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Trapped fluid in contact interface

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Abstract

We study the mechanical contact between a deformable body with a wavy surface and a rigid flat taking into account pressurized fluid trapped in the interface. A finite element model is formulated for a general problem of trapped fluid for frictionless and frictional contact. Using this model we investigate the evolution of the real contact area, maximal frictional traction and global coefficient of friction under increasing external pressure. Elastic and elasto-plastic material models, compressible and incompressible fluid models and different geometrical characteristics of the wavy surface are used. We show that in case of incompressible fluid, due to its pressurization, the real contact area and the global coefficient of friction decrease monotonically with the increasing external pressure. Eventually, the contact opens and the fluid occupies the entire interface resulting in vanishing of static friction. An asymptotic analytical result for the critical trap-opening pressure is found and shown to be independent of the surface slope if it is small. In case of compressible fluids with pressure-dependent bulk modulus we demonstrate a non-monotonous behaviour of the global coefficient of friction due to a competition between non-linear evolution of the contact area and of the fluid pressure. However, for realistic compressibility of solids and fluids, contact-opening cannot be reached at reasonable pressures. On the other hand, in case of elastic-perfectly plastic materials, we again observe fluid permeation into the contact interface. Finally, we study the distribution of frictional tractions during the depletion of the contact area under increasing external pressure. This process leads to emergence of singularity-like peaks in tangential tractions (bounded by the Coulomb's limit) near the contact edges. We point out the similarity between the processes of trap opening and interfacial crack propagation, and estimate the complex stress intensity factor in the framework of linear elastic fracture mechanics.

Keywords: trapped fluid, contact, surface roughness, local and global coefficient of friction, linear elastic fracture mechanics

1. Introduction

The study of mechanical contact and friction is a subject of high importance in many fields, from biological and engineering applications to geological sciences. Since natural and industrial surfaces always possess roughness under certain magnification, the contact between solid bodies occurs on separate patches corresponding to asperities of contacting surfaces, (Archard, 1953, 1957; Bowden and Tabor, 2001; Greenwood and Williamson, 1966). The evolution of the ratio of real contact area to apparent one under increasing external load determines essential contact properties such as friction, wear, adhesion, and is responsible for heat transport through contact interfaces. At the same time, the distribution of the free volume between contacting surfaces governs the fluid transport along the interface and is responsible for leakage/percolation phenomena, see for example (Dapp et al., 2012; Paggi and He, 2015).

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