Adhesion hysteresis of rough spheres: pinning of a crack front

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The hysteresis of the indentation force of a sphere adhering a soft elastic substrate can be caused by surface roughness or chemical heterogeneity leading to variations in local work of adhesion. In the small roughness regime, where the contact area consists of a single nearly circular junction, the indentation process can be described by the propagation of an elastic line through a random potential, similarly to fracture of heterogeneous materials and wetting angle hysteresis. Our simulations show that the crack front is pinned at inhomogeneities and that the strength of pinning depends on the geometry of the random pinning field.

Keywords (from 3 to 5 max): adhesion hysteresis, rough contacts, fracture mechanics, contact mechanics modelling

1. Introduction

Understanding how roughness affects dry adhesion is important for tires, seals and triboelectric generators. The hysteresis of the indentation force in adhesive contacts is often attributed to viscoelasticity, but can emerge from instabilities in rough contacts [1]. However, no quantitative description of pinning in randomly rough elastic contacts exists to date. Our work focuses on the contact of spheres with roughness small enough that the contact area consists of a single nearly circular junction. The equilibrium position of the contact perimeter results from the competition between elastic deformation energy and local adhesion. Local fluctuations of the elastic deformation energy (resulting from roughness) create energy barriers leading to local instabilities and hysteresis. Fluctuations of the work of adhesion have the same effect but relate to the instabilities in a simpler way. More importantly, the latter case can be simulated with an efficient crack propagation model [2]. We use the boundary element method and the crack propagation model to study how the hysteresis depends on the geometry and strength of the heterogeneities and discuss the similarities between topographical and work of adhesion heterogeneity.

2. Methods

2.1. Boundary element method
The surfaces interact with finite range attraction and hard-wall repulsion, the elastic surface deformations are computed using a Green's function method [3]. This method allows to simulate contacts with roughness or heterogeneous work of adhesion for arbitrary geometries of the contact area (e.g. partial contact).

2.2. Crack propagation model
The stress intensity factor for a nearly circular connection is computed using a first order perturbation [2] to the JKR solution of the smooth sphere. The shape of the contact is such that the stress intensity factor equals the local fracture toughness. This method is suitable for work of adhesion heterogeneities and nearly circular contact areas and allows to simulate softer materials (higher tabor parameter) and finer heterogeneities then the boundary element method.

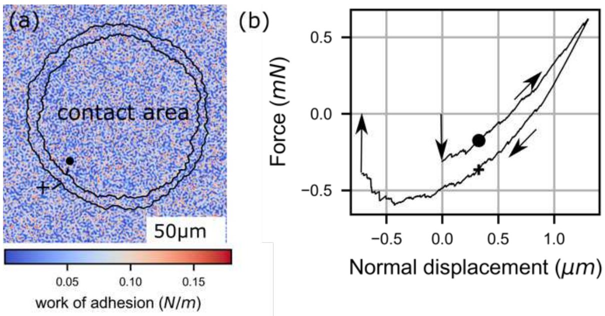

Figure 1: Contact of a sphere (radius 2mm, contact modulus 10MPa) against a spatially varying work of adhesion (a) Contact perimeter calculated by the crack propagation model at the normal displacement 0.3µm. The contact radius during retraction is bigger because of pinning by the heterogeneities. (b) Force displacement curve for the contact shown in (a).

3. Discussion

We verify that the boundary element method and the crack propagation model are equivalent for weak heterogeneity. We clarify the relationship between surface roughness and work of adhesion fluctuations. This helps to understand adhesion hysteresis in light of previous work on crack pinning in heterogeneous materials and contact angle hysteresis of droplets.

4. References

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