Investigating interfacial behavior of PDMS using an advanced JKR apparatus

Investigating Interfacial Behavior of PDMS using an Advanced JKR Apparatus

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Introduction

Johnson Kendall and Roberts (JKR) method is a technique to study the adhesive properties of soft polymeric systems that allows the determination of the work of adhesion (W) at an interface by means of contact mechanics. The evolution of W as a function of time for a contact is a natural extension of this subject and is expected to impact the adherence and frictional behavior of a contact as well. We developed an apparatus that is able to carry out JKR analysis, and also measure friction forces on a single contact. Additionally, the placement of the apparatus on a confocal microscope enables one to study the volume affected by the contact pressure along with the contact area.

Adhesion Studies

The JKR model allows a direct estimation of W & elastic modulus (E) of two elastic bodies in contact by the measurement of applied load (P), the resulting displacement (δ) and the radius of deformation (a) at the interface under equilibrium conditions.

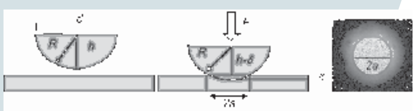

Fig 1. Schematic representation of the geometrical changes when an elastic semi-sphere and a sheet are brought in contact under a load P along with an image of the resulting contact area.

For the case of an elastic semi-sphere in contact with a flat sheet, the following equations describe the JKR model:

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

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

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

ν- Poisson ratio

R- radius of curvature of lens

Instrument

A double-leaf spring unit moved using the motors is used as the force probe. The deflection of the leaf-spring on contact of samples is proportional to the applied force. The system is mounted on a microscope to record the contact area.

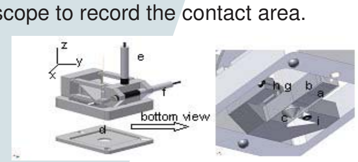

Fig. 2. Schematic of the JKR instrument: a, b –vertical & horizon tal leaf-spring unit; c – sample holder (lens); d – sample holder (sheet); e, f – motors; g, h – capacitative sensor for vertical and horizontal orce detection (resolution ~ 15 µN); i – capacit- -ative sensor for indentation (resolution ~ 10 nm) measurement.

Materials

Influence of molecular mass (M_C) between crosslinks in poly(dimethylsiloxane) (PDMS) on its elastic modulus, work of adhesion and its friction dynamics has been investigated.

Results

In a typical experiment, PDMS samples were mounted on the sample holder and a and δ were recorded as a function P. The behavior of P - δ and P - a curves with changing M_C is shown in Fig. 3. Values obtained from fitting of the curves to Eq. (1) & (2) is shown in Table 1.

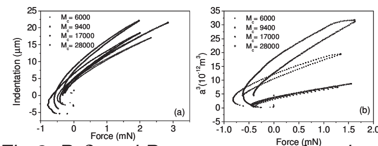

Fig.3. P-δ and P-a curves as a function of M_c.

M_C (g.mol^{-1})	E_δ (Eq. 1) (MPa)	E_L (Eq. 2) (MPa)	W_L (mJ/m^2)
6000	0.94±0.10	1.16±0.14	45±3
9400	0.91±0.05	1.03±0.05	45±3
17000	0.84±0.02	0.93±0.03	44±2
28000	0.60±0.11	0.71±0.14	42±3

Table 1. Shows the influence of M_c on E & W of PDMS.

Friction Studies

Influence of M_C and sliding speed on friction dynamics (lens sliding on sheet) of PDMS was investigated and is shown in Fig. 4.

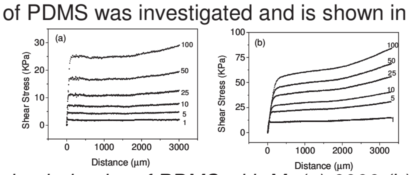

Fig. 4. Friction behavior of PDMS with M_c (a) 6000 (b) 28000 : lens was slid on sheet at various speeds (µm/s) under a normal stress of 20 KPa.

Confocal Imaging

Fig. 5 shows a composite of confocal images recorded along the z-axis of PDMS lens in contact with a flat surface and surrounded by a fluorescent dye. The image gives an impression of the lens shape above the contact area and also the shape of the meniscus of the dye solution.

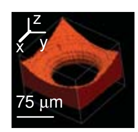

Fig. 5. Confocal image of PDMS lens in contact with a flat surface.

Conclusions

- The instrument is an excellent tool for performing adhesion and friction studies on a single contact of soft materials in a dynamic mode.[2] Imaging of the sample interface and volume during such processes is also possible.
- Novelty of the instrument allows accurate measurement of δ and determine E using Eq. (1) independent of Eq. (2).
- The E of PDMS decreases with increasing M_C though W remains largely unaffected. Adherence increases with increasing M_C (indicated by hysteresis behavior in Fig. 3).[3]
- Both adherence and friction are correlated in PDMS increasing with increasing M_c.[3]

References

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