# MSL Lab Experiment # 5

# Contact, Friction, and Wear

A) Reading Materials & Homework:

* J.A. Collins et al., ***Mechanical Design of Machine Elements and Machines***, (2nd edition), pp. 59-63 and 174-177.
* **Homework HW5:**

1. Suppose a 50 mm diameter stainless steel ball (*E*=190 GPa, **=0.3) is in contact with a plastic surface (*E*=3 GPa, **=0.4). Plot the deflection, *s*, vs. the normal force, *F*, for forces up to 100 N for the following surface geometries for the plastic: (i) a solid sphere of diameter 20 mm and (ii) a flat plate. Would you classify these force-deflection curves as linear, stiffening, or softening (see Figure 4.21 in Collins)? What is the maximum contact pressure *pmax* and the radius of the circular contact area *a* for each geometry at the maximum load?

(b) An experiment was performed using a cylindrical PTFE slider with a 3-mm diameter pressed edgewise (with flat end) against an aluminum 2024-T3 disk with an axial force of 80N. For a sliding velocity of 0.2 m/s, a wear depth of 0.21-mm was measured after a 30-minute test. If the same material combination is to be used in a slider bearing application with a sliding velocity of 0.1 m/s and a bearing load of 50N, and if the slider is to remain cylindrical, what diameter should the slider be to allow for a life of 100 hours if the maximum allowable wear depth is 1.25mm?

B) Goals of this Experiment:

* Observe the dependencies of contact pressure, size of contact patch, and approach of centers on normal load in sphere-on-sphere concentrated contacts.
* Learn how to use the Instron machine in a reciprocating cycle mode to perform pin-on-disk sliding tests, measuring friction forces and wear volumes.
* Learn how to characterize friction and wear behavior in quantities that are transportable from experiment to other applications.

C) Lab Experiment:

a. Sphere-on-Sphere Contact Experiment

1. Secure larger (d=59 mm) rubber hemisphere in upper grip, then zero out Load register. Center on the tile beneath it the smaller (d=33.5 mm) rubber hemisphere so that its vertical axis of symmetry is approximately in line with the upper hemisphere. Jog the crosshead downwards until a very small negative load indicates the initiation of contact. Set the Extension register to zero, thus any Approach of Centers s from this position will be indicated by the Extension register. Set the crosshead speed to10mm/min.
2. Set a minimum Load Limit of –0.1kN, with ‘Return’ as the corresponding crosshead action to unload the contact after reaching this load limit. Begin data acquisition using Labview, and initiate the contact loading by hitting the down arrow on the Instron console. Watch the load register and make sure the Load Limit and corresponding crosshead action does in fact activate, if load goes beyond –0.1kN then stop crosshead displacement manually. Once contact motion complete, halt data acquisition.
3. From the data file remove any load/displacement data points occurring during the Return crosshead action at the end of the file. Plot the Approach of Centers s (the magnitude of the extension register) on the y-axis as a function of the Normal Load F (the magnitude of the load register), and note the non-linear relationship. Using the Excel software, add a trendline power law curve-fit and check whether the exponent is approximately 2/3, as predicted from theory. From the value of the coefficient of this curve fit, estimate the modulus of elasticity of the rubber comprising these hemispheres. (As with nearly all other rubbers and polymers, the Poisson’s ratio is approaching the upper limit of 0.5).

b. Sphere-on-Flat Contact Experiment

1. In this portion of the experiment the flat ceramic tile will be used as the lower contacting body, instead of the smaller rubber hemisphere. Apply chalkdust to smooth tile surface (*place tile on lab table while doing this so as not to get chalkdust on/into Instron machine*). While contact bodies are separated, zero out the load register. Then jog the crosshead downwards until a very small negative load indicates the initiation of contact. At this point zero out the Extension register. Set a minimum Load Limit of –0.1kN, again with ‘Return’ as the corresponding crosshead action. Start contact motion by depressing the down arrow on the Instron console, and simply record the Approach of Centers at that limiting load. (Note it is not necessary to run Labview during this contact, the value of Approach of Centers corresponding to that limiting load can be found upon contact completion from the Extension register by employing the ‘Peak’ button). Also, measure from the tile the diameter 2a of the contact patch produced by that limiting value of normal load.
2. Repeat step #1 for minimum Load Limits of -0.05kN, -0.025kN, and -0.01kN
3. Construct another plot of Approach of Centers versus Normal Load for this contact case (only four data points at loads of 0.01, 0.025, 0.05, and 0.1kN). From the power law curve-fit of the trendline, is an exponent of approximately 2/3 again observed? From the coefficient of the power law curve-fit, determine the modulus of elasticity for the rubber indicated by this data set. Does it agree with that previously determined? Given that it is very stiff relative to the rubber, why is it unnecessary to know the exact value of modulus of elasticity for the ceramic flat in order to make this approximate determination of the modulus of the rubber?
4. Construct a plot of the diameter of the circular contact patch 2a versus normal load, and note that it is also a non-linear relationship. Does the exponent of the power law curve-fit to the trendline approximate 1/3, as would be predicted by theory? What modulus of elasticity of the rubber is indicated by the value of coefficient of this power law curve-fit? How does this compare with previous determinations of the rubber’s modulus?
5. For each of the four loads, calculate an average contact pressure pavg by dividing normal load by the contact area a2. (How much larger than this average value is the maximum contact pressure existing at the center of the contact patch?) Construct a plot of the average contact pressure versus normal load. Having already shown that contact radius a increases with normal load to approximately the 1/3 power, what would you expect the exponent to be in the power law relationship of pressure to normal load in such concentrated contacts? How would this exponent change if instead we were studying the contact of a cylinder against a flat (which is a cylinder of infinite diameter)?

c. Friction and Wear Experiment

*Overview*: In this experiment you will be clamping an aluminum plate (countersurface) between two hemisperically-tipped polymer pins. While the pins remain stationary, a sliding contact will be produced by reciprocating the counter-surface up and down on the crosshead. While the imposed clamping load is the common normal load for both of the pin/countersurface contacts, the load cell on the crosshead will indicate the sum of the friction forces from both contacts. Pin wear will be determined by two means: mass loss; and dimensions of circular scar worn on hemispherical-tip.

### Experimental Set-up Procedure

1. Weigh each of the polymer pins, with 0.0001g precision, on the analytical balance. For each pin, make sure balance is ‘zeroed’ before measurement, and that the balance returns to zero upon removal of pin. Repeat measurement to check reproducibility. Also, measure dimensions of each pin sufficiently to allow later determination of total volume and density.
2. Roughen both sides of countersurface with abrasive paper. Mount countersurface in upper grip*, then* calibrate and balance the load. (In light of the stated overview above, consider why load calibration and balancing is perform after the counter-surface is mounted).
3. Mount the pins in the pin holder and rotate wings nuts to produce ‘zero-load’ contact state (point at which any further wing-nut rotation will compress springs) against the counter-surface. Estimate the thread pitch. Thereafter, provide normal loading by simultaneously giving each of the wing nuts an additional thirteen full turns.
4. Manually jog the crosshead down until the bottom of the counter-surface is about 1” from hitting the pin-holder pivots, then perform GL RESET. Making sure the Instron machine is setup for English units, manually jog the crosshead back up to an EXTENSION position anywhere between 0 and 3”.
5. Set the lower EXTENSION limit by pushing <MIN>, <CYCLE>, <0>, <ENTER>. Set the upper EXTENSION limit by pushing <MAX>, <CYCLE>, <3>, <ENTER>. This will instruct the crosshead that it is going to cyclically reciprocate between EXTENSION positions of 0 and 3”. Set the SPEED to 40 ”/min.
6. Push <S1>, <8>, <ENTER>, <1>, <ENTER>, <200>, <ENTER> to instruct the Instron machine that it will perform 200 cycles of reciprocation (which for such a 3” stroke at 40”/min will be achieved in a half-hour). Push <S1>, <8>, <ENTER>, <-3>, <ENTER>, <S1>, <ENTER>, <+>, <ENTER> to display number of cycles completed. \*Note: after inputting any specified number (for example 1, 3, 8 in the keystrokes indicated above), use <+/-> before pushing <ENTER> to produce correct sign.
7. We will first collect data most rapidly, so that we can see friction as a function of position (extension) within the wear track and how that evolves over the first few sliding cycles. Setup instron.vi data acquisition to collect samples of LOAD (R2) and EXTENSION (R3) data at an acquisition rate of 10 samples/s (by entering 100ms as the time to wait between samples). Then start computer data acquisition software, and subsequently the upwards crosshead motion. \*Note: during first reciprocation cycle, be prepared to hit <STOP> in case minimum extension limit is not properly set and bottom of counter-surface comes within 1” of the pin holder pivots apparently en route to ‘bottoming out’ on it.
8. Allow sliding to proceed until the Instron machine automatically brings it to a halt at 30 minutes after reaching the prescribed 200 cycles. Once sliding has been completed, remove any loose debris and measure the final mass as well as the diameter d of the flat circular wear scar formed on the tip for each pin.

*While Experiment is Running*

* + - 1. Estimate polymer density, and determine the total sliding distance that will be accumulated during the half-hour sliding duration.
      2. Inspect the threading of the wing nuts and, considering each spring has a manufacturer-quoted stiffness of 38.07 lb/in, determine the common normal load that each pin/countersurface contact experiences.

### After Experiment Completion

1. Determine the mass lost from each pin, and using density calculate from mass loss a corresponding volume loss for each. For each pin, determine a dimensional wear coefficient (mm3/Nm) by dividing wear volume by the product of normal load and sliding distance. Are these values similar for both pins? If not, what is the average of these two values?
2. For small wear scar diameters, wear volume on such hemispherically-tipped pins is often simply approximated as d4/(64R). Calculate wear volumes using this approximation, and compare to those determined from mass loss measurements. What are the possible sources for error in each of these wear measurements? If they differ considerably, which measurement do you feel is most correct? Justify your response.
3. For the first minute of the test (first 600 data points), plot friction force as a function of position (extension), to see if friction varied in any orderly way along the length of the wear track on the countersurface. Do there appear to have been any particularly sticky or slick locations? In the spreadsheet from the initial ‘run-in’ period, does the friction appear to be evolving with number of cycles? How does friction during this initial transient period compare with friction measured under steady-state conditions, say from the final minute of the test?
4. Plot friction *coefficient* (always a positive quantity, equal to the *magnitude* of the friction force divided by the normal load) as a function of time throughout your test. Identify the coefficient of friction that is achieved under steady-state conditions.
5. Distributing the normal load over the circular wear scar of diameter d that you have measured, what value of average contact pressure results?
6. Typically in friction and wear testing of a bearing material, the experimentalist will try to match the contact pressure (as well as other attributes of a contact situation such as speed) to that anticipated in its subsequent application. Is it possible to match such a contact pressure throughout such a pin-on-disc test as we are conducting here? Why? How could the test be modified to achieve this match? What are some consequences of such a modification?
7. A purposeful aspect of the design of this test fixture is that the counter-surface thickness is equal to the separation of the two pin holder pivots, and that the two counterface surfaces are lined up with those pivots. Why is this critical to the determination of friction coefficient? As a hint, consider an experiment where the countersurface thickness exceeds the pivot spacing. Will friction be greater in magnitude when that counter-surface is translating up or down? Will the pin/counter-surface normal load be the same for translation in both directions? A pin holder free-body diagram with torque analysis about its pivot will be useful in answering these questions.
8. Find the energy dissipated over a single cycle early in the test; and at the end after 200 cycle. The energy dissipated is the area of the force versus extension curve. Comment on the differences.