Detailed finite element analysis of FDM printing for predicting residual stresses and bond strength

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ABSTRACT

Fused deposition modeling, or FDM printing, is widely used within additive manufacturing due to its wide availability, relatively low cost and ease of use. It is therefore increasingy applied in 4D printing, as an alternative to PolyJet printing. Due to the heat-driven nature of FDM printing, researchers are presented with new challenges in 4D printing of shape memory polymers. The repetitive heating and cooling cycles which occur during FDM printing are known to result in non-uniform thermal gradients which lead to residual stresses in printed specimens [2]. This effect can lead to distortion and warping of printed parts. In the case of shape memory polymers, the material undergoes thermo-mechanical programming during the printing process. The stored residual stresses will be released as soon as the material is heated above the glass transition temperature. [1] used this mechanism to program the preferred shape memory effect while printing, avoiding a post-printing thermo-mechanical programming cycle.

Thus, understanding the nature of the development of these residual stresses and being able to predict them, is not only crucial to repetitively print parts of high quality, but it is also important to enable in-situ thermo-mechanical programming of a predefined shape memory effect. Numerical simuation of the heat transfer process which occurs during FDM printing with a focus on the influence of the mesostructure discretization, can lead to such understanding. Several studies have simulated the FDM printing process numerically to gain more understanding of the complex physical phenomena which occur during and after printing in order to predict part distortion [2, 3] and to predict bond srength between the filaments [4]. In these models, heat transfer during printing was computed through finite element analysis with element activation for simulating the material deposition from the heated nozzle. Even though this approach showed great potential, the results were not sufficiently accurate. A reason for this is the fact that the material was modeled as a continuum without representing the characteristic mesostructure and the inherent voids, which affect the heat transfer in the material. In this work, we perform heat transfer simulations, precisely resolving the mesostructure by discretizing both the filament material and the (air-filled) voids. This approach results in accurate computations of the temperature distribution and, thus, accurate predictions of residual stresses and bond strength of the filament.

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