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Short communication

The use of the pin-on-disk tribology test method to study three unique industrial applications

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ABSTRACT

In addition to manufacturing tribometers to cover a variety of testing parameters (such as high temperature or vacuum), CSM Instruments is continually pushing their equipment to new limits by developing unique applications. Such applications are often initiated by an industrial need to simulate certain *in-service* conditions. This paper will demonstrate a few of these applications which are of particular interest, notably:

- Wear properties of ice.
- Frictional properties of hard coatings at elevated temperatures.
- Contact resistance measurements in situ during pin-on-disk testing.

Each case study will include a thorough explanation of particular modifications required to the test setup, including both hardware and software setups. These brief case studies represent a few of the application areas which make up some of the 200 test reports generated annually by the CSM Instruments Testing Laboratory.

1. Introduction

The pin-on-disk wear test to measure of the lifetime of the coating is performed using an instrument known as a *Tribometer*, a schematic of which is shown in Fig. 1(a). The sample is mounted on a chuck which can be rotated at a predetermined speed. A ball or other static partner is mounted in contact with the rotating sample via an elastic arm which can move laterally and therefore measure the tangential forces (friction) between sample and ball with a sensor. The data acquisition system records the frictional force as a function of time or number of revolutions, although it is often recalculated so that the coefficient of friction (COF, μ) is displayed on the same axes. A typical example of the acquired data is shown in Fig. 1(b). Once a test is complete, the actual wear rate of the sample and partner can be calculated by one of two ways: the first is to use a profilometer to measure the profile across the wear track and calculating the sectional area removed. If this is multiplied by the wear track circumference then the volume of material removed can be calculated and thus the amount removed as a function of time, the wear rate (usually quoted in mm^3/N/m) is found. The second method is to weigh the sample before and after testing with a highly accurate balance and calculate the material removed, although this method is more problematic because the debris produced during the test must be completely removed to prevent significant error. This is often difficult with polymers because the debris tends to stick to both surfaces. Most Tribometers now offer both rotation of the sample and/or linear reciprocating movement of the sample. The choice will depend on the end use application. Useful standards for this test include ASTM G99, ASTM G133 and DIN 50324.

The advantage of a wear test, when compared to indentation or scratch testing, is that it can give a measure of the lifetime of a particular coating-substrate system. In many applications of coatings, the resistance to wear can be more important than the load required to permanently damage the material. A typical set of data is shown in Fig. 2, for a pin-on-disk test made on a coated sample. The static partner was a 6 mm diameter 100Cr6 steel ball applied with load 1 N and speed 20 cm/s. The graph of COF versus distance shows a steady value of friction until the coating fails (i.e., is completely worn away). The onset of failure corresponds, in this case, to a distinct change in the friction signal, due to breakdown of the coating and formation of a tribological transfer film which is a mixture of the coating, substrate and static partner materials mixed together. The properties of the coating being tested and the substrate on which it has been deposited will influence the friction signal when the coating is worn through: in some cases this signal will rise dramatically, in others it may drop. Whichever the change, the breakdown of the coating will nearly always manifest itself as a sharp change from the steady sliding state.

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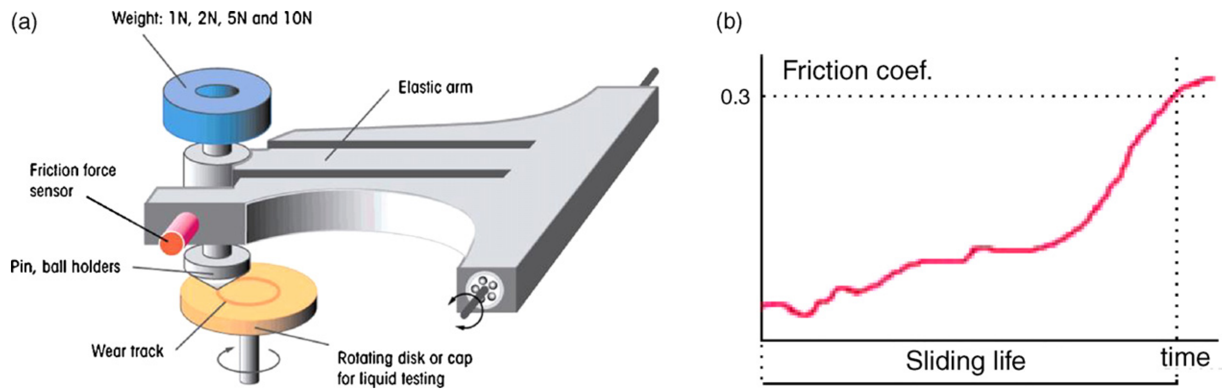

Fig. 1. Principle of the pin-on-disk wear test (a) and typical example of test data (b) from which the friction coefficient between the coating and the static partner (usually a ball) can be assessed. A significant change in friction corresponds to the ball wearing through the coating and thus gives a measure of the lifetime of the coating.

In the example shown in Fig. 2, the coating has failed after a sliding distance of 37 m and subsequent optical microscopy of the wear track shows that the coating has been almost completely removed. A profile across this wear track would enable the worn sectional area to be calculated and thus the wear rate of this coating material. The choice of applied load and geometry of the static partner will determine the lifetime of the coating. If one wants to simulate harsh conditions then a higher load and smaller static partner radius may be used in order to increase the contact pressure and make the coating fail sooner. On the other hand, one might want to evaluate the evolution of the friction coefficient over a long period of time without damaging the coating, in which case a lower load and/or larger contact geometry might be chosen.

A summary of three unique case studies has been presented in the paper. The first includes tests carried out to study the effect of different road salt reagents on the COF of ice on concrete. On the roadways every winter State Highway Administrations (SHA) fight freezing conditions with the addition of ionic ice melting compounds which are commonly referred to as 'rock salt'. The purpose of adding rock salt to the road is to increase the COF between the tire and roadway surface by melting the layer of snow and ice. There are many different types of rock salt, each with the ability to depress the freezing point of water by the dissociation of free ions in the liquid.

The second study consists of a high temperature wear analysis of titanium nitride (TiN) coatings. TiN coatings have a wide range of application in cutting tools, punching and forming, injection molding, medical and other wear components. An increase in temperature results in oxidation of TiN thus affecting its mechanical properties.

The final study was carried out using the electrical contact resistance (ECR) option to detect the failure of polypropylene coatings on a steel substrate by direct monitoring of electrical contact resistance. Detecting the failure of a polymeric coating on a metal substrate can be quite difficult due to the cold welding of the polymer surface to a steel static partner. Through the use of an ECR model it is possible to detect the initial coating failure and correlate it to a possible change in the coefficient of friction. This is especially useful in an application where any wear failure through to the underlying substrate will result in unit failure.

2. Experimental setup

2.1. Case study 1: comparison of different ice melting compounds

The purpose of the first case study was to compare how the addition of different ionic ice melting compounds affects the coefficient of friction of ice on a concrete substrate. This testing was performed in conjunction with the Western Transportation Institute (WTI), a division of Montana State University, to test what different ice melting salts would be most applicable based on the COF on ice as a solid, as slurry during the melting phase and as a liquid brine solution on concrete as shown in Fig. 3. The overall mean and maximum measured COF was also compared to give a quantitative value to the testing. The compounds used were: sodium acetate (NaAc), potassium acetate (KAc), magnesium chloride in an aqueous solution ($MgCl_2$-liquid), sodium formate (Na formate), sodium acetate formate (Na acetate-formate), sodium chloride: reagent grade (NaCl reagent) and the commercially available compound Ice Slicer.

Precast concrete pucks prepared by WTI were attached to 3 cm diameter steel blank samples in order for the samples to be mounted on the Tribometer. Each concrete sample was then wrapped in tape with a 3 mm lip protruding above the top of the puck. Water was added to each puck and then the pucks were placed into a freezer and allowed to solidify at a temperature of $-15 \pm 5\,^{\circ}C$. The test configuration and an example of a typical wear track in ice are shown in Fig. 4.

Each sample spent no more than 1 min from freezer to testing. Prior to testing, 2 g of ice melting compound was evenly distributed on the surface of the ice. Using a standard CSM Instruments Tri-

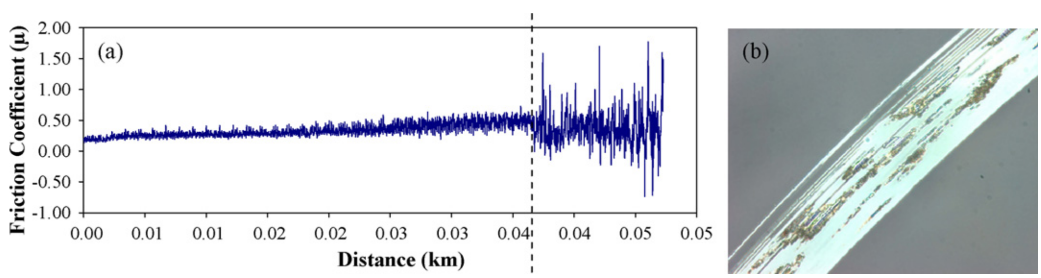

Fig. 2. (a) A typical test data from a pin-on-disk Tribometer test where the coating failure occurs after a distance of 37 m (dotted line) and (b) the optical micrograph of the wear track confirming that the coating has been completely removed.