Adhesion instability of rough surfaces

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Adhesion instability of the boundary of the adhesive contact zone is numerically studied using Boundary elements simulations It is found that adhesion instabilities are caused by energy dissipation at small scale surface topography features. Different values for the effective work of adhesion when the contact area expands and contracts (adhesion hysteresis) are a direct consequence. The effect is interpreted in terms of "friction" to the movement of the contact boundary. The value of friction due to adhesion instabilities to be governed by the Johnson parameter.

Keywords: adhesion, instability, roughness, boundary element method,

1. Introduction

Instable, jerky movement of the boundary of the adhesive contact zone in tangential motion of a rough body is very often observed. We argue that the "adhesion instabilities" at the contact boundary cause energy dissipation similarly to the elastic instabilities mechanism. This leads to different effective works of adhesion when the contact area expands and contracts. This effect is interpreted in terms of "friction" to the movement of the contact boundary. Numerically this behaviour is studied by use of the BEM for the JKR(Johnson, Kendall, Roberts)-type adhesive contact.

2. Numerical results

Figure 1 shows typical simulation results for the force-contact area relations of a parabolic indenter with waviness during the indenting and pull-off. During approach and detachment the movement of the contact boundary proceeds in both continuous changes and instable jumps. Each jump is irreversible and energy is lost. Due to the multiple microscopic instabilities, the indentation differs from the detachment curve at all values of the indentation depth: the dissipation leads to an apparent "friction" counteracting the movement of the contact boundary [1].

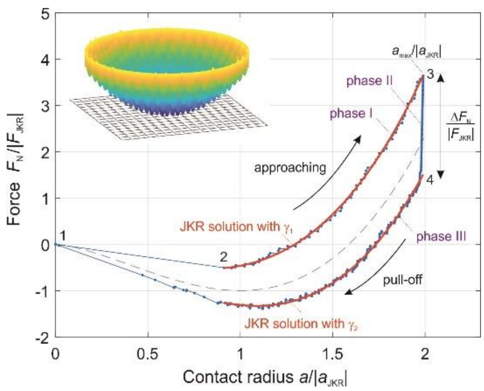

Figure 1: A simulation example of force-contact radius dependencies during indenting and pull-off of a parabolic indenter with waviness.

The other observation is that the contact area remains constant immediately after turning from indentation to pull-off (phase II). The gray dashed line in the Figure 1 is the JKR solution without waviness. The instabilities are clearly visible in the curves as microstructure of the lines.

Both indentation and pull-off curves follow very closely JKR solutions, as shown in Figure 1 with red lines, but with different values for the specific work of adhesion. The value γ_1 for the approach is smaller than γ_2 for pull-off. A parameter study shows that these two values are determined by the Johnson parameter [2]

$$\alpha = \sqrt{\frac{2\lambda\gamma_0}{\pi^2 h^2 E^*}}. \tag{1}$$

The specific work of adhesion γ_1, is continuously decreasing together with the Johnson parameter. A particularly sharp drop to almost zero occurs in the vicinity of α=0.5. A closer analysis of the contact configuration shows that this sharp drop is associated with the change from the compact contact area to a cloud of separated contact spots. A slightly different behavior is found in the effective determining the detachment process. Specific energy γ_2 increases with a decrease of the Johnson parameter. an abrupt change occurs at $\alpha\approx0.5$.

Pure rolling is essentially a normal contact problem because the surfaces at the leading edge are approaching each other in the normal direction and on the rear edge they separate in normal direction, both without any tangential movement. Tangential force in this case is also determined by the Johnson parameter, and in the range of α>0.5, it is proportional to the contact radius and difference between two values of specific work of adhesion.

3. References

[1] Popov VL, Li Q, Lyashenko I,Pohrt R, "Adhesion and Friction in Hard and Soft Contacts: Theory and Experiment," Friction, 2020.

[2] Johnson K L, "The adhesion of two elastic bodies with slightly wavy surfaces," Int J Solids Struct, 1995, 32: 423–430.