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Short Communication

Nanotribological behavior of graphene nanoplatelet reinforced ultra high molecular weight polyethylene composites

Debrupa Lahiri [a,b], Francois Hec [a,c], Mikael Thiesse [a,c], Andriy Durygin [d], Cheng Zhang [a], Arvind Agarwal [a,*]

[a] Nanomechanics and Nanotribology Laboratory, Department of Mechanical and Materials Engineering, Florida International University, Miami, FL 33174, USA

[b] Department of Metallurgical and Materials Engineering, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India

[c] Universite de Lyon-INSA de Lyon, 7, av. Jean Capelle F-69 621, Villeurbanne, France

[d] Center for Study of Extreme Materials at Extreme Conditions (CeSMEC), Department of Mechanical and Materials Engineering, Florida International University, Miami, FL 33174, USA

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ABSTRACT

Nano-scratch behavior of ultrahigh molecular weight polyethylene (UHMWPE) reinforced with graphene nanoplatelet (GNP) in varying composition of 0, 0.1, 0.5 and 1 wt% is reported. Hot pressed composite structures are characterized for their tribological behavior in scratch mode using a normal load of 100–300 μN. Increasing GNP content from 0.1 to 1 wt% results in lowering of the coefficient of friction due to easy shear of graphene nanoplatelets. Graphene reinforcement also increases the wear resistance by more than four times, which is a combined effect of lubrication as well as toughening offered by GNPs.

Graphene's excellent mechanical properties, in terms of elastic modulus (0.5–1 TPa) and tensile strength (~130 GPa) [1,2] has ensured its bright prospect as a reinforcement for composite materials for structural applications. Graphene has also shown great promise in tribological applications [3]. Weak van der Waal force between the 2D layers results into easy inter-layer sliding in multilayer graphene, leading to reduction in coefficient of friction. This unique feature has motivated researchers to evaluate the potential of graphene in tribological applications. Lin et al. reported significant improvement in the wear resistance and reduction in coefficient of friction (COF)of silicon substrate by introduction of 4 nm thick graphene membrane [4]. Graphene platelets are also found to reduce the friction when used as lubricant, dissolved in organic solvent [5]. The lubricating behavior of graphene is retained in harsh environment exposed to space irradiation, making it suitable for applications in outer space [6].

Graphene reinforcement is found to be beneficial for tribological performance for polymer matrix composites, in two ways: (i) reduction in COF and (ii) increase in wear resistance [7–10]. Graphene platelet addition by 10 wt% decreased the wear rate of polytetrafluoroethylene, a solid state lubricant, by almost four orders of magnitude [8]. A thin transfer film and fine wear debris generated in graphene reinforced polyphenylene sulfide composite coatings leads to improvement in the wear resistance [9]. A mere 0.05 wt% graphene reinforcement improved the nanoscale tribological performance of epoxy based vinyl ester resin, [10]. Decrease in COF is due to the lubricating effect shown by graphene through interlayer sliding, whereas the increasing wear resistance is the dual effect of toughening by graphene reinforcement and lubrication. The above discussion makes it clear that graphene is an attractive reinforcement for polymers that need simultaneous improvement in toughness and wear resistance. Biograde ultrahigh molecular weight polyethylene (UHMWPE) polymer is in clinical use as the acetabular cup liner in orthopedic hip implant. The purpose of this liner is to prevent the metal–metal abrasion between femoral head and acetabular cup and reduce generation of cytotoxic metallic particles as wear debris. But UHMWPE suffers from inherent low strength leading to wear and failure of the liner. This leads to osteolysis due to wear debris induced inflammatory reactions and finally premature replacement of implants [11,12]. Thus, it is important to improve the mechanical and tribological performance of UHMWPE, which can be achieved by second phase reinforcement. A previous study by the present authors has shown 54% improvement in fracture

* Corresponding author. Tel.: +1 305 348 1701; fax: +1 305 348 1932.
E-mail addresses: agarwala@fiu.edu, arvind872@gmail.com (A. Agarwal).

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toughness and 71% in tensile strength with 0.1 wt% graphene nanoplatelet reinforcement in UHMWPE [13]. Moreover, the addition of GNP to UHMWPE did not compromise on the biocompatibility [13]. These findings drove the interest to understand the tribological behavior of UHMWPE–GNP composites. As per the authors' knowledge, no reports are available on tribological behavior of UHMWPE–graphene composite. Tai et al. have studied the tribological behavior of UHMWPE–graphene oxide (GO) composite under reciprocating friction tests and noticed an increase in the wear resistance up to 1 wt% of nanofiller content, but coefficient of friction (COF) also increased simultaneously [14]. Such behavior was attributed to the increase in microhardness, domination of abrasive wear and formation of a transfer layer. However, the aim should be to decrease the COF for acetabular cup lining to reduce the friction generated during the limb movement. In this context, graphene should be more attractive than GO.

This study reports nano-scale scratch induced tribological behavior of UHMWPE–Graphene nanoplatelet composite. The damage in most of the surfaces under frictional force starts at a nano-scale depth. Once the nano/micro scale asperities are formed on the surface, they increase the roughness. Further movement of the surfaces causes an increase in the frictional force due to roughness and mechanical locking against these asperities. The wear and loss of material on surface gets aggravated in this process. Thus, it is very important to control the wear of the surface at the initial stage. This research explores the effect of graphene nanoplatelet addition on the scratch resistance and COF of UHMWPE composite surface at nano-scale depth.

Graphene nanoplatelets (xGNP-M-5) with ~6–8 nm thickness, 120–150 m^2/g surface area and average particle diameter of 5 μm were obtained from XG Sciences, Inc. (Lansing, MI, USA). UHMWPE

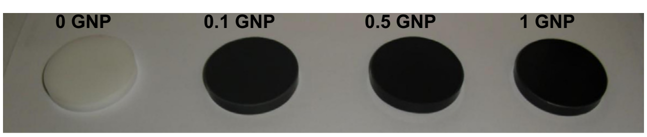

Fig. 1. Digital image of hot pressed UHMWPE pellets with 0, 0.1, 0.5 and 1 wt% GNP reinforcement.

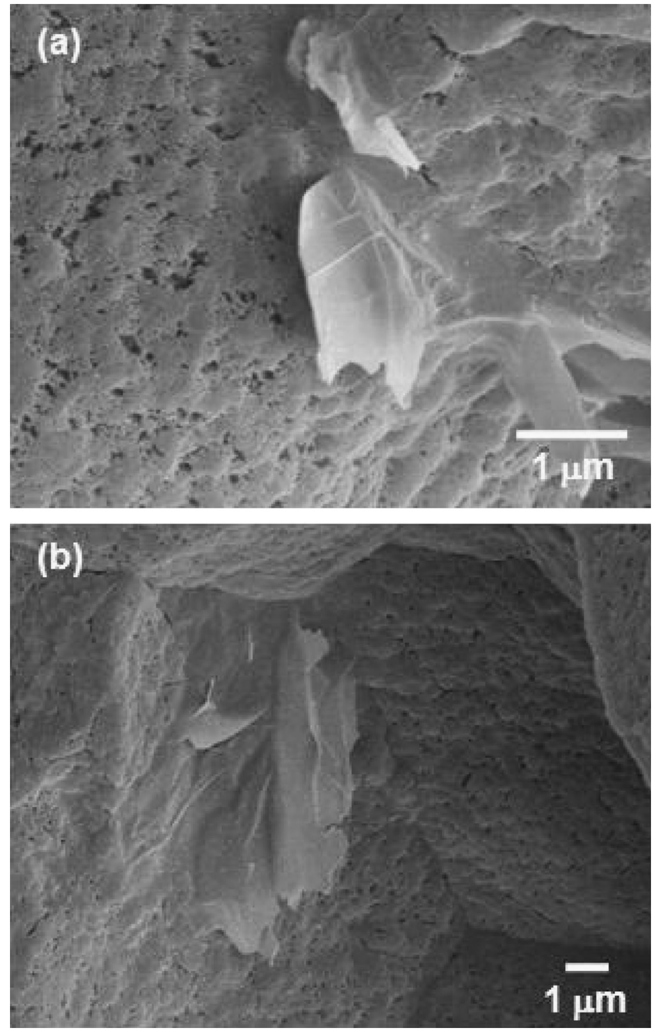

Fig. 3. High magnification micrographs of fracture surfaces of UHMWPE-0.1GNP revealing good bonding of GNP with UHMWPE matrix.

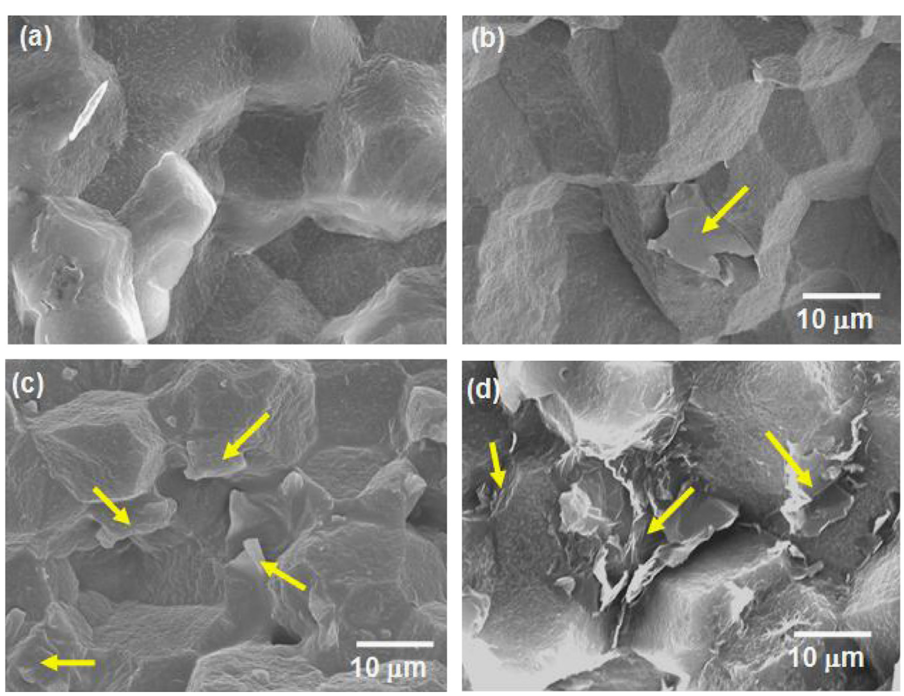

Fig. 2. SEM micrographs of fracture surfaces of (a) UHMWPE, (b) UHMWPE-0.1GNP, (c) UHMWPE-0.5GNP and (d) UHMWPE-1GNP. The arrows indicate GNPs.