

SELF-HEALING IN THIN POLYMER MEMBRANES

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ABSTRACT

As man's curiosity for deep space exploration increases, so does the demand for long duration space systems. To be able to explore deeper into space, a system is required in which little or no fuel is required for propulsion. Solar sails meet this challenge by using solar photon momentum exchange for propulsion. Solar sails are large gossamer structures spanning as long as three football fields in width and length, but only microns in thickness. The main photon catching structure is constructed of thin polymeric membranes, which are quite susceptible to damage. Direct human repair of the damage is nearly impossible in deep space, and therefore a system that is able to repair itself (self-heal) is essential. We describe such a system in this paper. Other applications for similar self-healing include flex circuits, thermal control membranes, and other structural polymers (see companion paper [1]).

In order to analyze the effects of self-healing of thin polymeric membranes, an ultrasonic transducer was used (Branson Sonifier 450, 400W, 20 kHz). The idea behind the transducer is two-fold [2]. Firstly, ultrasonic flaw detection is a mature technology. A signal is transmitted and then received by the transducer and the presence of a crack or flaw can be determined. Secondly, if a flaw is present within the material, a high frequency signal can be sent out to locally heal the area around the damaged area using time-reversed acoustics [3]. The transducer initiates a thermal process that, in the membranes studied here, resulted in a hole formation near the crack (tear) tip. The hole provided significant healing through crack-tip blunting.

In this study, single edge-notched tensile (SENT) specimens were created from 25.4 μm (1 mil), 50.8 μm (2 mil), and 76.2 μm (3 mil) thick metalized Mylar. Specimen geometry included a gauge length Z of 127 mm (5.0 in.), specimen width W of 25.4 mm (1.0 in.), and crack length a of 3.175 mm (0.125 in.), (see Figure 1). Holes were formed with the ultrasonic transducer, and hole placement e was varied from directly at the crack tip ($e = 0$ mm) to the center of the specimen ($e = 6.35$ mm) to investigate probe placement accuracy. (For comparison, holes were also created using a circular hole

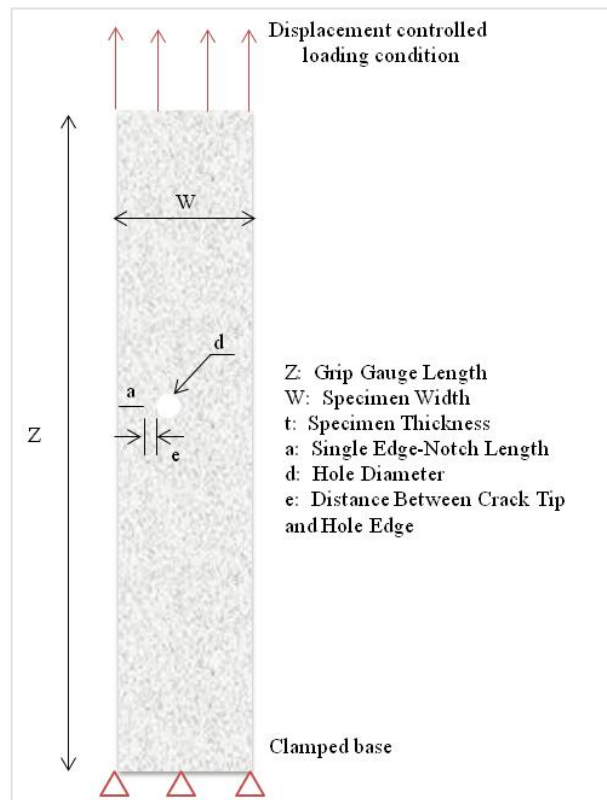


Figure 1: SENT Specimen Layout

punch, but these results are reported elsewhere [4]). Specimens were then tested until failure using a 5543 Instron in uni-axial tension tests.

Load vs. displacement graphs were constructed from the raw data for each test, as seen in Figure 2. Figure 2 shows the results for all three thicknesses of Mylar for unhealed specimens (dotted line), healed specimens with $e = 0$ mm (dashed line), and healed specimens with $e = 6.35$ mm (solid line). Using numerical integration, the area under the curves were determined to give the energy required to tear the material. Energy values were compared between ultrasonic healed SENT specimens and unhealed SENT specimens.

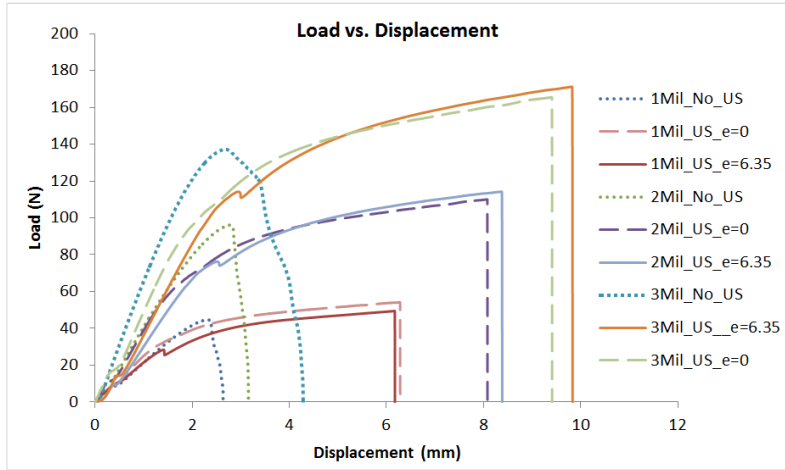


Figure 2: Load vs. Displacement Graphs for 25.4 μm , 50.8 μm , and 76.2 μm Mylar with and without Ultrasonic Healing

As seen in Figure 2, the placement of the hole did not significantly affect the overall energy required to tear the specimen. By blunting the area around the crack tip using the ultrasonic transducer, the energy required to tear the Mylar is dramatically increased (as seen in Table 1), showing the ability of self-healing in thin polymer membranes. (Even larger increases were observed with the circular hole punch specimens [4]). The holes for both ultrasonic and hole punch specimens were viewed under a microscope to observe the surface morphology [4].

Table 1: Summarized Results for Ultrasonic (US) Healing for 25.4 μm , 50.8 μm , and 76.2 μm Mylar

| | No US | US ($e = 0\text{mm}$) | US ($e = 6.35\text{ mm}$) | % Increase with US |
|-----------------------------------------------------------------------|-------|----------------------------|--------------------------------|-----------------------|
| Fracture Energy for 25.4 μm Specimen (J) | 0.068 | 0.224 | 0.230 | 328% |
| Fracture Energy for 50.8 μm Specimen (J) | 0.168 | 0.665 | 0.660 | 396% |
| Fracture Energy for 76.2 μm Specimen (J) | 0.361 | 1.155 | 1.149 | 320% |

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