

Mechanical, Tribological Properties and Surface Characteristics of Developed Polymeric Materials Reinforced by CNTs

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ABSTRACT

The aim of this research is to assess and develop a polymeric material consisting of a mixture of high-density polyethylene (HDPE) and ultra- high- molecular- weight polyethylene (UHMWPE) reinforced by carbon-nanotube (CNT) by optimizing the mixing concentration of the three constituents. This optimized mixture is accomplished by using a melt extruder-mixing process. An experimental evaluation for accurate assessment of the developed nanocomposite material characteristics is achieved by using a universal tensile test machine and a plint-tribometer pin-on-disc machine. Moreover, the hardness of the material surface and its surface topography are assessed by a hardness tester machine and SEM technique, respectively. Developed samples for testing are classified into two groups of nanocomposites. The first group is created through mixing two pure polymeric UHMWPE and HDPE with different mass ratios of each. While, the other group is created through mixing three components UHMWPE, HDPE and CNTs with constant 50 wt.% of UHMWPE. Thereafter, CNTs with rations of 0.5, 1.0, 2.0, 3.0 and 4.0 wt.% to 49.5, 49.0, 48.0, 47.0 and 46.0 wt.% of HDPE to create different nanocomposite materials. The mechanical and tribological properties of this new developed material are obtained through testing of the two groups' samples to measure the tensile strength, friction coefficient, wear rate and surface hardness. Then, the best developed nanocomposite material is selected based on its mechanical and tribological properties. To ensure that the obtained nanomaterial has proper surface morphology, the SEM technique as a surface metrology tool is used to characterize the selected sample and to predict the CNTs dispersion homogeneity. The results show that the developed nanomaterial has achieved mechanical and tribological properties which outperform currently available materials with reasonable surface homogeneity.

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INTRODUCTION

Mechanical and tribological properties beside the surface behaviors of materials are very important and necessary characteristics for many engineering applications. Nowadays, nanocomposite polymeric-base materials have become commonly used in many different applications such as aerospace, airplane, automotive and biomedical industries.

Since the discovering of the carbon nanotubes (CNTs) (ten years ago), they have been considered as smart materials possessing the highest strength and stiffness among all the known traditional materials with lowest density. CNTs have become strongly promising for developing novel smart polymer matrix nanocomposites to satisfy the ever increasing design requirements of the future era [1].

Today, the polymeric materials reinforced by CNTs have potential applications such as gears, drive shafts, instrumentation sensors and fuel cells beside body panels in automotive, airplane and aerospace industry [2, 3]. Polymeric nanomaterials are also promising for implanted biomaterials in human body such as knee meniscus and

shoulder glenoid and can act as delivery vehicles for a variety of molecules relevant to therapy and diagnosis [4, 5]. Recently, there is a research group working to use the CNTs in the surface coating for the most accurate mechanical parts such as the tip of atomic force microscopy to improve its performance in precise measurements [6]. Because the nanomaterial composite showed better mechanical performance compared with that of the micro-particle-filled composite [7].

Multi-walled carbon nanotubes were tested to have a tensile strength of 63 GPa. Further studies conducted in 2008 [8] revealed that individual CNT shells have strengths which can be reached to 100 GPa, which is in good agreement with quantum/atomistic models. Since carbon nanotubes have a low density for a solid of 1.3 to 1.4 g/cm³. While, the specific strength of carbon nanotubes may reaches up to 48,000 kN·m/kg which is considered the best of the known materials, compared to high-carbon steel's 154 kN·m/kg [9].

Although, the strength of individual CNT shells is extremely high, weak shear interactions between adjacent shells and tubes leads to a significant reduction in its effective strength down to only a few GPa's [10]. This limitation has been recently addressed by applying high energy electron irradiation which crosslinks inner shells and tubes and effectively increases the strength of these materials up to 60 GPa for single-walled carbon nanotubes and 17 GPa for multi-walled carbon nanotubes bundles. Standard single-walled carbon nanotubes can withstand a stress up to 24GPa without deformation. A maximum stress was measured using current experimental techniques and found to be around 55GPa [11]. However, these new super-hard phase nanotubes collapse at an even higher, albeit unknown stress.

MATERIALS AND METHODS

Ultra-high molecular weight polyethylene (UHMWPE) and high density polyethylene (HDPE) are two types of thermoplastic polymers made from petroleum. UHMWPE is a linear homo-polymer with a simple composition material. UHMWPE is an abrasion resistant and bonier polymer widely used as a bearing material, but it is very expensive compared to HDPE. Carbon nanotube (CNT) is an expensive and innovative material possess excellent mechanical and physical properties enable it to be used as a reinforced nanoparticle to many engineering polymeric- and metal-matrix composites. The technical specifications of the used UHMWPE and HDPE powder used in the experimental work of this study are given in Tables 1 and 2. Whereas, the technical specifications of the short purified CNTs used as a reinforcement powder are shown in Table 3.

Table 1. Technical specifications of the UHMWPE powder [12]

Property	Value
Molecular weight (10^4 g/mol)	400-460
Density (g/cm^3)	0.93 ~ 0.94
Water absorption (%)	0.15
Granularity (99%)	10 - 60 Mesh
Temperature of deformation ($^{\circ}\text{C}$)	80
Izod impact strength (kJ/m^2)	No break
Charpy notched impact energy (kJ/m^2)	90
Tensile strength at break (MPa)	35 ~ 40
Elongation at break (%)	330
Wear by the sand slurry (%)	0.50

Table 2. Technical specifications of HDPE powder [13]

Property	Value
Outer diameter (mm)	1- 2
Length (mm)	3
Melting point ($^{\circ}\text{C}$)	150 $\pm$ 5
Density (g/cm^3)	0.94

Table 3. Technical specifications of the short purified CNTs [14]

Property	Value	Method of measurement
Outer diameter (nm)	< 8	HRTEM, Raman
Length (μm)	0.5-2.0	TEM
Purity (Wt %)	> 95	TGA & TEM
Electric conductivity (EC) (s/cm)	>100	---
ASH (Wt %)	< 1.5	TEG
Tap density (g/cm^3)	0.27	---
Melting point ($^{\circ}\text{C}$)	600-700	---

Mechanical, tribological and surface testing are common methodologies used to evaluate the properties of new materials. Hot-melt extrusion (HME) method is a recognized process for the manufacturing of solid products used currently at the National Institute for Standards (NIS) in Egypt. HME method is used for processing the proposed composite materials at constant temperature condition (220°C) by using twin-screw extruders. This method is used to perform a mixture of UHMWPE and HDPE particles with CNTs.

A universal tensile testing machine and a plint-tribometer pin-on-disc machine were used to measure the mechanical and tribological properties of the proposed new nanocomposite materials, respectively. The hardness tester and SEM technique were also used to measure the surface characteristics of the proposed composites materials.

EXPERIMENTAL WORK

CNTs have been added for reinforcing UHMWPE as a matrix material by using a melt extruder. The mechanical and tribological properties of the resulted composite have been investigated through tensile and tribological testing machines. Two groups of raw materials are blinded with different contents (UHMWPE-HDPE-CNTs) and ratios followed by a preparation process for the test requirement, as shown in Table 4. It must be mentioned here, that the weighting process is an important step to set the blinding ratio for all the three raw materials UHMWPE-HDPE-CNTs.

Table 4. Mass ratio concentration of the proposed test samples

Group no.	Sample no.	Weight percentage ratio, (wt.%)		
		UHMWPE	HDPE	CNTs
I	1	50.0	50.0	0.0
	2	60.0	40.0	0.0
	3	80.0	20.0	0.0
	4	100.0	00.0	0.0
II	5	50.0	49.5	0.5
	6	50.0	49.0	1.0
	7	50.0	48.0	2.0
	8	50.0	47.0	3.0
	9	50.0	46.0	4.0