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AN APPRAISAL ON NANOCOMPOSITES: A COROLLARY OF PAST PRESENT AND FUTURE

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ABSTRACT

Solid material of dimensions less than 100 nanometers (nm), having the nanoscale structures distance between different phases that makes the material. The nanocomposites are used to make building blocks having dimensions in nanometer to create and design new materials with good and remarkable flexibility and improves physical property. Therefore the definition of the nanocomposites include colloidal porous media usually taken for the solid combination of nano dimensional phases and bulk properties which differ in properties due to structure and chemical dissimilarities. From the component materials, the mechanical, thermal, electrical, optical, electrochemical, catalytic properties will differ. Nanocomposites have been used in various fields like in food packaging, agriculture and food, health and medicines, producing structural components to weight ratio, making tumours easier to see and remove. Also, nanocomposites are available in various marketed preparations.

KEYWORDS

Nanotechnology, Nanocomposites, Nanoparticles, Dielectric spectroscopy, Biocomposites, Melt intercalation and Sol-gel process.

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INTRODUCTON

The term "Nanotechnology" can be defined as the controlled manipulation of materials with at least one dimension less than 100nm. For creating the new material properties which can be persecuted to develop facile processes for producing electronic devices, biomedical products, high-performance materials and consumer articles, this technology attempts to integrate chemistry, physics, material science and biology. Basically in all technical disciplines, the field of nanotechnology is one of the most popular areas for current research and development. Nanocomposites composed of multiphase materials such as polymers inorganic ceramics, metals in which has dimension less than 100nm.

Nanocomposites are the materials of the twenty-first century having an annual growth rate of 25% due to their multifunctional capabilities as well as with unique design possibilities and properties. The materials used for nanocomposite used to enclose a large variety of systems which are one-dimensional, two-dimensional, three-dimensional. The amorphous materials made up of distinct dissimilar components and at the nanometer scale, these components are mixed. Polymer nanocomposites comprising nanoparticles. The methods used for preparing nanocomposites depends upon the types of matrix used, may vary from mechanical and chemical routes vapour phase deposition. Chemical property like resistance or passiveness to corrosion is very important[1].

CLASSIFICATION

Based on their engineering applications, nanocomposites can be classified either,

1. Functional Materials i.e. based on the electrical, magnetical, and/or optical behaviour, the example is a nanolayered semiconductor (semiconductor superlattice)[2].
2. Structural materials i.e. based on their mechanical properties.

Nanocomposites can also be classified as,

1. Polymer-based
2. Non-polymer based

Polymer-based Nanocomposites

Polymer- based nanocomposites can further divided as:

Polymer /Ceramic Nanocomposite
Inorganic/Organic Polymer Nanocomposite
Inorganic/Organic Hybrid Nanocomposite
Polymer/Layered Silicate Nanocomposite
Polymer/ Polymer Nanocomposite
Biocomposite

Non- polymer based Nanocompsites

Non-polymer based nanocomposites can further divided as:

Metal/Metal Nanocomposites
Metal/Ceramic Nanocomposites
Ceramic/Ceramic Nanocomposites

Based on the type of filler, i.e., nanocomposites containing nanoscale material, for sensing applications they are divided into,

1. Metal oxide- metal oxide-based nanocomposites.
2. Polymer-based nanocomposites
3. Carbon-based nanocomposites
4. Noble-metal-based nanocomposites

Polymer-based Nanocomposites

Polymer-based nanocomposites are polymer matrix which is filled with at least one dimension less than 100nm. The fillers used may be clay, high aspect ratio, nanotubes and lower aspect ratio or Nanoparticles.

Polymer/ceramic nanocomposite

In polymer/ceramic nanocomposites the single ceramic layer is dispersed in a continuous matrix. Nanocomposite-bone i.e. natural bone consists of approximately 30% matrix (collagen) material and 70% nanosized minerals (hydroxyapatite).

Inorganic/organic polymer nanocomposites

Metal-polymer nanocomposites attract attention Because of the unique properties of metal clusters, metal polymer nanocomposites attract attention, which are dispersed in a polymer matrix. The approximate size of such metal cluster is 1-10nm. The properties of clusters and nanoparticles are very different from those of bulk materials and individual atom or molecules.

Inorganic/Organic Hybrid Nanocomposites

The inorganic/organic hybrid nanocomposites can be broadly defined as the nanocomposites with organic and inorganic components mixed and they are not simply the physical mixtures.

Polymer/Layered Silicate Nanocomposites

In polymer science research, polymer/Layered silicate (PLS) nanocomposites have considerable interest. In recent years, both in industry and academics, the PLS Nanocomposites have more importance, because they manifest remarkable improvements in materials when compare with virgin polymer and conventional macro and micro composites.

Polymer/polymer Nanocomposites

In this type of nanocomposites, mixtures of different polymers often phase separate, even when their monomer mixed homogenously.

Biocomposites

In orthopaedics, dentistry and other load-bearing applications, metals and metal alloys are used. Ceramics are used either with their chemically inert nature or high bioactivity; all polymers are used for soft tissue replacements and used for many other non-structural applications.

Non- polymer-based Nano-composites

Metal/Metal Nanocomposites

In the form of alloy or core-shell structures or being investigated in some depth, bimetallic nanoparticles are used because of their improved catalytic properties and changes in the electronic /optical properties related to individual separate metals. It is postulated their interesting their physic-chemical properties, result from the combination of two kinds of metals and they are fine structures.

Metal/Ceramics Nanocomposites

In metal/ceramics types of nanocomposites, the magnetic, electric, optical, and mechanical properties of both phases are combined. The nanocomposite properties and results in the new application improves due to the size reduction of the components.

Ceramic/Ceramic Nanocomposites

Ceramic Nanocomposites can be used in the fracture failures in artificial joint implants; this can helps in the patient's mobility and helps in the elimination of the high cost of surgery. Zirconia-toughened alumina nanocomposite for the formation of Ceramic/ceramic implants Zirconia-toughened with potential life spends of more than 30 years can be used.

Broad Classification of Nanocomposites

Metal oxide-based nanocomposites

Uniform sized nanocomposite synthesis is very important as their properties include optical, magnetic and biological properties depending on their dimensions and size. The synthetic methods are frequently classified into three classes i.e. synthesis based on solution, synthesis of vapour phase and synthesis of the gas phase. Another approach is to divide these synthetic approaches into two broad categories i.e. a) top-down approach which includes physical methods and b) bottom-up approach which encompasses wet methods.

Polymer-based nanocomposites

Polymer-based nanocomposites also called as nano filled polymers are polymer matrices which contain organic or inorganic fillers with a homogeneous nanoscale distribution (having dimensions from 10 to 100nm), prepared by physical blending or chemical polymerizing technologies.

Carbon-based nanocomposites

Amazing structures can be formed by the elemental carbon inn sp^2 hybridization. Carbon can build open and closed cages like honeycomb atomic arrangement, besides from the well-known graphite. Several tons of graphite shells (so-called multi-walled carbon nanotubes (MWNT). Two years later, single-walled carbon nanotubes (SWNT) was synthesized. The carbon nanotubes are of two types which have high structural perfection. Single-walled carbon nanotubes (SWNT) consists of a single graphite sheet wrapped into a cylindrical tube. Multiwalled nanotubes (MWNT consists of an array of such nanotubes that are concentrically nested like rings of a tree trunk[4].

Noble metal-based nanocomposites

From the ancient time in medicine for the treatment of various infections, noble metals and their compounds have been used as therapeutic agents. Recently, much progress has been made in the field of nanotechnology towards the developments of different kinds of nanomaterials with a wide range of applications.

PROCESSING OF NANOCOMPOSITES

Raw materials

As with micro composites, CMNC matrix materials include Al_2O_3, SiC, SiN, etc., a whole range of polymers, e.g. vinyl polymers, condensation polymers, polyolefines, speciality polymers which includes a variety of biodegradable molecules used in PMNC, while metal matrices employed in MMNC are mainly Al, Mg, Pb, Sn, W and Fe[5].

Processing Methods

Despite of their nano dimensions, the three types of nanocomposites remain almost the same as in micro composites. For CNT- reinforced composites, this is also true. Details on these techniques are given below:

Ceramic Matrix Nanocomposites (CMNC)

Many methods have been described for the preparation of ceramic matrix nanocomposites[6]. Table No.5 lists systems and some of these methods, Table No.6 shows their advantages and limitations.

Metal Matrix Nanocomposites (MMNC)

Liquid metal infiltration, spray pyrolysis; rapid solidification; vapour techniques (PVD, CVD); electrode position and chemical methods, which include sol-gel and colloidal processes are the most common techniques for the processing of metal matrix nanocomposites. In Table No.8 there are various systems prepared by these methods.

Polymer Matrix Nanocomposites (PMNC)

For the preparation of polymer nanocomposites, many methods have been described which includes layered materials and those containing CNTs 151-308. The most important layered materials are i) Intercalation of the polymer or pre-polymer from solution; ii) In-situ polymerization; iii) Melt intercalation; iv) Direct mixture of polymer and particulates; v) Synthesis of template; vi) Sol-gel process, vii)In-situ polymerization. There are various methods for the incorporation of nanodispersions into conducting polymers are also available; the most prominent one is probably the incorporation of inorganic building blocks in organic polymers.

Table No.10 shows the procedures adopted in some of these processes, while their advantages and limitations are listed in Table No.11.

The preparation of CNT-reinforced polymer nanocomposites are generally prepared by different methods which include direct mixing, solution mixing, melt-mixing and in-situ polymerization. These, as applicable to various systems are listed in Table No.12.

BENEFITS OF NANOCOMPOSITES

Generally, nanocomposites produce in the barrier, flame resistance, structural, and thermal properties without significant loss of impact or clarity. The tightly bound structure in a polymer matrix is impermeable to gases and liquids, however, with surface dimensions extending to 1 micron and offers superior barrier properties over the neat polymer[59].

Barrier and mechanical properties are enhanced by the polymer clay nanocomposites and are less flammable. Properties which have been shown to undergo substantial improvements include:

Mechanical properties e.g. strength, modulus and dimensional stability

Decreased permeability to gases, water and hydrocarbons

Thermal stability and heat distortion temperature

Flame retardancy and reduced smoke emissions

Chemical resistance

Surface appearance

Electrical conductivity

Nanocomposites have many benefits such as barrier properties, Flexural strength, improvement in modulus, heat deviation temperature. In plastics, the advantages of nanocomposites conventional ones are unable to at strength. To use as insulators and wire coverings, the high heat resistance and low flammability of soma nanocomposites also make them good choices. The Nanocomposites are less porous than regular plastics, for use in the packaging of foods and drinks, vacuum packs, and to protect medical instruments, film, and other products from outside contamination are the most important property of nanocomposites.

APPLICATIONS

Nanocomposites have been used in various fields and new applications are being continuously developed.

Food Packaging

Nanocomposites have the greatest interest in food packaging applications, both flexible and rigid. Specific examples embody packaging for processed meats, cheese, confectionery, cereals and boil-in-the-bag foods, additionally extrusion-coating applications in association with cardboard for a drink and farm product, alongside co-extrusion processes for the manufacture of brewage and effervescent drinks bottles. The use of nanocomposite packaging would be expected considering the shelf life of many types of food.

Application in Agriculture and Food

The MONC are widely used in packaging of foodstuff, not only provides strength as a filler material (silicates, clays, TiO2) while in the agriculture sector, MONC used as a nanosensor for pesticide and pathogen detection in plants and source for delivery of genetic material for the improvement of crops[60,61]. Nanoparticles containing metal oxides (ZnO and CuO) and their nanocomposite (with fertilizers and zeolite) used as slow and controlled release of fertilizers provide nutrients to plants for a prolonged period and also helps in prevention of soil degradation and improvement of sustainable agriculture[62,63].

Application in Health and medicine

The metal oxide nanocomposites found many applications in drug delivery, medicines, imaging, diagnosis and screening of diseases, DNA sequencing, in gene therapy and tissue culturing and in cancer treatment[64].

Spreading up the healing process for broken bones

Replacement bone growth is speeding once a nanotube-polymer nanocomposite is placed as a sort of scaffold that guides the growth of replacement bone. The researchers' area unit conducting studies to higher perceive however this nanocomposite will increase bone growth.

Making tumours easier to see and remove

Researchers try to affix magnetic nanoparticles and fluorescent nanoparticles in an exceedingly nanocomposite particle that's each magnetic and fluorescent. The magnetic property of the nanocomposite particle males the tumors more visible during an MRI done before surgery.

FUTURE OUTLOOK

The pace of revolutionary discoveries currently in applied science is predicted to accelerate within the next decade worldwide. This has a profound impact on existing and emerging technologies in almost all industry sectors, in the conservation of materials and energy, in bio-medicine and environmental sustainability. Potential technological applications with high business impact is predicted in areas of super plastic forming of ceramics, extortionate high strength and arduous structural materials.

One question unremarkably asked is "How typically will these compounds be applied within the long?" It is impossible to give a definitive answer at this state of knowledge. Polymer nanocomposites can do much more than enhancing classic engineering properties and barriers. Range finding work provides evidence for improvement in electrical phenomena, UV stabilization, fire retardancy and control of polymer crystallization. A decade pas nanocomposite technology was a plan with nice potential. Today it is a reality and tomorrow it will flourish[66].

Table No.1: Different types of nanocomposites

S.No	Class	Examples
1	Metal	Fe-Cr/Al_2O_3, Ni/Al_2O_3, Co/Cr, Fe/MgO, Al/CNT, Mg/CNT
2	Ceramics	Al_2O_3/SiO_2, SiO_2/Ni, Al_2O_3/TiO_2, Al_2O_3/SiC, Al_2O_3/CNT

Table No.2: Advantages and limitations of Ceramic nanocomposite processing methods

S.No	Methods	Advantages	Limitations
1	Powder process	Simple	Low formation rate, High temperature, agglomeration, poor phase dispersion, forms secondary phases in the product.
2	Polymer precursor process	Possibility of preparing finer particles; better reinforcement dispersion	Inhomogeneous and phase segregated materials due to agglomeration and dispersion of ultrafine particles[3].

Table No.3: Advantages and limitations of processing methods for metal-based nanocomposites

S.No	Methods	Advantages	Limitations
1	Pyrolysis of Spray	Effectively used for the preparation of spherical, homogeneous, very fine, and produce reproductive size and quality	For producing large quantities of uniform, nanosized particles, high cost is required.
2	Infiltration of liquid	Matrix and reinforcements, moulding into different and near net shapes of different stiffness and enhanced wear resistance; rapid solidification, requires a short time for both lab-scale and industrial-scale production.	Segregation, use of high temperature, during processing formation of undesired products during processing.
3	Rapid solidification process (RSP)	Effective and Simple	Metal-metal nanocomposites; activates agglomeration and non-homogeneous distributes fine particles.
4	RSP with ultrasonics	Distribution without agglomeration with fine particles	
5	High energy ball milling	Uniform distribution and Homogeneous mixing	

Table No.4: Advantages and limitations of polymer-based nanocomposite processing methods

S.No	Methods	Advantages	Limitations
1	Prepolymer/intercalation from solution	Inserated nanocomposites synthesis based on polymers having low or no polarity. Homogeneous dispersive fillers preparation.	Large amounts of industrial solvents requires
2	Inserted polymerization in situ	Based on the dispersion of the filler in the polymer precursors, having an easy procedure	Difficulty in controlling polymerization. Have limited applications.
3	Melt intercalation	Benign environmentally, polymers not suitable for the other processes, able to exist with industrial polymer processes.	Polyolefines have limited applications, requires majority of the polymers.
4	Synthesis of template	Easy procedure and large scale production	Based on water-soluble polymers, can be contaminated by side products, limited applications.

Table No.5: Processing methods for ceramic nanocomposites

S.No	Process	System	Procedure
1	Powder process	Al_2O_3/SiC	i) Selection of raw materials[mostly powders- uniformity, small average size and high purity]; ii) Wet ball milling mixing or attrition milling mixing techniques in organic or aqueous media; iii) Using lamps and/or ovens, or by freeze-drying, drying by heating; iv) Consolidation of the solid material by either hot pressing or gas pressure sintering or slip casting or injection molding and press filtration.
2	Sol-Gel Process	SiO_2/Ni, ZnO/Co, TiO_2/Fe_2O_3, La_2O_3/TiO_2, Al_2O_3/SiO_2, $Al_2O_3/SiO_2/ZrO_2$, TiO_2/Fe_2TiO_5, $NdAlO_3/Al_2O_3$	Hydrolysis and polycondensation reactions of an (in) organic molecular precursor dissolved in organic media. Reactions lead to the formation of three-dimensional polymers containing metal-oxygen bonds (sol or gel)→ drying to get a solid material and further consolidation by thermal treatment.

Table No.6: Advantages and limitations of ceramic nanocomposites

S.No	Method	Advantages	Limitations
1	Powder process	Simple	Low formation rate, high temperature, agglomeration, poor phase dispersion, the formation of secondary phases in the product[7].
2	Sol-Gel Process	Versatile, Simple, low -temperature requirement, versatile, purity of products, high chemical homogeneity, rigorous stoichiometry control, preparation of three- dimensional polymers which contains oxygen-metal bonds. Single and multiple matrices.	Greater shrinkage and lower amounts of voids, compared to the mixing methods.

Table No.7: Processing methods for ceramic-CNT nanocomposites

S.No	Process	System	Procedure
1	Hot pressing	SiC/CNT, SiO_2/CNT	Into ethanol, dispersion of CNTs and SiO_2 glass powders stirring and ultrasonic treatment, hot pressure sintering and drying in pure N_2 atmosphere. Nanoparticles mixing of SiC and carbon nanotubes[8].
2	CVD or Spray Pyrolysis	Al_2O_3/CNT	Preparation of alumina matrix by anodizing growth of CNTs into its porous walls. CNTs grow into a hexagonal array of straight pores extending from the substrate to the matrix surface[9].
3	Catalytic decomposition	Al_2O_3/CNT	Use of acetylene over Al_2O_3 powder impregnated with iron catalysts[10].
4	Solvothermal process	CNT/ Fe_3O_4	CNTs dispersion in EDA (ethylenediamine) by using ultrasonic treatment; urea complex addition; By using Teflon-lined autoclave, maintained at 200^oC for 50 hours, followed by cooling to room temperature[11].

Table No.8: Processing methods for metal-based nanocomposites system

S.No	Process	System	Procedure
1	Liquid Infiltration	Pb/Cu, Pb/Fe, W/Cu, Nb/Cu, Nb/Fe, Al-C_{60}	i) Mixing of fine reinforcement particles with the matrix metal material; ii) Thermal treatment, whereby the matrix melts and surrounds the reinforcements by liquid infiltration; iii) Further thermal treatment below the matrix melting point to promote consolidation and eliminate internal porosity[12-14].
2	Rapid Solidification Process (RSP)	Al/Pb, Al/X/Zr (X=Si, Cu, Ni), Fe alloy	i) The metal components are mixed; ii) Melt above the critical line so that the miscibility gap between the different components ensures homogeneity. iii) Melt by any process for rapid solidification such as melting spinning[15,16].
3	RSP with ultrasonics	Al/SiC	Use of ultrasonic for mixing and for improving wettability between the matrix and the reinforcements[17].
4	High energy ball milling	Cu-Al_2O_3	Milling the powders together till the required nanosized alloy is obtained $\longrightarrow$ Nanocomposites[18].
5	Chemical Processes (Sol-gel, Colloids)	Ag/Au, Fe/SiO_2, Au/Fe/Au	Colloidal method: i) Chemical reduction of inorganic salts in solution to synthesize metal particles; ii) Consolidation of the dry material; iii) The resulting solid undergoes drying and thermal treatment in reducing atmosphere, such as H_2, to promote selective oxide reduction and generate the metal component. Sol-Gel Process: i) By using mesoporous silica containing 0.1 M $HAuCl_4$ (aq.) and 0.6 M $NaBH_4$ (aq.), prepared two micelle solutions; ii) Mixing under ultraviolet light till complete reduction of gold. For Fe/Au-containing nanocomposites: i. Synthesis of iron shell; ii. Drying of the powders after second gold coating, and preparation of the second shell. iii. Pressing of the mixture to get the final material[19-21].

Table No.9: Processes for preparing metal-CNT nanocomposite systems

S.No	Process	System	Procedure
1	Electroless coating	Co-CNT	i) Use of electroless plating both containing the activated CNTs, the cobalt precursor, the reducing agent $CoSO_4.7H_2O$, the complexing agent and buffer. CNT with deposit of Co coating results; ii) Thermal treatment at 873K, 200 torr, under a 10% H_2/N_2 flow gas[22].
2	Electroless coating	Sn/CNTs, SnSb/CNT and Sn_2Sb/CNT	Reduction of $SnCl_2$ precursors by KBH_4 in the presence of CNTs[23].
3	Hot pressing	Al/CNT	Mixing of powders through grinding for 30 minutes and hot pressing at 793K under a pressure of 25MPa[24].
4	Nanoscale Dispersion	Al/CNT	Preparation of the precursor of MWCNT (13nm dia and 10-50μm long) with natural rubber ethyl propylene; mixing with Al powder, rolling into sheets by compression moulding at 353K; placing of this precursor on an Al (99.85%) plate of 28μm grain size; heating to 1073K in N_2atmosphere for 1 hour; final cooling[3,25].

Table No.10: Methods for preparing polymer-based nanocomposite systems

S.No	Process	System	Procedure
1	Prepolymer/ Intercalation from solution	Clay containing PLA,HDPE, PCL, PEO, PVA, PVP, PVA, etc.	Usually employed for layered reinforcing material in which the polymer can be incorporated. Use of a solvent in which the polymer or pre polymer is soluble and the silicate layers are swellable[26-28].
2	In-situ Intercalation Polymerisation	Montmorillonate with N6/PCL/PMMA/PU/ Epoxy	Encasing of The layered silicate is encased within the liquid monomer or a monomer solution and forms the polymer between the intercalated sheets. By the diffusion of a suitable initiator or by a catalyst fixed through cation exchange inside the interlayer, before the swelling step and polymerization of heat and radiation[29-33].
3	Template synthesis	Hectorite with PVPR, HPMC, PAN, PDDA, PANI	In situ formation of the layered structure of the inorganic material in an aqueous solution containing the polymer. The water-soluble polymer acts as a template for the formation of layers[34-36].
4	Sol-Gel Process	Polyimide/SiO_2; 2- hydroxyethyl acrylate (HEA)/SiO_2, Poluimide/silica, PMMA/SiO_2, polyethylacrylate/ SiO_2, Polycarbonate/SiO_2 and poly (amide-imide)/TiO_2	Embedding of organic molecules and monomers on sol-gel matrices; introduction of organic groups by the formation of chemical bonds → In-situ formation of the sol-gel matrix within the polymer and /or simultaneous generation of inorganic/organic networks[37,24,3,38].

Table No.11: Advantages and limitations of polymer-based nanocomposites processing methods

S.No	Process	Advantages	Limitations
1	Prepolymer/Intercalation/ from solution	Preparation of homogeneous dispersions of the filler.	Industrial use of large amount of solvents[39].
2	In-situ Intercalative Polymerization	Easy procedure.	Difficult control of polymerization. Limited applications[29,40,41,31-33,42].
3	Melt Intercalation	Use of polymers not suited for other processes; Environmentally benign; suitable with industrial polymer processes.	Polyolefins have limited applications, which represent the majority of used polymers[43-45].

Table No.12: Processing methods for polymer -CNT nanocomposites systems

S.No	Process	System	Procedure
1	Direct Mixing	Thermoset resins	Dispersion of CNTs; cure[46].
2	Solution Mixing	Thermoplstic resins	Dispersion of 0.2% CNTs, (100nm dia, 10μm long); Removal of solvent or precipitation of polymer; Cure[47-51].
3	Melt Mixing	Polymer, N6	Mechanical mixing of CNTs with prepolymer melt followed by extrusion, injection or compression moulding[52-54].
4	Others	PP-CNT, PVK-SWCNT, PA Ni-SWCNT	Solid-state mechanochemical pulverization; blending + sonication; melt blending; VDP[55-58].

Marketed Formulations

Table No.13: Marketed formulations of Nanocomposites

S.No	Product Name/Company	Drug	Final Dosage	Year Approved
1	Avinza®/King Pharma	Morphine sulfate	Capsule	2002
2	Cesamet®/Lilly	Nabilon	Capsule	2005
3	Emend®/Merck	Aprepitant	Capsule	2003
4	Herbesser®/Mitsubishi	Diltiazem	Tablet	2002
5	Invega Sustenna®	Paliperidone palmitate	Suspension	2009
6	Megace ES®/Par Pharmaceutical	Megestrol acetate	Suspension	2005
7	Neprelan®/Wyeth	Naproxen sodium	Tablet	2006
8	Rapamune®/Wyeth	Sirolimus (rapamycin)	Suspension, Tablet	2000
9	Ritalin LA®/Novartis	Methylphenidate HCl	Capsule	2002
10	Theodur®/Mitsubishi Tanabe Pharma	Theophylline	Tablet, Capsule	2008
11	Tricor®/Abbott	Fenofibrate	Tablet	2004
12	Triglide®/SkyePharma	Fenofibrate	Tablet	2005
13	Zanaflex®/Acorda	Tizanidine HC	Capsule	2002[65]

CONCLUSION

The number of business applications of nanocomposites are growing at a fast rate. It has been reported that in but 2 years, worldwide production is calculated to exceed 600,000 tones and is about to hide the subsequent key areas in the next five to ten years:

- Drug delivery systems
- UV protection gels
- Lubricants and scratch-free paints
- New fire retardant materials.

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CONFLICT OF INTEREST

We declare that we have no conflict of interest.

BIBILIOGRAPHY

1. Sachinjith K R, Swathi Krishna K R. A review on types of nanocomposites and their applications, *International Journal of Advance Research, Ideas and Innovations in Technology,* 4(6), 2018, 235-236.
2. Fernado W, Satyanarayana K G. Functionalization of single layers and nanofibres, a new strategy to produce polymer nanocomposites with optimized properties, *Journal of Colloid and Interface Science,* 285(1), 2005, 532-543.
3. Alexandre M, Dubois P. Polymer -layered silicate nanocomposites; preparation, properties and uses of a new classes of materials, *Materials Science and Engineering,* 28(1-2), 2000, 1-63.
4. Nakahira A, Niihara K. Structural ceramics - ceramics nanocomposites by sintering method: roles of nano-size particles, *Journal of the Ceramic Society of Japan,* 100(4), 1992, 448-453.
5. Thosterson E T, Renz Z, Chau T W. Advance in the Science and technology of carbon nanotubes and their composites: a review, *Composites Science and Technology,* 61(13), 2001, 1899-1912.
6. Xiaz, Riester L, Curtin W A, Li H, Sheldon B W, Liang J, Chang B, Xu J M. Direct observation of toughening mechanisms in carbon nanotube ceramic matrix composites, *Acta Materialia,* 52(4), 2004, 931-944.
7. Md Rezaur Rahman. Silica and clay dispersed polymer nanocomposites,

Woodhead Publications, 1st Edition, 2018, 677-681.

8. Jiang L, Gao L. Carbon nanotubes magnetide nanocomposites from solvothermal processes: formation, characterization and enhanced electrical properties, *Chemistry of Materials,* 15(14), 2003, 2848-2853.
9. Xiaz R L, Curtin W A, Sheldon B W, Liang J, Chang B, Xu J M. Direct observations in toughing mechanisms in carbon nanotube ceramic matrix composites, *Acta Materialia,* 52(4), 2004, 931-944.
10. Yoon E S, Lee J S, Oh S T, Lim B K. Microstructure and sintering behavior of W-Cu nanocomposite powder produced by thermo-chemical process, *International Journal of Refractory Metals and Hard Materials,* 20(3), 2002, 201-206.
11. Khalid F A, Beffort O, Klotz U E, Keller B A, Gasser P, Vaucher S. Study of microstructure and interfaces in an aluminium-C_{60} composite material, *Acta Materialia,* 51(15), 2003, 4575-4582.
12. Bhattacharya V, Chattopadhyay K. Microstructure and wear behavior of aluminium alloys containing embedded nanoscale lead dispersoids, *Acta Materialia,* 52(8), 2004, 2293-2204.
13. Bhattacharya V, Chattopadhyay K. Microstructure and tribiological behavior of nano-embedded Al- alloys, *Scripta Materialia,* 44(8-9), 2001, 1677-1682.
14. Srinivasana D, Chattopadhyay K. Hardness of high-strength nanocomposites Al-X-Zr (X= Si, Cu, Ni) alloys, Materials Science and Engineering A - Structural Material Properties Microstructure Properties Microstructure and processing, *Materials Science and Engineering,* 375(1), 2004, 1228-1234.
15. Xiaochun Li, Yang Y, Chang X. Ultrasonic assisted fabrication of metal matrix nanocomposites, *Journal of Materials Science,* 39(9), 2004, 3211-3212.
16. Choy K L. Chemical vapour deposition of Coatings. *Progress in Materials Science,* 48(2), 2003, 57-170.
17. West R, Wang Y, Goodson T. Nonlinear absorption properties in novel gold nanostructured topologies, *Journal of Physical Chemistry B,* 107(15), 2003, 3419-3426.
18. Kamat P V, Flumiani M, Dawson A. Metal - Metal and metal-semiconductor composite nanoclusters, *Colloid surface A-Physicochemical and Engineering Aspects,* 202(2-3), 2002, 269-279.
19. Roy S D, Chakravorty D, Agrawal D C. Magnetic properties prepared by the sol-gel route and hot pressing, *Journal of Applied Physics,* 74(7), 1993, 4746-4749.
20. Chen W X, Lee J Y, Liu Z. The nanocomposites of carbon nanotube with Sb abd $SnSb_{0.5}$ as Li-ion battery anodes, *Carbon,* 41(5), 2003, 959-966.
21. Carpenter E E, Kumbhar A, Wiemann J A, Wiggins H J, Zhou W. Synthesis and magnetic properties of gold-iron-gold nanocomposites, *Material Science and Engineering,* 286(1), 2000, 81-86.
22. Noguchi T, Magario A, Fuzukawa S, Shimizu S. Carbon nanotube/aluminium composites with uniform dispersion. *Materials Transactions,* 45(2), 2004, 602-604.
23. Yang J, Schaller R. Mechanical spectroscopy of Mg reinforced with Al_2O_3 short fibres and carbons nanotubes, *Materials Science and Engineering,* 370(1-2), 2004, 512-515.
24. Kamigaito O. What can be improved by monomer composites? *Journal of Japan Society of Powder Mettalergy,* 38(3), 1991, 315-321.
25. Jimenez G, Ogata N, Kawai H, Ogihara T. Structure and thermal/mechanical properties of poly(ε - caprolactone)-clay blend, *Journal of Applied Polymer Science,* 64(11), 1997, 2211-2220.

26. Usuki A, Kojima Y, Kawasumi M, Okada A, Fukushima Y, Kurauchi T, Kamigaito O. Synthesis of Nylon-6-clay hybrid, *Journal of Materials Research,* 8(5), 1993, 1170-1183.
27. Usuki A, Kawasumi M, Kojima Y, Okada A, Kurauchi T, Kamigaito O. Swelling behavior of montmorrinollitecation exchanged for amino acid by ε-caprolactum, *Journal of Materials Research,* 8(5), 1993, 1174-1178.
28. Messersmith P B, Giannelis E P. Polymer Layered Silicate Nanocompoaites in situ intercalative polymerization of ε - caprolactone in layred silicates, *Chemistry of Materials,* 5(8), 1993, 1064-1066.
29. Okamoto M, Morita S, Taguchi H, Kim Y H, Kotaka T, Tateyama H. Synthesis and structure of smectic clay/poly (methyl methacrylate) and clay/polystyrene nanocommpsoites via in situ intercalative polymerization, *Polymer,* 41(10), 2000, 3887-3890.
30. Okamoto M, Morita S, Kotaka T. Dispersed structure and ionic conductivity of smectic clay/polymer nanocompposites, *Polymer,* 42(6), 2001, 2685-2688.
31. Vaia R A, Giannelis E P. Lattic of polymer melt intercalation in organically modified layered silicates, *Macromolecules,* 30(25), 1997, 7990-7999.
32. Gilmann J W. Flammability and thermal stability studies of polymer -layered silicate (clay) nanocomposites, *Applied clay science*, 15(1-2), 1999, 31-49.
33. Vaia R A, Vasudevan S, Krauiec W, Scanion L G, Giannelis E P. New polymer electrolyte nanocomposites melt intercalation of poly (ethylene oxide) in mica-type silicates, *Advanced Materials,* 7(2), 1995, 154-156.
34. Wakins J J, Mccarthy T J. Polymer/metal nanocomposite synthesis in supercritical CO_2 -swollen poly (chlorotrifluroehtylene), *Macromolecules, American Chemical Society,* 7(11), 1995, 1991-1994.
35. Aymonier C, Bortzmeyer D, Thomann R, Lhaupt R M. Poly (methyl mathacrylate) /palladium nanocomposites: synthesis and characterization of the morphological, thermomechanical, and thermal properties, *Chemistry of Materilas,* 15(25), 2003, 4874-4878.
36. Evora V M, Shukla A. Fabrication, characterization and dynamic behavior of polyster/TiO_2 nanocompsoites, *Material Science and Engineering,* 361(1-2), 2003, 358-366.
37. Avadhani C V, Chujo Y. Polyimide- silica gel hybrids containing metal salts: Preparation via the sol-gel reaction, *Applied Oraganometric Chemistry,* 11(2), 1997, 153-161.
38. Jimenez G, Ogata N, Kawai H, Ogihara T. Structure and thermal/ mechanical properties of poly (ε- cprolactone)-clay blend, *Journal of Applied Polymer Science,* 64(11), 1997, 2211-2220.
39. Ogata N, Jimenez G, Kawai H, Ogihara T. Structure and thermal/mechanical properties of poly (1-lactide)-clay blend, *Journal of Polymer Science part B: Polymer Physics,* 35(2), 1997, 389-396.
40. Yao K J, Song M, Hourston D J, Luo D Z. Polymer /layered clay nanocomposites: 2-polyurethane nanocomposites, *Polymer,* 43(3), 2002, 1017-1020.
41. Messersmith P B, giannelis E P. Synthesis and characterization of layered silicate - epoxy nanocomposites, *Chemistry of Materials,* 6(10), 1994, 1719-1725.
42. Kawasumi M, Hasegawa N, Kato M, Usuki A, Okada A. Preparation and 168, mechanical properties of polypropylene-clay hybrids, *Macromolecules,* 30(20), 1997, 6333-6338.
43. Qian D, Dickey E C, Andrews R, Rantell T. Load transfer and deformation mechanisms in carbon nanotube-polystyrene composites, *Applied Physical Letters,* 76(20), 2000, 2868-2870.

44. Ding W, Eitan A, Fisher F T, Chen X, Dikin D A, Andrews R, Brinson L C, Schadler L S, Ruoff R S. Direct observation of polymer sheathing in carbon nanotube-polycarbonate composites, *Nano Letters,* 3(11), 2003, 1593-1597.
45. Lin Y, Zhou B, Fernando K A, Liu P, Allard L F, Sun Y P. Polymeric carbon nanocomposites from carbon nanotubes functionalized with matrix polymer, *Macromolecules,* 36(19), 2003, 7199-7204.
46. Wong M, Paramsothy M, Xu X J, Ren Y, Liao K. Physical interactions at carbon nanotube-polymer interface, *Polymer,* 44(25), 2003, 7757-7764.
47. Koerner H, Price G, Pearce N A, Alexer M, Vaia R A. Remotely actuated polymer nanocomposites-stress-recovery of carbon-nanotube filled thermoplastic elastomers, *Nature Materials,* 3(2), 2004, 115-119.
48. Kubayashi K, Hayashi S. Woven fabric made of shape memory polymers, *United States, Patent 5,* 128, 1992.
49. Liu T X, Phang I Y, Shen L, Chow S Y, Zhange W D. Morphology and mechanical properties of multiwalled carbon nanotubes reinforced nylon-6 composites, *Macromolecules,* 37(19), 2004, 7214-7222.
50. Tang W, Santare M H, Advani S G. Melt processing and mechanical property characterization of multi-walled carbon nanotube/high density polyethylene (MWNT/HDPE) composite films, *Carbon,* 41(14), 2003, 2779-2785.
51. Andrews R, Jacques D, Minot M, Rantell T. Fabrication of 195, carbon multiwall nanotube/polymer composites by shear mixing, *Macromolecular Materials and Engineering,* 287(6), 2002, 395-403.
52. Park S J, Cho M S, Lim L T, Choi H J, Jhon M S. Synthesis and dispersion characteristics of multi-walled carbon nanotube composites with poly(methyl methacrylate) prepared by in-situ bulk polymerization, *Macromolecular Rapid Communications,* 24(18), 2003, 1070-1073.
53. Maser W K, Benito A M, Callejas M A, Seeger T, Martinez M T, Schreiber J *et al.* Synthesis and characterization of new polyaniline/nanotube composites, *Materials Science and Engineering,* 23(1-2), 2003, 87-91.
54. Park C, Ounaies Z, Watson K A, Crooks R E, Smith J J, Lowther S E *et al.* Dispersion of single wall carbon nanotubes by in situ polymerization under sonication, *Chemical Physics Letters,* 364(3-4), 2002, 303-308.
55. Kim J Y, Kim M, Choi J H. Characterization of light emitting devices based on a single-walled carbon nanotube-polymer composite, *Synthetic Metals,* 139(3), 2003, 565-568.
56. Valentini L, Biagiotti J, Kenny J J, Santucci S. Morphological characterization of single-walled carbon nanotubes-PP composites, *Composites Science and Technology,* 63(8), 2003, 1149-1153.
57. Ramamurthy P C, Malshe A M, Harrell W R, Gregory R V, McGuire K, Rao A M. Polyaniline/signle-walled carbon tube composite electronic devises, *Solid State Electrochemistry,* 48(10-11), 2004, 2019-2024.
58. Charles C Okpala. Nanocomposites- An overview, *International Journal of Engineering Research and Development,* 8(11), 2013, 21-22.
59. Bansode R, Kumar S, Aglawe S. Application of Nanotechnology in Agriculture, *Trends in Biosciences,* 8(10), 2015, 2647-2649.
60. Ghormade V, Deshpande M V, Paknikar K M. Perspective for nano-biotechnology enabled protection and nutrition of plants, *Biotechnology Advances,* 29(6), 2011, 792-803.
61. Naderi M, Danesh-Shahrati A. Nanofertilizers and their roles in sustainable agriculture, *International Journal of Agriculture and Crop Science,* 5(19), 2013, 2229-2232.
62. Khot L R, Sankaran S, Maja J M, Ehsani R, Schuster E W. Applications of

nanaomaterials in agricultural production and crop protection: A review, *Crop Protection,* 35, 2012, 64-70.

63. Singh M, Singh S, Prasad S, Gambhir I. Nanotechnology in medicine and antibacterial effect of silver nanoparticles, *Digest Journal of Nanomaterials and Biostructures,* 3(3), 2008, 115-22.
64. Pedro C C, Kestur G S, Fernando W. Nanocomposites: Synthesis, Structure, Properties and New Application Opportunities, *Materials Research,* 12(1), 2009, 1-39.
65. Bhakay A, Rahman M, Dave R N and Bilgili E. Bioavailability Enhancement of poorly water soluble drugs via Nanocomposites: Formulations processing aspects and Challenges, *Pharmaceutics,* 10(3), 2018, 1-62.
66. Thomas S P, Stephen R, Thomas S, Bandopadhyay S. Polymer nanocomposites: Preparation, Properties and applications, *RFP1*, 2(1), 2007, 49-56.

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