Predictive Modelling of Fast-curing Thermosets in Nozzle-based Extrusion

IMECE Topic 12-22: Mechanics of Soft Materials

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Abstract

This work presents an approach to modeling the dynamic spreading and curing behavior of thermosets in nozzle-based extrusions. Thermosets cover a wide range of materials, some of which permit low-temperature processing with subsequent high-temperature and high-strength working properties. Extruding thermosets may overcome the limited working temperatures and strengths of conventional thermoplastic materials used in additive manufacturing. This project aims to produce technology for the fabrication of thermoset-based structures leveraging advances made in nozzle-based extrusion, such as fused deposition modeling (FDM), material jetting, and direct writing. Understanding the synergistic interactions between spreading and fast curing of extruded thermosetting materials will provide essential insights for applications that require accurate dimensional controls, such as additive manufacturing [1], [2] and centrifugal coating/forming [3].

Two types of thermally curing thermosets -- one being a soft silicone (Ecoflex 0050) and the other being a toughened epoxy (G/Flex) -- served as the test materials in this work to obtain models for cure kinetics and viscosity. The developed models align with extensive measurements made with differential scanning calorimetry (DSC) and rheology. DSC monitors the change in the heat of reaction, which reflects the rate and degree of cure at different crosslinking stages. Rheology measures the change in complex viscosity, shear moduli, yield stress, and other properties dictated by chemical composition. By combining DSC and rheological measurements, it is possible to establish a set of models profiling the cure kinetics and chemorheology without prior knowledge of chemical composition, which is usually necessary for sophisticated mechanistic modeling. In this work, we conducted both isothermal and dynamic measurements with both DSC and rheology. With the developed models, numerical simulations yielded predictions of diameter and height of droplets, along with width and height of extruded lines cured at varied temperatures. Experimental results carried out on a goniometric platform and a nozzle-based 3D printer showed agreement with the numerical simulations. Finally, this presentation will show how the models are adaptable to the planning of tool paths and designs in additive manufacturing.

This abstract is intended for the 3D-Printed Soft Materials session

Reference

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[3] A. D. Mazzeo and D. E. Hardt, “Centrifugal Casting of Microfluidic Components With PDMS,” *J. Micro Nano-Manufacturing*, vol. 1, no. 2, pp. 021001–021001, Apr. 2013.