AN INTEGRATED CRACK-OPENING METHOD FOR DETERMINING THE WORK OF FRACTURE OF BONDED POLYMER INTERFACES

Hayden Taylor and Duane Boning
Massachusetts Institute of Technology, USA

ABSTRACT

We describe a non-destructive and inexpensive way of measuring the interface toughness between polymeric layers in microfabricated devices. A flat surface is bonded under pressure to a surface patterned with microscopic steps. When the pressure is removed, cracks develop at the interface as the material peels away from the steps. The toughness of the bond can be inferred from the crack lengths. If the step height is ~1 μm, the cracks are shorter than a millimeter for typical bond toughnesses. Therefore if the substrate is arrayed with recesses, the spatial uniformity of the interface toughness can be assessed.

KEYWORDS: Bonding, polymers, polymethylmethacrylate, interface toughness

INTRODUCTION

The plasma- and UV/ozone-activated bonding of polymeric layers has received widespread attention because it can form a sufficiently tough interface without the use of adhesives and without softening the material and thereby destroying microstructures at the interface. There have been several efforts to characterize interface toughness in relation to the processing parameters used [1, 2]. Yet exhaustive parametric studies remain elusive because present testing methods [*e.g.* 3] are laborious. What is needed is a simple, reliable test for process development and monitoring.

THEORY

If the cover layer is thick, the final length of the crack is approximately inversely proportional to the interface toughness [4]. If, instead, the crack length is more than about twice the cover layer's thickness, the film bends as a plate. Our estimate of the interface toughness is then inversely proportional to the fourth power of the length of the crack (Fig. 1). The applied bonding pressure must be large enough that the crack length obtained after bonding is longer than that during bonding. For thick covers, the required pressure can readily be obtained by numerical modeling; for thin covers, it can be shown that the applied pressure should exceed $4G/3h$, where G is the bond toughness and h the step height.

EXPERIMENTAL

We have used the method to investigate the toughness of a set of polymethylmethacrylate (PMMA) and polycarbonate interfaces. One of each pair of surfaces was hot-embossed with a set of 1.1 μm-deep steps of 4 mm pitch. The surfaces were given a 1-minute oxygen plasma exposure at 500±50 mTorr and bonded under 20 MPa at 80±5 °C. Crack lengths were then measured using an optical microscope.

978-0-9798064-1-4/μTAS2008/$20©2008CBMS

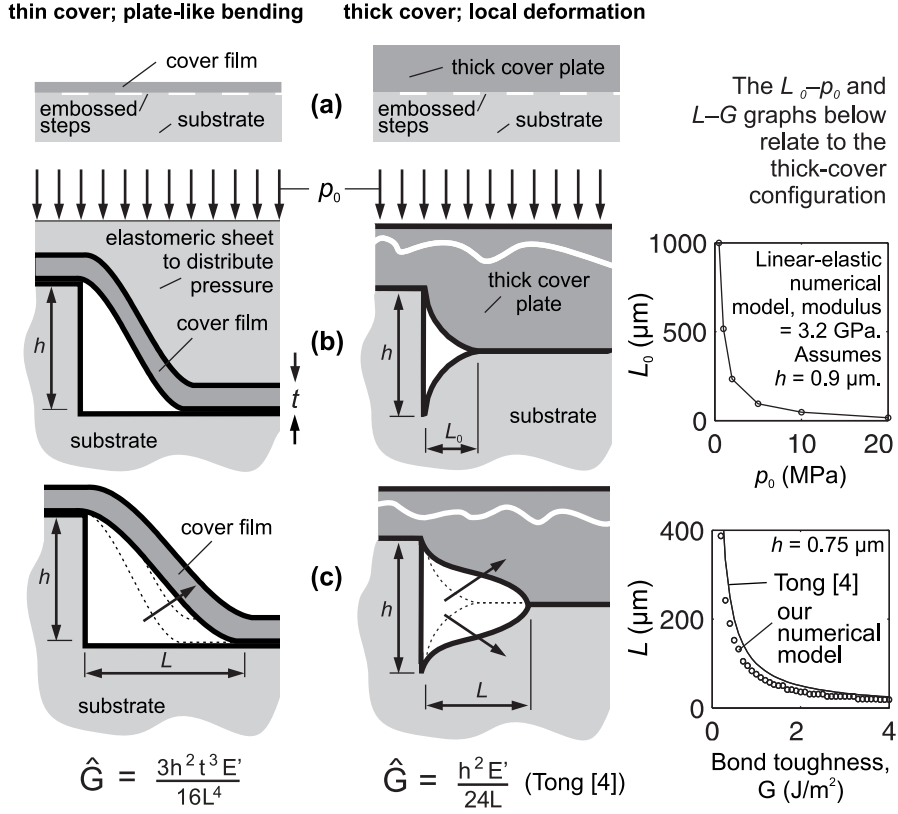

Figure 1. Two test configurations: thin and thick covers. Sample cross-sections (a), configuration during bonding (b), and post-bonding crack growth (c).

RESULTS AND DISCUSSION

The interface toughnesses estimated for PMMA five minutes after bonding were generally in the range 0.5–1.5 J/m^2 (Fig. 2). Plastic deformation of the PMMA layers during bonding was compensated for by delaminating and measuring a sample immediately after bonding (Fig. 3b) and setting the assumed step height, h, to 0.75 μm, the separation of the plastically deformed surfaces without elastic deformation.

The toughness values obtained are in agreement with those obtained using a macroscopic razor-blade test. Sample-to-sample and within-sample crack length variations are substantially larger than can be explained by the measured variation of the heights of the embossed micro-steps, and are therefore attributable to variability of the particular bonding process used.

Crack lengths were observed to grow for at least nine weeks after bonding. Profilometry of the interface steps of a representative sample, delaminated ten weeks after bonding, indicated that the PMMA had flowed so as to relax a portion of the tensile stress at the bonded interface (Fig. 3c). That the cracks continued to grow in spite of this stress relaxation supports a hypothesis of progressive bond weakening.

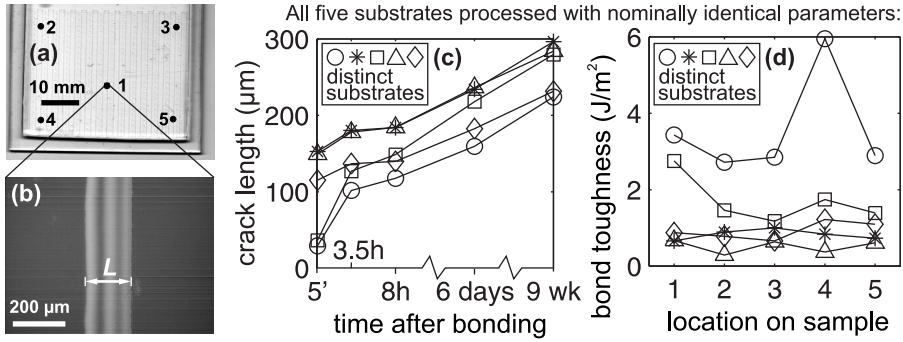

Figure 2. Image of a bonded PMMA sample (a), and a crack (b). Post-bonding crack growth at location 1 on each of five PMMA substrates (c), and bond strengths extracted at five locations on each of five samples immediately after bonding (d).

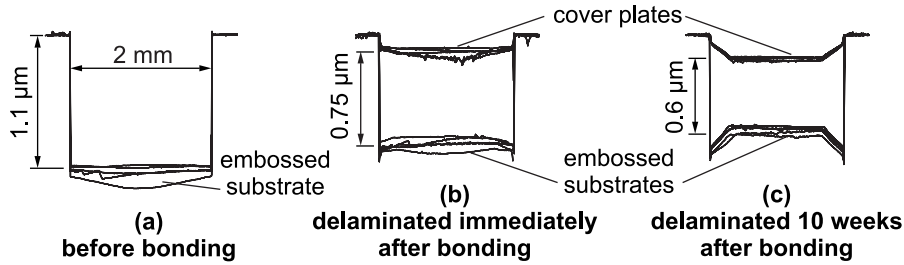

Figure 3. Superimposed topographies of patterned substrates at five step locations. (a) and (b) are the same substrate; (c) is a different but equivalently bonded one.

CONCLUSIONS

The method is an effective way of characterizing and monitoring certain polymer bonding processes, and has been successfully used to estimate plasma-activated PMMA–PMMA bond toughnesses. Results imply a reduction in toughness of the bonds over several weeks. Test sites are sufficiently compact to measure spatial non-uniformity of bond toughness and to be interspersed with manufactured devices.

ACKNOWLEDGEMENTS

We acknowledge funding from the Singapore–MIT Alliance and use of the Microsystems Technology Laboratories at MIT. Helpful discussions with Matthew Dirckx, Aaron Mazzeo, Ivan Reading, and Li Shiguang are acknowledged.

REFERENCES

[1] A. Bhattacharyya and C.M. Klapperich, *Lab on a Chip*, **7**, 876–882 (2007).

[2] C.W. Tsao, L. Hromada, J. Liu, P. Kumar and D.L. DeVoe, *Lab on a Chip*, **7**, 499–505 (2007).

[3] Ö. Vallin, K. Jonsson and U. Lindberg, *Materials Science and Engineering*, **R 50**, 109–165 (2005).

[4] Q.-Y. Tong and U. Gösele, *Semiconductor Wafer Bonding: Science and Technology*, Wiley (1999).