Nanoscale adhesive elastic contact incorporating intermolecular interactions

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Adhesion plays an essential role in the tribological behaviour of surfaces in contact. Adhesive interaction between asperities influence friction between surfaces in sliding contact. Understanding asperity-asperity interaction is important to understand friction and related tribological phenomena. Most analytical models (JKR, DMT) for asperity interaction assume small deformation and adhesion as surface traction, which is often violated at nanoscale contact under large deformation and strong adhesion. We have used a continuum-based finite element model incorporating adhesion due to van der Waals interaction as a body force to study the contact between elastic bodies and compare it with analytical models.

Keywords: Adhesion, Van der Waals interaction, body force, Finite element analysis.

1. Introduction

Adhesion in nanoscale contact is significant in various problems, including friction, failure in NEMS/MEMS devices, instability in AFM, and adhesive foot-pads of many insects. Due to surface roughness, multiple asperities interact when the two bodies are in contact. The single asperity-asperity interaction is the fundamental unit of contact between surfaces. Many continuum-based analytical adhesive contact models assume surface force approximation, small deformation and special geometry. However, with strong adhesion and large deformation at the nanoscale, such an assumption is often violated. It is crucial to consider the adhesive forces as distributed over the volume of the body. Computational studies can help to overcome such restrictions. This article studies the nanoscale contact between an elastic sphere and a rigid half-space using a finite element model incorporating adhesion due to van der Waals interaction as a body force.

2. Finite Element Modelling

2.1. Finite element modelling

The adhesion due to Van der Waals interaction and steric repulsion is modelled using the Lennard-Jones potential. The force per unit volume of the elastic body due to rigid half-space is implemented as body force in large deformation, static/transient finite element code. Further details about the formulation can be found in [1].

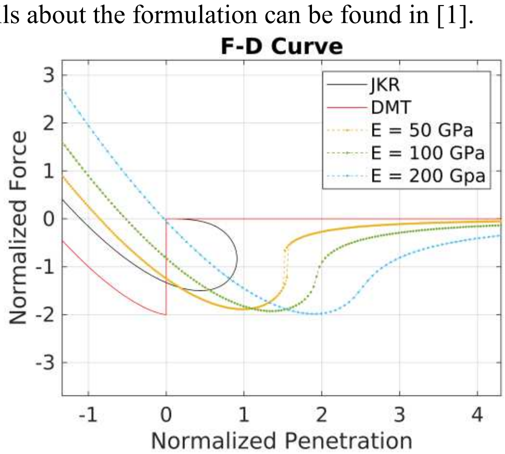

Figure 1: Force distance for different elastic spheres and comparison of pull-off force with JKR and DMT-M model.

2.2. Results

Fig. 1 shows the typical force-distance curve for three different elastic moduli of the sphere. For the 200 GPa sphere, the pull-off force matches closely with the normalized DMT value of -2. As the elastic modulus of the sphere is reduced, the pull-off force approaches the JKR value. Fig.2 shows the axial stress contour for the 50 GPa sphere. Compressive stresses are produced in the contact zone, whereas the tensile stress due to adhesive force is just outside the contact region.

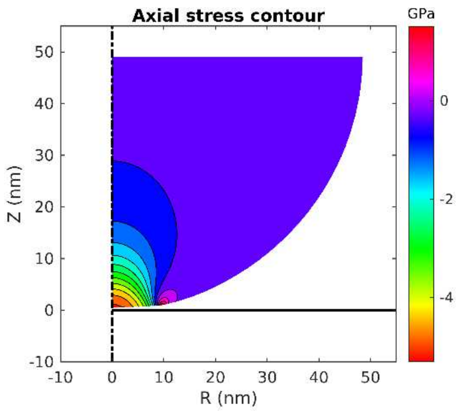

Figure 2: Axial stress contour for 50 GPa solid in contact with the half-space.

3. Discussion

In this work, we have found that the total force in the case of pure repulsion and pure adhesion and instability gap to be in excellent agreement with the analytical models. The understanding of contact parameters such as contact area, complex contact stresses and pull-off force in the presence of adhesion can be better understood with the aid of the present formulation. Moreover, the restrictive assumptions in analytical models can be overcome with this study to re-visit the fundamental problem of asperity-asperity contact, which needs better understanding.

4. References

[1] Jayadeep, U. B. et al., “A body-force formulation for analyzing adhesive interactions with special considerations for handling symmetry”. Finite Elements in Analysis and Design, 117–118, 2016 1–10.