Energy Analysis of Multi-Lens Adhesion Measurements*

Aaron M. Forster, Christopher M. Stafford, Alamgir Karim

Polymers Division, National Institute of Standards and Technology, Gaithersburg, MD 20899

INTRODUCTION

Adhesive contact tests provide a method to probe the effect of interfacial characteristics important to adhesion such as chemical bonding, roughness, or mechanical interlocking. The Johnson, Kendall, and Roberts (JKR) test utilizes a single hemispherical lens compressed against (loading) and removed from (unloading) a substrate. The JKR theory models the contact behavior between two elastic solids to account for adhesive forces as a function of contact area, contact geometry, and load or displacement. The NIST Combinatorial Methods Center (NCMC) has adapted the JKR test to develop a high-throughput adhesion measurement platform [2]. This test utilizes an array of hemispherical lenses, rather than a single lens, to conduct multiple adhesion tests during one loading/unloading cycle. A schematic of the lens array along with the multi-lens JKR test apparatus is given in Figure 1.

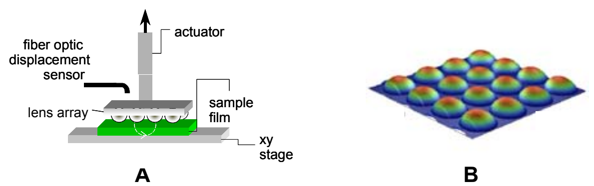

Figure 1. A) Schematic of the multi-lens array apparatus. The lens contact area is imaged from below through an inverted microscope. B) Profilometer scan of a microlens array. Each lens is 900 μm in diameter and 300 μm high.

Essential to the quantification of adhesion energies with the JKR equation is the measurement of two of three variables: load, contact area, and displacement. Typically, the contact area and load are measured during the test and this data is fit to the JKR equation to determine *E* and $\mathcal{G}$, the system modulus and energy release rate, respectively [3]. Experimentally, displacement is not used due to difficulties in determining the initial contact point. In the case of linear elastic deformation and contact equilibrium $\mathcal{G}$ is equal to the thermodynamic work of adhesion. In the case of the multi-lens adhesion test, where the load on each lens is not available, calculations are performed with respect to the strain energy release rate [3, 4].

$$\mathcal{G} = \frac{2E(\delta' - \delta)^2}{3\pi a} \quad \textbf{E.1}$$

where *E* is the lens modulus, δ is the lens displacement, a is the contact area, and $\delta' = a^2/R$ is the displacement required to establish a contact radius of a without the presence of surface or adhesion forces [3, 4]. This value represents the energy required to change the contact area by a unit amount. The strain energy release rate is not constant, but depends on the rate at which the contact area changes during unloading.

EXPERIMENTAL

Single lens adhesion tests were conducted in conjunction with multi-lens adhesion tests. Initially, a single glass lens was brought into contact with a polydimethylsiloxane (PDMS) film. The film is

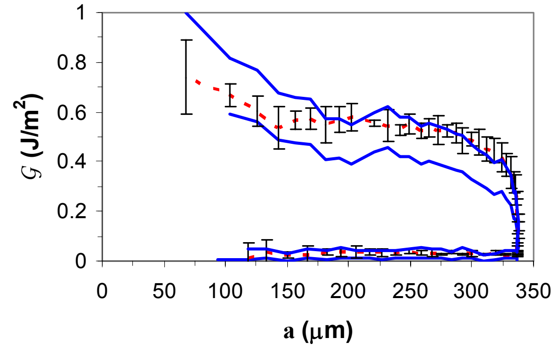

Figure 2. The solid lines (blue) represent the strain energy release rate calculated from E.1 at the upper and lower displacement uncertainty bounds. The dotted line (red) is the strain energy release rate calculated from the load values.

composed of Dow Sylgard 184 [5] mixed in a mass ratio of 15:1 (prepolymer:catalyst) and cured for 1 h at 75 °C. The loading and unloading velocity was kept constant at 0.2 μm/s without dwell time. For the single lens tests, both load and displacement were measured along with contact area. After the loading/unloading cycle, the strain energy release rate was calculated. For the multi-lens tests, four of the single lenses were fixed to a glass slide on a square grid to create a multi-lens array.

DISCUSSION

Figure 2 shows the strain energy release rate as a function of contact radius measured for a single glass lens against a PDMS film. The solid lines are the strain energy release rate calculated from two potential displacement points of initial contact for the lens against the PDMS film. As seen from the figure, the uncertainty in the initial contact point may create a large difference between the load and displacement determined strain energy release rate. The question we attempt to answer is whether a multi-lens test, with displacement rather than load measurements, will better match the strain energy release rate calculated from a single lens measurement using displacement values. This process will determine the validity of the multi-lens test as a high-throughput adhesion measurement technique.

In this presentation, multi-lens adhesion tests will be compared to single lens tests to determine the potential for utilizing displacement of the multi-lens array as an experimental variable to quantify strain energy. First, the model PDMS-glass system will be discussed. Second, the comparison will be made for adhesion across more complicated systems such as surface energy gradients and polymers films encompassing a wide range of mechanical properties from glassy to elastic. We intend to provide the guidelines by which the multi-lens adhesion test can be used to measure the work of adhesion when the load on each lens is unavailable.

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5. Certain equipment and instruments or materials are identified in the paper to adequately specify the experimental details. Such identification does not imply recommendation by NIST.