Adhesion of hard, rough contacts

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Sphere-on-flat adhesion tests were performed on diamond coatings with varying, and well-characterized, roughness. Data from more than 8000 measurements were fit using numerical analysis, where an interaction potential was integrated over measured topography, while accounting for plasticity. The fit yielded an intrinsic work of adhesion of 46.3 mJ/m^2 and a range of adhesion of 5.6 nm. Finally, the numerical analysis was repeated while filtering out different length-scales of roughness. Results demonstrate a critical range of length-scales, 85—1400 nm, that most significantly modifies the macroscopic adhesive force for these hard, rough contacts.

Keywords: adhesion, nanocrystalline diamond, multi-scale surface roughness, pull-off force

1. Introduction

Surfaces often have hierarchical, multi-scale roughness. Important questions remain about which scales have the most significant effect on hard-material adhesion.

2. Methods

Polycrystalline diamond substrates with varying grain size were used to modify roughness while maintaining similar surface chemistry. Topography was characterized by atomic force microscopy (AFM, shown in Fig. 1), and by stylus profilometry and transmission electron microscopy (TEM) [1]. Adhesion forces were measured in dry air (<1% RH) with 0.5-mm-diameter ruby spheres contacting at >2000 different locations on each substrate.

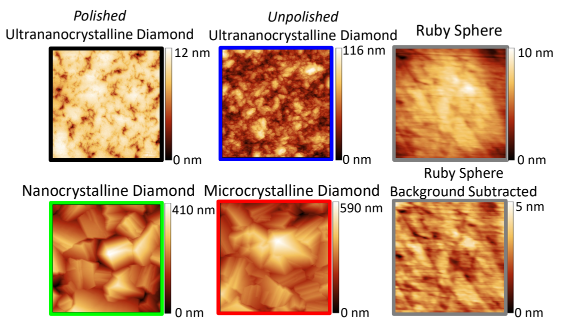

Figure 1: 2.5-µm AFM scans of diamond coatings. [2]

3. Results and Discussion

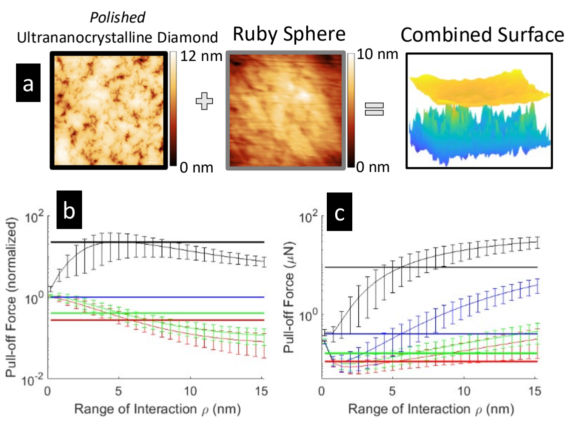

Figure 2: Experimental results (horizontal lines) were fit by integrating an interaction potential over measured topography. (Colors match Fig. 1.) Best-fit values were extracted for work of adhesion and interaction range. [2]

Using numerical analysis, an interaction potential was integrated over the AFM-measured topography (Fig. 2). Experimental results could only be reproduced with an intrinsic work of adhesion of 46.3 ± 3.5 mJ/m^2 and an interaction range of 5.6 ± 0.5 nm.

To understand which scales of topography most strongly affect bulk adhesion, the numerical analysis was repeated with different scales of roughness filtered out. Specifically, multi-scale roughness was created by superimposing AFM scans with statistical topography from stylus and TEM. Then, pull-off force was computed with different short- or long-wavelength cutoffs (Fig. 3). The adhesion was unaffected (within 10%) by roughness at scales smaller than 85 nm or larger than 1400 nm.

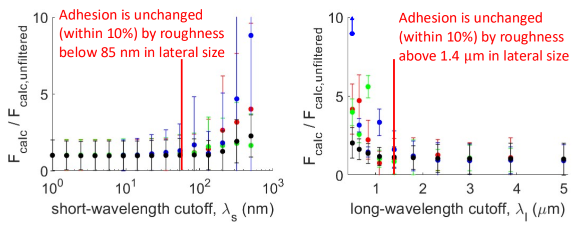

Figure 3: For each substrate, the pull-off force F_{calc} was calculated with all scales of roughness included, and with a short- or long-wavelength cutoff. (Colors match Fig. 1.) The fractional difference in pull-off force indicates the relative contribution of the filtered scales. [2]

4. Conclusions

In these hard contacts with multi-scale roughness, topography in a critical range of size scales most strongly impacted macroscopic adhesion. Full results in Ref. [2]

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5. References

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