MODELING AND MEASURING FRICTION-GENERATED TEMPERATURE OF POLYMERS AND THEIR COMPOSITES

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ABSTRACT
An instrument is being developed to simultaneously measure friction and friction-generated temperature of polymers and composites in a dry sliding configuration. This thermo tribometer is being carefully evaluated and characterized with nylon specimens to ensure that material response and instrument response are separable and identifiable. The thermo tribometer will be used to evaluate and qualify more advanced polymers for tribological applications.

INTRODUCTION
Polymers and their composites are useful for unlubricated bearings and other tribological applications due to their flexibility of form and their part-reducing ability. However, they are far more sensitive to temperature than are metals and ceramics. As would be expected, then, their friction and wear properties change as the ambient temperature increases [1-3]. Of particular importance to this project is the long standing recognition that dissipated mechanical energy in tribology is converted into heat [4,5]. Thus the friction-generated temperature of the polymer can rise even while the ambient temperature is moderate. Elevated temperatures can cause molecular transitions that reflect the viscoelastic character of polymers [6-9]. As a result, friction often increases in these transition temperature ranges so friction-generated temperature can have a profound effect on tribological applications of polymers.

The objective of this project is to develop an instrument that will simultaneously measure both friction and friction-generated temperature of polymers in a dry sliding configuration. The polymers slide against metals that are chosen for their different thermal characteristics. The design philosophy is to use off-the-shelf parts as much as possible and to construct specialized equipment only when absolutely necessary. But whether bought or built, all components must be characterized so that the response of the instrument can be separated from that of the polymer/composite being tested [10-12]. This presentation will describe the development of that instrument, a thermo tribometer.

PROTOTYPE
A prototype of the tribometer had been built previously to measure the back face temperature of friction materials for braking applications. The purpose of the prototype was to evaluate the suitability of bonding friction materials that likely would be heated to elevated temperatures during the braking operation. Under some conditions the measured temperature exceeded 100 C indicating that high performance, and expensive, adhesives would be needed for the intended application. Of more importance to the present research, the prototype revealed some deficiencies that are being resolved in the new instrument undergoing development.

THERMO TRIBOMETER
The thermo tribometer under development captures additional information about polymer performance in dry sliding friction. The tribometer uses a bench style drill press [13] which simultaneously provides both rotary motion in the horizontal plane and translation in the vertical direction. Thus the polymer is tested in the thrust washer configuration [14]. Thrust to the rotating polymer specimen is supplied by a dead weight loading system acting through a rack and pinion with a mechanical advantage of 18.62. Thrusts can range as high as 275 N which provides a bearing pressure on the polymer of 700 kPa.
The polymer specimen is rotated against a metal anvil, currently a ring with inside and outside diameters of 20 and 30 mm respectively and 10 mm high. This arrangement of polymer sliding against metal without lubrication is typical of the majority of tribological applications of polymers. To obtain estimates of temperature rise at the polymer-metal interface, three Type J thermocouples are mounted at three equally spaced positions around the ring anvil. The thermocouples are located within 2 mm of the rubbing surface and they are bonded in place by an epoxy adhesive that contains silver particles to facilitate heat transfer from that surface. The instrumented anvil is calibrated to obtain a correlation between the thermocouple temperature and the rubbing surface temperature. It is mounted on the inertia disk of the torque cell and has a thin layer of silicone heat sink compound on the bottom surface. Thus the inertia disk acts as a room temperature reservoir. Thermal diffusivity of polymers is lower than that of metals. So anvils of stainless steel, brass and aluminum with their different but still higher diffusivities are used to evaluate the response of a given polymer.

One of the deficiencies of the prototype tribometer was the purpose-built torque cell. It was far too flexible, requiring a pre-load to stabilize it but that also reduced sensitivity. The cell has been completely redesigned to provide both stiffness and sensitivity as well as reduce the number of parts and simply machining. As a result, the present torque cell has a stiffness of 6.19 N-m/deg and a capacity of 6.17 N-m. A motion limit prevents the cell from being loaded beyond its capacity.

Rotation of the polymer specimen at five fixed speeds is supplied by a 186 W electric motor operating through a belt and pulley system. The rotational speeds are 620, 1100, 1720, 2340 and 3100 RPM. The resulting sliding speeds range from 0.81 to 4.06 m/sec based on anvil inside and outside diameters of 20 and 30 mm respectively. Higher sliding speeds are obtained by using larger diameter anvils. The rotational speed is monitored by a tachometer that uses an optical pick-up.

**CHARACTERIZATION**

Characterization of the thermo tribometer is being done using nylon washers as test specimens. The washers are 31.75 mm in diameter, 1.58 mm thick and have a 6.35 mm hole in the center. Estimates of the heat generated at the sliding interface were made using a friction stir welding expression [15]. Finite element analyses of temperature of the anvil, polymer and aluminum drive plate provided polymer temperatures from a modest 48 C to high values that would make the nylon useless. Once the behavior of the thermo tribometer is established it will be used to evaluate and qualify more advanced polymers for tribological applications.

**REFERENCES**


2. Hanchi, J. and Eiss, N. S., 1996, “Tribological behavior of polyetheretherketone, a thermotropic liquid crystalline polymer and in situ composites based on their blends under dry sliding conditions at elevated temperatures” Wear 200, p 105-121


