Thin Film Adhesion in the Presence of Long-Range Intersurface Forces: 1-D Rectangular Membrane vs 2-D Circular Diaphragm

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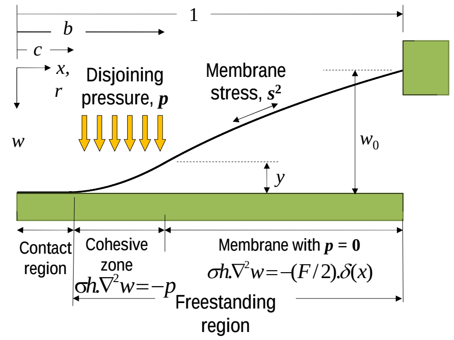
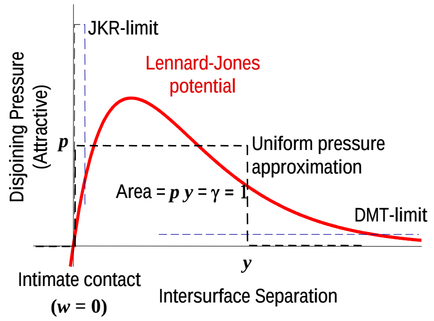
Introduction

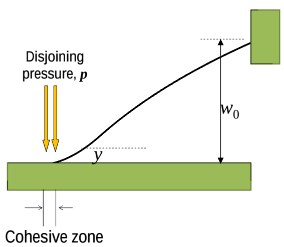
Thin film adhesion is ubiquitous in microelectronics and life-sciences. Intersurface forces possess finite range (y) and magnitude (p). Adhesion-delamination mechanics is derived based on linear elasticity for (i) a 1-D rectangular membrane clamped at the ends and (ii) a 2-D circular diaphragm clamped at the periphery. Comparison between the 2 configurations are stated.



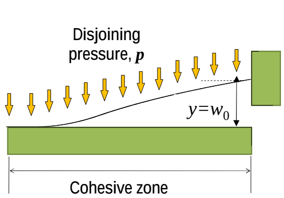
A uniform disjoining pressure with finite range is assumed using the Dugdale-Barenblatt-Maugis approximation: $\Phi(w) = p$ within the cohesive zone ($0 < w \le y$) and $\Phi = 0$ without ($y < w \le 1$). The adhesion energy is always $\gamma = p\,y = 1$.



Fixed adhesion energy ($\gamma = 1$)	Force Range (y)	Disjoining Pressure (p)
1. DMT-limit (Derjaguin-Muller-Toporov)	∞	0
2. JKR-limit (Johnson-Kendall-Roberts	0	∞
3. DMT-JKR Transition (Maugis)	finite	finite



JKR-limit



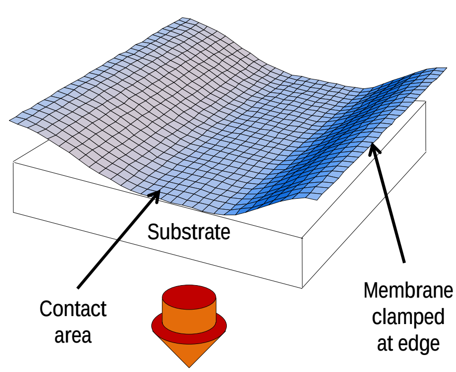
DMT-limit

Discussion

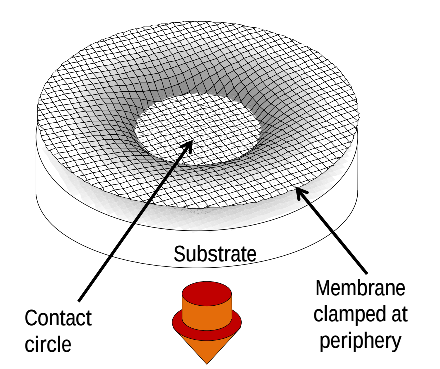
The adhesion-delamination mechanics of the 1-D and 2-D clamped membranes possess distinct characteristics in terms of membrane profile and relation between the measurable quantities of applied load (F), punch displacement (w_0) and contact area (c). In the DMT limit, delamination is always accompanied by an increase in external load, and the contact area always shrinks to zero before the membrane spontaneously detaches from the substrate leading to "pinch-off". In the 1-D JKR limit, a constant applied load drives delamination to pinch-off. The 2-D counterpart leads to a decreasing load and "pull-off" at non-zero contact radius.

These results are in reminiscent of the classical JKR and DMT solid-solid adhesion theories where "pull-off" and "pinch-off" are also predicted. A major distinction of the present models is that the sample film is mechanically deformed by membrane stretching only. There is no compression in the contact area, and no shearing in the membrane.

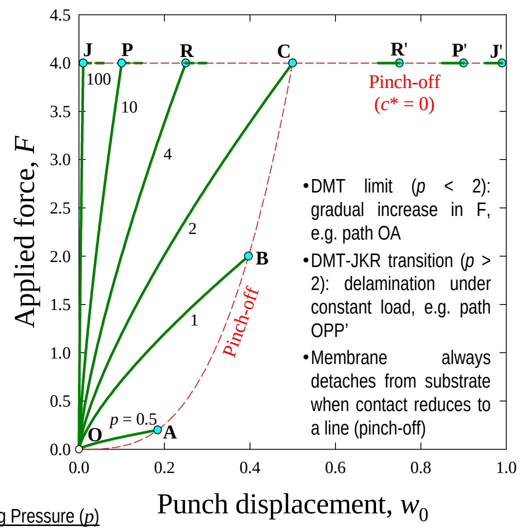
1D rectangular membrane

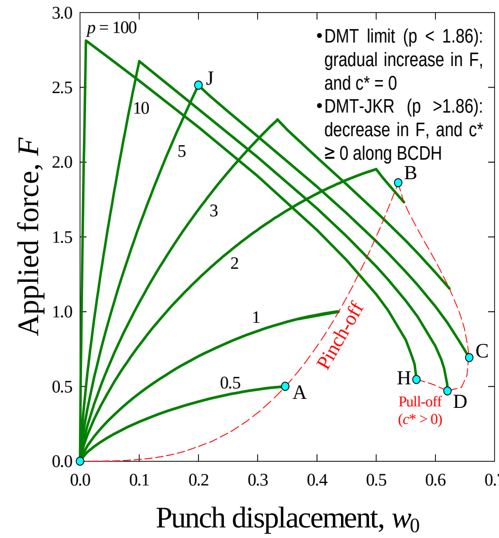


2D circular membrane



Mechanics and trajectory of membrane delamination: $f(F, w_0, c)$



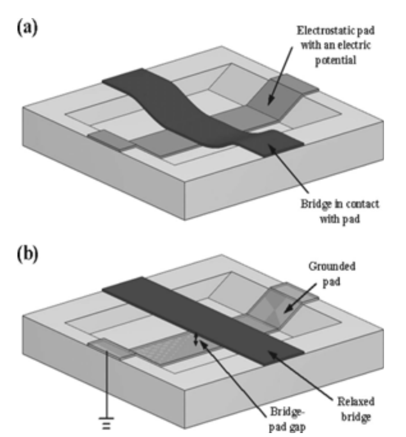


Applications:

(i)Micro-electromechanical systems (MEMS / NEMS): Adhesion of moveable bridge (e.g. RF-switch) and diaphragms (e.g. micro-pumps) hinders device operation and shortens lifespan. Right figures are a MEMS-RF switch. A bridge is controlled by an applied voltage to yield "1" or "0". In the presence of large intersurface forces, the bridge fails to resume its undeformed geometry.

(i)Nanotechnology: the models allows one to evaluate stability of nano-structures when expose to an environment such as moisture. Excessive intersurface forces lead to collapse of trusses.

(i)Life sciences and biomedical engineering: Cell adhesion leads to aggregation, tissue formation (e.g. stem cell chondrogenesis), cell-cell communications (e.g. Alzheimer), detection of malignant cells (loss of adhesion in cancerous tissues) etc .



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Acknowledgements

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3. G Duan, KT Wan, "Analysis of One-Dimensional and Two-Dimensional Thin Film ""Pull-in" Phenomena Under the Influence of an Electrostatic Potential, *Journal of Applied Mechanics*, 927-934, 2007.