

Polymer nanocomposite tribology improved with nanoclay reinforcements

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The specific wear rate and coefficient of friction of ultrahigh-molecular-weight polyethylene samples are substantially reduced with the use of three different types of nanoclay filler.

Polymers and their composites present much potential for use as weight-bearing materials. This potential arises from their relative chemical inertness (i.e., compared with metals and ceramics), resistance to corrosion, and high strength-to-weight ratio. Greater strength and superior mechanical properties, however, are desired for these materials so that they can be used to achieve better performance in demanding applications (e.g., for bearings).

Various approaches to improve the strength of polymers have so far been employed. For instance, different nanofillers (e.g., carbon nanotubes, graphene, metallic nanoparticles, and ceramic nanoparticles) have been used to reinforce polymer matrices.^{1–3} In particular, nanoclays are one such type of nanofiller that have good mechanical and barrier properties (because of their inherent platelet-like structure).⁴ To date, however, only very limited studies have been conducted on the use of nanoclays in this way.

In this work,⁵ we were thus motivated to investigate the use of nanoclays to reinforce a particular polymer—ultrahigh-molecular-weight polyethylene (UHMWPE)—with the ultimate aim of improving the mechanical and tribological properties of the polymer. To that end, we produced nanocomposites of UHMWPE and three different organically modified clays. We also evaluated the different aspects of their tribological performance (e.g., specific wear rate and coefficient of friction) under dry conditions.

To fabricate our nanocomposite samples, we reinforced the UHMWPE matrix with 1.5wt% of the three different nanoclays, i.e., Nanomer I.28E, Nanomer I.30E, and Cloisite C15A. We used a two-step process that involved high-energy ball milling (to obtain uniform powders) and then molding in a press (at 170°C and 25MPa) for 15 minutes, followed by cooling to room temperature. After we had formed our cylindrical samples, we used a stainless steel ball (6.3mm

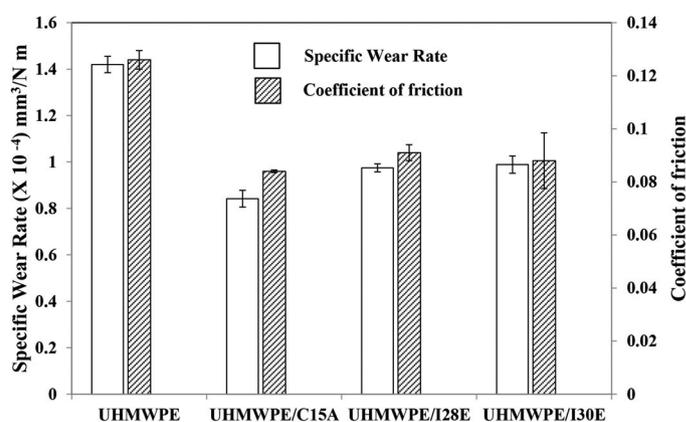


Figure 1. Specific wear rate and coefficient of friction results for a pristine ultrahigh-molecular-weight polyethylene (UHMWPE) sample, and for UHMWPE nanocomposite samples reinforced with three types of nanoclay, i.e., Cloisite C15A, Nanomer I.28E, and Nanomer I.30E. These ball-on-disc wear measurements were made over a sliding distance of 68m, at a normal load of 30N and a sliding speed of 0.06m/s.

in diameter) to conduct ball-on-disc wear tests, at a normal load of 30N and a sliding speed of 0.06m/s (over a sliding distance of 68m). In addition, we used scanning electron microscopy and 3D optical profilometry to characterize the wear tracks, in terms of their morphology and depth, to study the underlying wear mechanisms. We also used optical microscopy to obtain images of the counterface ball after the wear test, to examine the transfer film phenomenon.

The results of our ball-on-disc wear tests on all three nanocomposite samples, as well as a pristine UHMWPE sample, are shown in Figure 1. We find that all the nanocomposites exhibit better performance—in terms of wear rate and coefficient of friction—than the pristine sample. From our optical profilometry of the wear tracks after the ball-on-disc wear tests (see Figure 2), we see that the wear track of the pristine UHMWPE sample is characterized by deep grooves that exhibit significant abrasive wear. This is caused by the continuous ploughing of

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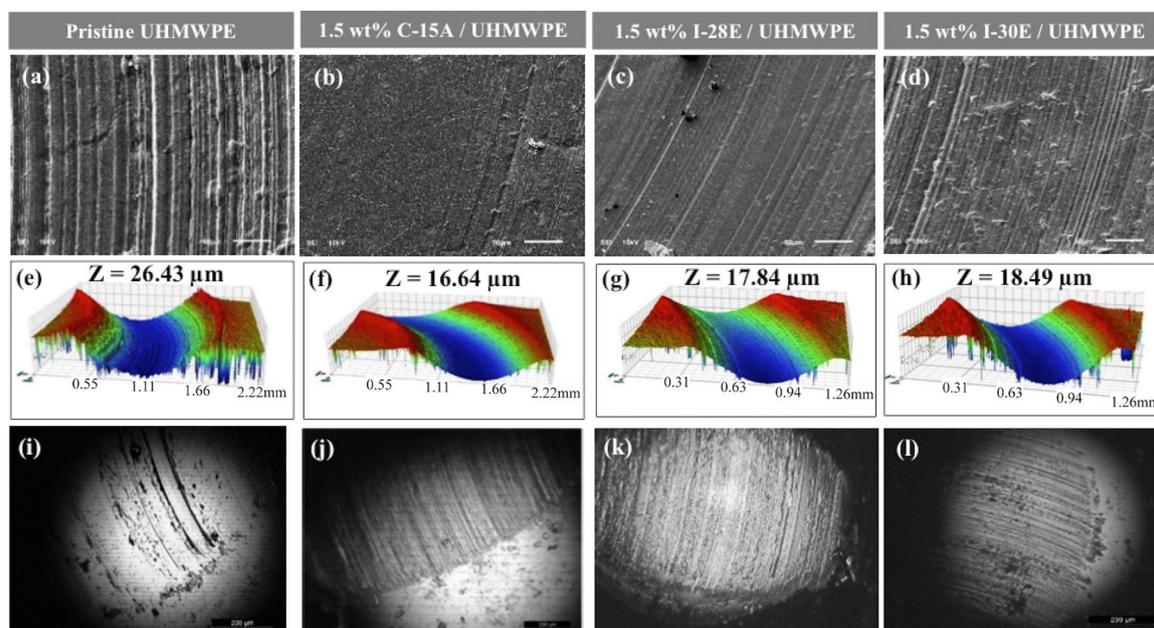


Figure 2. (a–d) Scanning electron microscope images (scale bars indicate 50 μ m) and (e–h) 3D optical profilometry of the wear tracks in the pristine UHMWPE and three nanoclay-reinforced UHMWPE samples. (i–l) Optical images of the counterface ball after the ball-on-disc wear tests had been conducted over a sliding distance of 68m, at a normal load of 30N and a sliding speed of 0.06m/s. Scale bars indicate 200 μ m.

the hard asperities of the counterface ball against the polymer, because there is no adherent transfer film: see Figure 2(i). Moreover, we find that the wear track depth of the pristine UHMWPE—see Figure 2(e)—is larger than the other samples and indicates the removal of a large amount of material. We attribute this result to the absence of nanoclays, which otherwise act as bridges to anchor the polymer chains and prevent their removal.

Our results (see Figure 1) also indicate that the C15A-reinforced UHMWPE composite exhibited the lowest wear rate (i.e., 41% reduction in specific wear rate compared with the pristine sample and the lowest coefficient of friction (38%). We believe these characteristics are caused by the larger size of the C15A organic modifier—which gives rise to an exfoliated morphology and leads to better dispersion—compared with the other nanoclays. We also attribute the better tribological performance of the nanoclays to a thin, tenacious transfer film that forms on the surface of the counterface steel ball, as can be seen in Figure 2(i–l). This film protects the polymer surface from being continuously scratched by the asperities of the hard ball during the wear tests.

In summary, we have used three different types of nanoclay to reinforce a UHMWPE matrix, and thus improve the mechanical and tribological properties of the polymer material. We find that all the nanoclay-reinforced samples have improved wear resistance and coefficient of friction compared with pristine UHMWPE samples.

In addition, we observe that the nanoclay (C15A) with the largest particle size gave rise to the best performance. In our future work, since nanoclays have good barrier properties (i.e., resistance to water uptake), we plan to evaluate the performance of C15A-reinforced UHMWPE nanocomposites under water lubrication conditions. We also hope to develop and test hybrid UHMWPE nanocomposite samples.

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