Temperature Measurement at the Polymer-Metal Contact: A Tribometer Design

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Abstract:

In dry (unlubricated) sliding of two solid-bodies in contact heat is generated. A thermo-tribometer is being developed to measure friction generated temperature at the polymer-metal interface. This paper describes design, development, and characterization of the thermo tribometer using polymer specimens. The thermo-tribometer will be used to evaluate and qualify more advanced polymers for tribological applications.

Introduction and Problem Definition:

Polymers are used in a variety of applications such as bearings, grinding tools, clutch plates and even nano-technology. The friction contact between polymers and metals generates heat [1-2] which rises the temperature of the contact surface. The polymers are more sensitive to temperature then are metals or ceramics. The temperature increases greatly affects the tribological properties of the polymer such as friction and wear [3-5]. Hence there is a need to identify pressure and sliding speed conditions under which a given polymer will operate satisfactory for a design lifetime. This paper will report a design and development of a tribometer using a trust washer configuration [6-7] in which the polymer specimen is rotated against a stationary metal anvil. The type of tribometer being developed will be based upon a bench style drill press. It will measure the temperature of the interaction between two different materials; it will also measure pressure and force applied to the samples.

Design Procedure and Results:

Following are the steps used to make a functional tribometer from a drill press:

- Removal of Spring
  - o <u>Procedure:</u> The first modification made was to remove the coil-like spring from the vertical translation mechanism. The purpose of this was so the vertical displacement of the chuck and the downward thrust of the mechanism could be controlled.
  - o <u>Result:</u> The spring was successfully removed. There is enough internal friction to keep the chuck in position and therefore thrust measurements are not needed for the chuck.

- Mechanical Advantage of Rack and Pinion
  - o <u>Procedure:</u> An internal rack and pinion provides the vertical translation of the chuck and associated mechanism (Price). The mechanical advantage is used to compare force and travel of the spoke's circular travel to the chuck's vertical travel.
  - o Another use of the rack and pinion would be to apply the load to the testing material. A load will be applied to the spokes that it will press the two materials together to start the experiment.

- <u>Result:</u> The radius of the spokes was measured as 17.78 cm. This yields a circumference of 111.715 cm. The vertical translation for one half turn is 30mm. The mechanical advantage using the above values is:

$$\frac{1}{2} \text{ Circumference / vertical translation} = 18.62 \qquad (1)$$

- Motor Power
  - <u>Procedure:</u> The drive motor has a certain horsepower that needed to be converted to Watts. The value of power in Watts will be used in future calculations.
  - <u>Result:</u> The power of the drive motor given by the manufacturer was ¼ horsepower. Using conversions, the power is equal to 186.425 W.

- Power Transmitted by Belt, Belt Speed
  - <u>Procedure:</u> The drive motor operates at a given speed, while the speed of the chuck varies due to different sized pulleys and belt position. For the drill press being used, there are five different belt positions meaning five different rotary speeds. It is important to know the speed in revolutions per minute for each belt position; the manufacturer gave the average speeds for each belt position. Using the speeds, the forces acting on the pulleys, belt velocity, power of driver and driven pulleys, and percentage of power transmitted was calculated.
  - <u>Result:</u> Located in Table 1 are the five fixed rotary speeds of the drill press. Also following is Table 2, 3, and 4. Please note that all values have three significant figures following the decimal point.

Belt speed (rpm)	Belt speed (rad/sec)
3100	324.622
2340	245.037
1720	180.113
1100	115.188
620	64.924

Table 1: Belt Speed

Pulley number	Diameter of pulley (in)	Diameter of pulley (cm)	Radius of pulley (cm)	Radius of pulley (in)
1	1.631	4.144	2.072	0.816
2	1.989	5.053	2.527	0.995
3	2.407	6.114	3.057	1.204
4	3.024	7.681	3.840	1.512
5	3.621	9.197	4.598	1.810
6	3.223	8.186	4.093	1.611
7	0.817	2.074	1.037	0.408
8	2.407	6.114	3.057	1.204
9	1.830	4.649	2.324	0.915
10	1.194	3.032	1.516	0.597

Table 2: Diameter and radius of pulleys

S (in) measured	θ (rad)	θ (deg)	φ (deg)
2.313	2.835	162.444	197.556
2.750	2.765	158.405	201.595
3.250	2.700	154.715	180.000
3.750	2.480	142.109	205.285
4.188	2.313	132.531	217.891

Table 3: Wrap Angle. S = arc length, θ = arc angle, φ = wrap angle

$$\theta = S / r,\ r = \text{radius},\ \phi = 360 - \theta \quad (1)$$

Linear velocity (m/s)	Pulley driver force (N)	Pulley driven force (N)	Power of driver (W)	Power of driven (W)	Power transmitted (W)	% of Power transmitted
6.726	42.185	14.994	283.716	100.842	182.874	98.095
6.191	46.185	16.079	285.933	99.548	186.385	99.978
5.506	55.400	21.620	119.051	305.501	186.450	100.013
4.424	63.992	21.843	283.083	96.628	186.455	100.016
2.985	87.545	27.974	261.362	83.516	177.846	95.398

Table 4: Power Transmitted, Linear Velocity and Forces

Where U(m/s) = linear velocity, D = diameter (m), N = revolutions per minute

$$U = (\pi * D * N)/12 \quad (2)$$

F1 = pulley driver force, F2 = pulley driven force,

μ = coefficient of friction (assumed 0.3)

$$F1/F2 = \exp(\mu * \phi * \pi / 180) \quad (3)$$

$$\text{Power (W)} = (F1 - F2)\ U \quad (4)$$

$$\text{Power} = F * U \quad (5)$$

$$\text{Power transmitted} = \text{Power of driven} - \text{Power of driver} \quad (6)$$

$$\%\text{Power transmitted} = \text{Power transmitted} / \text{motor Power} \quad (7)$$

The sliding surface speeds (m/s) depend on the diameters of the anvil. As the diameter increases the surface speed increases and the lever arm of the tangential friction force also increases. Keep in mind that the capacity and location of the force cell are fixed. Consequently the thrust and thus the friction force must decrease as the diameter increases so the force cell limit is not exceeded. The important values are:

- Force cell limit – 98 N
- Force cell lever arm – 63 mm
- Design friction coefficient (μ) – 0.5 (the friction force will be one half the thrust)
- Anvil width – 10mm

- Anvil lever arm – from center of rotation to width mid-point; for ID20 - OD30 anvil the lever arm is 12.5 mm

- Nominal Rotary Speed
  - Procedure: The belt speeds given by the manufacturer are all nominal, meaning they are averages and not necessarily the actual speeds on the drill press being used. To measure the actual speed a strobe light was used. For later applications an optical tachometer will be built.
  - Result: See Table 5 for more information.

Gear pair	Nominal Speed (rpm)	Actual Speed (rpm)	Percent error
1	3100	3202	3.290
2	2340	2366.4	1.128
3	1720	1774	3.140
4	1100	1142.5	3.864
5	620	691.1	11.468

Table 5: The actual belt speeds measured by the strobe light.

  - A tachometer circuit is being built that will measure the revolutions of the chuck of the drill press as it is spinning. This circuit will be comprised of a photo sensor and a transistor that will ultimately have its signal processed such that it will read out the revolutions on a series of four seven-segment displays. This is currently being built and troubleshooted.

- Design of Torque Cell
  - Procedure: The torque cell must be designed in such a way that it has a high stiffness with low inertia. Dr. Price provided information about the original design concept. The original design was not stiff enough which created excessive motion. This obscured the results and compromised the entire experiment.
  - Results: A torque cell was bought around mid-semester. Currently it is assumed that this particular torque cell will be able to accurately obtain data.

- Detailed Drawings
  - Procedure: Drawings of the anvil, toque cell, base plate, inertia disk, force cell mount, force cell connector, and motion limit were drawn in Pro/E and fabricated in the machine shop. All necessary components for the tribometer have been manufactured and assembled.
  - Results: The tribometer assembly details, rotating shaft and disk, base plate, polymer specimen, anvil, and inertia disk, are shown in figures 1. Figures 1 do not show dimensions; this drawing is drawn in Wildfire ProEngineer.

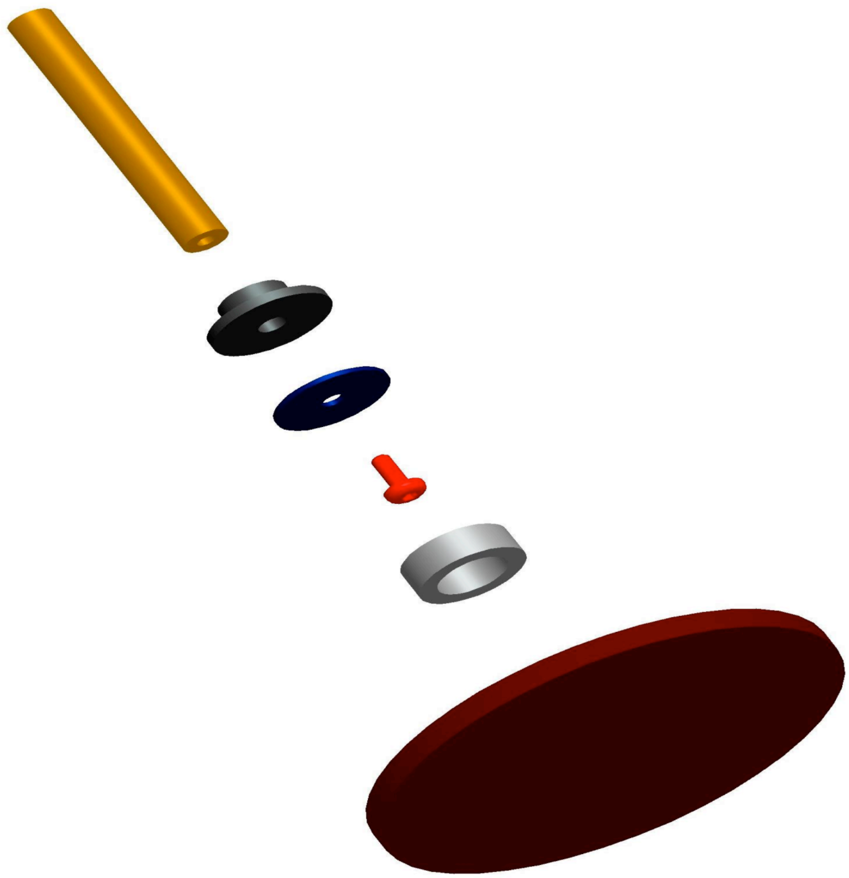

Figure 1: Tribometer Parts

- Microcontroller
  - Procedure: A microcontroller program is being developed to accept and read all of the data that is to be collected when the tribometer is running; such as the temperatures from the thermocouples, pressure/forces, and the tachometer reading. A manual procedure of how the data would be taken if there were no microcontroller is being written to aid in the development of the microcontroller program. Also being developed will be the circuitry that will process the signals coming from the various thermocouples. The microcontroller must be calibrated before official measurements take place. It is must be verified that the microcontroller is measuring the correct information and in the right units.
- To remedy the problem of keeping the handle on the press horizontal so that a weight could be hung from it was solved by removing a rubber gasket on the chuck shaft that served as a rest for the chuck when it is in its highest position. This allows the chuck to rest at an almost nearly horizontal position.

Numerical Analysis

The steady state heat transfer analysis of the tribometer was carried out using Pro/E software. The tribometer assembly of figure 3 was modeled. Conduction and convection were taking into account. Figure 4 indicates the estimated interface temperature as a function of sliding speed for a range of coefficients for UHMWPE sliding against stainless steel. This results traces the experimental results fairly closely.

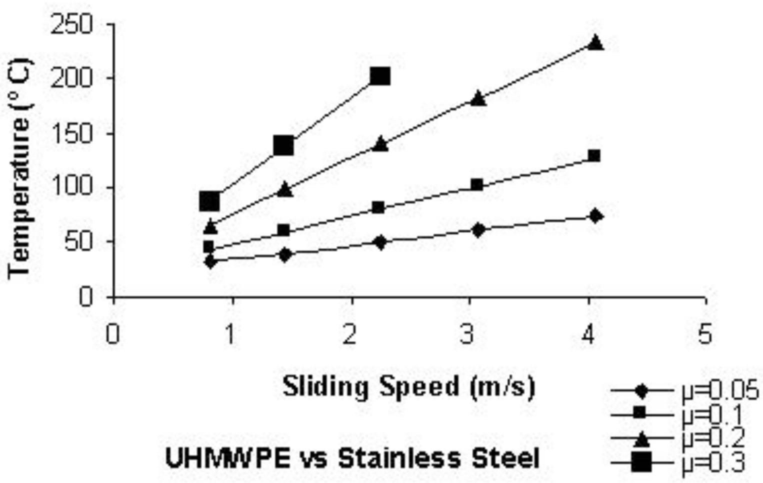

Figure 4-Estimated interface temperature as a function of sliding speed for a range of friction coefficients for UHMWPE sliding against Stainless Steel

Conclusion:

The interface temperature data can be collected and stored and plotted using spreadsheet using themo-tribometer. These data may be use to extract the polymer life cycle for specific application.

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