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Recent Developments in Bio-nanocomposites: A Review

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ABSTRACT

Bio-nanocomposites, are made of biopolymers and inorganic solids, having dimensions in the nanometer range (1–100 nm). A wide range of available biopolymers and inorganic nanoparticles offers means of developing different bionanocomposites with different structural properties, functionalities and applications. This is achieved by mixing nano particles in various combinations. Biopolymers form the matrix, determining the shape and structure of bionanocomposites. Interface also plays a very important role in determining the resultant properties of these types of composites. Dispersed nano - particles modify the matrix resulting in improved properties. Considering these versatile properties this review focuses on synthesis, characterization and applications of bio-nanocomposites. All the technical and scientific issues have been addressed highlighting the recent advancement.

Keywords: *a) Biocomposites b) Nano particles c) Biopolymers d) Mechanical properties*

INTRODUCTION

Bio-nanocomposites, are made of biopolymers and inorganic solids, having dimensions in the nanometer range (1–100 nm) [1,2]. These materials have vast applications due to their multidimensional properties like biocompatibility, antimicrobial activity and biodegradability. Growing need for bio based polymers and there processing technology results in the reduction of fossile fuel usage. Bio-nanocomposites have become a potential and sustainable material for use in new and high performance applications. Being light weight, eco friendly these nanocomposites replace conventional non-biodegradable petroleum-based plastic. These materials also used for packaging applications. Considering these versatile properties this review focuses on synthesis, characterization and applications of bio-nanocomposites. All the technical and scientific issues have been covered highlighting the recent developments.

NANOPARTICLES

In nanoparticles, all three dimensions of the particles are of the order of nanometers. They are three-dimensional particulates, this category of nanosized particles is called "isodimensional". It can be spherical, cubic, and shapeless nanoparticles with a size up to 100 nm. A special case is the hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$). It is a major mineral component of bones (up to 70 wt %). Nanosized hydroxyapatite as the active component of scaffolds and implants is widely employed in orthopedic surgery and dentistry to repair the mineralized hard tissues in the living body owing to its excellent biocompatibility and osteogenic effect [2-7].

NANOFIBERS

Nanofibers, nanotubes, nanorods, whiskers are two dimensions of nanoparticulates are in the nanometer scale range. Carbon nanotubes consisting of a single sheet or more sheets of graphene are likely to be the best known example [5-9]. Their extraordinary stiffness, strength, and resilience provide a significant improvement of the mechanical properties of composite materials. This category of nanoparticulates, along with inorganic carbon nanotubes, also includes nanosized fibers of biological origin that come from plants and animals. Plants like cotton, wood, soy, hemp, flax, jute, sisal, banana, and kenaf serve as a source of the cellulose and starch nanofibers [8-13]. Animal nanofibrils are represented by chitin. It is also a linear polysaccharide forming crystalline fibrils like the cellulose [9-14]. Although cellulose has been widely used in the textile industry for many decades, its application in nanofibrillar form as well as starch and chitin has recently attracted much attention for the reinforcement of composite materials, owing to unique mechanical properties that go together with biocompatibility and biodegradability. Polysaccharide nanofibrils are considered as a sustainable alternative for carbon nanotubes because of abundant renewable raw sources. They are low-cost materials as well. Among their advantages over carbon nanotubes are also their hydrophilic nature and well-developed synthetic methods of carbohydrate chemistry, which enable one to tailor the surface functionality. The reinforcement of bionano composites by nanoparticulates of this category depends strongly on the aspect ratio (length to diameter). With increasing the ratio and providing the uniform orientation of nanofibrils in the matrix, one can reach, as expected, a reinforcing effect like in Kevlar [13-17].

Nanoplatelets

The thickness of nanoplatelets is only in the nanometer scale range. This category includes phyllosilicates, silicic acid (magadiite), layered double hydroxides [M6Al2 (OH)16CO3nH2O; M = Mg, Zn], zirconium phosphates [Zr(HPO42H2O], and di-chalcogenides [(PbS)1.18(TiS2)2, MoS2] [16-19]. The most popular nanoplatelets applied in bionanocomposite formulations are layered or plate-like clay minerals [19-21].

Bio Nanocomposites: Synthesis and Applications

Many researchers have reported the results on bio nanocomposites based on starch and cellulose derivatives, polylactic acid (PLA), polycaprolactone (PCL), poly(butylene succinate) (PBS) and polyhydroxybutyrate (PHB). Some researchers report Bio nano composites based on different polysaccharides functionalized by different nanofillers such as MMT, Ag, SiO_2, TiO_2 and ZnO. Electronics, regenerative medicine, drug delivery, tissue engineering, and food packaging have become prime areas of application of these materials. Modified clays with biopolymers play a very important role in pollutants removal [20-22].

Nanoscale fillers like layered silicate nanoclays such as montmorillonite and kaolinite have also become a promising candidates. Development of high barrier properties against the diffusion of oxygen, carbon dioxide, flavor compounds, and water vapor is of utmost importance in food packaging. There are some challenges in increasing the compatibility of clays in polymers and attaning complete dispersion of nanoparticles.

Several nanostructures materials provide active and/or smart properties to food packaging systems, like antimicrobial properties, oxygen scavenging ability, enzyme immobilization, or indication of the degree of exposure to some detrimental factors such as inadequate temperatures or oxygen levels.

Natural microfibrous clay minerals such as Sepiolite and palygorskite are useful for the preparation of a wide variety of advanced nanostructured materials because of their particular structural, morphological and textural features. These nano clays have good interactions with biopolymers, such as polysaccharides, proteins, lipids and nucleic acids. sepiolite- and palygorskite-based bio nanocomposites are widely used for diverse applications such as bio plastics and membranes, biomedicine as drug delivery systems and adjuvants of vaccines as well as in tissue engineering. Other applications include components of sensor devices and bioreactors and as source of supported graphene.

Researchers are also using nanoclays, predisposed nanosilica, nanoalumina, multi-wall carbon nanotubes (MWCNT), carbon nanofibers (CNF), nano SiC particles, and HNT™ (Halloysite Nanotubes), in liquid thermo set resins to enhance mechanical/thermal properties [18-23].

MWCNT and CNF are expensive, so their use in large-scale composites production is limited. Nanoclays are inexpensive, but their dispersion in liquid thermo set resins is a problem a high shear mixing method is used for nanoclay dispersion in liquid thermo set. Implementation of such a method on a large scale is a costly affair. These researchers propose to use low cost halloysite nanotubes (HNT) that are naturally available. Halloysite, is a naturally occurring aluminosilicate nanotube. Halloysite (Al2Si2O5(OH)4•2H2O) is hollow tubular structure in the submicron range having two-layered aluminosilicate, chemically similar to kaolin. Halloysite is an economically material with easy availability [20-24]. It can be dispersed uniformly using simple centrifugal mixing. Considerable improvement in mechanical properties takes place by adding HNT to composites. The composites industry is very large. Biobased nanocomposites are the future of the composite industry these are being used in making Boat Made of Glass Fiber Reinforced Composite, Wind Turbine, Blades of Boeing 787, and Fuselage and in packaging industry [17-24]. Polyurethane Resin Polyurethanes (PUR) is a thermoset product with the addition of polyisocyanates and polyols. PUR exhibit good toughness and is useful in coatings, structural foams, and composites. Polyols can be fossil oil based or, vegetable oil based. There is a feasibility of using a soybean oil-based polyol as a component of PUR composites. PUR Composites Polyurethanes have been used extensively mainly because they show high toughness, good mechanical strength, excellent abrasion resistance, chemical and corrosion resistance. Polyurethane can be used to produce various forms including both flexible and rigid structures with negligible emission[26-28]. PUR foam composites have been used primarily for automotive interior and exterior parts. Non-foamed, full-density PUR composite systems are widely used for applications such as bathtubs, electric light poles, and large parts for trucks and off road vehicles. PUR composites possess superior tensile strength, impact resistance, and abrasion resistance compared with composites based on unsaturated polyester and vinyl ester resins Cure times is much less approx about 20 minutes [27-32].

CONCLUSION

A wide range of available biopolymers and inorganic nanoparticles are used to develop diverse types of bionanocomposites possessing different structure, properties, functionalities, and applications. This is achieved by dispersing them in various combinations. Biopolymers are used as matrix and nano particles as reinforcing agent in the synthesis of bionanocomposites.

Dispersed nano - particles modify the matrix. They tailor the physical, structural, mechanical propertie of the composites. Interface also plays a very important role in determining the resultant properties of these types of composites. The nanoparticles are also used for incorporating a special functionality that is not provided by biopolymers themselves. A wide variety of both biopolymers and nanosized particles makes possible materials for any desired application. They await wider applications. Bionanocomposites are biocompatible this makes them suitable for biomedical applications. Green sustainable materials for the near future bionanocomposites have dominant significance. They are used to prepare biomaterials like scaffolds and implants, drug-delivery systems, diagnostics, and biomedical devices. The biocompatibility makes them also suitable for cosmetics and biotechnology applications. Very soon, bionanocomposites will substitute the current petroleum-based polymers.

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