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Review

Engineered Polymer and Nanodiamond

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Abstract:
Nanodiamond possess several outstanding properties such as hardness, strength, Young's modulus, heat stability, and thermal conductivity. Nanodiamond is stable and may offer a biocompatible interface. Due to high strength to weight ratio and low friction coefficient, these nanocomposites find applications in structural, tribological, engineering, and other sectors. Nanodiamond has large specific surface area to develop polymer-nanofiller interactions. Interphase has been developed in the vicinity of nanodiamond surface and polymer. The interphase holds great potential for obtaining high performance engineered nanocomposites. Polymer/nanodiamond nanocomposites have also been used to form multifunctional tissue scaffolds.

Keywords: Nanodiamond; engineering; polymer; scaffold
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1. Introduction

Nanodiamond has small diameter of 5 nm [1]. Nanodiamond has been produced by detonation and clusters may compose of several small nanoscale particles (Fig. 1). Nanodiamond possess rich surface chemistry for reinforcing polymer matrices [2-5]. The physical and tribological properties of polymer/nanodiamond nanocomposites have been studied. Functional nanodiamond nanoparticles have also been used as nanofillers. The nanodiamond can be physically/covalently incorporated in structure of epoxy, thermosets, and biodegradable polymers resulting in strong nanofiller-matrix interface [6-8]. The enhanced hardness, stiffness, fracture toughness, and low friction coefficient of nanocomposites have been enhanced for aerospace, automotive, sports and other engineering industries. Nanodiamond surface can be hydrophobized by grafting. For tissue engineering, biodegradable polymers have been used. Better mechanical properties and biocompatibility can be achieved through improved dispersion of ND in the matrix [9, 10]. This article provides new insights on the reinforced engineered polymer/nanodiamond nanocomposites. Further research efforts must focused on new functional nanoparticles and uniform dispersion in polymer matrices. New design of polymer/nanodiamond nanocomposites may lead to new engineering potential of these materials.

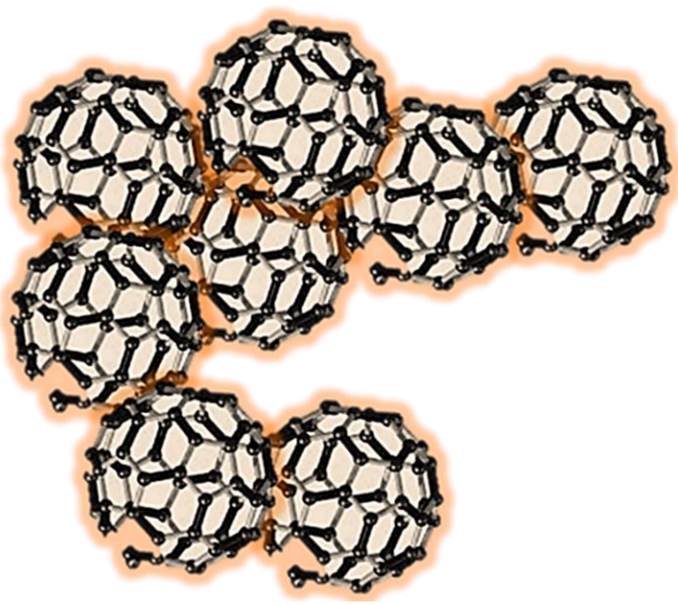

Fig. 1 Nanodiamond clusters.

2. Nanodiamond-based composite

Due to the need for light and strong materials, engineering composite materials have been developed [11-15]. The combination of light weight polymers and nanofillers may result in high strength-to-weight ratio polymer composites [16-20]. Epoxy and thermosetting polymers have been reinforced with nanodiamond and other nanofillers to form epoxy nanocomposites. Hardness, stiffness and fracture toughness of nanocomposites have been enhanced to be employed for aerospace, boating, sports and automotive industries. Biodegradable polymers such as polyvinyl alcohol and polylactic acid have been used in biomedical applications with nanodiamond [21-25]. Several multifunctional materials can be designed using nanofillers with desired properties [26-30]. Polymer/nanodiamond nanocomposite properties such as mechanical, electrical and thermal features can be improved using functional nanoparticles (Fig. 2).

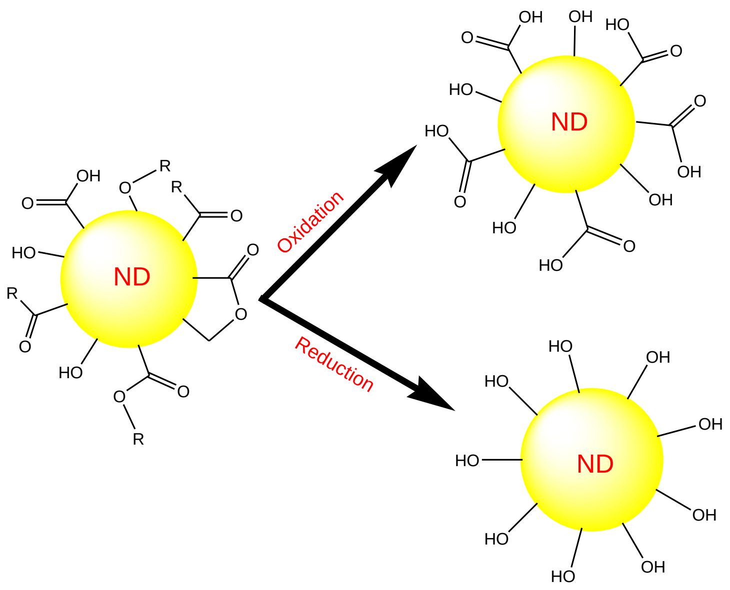

Fig. 2 Nanodiamond reactivity.

Interphase material may develop around the nanodiamond. Optimization of nanodiamond properties can significantly improve its utilization for polymers. Depending on the functional nanodiamond features and nanocomposites, future challenges for energy efficient, stronger, lighter, and multifunctional engineering materials can be designed.

3. Properties of engineered nanodiamond-based composite

Numerous options have been used to adjust the surface chemistry of nanodiamond. Covalent interfaces have been introduced between carbon nanotube, ND, nanoparticles, and epoxies and other polymers [31-35]. Consequently, it is important to study interactions between the nanofiller and polymer. Mechanical properties of engineered polymer/ND are most important to study. Fig. 3 shows Young's modulus of the polymer/ND nanocomposites between 0 vol.% ND and 7 vol.%. If ND has reactive functional groups on surface, the curing chemistry of epoxy system can be further altered. Very high nanofiller content may cause detrimental effect on the Young's modulus of nanocomposites. Thermal properties of polymer/ND nanocomposites have been studied using differential scanning calorimetry (DSC). This technique has been used to study the glass transition (T_g), cold crystallization (T_c), and melting temperature (T_m) of engineered materials [36]. The nanocomposites containing 1 wt.% ND have increased T_g, T_c and T_m compared with the lower wt.% nanocomposites. However, the T_g and T_m were decreased at ND concentrations above 1 wt.%. The increase in T_c indicated that the presence of nanodiamond hinders the crystallization of polymer. It was found that the uniformly distributed nanofiller in polymers may decrease the crystallinity due to interactions between the nanofiller and matrix. The polymer chain mobility was restricted before the transition to crystalline state [37]. The higher concentration range of 7-10 wt.% may induce reorganization and nucleation within the amorphous regions of polymers, which result in the transformation from amorphous to crystalline state [38-40].

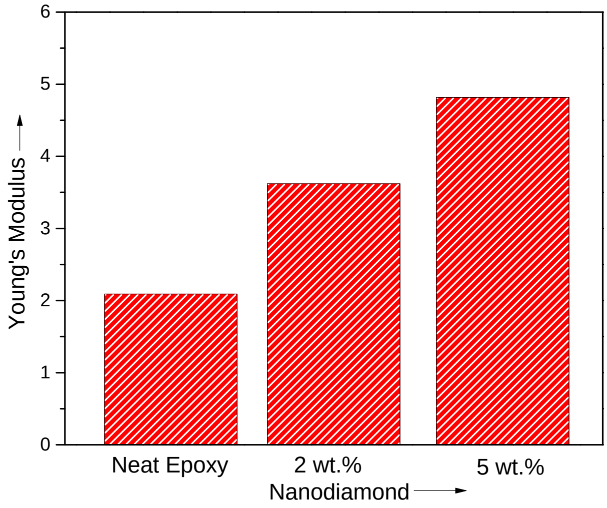

Fig. 3 Effect of nanodiamond on mechanical properties of nanocomposites.

4. Engineering applications of nanodiamond-based composite

4.1. Automotive and aircraft structures

Among engineered nanodiamond nanocomposites, epoxy/ND and carbon-fiber reinforced composites have been used in aerospace, automobiles, ships, and sports industries [41-45]. The essential engineering applications of polymer/nanodiamond are given in Fig. 4. Epoxy is a common thermosetting polymer used in these sectors. The fracture toughness and tensile properties of nanodiamond nanocomposites were found better compared with the epoxy/carbon nanotube nanocomposites. The similar nanofiller concentrations of ND and CNT in the range 0.1-0.5 wt.% showed superior properties for nanodiamond compared with the nanotubes in epoxy composites [46-50]. The 35 vol.% of ND in epoxy may enhance the hardness and Young's moduli by 300% and 700%, respectively. The interaction between ND nanoparticles and uniform dispersion may result in improved thermal conductivity. The engineering applications of these materials have also been focused owing to increased scratch resistance. The tribological studies of polymer/ND coatings on metal or alumina body has shown increased abrasion, hardness, and strength properties with uniformly dispersed nanoparticles. These materials have been used in tires as filling materials. In lubricating oils, polymer/ND has played essential role to improve the properties. For heat removal purposes, these materials have definitely found wide scope. Due to strength and hardness, these nanocomposites can also be used in drilling and cutting tools. The macroscale friction coefficients of nanodiamond nanocomposites was found much reduced compared with the other composites [51].

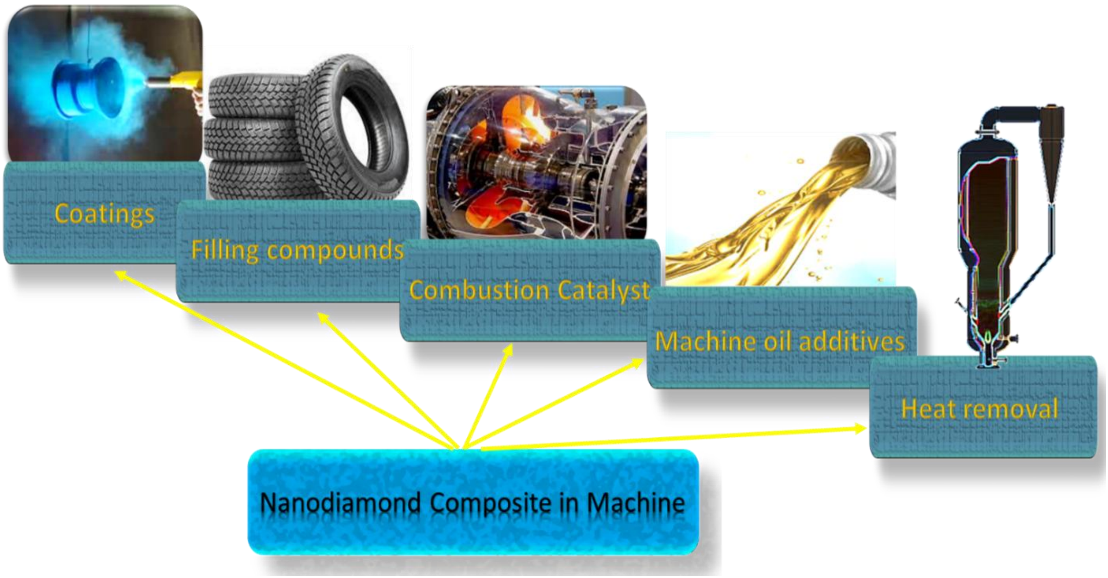

Fig. 4 Engineering applications of polymer/nanodiamond.

4.2. Bone Tissue Engineering

For several applications, solvent casting has been used as a simple conventional synthesis method. The microstructure and physical properties such as structural, mechanical, and biomedical features of these composites have been studied [51-55]. For bone tissue engineering, biodegradable polymer and ND nanocomposites have been deliberated for bone tissue scaffolds (Fig. 5).

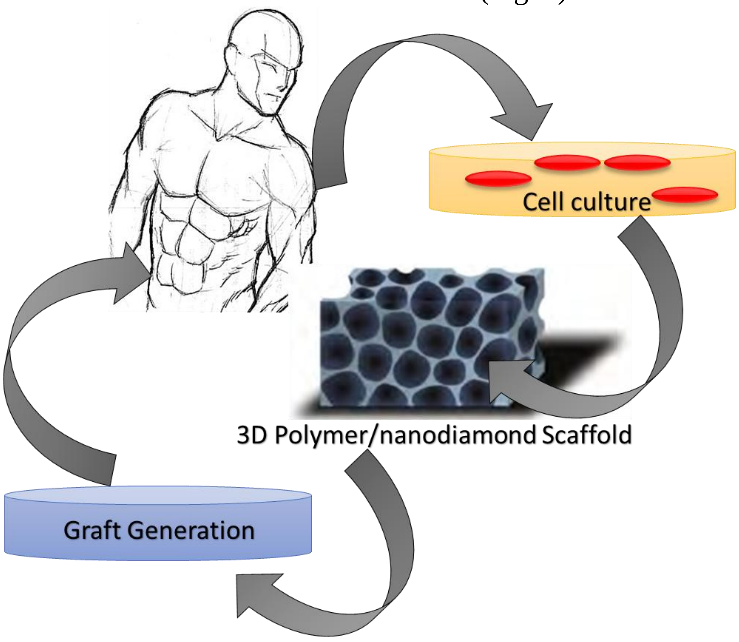

Fig. 5 Bone tissue engineering.

The ND nanoparticles uniformly dispersed in the matrix may have good affinity with polymer. Addition of ND or functional nanofiller in biodegradable polymers may decrease the crystallinity of materials forming a complex network. The mechanical properties of these nanocomposites have been investigated by nanoindentation. The Young's modulus and hardness were found to improve several times through nanofiller incorporation. The glass transition temperature was also increased with increasing ND content. The biocompatibility and cytotoxicity of engineered nanodiamond nanocomposites were also evaluated for the tissue cultures [56, 57].

5. Conclusions

Nanodiamond is a promising nanofiller due to superior optical, electrical, mechanical, and heat stability properties. The unique properties of ND have been explored in composites, electronics, packaging, membranes, biomedical applications, etc. The characteristics of nanocomposites can be further improved *via* incorporation of modified nanofillers for advance application. Engineering applications of these materials have been observed in automotive and aircraft structures and bone tissue engineering. This article states basic knowledge of nanodiamond-based composites, their properties, and engineering applications. Nevertheless, there are several challenges need to be addressed for future potential in this field.

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