Some open problems in adhesion (of rough surfaces).

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Adhesion for ‘‘soft’’ bodies shows instabilities like in the simple case of a single sinusoid even in the so called JKR regime (Johnson 1995) which leads to hysteretic behavior. Hence, for very soft and large bodies, and special types of roughness, this could be maximized (Guduru, 2007) with possible enhancement of adhesion. However, at nanoscales and for hard solids, very simple equations like Rumpf-Rabinowicz (Rumpf, 1990, Rabinovich et al., 2000) work very well for the spherical geometry, and show large reduction with roughness. These show only dependence on rms heights of roughness and not slopes or curvatures, as confirmed by extensive AFM experiments by Jacobs et al (2013) where from atomic corrugation up to a few nm, the measured work of adhesion was found to decrease by more than an order of magnitude. This naturally also raise the very delicate issue of what is “work of adhesion” in experimental measurements of adhesion forces.

In a recent note BAM (Bearing Area Model) was introduced by Ciavarella (2017b), a single-line equation estimate for adhesion between elastic (hard) rough solids with Gaussian multiple scales of roughness. It was successfully validated with high quality numerical data from the literature from Pastewka and Robbins (2014) for pull-off. The reason why the area-slope relationship seems to depend on rms slopes and curvature in Pastewka and Robbins (2014), while pull-off primarily on rms heights, has been the subject of a few efforts (Ciavarella, 2016, 2017a,b, Ciavarella and Papangelo, 2017a,b,c, Ciavarella, Papangelo and Afferrante, 2017), yet calls for more investigations. BAM starts from the observation that the entire DMT solution for ‘‘hard’’ spheres (Tabor parameter tending to zero) assuming the Maugis law of attraction, is very easily obtained using the Hertzian load-indentation law and estimating the area of attraction as the increase of the bearing area geometrical intersection when the indentation is increased by the Maugis range of attraction. BAM is therefore an equation similar to Rumpf-Rabinowicz for the sphere, but as applied to elastic nominally flat surfaces. BAM shows that adhesion, as already well known, for hard solids at macroscopic scale is destroyed quite easily and the problem remains that contact area is a ill-defined “magnification” dependent quantity (Ciavarella and Papangelo, 2017b). When elastic modulus decreases sufficiently, observable adhesion may be possible, although then the assumptions of BAM may become questionable. In 1969 Carl Dahlquist at 3M suggested a "Criterion" bearing his name: "For measurable quick tack, the elastic modulus must be below a certain fixed value (0.3MPa) which is fairly independent of the nature of the adhesive, the adherend and the applied pressure". While this is clearly a rule-of-thumb, it has been a useful rough guide for more than 40 years. Some comparisons with BAM follow.

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