DETERMINATION OF WEAR IN A TRIBO-SYSTEM

Carrie K. Harris, Justin P. Broussard and Jerry K. Keska

ITEC, College of Engineering
Lafayette, Louisiana 70504, USA

Abstract

With the advancement of technology, industry is constantly searching for more efficient ways of designing products prolonging wear. Abrasive wear is one of the prime causes of secondary failure and the mostly costly in design and operation of mechanical machines and equipment. Wear limits must be known and measured to assure quality and durability of products by an experimental process of determination of an optimal material composition. This process consists of many components including: anticipated results from theory using Archard’s and Holm’s Equations¹,²; comparable with published results; and using concomitant measurement systems in experimentation. Because wear is dependent on independent parameters such as: distance, velocity, stress, material composition, and surface properties the wear needs to be determined by experiments. Experimental results are presented in this paper on abrasive wear of chosen materials versus sliding distance in pin-on-disk tests conducted as an open-ended project in an introductory class in mechanical technology.

NOMENCLATURE

\[ d = \text{distance [in]} \]
\[ h = \text{hardness [kg/mm}^3\text{]} \]
\[ k = \text{coefficient of wear [-]} \]
\[ l = \text{load [g]} \]
\[ n = \text{angular velocity [1/min]} \]
\[ r = \text{radius[in]} \]
\[ t = \text{time [s]} \]
\[ w = \text{absolute wear [in, g]} \]
\[ v = \text{volume [in}^3\text{]} \]
Introduction

Wear processes in metals have been classified into many types depending on the mechanism responsible for removal of material from the surface. The following classification of mechanical wear suggests few distinct mechanisms for the removal of material from sliding metal surfaces.

Adhesive wear arises primarily from adhesion between the sliding surfaces. Erosive wear can be attributed to the action of numerous small particles, which impinge on a surface, such as sand blasting. Fretting wear is a process in which surfaces slip by a very small amplitude relative to each other thereby resulting in an oscillatory movement. Abrasive wear is a process in which a hard sharp indenter is pressed into the surface of a softer work piece and plows a groove thereby resulting in the removal of material from the softer surface. (citation of 4 & 5).

Abrasive wear is the removal of material by plowing, cutting, or scratching processes. The wear coefficient is determined mainly by the abrasive geometry, the effective sharpness of the abrasive, and to a smaller extent by the lubrication which determines the ease with which wear debris can be removed from the sliding interface. Abrasive wear only occurs when the sharp materials produce loose grains that have a higher hardness than the surface subject to the abrasive wear. In this paper, experimental research results on abrasive wear versus sliding distance for the following materials: aluminum, brass, zinc-plated steel, and steel measured by using a concomitant measurement system and compounded with theoretical wear values are offered.

Background

Experiments have revealed that wear is a very complex system. Wear predictions, even though flawed, can be used in a number of ways besides estimating the wear rate. First, an equation for wear indicates the relative influence of various parameters, such as load hardness, velocity, and surface roughness that suggest changes in wear that might result if the sliding system is changed. Second, comparison of the wear is also important in the failure analysis or in the study of any worn component of a system. Quantitative analysis of wear starts with the concept that while a sliding system may be losing material in more than one way, another mechanism will dominate the overall wear rate. In this paper it is identified as abrasive wear.

In experiments testing wear mechanisms, once equilibrium surface conditions have been established the wear rate is normally independent of the area of contact. The wear rate is therefore proportional to the load for only a small numbers of variations, but there is still a small deviation between wear rate and load that forms a direct proportionality.
The dependence of wear rate, load and pressure was published by Burwell and Strang\textsuperscript{2}, who concluded that wear rate is proportional to the load and independent of pressure unless the area of contact was equivalent to one-third of the materials' hardness. The most widely used quantitative relationship among abrasive wear rate, material properties, load and sliding speed, at the interface of two bodies loaded against each other in relative motion was formulated by Archard\textsuperscript{2}. Archard\textsuperscript{1} also reported that wear rates of some materials vary linearly with the applied load and are independent of pressure over a wide range. The widely used quantitative relationship among abrasive wear rate, material properties, load, and sliding speed at the interface between two bodies loaded against each other in a relative motion was formulated by Archard\textsuperscript{2}. Where $k$ in the Archard wear equation is a non-dimensional phenomenological constant (eq. 1).

$$w = k \frac{ld}{h}$$

(1)

Hugh and Spurr\textsuperscript{2} however, observed an inverse relationship between wear rates and hardness. Wear is quantified by weight or volume loss ‘per unit of time’ or ‘per sliding distance’. These simple results are marked in contrast to the majority of wear experiments reported in literature; these suggest that wear is dependent on a large number of variables and there is no general agreement about how the wear depends on such quantities as the load, speed, and apparent area of contact.

However, it was found that wear rates are independent of the apparent area of contact, and usually reasonable explanations could be advanced with this did not occur. Also, although the wear rate often increased roughly proportionally with the load this was accurately true for only limited number cases found in literature\textsuperscript{2}. To determine the experimental coefficient of wear ($k$) a pin on disk test is used\textsuperscript{4}. A typical construction and procedure for pin-on-disk test is widely published in literature\textsuperscript{4, 6, 8}. The used pin-on-disk system is shown in detail in Figure 1. The correlation between wear and independent variables are determined based on experimentation results.

The existing Archard’s – Holm’s equation is phenomenological in nature, and there are contradicting reports on the impact of some parameters on the wear standard procedure in testing the tribological properties of materials, material composition, wear in pin-on-disk system and wear from literature.

**Measurement Method of Wear**

Unfortunately in published literature, any validation and identification procedure of wear results were not offered. In experimental investigation a determination of reduction of bias and precision errors as well as data verification and identification process need to be used to increase the accuracy. Because most significant impact on this process may have been generated by bias error, its reduction and determination is the key issue. This theory
and using concomitant measurement systems for determination of wear measurement. In this research all above methods were used including concomitant methods to measure the wear of pin by mass and distance and the results were compared with calculations and those published in literature. To determine wear volume and length, the following equations were used:

Relative wear by volume was defined

\[
\text{w} = \frac{w_0 - w}{w_0} 
\]

(2)

\[
\text{w} = \frac{d_0 - d}{d_0} 
\]

(3)

and by mass:

\[
\text{v} = \frac{m_0 - m}{m_0} 
\]

(4)

\[
\text{v} = \pi r^2 l 
\]

(5)

\[
d = 2\pi r n t 60 
\]

(6)

Experiments

For the experiment, the pin-on-disk wear test system (Figure 1) was developed and used. The pin on disk system consisted of a pin positioned perpendicular to a flat circular disk with the abrasive surface made up of metal sandpaper. The pin specimen revolves about the disk with the sliding path a circle on the disk surface. The plane of the disk is horizontal. The pin is pressed against the disk at a specified load by means of an arm and attached weights. Immediately prior to testing and measuring, cleaning and drying of all pins were required. Care was taken to remove all foreign particles from pins. More information on pin-on-disk systems and tests are available in wear publications and patents. For measurement of wear, a concept of concomitant methods was implemented by length using a micrometer [+/− 0.0001 in.] and by weight using a digital scale [+/− 0.1g].
The amount of wear was determined by measuring appropriate linear dimensions of all pins before and after the test, and by weighing all pins before and after the test. In the research four different materials were used for the pins: steel, mild steel, aluminum, and brass.

A.              B.              C.              D.              

Fig. 1 A, B, C, D, Details of the pin-on-disk wear test system with hydraulic control.

A variable speed hydraulic system with a motor capable of maintaining constant speed under load, mounted where as that the pins vibration does not affect the test. The stationary pin holder is attached to a lever arm that has a pivot. Adding weights, as an option of loading, produces a test force proportional to the mass of the weights applied.

**Results**

By using concomitant measurement systems, wear versus sliding distance for aluminum, brass, zinc-plated steel, and steel were determined. Example of experimental results of cumulative wear versus sliding distance for used materials determined by length is shown in Figure 1 B and determined by mass on Figure 1 A.
In comparison one may observe the same characteristic of wear versus distance determined by mass and length. However, abnormal characteristics for aluminum could be observed. This abnormality was caused by increases in temperature of the aluminum pin due to the friction above the plastic range. This phenomenon gives a proof of the usefulness of using a concomitant measuring system in the data verification process.

A. Absolute Wear by Mass

![Absolute Wear by Mass](image)

B. Absolute Wear Length

![Absolute Wear Length](image)

Fig2. Absolute wear versus wear distance for different materials based on concomitant measurement of wear: (A) by mass (B) by length
Discussion

As mentioned earlier, wear depends on a number of parameters including material hardness. The materials used in the experiment were all subjected to the same load (400g), and velocity, but due to their individual hardness, some of the materials such as brass were more susceptible to wear over a shorter distance and time, compared to aluminum, zinc-plated steel, and steel as shown in Figures 2A and B. Although temperature was not measured, it was noted that as sliding distance increased so did the temperature. This was especially noticed for aluminum which started to deform despite the increase in distance. The mass of aluminum did not decline or increase compared to its length. Zinc-plated steel and steel wear intensity was very low in comparison to brass. The experimental results in Figure 2 were non-dimensionalized and compared with results from literature. The comparison is illustrated in Figures 4, 5, and 6.

![Graph](image.png)

Fig. 3 Nondimensional cumulative wear of aluminum vs. wear distance from experiments in comparison with theory.

In Figure 3 the results of nondimensional wear of aluminum obtained form experiment versus wearing distance are projected. The experimental data were obtained by using two concomitant methods which measured the change of length of the pin and the mass versus wearing distance. The absolute volume of change due to the wear was related to the maximal wear generating nondimensional wear. The theorical wear characteristic is obtained by calculating the wear from the Archard’s equation for aluminum for the given conditions versus the wearing distance and nondimensionalizing by maximum volume of the wear. The same process was applied for brass, zinc-plated steel, steel as illustrated in Figures 4 to 6.
Fig. 4 Nondimensional wear of brass versus wear distance from experiments in comparison with theory.

Fig. 5 Nondimensional wear of zinc plated steel versus wear distance from experiments in comparison with theory.

Fig. 6 Nondimensional wear of steel versus wear distance from experiments in comparison with theory.
By comparison the experimental results and theoretical results in Figures 3-6, and excellent conformity is observed, which is determined by small differences between respective characteristics. Plotting error versus sliding distance, which is illustrated in figures 7A and 7B, could perform more detailed analysis by using a criterion of defined error values, which are acceptable.

A.

Fig. 7 Relative errors of wear versus wear distance for different materials.
A. by length
B. by mass

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Conclusion

Based on experimental research on abrasive wear of chosen materials vs. sliding distance in pin-on-disk tests conducted as an open-ended project in an introductory class in mechanical technology the following conclusions are drawn:

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

2. Use of nondimensional (relative) values in the form of relative wear allowed the comparison of different wear values obtained by concomitant measurement systems (measured by length and mass) used and other different values published in the literature (by volume).

3. Using a criterion of defined error values, which are acceptable, the conformity of the theoretically and experimentally obtained data is very good. The amount of wear depends on the material properties, surface properties, sliding speed and sliding distance, and the stress applied.

References


9. www.uspto.com
CARRIE K. HARRIS

Carrie K. Harris is currently an undergraduate majoring in Industrial Technology. She has a diploma in Drafting/Design Technology, which she received at Gulf Area Technical Institute in Abbeville, Louisiana. She has worked in the oilfield industry as a CAD/CAM Draftsperson onshore/offshore, and has generated/Designed commercial and residential properties.

JERRY K. KESKA

Dr. Keska, a mechanical engineer, currently serves as an Associate Professor of Fluid Power and Mechanical Systems in the Industrial Technology Department at the University of Louisiana at Lafayette. His research interests are in the areas of Microelectromechanical Systems (MEMS), fluid dynamics of complex heterogeneous mixtures (multiphase, slurries), tribology, microheatexchangers, computer-aided measurement systems and instrumentation, electromagnetic sensors, turbulence and flow pattern phenomena in mixtures, and deterministic and random signal analysis including validation process.