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METHODS PAPER

A Little Analysis of Errors in Friction for Small Wear Tracks

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Abstract This 'methods' paper examines the error associated with performing rotating pin-on-disk experiments under the condition of varying contact width and wear track circumference. The integral solution and a chart of the errors associated with performing relatively small wear track experiments are given. The error is shown to be less than 10% soon after the wear track diameter becomes greater than the wear track width.

Keywords Uncertainty · Pin-on-Disk · Tribometers

Recently, it has become desirable to perform tight radius of wear track experiments to support modern scanning spectroscopy experiments [1–3]. Numerous experiments and models of uncertainties have been performed on pin-on-disk tribometers [4, 5], but the error associated with small wear tracks has either been ignored or assumed to be negligible. It should also be noted that the majority of the small wear-track experiments are performed under reciprocating contacts [2, 3, 6] where such errors are not present. The popularity of small reciprocating tribometers is due, in-part, to the perception that the errors associated with small wear tracks are large. In this methods paper, we have developed a treatment for the problem that assumes the contact pressure, P_o, is uniform (the average pressure) through a circular contact area, πa^2. The nomenclature and contact schematic are shown in the inset of Fig. 1.

For simple pin-on-disk tribometers, the lateral force is measured and assumed to be the friction force. However, as seen in the inset of Fig. 1, for small wear track radii, R, and large contact radii, a, the local slip velocities through the contact cannot be perfectly aligned with the lateral direction. Thus, the lateral force is equal to the friction force only for large ratios of the wear track radius to the contact radius, R/a.

The lateral force is the integral of the component of force from the differential friction forces along the lateral direction. This is given by Eq. 1, where θ is the angular coordinate through the contact, s is the radial distance through the contact $s = 0 \rightarrow a$, and R is the radius of the wear track along the midpoint of the contact area ($s = 0$).

$$F_{\mathrm{L}} = 2\int_0^{\pi}\int_0^{a} \mu P_o \frac{(R + s\cos\theta)}{(R^2 + 2sR\cos\theta + s^2)^{\frac{1}{2}}} s \, \mathrm{d}s\mathrm{d}\theta \tag{1}$$

The inferred and often reported friction coefficient, μ', is the ratio of the lateral force to the normal force as given in Eq. 2.

$$\mu' = F_{\mathrm{L}}/F_{\mathrm{N}} = F_{\mathrm{L}}/(P_o \pi a^2) \tag{2}$$

As there are no trigonometric functions in the solution to the normal force, the inferred friction coefficient can be expressed by Eq. 3.

$$\mu' = 2\frac{\mu P_o}{P_o \pi a^2}\int_0^{\pi}\int_0^{a} \frac{(R + s\cos\theta)}{(R^2 + 2sR\cos\theta + s^2)^{\frac{1}{2}}} s \, \mathrm{d}s\mathrm{d}\theta \tag{3}$$

The natural dimensionless groups for this analysis are $a' = a/R$ and $s' = s/a$. The dimensionless form of Eq. 3 is thus given by Eq. 4.

$$\mu' = \frac{2\mu}{\pi}\int_0^{\pi}\int_0^{1} \frac{(1 + s'a'\cos\theta)}{(1 + 2s'a'\cos\theta + s'^2 a'^2)^{\frac{1}{2}}} s' \mathrm{d}s'\mathrm{d}\theta \tag{4}$$

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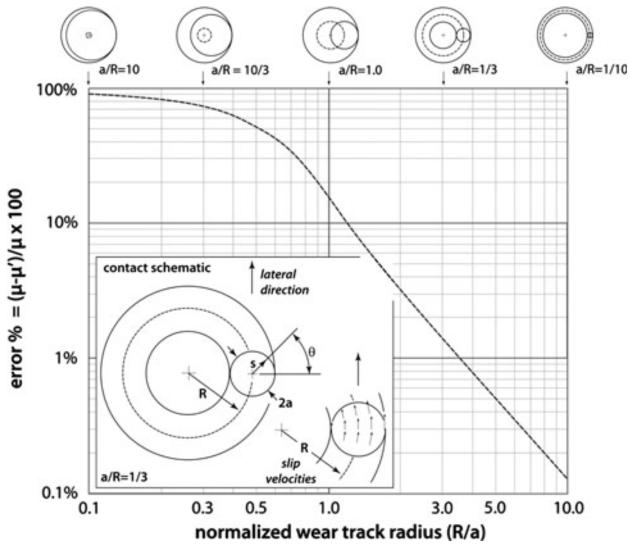

Fig. 1 Error graph in friction coefficient due to a small normalized wear track radius. The inset gives the contact schematic. The circular pin contact is shown to the right of the axis of rotation and has a contact half-width of a. The wear track radius is R, and the associated parameters necessary for the integration of surface shear stresses are given. The result is plotted over a range of normalized wear track radius $R/a = 0.1 \rightarrow 10.0$

As it can be directly seen from Eq. 4, only under conditions where the integral solution is equal to $\pi/2$ will the inferred friction coefficient be equal to the true value (this will happen when $a' = 0$).

The double integral shown in Eq. 4 will always be greater than 0 less than $\pi/2$ for conditions of $a' = 0 \rightarrow \infty$. Equation 5 defines the error as the difference in the measured and true value of the friction coefficient divided by the true value.

$$\text{error}\% = \frac{\mu - \mu'}{\mu} \times 100 \qquad (5)$$

A graph of the error as a function of an increasing normalized wear-track radius ($1/a'$) is given in Fig. 1 over two orders of magnitude. For experiments where the pin does not contact the axis of rotation of the disc, the error in friction coefficient is less than 11% and rapidly decreases with increasing track radius.

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