NANOCOMPOSITES-A review

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ABSTRACT

Composites are the materials which are prepared as new product and innovation which eventually replace petroleum-based composite materials in several applications. Composite are used in several application and act a promising materials to design materials of interest. The main motivation of study paper to give the comprehensive view of composites, application and its classification. The composite materials are competitive with glass ,metal etc.They are environmentally compatible in terms of products, and renewal source. There is an immense opportunity in developing new products from the composites, but it is the real challenge in future.

INTRODUCTION

Composite is a mixture of two or more substances mixed together. This composites exhibits more properties than the total properties of elements used to form a composite.[1] Basically, the name 'Nano' itself suggest that the particle having size in nanometers are nanoparticles.

Nanocomposites are made up of different phases which contain solid material particles having size less than 100 nm. These make the material nanocomposite.[2] A nanocomposite is made by a matrix and a reinforcement where matrix includes resin and filler.

The purpose of this is to improve the characteristics of resin and reducing production cost. A filler resin system is homogenous material.[1] Nanocomposites are found in nature, for example in the structure of the abalone shell and bone. [3] Nanocomposites are different from conventional composites. As they have high surface to volume ratio of the reinforcing phase or its high aspect ratio. The examples of reinforcing materials are minerals, sheets of exfoliated clay, carbon nanotubes, etc. For nanocomposites the area of matrix and reinforcement are greater than conventional composite materials.[4]

Carbon nanotubes(CNT) were discovered in 1991.[5] These CNTs sometimes are used to fabricate the nanocomposites which exhibits CNTs' related properties like mechanical, thermal, electrical, etc. This work added a new dimension to this field.[6,7,8]
Nanocomposites are environment friendly and nowadays they are offering new technology and business opportunities in various sectors.[9]

I. General approaches to Nanocomposite Fabrication

There are various techniques to prepare nanostructures of materials used for fabrication of nanocomposites. e.g. nanocomposite systems such as metal nanoparticle on ceramic supports can be prepared simply by evaporating metal onto chosen substrate or via solvent chemistry.[10] These methods cannot be used to prepare nanocomposites having complex structures with coexisting ceramic and polymeric phases. But such materials can be prepared by novel processing techniques like template synthesis, scanning probe electrochemical methods, electrospinning, etc. [11]

Although, there are various approaches to synthesize nanostructures, there is need of method which is capable of making pure, uniform, template-free nanostructures. Ordered structure can be achieved by only mixing of components. This is the requirement for the fabrication strategy and is appealing for its simplicity and its potential efficiency. Simple synthesis and purification with no template-removing steps needed are the advantages of Template-free methods of synthesizing nanostructures. Also, easily scalable and reproducible uniform nanofibers are formed. As the diameter of nanomaterials is at nanoscale, they show superior performance as sensors. And also they are water dispersible, the processing is environment friendly.[10,11]

II. TYPES OF NANOCOMPOSITES

Depending on the matrix material Nano composites are divided into many typer three major types are taken into

i. Ceramic Matrix Nano composites

ii: Metal Matrix Nano composites

iii: Metal Matrix Nano composites

➢ Ceramic matrix nano composites:

The Ceramic Matrix Nano composite system is mainly composed of Al2O3 or SiC. The studies so far have confirmed the strengthening Al2O3 matrix after addition of low volume fraction (Approx. 10%) of SiC molecule particles of suitable size and hot pressing the resultant mixture. These material composites are very useful for high temperature structural applications.

This material type offers high strength to density ratio, also there high temperature capabilities provides slight edge over conventional alloys thus these components require little to no cooling. This benefit could be applied for light weight body structures where heat is generated, these components will also provide higher operating efficiency as high operating temperature is achieved.

In structural engineering the use of carbon/carbon composites with the help of nanotechnology can significantly decrease the overall production cost. These material composites can withstand higher stress and temperature than conventional alumina, silicon carbide composites which used to get fracture easily under mechanical loads. Before optimizing the fundamental structural properties of this material type, thorough analysis and characterization of the composed material is required.

Generally ceramic materials are resistant to high temperatures and can withstand very high temperature before it loses its structural property; also these are chemically inert and have low densities thus increasing its applications on many fields such as aerospace shuttle designing, material casting etc. However these materials are more likely to get damaged in case of thermal shocks hence, sometimes get out of use during fabrication.

Ceramic fibers embedded in ceramic matrix forms ceramic fiber reinforced ceramic, as these materials are more reliable at high temperatures than metals and are also resistant to corrosion. The ceramic matrix composites are mainly used in heat shield system of space shuttles, for manufacturing the components of gas turbines, burners and flame holders.

Applications in the past:

Boron carbide has many applications in lightweight armors because of its high hardness and low density. Silicon carbide is also used when reinforced with shape-modified SiC fibers in armors, as well as tungsten carbide is used with diamond.

Researches at the German Aerospace Centre has improved efficiency of these discs by applying thin coating based on Si-SiC ,also called SiCraleen during fabrication. These discs are made by hot pressing half shell C/C preforms, pyrolysis at 900-1600°C, joining the two halves and then infiltrating the two halves with liquid Si. In situ joining via reaction bonding during siliconisation also allows production of complex parts.

The improved discs have almost no wear and are expected to last a lifetime or 300,000 km for a car and reduce costs by 75-80% compared to C/C disks. No distortion or corrosion has been observed.
In 2002 a new production plant for these disks was built, which currently can produce 35,000 disks per year. By 2004-2005, production is expected to increase to 300,000 disks per year. However, process costs still need to be reduced since the discs are quite expensive.

If costs come down the discs could have application as service brakes for cars/planes and emergency brakes for trains. In addition to gas turbines,SiC/SiC composites are being considered for advanced nuclear applications such as fusion blanket/first wall structures and fission core structures/liners.
These materials are promising because of the radiation resistance of the SiC beta phase and their excellent high-temperature fracture, creep, corrosion and thermal shock resistance.[5,12,31,32]

- <u>Metal matrix nano composites:</u>

- Metal matrix nano composites (MMNCs) have wide variety of applications e.g. aerospace, automotive, and biomedical engineering as their lightweight high-strength nature provides susceptibility to high tension-stress and also improved temperature and corrosion resistance. Commonly a metal matrix comprises light aluminum or magnesium alloys which significantly increases the strength and by very low weight fraction (~ 1 Wt%) due to its well dispersed nanoparticles.

  The targeted property of the metallic matrix can be enhanced and controlled by selecting the correct type, size and the amount of reinforcement used to form the core of composite design.[5]
- In 1970s the researchers attempted, rheocasting, stir casting and powder metallurgy routes to combine metal/alloys with ceramic reinforcements, it is then when metal based composites gained pace through captivating results [13,14].Researchers reported improvements_in mechanical properties, such ascreep, damping, elastic modulus and wear resistance [15,16].Micron scale continuous and discontinuous reinforcements were used by the researchers, approximately at the end of 20th century, to enhance the properties of different metallic matrices.

  Due to high cost and complexities involved in synthesis of metal matrix composites, the development of continuous reinforced metal matrix composites was limited for highly specialized sectors such as space segments.

However the synthesis of discontinuous reinforced MMCs was successfully attempted using a series of processing techniques [17,18,19].
In nano MMCs, the minimization of particle based damage mechanism is another important attribute that assists in improving the properties these are prevalent in micron scale ceramic reinforcement particles.

The particles damage mechanism includes:
A: The breakage of particle under stress, triggering the initiation of cracks.
B: Under application of stress debonding of matrix reinforcement interface

- Inferior mechanical properties of MMCs lead by particle based damage mechanisms, especially elongation to failure and fracture toughness that is not desirable in engineering /biomedical applications. In many applications due to their distinct combinations of properties, nano-MMCs have an advantage over micro-MMCs.
- Additionally the improvement in properties of MMCs essentially depends on the processing path and the processing parameters which provide a uniform distribution of reinforcements and better matrix reinforced interface. Mixing of reinforcements in molten metal gives significant thermal exposure to the reinforcements, especially in mass production industrial level, techniques as casting. The dispersion in ceramic reinforcements in molten metal is attempted using:

a: Stirring to ensure a vortex [14,17] ; or
b: The ultrasonic method [20,21]

- In stir-casting method it is crucial to look over important parameters such as stirrer speed, design and its position within crucible. Recently attempted ultrasonic cavitation-based dispersion of reinforcements [21-23], employs the transient micro hot spot that reaches temperatures of about 5000 Celsius and pressure above 1000atm and the rates of heating and cooling above 1010 Celsius/sec [23].

- Stir-Casting: - Is economical, fairly simple and hence more common method of producing MMNCs, in which the reinforcement particles are combined with the molten matrix metal (i.e. aluminum). A stirrer is inserted in the molten metal applies mechanical stirring with some rpm to achieve a uniform distribution of the particles and molten metal. The process is used to combine carbon nanotubes, ceramics, metal oxide and graphene particles to aluminum and magnesium matrix [24-27]. Challenges faced in this technique are (i) Due to high resulting Van-der-waal forces and high surface area the nanoparticles forms cluster.(ii) Solid nanoparticles have very poor wettability with the molten metal; (iii) Air induced by rotating stirrer increases porosity [28-30].

➢ Polymer nano composite:

- Materials which comprises nanoscopic inorganic particles having dimensions around 10-100 A, are incorporated with organic polymer to improve overall performance of the polymer. System comprising individual layer of inorganic lamellar compound typically a smectite clay or nano composites (nylon) dispersed among other layers of silicates shows altered physical properties compared to pristine polymer.

- Properties such as the polymer silicate nano composites exhibit stiffness, layer orientation, strength and dimensional stability in two dimensions. Usually nano composites are measured using nanometer length scale that reduces scattering of light they are mostly transparent.
- Polymer nano composites adds new alternative to conventional filled polymers. When compared to the pure polymers and their traditional composites filler dispersion nano composites shows improver properties, including increased strength and modulus, incredible barrier properties, decreased flammability, increased resistance and improved solvent.
- Polymer containing transition metals complex either attached to or are directly in a pi conjugation backbone. Organic transitional metal containing polymer and pi conjugated polymer hybrid forms these macromolecules.
- Pi conjugated organic polymers as, polythiopene, polyacetylene and polypyrrole-olgomers and their derivatives have very important properties such as, electronic conductivity luminescence and nonlinear optical properties, hence these are used for various purposes including electroluminescent devices, chemical sensors, batteries, smart windows, memory devices and electro catalysts.

III. Applications

Below are the applications of ceramic, metal and polymer type nanocomposites.[33,34,35]

Potential applications of ceramic nanocomposite systems.

Nanocomposites	Applications
SiO_2 /Fe	High performance catalysts, data storage technology.
ZnO/Co	Field effect transistor for the optical femtosecondstudy of interparticle interactions.
Metal oxides/Metal	Catalysts, sensors, opto-electronic devices.
$BaTiO_3$ /SiC, PZT/Ag	Electronic industry, high performance ferroelectric devices.
SiO_2 /Co	Optical fibres.
SiO_2 /Ni	Chemical sensors.
Al_2O_3 /SiC	Structural materials.

Si3 N4 /SiC
Structural materials.
Al2 O3 /NdAlO3 & Al2 O3 /LnAlO3
Solid-state laser media, phosphors and opticalamplifiers.
TiO2 /Fe2 O3
High-density magnetic recording media, ferrofluids and catalysts.

Al2 O3 /Ni
Engineering parts.
PbTiO3 /PbZrO3
Microelectronic and micro-electromechanical systems.

Potential applications of metal nanocomposite systems.

Nanocomposites Applications

Fe/MgO Catalysts, magnetic devices.
Ni/PZT Wear resistant coatings and thermally graded coatings.

Ni/TiO2 Photo-electrochemical applications.
Al/SiC Aerospace, naval and automotive structures. Cu/Al2 O3 Electronic packaging.
Al/AlN
Microelectronic industry.
Ni/TiN, Ni/ZrN, Cu/ZrN High speed machinery, tooling, optical and magnetic
Nb/Cu Structural materials for high temperature applications.

Fe/Fe23C6/Fe3 B Structural materials.
Fe/TiN Catalysts.
Al/Al2 O3 Microelectronic industry.
Au/Ag
Microelectronics, optical devices, light energy conversion.

Potential applications of polymer nanocomposite systems.

Nanocomposites Applications

Polycaprolactone/SiO2 Bone-bioerodible for skeletal tissue repair.
Polyimide/SiO2 Microelectronics.
PMMA/SiO2 Dental application, optical devices. Polyethylacrylate/SiO2
Catalysis support, stationary phase

for chromatography.
Poly(p-phenylene vinylene)/SiO2
Non-liner optical material for optical waveguides.

Polycarbonate/SiO2 Abrasion resistant coating. Shape memory polymers/SiC Medical devices for gripping or releasing therapeutics within bloodvessels.
Nylon-6/LS Automotive timing-belt – TOYOTA. PEO/LS Airplane interiors, fuel tanks,components in electrical andelectronic parts, brakes and tires.
PLA/LS Lithium battery development. PET/clay
Food packaging applications.Specific examples include packagingfor processed meats, cheese, confectionery, cereals and boil-in-the-bag foods, fruit juice and dairyproducts, beer and carbonateddrinks bottles.
Thermoplastic olefin/clay
Beverage container applications.
Polyimide/clay
Automotive step assists - GM Safari and

Astra Vans. Epoxy/MMT Materials for electronics. SPEEK/laponite Direct methanol fuel cells.

Metal and ceramic type nanocomposites are able to create a great impact over a wide variety of industries. These industries include aerospace, electronic and military[36]. And polymer nanocomposites will have greater impact on battery cathodes[5,37], microelectronics[38], nonlinear optics[39], sensors[40],etc.

To meet the requirements of specific applications various types of nanocomposites are developed. These contains insulating, semiconducting or metallic nanoparticles. Nowadays, PLS nanocomposites are becoming available commercially[41]. They are being applied as ablatives[42]. PLS also being used as high performance biodegradable composites[43-47]. Also in electronic and food packaging industries [47,48].

Nanofillers are high performance systems and there demand is increasing as many sectors looking for them at low costs[49]. In future, many leading industrial laboratories like Argonne National Laboratory are ready to commercialize their nanoproducts(organoclays). Also in USA, GE and Cobot uses electroconductive polymers, nanosmart switches and sensors for automotives. General Motors in USA are using nanocomposites containing clay and talc in their exteriorstructural components.

IV. CONCLUSION

New innovations require materials showing new or novel properties and/or improved performance compared to traditionally processed components. In this context, nanocomposites have large number of applications and are ready to meet the emerging demands from scientific and technological advancements, processing methods for different types of nanocomposites (CMNCs, MMNCs and PMNCs) are there but some of these are still difficult to carry out and are not yet feasible for some applications. A number of applications exist and many more are potentially possible, which opens new windows for the future of composites.

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