

Recent advancement in understanding vibroadhesion: experiments and modelling

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Modulation of interfacial adhesion in soft materials is of growing importance for engineering systems such as soft robotic grippers, programmable manipulators, and reversible adhesive interfaces [1]. A promising emerging approach, referred to as vibro-adhesion [2,3], exploits fast (>100 Hz), low-amplitude (<100 μm) substrate vibrations to rapidly tune interfacial toughness. Although vibrations are known to influence frictional and contact phenomena, their role in adhesion of soft viscoelastic materials has remained comparatively unexplored. This work presents an integrated experimental–theoretical investigation that reveals how high-frequency excitations can dramatically strengthen or weaken soft adhesive contacts through viscoelastic dissipation mechanisms. The study focuses on the axisymmetric contact between a rigid borosilicate spherical lens and a soft PDMS (polydimethylsiloxane) substrate. The lens is hang on a compliant spring while the nominally flat PDMS substrate is harmonically excited using a pair of electrodynamic shakers [3]. Under excitation the contact patch behaves as a dynamically evolving external crack, in which the processes of crack propagation and healing are strongly rate dependent. Because of viscoelastic energy losses the maximum adherence force (pull-off) can be increased by about 15 times with respect to the quasi-static unloading case without vibrations [3]. A reduced-order model is developed that couples a viscoelastic adhesive contact formulation with the nonlinear dynamics of the suspended spherical indenter. The model captures how vibration-induced oscillations of the contact radius interact with the system’s resonance behavior [3,4,5]. Near resonance, the contact edge undergoes rapid cyclic motion, amplifying viscoelastic dissipation within the substrate bulk and dramatically increasing adhesion. The framework enables prediction of the dependence of pull-off force on excitation frequency and amplitude, and demonstrates that adhesion regulation is fundamentally linked to the interplay between material rheology and oscillator dynamics. Comparison between model predictions and experimental measurements shows excellent agreement across a broad operating range although deviations emerge for vibration amplitudes exceeding approximately 100 μm , suggesting the onset of nonlinear effects leading to contact instabilities [3,4,5]. The effects of material properties, preload, substrate thickness, unloading rate is also investigated, showing a rich behavior which could be exploited for the development of smart interfaces capable of actively tune adhesion for robotics applications.

References

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