Superior Wear Resistance of PTFE Composites in Sliding Reciprocation by Alumina Nano-particle Fillers

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ABSTRACT

Polytetrafluoroethylene's (PTFE) ability to form low shear strength surface films during sliding makes it an attractive candidate for use as a solid lubricant in dry sliding conditions. However, the wear resistance of unfilled PTFE is poor, with wear rates as high as 10^{-3} mm^3/N-m at typical engineering speeds and temperatures. Micron-scale hard fillers have long been used to enhance PTFE's wear resistance, decreasing wear rates by up to two orders of magnitude to about 10^{-5} mm^3/N-m. Various theories including preferential load support by the filler, regulation of debris size, and filler induced transfer film-countersurface adhesion have been put forward by researchers seeking to explain the mechanism of wear reduction in PTFE micro-composites. These theories suggest that nano-fillers would at best be as effective as micro-fillers in imparting wear resistance or in the worst case not impart any wear resistance to the matrix at all. However, recent findings indicate that nano-fillers result in exceptional wear resistance in PTFE, decreasing wear rates by four orders of magnitude to about 10^{-7} mm^3/N-m.

This study investigates the tribological properties of alumina-PTFE nano-composites in comparison with those of alumina-PTFE micro-composites. A high throughput reciprocating sliding wear tester was adopted to enable investigation into the effects of various parameters like filler size, filler weight fraction and filler dispersion methods on the wear behavior of micro- and nano-composites. To examine any potential effects of stroke of reciprocation on the wear behavior of these composites, wear tests were conducted on 5 wt % micro(0.5 and 20μm)- and nano(40 and 80nm)- composites at three different strokes of reciprocation: 44.5mm; 15.2 mm; and 7.6 mm. Results of the wear testing indicate that the wear behavior of the composites is independent of the stroke of reciprocation within the range of stroke lengths considered and that at each stroke length, the micro-composites wore at rates of the order of 10^{-5} mm^3/N-m, while the nano-composites wore even slower at rates of the order of 10^{-7} mm^3/N-m.

Next, the effects of weight fraction were studied by wear and friction testing of micro(1μm)-composites and nano(40nm)-composites with filler loadings of 0.32%, 0.8%, 2% and 5% by weight. At a stroke length of 44.5mm, the low filler wt% micro-composites wore rapidly, with the 0.32% micro-composite exhibiting a wear rate similar

to that of unfilled PTFE. The 5 wt% micro-composites wore less rapidly with a wear rate of the order of the 10^{-5} mm^3/N-m. On the other hand, the nano-composites exhibited steady-state wear rates of the order of 10^{-7} mm^3/N-m regardless of the filler wt% within the range tested here. Additionally, as determined by EDXS analysis of the wear surfaces, countersurface abrasion decreased by a factor of two as the wt% of the nano-filler decreases from 5% to 0.32%.

During sliding on a unidirectional tribometer, the friction coefficients of both PTFE and its micro(1μm)- and nano(40m)- composites are measured to be near μ=0.2 at a speed of 10 cm/s, while at a reduced speed of 0.7 cm/s the friction coefficients of PTFE's micro and nano-composites reduced somewhat though remaining higher than the μ=0.1 levels to which unfilled PTFE dropped. Next, the effects of filler dispersion method on the wear behavior of alumina-PTFE micro(20μm)- and nano(40nm)-composites were studied by comparing the wear behavior of composites processed on the Hauschild mixer with those processed on the Jet Mill at a stroke length of 44.5mm. Results of the wear testing indicate similar wear rates for nominally similar composites processed on either mixer.

DSC studies of the composites indicate that micro- and nano-fillers may slightly increase the crystallinity of PTFE. However, there appears to be no correlation between wear resistance and crystallinity. SEI of the wear surfaces of the nano-composites shows extensive fibrillation in nano-filled PTFE, perhaps indicating the stabilization by the nano-filler of a tougher and more wear-resistant phase I in PTFE at temperatures which otherwise dictate the existence of phase II PTFE.