ELASTO-PLASTIC CONTACT BEHAVIORS OF NOMINALLY FLAT SURFACES: MODELING AND PARAMETRIC STUDY

W. Wayne Chen¹, Yuchuan Liu¹, Wei Chen¹, Jiao Cao¹, Cedric Xia², Raj Talwar³, Rick Lederich³ and Q. Jane Wang¹

1. Department of Mechanical Engineering, Northwestern University, Evanston, IL 60208
2. Scientific Research Laboratories, Ford Motor Company, Dearborn, MI 48121
3. The Boeing Company, P.O. Box 516, MC S 245-1003, St. Louis, MO 63166

ABSTRACT

Interactions of nominally flat surfaces can be modeled based on the periodic similarity of surface topography and a numerical three-dimensional elasto-plastic contact model with the assistance of the continuous convolution and Fourier transform (CC-FT) algorithm. The rough surfaces were generated by a digital filtration technology with a wide range of topographical parameters. A group of contact simulations were conducted to investigate the effects of surface geometrical characteristics (including RMS roughness, correlation length ratio, skewness and kurtosis), material properties, and load on the elasto-plastic contact performance of materials.

INTRODUCTION

Many numerical contact models for rough surfaces have been developed in the past several decades. Liu et al. [1] presented an elasto-plastic contact model, where the linear hardening and elastic-perfectly-plastic behaviors were included and solved by using the finite element method (FEM) and the simplex method. Jacq et al. [2] developed a fast semi-analytical model for elasto-plastic counterformal contacts. Chen et al. [3] advanced this model to solve the contact involving two nominally flat surfaces with the assistance of the CC-FT algorithm.

The present work utilizes the three-dimensional elasto-plastic model in [3] to simulate a group of conformal contacts involving non-Gaussian rough surfaces, which can be numerically generated with various topographical parameters, for materials with a linear hardening behavior expressed by the elasto-plastic tangential modulus, $E_T$. The results of contact area ratio, the average gap, and the plastically deformed volume can be exported as the performance variables. Correlations between performance variables and roughness parameters, material properties and load have been constructed.

MODELING

The surface autocorrelation function (ACF) in this paper is assumed to have an exponential form,

$$R_y(k,l) = R_q^2 \exp \left[ -2.3 \sqrt{\left( k/\beta_x \right)^2 + \left( l/\beta_y \right)^2} \right]$$

where $\beta_x$ and $\beta_y$ are correlation lengths. The statistical moments: RMS roughness $R_q$, skewness $Sk$, and kurtosis $K$ determine the shape of the probability density function (PDF) of asperity heights distribution. A two-dimensional finite-impulse response (FIR) digital filter [4] can be employed to generate a non-Gaussian surface with specified ACF and the first four statistical moments.

In the CC-FT algorithm, deformation in the frequency domain becomes a product between the discrete Fourier transform (DFT) of excitation $\hat{e}$ (either surface tractions or subsurface plastic strains) and the Frequency response function (FRF) $\hat{G}$.

$$\tilde{u}_n (m,n) = \tilde{G}(m,n) \ast \hat{e}(m,n)$$

Deformation in one single period can be calculated by applying the inverse (DFT) on $\tilde{u}_n$. Reader may refer to [3] for the detailed discussion. The von-Mises criterion is used to detect the onset of plasticity, and the plastic strain can be calculated based on an increment-based approach [2]. The fast Fourier transform (FFT) [5] and the conjugate gradient method (CGM) [6] are utilized to accelerate the simulation process.
RESULTS AND DISCUSSION

Three-dimensional simulations were conducted for contacts between a rigid smooth plane and a rough elasto-plastic surface. This study chose seven dimensionless input factors: \( \gamma' = \beta_z / R_q \), \( \chi = \beta_x / R_q \), \( Sk \), \( K \), \( E' / \gamma \), \( E_t / E \), \( \bar{p} / \gamma \), and three output performances: average gap \( \bar{h} / R_q \), contact area ratio \( A / A_n \), and plastic volume \( V_p / A_n R_q \). Here, \( \gamma \) is the yield strength, \( \bar{p} \) the average pressure, \( A_n \) the nominal contact area, and \( V_p \) the total volume in plastic zone. The simulation domain is discretized into \( 128 \times 128 \times 19 \) mesh grids, and the element size is \( 7 \mu m \times 7 \mu m \times 7 \mu m \). Figure 1 presents the simulation results for an isotropic Gaussian surface.

Figure 1. Simulation results in a cross section, (a) Von-Mises stress normalized by the yield strength, and (b) Effective plastic strain.

Figure 2 shows the effect of asperity shape factor \( \chi = \beta_x / R_q \). For the surface with wider and shorter asperities (larger \( \beta_x \) and smaller \( R_q \)), the interfacial gap is smaller, contact area ratio is larger. Figure 3 presents the variation of plastically deformed volume as a function of the average pressure with varying elasto-plastic tangential modulus. The increase in the material hardening effect shrinks the volume of plastic zone. The results also show that the average gap drops exponentially with the average pressure, however, the contact area ratio and the plastically deformed volume increase proportionally with the average pressure.

The regression formula for contact area ratio was developed as,

\[
\Lambda = 10.0172 \cdot \gamma^{-0.0225} \cdot \chi^{p1} \cdot (Sk + 1)^{p2} \cdot 10^{p3} \cdot K^{(0.0041)} \cdot M \cdot L^{p3}
\]

where, \( p1 = -0.2082 + 0.0365 \ln \chi \),

\( p2 = -0.9146 + 0.0685 \ln M \),

\( p3 = 0.8219 - 0.021 \ln \chi + 0.0273 \ln (Sk + 1) + 0.0411 \ln K + 0.0292 \ln M \)

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REFERENCES


