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A Stochastic Analysis of Plastic Area on Rough Surface Contact in Relation with Transition from Mild to Severe Wear

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1. Introduction

Burwell and Strang [1] considered that the transition from mild to severe wear mode would occur when the total area of plastic regions on a soft surface contacting with a hard surface reaches to the apparent contact area. This paper presents a stochastic analysis of the total area of plastic regions on a flat surface contacting with a rough surface to estimate severity of contact.

2. Analysis

The contact analysis has been made for Greenwood-Williamson’s roughness model [2] consisting of a series of spherical caps each with the same radius of curvature, R, and having a Gaussian distribution of heights of standard deviation $\sigma$. Johnson’s cavity model [3] has been employed for an indentation of each rigid spherical asperity against a flat surface to estimate the plastic area at each asperity contact, shown in Fig. 1 and Eq. (1).

\[ \frac{\xi}{a} = \left( \frac{E \tan \beta}{Y} + \frac{4(1-2\nu)}{6(1-\nu)} \right)^{1/3} \] (1)

where $c$ is radius of plastic region, $a$ is radius of contact area, $E$ is equivalent Young’s modulus, $Y$ is yield stress of softer material, $n$ is Poisson’s ratio. If the indent depth $\delta << R$, $\tan \beta$ in Eq. (1) becomes approximately as

\[ \tan \beta = \frac{a}{R-\delta} \approx \frac{\sqrt{2R\delta} - \delta^2}{R-\delta} \approx \frac{2\delta}{R} \left( 1 + \frac{\delta}{2R} \right) \]

Neglecting the overlap between adjoining plastic regions, the ratio of the total plastic area to the apparent contact area, $A_p/A_n$, which denotes severity of the contact, can be expressed in terms of the asperity summit height distribution function $\phi(z)$ as

\[ A_p / A_n = \frac{1}{\{6(1-\nu)\}} \int_0^\infty \sigma^2 \phi(z) F_p(d\sigma) \] (2)

where $\eta$ is the areal density of asperities and $F_p(d\sigma)$ is the areal density of asperities.

3. Results and Summary

The product of $\eta$, $R$, and $\sigma^2$ in Eq. (2) is approximately constant and the Eq. (3) indicates that the function depends only to $1/R^2 = \sigma^2 R$ as for the roughness parameters and thus the ratio of the total plastic area to the nominal contact area, i.e. severity of contact, has good correlation with $\sigma^2 R$. In the meantime the plasticity index is written as $\psi = (E/H) (\sigma^2 R)^{3/2}$ and Hirst and Hollander [5] showed that the upper boundary between unsafe and safe surfaces coincides with a line of constant in plasticity index on the criterion map of the transition load. The analysis in this paper supports the experimental results by Hirst and Hollander [5].

4. References