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Tribological behaviour of 1D and 2D nanofiller based high densitypoly-ethylene hybrid nanocomposites: A run-in and steady state phase analysis

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ABSTRACT

Hybrid nanocomposites are a class of materials with exceptional properties due to the synergizing effect of individual fillers. Current work reports the tribological behaviour of high densitypolyethylene-(HDPE) reinforced with 1D-(Multi walled carbon nanotubes-(MWCNTs) and 2D-(h-Boron Nitride nanoplatelets-(BNNP) nanofillers. MWCNTs and BNNPs are chemically modified prior to solution deposition on HDPE and then processed through injection moulding. Testing was performed by varying Load, Speed and Sliding distance for all samples. Parameters such as wear volume, static and kinetic friction co-efficient, surface roughness in steady state and run-in phases, hardness, plasticity index and thermal expansion coefficient were reported. The wear volume of 0.1BNNP composite has shown reduced values as compared to 0.1MWCNTfor all parameters of testing. Highest wear resistance is exhibited by HDPE/0.25MWCNT/0.15BNNP hybrid nanocomposite. Plasticity index was reduced by 40% for HDPE/0.25MWCNT/0.15BNNP sample. The surface roughness increased with speed and sliding distance, while reduced with increasing load. Static and kinetic friction coefficients were also estimated. The surface morphology was examined at the end of Run-in and Steady state to identify prominent wear mechanisms. It is concluded that BNNP based composites possess better properties compared to MWCNT for equal loading, however, Hybrid composites of 1D/2D nanofillers has been shown superior properties.

1. Introduction

Components such as gears, cams, and bearings are being made of polymer for low load applications due to its specific advantages like low weight, corrosion resistance, and less cost. High density-poly ethylene (HDPE) is widely used in different segments including medical devices, airplane interiors, machinery parts of automobiles, other grinding systems owing to its excellent chemical and mechanical properties [1,2]. Although HDPE exhibits superior properties compared to rest of existing engineering polymers, it still poses some critical problems such as lack of stiffness, rigidity and wear resistance [3]. Owing to its applications, it was found that wear resistance is an important parameter; therefore, an attempt has been made to improve the wear resistance of the HDPE by adding multi walled carbon nanotubes (MWCNTs) and Hexagonal Boron Nitride Nano Platelets (BNNP) to form a hybrid nanocomposite. MWCNT has been taken as reinforcement due to its largest aspect ratio, superior mechanical properties, high elastic modulus, good thermal and electric properties [4,5]. BNNP has taken as reinforcement owing to its lubricating property and high dimensional stability [6].

Literature available on wear properties of HDPE-MWCNT polymer composite is scarce, and a few are discussed below. Johnson et al. [7] studied the wear behaviour of HDPE/CNT composite with different weight fractions of nanotubes and reported that the overall wear rate decreased by up to 50% and friction coefficient decreased by 12% by addition of 5% weight of CNTs. Thakur et al. [8] observed a considerable improvement of wear resistance by addition CNT to HDPE due to good load transfer and interfacial link, it was noticed that the nanocomposites has shown higher toughness and reduced friction, which in turn enhances the wear resistance. Xu et al. [9] reported wear behaviour of carbon

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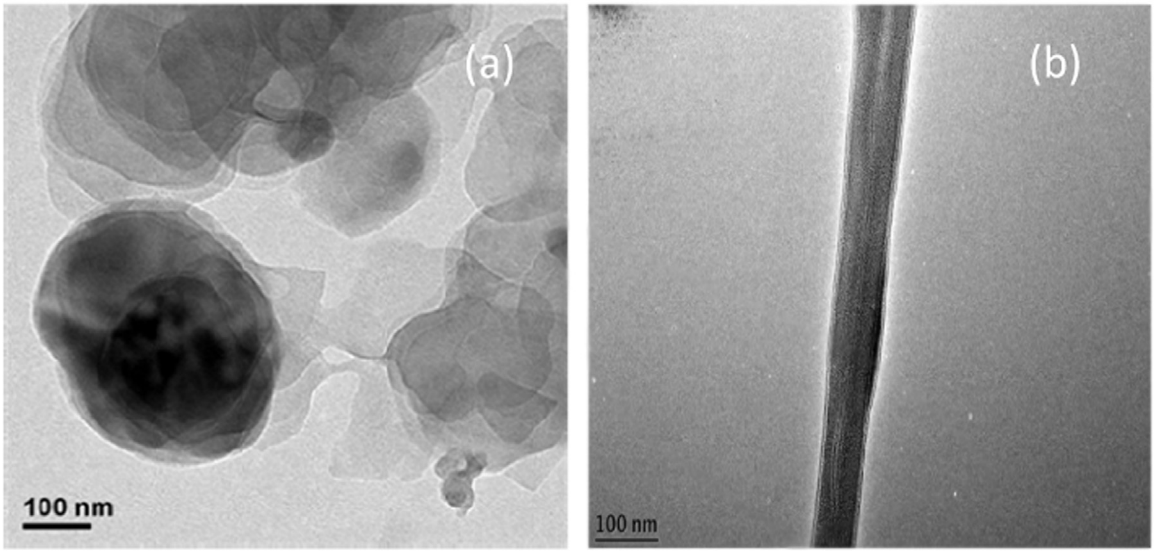

Fig. 1. TEM morphology of the fillers a) h-BNNP b) MWCNT.

nano-fiber reinforced HDPE composites under lubricated condition; it was observed that wear rate was lowered by 35% and 29% for 0.5 wt% and 1 wt% of CNT for the composites compared to pure HDPE. Sreekanth and Kanagaraj [10] studied the influence of multi walled carbon nanotubes reinforcement on the wear behaviour of UHMWPE. Wear studies on the test samples revealed that the wear volume of unirradiated UHMWPE was reduced by 73% upon dispersing 2 wt. % MWCNT at 100KGy irradiation, it was also noticed that the severity of wear mechanisms was found to be reduced for irradiated composites compared to unirradiated UHMWPE.

Xue et al. [11] studied the tribological behaviour of UHMWPE/HDPE blend reinforced with MWCNT. The CNT content was varied between 0.2 and 2 wt. %, and the results showed that the specific wear rate of the composites decreased by 50% with an addition of 0.5 wt. % CNT. Jacobs et al. [12] studied the thermo-mechanical, wear and fracture behaviour of HDPE/Hydroxyapatite Nano-Composite. The wear resistance was reported to have increased by 36% at 30 wt. % of hydroxypatite particles due to increased hardness and crystallinity. Although several other nanofillers were used as reinforcement with HDPE were reported in the literature, but none were pertaining to h-BNNP as filler.

BNNP also known as "white graphite" has good lubricating properties similar to graphite or Graphene Nanoplatelets (GNPs). GNPs have also exhibited good tribological properties. Liu et al. [1] evaluated tribological properties of HDPE nanocomposite reinforced with three different variants Graphite Nanoplatelets (GNP); as received GNPs, high temperature purified GNPs (ht-GNPs) and silanized GNPs (s-GNPs). The filler loading was kept at 3 wt %. The optimum sliding velocity was recorded as 1.3 m/s on a Pin On Disc tribometer where both ht-GNPs and s-GNPs exhibited 78.4% and 96% increase in wear resistance as compared to as received GNPs. GNPs are carbon based and can be used as fillers where extraordinary stiffness and high electrical conductivity [13], is essential whereas BNNPs are electrical insulator and layered structure. Literature reports studies related to GNP based polymer composites, but studies related to HDPE/BNNP-MWCNT based composites could hardly be traced in the available literature. In addition Hybrid nanocomposites are an emerging class of materials with exceptional properties due to synergizing effect of individual fillers on the properties of the composite.

To the best of author's knowledge, no work has been reported in the context of HDPE-MWCNTs-BNNPs hybrid nanocomposites, MWCNTs are a tube like 1-D nano structure while BNNPs are 2-D platelets; apart from forming a hybrid composite with two different nanofillers, the combination also brings 1-D (tube) and 2-D (platelets) geometry to form a composite. Thus an attempt was made to study the wear behaviour of HDPE/MWCNT/BNNP hybrid nanocomposite. HDPE/MWCNT, HDPE/BNNP nanocomposite were evaluated initially to assess the influence of each on the wear behavior of polymer. Hybrid composites were prepared at later stages and the wear studies were performed. The influence of load, speed and sliding distance was observed for both nanocomposites and hybrid nanocomposites. The analysis was performed both at run-in and steady phase. Typical parameters like wear volume, surface roughness, prominent wear mechanism were assessed for all the composites. Related parameters such as Hardness, Plasticity index and thermal expansion were also evaluated for all the developed composites to augment the wear studies.

2. Materials & methods

2.1. Materials

HDPE pellets were received from Indian Oil Corporation Ltd. Panipat, India, with following specifications: Density >0.940 g/cm^3, melting point of 125–135 °C. The MWCNTs were purchased from Reinste Nano Venture, India with diameter 60–100 nm, length 5–15 μm, purity $>95\%$ and density 2.15 gm/cm^3, Hexagonal Boron Nitride Nanoplatelets (h-BNNP) were purchased from Sisco Research Labs with an average particle size of 70 nm, specific surface area 19.4 m^2/gm and with hexagonal morphology. The TEM images of h-BNNP & MWCNT are shown in Fig. 1a and b respectively. MWCNTs were surface modified with acid treatment as described by Sreekanth and Kanagaraj [14] with HNO_3:H_2SO_4 in the ratio of 1:3 at 140 °C for 45 min. BNNP were also surface modified as suggested Xie et al. [15] by mixing 30% H_2O_2 in powder of BNNP at 0.1 g/ml. Obtained blend was autoclaved for 24 h, In order to remove moisture content from the mixture, it was then heated at 100 °C for 24 h and then cooled to room temperature. The mixture was finally filtered and washed with deionized water and dried in vacuum at 50 °C, to obtain surface modified h-BNNP.