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Abstract (English)

Quantitative and qualitative investigation of adhesion and friction on textured surfaces: inspiration from insect-plant interactions

Adhesion and friction exist in many technical systems as well as in natural ones. Both phenomena have a profound influence on the durability and efficiency of technical systems, of particular note are micro-contact applications with high surface to volume ratio. A well-recognised approach to precisely tune these characteristics - besides altering the physicochemical properties - is the micro and/or nano-structuring of the interacting surfaces. Inspiringly, plant leaf surfaces are often decorated with diverse and species-specific surface morphologies, and so show remarkable surface functionalities: slipperiness, self-cleaning and anti-adhesive, just to name a few. However, these biological surface functionalities are driven by an interplay of surface structuring and chemistry, making it a highly intricate system to investigate with many unsolved questions. Altogether, this interdisciplinary work aimed to perform a systematic investigation of adhesion and friction mechanics on micro-structured surfaces directly replicated from the surface of plant leaves, in contact with a model adhesive system which is inspired from the adhesive pad (Arolium) of an insect.

Three different model plant leaves and a technical surface, with variable size range (0.5 - 100 µm), shape and complexity (hierarchical levels) of their surface morphologies, were chosen in this work. Surface morphologies of the fresh leaves were directly transferred onto a soft viscoelastic polymer. For this, three different replication approaches were established and comprehensively investigated. Scanning electron microscopy was utilised to analyse the surface morphology of the leaves and to qualitatively compare the replication accuracy of the replication techniques. Furthermore, a quantitative evaluation of the replication quality was performed, by applying two model parameters (cross-covariance function ratio and relative topography difference) on the line profiles and the surface profiles recorded with confocal laser scanning microscopy. Both qualitative and quantitative investigations came out well in-line, confirming the precise replication ability of Epoxy-PDMS technique.

For the contact mechanics investigation, a high-resolution (load or displacement control) nanoindenter was modified, with incorporating a unique feature to record the *in-situ* real-contact images. A JKR (Johnson, Kendall and Roberts) contact mechanics based pull-off force test, at a low force range, was performed on the bio-replicated samples by forming contact against a model adhesive tip. A series of tests were carried out to quantitatively evaluate and thoroughly understand the effect of pre-load on adhesion force characteristics. A significant

enhancement in adhesion force with increasing in pre-load was observed on *Hevea* replica (fine micro-structuring) and *Litchi* replica (complex hierarchical morphology), unlike the other two surfaces: no specific influence was noted on smooth PDMS and *Ludisia* replica (coarse conical shape patterns). An overall comparison between the surfaces clearly demonstrated significant differences in the resulting adhesion force, discussed according to each surfaces topographic profile. Furthermore, results from real-time synchronization of the exact real contact image with corresponding force value pointed out distinct attachment-detachment modes, based on different pre-load conditions and distinct surface topographies.

Next study was achieved to investigate the friction mechanism on all four substrates that were utilised in the preceding study of adhesion mechanics. Friction tests were carried out in the unidirectional sliding configuration (with the same nanoindenter apparatus used in previous section), to examine the effect of normal load and sliding speed on the friction characteristics. All surfaces showed a decrease in friction coefficient with increasing the normal load, however, each surface exhibited distinct decreasing behaviours. Examination of synchronized *in-situ* videos revealed the different real contact evolution behaviours and the distinct sliding mechanisms, arising from surface-specific topographies. A clear dependency of the friction response on sliding speed was recorded for all surfaces, attributed to the rate-dependent viscoelastic behaviour of PDMS. Accordingly, the friction behaviour was correlated and analysed with the PDMS loss factor in the same frequency range. The overall comparison manifests, the *Ludisia* and *Litchi* replicas significantly lowered the friction coefficient as compared to the smooth PDMS and *Hevea* replica.

The replication technique advancement achieved in this work may represent an effective alternative for future bio-replication studies. In addition, insights and concepts gained from this study may provide valuable assistance for designing the bio-inspired functional surfaces, particularly to fine tune the adhesive and frictional characteristics of smart surfaces.