

Techniques of Measuring Wear for Bulk Materials and Advanced Surface Coatings

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Abstract: Wear occurs to the hardest of materials, including diamond, wear studies having focused on surface damage in terms of material-removal mechanisms, including transfer film, plastic deformation, brittle fracture and tribochemistry. Within most industry segments, significant financial losses may be incurred due to accelerated wear of various components. In order to minimize the effects of mechanical wear and extend product life, coating solutions introduced into production and is further developing them to meet even more demanding wear applications. Applying coatings is an established industrial method for resurfacing metal parts. Failure of mechanical components due to wear is the most common and unavoidable problem in mechanical processing industries. This paper explore various techniques of assessing the wear resistance of coated and uncoated materials. Test equipment for sliding wear, erosion, impact and dynamic wear tests is induced, Processes for measuring wear rates are highlighted and Procedure for measuring wear of a specimen is discussed.

Keywords: Industrial wear problems; Test equipment; Wear testing.

I. Introduction

In materials science, wear is considered to be the erosion of material from a solid surface by the action of another solid. According to the German DIN standard 50 320, “the progressive loss of material from the surfaces of contacting body as a result of mechanical causes” is defined as wear. The parameters that affect wear are loads, speed, temperature, contact type, type of environment etc. The wear is the loss of material and is expressed in terms of volume. Wear is a process of removal of material from one or both of two solid surfaces in solid state contact, occurring when two solid surfaces are in sliding or rolling motion together according to Bhushan and Gupta (1991). The rate of removal is generally slow, but steady and continuous.

The prediction and control of wear is one of the most essential problems emerging in the design of cutting operations. A useful definition for a worn out part is: “A part is considered to be worn out when the replacement cost is less than the cost for not replacing the part” [1]. Part failure is said to occur when it no longer performs the desired function whereas total failure (ultimate failure) is defined as the complete removal of the cutting edge, a condition obtaining when catastrophic failure occurs. The wear problem selected as case study in this thesis work is being faced in wire drawing pulleys, brake disc rotors. Wear is the gradual removal of material obtained at contacting surfaces in relative motion. While friction results in important energy losses, wear is associated with increased maintenance costs and costly machine downtime. Wear is caused due to many factors but friction is most important of them. Few more causes for occurrence of wear can be: Improper component design, Excessive Pressure, Contact area, Inadequate Lubrication, Environment, Material properties.

Wear occurs to the hardest of materials, including diamond, wear studies having focused on surface damage in terms of material-removal mechanisms, including transfer film, plastic deformation, brittle fracture and tribochemistry [2]. With the development of surface engineering design, the need to evaluate the properties of new raw materials and substrate-coating combinations is important. In many research works to date, the authors have investigated the effects of contact abrasion, erosion and impact effects on uncoated components, mainly as separate problems [3]. More recently, experiments and testing on coated materials have occurred and some standardized and experimental test equipment has been produced to meet specifications on wear resistance. Standard test methods such as pin-on-disc are used extensively to simulate rubbing action in which plastic yielding occurs at the tip of individual asperities. This testing is mainly carried out on a microscopic scale and in thin films technology [4].

1.1 Wear of Engineering Materials

There are many types of wear that are of concern to the user of coatings, including sliding wear and friction, low- and high-stress abrasion, dry particle erosion, and slurry erosion [5]. Reducing the coefficient of friction has many advantages in machining processes but it may also require a change in tool design [6]. In practice it is possible for a coating to wear and the substrate to be unaffected. Also, the substrate may deform without any noticeable wear of the coating. It is claimed by Wick [7] and confirmed from practice, that hard

coatings applied to cutting tools increase tool life by two to ten times that of uncoated tools. Hard coatings have some disadvantages, which include porosity, insufficient bonding to the substrate and, in some cases and limited thickness [8]. Coatings experience shear, tensile and compressive stresses which may lead to failure by cracking and spalling [9]. In applications of material wear, one or more of the following will be operational [10,11]: (i) abrasive wear; (ii) adhesive wear; (iii) erosive wear; (iv) fretting wear; (v) surface fatigue; and (vi) delamination.

1.2. Coating Characteristics

In practice, coatings may confer one or more of the following wear resistant properties: (i) corrosion protection; (ii) wear resistance; (iii) hardness; (iv) high melting temperature; (v) low permeability and diffusion for oxygen to prevent internal substrate corrosion; (vi) high density, To avoid gas flux through open pores to the substrate; (vii) stress free or in a state of compressive stress at the working temperature; and (viii) good adhesion.

II. Wear Test Selection

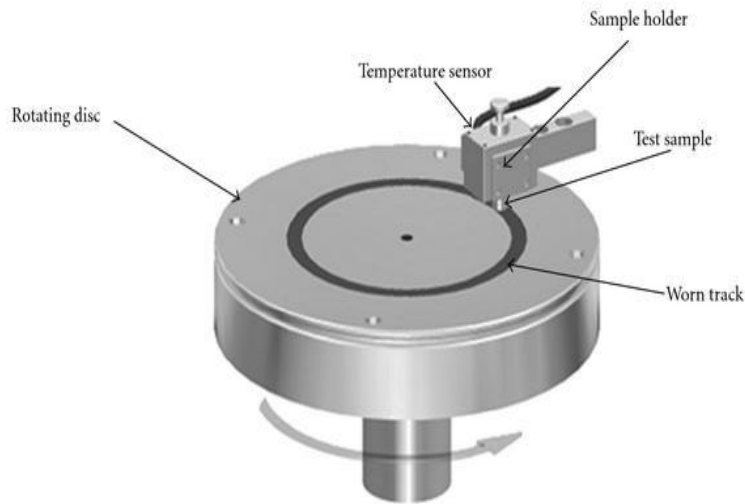
In selecting a suitable wear test, the following points should be considered: (i) ensure that the test selected is measuring the desired properties of a material; (ii) whether the material is in bulk form or is a thick or thin coating; (iii) whether the forces and stress limited are suitable for the test; (iv) whether abrasives be present, considering the abrasive size, form and velocity; (v) whether the contact between the components is rolling, sliding, impact or erosion only, or a combination of these, bearing in mind that the surface finish of the test samples should be similar to that of the actual components; (vi) whether temperature and humidity factors are important; (vii) whether the test environment is similar to the actual working environment; (viii) the duration of the test; and (ix) whether the materials used in testing is typical of the actual materials used in the machine parts.

III. Methods Of Wear Test

Tests are used for quality control functions such as thickness, porosity, adhesion, strength, hardness, ductility, Chemical composition, stress and wear resistance. Non-destructive tests include visual, penetrant dies, magnetic particle and acoustic techniques. Many tests for coated and uncoated cutting tools are conducted on machine tools, including lathes, mills, drills, punches and saws [12,13]. These test methods provide almost identical conditions to those experienced in manufacturing. Machining tests subject cutting tools to many wear parameters, including impact and shock, abrasion, adhesion and hot corrosion. The limitations of these tests depend on the machine power available and the quality of the machine tool. Other coated components that are not used as cutting tools are assessed by laboratory wear tests and compared to field studies. Such equipment includes nano- and micro-hardness testers, fatigue testers, acoustic and scratch-type test equipment, etc.

3.1. Pin-On-Disc

Pin-on-Disc wear testing is a method of characterizing the coefficient of friction, frictional force, and rate of wear between two materials. During this tribological test, a stationary disc articulates against a rotating pin while under a constant applied load. As shown in **Figure.1**, A pin on disc test consists of a stationary "pin" under an applied load in contact with a rotating disc. The pin can have any shape to simulate a specific contact, but spherical tips are often used to simplify the contact geometry. The pin specimen is pressed against the disc at a specified load usually by means of an arm or lever and attached weights. Other loading methods have been used, such as hydraulic or pneumatic. Wear results are reported as volume loss in cubic millimeters for the pin and the disc separately. When two different materials are tested, it is recommended that each material be tested in both the pin and disc positions. The amount of wear is determined by measuring appropriate linear dimensions of both specimens before and after the test, or by weighing both specimens before and after the test. Coefficient of friction is determined by the ratio of the frictional force to the loading force on the pin. The pin on disc test has proved useful in providing a simple wear and friction test for low friction coatings such as diamond-like carbon coatings on valve train components in engines. Pin-on-disc wear testing can simulate multiple modes of wear, including: unidirectional, bidirectional, omnidirectional, and quasi-rotational.



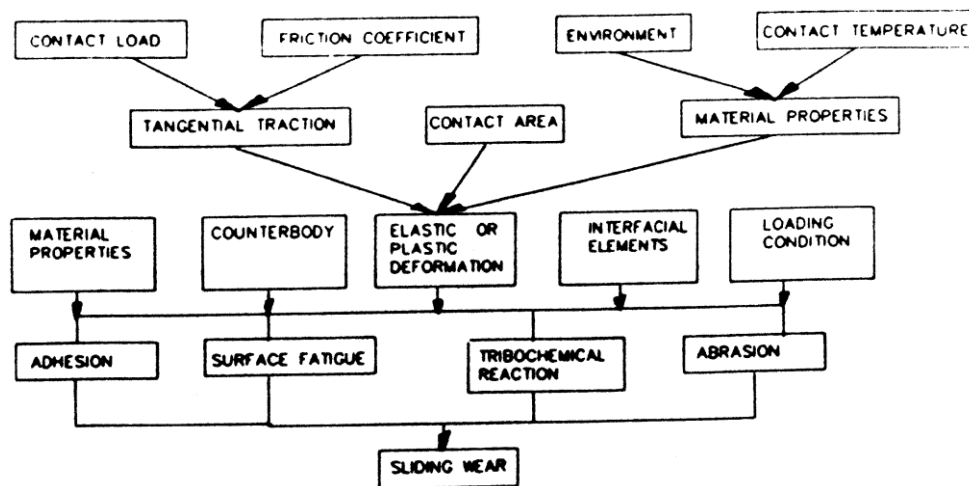
**Pin-on-disc apparatus
(Figure.1)**

Research conducted by Glaeser and Ruff reported that pin-on-disc were the most widely used wear test processes, followed by pin-on-flat [14]. Other applications of pin-on-disc include material wear and friction properties at elevated temperatures and in controlled atmospheres. Almond et al. [15] used a pin-on-disc apparatus for testing ceramics and cemented carbides on alumina discs using the pin as the test material. In a two-body abrasion test, a coated pin is pressed against a rotating abrasive paper making a spiral path to avoid overlapping [16,17]. This test process is very common for thin coatings.

3.2. Abrasive and Adhesive Test Equipment

Hardness is often used as an initial guide to the suitability of coating materials for applications requiring a high degree of wear resistance. The effect of the hardness of a wearing material however is complicated, as different wear mechanisms can prevail in service. Scratch hardness is the oldest form of hardness measurement. Mohs in 1822 categorized materials using this process, giving diamond a maximum scratch hardness of ten. Most scratch type tests developed from this simple technique. Abrasive tests are described by Kato et al. [18] and others [19,20]. Adhesion is characterized by both scratch- and indentation-tests as reported in the literature [21,22]. In indentation adhesion tests, a mechanically stable crack is introduced into the interface of the coating and substrate. The resistance to

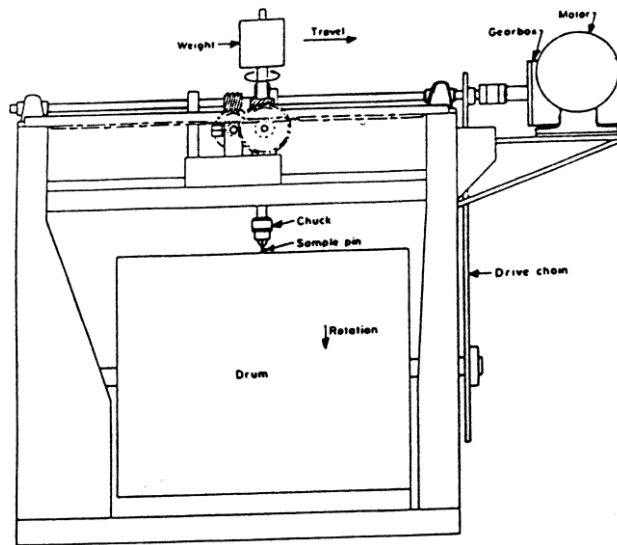
Propagation of the crack along the interface is used as a measure of adhesion. In scratch-adhesion tests, a stylus is drawn over the surface under a continually increasing normal load until the coating fails. Factors influencing the wear mechanisms during sliding contact are shown in **Figure.2**



**Factors influencing the wear during sliding contact
(Figure.2)**

3.3. Pin-on-Drum Abrasive Wear Test

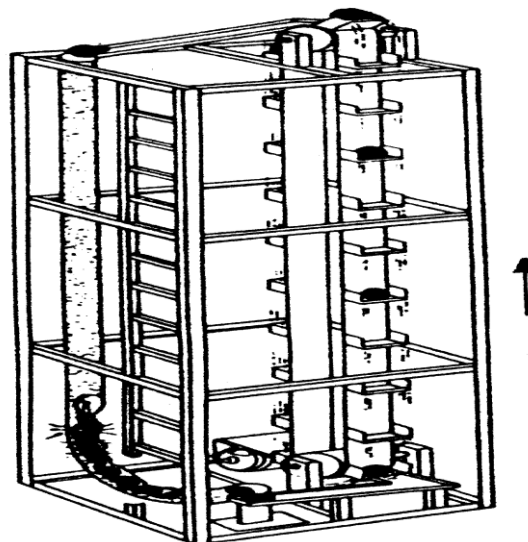
In this test, one end of a cylindrical pin specimen is moved over abrasive paper with sufficient load to abrade material from the specimen and crush the fixed abrasive grains. This test simulates the wear that occurs during crushing and grinding of ore in which the abrasive (the ore) is crushed. The pin also rotates while traversing, as indicated in **Figure.3** this ensures that the pin always contacts fresh abrasive. This is a high-stress Abrasion test, as the load is sufficient to fracture the abrasive particles.



Pin-on-drum apparatus
(Figure.3)

3.4. Repeated Impact Wear Test

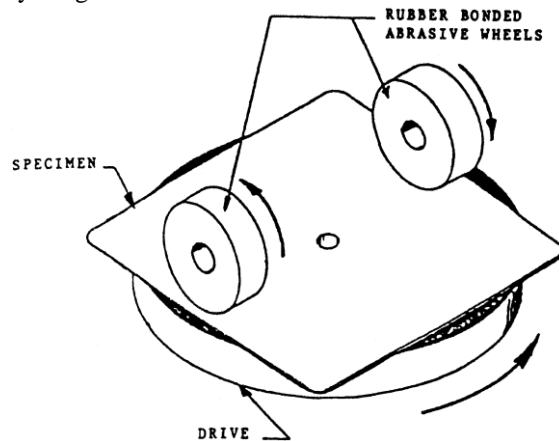
Equipment described by Blickensderfer and Tylczak [23] involved balls made from alloys being dropped 3.4 m onto a column of balls, with each successive ball receiving an impact on each side. This rig, as shown in Figure.4, tests materials for spalling due to impact and shock only. It does not take account the orientation of the samples, which latter can be up to 50 mm diameter. The samples are also subjected to rebound, which gives a double-impact effect. An impact testing machine for determining the dynamic cushioning properties of plastic foams is reported by Shestopal and Chilcott [24] and shown in **Figure 4**. This process is pure impact and has many limitations, as described in the reference. Brenner et al. [25] used a test rig to combine impact and its effect on adhesion at elevated temperatures for iron spheres impacting on an iron plate. The impact forces are transmitted to piezoelectric load cells, which produces a pulse on a screen that equivalent to the applied load.



Schematic diagram of impact test apparatus.
(Figure.4)

3.5. Taber Test

The Taber Abraser, ASTM 1044, is used to measure the low-stress abrasive wear resistance of materials and Coatings. Low-stress abrasive wear occurs when hard particles are forced against and move along a flat, solid Surface where the particle loading is insufficient to cause fracture of the hard particles. Two- and three body Abrasive wear can be assessed with this method. The Taber apparatus is shown in **Figure.5**. The specimen, which is coated or uncoated, is rotated, causing the abrasive wheels to drag and abrade the surface. Wear is normally determined by weight loss.



**Schematic diagram of the Taber abrasion apparatus.
(Figure.5)**

IV. Measuring Wear Of Specimens

One of the simplest ways of measuring wear is based on weight loss during and after a test. This is simple and direct provided that the materials considered are similar and care is taken in the measurements. The mass loss can be converted to volume loss and the wear rate calculated with respect to time. For coating applications, if the coating is penetrated, the weight loss is a combination of both substrate and coatings. In some cases, wear may occur but no mass loss may be experienced, as in the case of plastic flow or deformation. The wear volume can be calculated from equations based on the wear scar shape. If the scar shape is regular and symmetrical, accuracy with this approach is possible. The volume of material removed can be measured at intervals using equipment for measuring the depth and width of the wear scar or impact zone. If the wear scar or crater can be drawn accurately on 3-dimensional or solid modeling software, the volume wear can be calculated directly from the software. The dimensions of the abrading tool can also be checked to assist in the volumetric loss. For multi-layered coated systems, the wear volume can be an indication of the total wear loss of the system. A wear coefficient is often used to categorize resistance to contact wear. The method most commonly used is to calculate a wear coefficient K, where:

$$K = \frac{\text{Volume}}{\text{Load} * \text{Sliding distance}} \frac{(\text{mm}^3)}{(\text{N}\cdot\text{m})}$$

This coefficient is based on the assumption that the volume wear varies directly with the contact load and the sliding distance. This wear coefficient was suggested by Holmberg and Matthews as a standard for wear testing [26], and coefficient is used for comparing test samples to standards.

V. Conclusions

If wear tests are carried out with a high degree of simulation of the service situation, then the results can be used with considerable confidence in selecting the best wear-resistant coating system. Every wear test, whether for bulk material or coatings, can be complicated by equipment problems, test procedures, sample preparation, inconsistency in abrasive materials and the wrong interpretation, of the test information. Thin coatings require greater care in wear tests in order to avoid penetration, which requires lighter loads and shorter test durations. Surface roughness also influences the tribological performance of a mechanical system. It has also been shown for thin, hard coatings that the rougher the surface finish, the lower the coating adhesion, as measured by scratch-testing methods. If significant plastic flow or deformation of materials occurs in wear testing, using weight loss may give different results to using wear volume loss. The benefits of applying surface coatings to reduce wear can be measured in many practical ways such as machine efficiency, reduced power requirements and longer running life.

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