EFFECT OF REINFORCING CARBON FIBER MORPHOLOGY ON TRIBOLOGICAL BEHAVIOR OF PEEK POLYMERS

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ABSTRACT
This paper evaluates the effect of reinforcing carbon fiber morphology on friction and wear behavior of polyether ether ketone (PEEK) under relatively severe high-speed sliding contact conditions. Three materials are evaluated in the study: (1) un-reinforced PEEK, (2) short and randomly oriented carbon fiber reinforced PEEK (450FC30), and (3) continuous woven fiber reinforced PEEK (CPK53). Test results show that the existence and morphology of the reinforcement has a significant effect on both the wear and friction under these severe contact conditions.

INTRODUCTION
Polymeric materials are increasingly being used in a number of engineering applications. This is typically due to the low cost of the material, ease of manufacturing, high strength/weight ratio, and non-lubricated tribological performance. In order to increase the strength and durability of polymeric material, composites are formed using reinforcing fiber additives. There are several different forms of reinforcing fibers which, in the polymer composite, exhibit varied surface morphologies. It should be expected then that this morphology would have an effect on the tribological performance of the composite material [1]. This performance may also depend on the conditions of the contact, such as: load, sliding speed, and humidity in surrounding environment. Therefore, it is the interest of this study to test the dependence of friction and wear caused by the different forms of reinforcement morphologies and, in particular, under severe contact conditions.

EXPERIMENTAL DETAILS
In this study, three different forms of polyether ether ketone (PEEK) based polymeric materials were tested: base PEEK (no additives), PEEK 450FC30, and PEEK CPK53. PEEK 450FC30 consists of short randomly oriented carbon fiber reinforcement, while PEEK CPK53 consists of continuous carbon fibers that are woven in ribbons oriented at 0/90° parallel to the surface. These polymer materials where cut into disc shapes and tested against highly polished 440c stainless steel balls.

The test rig used in this study was a custom built three ball-on-disc bench top rig (fig.1). This tribotester is able to perform unidirectional pure sliding, using rotational motion, while monitoring the applied load and torque developed between the contact. From this, an absolute value for the friction coefficient could be calculated through the duration of the test. The test parameters, for this study, where set to mimic the situation observed in a compressor/expander device, specifically the Toroidal Intersecting Vane Machine (TIVM) developed by Mechanology LLC. Tests consisted of measuring the frictional profile over sliding velocities of 0 to ~70 m/s. There were four separate applied loads used: 0.73,
2.5, 5, and 10 N. The other parameter tested was the humidity of the surrounding environment, for which tests were conducted at the ambient humidity (30-40% RH) and saturation humidity (~99.9% RH). After each test the wear volume of the disc and the ball were measured using a white light interferometer. The wearing mechanisms were also examined using an optical microscope and a scanning electron microscope.

RESULTS
Friction: The friction profile, showing the relation of friction coefficient to sliding velocity, for each test was studied, three examples are shown (fig. 2). This example shows the profiles for the three materials tested in saturation humidity with a 2.5 N load. Here it is shown that there is a decreasing trend for friction corresponding with increasing sliding speeds for each material, with the base material having the strongest relation. Overall these profiles are consistent with the other tests at the various conditions.

Wear: The wear rates of the ball and the disc surface are shown for the ambient humidity trials (fig. 3). The base material did not cause any wear on the steel ball for any tested trial, however, the disc material itself experienced excessive wear during high loading conditions (5 and 10 N). The reinforced material showed increased durability at the high loading conditions compared to the base material, but also caused more wearing to occur on the ball counterface. The discontinuous fiber reinforced material (450FC30) sustained greater wear compared to the other reinforced material, and in the low load trials (0.73 and 2.5 N) 450FC30 was even outperformed by the base material. The trend of the ball wear caused by the continuous fiber reinforced material (CPK53) seems to correlate to the increase in fiber fracture that was observed with the optical microscope. The presence of material transfer from the polymer disc to the steel ball was also observed, which seems to give some explanation to the wear results.

CONCLUSION
Testing was performed to study the tribological effects of morphology in reinforced polymer composites at severe contact conditions. The major results of this study are as follows:
- Presence of reinforcement causes less dependence of friction on sliding speeds
- Reinforcement morphology affects the amount of material transfer to counterface (determined from images not shown in this abstract)
- Continuous reinforced material (CPK53) showed higher wear resistance

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