HEALING OF THERMOPLASTIC STRUCTURAL COMPONENTS

V. S. Francischetti[1], D. L. Zignego[1], and C. H. Jenkins[2]

[1]Graduate Research Assistant
[2]Professor and Head
Mechanical and Industrial Engineering, Montana State University, 220 Roberts Hall, PO BOX 173800, Bozeman, MT.
Email: cjenkins@me.montana.edu

Keywords: Self-healing, Ultrasonic, Thermoplastic, Bio Inspired, Four Point Bend Testing

ABSTRACT

By and large, all healing in nature is associated with generation of new material. Material generation, one way or the other, requires external energy input. Hence, healing in nature is an active process, one that can be intrinsic (autonomous) or conscious (semi-autonomous).

We propose that ultrasonics can form the basis of a damage detection and healing system that takes inspiration from the systems level approach that biology takes to healing wounds in living organisms. Ultrasonic inspection has been well established as a method of nondestructive damage detection [1]. Healing with ultrasonics is realized through focusing ultrasonic energy into the damage site, which results in a thermal process that occurs in the vicinity of the damaged area [1-3].

In our work, we used a high powered (Branson Sonifier 450, 400W, 20 kHz) ultrasonic slurry mixer to introduce a large amount of ultrasonic energy into the immediate vicinity of the damaged area of our polymer samples. The appropriate power level and application time for healing specimens is highly dependent on the type of thermoplastic being used. Tests were conducted on Nylon 66, PVC, Acrylic, and Polycarbonate. Polycarbonate provided the best results due to a combination of material properties, damageability, and response to ultrasonic healing.

A four point bend test was developed to test crack propagation and failure. ASTM 6272-02 (method for determining the flexural properties of plastics) was used as a reference for apparatus configuration, and displacement rates. Finite element modeling was used to guide crack placement, and crack orientation, so that the tough polymer specimens would fail within the available stroke of the Instron 5543 test machine (see [4] for details).

The specimens were a rectangular beam cross section with a width of 25.4 mm (1.00 in), a length of 210 mm (8.25 in), and a depth of 9.53mm (0.375 in). A razor cut 1.27 mm (0.050 in) deep was imparted to the bottom of the beam, where the crack would propagate in mode one during the course of the bending. Testing of the polycarbonate revealed that, when damaged with a razor cut, the samples were able to withstand an average of 6.69% strain. The crack in the samples initially propagated in a ductile manner, but after a certain amount of crack propagation brittle failure occurs.

With sufficient amount of ultrasonic treatment to the damage location, the healed samples outperform the damaged samples in general by a minimum of 12% increase in maximum strain to failure, compared to the average strain to failure of the damaged but unhealed samples see **Figure 1**. In fact, a majority of the healed specimens did not fail within the available stroke of the Instron, although every damaged but unhealed specimen failed.

[If the ultrasonic treatment is too light the samples fail in a brittle manner. This is most likely due to an ineffective layer of melted material closing the crack, which suddenly fails, causing a rapid transfer of strain to the crack tip and resulting in rapid crack extension and ultimately sample failure. This can be seen in two of the samples in **Figure 1** (PCNRCUS4 and PCNRCUS5).]

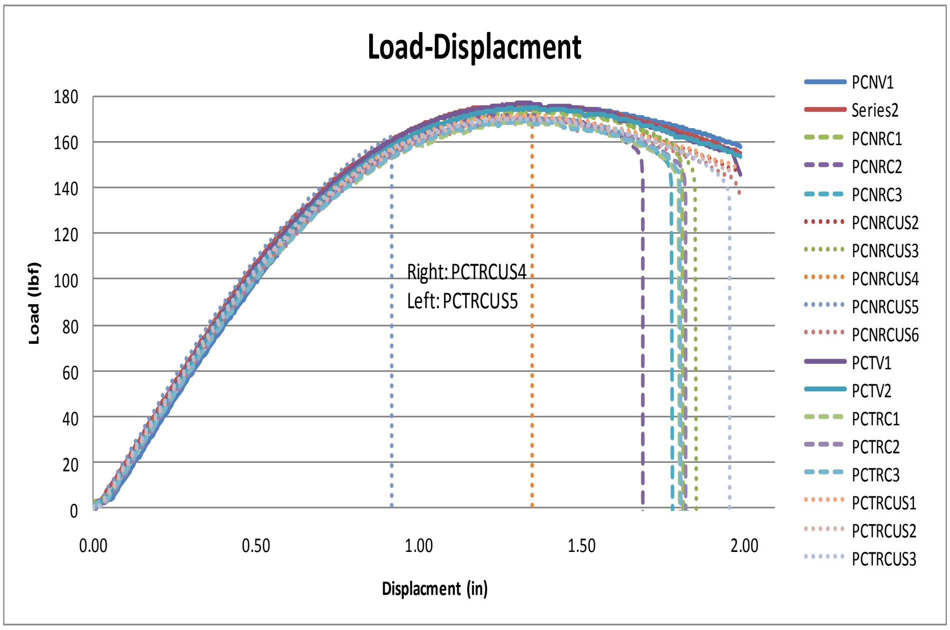

Figure 1: Results of four point bend testing of polycarbonate samples. Virgin samples are indicated by a solid line, damaged samples are denoted by a dashed line, and healed samples are dotted lines.

Comparing failure surfaces of the damaged samples and the healed samples clearly shows that healed samples have material bridging the razor cut, this material bridging the crack results in an increased performance of the samples. Images of the damages and healed surfaces can be seen in **Figure 2.**

Initial testing was promising with the vast majority of healed samples outperforming the damaged samples in strain to failure criteria, and in many cases matching the performance of the virgin specimens. Research is continuing to improve the ultrasonic healing process and increase the level of damage so that failure of healed specimens occurs within the test machine limits [4].

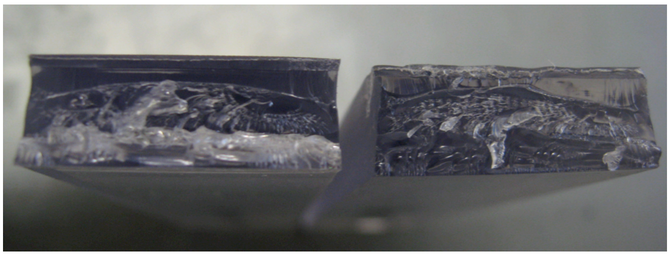

Figure 2: Failure surfaces of polycarbonate specimens. Left: Unhealed specimen with clean razor cut on the top of the sample. Right: Ultrasonically healed specimen, where the razor cut is no longer clean because the material has melted and bridged the damaged section.

REFERENCES

[1] Fink, M., 1999, "Time-reversed acoustics," Scientific American, 281(5), p. 91(97).
[2] Sarrazin, J. C., Tortop, R., Francischetti, V. S., Jenkins, C. H., and Rutherford, S. A., 2009, "Ultrasonic Self-Healing of Polymers," 2nd Int. Conf. Self-Healing Materials-ICSHM 2009Chicago, IL.
[3] Zignego, D. L., Francischetti, V. S., and Jenkins, C. H., 2011, "Thin Polymer Fracture Mechanics and Healing with Ultrasonics," 3rd Int. Conf. Self Healing Materials-ICSHM2011Bristol, UK.
[4] Francischetti, V. S., 2011, "Healing of Thermoplastic Structural Components," Masters of Science, Montana State University, Bozeman.