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Effect of Self-Lubricating Carbon Materials on the Tribological Performance of Ultra-High Molecular Weight Polyethylene

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Abstract : Ultra-high molecular weight polyethylene (UHMWPE) has been the gold standard material for total knee replacements for almost five decades. Wear damage to UHMWPE articulating surface is inevitable due to the natural sliding and rolling movements of the knee. This generates a considerable amount of wear debris, which results in mechanical instability of the joint, reduces joint mobility, increases pain with detrimental biologic responses, and causes component loosening. The presence of wear particles has been closely related to adverse reactions in the knee joint surrounding tissue, especially for particles in the range of 0.3 to 2 μm. Carbon-based materials possess excellent mechanical properties and have shown great promise in tribological applications. In this study, diamond-like carbon coatings (DLC) and carbon nanotubes (CNTs) were used to decrease the wear rate of ultra-high molecular weight polyethylene. A titanium doped DLC (Ti-DLC) was deposited by magnetron sputtering on stainless steel precision spheres while CNTs were used as a second phase reinforcement in UHMWPE at a concentration of 1.25 wt.%. A comparative tribological analysis of the wear of UHMWPE and UHMWPE-CNTs with a stainless steel counterpart with and without Ti-DLC coating is presented. The experimental wear testing was performed on a pin-on-disc tribometer under dry conditions, using a reciprocating movement with a load of 1 N at a frequency of 2 Hz for 100,000 and 200,000 cycles. The wear tracks were analyzed with high-resolution scanning electron microscopy to determine wear modes and observe the size and shape of the wear debris. Furthermore, profilometry was used to study the depth of the wear tracks and to map the wear of the articulating surface. The wear tracks at 100,000 and 200,000 cycles on all samples were relatively shallow, and they were in the range of average roughness. It was observed that the Ti-DLC coating decreases the mass loss in the UHMWPE and the depth of the wear track. The combination of both carbon-based materials decreased the material loss compared to the system of stainless steel and UHMWPE. Burnishing of the surface was the predominant wear mode observed with all the systems, more subtle for the systems with Ti-DLC coatings. Meanwhile, in the system composed of stainless steel-UHMWPE, the intrinsic surface roughness of the material was completely replaced by the wear tracks.

Keywords : CNT reinforcement, self-lubricating materials, Ti-DLC, UHMWPE tribological performance
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