Micromechanics of Surfaces: Role of Surface Roughness in Hysteresis During Adhesive Elastic Contact

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In experiments that involve contact with adhesion between two surfaces, as found in atomic force microscopy or nanoindentation, two distinct contact force (P) vs. indentation-depth (h) curves are often measured depending on whether the indenter moves towards or away from the sample. The origin of this hysteresis is not well understood and is often attributed to moisture, plasticity or viscoelasticity. We present experiments [1] and continuum mechanics models [2] that will show that hysteresis can exist without these effects, and that its magnitude depends on surface roughness. We explain the observed hysteresis as the smeared out effect of a large series of surface instabilities that are induced by the surface's roughness and adhesion. These instabilities cause the size of the nominal contact region to be significantly different during the loading and the unloading phases of the contact experiment. We also demonstrate that when this is the case material properties can be estimated uniquely from contact experiments even when the measured P-h curves are not unique.

The hysteresis energy loss during contact is also a measure of the adhesive toughness of the contact interface. We show experimentally that roughness can both increase and decrease the adhesive toughness of the contact interface. We show through numerical simulation of continuum adhesive contact models that the contact interface is optimally tough at conditions at which the contact region is at the cusp of the transition at which it turns from being mostly simply connected to being predominantly multiply connected. This insight is useful in increasing an interface's toughness by modifying its small scale structure through microfabrication techniques.

References

[1] H. Kesari, J. Doll, W. Cai, B. Pruitt, and A. Lew. Role of surface roughness in hysteresis during adhesive elastic contact. *Philosophical Magazine Letters*, 90(12):891–902, 2010.

[2] H. Kesari and A. J. Lew. Effective macroscopic adhesive contact behavior induced by small surface roughness. *Journal of the Mechanics and Physics of Solids*, 59:2488–2510, 2011.