The Reversible Fracture Energy of a Pressure Sensitive Adhesive: Effects of Cycling

Vi Le, Fernando Novoa, Professor Reinhold Dauskardt
Materials Science and Engineering, Stanford University

Introduction

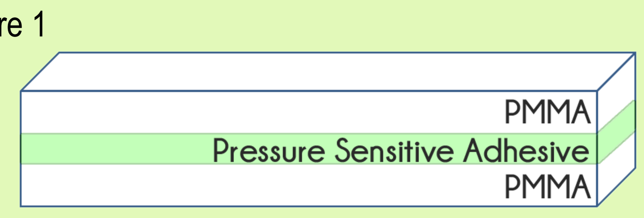
The applications of adhesives that can readhere under pressure, are useful in many fields of study. However, these adhesives lose their initial interfacial fracture energy each time they debond, hindering their practicality. The behavior and mechanisms behind the fracture are currently not known. While extensive research has been done on the fracture energy of various materials, the effects of cycling on pressure sensitive adhesives remain unexplored.
In this study, we determine the fracture energy of the pressure sensitive adhesive over several debonding and bonding cycles. We conducted two types of tests; the double cantilever beam (DCB) test and square cantilever test. After progressive debonding cycles, the fracture energy of the pressure sensitive adhesvie decreased and each progressive crack began at greater crack lengths

Materials & Methods

DCB Test

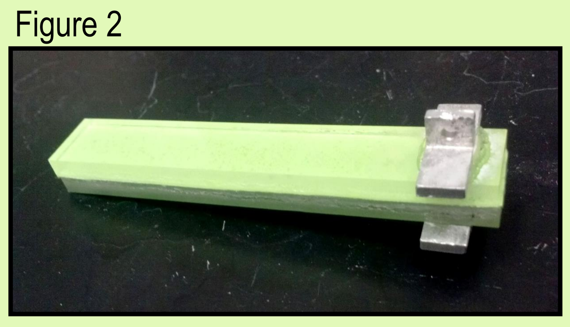
DCB specimens were prepared by placing the pressure sensitive adhesive between two 0.003m polymethyl methacrylate (PMMA) beams, attaching them with a cyanoacrylate (Loctite 495) as shown in Figure 1.

Figure 1



Loading tabs were also attached using this adhesive to both sides of a specimen (Figure 2). The loading tabs were then fixed to a mechanical testing system consisting of a displacement-controlled actuator and a mechanical load cell.

Figure 2



A debonding test using a double cantilever beam (DCB) was conducted on each specimen with a starting velocity of 4 microns/sec. After each test, a clamp was used on the specimen to readhere the pressure sensitive adhesive. Then, another DCB test would be conducted on the same specimen under the same conditions. The process would be repeated until the specimen had undergone at least 7 DCB tests.

Square Cantilever Test

To further explore the behavior of the fracture, we developed the square cantilever test.

The same process as above was used to prepare aluminum substrate specimens (Figure 3), only this time, between two 0.003m by 0.050m by 0.050m aluminum squares.

Figure 3

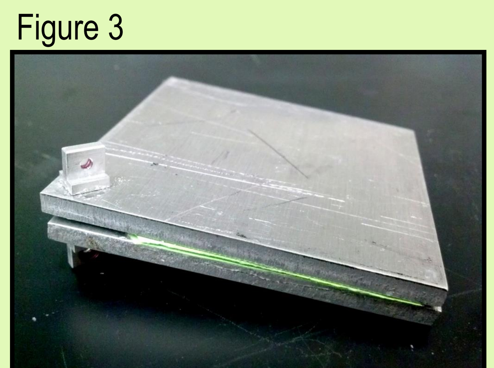
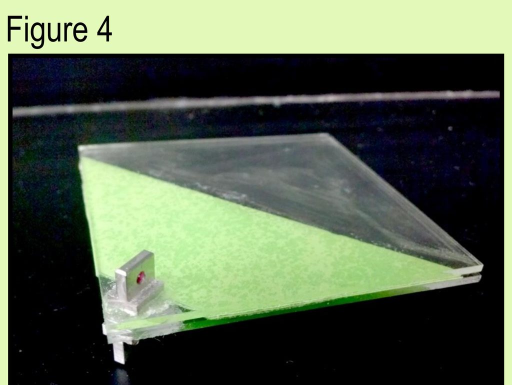


Figure 4



We prepared glass substrate specimens (Figure 4) in the same manner except this time, placing the adhesive between two 0.001m by 0.050m by 0.050m glass squares.

Materials & Methods

In the square specimens, loading tabs were then attached on each side. The loading tabs were then fixed to the same mechanical testing system as the DCB tests.
A debonding test with a square specimen was then conducted on each specimen, applying tension at 10 microns/sec. After each test, a clamp (Figure 5) was used to readhere the pressure sensitive adhesive. Then, we conducted another debonding test the same specimen under the same conditions and repeated the process 7 times.

Figure 5

Calculations

The mechanical compliance of the tensile specimens was measured and calculated with:

$$C = \frac{\triangle x}{\triangle f}$$

where C is the compliance, $\triangle x$ is the change in position, and $\triangle f$ is the change in force.

In order to compare the effects of cycling on the fracture energy, both the fracture energy and crack length were measured and calculated.

For DCB:

$$G = \frac{12\triangle f^2 a^2}{B^2 h^3 E} \qquad a = \sqrt[3]{\frac{CEBh^3}{18}}$$

For Square Cantilever:

$$G = \frac{3\triangle f^2}{Eh^3} \qquad a = \frac{1}{2}\sqrt{\frac{2Eh^3\triangle x}{\triangle f}}$$

Where, $\triangle f$ is the change in force, a is the crack length, h is the thickness of the substrate, B is the width of the substrate, E is the Young's Modulus of the substrate, C is the compliance, and $\triangle x$ is the change in position.

Results

Figure 6

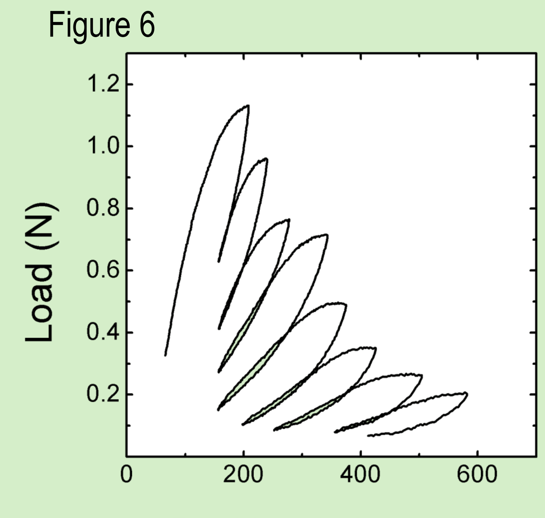


Figure 6: Position (microns) vs. Load (N) of a DCB test of a specimen with PMMA substrates on the first cycle.

Figure 7

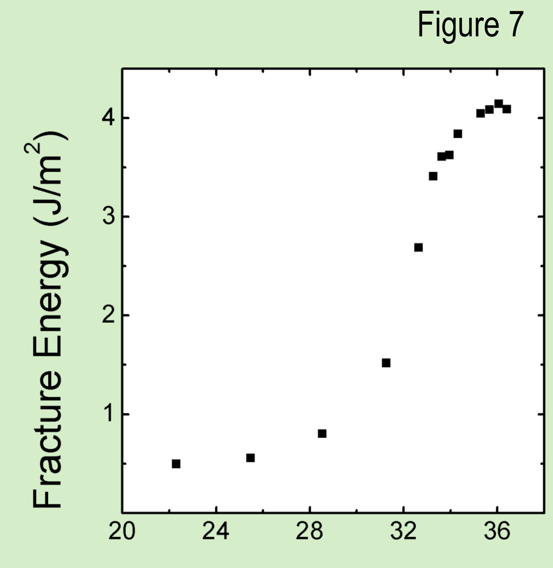


Figure 7: Crack Length (mm) vs. Fracture energy (J/m^2) of a DCB test of a specimen with PMMA substrates on the first cycle.

Figure 8

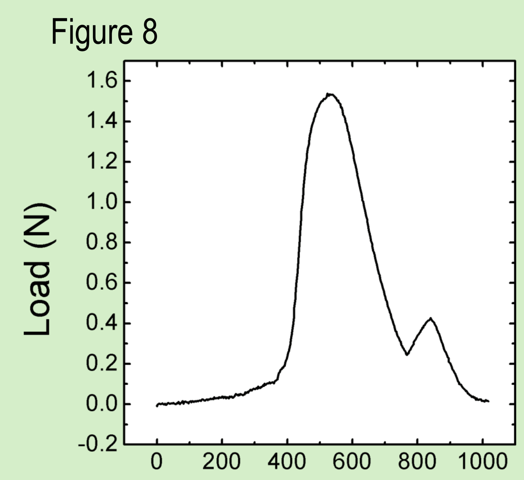


Figure 8: Position (microns) vs. Load (N) of a square cantilever test of a glass substrate specimen on the first cycle.

Results

The fracture energy of the pressure-sensitive adhesive decreases after each bond-debond cycle. The start of the resistance curve (inflection point) occurs at progressively longer crack-lengths after each debond cycle.

Figure 9

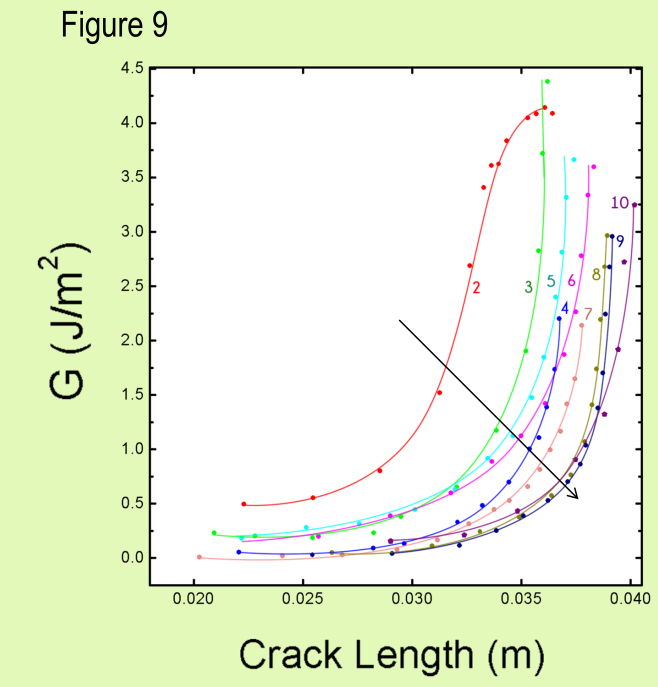


Figure 9: Crack Length (m) vs. Fracture Energy (J/m^2) for a DCB specimen from cycles 2 to 10.

Figure 10

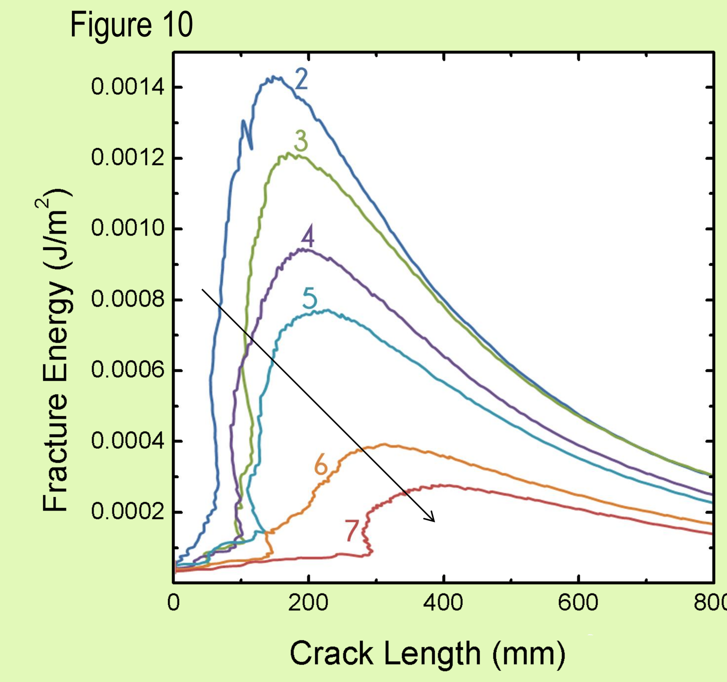


Figure 10: Crack Length (m) vs. Fracture Energy (J/m^2) for an aluminum substrate specimen from cycles 2-7.

Conclusion

-Two methods were developed to determine the fracture energy of the pressure sensitive adhesive; the DCB and the square cantilever test.
-After undergoing progressive debonding and bonding cycles, the fracture energy of the pressure sensitive adhesive exhibited a downward trend and began to crack at larger crack lengths each time.
-This study establishes a method in which pressure sensitive adhesives can be tested to further research the behavior of fracture energy.

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