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PROCEEDINGS

4D Printed Shape Memory Polymer Behavior Simulation and Validation

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ABSTRACT

Shape memory polymers (SMP) have many applications as actuators in soft robotics. However, predicting their shape change behavior is challenging, which makes designing suitable actuators difficult. For thermally stimulated shape memory polymers, constitutive models of shape change behavior show promise in enabling predictable shape changes, which is necessary for actuator design. These models are usually classified as either rheological or phase transition, with the former being more general, although non-physical in nature, and the latter being more physically significant [1]. Of interest in this work is 2-state shape change transitions for single-material actuators; that is, actuators that switch between two different shapes repeatedly. This scenario requires training to which both types of models can be applied.

Rheological models were chosen for this work due to their generality and relative ease with which relevant material properties can be measured. These SMP models include a viscosity coefficient to account for time and temperature dependence and can describe creep, relaxation, and rate dependence mechanical behaviors [1]. Conceptually, they utilize springs and dashpots to capture their effective viscoelastic properties and vary in their configurations to account for SMP deformation storage and recovery with temperature fluctuations. SMPs exhibit reversible phase transitions with temperature variations described by, e.g. Prony series with the Williams-Landel-Ferry (WLF) equation to reflect time and temperature dependencies [2]. Although suffering from lacking physical significance, these models remain valuable to describe and predict shape changes, as evidenced by previous research.

In this work, the authors propose a rheological model of 3D printed PLA (PolyLactic Acid), a common thermoplastic in 3D printing. The engineering analysis code Abaqus was used to implement the rheological model using the generalized Maxwell model and the WLF equation. By 3D printing PLA samples, characterization experiments were performed to determine important material properties needed for the constitutive model. The characterized property values were entered into the Abaqus material model and used to simulate the training and actuation behaviors of several test specimens. First, a rectangular beam model was trained by twisting it 360 degrees. The shape memory recovery motion of untwisting was simulated, and the recovery motions matched well with literature results [2]. Second, a rectangular beam model was subject to bending of 130 degrees; again, training and recovery motions were simulated. Third, a living (film) hinge between two plates was folded by 180 degrees, to test hinge designs for origami mechanisms. Finally, an origami mechanism with 8 plates and living hinges was simulated and tested. Validation experiments with printed PLA samples demonstrated good agreement between simulations and experimentally tested motions.

KEYWORDS

4D printing; shape memory polymer; rheological model; origami mechanism

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