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Image-Based Thermal and Mechanical Analysis of Polymers

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Abstract

In recent years, application of polymers have rapidly expanded across industries due to their versatility, cost-effectiveness, and adaptability to diverse manufacturing techniques, including 3D printing. Innovations in PolyJet technology enable the creation of complex geometries with tailored color combinations, transparency, and flexibility, broadening applications in medical, aerospace, and automotive sectors. Advances in processing viscoelastic rubbers like PDMS (Polydimethylsiloxane) have further enhanced its mechanical properties, expanding its use in biomedical devices and electronic components. However, polymers are susceptible to complex deformation and failure under thermal and mechanical stresses, which can impact their performance and safety. This research examines the thermal behavior of photopolymers under infrared laser exposure and investigates the mechanical properties of PDMS when influenced by defects of various sizes.

The first part of the study develops a computational heat transfer model to analyze temperature profiles and heat distribution in thin samples. Realistic boundary conditions are applied to the sample surfaces, including a spatially varying convection coefficient. Two digital materials are examined: Vero Black, a rigid material, and Agilus Black, a tear-resistant rubber-like material. Model results align well with experimental data, showing that as sample thickness increases, peak temperatures also rise, but steady state takes longer to achieve. Additionally, thicker samples exhibit a more dispersed radial heat distribution.

The second part of this study investigates the mechanical behavior of PDMS samples with five types of defects, each designed with a decreasing magnitude of theoretical stress concentration. The defects vary in size and orientation, including both horizontal and vertical elliptical shapes. Defective samples were compared to a non-defective control, and tensile tests were recorded with a high-speed camera for Digital Image Correlation analysis. Although theoretical predictions suggested a specific failure order, the experimental results did not follow this pattern due to the presence of crack blunting and mixed mode failure mechanisms.