Tribology of PTFE Filled Composites against DLC Countersamples

Collin Nester and Catherine Fidd

FAMU-FSU College of Engineering

FSU Undergraduate Research Opportunity Program
Center for Undergraduate Research & Academic Engagement

Abstract:

Polytetrafluoroethelyne (PTFE) is a low friction polymer with a high wear rate. Thus, it is commonly filled with other polymers/metal powders to add structure and reduce the wear rate. Diamond-like carbon (DLC) coatings have high hardness and low friction, but filled PTFE has yet to be tested on a DLC countersurface to determine its frictional and wear properties. In this experiment, samples of PTFE+Al_2O_3 and PTFE+PEEK were tested under load on a DLC countersurface in a reciprocating tribometer. The wear rate and frictional coefficient for the Alumina-containing samples were significantly reduced as compared to stainless steel (SS), with moderate improvements for the PEEK samples as well. Fourier Transform Infrared (FTIR) spectroscopy revealed differences in tribochemical formation on the DLC countersurface compared with the SS countersurface.

PTFE Filler	Alumina		PEEK	
Counter Sample	DLC	SS	DLC	SS
Average μ (coefficient of friction)	0.1673	0.2147	0.1470	0.1381
Standard deviation of μ	0.0155	0.0126	0.0081	0.0076
Steady state μ	0.1395	0.2291	0.1487	0.1308
Standard deviation of steady state μ	0.0139	0.0144	0.0075	0.0039
Average total wear rate [10^{-8} mm^3/N×m]	5.3661	9.3219	5.5822	11.368
Total wear rate at steady state [10^{-8} mm^3/N×m]	3.9333	8.0616	0.7887	9.8326

Figure 1: Experimental Friction and Wear Data

Background/Introduction

Energy waste and maintenance in mechanical systems increase the costs associated with such systems. Finding materials that can reduce friction and wear rates in these systems can substantially reduce their costs and improve their efficiencies. Polytetrafluoroethylene (PTFE) is a low friction polymer, commonly known by the brand name Teflon. It functions by creating a thin transfer film as it wears that aids in lubrication, a property known as "self-lubrication". However, it is prone to high wear from delamination (on the order of 10^{-3} mm^3/N×m). Thus, it is common to mix PTFE with fillers like polyetheretherketone (PEEK) or alumina particles, which are hypothesized to provide a more stable structure less prone to delamination. This improves the wear rate of unfilled PTFE on a stainless steel (SS) countersurface by up to five orders of magnitude without significant increases in the coefficient of friction. Diamond-like carbon (DLC) coatings are commonly used in tribology research due to their typically low coefficients of friction and high resistance to wear. Some experiments have been performed testing PTFE on a DLC countersurface, but none have tested PTFE with these fillers. Thus, it is unknown if the tribochemistry at play with stainless steel might be altered when replaced with DLC. This experiment tests PTFE and fillers on DLC countersamples to determine if improvements in wear rate or frictional coefficient are possible in these conditions and to further elucidate the tribochemical mechanisms of these polymers.

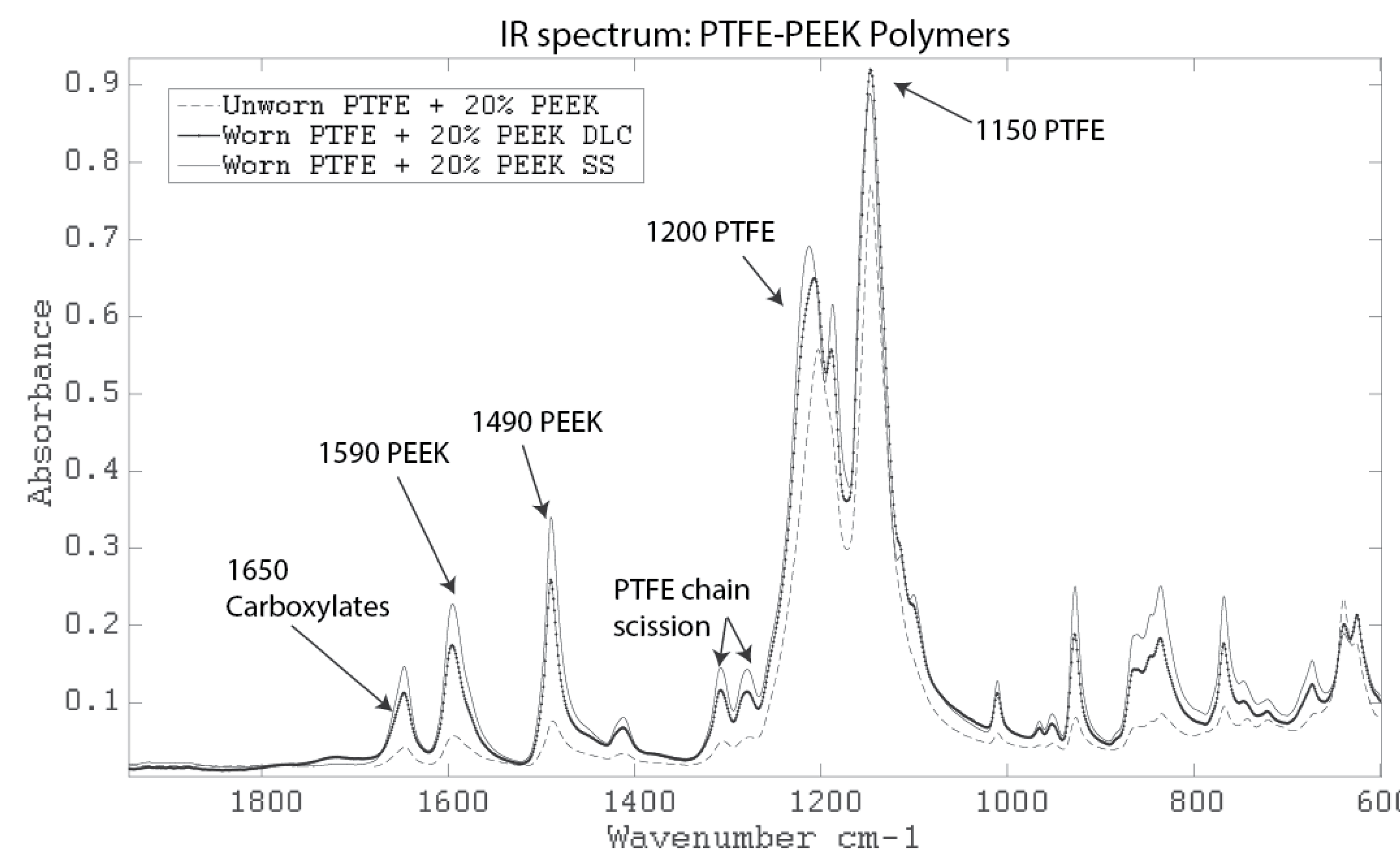

Figure 2: PEEK FTIR Comparison

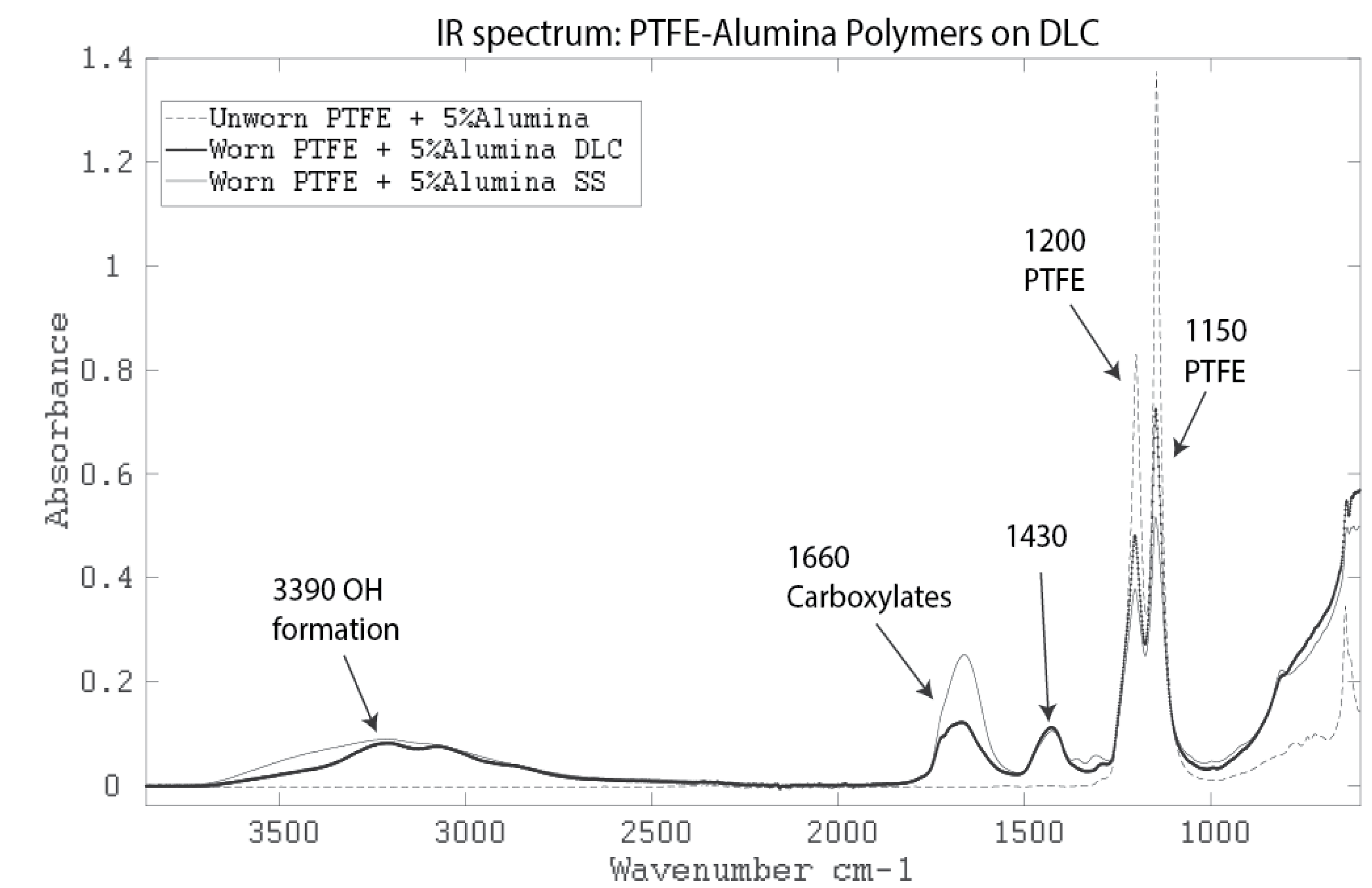

Figure 3: Alumina FTIR Comparison

Methods:

Two polymer mixtures were prepared: PTFE filled with 5% alumina (Al_2O_3) by weight and PTFE filled with 20% PEEK by weight. The powders, in their specified ratios, were added to isopropyl alcohol (IPA) and mixed via sonication in three intervals of five minutes. The IPA was allowed to evaporate fully from the mixture over a week. After drying, the dry mixtures were placed into a cylindrical mold and compressed under a 25 kN load for one minute. These cylinders were sintered at 500° C on a controlled heating curve and machined into 6.25x6.25x12.5 mm rectangular prisms. These samples were sonicated in IPA and allowed to dry. The samples were loaded into a reciprocating tribometer. Diamond-like Carbon (DLC) thincoating was deposited on SS 304 to create the countersamples, which were secured in the tribometer. A normal load of 250 N was applied to each sample. The samples underwent multiple sets of 40 mm cycles, ranging from 1k to 200k cycles in a chamber at 25° and 26% humidity. The samples and their holders were massed before and after each cycle to determine wear rate. Frictional force was recorded by the tribometer, which was divided by normal force to obtain each sample's coefficient of friction. Steady state data was defined as the last 5 sets (400k to 1200k cycles).

Results and Discussion:

The frictional properties of the PTFE-Alumina composite improved significantly from SS to DLC. A reduction in the coefficient of friction of 39% was observed on DLC as compared to SS, while the Alumina composite's wear rate was more than halved at steady state (Figure 1). The PEEK-PTFE composite demonstrated an extreme reduction in wear rate of over an order of magnitude, though a mild increase in the coefficient of friction was observed on the DLC. For the IR of the surface of the PEEK-PTFE composite, the peaks at 1490 cm^{-1}, 1590 cm^{-1}, and 1650 cm^{-1} which are characteristic of PEEK increased more for the samples slid against steel than the DLCs (Figure 2). This suggests that the surface of the sample slid against steel had more robust PEEK presence at the surface. The IR of the PTFE-Alumina surface had decreasing 1200 cm^{-1}, and 1150 cm^{-1} peaks indicating less PTFE at the surface compared to the unworn samples (Figure 3). The PTFE-Alumina sample slid against DLC had more PTFE present at the surface. More carboxylates, indicated by the peaks at 1660 cm^{-1}, were produced on the surface of the samples rubbed against stainless steel counter samples compared with the DLC counter samples. Taken together, this data indicates that while DLC does reduce the wear rate of both composites, the primary mechanism in the reduction of wear in Alumina is indirect through the reduction in friction, while the reduction of wear in PTFE occurs through some combination of physical and tribochemical mechanisms which do not significantly impact its frictional properties. Further investigation into the tribochemical differences between Alumina and PEEK on DLC countersamples could prove valuable in determining what other compounds are likely to exhibit improved tribochemical properties when rubbed on DLC.

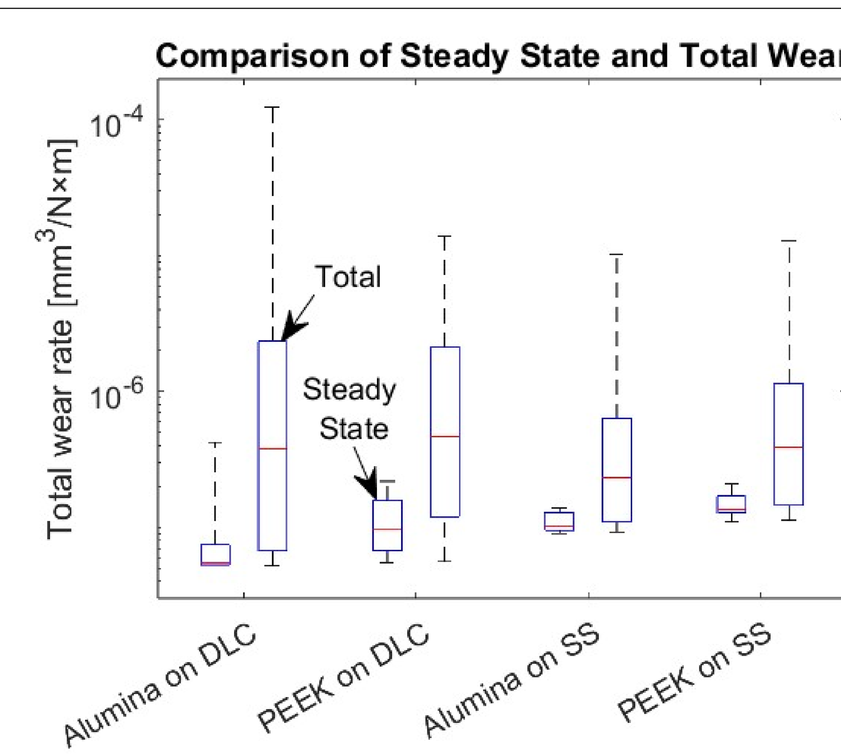

Figure 4: Steady State and Total Wear Rate Comparison

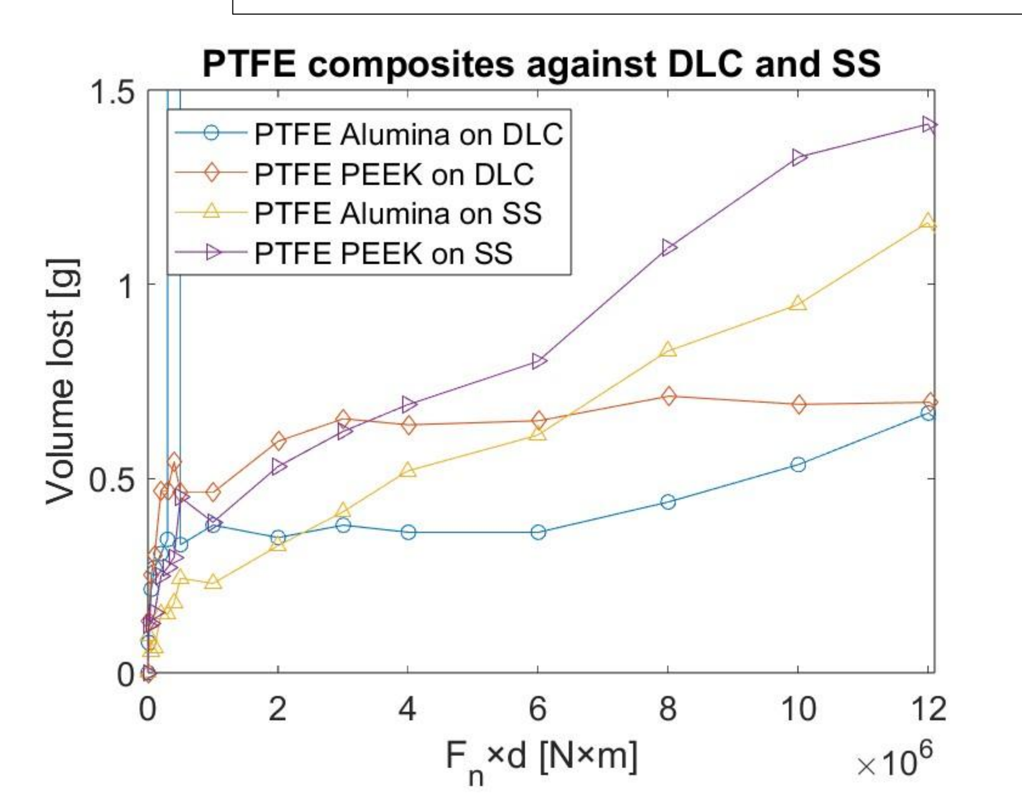

Figure 5: Volume Lost vs Normal Load times Distance

Acknowledgments:

Much thanks to my research mentor, Catherine Fidd, and lab head, Dr. Brandon Krick. Additional thanks to Santiago Lazarte, Craig Barbour, and Adam Delong.

Resources