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Physics-based modeling for fretting behavior of nominally flat rough surfaces

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ABSTRACT

A physics-based modeling approach for fretting behavior of nominally flat rough contact is proposed. This approach employs physics-based models for partial slip of spherical contacts to formulate the contact forces at asperity tips. The individual asperity forces are added by a statistical method to obtain the fretting response of a flat rough contact. This approach suggests the plasticity index as an important parameter for studying the surface roughness effects on fretting. Fretting responses obtained by one of the models favorably compare with experimental results obtained from bolted steel lap joints. Tangential stiffness and energy loss per cycle obtained from the experiments and the model predictions deviate at higher preloads. This discrepancy is due to limitations of the modeling approach in accounting for plastic response to tangential loading.

1. Introduction

When a low-amplitude oscillatory tangential displacement or force is imposed on a preloaded contact, fretting occurs. During fretting, the contact can be under partial slip (some portion of the contact area is fully adhered whereas the remaining area slips) or both partial and gross slip conditions. This pre-sliding response was worked out first for preloaded spherical contacts by Cattaneo (1938) and independently by Mindlin (1949). The response to cyclic loading was presented by Mindlin et al. (1952) for elastic contacts and it was subsequently extended to the elastic–plastic contact case by Ödfalk and Vingsbo (1992).

In all these works, *the Coulomb law of dry friction*, which couples normal to tangential tractions by a constant, μ, called the friction coefficient, is employed. This constant can be determined from experiments or found in look-up tables; alternatively, it can be varied arbitrarily to investigate the effect of frictional coupling on the response. Eriten et al. (2010) incorporated preload-dependent friction coefficient models into Mindlin's model to formulate *physics-based* models for partial slip behavior of spherical contacts. The approach presented in Eriten et al. does not require any curve-fit or experimentally-determined parameters and assumes that constitutive material models hold for the contacting materials (i.e., Young's modulus, shear modulus, Poisson's ratio and yield strength can be defined from standard techniques). In these models, material and geometric properties of the contacting materials are needed to determine the load-deformation response of the spherical contact under partial slip conditions.

Nominally flat contacts are found in many applications such as shrink fits, bolted joints and brakes. Modeling the fretting of a smooth flat-on-flat contact is more challenging than of a spherical contact due to the stress concentrations at the contact edges (Hills and Nowell, 1994). An early attempt to solve the flat-on-flat frictional contact problem with stress singularities was made by Comninou (1976), where the contact between the wedge and elastic half space was assumed to be complete and smooth. However in practice, it is nearly impossible to machine a perfectly smooth engineering surface (except for mica surfaces). Surface geometry will involve micro irregularities, called asperities, which essentially look like peaks and valleys on the surface. When such two nominally flat rough surfaces are brought into contact, contact occurs at asperity tips, and the real contact area constitutes only a few percent of the nominal contact area. Furthermore, the contact, and, thus, traction distribution over the contact patch becomes discontinuous, which drastically complicates the boundary value problem. Besides, stress intensification occurs at the asperity tips, and plastic yielding initiates even in the presence of very low normal loads. Therefore, purely elastic models are unable to model all the physics of fretting contact. In this study, we employ elastic–plastic models presented in Eriten et al. (2010) to account for the effect of surface roughness on fretting of nominally flat rough surfaces.

Using various methods, researchers have long attempted to build-up contact models for nominally flat rough surfaces from asperity-scale mechanics. Four commonly used methods are as follows: analytical solutions by assuming regular roughness profiles such as contact of surfaces filled with periodic undulations. (Johnson, 1987); numerical solutions or Finite Element Analysis (FEA) with a limited number of asperities (Dini and Hills, 2009;

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