8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

EFFECT OF MULTI-SCALE CONTACT DEFORMATION ON INTERFACIAL FORCES

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Key Words: *Adhesion, Asperities, Fractal Geometry, Interface, Multi-scale Contact Deformation, Roughness, Self-affinity*.

ABSTRACT

In view of the multi-scale roughness of surfaces, it is imperative that contact mechanics analyses account for deformation occurring over the entire wavelength range of interacting surfaces. Therefore, accurate contact analysis greatly depends on accurate representation of the interfacial topography. The objective of this article is to discuss the evolution of attractive and repulsive forces at rough contact interfaces in light of results obtained from multi-scale contact analyses. Based on elastic-plastic deformation models derived at the asperity level and the description of the surface topography by fractal geometry, the development of capillary, electrostatic, and van der Waals attractive forces and deformation repulsive forces is interpreted in terms of surface roughness parameters, material properties, and global surface interference. Implications of the present analyses in microelectromechanical systems (MEMS) and hard disk drives are discussed in light of representative numerical results.

Early studies considered elastic contact of homogeneous half-space and layered media. However, later studies based on the finite element method (FEM) demonstrated significant deviations from elastic (Hertzian) analyses due to the accumulation of plastic deformation in indented elastic-plastic homogeneous media may result in contact pressure distributions that deviate significantly from that predicted by Hertz theory [1,2]. In particular, the contact pressure and subsurface stresses and plastic deformation were found to depend on the indentation (loading) cycles [3], the thickness and material properties of the surface layer, friction coefficient, and applied normal load [4], and the interaction of the stress fields of neighboring asperity contacts [5,6]. More recently, the self-affinity property demonstrated by most surfaces led to the description of the interfacial topography by fractal geometry [7]. Fractal geometry was used in to investigate adhesion forces at MEMS interfaces [8], elastic-plastic contact of layered media with fractal surfaces [9], friction induced flash temperatures at sliding interfaces [10], deformation below asperity contacts of elastic-plastic layered media [11], and thermomechanical deformation in elastic half-spaces [12].

The previous studies suggest that accurate analysis of interfacial forces requires accurate description of the surface topography (to account for asperity interaction effects over a wide range of length scales) and elastic-plastic deformation models derived at the asperity level. In this article, analytical results of the contributions of elastic-plastic asperity deformation repulsive forces and different attractive (adhesion) surface forces, such as van der Waals, capillary, and electrostatic forces, on the total surface force are presented for different topographies and material properties. It is shown that surface topography modification (e.g., texturing) and chemical alteration (e.g., solid coatings and self-assembled monolayers) are effective means of reducing high adhesion forces at contact or proximity interfaces.

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