Interfacial studies on PDMS using an advanced JKR apparatus

Interfacial Studies on PDMS using an Advanced JKR Apparatus

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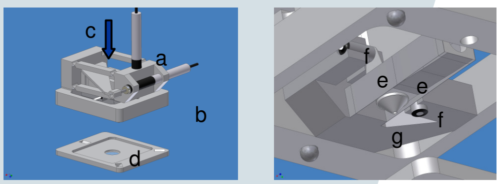
Introduction

Adhesion, friction are relevant phenomenon present in many aspects of everyday life and thus need to be understood at a fundamental level. An instrument facilitating the study of both these phenomena at a mesoscopic scale has been designed and developed within our group. Adhesion studies on elastomers using the contact mechanics method of Johnson-Kendall-Roberts (JKR) has been performed. Frictional dynamics of these materials have also been investigated.

Instrument

A double leaf-spring unit is used as the force probe and is attached to a double hinge system. The hinge system can move in vertical and horizontal direction and is controlled by motors.



Schematic of the JKR instrument: a, b - motors for vertical and horizontal motion (speed 0.05 - 1500 µm/s); c - microscope; d - counter surface; e - leaf-spring unit (spring constant – K_V= 1320 & K_H = 360 N/m) ; f - capacitive sensors (force range 0.01µN-33 mN, displacement resolution 1nm); g - sample holder.

Materials

In this study, influence of molecular weight of crosslinked poly(dimethylsiloxane) (PDMS) on elastic modulus (*E*) & work of adhesion (*W*) and friction dynamics has been investigated.

Adhesion Studies

The JKR model allows a direct estimation of work of adhesion (*W*) & elastic modulus (*E*) of two spherical elastic bodies in contact by the simultaneous measurement of applied load (*P*), the resulting displacement (δ) and the radius of deformation (*a*) at the interface under equilibrium conditions. For the case of an elastic semi-sphere in contact with a flat sheet, the following equations describe the JKR model:[1]

$$\delta = \frac{a^2}{3R} + \frac{2P}{3aK} \qquad (1)$$

$$a^3 = \frac{R}{K}\left[P + 3\pi WR + \sqrt{6\pi WRP + (3\pi WR)^2}\right] \qquad (2)$$

$$\frac{1}{K} = \frac{3}{4}\left[\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2}\right]$$

ν- Poisson ratio

R- radius of curvature of lens

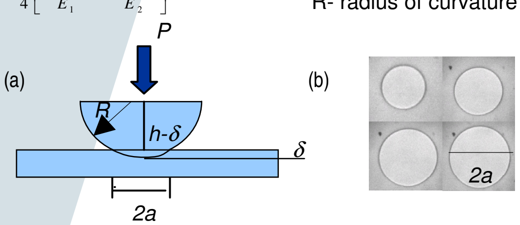


Figure 1. (a) Schematic representation of contact between an elastic semi-sphere and a flat sheet (b) images of the resulting contact between PDMS lens and sheet at different loads.

Results

Force *P* & displacement δ were detected by the leaf-spring unit (e) and the sensors (f). The instrument was mounted on an inverted microscope to observe the interface (and subsequently radius *a*).

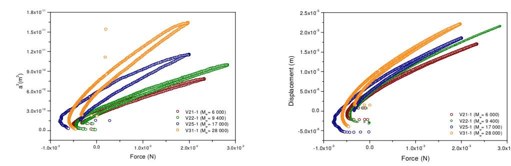


Figure 2. Curves showing the behavior of PDMS samples (lens on sheet) of varying molecular weights during loading-unloading cycle.

The loading curves were fitted to Equation 1 & 2. The resulting values of *E* & *W* are given in the following table.

Sample	Molecular Weight	*E* (MPa)	*W* (mJ/m²)
V21-1	6 000	1.14	55
V22-1	9 400	0.82	54
V25-1	17 000	0.76	49
V31-1	28 000	0.49	55

Friction Studies

Influence of sliding speed and molecular weight on friction dynamics (lens sliding on sheet) of PDMS was investigated.

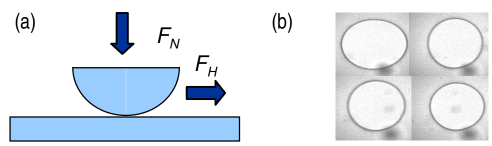


Figure 3. (a) Schematic representation of the experiment (b) images of interfacial deformation during sliding of PDMS lens against a sheet.

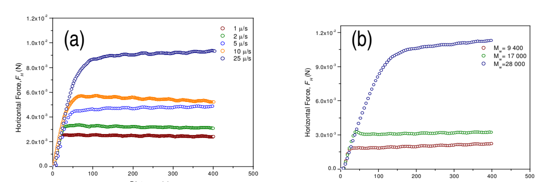


Figure 4. F_H curves at the same F_N (a) V22-1 at different velocities (b) samples of varying molecular weight at same velocity (5µ/s).

Conclusions

- The instrument is clearly an excellent tool for performing accurate studies on adhesion & friction behavior of soft materials.
- Molecular weight strongly influences elastic modulus. This can be understood in terms polymer chain length and cross link density.[2]
- Increasing F_H with velocity suggests extreme deformations at the interface.[3] Increasing molecular weight results in higher F_H which is perhaps related to the varying material properties.

References

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