DYNAMIC TEMPERATURE MEASUREMENTS ON A THERMALLY ACTIVATED SELF-HEALING IONOMER

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ABSTRACT

The material investigated in this study is poly(ethylene-co-methacrylic acid) which has some of its acid groups neutralized with sodium. This polymer is also known as Surlyn® 8940 from DuPont and belongs to the group of ionomers. It is able to self-heal the damage caused by an impacting projectile [1, 2] if the impact velocity lies within a certain range [3]. The self-healing ability of this polymer is the result of a favorable combination of mechanical and thermal material properties. After the projectile has penetrated the polymer sheet, the petals formed during impact fold back elastically and close the hole. Afterwards, the cracks are sealed by the molten material around the impact point [4].

A temperature increase in the polymer is necessary for successful self-healing. By now, it is only known that during the impact process the material is heated up to a temperature around its melting point at 94°C [4], but nothing is known about the origin of this heating. There are several processes that could be responsible for this. Those can be divided into two classes: intrinsic processes related to the thermal material behavior (plastic and viscous dissipation, reversible processes connected to the entropy), and extrinsic processes related to the interaction of the material with the projectile (friction, projectile temperature).

To get a first idea of the contribution of the intrinsic processes to the heating of the polymer, its temperature at different positions has been measured during dynamic puncture tests at room temperature using embedded thermocouples. The experimental setup is shown in Figure 1. An impactor, with a shape similar to the projectiles used in ballistic impact tests and a maximum diameter of 5.6 mm, was pushed through a polymer sheet (thickness 1.3 mm) with a constant speed of 1 m/s. These tests had a duration of about 20 ms. This is much slower than a ballistic impact at 300 m/s which takes place in about 60 µs. But it is still fast enough to ensure adiabatic test conditions due to the low thermal conductivity of the polymer.

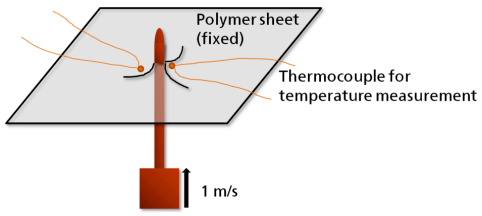

Figure 1: Experimental setup for dynamic puncture tests with temperature measurements.

The temperature was measured using type E thermocouples with wires of 130 µm in diameter. Those extremely thin thermocouples still have a response time (determined using thermal finite element simulations) which is of the order of magnitude of the test duration. Therefore, deconvolution was used to reconstruct the true temperature-time signal from the measured data. Three of those thermocouples had been embedded in the polymer sheet at different distances from the impact point:

0 mm, 1.5 mm, and 3 mm. The temperature increase that was measured by the embedded thermocouples was almost solely caused by intrinsic processes. Any heating through friction or cooling through contact with the surrounding air can be neglected during the duration of the test as a result of the low thermal conductivity of the polymer.

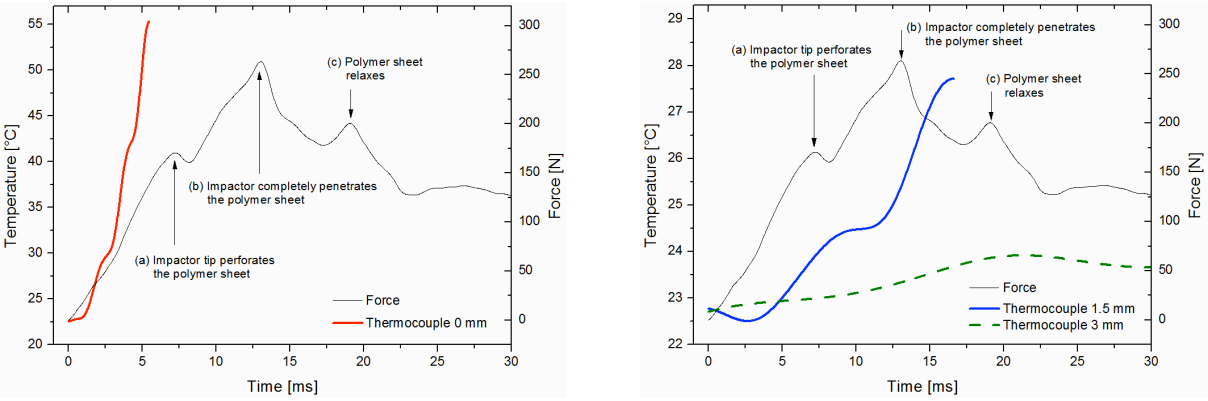

Figure 2: Force-time curve (thin black line) and temperature-time curves for the thermocouple at 0 mm (left, red solid line), 1.5 mm (right, blue solid line) and 3 mm (right, green broken line) distance.

The measured temperatures and the force during a puncture test are shown in Figure 2. The left diagram shows the temperature increase at 0 mm distance from the impact point and the right diagram the results at 1.5 mm and 3 mm. Three relevant points are marked on the force-time curve: (a) the time when the first crack occurs when the tip of the impactor perforates the polymer sheet. (b) The time the impactor penetrates the sheet with its full thickness, and (c) the time the polymer sheet relaxes. The two thermocouples at 0 mm and 1.5 mm separate from the polymer sheet at around 6 ms (close to point (a)) and 17 ms, respectively, as the crack propagates in the sheet. The maximum temperature increase from 23°C to 55°C is registered at 0 mm distance from the impact point. An extrapolation up to point (a) yields a maximum temperature of around 70°C. Further away from the impact point, much lower temperatures of 28°C and 24°C, respectively, occur.

These measurements show that the intrinsic processes close to the impact point cause a temperature increase which is almost high enough to reach the melting point of the polymer. The higher strain rates, which occur during a ballistic impact, result in more viscous dissipation which causes even higher temperatures. Therefore, the intrinsic processes alone are presumably responsible for the heating of the material necessary for self-healing.

REFERENCES

[1] R. Fall, Puncture Reversal of Ethylene Ionomers – Mechanistic Studies (Master Thesis), 2001, Virginia Polytechnic Institute and State University.

[2] R. J. Varley and S. van der Zwaag, Autonomous damage initiated healing in a thermo-responsive ionomer, *Polymer International,* **59**, 2010, pp. 1031-1038.

[3] T. Haase, I. Rohr and K. Thoma, Investigation of the self-healing behavior of an ionomer at projectile velocities up to 6 km/s, *19th DYMAT Technical Meeting: Dynamic mechanical behaviour of Polymers and Composites, Strasbourg, France, December 1-3, 2010,* pp. 71-75.

[4] S. J. Kalista and T. C. Ward, Thermal characteristics of the self-healing response in poly(ethylene-co-methacrylic acid) copolymers, *Journal of the Royal Society Interface,* **4**, 2007, 405-411.