Validation of the constitutive model for 3D printed shape memory polymers

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Abstract

Shape memory materials are smart materials characterized by the ability to return from a deformed (temporary) state to their original (permanent) shape when induced by an external stimulus. Triggers for shape recovery include heat, hydration, magnetic fields, or light. Because of this feature, one such alloy, nickel-titanium alloy (NiTi, nitinol), is used as a base material for a variety of medical devices, such as flow diverters, stents, catheters, wires connecting the teeth and many more.
With the recent advancement of biocompatible shape memory polymers, their applicability in the field of medical technology industry is increasing. While mechanical properties of metals and metal alloys are generally considered better compared to polymers, a significant difference in stiffness between soft tissue and metals can lead to various medical complications. Additionally, most shape memory polymers (SMPs) can be easily 3D printed, whereas such additive manufacturing for nitinol is still challenging (1).

Stereolithography (SLA) is a 3D printing technology that uses a light source to cure liquid resins. Given the very high printing precision, this technology can be used to print small parts, e.g. stents with a strut thickness of about 0.1 mm. This approach enables the creation of patient-specific stents tailored to follow the unique curvature of individual arteries and atherosclerotic plaque. Furthermore, self-expanding stents (made from shape memory materials) have been shown to reduce the risk of restenosis compared to balloon-expanding stents (2).

The aim of this work is to ensure the accuracy of the constitutive model for chosen biocompatible shape memory polymers (SMPs) so that they can later be used for numerical analysis of carotid stents. Thus, we conducted uniaxial tests for the selected biocompatible SMPs at different strain rates. Based on the experimental results, the optimal material model was chosen and associated material parameters determined. This constitutive model was verified on mesh plates with the cell shapes that can be used for stents. The plates were 0.1 mm thick, and several cell shapes were used for the mesh. Cell shapes, size, and cell density were chosen based on ability of such stent to narrow the cross section during elongation sufficiently for stent implementation in carotid artery, as well as on the preliminary numerical estimation of medical efficiency of such stent.

For each mesh plate, stresses and displacements in the plate were computed numerically for both uniaxial and biaxial loading. These results were compared to experimentally obtained results. Displacements were measured at several points on the plate; however, note

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that for mesh plates stresses cannot be experimentally assessed.

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