The Role of Filler Size & Content and Countersurface Roughness in the Wear Resistance of Alumina-PTFE Nano-Composites

by

Sashi S. Kandanur

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Approved by the
Examining Committee:

____

Dr. Thierry A. Blanchet, Thesis Adviser

____

Dr. Catalin R. Picu, Member

____

Dr. Nikhil Koratkar, Member

____

Dr. Linda S. Schadler, Member

Rensselaer Polytechnic Institute
Troy, New York

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ABSTRACT

A linear smooth molecular profile affords PTFE its desirable low friction properties. However, an extremely high wear rate of the order ~10^{-3} mm^3/Nm has stymied the adoption of unreinforced PTFE as a bearing material. Conventionally, to overcome this high wear rate, hard micron-scale fillers have been added to PTFE to yield composites that are two to three orders of magnitude more wear-resistant than unfilled PTFE. Recent research has revealed that PTFE nano-composites are able to display exceptional wear resistances, with wear rates as low as ~10^{-7} mm^3/Nm. A thorough understanding of the wear resistance mechanism of PTFE nano-composites is absent at this time. The goal of this research is to enable better understanding of PTFE nano-composite wear mechanism through exhaustive experimental investigation. The research consisted of studying the effects of a range of parameters like filler size, filler weight fraction, filler-matrix powder mixing method, countersurface roughness, countersurface chemistry, transfer films, etc on the wear behavior of alumina-PTFE composites. A reciprocating pin-on-flat tester with six stations was used in this wear study, to provide high wear testing throughput.

In tests of PTFE with 5 wt % alpha phase alumina nano-particles (40 or 80 nm) in sliding reciprocation against polished steel, wear rates of ~10^{-7} mm^3/Nm were measured which is four orders of magnitude lower than unfilled PTFE and two orders of magnitude lower than with micro-particles (0.5 or 20 μm) of more conventional filler size. The wear behavior did not vary greatly with stroke of reciprocation. For the alumina-PTFE micro-composite, the wear rate gradually increased towards that of unfilled PTFE as filler content was reduced, whereas the alumina-PTFE nano-composite maintained a relatively constant ~10^{-7} mm^3/Nm wear rate to filler contents as low as 0.32 wt % before reverting

towards the rapid wear rate of unfilled PTFE. Lightly-filled alumina-PTFE nano-composites depend upon low countersurface roughness to maintain such low wear rate, and with increasing roughness the wear rate was found to transition at a critical value to a wear rate of ~10^{-5} mm^3/Nm. Nano-composites with higher filler contents were able to maintain wear resistance to higher levels of countersurface roughness before transitioning to the higher wear rate. Upon encountering extremely high countersurface roughness in the range R_a = 6-8 μm, nano-composites at each filler content eventually increased in wear rate to ~10^{-4} mm^3/Nm. When sliding was performed in the presence of water, the alumina-PTFE nano-composite lost its wear resistance, exhibiting a wear rate approaching that of unfilled PTFE. The wear behavior of the alumina-PTFE nano-composites when sliding against CoCr and alumina countersurfaces was similar to their behavior against steel countersurfaces. The wear resistance of alpha alumina-PTFE nano-composite was greater than the wear resistance of PTFE filled with several other nano-fillers investigated, including alumina of other phases, by at least two orders of magnitude.

SEM and profilometric investigations of the countersurfaces of low wearing nano-composites revealed the presence of thin, uniform transfer films. It is hypothesized that the alpha phase alumina nano-filler is able to influence the PTFE matrix, augmenting its intrinsic wear characteristics which leads to thinner transfer films. It is offered that the nano-composite wears by a transfer wear mechanism and that the ~10^{-7} mm^3/Nm wear rates observed are a consequence of the slow removal rates of well-adhered thin transfer films.