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NANOCOMPOSITES - A REVIEW

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ABSTRACT

Nanocomposite is a multiphase solid material where one of the phases has one, two or three dimensions of less than 100 nanometres(nm) or structures having nano-scale repeat distances between the different phases that make up the material. Nanocomposites are found in nature, for example in the structure of the abalone shell and bone. Taking material dimensions down to nanometre level creates phase interfaces which are very important for enhancement of materials properties. The ratio between surface area and volume of reinforced material used during nanocomposites preparation is directly involved in understanding of structure-property relationship. Nanocomposites are useful in medical, pharmaceutical industry, food packaging, electronics and energy industry. This review focus on the preparation, types and applications of nanocomposites. Nanocomposites are high performance materials which reveal rare properties. Nanocomposites have an estimated annual growth rate of 25% and fastest demand to be in engineering plastics and elastomers.

KEYWORDS: Nanocomposites, Nanometres.

INTRODUCTION

Nanomaterials are any type of material of nano sized thickness, i. e; less than 100 nm in thickness. There are various types, many of which exhibit different properties than bulk materials. One common factor of nanomaterials is that this thickness range is also known as the quantum regime, where quantum effects play a major role in defining the properties. Because of this, nanomaterials often fall into different dimensional categories, be it 2D, 1D or 0D. Nanomaterials exist in different dimensions, not only because they can be one atomic layer thick, but by how their electrons can be confined to flow in a certain number of dimensions. For example 2D materials have their electrons confined in one direction, so the electrons then move in two directions, hence the name. The same principle applies for 1D and 0D materials which have their electrons confined in 2 and 3 dimensions respectively and their electrons can move in 1 and 0 direction respectively.

Classification

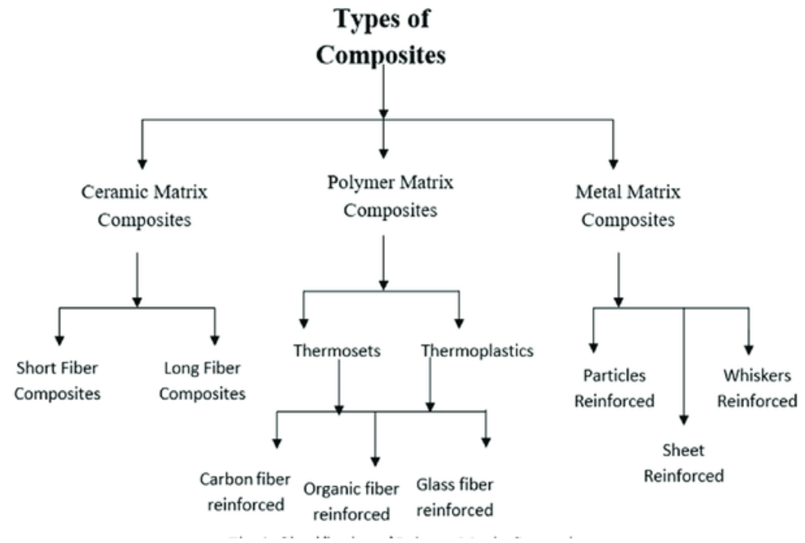

Figure No .1: Overall classification of nanocomposites.

Nanocomposites can be classified in three groups in terms of their matrices

1. Ceramic-matrix nanocomposites,
2. Metal-matrix nanocomposites,
3. Polymer-matrix nanocomposites.

1. Ceramic-matrix nanocomposites.

In materials science, ceramic matrix composites (CMCs) are a subgroup of composite materials and a subgroup of ceramics. They consist of ceramic fibers embedded in a ceramic matrix. The fibers and the matrix both can consist of any ceramic material, whereby carbon and carbon fibers can also be regarded as a ceramic material.

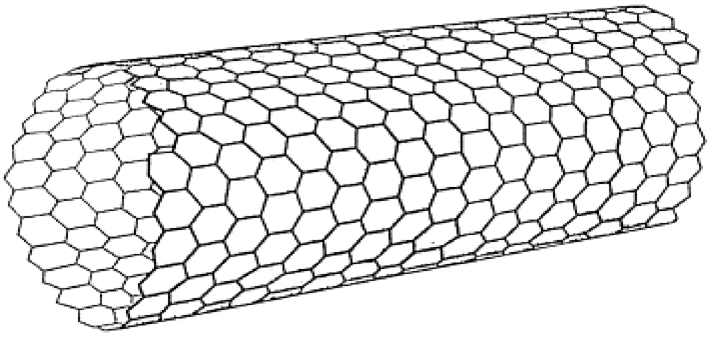

Figure No. 2: Ceramic matrix nanocomposites.

2. Metal matrix nanocomposites

In materials science, a metal matrix composite (MMC) is a composite material with fibers or particles dispersed in a metallic matrix, such as copper, aluminium, or steel. The secondary phase is typically a ceramic (such as alumina or silicon carbide) or another metal. They are typically classified according to the type of reinforcement: short discontinuous fibers (whiskers), continuous fibers, or particulates. There is some overlap between MMCs and cermets, with the latter typically consisting of less than 20% metal by volume. When at least three materials are present, it is called a hybrid composite. MMCs can have much higher strength-to-weight ratios, stiffness, and ductility than traditional materials, so they are often used in demanding applications. MMCs typically have lower thermal and electrical conductivity and poor resistance to radiation [citation needed], limiting their use in the very harshest environments.

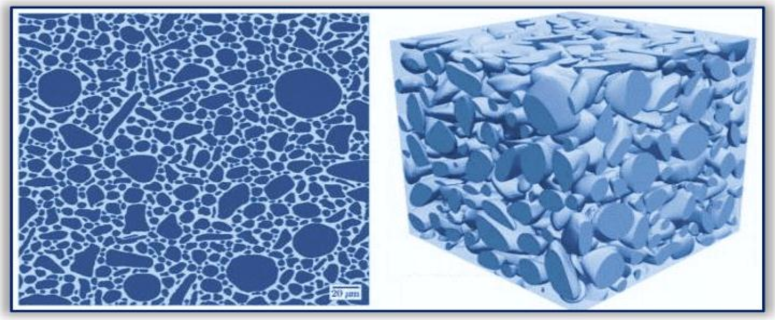

Figure No.3: Metal Matrix Nanocomposites.

3.Polymer matrix nanocomposites

In material science, a polymer matrix composite (PMC) is a composite material composed of a variety of short or continuous fibers bound together by a matrix of organic polymers. PMCs are designed to transfer loads between fibers of a matrix. Some of the advantages with PMCs include their light weight, high resistance to abrasion and corrosion, and high stiffness and strength along the direction of their reinforcements.

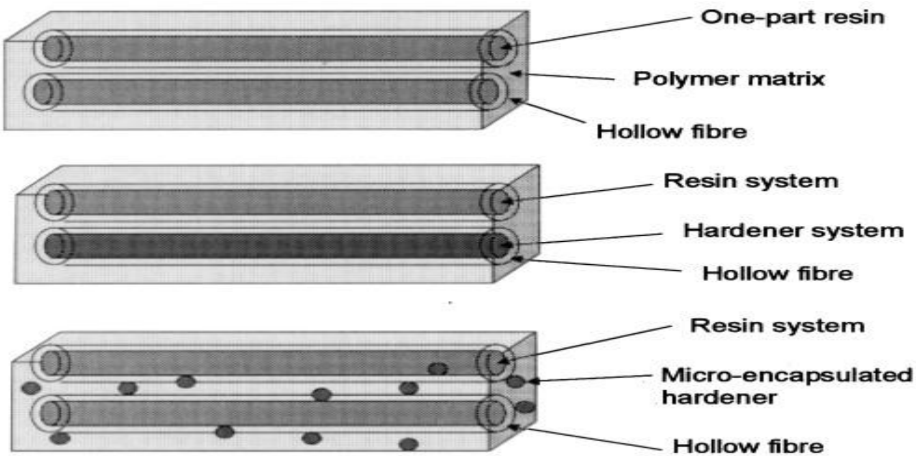

Figure No .4: Polymer matrix nanocomposites.

The nanocomposites can be divided into three categories according to the strength of interfacial interactions between the polymer matrix and layered silicate, such as.

1. Intercalated nanocomposites,
2. Flocculated nanocomposites and
3. Exfoliated nanocomposites

1. Intercalated Nanocomposites

In this class of nanocomposites, the polymer matrix is inserted into the layered silicate structure in a crystallo-graphically regular fashion so as to swell the spacing between the platelets. Generally, these nanocomposites are interlayered by a few molecular layers of polymer, and the properties are very similar to ceramics.

2. Flocculated Nanocomposites

These nanocomposites are very similar to intercalated nanocomposite. Sometimes, in this class of composite, the silicate layers are flocculated because of hydroxylated edge–edge interaction of the silicate layers.

3. Exfoliated Nanocomposites

In exfoliated nanocomposites, depending upon clay loading, the individual clay layers are separated in a continuous polymer matrix. The clay content of this class of nanocomposite is much lower than intercalated nanocomposite. Nano particles of metals, metal oxides, and nonmetal oxides are utilized in nanocomposites as reinforcement components. These nanocomposites show unique mechanical, thermal, and electrical characteristics. Metal nanoparticles have found use in nanocomposites developed for catalyst and biomedical applications. Nanoparticles of metal oxides are added to nanocomposites to obtain mechanical strength, electrical and thermal conductivity, barrier effect, antibacterial effect, UV protection, and self-cleaning property. Among metal oxide particles, TiO_2 and SiO_2 are commonly utilized.Nano clay-reinforced nanocomposites have been extensively studied in terms of their special properties including thermal resistance, flame retardant, stiffness, and strength. Nanowire-based nanocomposite have found use in energy storing and harvesting applications.

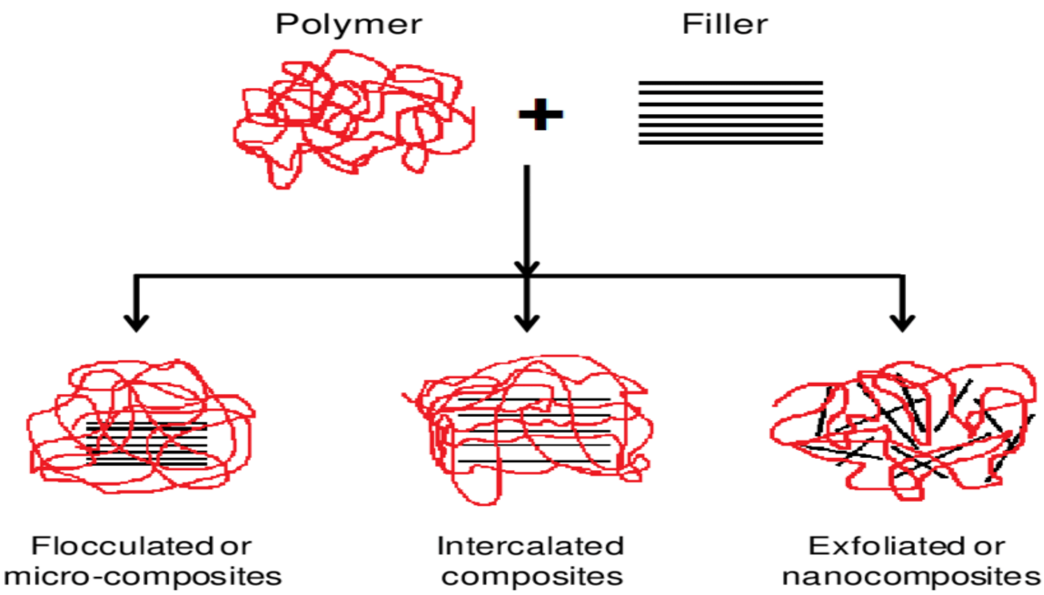

Figure No.5: Intercalated, flocculated and exfoliated polymer/layered silicates (clay) nanocomposites.

Properties of Nanocomposites

The properties of the nanocomposite depend upon the clay and polymer combination, the characteristics of the nanofiller and polymer as well as the structure of the composite produced. The nanocomposite poses noticeable differences in their thermal, mechanical, barrier and electrical properties when compared with traditional composites. The optimal structure of a nanocomposite for one physical property may not be the best for another physical property. This section highlights the properties of nanocomposites.

Thermal Properties

The thermal properties of nanocomposites can be analysed by DSC. From the weight loss on heating the nanocomposites, the thermal stability can be calculated. The heat resistance of nanocomposite on external loading can be measured from the HDT. The dependence of HDT on clay content has been investigated by several researchers. The nanocomposite with good thermal conductivity had multiple applications, such as printed circuit boards, thermal interface materials, heat sinks, connectors and high-performance thermal management systems.

Mechanical Properties

The mechanical properties of nanocomposites, such as tensile strength, elongation and modulus, are affected by the surface morphology and the material used for production. The improvement of mechanical properties of polymer nanocomposite can be attributed to the good affinity between the polymer and nanofiller along with the high rigidity and high aspect ratio of nanofillers.

Electrical Properties

The electrical properties of nanocomposites depend on several factors, such as aspect ratio, dispersion and alignment of the conductive nanofillers in the structure. The nanocomposites containing CNTs have superior electrical properties (high energy densities and low driving voltages). The nanocomposite of ether/clay (organically modified) exhibit ionic conductivity that is several orders of magnitude higher than that of the corresponding clay. The electrical conductivity increased by several orders of magnitude with a very small loading (0.1 wt.% or less) of nanotubes to the nanocomposite, without altering other properties such as optical clarity, mechanical properties and low melt flow viscosities. The conductive nanocomposite has found applications in many fields such as electrostatic dissipation, electrostatic painting, electromagnetic interference shielding, printable circuit wiring and transparent conductive coating.

Barrier Properties

The nanocomposites have very good barrier property against gases because of their high aspect ratio and by the creation of a tortuous path that retards the progress of the gas molecules through the matrix resin. Inside the nanocomposite structure, the presence of the filler introduces a tortuous path for diffusing penetrants. The permeability is reduced because of the longer diffusive path that the penetrants must travel in the presence of filler. The polyimide nanocomposite containing a small fraction of layered silicate exhibit barrier property against small gases such as oxygen, carbon dioxide, helium, nitrogen and ethyl acetate vapours.

Rheological Properties

The flow behaviour of PCL / nylon 6 nanocomposite was significantly different from the corresponding neat matrices. The thermo-rheological properties of the nanocomposite from the behaviour of matrices. The viscoelastic properties of nanocomposites are important in relation to composite processing and composite dynamics and microstructure analysis. Krishna-murti and Giannelis (1997) were the first to describe the rheological properties of in situ polymerized nanocomposite with end-tethered polymer chains.

Different methods for synthesis of polymer nano composites

1. In-situ polymerization

This method normally is suitable for polymers that cannot be produced economically or safely by solutions methods because the solvents used to dissolve them are highly toxic.This method promotes good dispersion and distribution of the nano particles in the polymer matrix. Some important aspects of this method should be pointed out. The first is related to the cost of the process, which can require some changes compared to the normal polymer synthesis. Care is also necessary to choose the most appropriate catalyst.

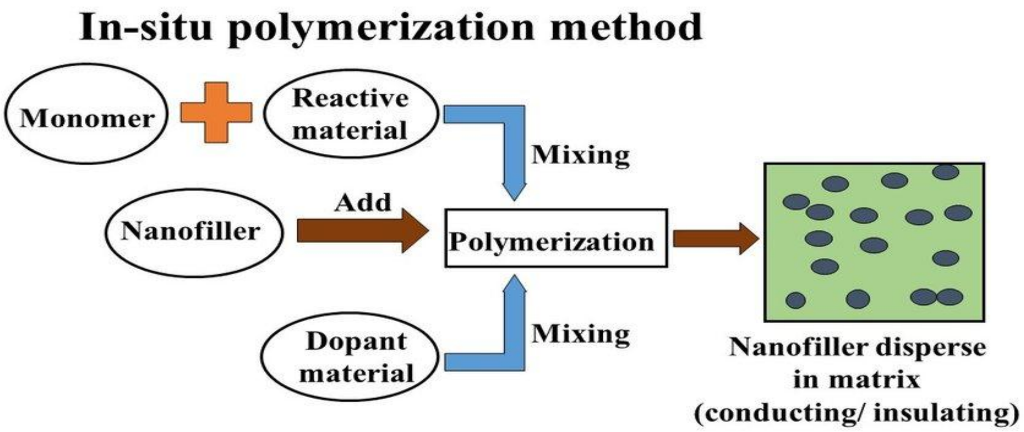

Figure No.6: In-situ polymerization method.

The nano materials were prepared by in situ polymerization employing different clay ratios, from 0.25 to 10% w\w. Solutions of vinyl acetate were poured into Erlenmeyer flasks containing the clay dispersions. After 2 hours of heating at 60-65°C, 5ml of benzoyl peroxide solutions in methanol was add to acetate vinyl solution and the polymerization reaction occurred during 24 hours.

2. Solution polymerization

This is a good method when the solvent used is less toxic (chloroform, acetone, alcohol or water). In this method, different quantities of nano particles can be dispersed due to the good interaction with the solvent and the polymer. This is the easiest method to obtain good nano composites. Some care must be taken in the manipulation of the solvent since it must be completely eliminated afterward. This apparatus is very simple shown in Figure No.7.

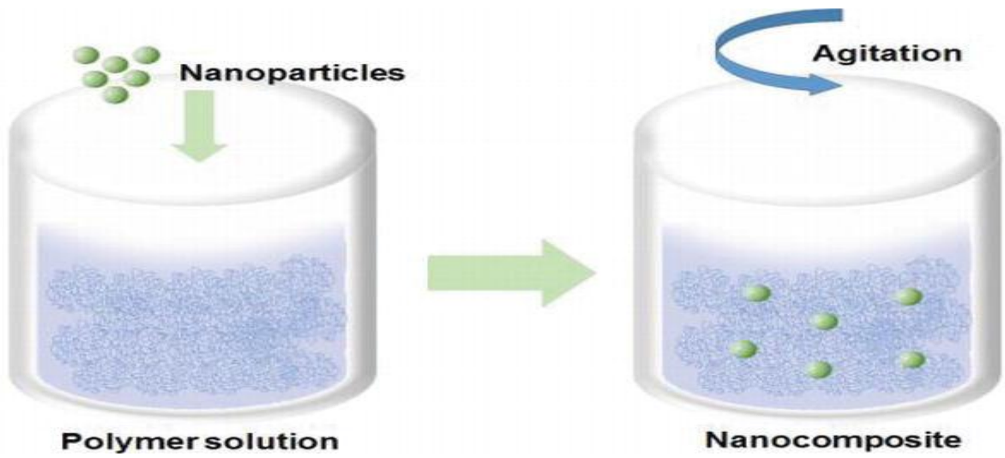

Figure No.7: solution method.

One interesting method is a combination of solution dispersion and spray drying. The dispersion containing the nano particles in the polymer solution, after some time for homogenization, is injected in the spray dryer, which dries the material into a powder. The major drawback of this technique is the final yield of the material. However, this procedure occurs in just one step after all conditions are adjusted and the final material presence good dispersion and distribution. In this process, drugs can be injected together with nano systems for controlled or targeted delivery. The equipment used in this process is shown in Figure No.8.

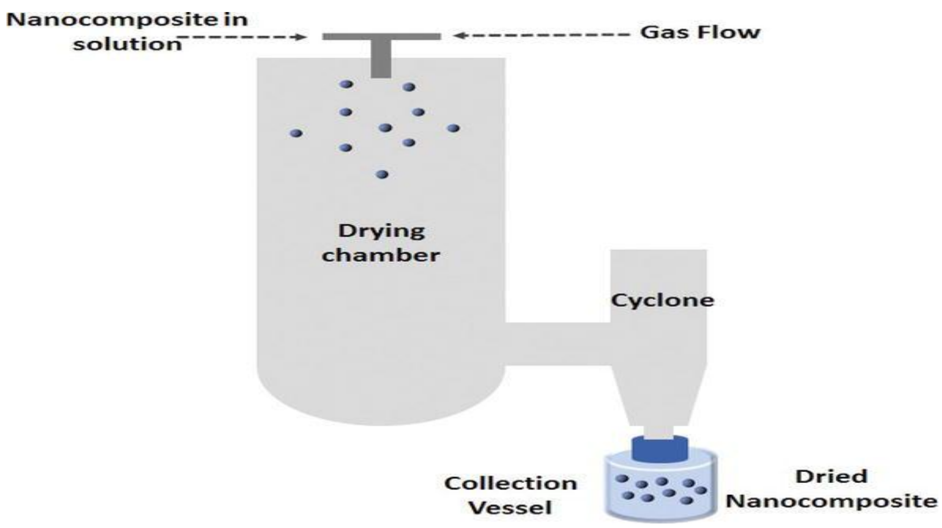

Figure No.8: spray drying method.

3. Melt extrusion

This method has a major advantage in relation to the others since no solvent is necessary. However, the quantity of nano particles to be dispersed is very important. This method requires close monitoring of nano particles dispersion, because this agglomerate easier than in other methods. The apparatus is the same used for polymer processing without nano particles. Therefore, the researcher needs to pay attention to the temperatures used so not to degrade the polymer during extrusion and also must pay attention to the time necessary for the nano particles to disperse properly. For natural polymers and few bio-polymers the degradation and melting temperatures are very close. A typical extruder is shown in Figure No.9.

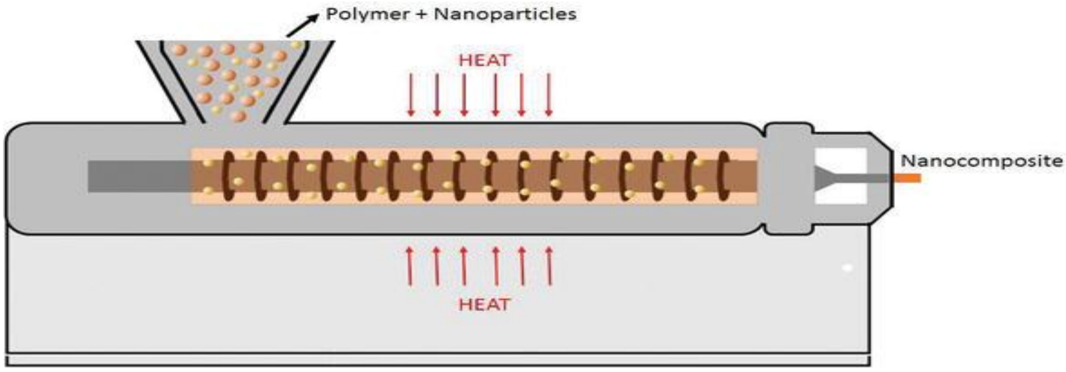

Figure No.9: melt extrusion method.

Applications

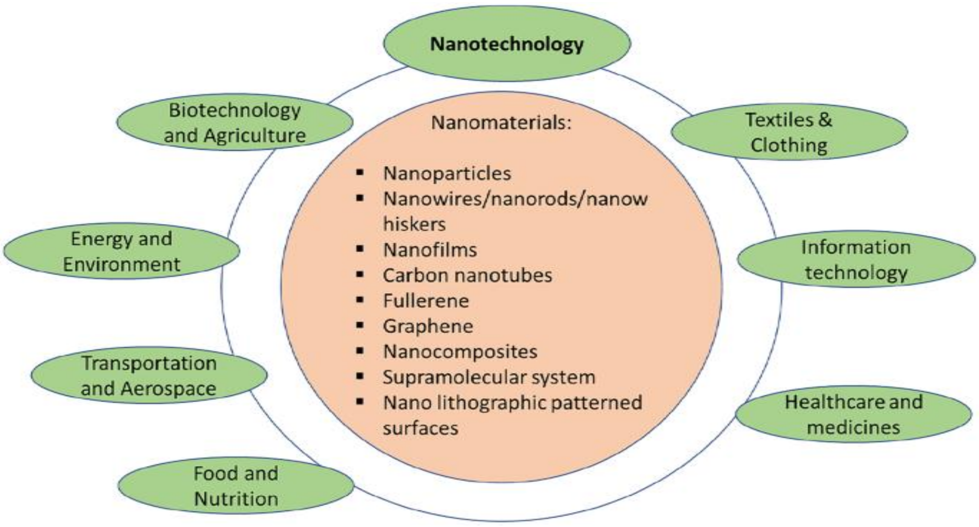

Figure No .10: Functional nanocomposites and their applications.

1. Dental Restoration

The enamel is formed mostly of hydroxyapatite nanocrystals. Dentin, on the other hand, has a more complex composition, presenting lower percentage of nanohydroxyapatite and calcosoherites, which compose about 70% of the tissue. They are dispersed between the organic matrix, which is composed mainly of extracellular matrix and collagen fibrils. The following example provides a better understanding of the role of nanoparticles in the properties of dental restorative materials.

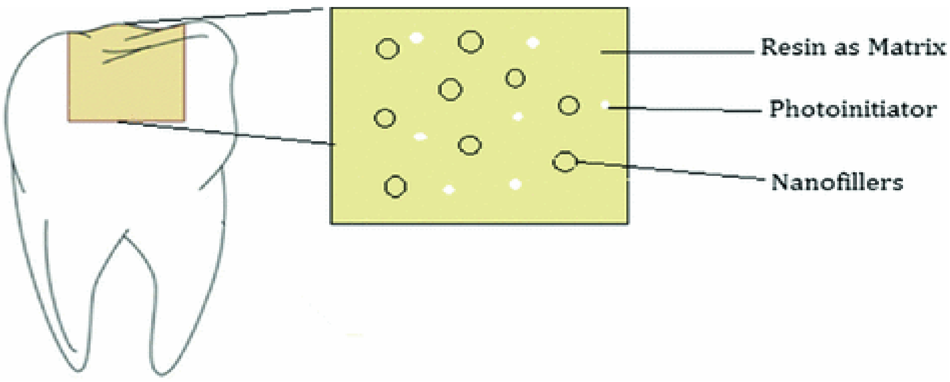

Figure No.11: Dental resin with nano particles.

2. **Drug delivery systems**

Polymeric nanoparticles or nanocomposites have promising features for drug delivery systems, including longer drug circulation time, better targeting to a specific tissue and reduced toxicity and adverse events, making disease treatment more tolerable to patients. In this context, nanocomposites using clay particles have drawn interest in recent years due to the significant changes promoted by small amounts of clay. These loads have several applications, including in polymer matrices aiming at improving mechanical properties, as also seen for dental restorations.

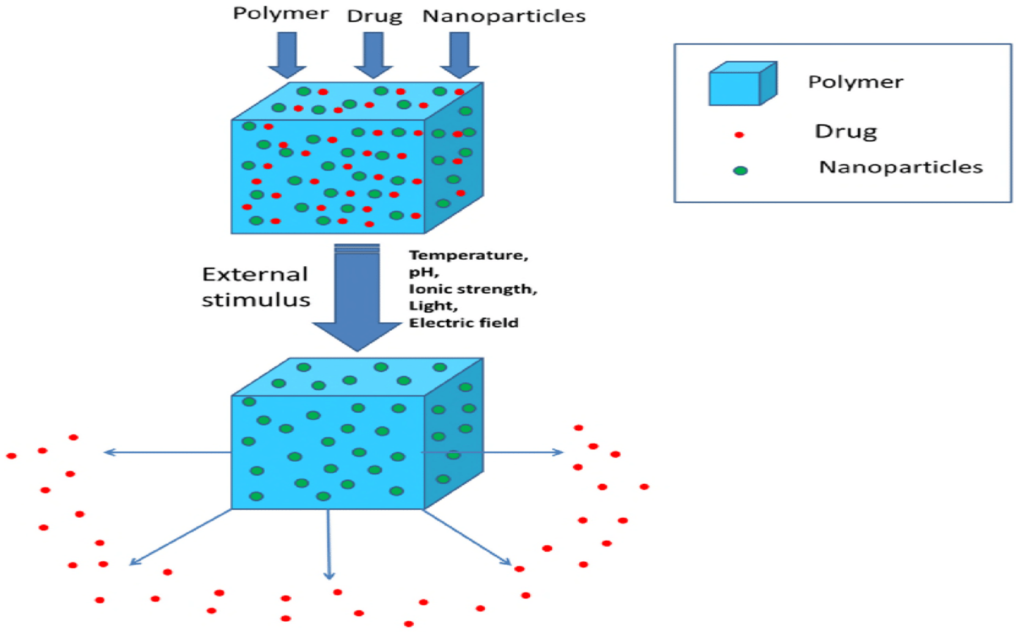

Figure No.12: Drug delivery systems.

The in vitro drug release profiles of these systems containing chlorhexidine and doxycycline in the presence or absence of clay nanoparticles were analysed.

3. Drug release of the systems containing clay.

The systems containing clay allowed prolonged drug release. This behaviour occurs due to the lamellar conformations within the polymeric matrix. The clay layers interfere in the preferential diffusion pathways of the drug, creating more tortuous pathways, delaying the drug diffusion. Thus, after the release of the more external drug molecules, the more internal ones will be gradually released.

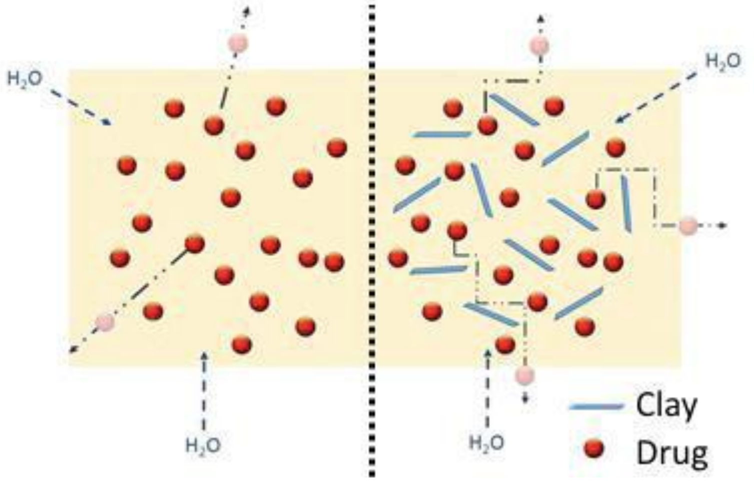

Figure No .13: Drug release of the systems containing clay.

4. Clay polymer nanocomposites

Various types of clay are widely used because they are versatile and can cause chemical modification of the matrix by changing the exchangeable cations. The small size of clay nanoparticles promotes better compatibility between clay polymer matrix. This helps to disperse the clay in the matrix, which can reduce photo-oxy-degradation by acting as a physical barrier to oxygen and reflecting UV light because of the particles large aspect ratio. Also, they can reduce the effect of thermal and chemical degradation due to stronger interactions between clay and matrix.

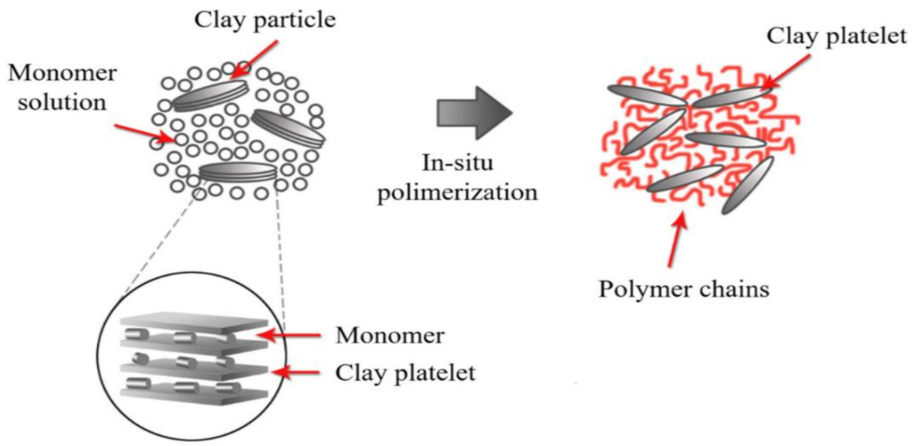

Figure No .14: Clay polymer nanocomposites.

5. Silver nanocomposites

Silver in nanoscale has bactericidal properties and provides UV light protection. This former happens because in nanoscale the asepsis of the oligodynamic effect is improved, killing bacteria. The latter effect is due to reflection of light, blocking photodegradation.

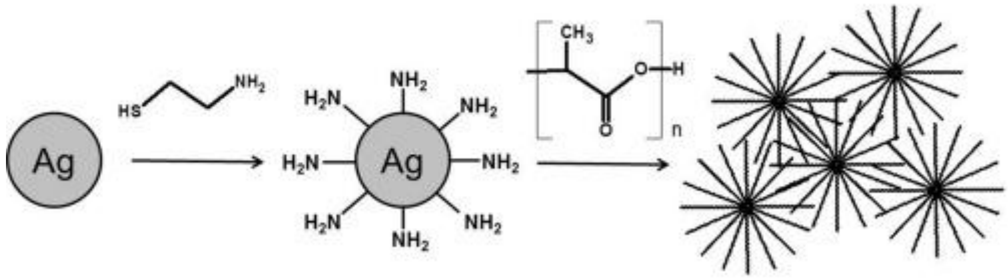

Figure No .15: Silver nanocomposites.

6. Silica nanocomposites

Silica is hydrophilic due to the presence of Si-OH. It can be used to speed up the degradation of synthetic polymer matrixes by microorganisms that need water. Alternatively, the surface can be modified to change it from hydrophilic to hydrophobic, thus improving the resistance of biopolymers against micro-organisms.

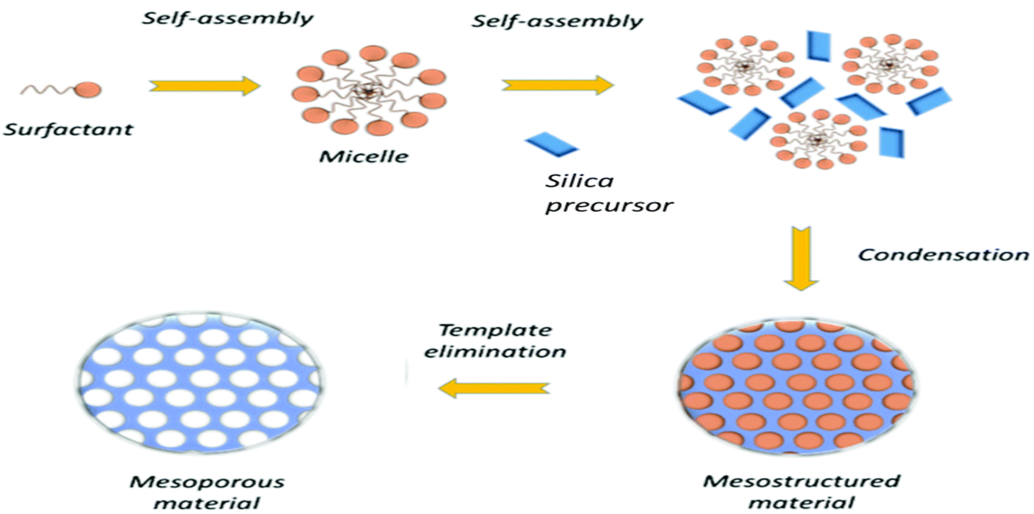

Figure No .16: Silica nanocomposites.

7. **Carbon nanotube nanocomposites**

Carbon nanotubes can have a single wall (CNTs) or multiple walls (MWCNTs).These nanoparticles are commonly used to change polymers that are non-conductors to semi-electrical conductors. Also, CNTs improve the resistance of polymers to UV degradation, mechanical stress and chemical degradation as well as reducing thermal stress.

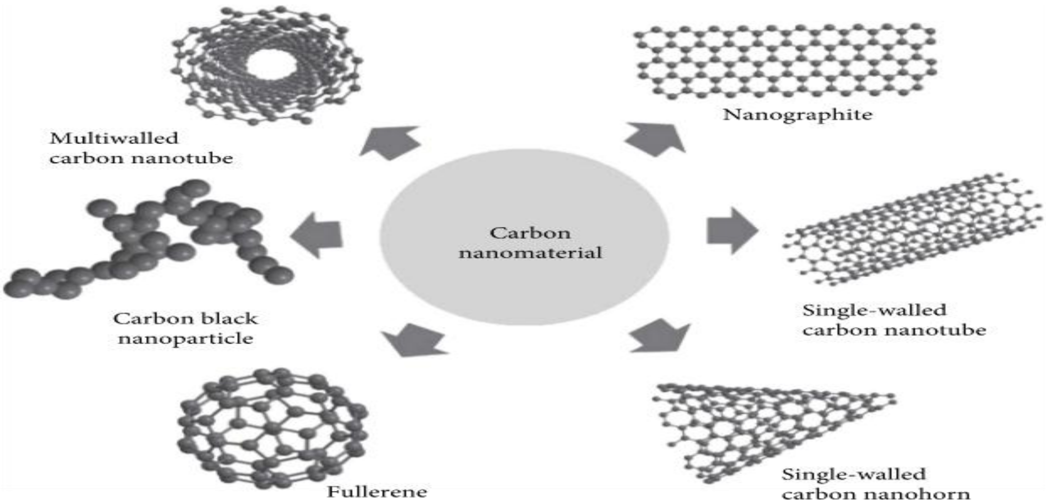

Figure No .17: Carbon nanotube nanocomposites.

Advantages

1.Superior mechanical properties [modulus and strength].
2.Structural and thermal stability.
3.Promising electrical conductivity.
4.Noise damping.
5.Corrosion resistance.
6.Low permeability of fluids.
7.Lower density than ceramic/metallic materials.
8.Low filler content.
9.Ease manufacturing.

Disadvantages

1.Non uniform distribution.
2.High viscosity.
3.Formation of agglomeration.

Abbreviations

CMC- Ceramic Matrix Composites.
MMC-Metal Matrix Composites.
PMC-Polymer Matrix Composites.
DSC-Differential Scanning Calorimetry.
HDT-Heat Distortion Temperature.
CNT-Carbon Nano Tube.
PCL-Poly-Caprolactone.
PVA-Poly Vinyl Alcohol.
FID-Free Induction Decay.
MWCNT-Multiple Wall Carbon Nano Tube.

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