Volume 5, Special Issue, June 2018 ISSN: 2348-8565 (Online)

International Journal of Modern Engineering and Research Technology

Website: http://www.ijmert.org Email: editor.ijmert@gmail.com

National Conference on
Advances in Mechanical Engineering and Nanotechnology (AMENT2018)
29-30 June, 2018
Organized by
Department of Mechanical Engineering, University College of Engineering (A),
Osmania University, Hyderabad, TS, India

A Review On Nano Composite Structures and its New Applications

K. Susheela
Department of Mechanical Engineering
Vignana Bharathi Institute of Technology
Hyderabad (T.S.) [INDIA]
Email: kattulasusheela037@gmail.com

I. Satyanarayana
Centre for Carbon Materials,
Sri Indu Institute of Engineering &Technology
Hyderabad (T.S.) [INDIA]
Email: isnmechprofessor@gmail.com

ABSTRACT

Nanocomposites have been attracting considerable interests in polymers science because of their advantages. There are many scientists who researched about this kind of material and demonstrated

that when polymer matrix was added to little weight of clay, properties were enhanced considerably. The field of nanocomposite is one of the most popular areas for current research and development in basically all technical disciplines. With an estimated annual growth rate of about 25% and fastest demand to be in engineering plastics and elastomers, their potential is so striking that they are useful in several areas ranging from packaging to biomedical applications. In this paper a review of nanocomposite structures and its applications have been discussed and some recent results on structure, properties and potential applications, perspectives including need for such materials in future space mission and other interesting applications together with market and safety aspects. Applications of nanocomposites offer new technology and business opportunities for several sectors of the aerospace, automotive, electronics and biotechnology industries.

Keywords:—*nanocomposites, polymers, structures, applications*

I. INTRODUCTION

Nano-composite is an innovative material having nano (one-billionth of a meter) fillers dispersed in a matrix. Typically, the structure is a matrix-fillers combination, where the fillers like particles, fibers, or fragments are surrounded and bound together as discrete units by the matrix. The term nano-composite encompasses a wide range of materials right from three dimensional metal matrix composites to two dimensional lamellar composites and nano-wires of single dimension to zero-dimensional core-shells all representing many variations of mixed & layered materials. Polymer nanocomposites are the new class of hybrid materials in this category. Polymer nanocomposites are nanoscale materials, in which at least one of the components has a dimension smaller than 100 nm. They offer an opportunity to explore new behaviors and functionalities beyond those of conventional materials. Nanoparticles often strongly influence the properties of the composites at very low volume fractions. This paper reviews the structure and applications of the Nanocomposites.

2. LITERATURE REVIEW

Composites comprised of a polymer matrix and inorganic fillers are one of the most important and significant engineering materials in today's society [1]. For the last decades, nanocomposites materials have been widely reported in the scientific literature to provide substantial properties enhancements, even at low nanoparticles content. In nanotechnology, polymer nanocomposites are defined as solids consisting of a mixture of two or more phase separated materials, where one or more dispersed phase is in nanoscale and a polymeric major phase. Materials can be referred to as nanoscale when their size, meaning at least one of the three external dimensions range from approximately 1 nm to 100 nm [2]. Nanocomposites can be processed by conventional wet and dry processing techniques, yet in adjusted conditions vs. their neat counterparts. Polymer nanocomposites and nanoparticles can also be applied as nanocoatings, meaning a deposited nanoscale layer on selected substrates to reach specific surface behaviour. The effect of adding different reinforcements at nano-scale, such as carbon nanotubes, nanoclay, graphene, or nanosilica to polymer matrices, is discussed and the improvement in mechanical properties of PMCs is evaluated. Some concluding remarks and new perspectives on the use of PMCs in structures are given [3]. Polymer clay composites exhibit three distinct morphologies, that is, conventional segregated clay phase and intercalated and exfoliated structures [4]. Improved mechanical, thermal, and barrier properties are usually obtained for an exfoliated architecture; that is, individual silicate lamellae are homogenously distributed in the polymer matrix.

Transmission electron microscopy (TEM) is the most commonly used method to characterize the microstructure of the nanocomposites. Figure 1 shows the TEM micrographs depicting the various idealized morphologies of the polymer nanocomposite structures [5]. Polymer clay nanocomposites (PCNs) are one of the ways for making new materials that frequently exhibit remarkable improvements of material properties to replace traditional products in many applications [6, 7]. The PCNs based on unsaturated polyester and nanoclay (MMT) also have been widely researched by scientists in the world for many years. The results showed that when clay dispersed in the form of exfoliated state or intercalated state, properties of PCNs such as tensile strength, flexural strength, gas permeability and biodegradability were improved significantly [8,11]. In recent time, the trend using nonion modifiers demonstrated that they had many promising applications in nanocomposite material field [9]. So in this study we have tried using poly(ethylene oxide) (PEO) as a new modifier to replace some traditional ionic surfactants such as primary, secondary, tertiary, and quaternary alkyl ammonium or alkylphosphonium cations having, disadvantages: disintegrate at high temperature, catalyze polymer degradation, and make nanoproducts colorific [10]. Then nanocomposite materials based on Unsaturated Polyester resin (UP) with PEO modified clay were prepared by solution method. The morphology and properties of PCNs were tested through XRD, TEM, mechanical strength, and thermal behavior.

One of the most significant developments in the past two decades or so has been nanocomposite materials in which at least one component has nanoscale dimensions [12, 13]. One of the best examples of such materials are polymer-layered silicate nanocomposites (PLSNs) [14–15]. In PLSNs, the large surface -to-volume ratios of the inorganic component leads to significant improvements in properties and, perhaps most importantly, these nanocomposites often avoid the usual trade-offs in properties integral to macroscopic filled composites. Notwithstanding the fact that polymer–silicate composites had been studied for several decades, the genesis of the modern PLSNs can be traced to the seminal work done at Toyota Central Research and Development Laboratories in the late 1980s [16].

Since the publication of these papers from the Toyota group, there has been an enormous push toward the development of new PLSN-based materials, not only from an industrial view-point of making products but also to answer more academic questions regarding the nano effect present in these materials. This review will concentrate on these developments in PLSNs since the Toyota publications. It is not intended to be a comprehensive treatise, but discusses the most salient aspects of PLSNs, including preparation methods, structure, and properties. They first demonstrated the significant improvement of several properties on the inclusion of only small percentages of silicate into nylon [16–19]. They polymerized intercalated "-caprolactam in montmorillonite (MMT) to produce a nylon 6 (N6)-clay nanocomposite [16–19]. This resulted in the silicate layers being uniformly dispersed within the polymer matrix, and resulted in the composite material having improved physical properties compared with virgin polymer. For example, the nanocomposite material showed an increase in tensile strength by 55% with only 4.2 wt.% of MMT [19]. The significance of these results is further compounded when it is noted that these improvements were obtained with only a few percent of silicate present.

III. NANOCOMPOSITE STRUCTURES AND CHARACTERIZATION

The microstructure of the composites generated owing to the interactions between the organic polymer and inorganic filler phases is ideally classified as unintercalated (phase separated), intercalated and exfoliated composites, as shown in figure 1 [29]. The composite microstructure is classified as exfoliated when the filler platelets are completely delaminated into their primary nanometer scale size and the platelets are far apart from each other so that the periodicity of this platelet arrangement is totally lost. This happens when the electrostatic forces of interaction between the platelets have completely been overcome by the polymer chains in the composites.

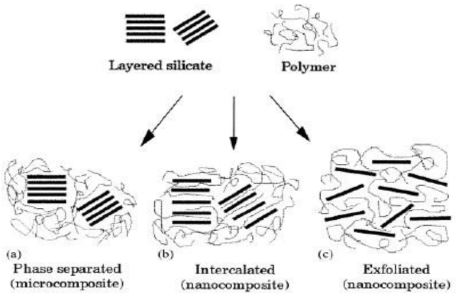

Figure 1: Schematic representation of the different types of composites generated based on the interactions of the layered silicate with polymer matrices. (a) Phase separated microcomposite, (b) intercalated nanocomposite and (c) exfoliated nanocomposite [29].

Transmission electron microscopy (TEM) is the most commonly used method to characterize the microstructure of the nanocomposites. Figure 2 shows the TEM micrographs depicting the various idealized morphologies of the polymer nanocomposite structures [30]. Figure 2a represents the exfoliated morphology, where the black lines are the cross-section of the aluminosilicate platelets. The platelets can be seen as single and uniformly dispersed, though they are completely misaligned. On many occasions, the bending and folding of the platelets has also been observed. Figure 2b shows the micrograph with intercalated platelets. The microstructure represents a well ordered multi layer morphology consisting of alternate polymer and inorganic layers. Such a periodicity gives a signal in the X-ray diffractograms and thus the amount of intercalation can then be quantified by the comparison with the basal plane spacing of the modified filler. The exfoliated morphology does not generate any diffraction signal owing to the loss of periodicity and the absence of diffraction peak is taken as the proof of the generation of completely exfoliated nanocomposites. Figure 2c shows the micro composite or phase separated morphology. Here the filler is not at all intercalated by the polymer chains and the thick filler tactoids are present separated from the polymer phase. However, it should be noticed that these classifications of the composite microstructure as exfoliated and intercalated are not very realistic as in reality, generally a mixture of different morphologies is present. Different extents of intercalation as well exfoliation are generally observed and at maximum, only qualitative classification of the morphology as more or less intercalated or exfoliated can be made.

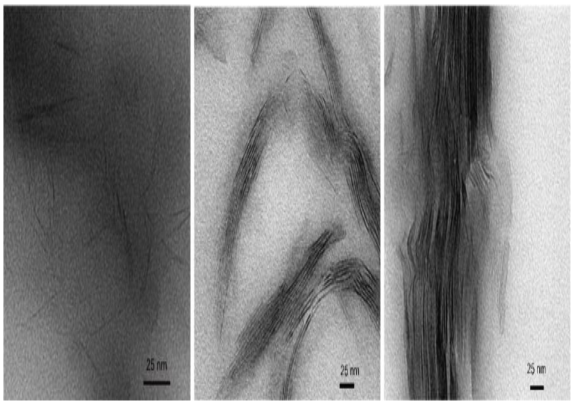

Figure 2: TEM micrographs indicating various possible morphologies in the composites as function of the filler distribution: (a) exfoliated, (b) intercalated and (c) unintercalated. Reproduced from reference [30].

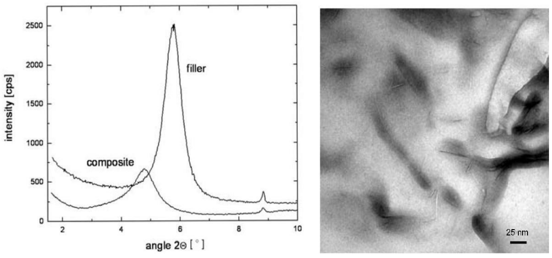

Figure 3: (a) X-ray diffractograms of benzyldibutyl(2-hydroxyethyl)ammonium modified montmorillonite and its nanocomposites with epoxy polymer containing 3 vol% filler and (b) TEM micrograph of the epoxy nanocomposite[30].

As an example, in figure 3 are shown the X-ray diffractograms of the montmorillonite modified with benzyldibutyl(2-hydroxyethyl) ammonium and its composite with epoxy [30]. The increase in the basal plane spacing of the filler after the composite synthesis was minimal and the diffraction signal of the filler in composite material was quite strong in the diffractograms indicating the intercalated structure.

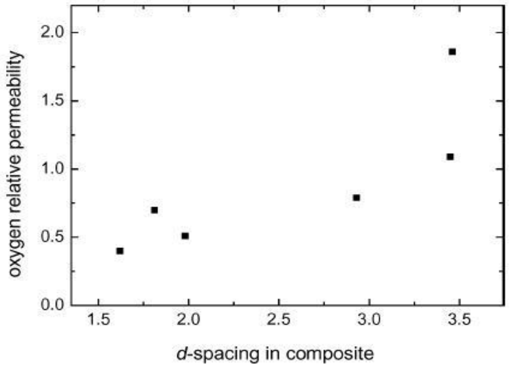

Figure 4: Correlation of the relative oxygen permeability through the nanocomposite films as a function of basal plane spacing of the filler in the composites [reference 31]

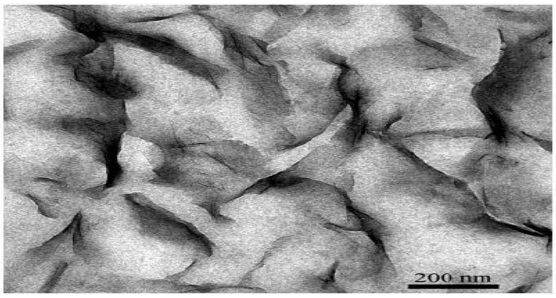

Figure 5: TEM micrograph of the epoxy composite containing 3 vol% of the filler [reference 31]

Increase in the basal plane spacing of the filler in the epoxy composites was plotted as a function of the oxygen permeation through the composite films containing the layered silicates modified with different surface modifications as shown in figure 4.

However, the evaluation of the aspect ratio of the filler platelets in the composite material is also not straightforward owing to the bending and folding of the platelets as shown in figure 5. In many reported studies, the TEM micrographs have been used to generate information on the average aspect ratio, but in the light of complexities associated with the evaluation of the aspect ratio from the micrographs, other means to obtain an average aspect ratio of the filler in the composites are required. High-resolution (Hi-Res) thermogravimetric analysis (TGA) of the modified fillers and nanocomposites, in which the heating rate is coupled to the mass loss, that is, the sample temperature is not raised until the mass loss at a particular temperature is completed, is another means of characterization of the modified fillers as well as synthesized composites.

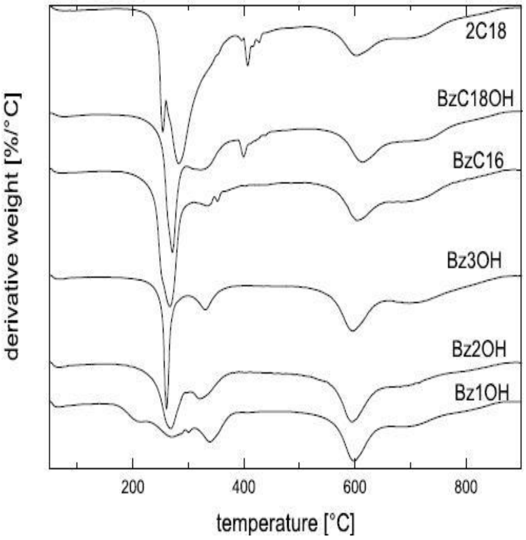

Figure 6: (a) TGA thermograms of the modified fillers with various ammonium ions and chemical structures of the ammonium ions exchanged on the filler surface [reference 31]

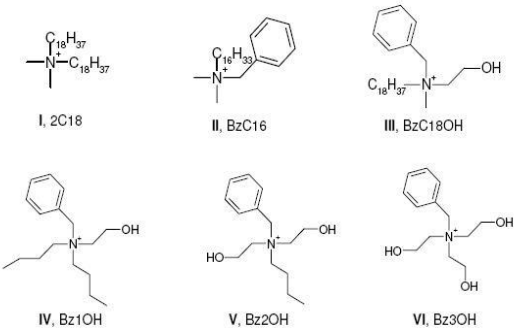

Figure 6a: TGA thermograms of the fillers modified with various ammonium ions, the chemical structures of which are demonstrated in Figure b [31].

IV. APPLICATIONS OF NANOCOMPOSITES

This review gives an insight on the application of nanocomposites and Nano coatings with a special focus on their prospects for:

- Food and cosmetic packaging
- Solar energy, especially organic photovoltaics
- Automotive structural parts

In terms of packaging, different properties can be enhanced through the use of nanocomposites such as the gas barrier, antimicrobial properties, etc. The most frequently tested Nano fillers are Nano clays montmorillonite (MMT) and kaolinite, carbon nanotubes (CNT) and graphene Nano plates (GNP) [21]. The improvement of barrier properties could more especially benefit biopolymers which generally have limited intrinsic barrier properties. Additionally, surface coatings can be used for modulating surface affinity of the packaging towards different liquids and pastes, e.g., to obtain water repellent paper-based packaging [22] or easy-to-empty features [23]. In terms of automotive applications, mechanical and electronic properties, thermal isolation, wear resistance and flame retardance are of interest among other improvements that can be provided by nanocomposites. In terms of mechanical reinforcement, whereas standard toughening additives and fillers normally lead to opposite variation of toughness and stiffness, the specific effect of nanoparticles allowing to improve both can benefit in the design of parts that comply similar structural functions at lower weight than micro-composites or neat polymers. Lighter but stronger materials allow optimal fuel consumption and increased safety. In terms of solar energy, contributing to the multifunctionality and efficiency of solar panels, nanocomposites and Nano coatings are of relevance either in the photoactive layers, in protective layers, or on the surface of the solar panels. Energy harvesting by fullerenes have already been reported in the organic photovoltaic (OPV) industry [24]. As for packaging, for the outer layer, the use of nanostructured materials has been found to improve humidity, gas and UV barrier properties of solar cells in general. Nano texturized surfaces and Nano coatings have been developed to provide self-cleaning effects to solar panels [25], therefore minimizing the requirements for maintenance while maximizing the energy yield.

In the subsequent sections, we review the different processing technologies that are used for nanocomposites conversion (including wet chemical and thermoplastic processing), as well as the Nanomaterials common and new Nano deposition approaches with a specific focus on electrospray. The limitations and required process improvements are then discussed showing the challenges in nanoparticles dispersion. In a following section, the different properties that can be enhanced using nanocomposites are reviewed, including barrier, mechanical, electrical/ electronic, microwave absorbing properties and flammability resistance. Processability and compatibilization issues are also commented. The surface properties resulting from Nano coatings are then reported. The polymer nanocomposites applications are covered with a main focus on packaging, solar panels, and automotive sectors as well as a few words on other applications of interest.

Finally, the review gives some insights on safety and regulatory aspects that would influence the market uptake for new nanocomposites.

V. CONCLUSIONS

Nanotechnology has been revolutionizing the world of materials with its high impact in developing the new generation of composites with enhanced functionality and a wide range of applications. The investigations in processing, characterization and applications help researchers understand and utilize the special chemical and material principles underlying these polymer nanocomposites. Although nanocomposites are realizing many key applications in numerous industrial fields, an array of technical and economic barriers exists to their widespread commercialization.

Researchers have made relatively awesome discoveries over the last decade, ever since the pioneering work on Nano clay by the Toyota Company. The dispersion of the silicate Nano layer with its high aspect ratio, large surface area, and high stiffness within a polymer matrix results in significant improvement of the properties of polymeric materials, including mechanical properties, barrier properties, resistance to solvent swelling, ablation performance, thermal stability, fire retardancy, controlled release of drugs, anisotropic electrical conductivity, and photo activity. Today nanocomposites are currently being used in a number of fields and new applications are being continuously developed.

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