Application of a Pin-on-Disk Test to Determine Abrasive Wear

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ABSTRACT

In the design process, one of the most important issues is to minimize the amount of wear being generated in an operation of any mechanical systems. One of the most effective solutions is to determine an optimal material composition of the cooperating parts based on the results of investigation on the amount of wear for different material compositions and configurations. Such investigation has a phenomenological nature and a final decision is made based on minimization of wear measured in experimental test systems.

This paper will describe an example of how the research on tribology can be integrated into the undergraduate classroom for an introductory class in mechanical technology by reporting results generated in such processes. A key in this process is an open-ended project in full cycle from an idea, through design and proof of concept, construction of the systems, to research on abrasive wear with data verification and identification, and finally report/paper writing and oral presentation experiences.

The research results were verified by using two concomitant systems to determine the wear, and were compared with results reported by J. F. Archard and W. Hirst[1]. The materials used in this experiment were nylon, aluminum, low carbon steel, and stainless steel. In the research, a developed pin-on-disk test system was utilized to generate an abrasive wear on pins that had a diameter of three-eighths of an inch and an initial length of about two and a half inches. In this paper, a pin-on-disk test is carried out as an open-ended project in an introductory class in mechanical technology.

NOMENCLATURE

l	Length	[in]
m	Mass	[g]
t	Time	[s]
W	Relative Wear	[-]
r	Radius	[in]
s	Sliding Distance	[in]
p	Hardness	[kg/mm^2]

L	Load	[g]
k	Coefficient	[-]
n	Angular Velocity	[1/min]
V	Volume	[in^3]

INTRODUCTION

In design and operation of mechanical equipment, the engineer is faced with a number of problems, related to wear. Here the wear limit must be known and is usually supplied by the manufacturer and needs to be determined by testing[2]. In an operating system, one approach is to disassemble the parts and measure the wear using different types of displacement measurement systems. This may not always be possible and is usually an expensive process. For many applications (e.g. brakes), it is possible to install wear gauges, which give a continuous measurement of the dimensional changes. Very often, indirect methods are used to determine wear during the operation, such as oil analysis, ferrography, or changes in operating parameters such as pressure, temperature, motions, or noise. Where direct or indirect measurements cannot be implemented, predictive methods must be used to estimate the dimensional change. A design process of new systems requires determining an optimal material composition where the amount of wear is minimized. This material composition is determined based on wear tests generated in pin-on-disk systems by using different materials, loads, and wearing distances. The main type of erosion that takes place is called impact erosion, which is the removal of material by plowing, cutting, or a scratching process on a surface. These properties are determined by using concomitant systems to detect the wear[1, 9.]

The main goal of this research was to measure the abrasive wear of four different kinds of materials. The first material being nylon, the next aluminum, the third 410 stainless steel, and low carbon steel. A pin-on-disk test apparatus was built and data was collected to analyze and formulate the material characteristics, conducted in an open-ended project in an introductory class of mechanical technology.

BACKGROUND

In general, there are four different types of wear in machinery: adhesive, abrasive, erosive, and fretting[9]. In adhesive wear the wear appears from the adhesion between two sliding surfaces. When the two surfaces rub each other a certain area of one surface comes in contact with a similar area on the other surface. These two surfaces start to wear and particles are released from the two surfaces as wear debris. Abrasive wear occurs, when a sharp object is pressed onto another surface. The softer material gets grooves that are cut into the surface; this removal of material is also called wear debris. Erosive wear is mostly dependent on nature and is mostly caused by impact erosion[1,9]. Fretting wear takes place when slipping occurs between two materials. The slipping that takes place is mostly caused by vibrations[9].

In the article by Archard and Hirst[1], the study was done on the basis the wear by volume removed versus sliding distance. The volume removed is the amount of material that was worn during the test runs of the pin. They estimated the volume removed using Archard's[1] equation. The calculations form the literature uses the wear coefficient, load, sliding distance, and hardness. Archard and Hirst defined a phenomenological coefficient (k) for abrasive wear, which is, used in the calculated values from literature. The length (l) was the length of the pins that were used in this research, as well as, sliding distance (s). The relative or absolute wear rate can be obtained from measurements of the mass loss, length loss, and volume loss.

Literature calculation
$$W = \frac{k \times L \times s}{p} \tag{1}$$

Where the sliding distance:
$$s = 2\Pi rnt \tag{2}$$

Relative wear by length:
$$W = \frac{\Delta l}{l} \tag{3}$$

And by mass:
$$W = \frac{\Delta m}{m} \tag{4}$$

EXPERIMENT

In the experiments a pins wear is measured using a scale for mass change and micrometer for the length change due to the wear process. Each pin parameter was measured three times to obtain an average value and reduce the impact of possible measurements errors in the calculations.

In figure 3, the curve represents an independent parameter such as wear characteristic vs. sliding distance. The radius for this formula is measured from the center of the disc to the center of the pin. The sliding distance is the amount of distance that a pin travels on the disc at a certain speed and time. The sliding distance was calculated for each of the runs. The initial run time started from zero and finished in thirty-five minutes. For example, the five-minute run will have a sliding distance of 18940 inches. This sliding distance is calculated, for five minutes at constant 265 rpm's and a radius of 2.275 inches.

The dependent variable is the relative wear, which is the length loss and mass loss (equation 3,4). For the length the pins had their initial length and the final length. The difference of the lengths a between each of the runs is the loss. The concept goes for mass loss.

The materials testing intervals were about thirty-five minutes. The nylon and aluminum runs were increased in five-minute intervals, whereas the low carbon steel and stainless steel were run at seven-minute intervals. The initial lengths of the pins started at two and a half inches. The heaviest pin was a stainless steel pin with an initial mass of twenty-seven grams. The selections of materials for experiments were chosen based on their ability to wear. Which covered a possibly broad range. The four types of materials are nylon, aluminum, low carbon steel, and stainless steel.

The test apparatus design (pin-on-disk) is adopted from literature studies[4,8] with significant modifications especially for power and speed control. This is constructed out of two-inch pre-punched angle iron. The angle iron has punched holes throughout the whole length, each of these holes is roughly and inch apart, which makes it adjustable for different conditions. The overall length of the apparatus is about three feet (see figure 1).

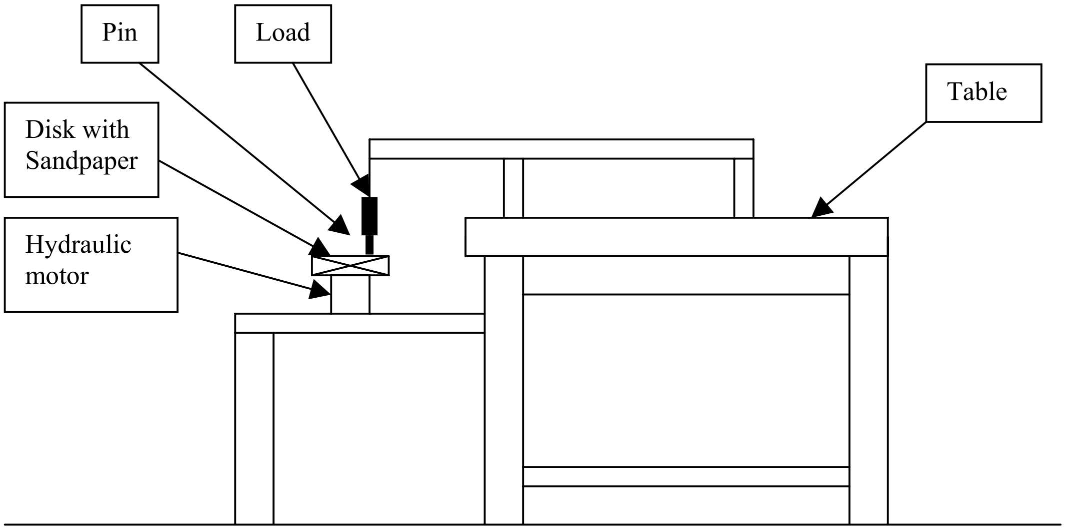

Figure 1: Pin-on-disk experimental setup

During the test runs the first time when stainless steel and low carbon steel were tested they were run for five minutes and no significant wear was made. Then the test run was increased to seven minutes for those two and the nylon and the aluminum pins where run for five minutes. The material was run on two types of abrasive surfaces the first being medium sandpaper with a grit surface of 80 and the second fine sandpaper has a grit surface of 120. The applied load on the top of the pins was equal to 202.4 grams and the same load was used for all of the pins that were tested.

A hydraulic motor powered the disc where the speed of the motor could be adjusted by a control valve, which controls the flow of hydraulic fluid. In the calibration process, the rpm's were measured by using a rpm meter and calibrated according to the pressure of the hydraulic fluid. By doing this, it provided two ways of controlling the speed of the system; one by the pressure gauge and the other by the measuring device.

DISCUSSION

Based on literature search, wear depends on a number of parameters including material hardness and surface properties. The materials used in the experiment were all subjected to the same load (202.4 g), and angular velocity 265 rpm, but due to their individual hardness some of the materials such as nylon were more susceptible to wear over a shorter distance and time, compared to aluminum and steel as shown in figures 9 and 10. By using concomitant measurement systems, the wear versus sliding distance for nylon, aluminum, and two types of steel were determined. The experimental results of wear versus sliding distance for different surfaces and used materials are shown in Figure 2 to 8.

In comparison, one may observe the same characteristic of wear versus distance determined in both ways, however abnormal wear characteristics for nylon could be observed. This abnormality was caused by and increases in temperature of the nylon pin due to the friction and increasing the temperature above the plastic range. Though temperature was not measured, it was noted that temperature increased with the increase in sliding distance. This was extremely noticeable when nylon, started to deform despite the increase in the noise generation made by the pin. From these observations, it seems that the origin of the noise was due to the wear of the debris after the first run and its melting and sticking to the sandpaper. Rubbing the same material on the same material generated the noise and process was no longer an abrasive wear. This unplanned phenomenon gives a proof of the importance of using concomitant measuring system in data verification process.

All results are presented graphically, where on the x-axis it is marked with sliding distance, and the y-axis consists of relative wear. The relative wear is calculated accordingly to eqs. 3 and 4. Finally, comparisons of wear determined by mass loss for fine and medium paper, and length loss for fine and medium grit paper is shown in Figure. 9 and 10.

The nylon pin that was run on fine paper does not have a steady wear. The line curves differently for both mass and length. The second point that is plotted for both mass and length are the furthest apart from each other (see figure 2), due to an uneven cutting surface.

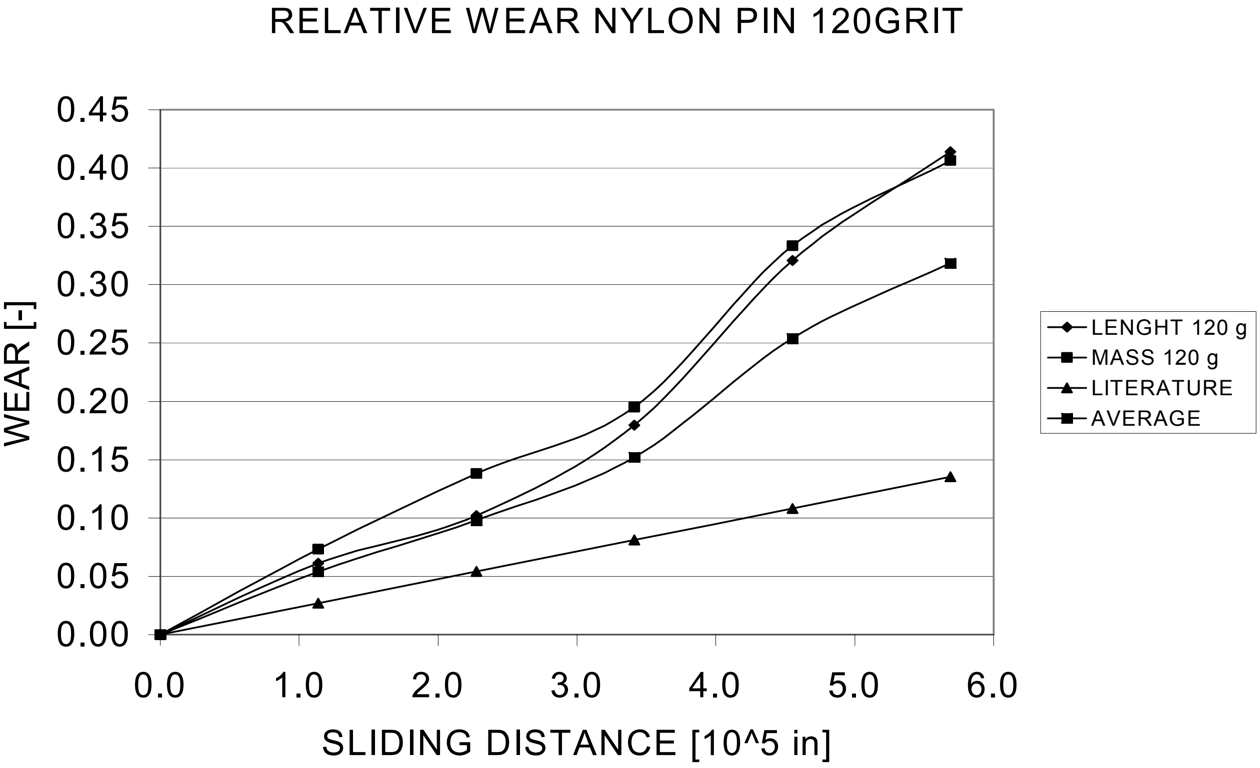

Figure 2: Relative wears of Nylon pin with 120-grit sandpaper

In other cases the comparison between wear measurements by the mass and length were very close together for this pin. This is another case of the pin not having a perpendicular cut.

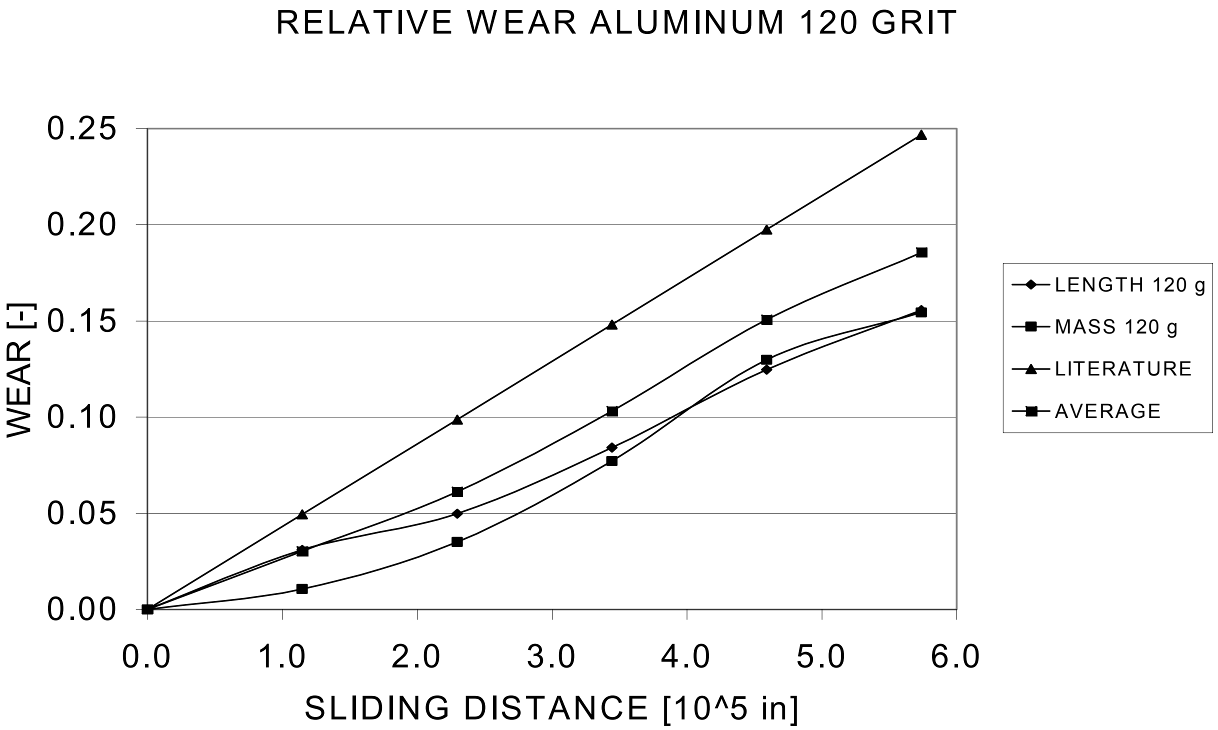

Figure 3: Relative wears of Aluminum pin with 120-grit sandpaper

The mass and the length start to wear at the same rate then the length wears significantly faster than the mass (see Figure 4).

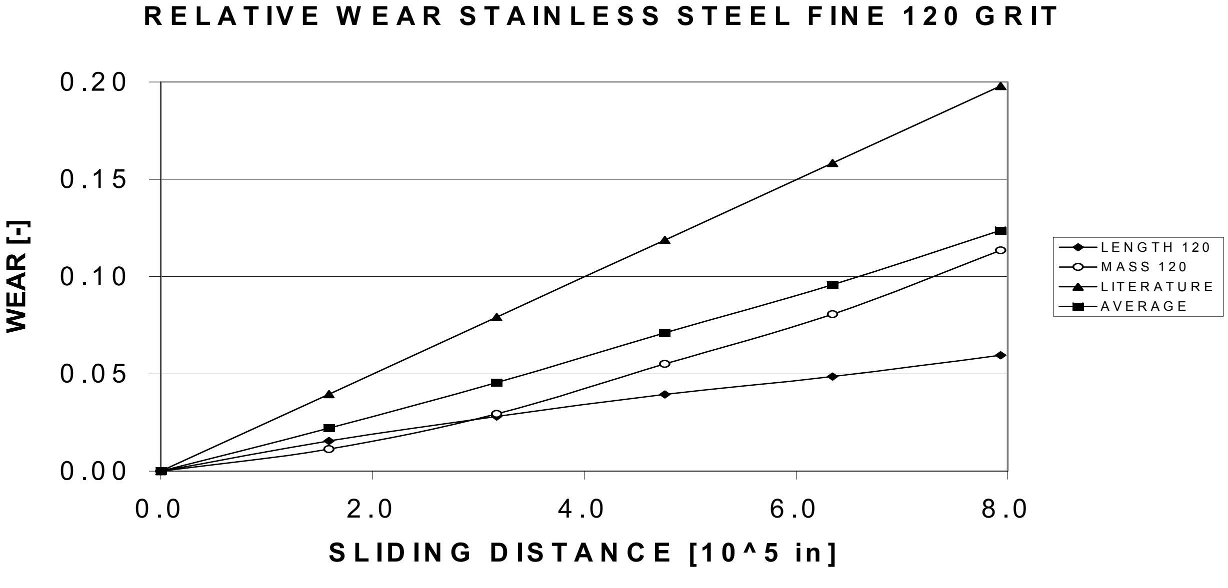

Figure 4: Relative wears of Stainless Steel pin with 120-grit sandpaper

The carbon steel pin was the pin, where the wear by mass and the length stayed relatively close together during the five runs (see Figure 5).

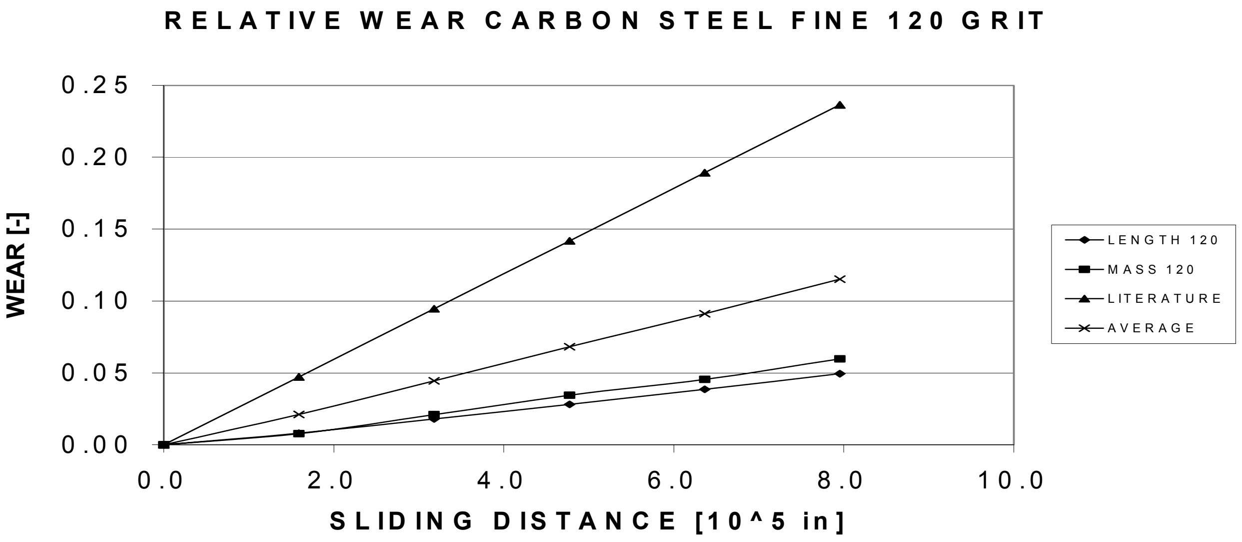

Figure 5: Relative wears of Carbon Steel pin with 120-grit sandpaper

The carbon steel pin that was grind on the 80-grit paper is another example, where the pin was not cut perpendicular. For the first two points, they are equally spaced apart, and then the mass line turns and curves between the second and the third point. At this time, the pin wore down to a perpendicular shape and more mass loss started taking place. The lines continue to separate, but at a certain point the mass will level off and the pins will continue on with the same distance apart (see Figure 6).

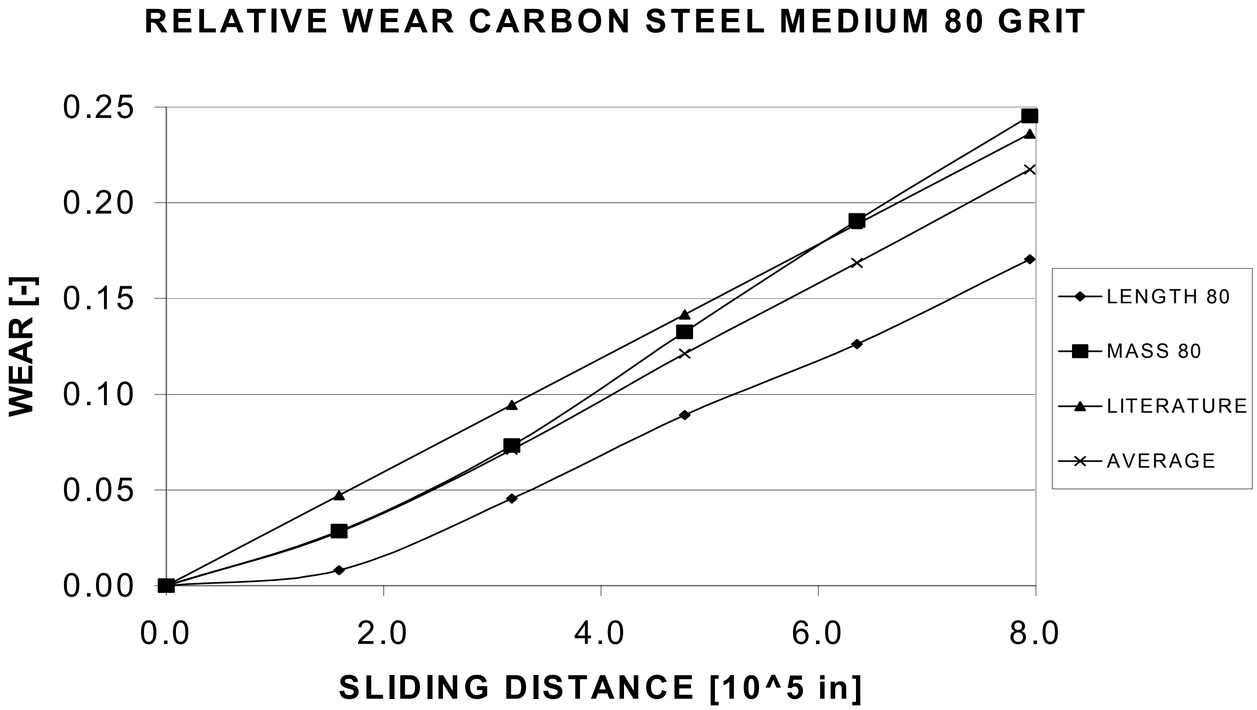

Figure 6: Relative wears of Carbon Steel pin with 80-grit sandpaper

The relative wears for the aluminum pin that was ground on the medium sandpaper is plotted on Figure 7).

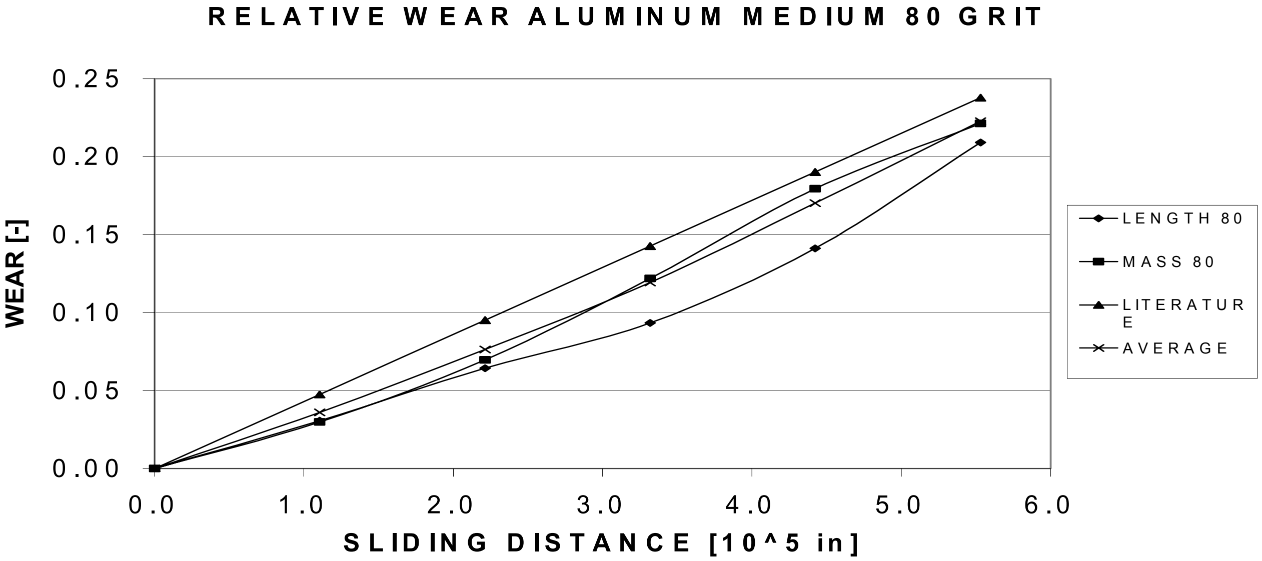

Figure 7: Relative Wears of Aluminum pin with 80 Grit sandpaper

The stainless steel pin that was ground on the medium (80 grit) sandpaper had similar results to the aluminum pin that was ground on the fine (120 grit) paper. The mass and length started off separate, but between the fourth and fifth point the two lines met and crossed (see Figure 8). The reasoning behind the separation of lines is because the pin started grinding on worn down sandpaper, and the sandpaper was changed after the third run for this pin.

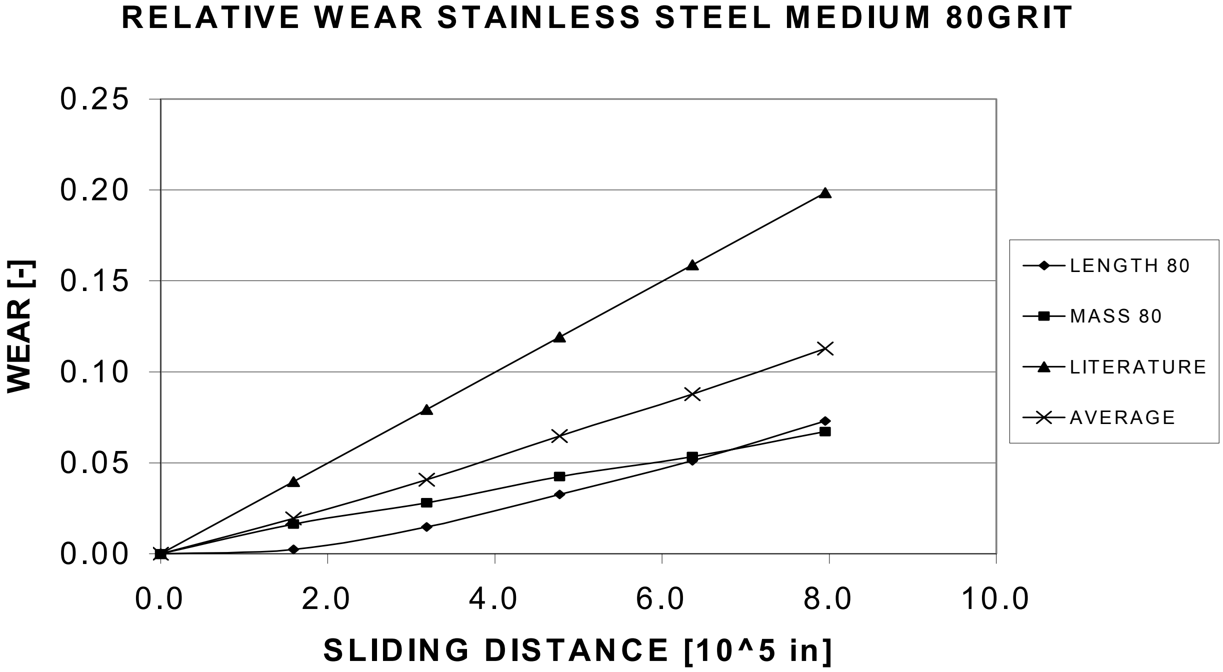

Figure 8: Relative Wears of Stainless Steel pin with 80-grit sandpaper

The wear determined by mass loss between the two surfaces of 120 grit and 80 grit was different than that of the length. For example, the stainless steel pin that was tested for the fine paper wore down more than that of the pin that was run on the 80-grit sandpaper. This was surprising, because the expected results were that the medium would cause a greater mass loss than the fine paper (see Figure 9).

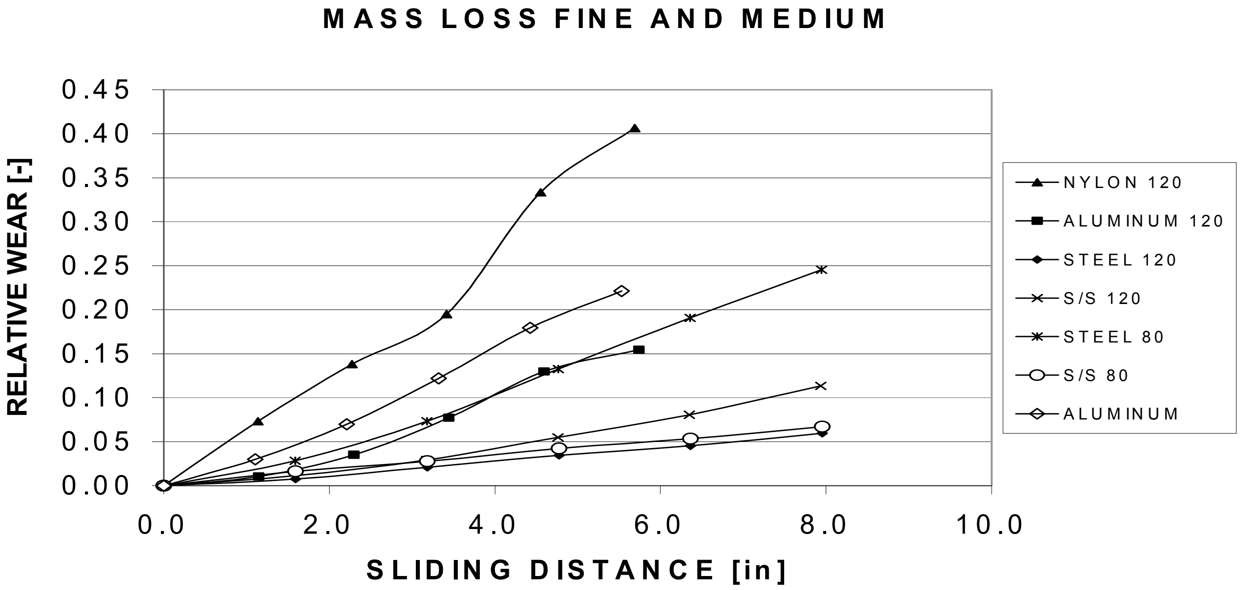

Figure 9: Relative Mass loss between fine sandpaper and medium snapper

There was another surprising finding during the experiment and it was by the comparison between length loss on the fine (120-grit) sandpaper and medium (80-grit) sandpaper. The steel pin wore down less than that of stainless steel. Knowing from literature that stainless steel is harder it was expected that the stainless pins would not wear down as much as the steel pins or any of the other pins (see Figure 10). In the literature the mild steel wore down more than the stainless steel.

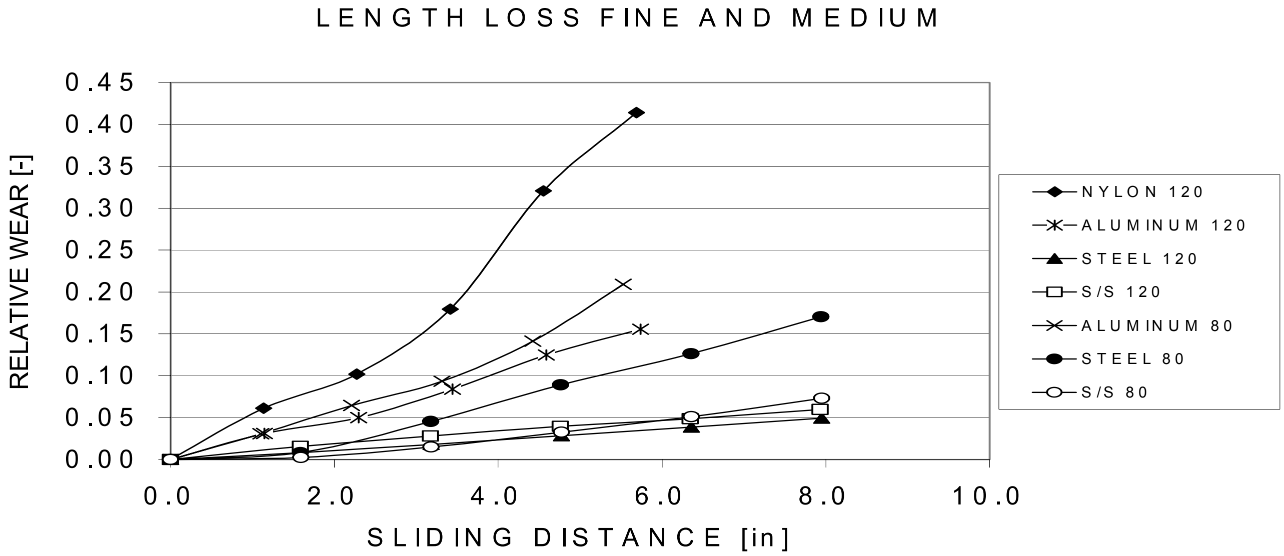

Figure 10: Relative wears Length Loss between Fine and Medium Sandpaper

CONCLUSION

The conclusions drawn on the basis of an experimental research on abrasive wear of selected materials versus sliding distance for different sliding surface grit conducted with a pin-on-disk test, performed as an open-ended project in a introductory class on mechanical technology are as follows:

1. The determination and reduction of bias error is essential to accurately measure the wear. This reduction and estimation of bias error could be accomplished by using redundancy in the measurement process by incorporating concomitant measurement systems to measure the wear.

2. Use of non-dimensional (relative) values in the form of relative wear allowed comparison of different wear values obtained by concomitant measurements systems (measured by length and mass) and other different values published in literature (by volume).

3. The agreement between experimental data theory is very good. The amount of wear depends on the material properties, surface properties, sliding speed and sliding distance, and the stress applied.

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