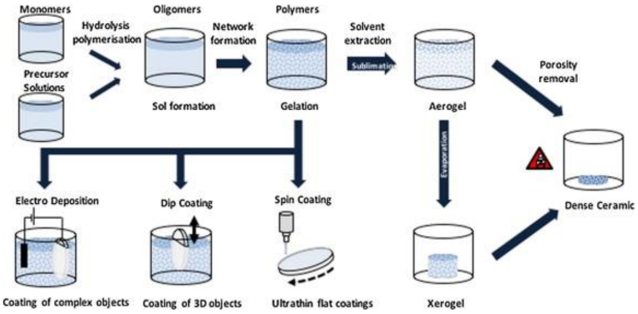

**Figure 5:** Sol - Gel Method

### *Direct Mixing Method of polymer and nanofillers*[1,44,49,50]

Direct mixing of a polymer matrix and nanofillers is a top down approach of [illegible] and it is based on breakdow[illegible]ers during mixing process. This method is suitable for fabricating polymer matrix nanocomposites and involves two general ways of mixing polymer and nanofillers as shown in Fig. 6. One way is mixing the polymer in absence of any solvent, with nanofillers above the glass transition temperature of the polymer generally called melt compounding method. The other way involves mixing of polymer and nanofillers in solution employing solvents generally called solvent method/solution mixing.

(Exfoliated Type)

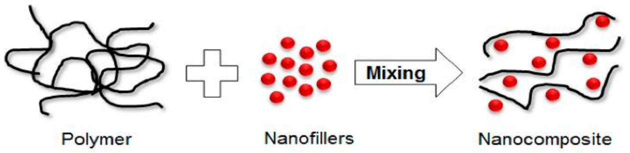

**Figure 6:** Direct Mixing Method of polymer and nanofillers

### *Melt Compounding*

This method involves addition of nanofibers to the polymer above the glass transition temperature. In this kind of method, the shear stress (hydrodynamics force) is induced in the polymer melt by the viscous drag, and this shear stress is used to breakdown the nanofiller aggregates to promote homogeneous and uniform nanofiller dispersion in the polymer matrix.

### *Solvent Method*

In this method, nanoparticles are dispersed in the solvent and polymer is dissolved in a cosolvent. The resulting nanocomposites are recovered from the solvent by solvent evaporation method or by solvent coagulation method. In this method, the shear stress induced in the polymer matrix is lower compared to that in the melt compounding. The nanofillers are predispersed in the solvent by sonication in order to breakdown the nanofiller aggregate. The polymer nanocomposites fabricated by one of the above methods are finally processed by conventional manufacturing methods like injection molding, calendaring, casting, compression molding, blow molding, rotational molding, extrusion molding, thermoforming, etc.

## 5. CHARACTERIZATION OF NANOCOMPOSITES

### Morphological characterization

Following techniques are used for morphological characterization:

### *XRD Techniques*[8,51-55]

XRD interpretation operates on principle of constructive interference formed by X-ray (monochromatic) and crystalline sample. Bragg's law is used to explain constructive interference. Here, XRD is used to determine shape, crystalline, and amorphous nature of nanofiller, drug, and polymer. It is also used to determine phase separation of nanofiller and polymer. Intercalation of layered silicate with polymer can be identified whether exfoliated or intercalated.

### *FTIR*[8,56-58]

Each functional group shows some fixed resonance frequency during infrared irradiation used to detect the functional group. It is used to determine changes in nanobiocomposite in terms of functional groups. Chemical changes occurred during composite preparation by different polymers and drug can be easily detected. It also identifies quality, consistency, presence of unknown metal in the sample and amount of component in the mixture. It is used to determine chemical composition of the intermediate and obtained particle.

### *TEM*[8,51,59,60]

Here, electrons are transmitted through an ultrathin sample. These electrons interact with the sample during their passage. An image is formed from interaction of the electrons during transmission which is detected and magnified. TEM is used to detect internal structure, any defects and space distribution of different phases. It provides comprehensive data about the state of dispersion of nanofiller in the polymer matrix. Nature of intercalation of layered silicate with polymer can be identified, i.e., exfoliated or intercalated.

### *Atomic Force Microscopy*[8,22,61,62]

Images are formed by measuring physical interaction between a sharp AFM tip and the sample. It provides three dimensional images of a particle and group of particles. Surface morphologies such as surface roughness, surface forces and size range of the nanoparticles are determined. Information such as mechanical, chemical and adhesive properties of the surface can be obtained.

### *SEM*[1,51-,53,63,64]

When accelerated electrons are allowed to incident on the sample a three-dimensional image gets formed by secondary electrons and backscattered electrons. It provides data about the morphology of a single polymer, drug and nanocomposite. It provides data about state of the dispersion of nanofiller in a polymer matrix. Surface fracture and aggregation of particles in nanocomposites can also be easily detected.

### Thermal Analysis

### *TGA*[8,24,65,66]

It is used to measure change in weight of a sample as temperature or time changes. Change in weight loss between single polymer and composite can be compared. It suggests physical changes such as melting which does not involve weight loss as well as chemical changes such as combustion which involves weight loss. The weight of the sample is plotted against time or temperature that suggests thermal changes in the material such as loss of solvent, water of hydration in inorganic materials, and finally decomposition of the material.

### *DSC*[8,51-53,59,61,66]

This technique is used to detect nature of crystallization, exothermic and endothermic reactions. In endothermic reactions, e.g., solid sample melts to a liquid; it requires more heat flowing to the sample to increase its temperature at the same rate as the reference because sample absorbs heat to convert into liquid state, hence more heat is required to raise temperature of sample as compared to the reference. Reverse is the case with endothermic reaction which occurs during crystallization.

It provides data about thermal stability of pure polymer and nanocomposite by melting point.

### Swelling Property[1]

Swelling study is mostly performed in nanocomposite hydrogel using hydrogel disc. Temperature, solvent and time of study varies according to the formulation. Solvents used are distilled water, hydrochloric acid, sodium hydroxide, etc. Swelling ratio can be determined by following formula.

$$\text{Swelling ratio} = \frac{\text{weight of swollen particle}}{\text{weight of dry particle}}$$

## 6. APPLICATIONS OF NANOCOMPOSITES IN DRUG DELIVERY SYSTEMS

### *Controlled release*

Nanocomposites of hydrogel with magnetic particles can be used in pulsatile drug delivery system. Remote controlled release of drug is designed using magnetic nanocomposite of N-isopropyl acrylamide (NIPAAm). Iron oxide is used as remote heating device and NIPAAm is a temperature sensitive hydrogel. Alternating the high-frequency magnetic field leads to heat generation in nanocomposites that forces the swelling transition of the hydrogel. It was found that the drug release decreased with increase in the temperature.[8,20]

Nanocomposite of sodium alginate/hydroxyapatite demonstrates controlled release of diclofenac sodium. Prepared nanocomposite beads could be used in the production of oral pharmaceutical formulations. Nanocomposites prolonged the release of diclofenac sodium for 8 h more compared to that of sodium alginate hydrogel beads.[8,16]

Controlled release of drug was also observed in glycolic acid-g-chitosan-gold-nanoflower nanocomposites. The nanohybrid scaffolds were found to be stable towards pH of the medium. The prepared nanohybrid scaffolds are biocompatible. These nanocomposites showed controlled drug release rate in the buffer solution of pH 7.4. It was observed that gold nanoflowers are the viable additive for the glycolic acid grafted chitosan-based system, for drug delivery.[8,67-71]

### *Sustained release*[8,17]

Nanocomposites for treatment of spinal cord injury were prepared successfully as sustained release product containing hyaluronan and methylcellulose hydrogel with PLGA nanoparticles. It was found to be safe and biocompatible. It was well tolerated in intrathecal space of injured rats for 28 days and showed no effect on locomotor functions and no increase in inflammation, scarring or cavity volume relative to the control.

### *Anticancer*[8,26]

Paclitaxel, an anticancer drug cannot be given orally because of low absorption through GIT and first pass effect. Nanocomposites of paclitaxel were prepared using PLGA-MMT for oral delivery. PLGA-MMT nanocomposites demonstrated increased GIT absorption and increases cellular uptake by CaCo-2 and HT-29 cells. The drug release study showed an initial burst release followed by a slow, sustained release which was not significantly affected by the MMT component.

A study showed that nanocomposite of hydroxyapatite-chitosan with celecoxib is effective and safe system for colon cancer drug delivery. It was found that nanocomposite particles overcome side effects shown by free celecoxib. Also nanocomposites of hydroxyapatite-chitosan with celecoxib showed more potent anticancer activity than free celecoxib.

### *Antianemic*[8,72]

Ferroarabinogalactan nanocomposite prepared from nanodispersion of iron oxide in arabinogalactan matrix showed enhanced antianemic activity. Arabinogalactan is obtained from Siberian larch (*Larix sibirica*) and possess antianemic activity. It has been observed that this nanocomposite produced a hemopoiesis stimulator and iron stabilizing effect due to the synergistic effect of iron nanoparticles and arabinogalactan.

### *Antibacterial and antifungal*[8,73]

The potent and safe targeted antibacterial and antifungal drug delivery can be achieved by magnetic nanocomposites of iron oxide and silver nanoparticles. At the observed minimum inhibition concentration, nanocomposites did not exhibit acute cytotoxicity against mice embryonal fibroblasts. The synergistic effect of magnetic properties of iron oxide nanoparticles and antimicrobial property of silver nanoparticles demonstrated the potential of these nanocomposites to be used in antibacterial and antifungal applications as targeted drug delivery systems.

## CONCLUSION

Nanotechnology is the study and control of matter at dimensions of 1 to 100 nanometer. When materials are reduced to nanosized they display unusual and exotic properties due to “nano-effect”. Recently field of nanotechnology has become one of the most effective areas of research and innovation with involvement of polymer science as an integral part. In recent years, polymer nanocomposites have attracted great interest, both in industry and in academia, since they exhibit remarkable improvement in properties when compared to conventional microcomposites. Polymer nanocomposites are made by combination of polymer and synthetic or natural inorganic filler materials employed to improve properties of polymer composites. Polymer nanocomposites contain nanofiller materials that cause “nano-effect” and drastically improve nanocomposite properties.

This article gives us the basic knowledge of nanocomposites with the preparation methods. New technologies require materials that have novel properties, nanomaterials possess these properties that help in improving the performance of components compared to conventionally processed components. In this context, nanomaterials are the most suitable materials to meet the emerging demands arising from scientific community. The article also covers the classification of nanocomposites based on matrix materials along with their processing. However, some of these techniques pose challenges as far as dispersion of nanophase in polymer matrix is concerned. It therefore gives opportunities for the researchers to overcome this problem being encountered with nanosized materials. Nanocomposites offer improved performance compared to conventional composites and monolithic counterparts. Polymer nanocomposites have already being used in many industrial sectors and their applications have been rising drastically.

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