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SELF-REGULATING ELASTOMERIC TUBES: AN EXPERIMENTAL AND ABAQUS-BASED STUDY

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ABSTRACT

Complexes of elastomeric and fibrous materials are well-documented for their distinctive material properties, such as the ‘J-shaped’ stress-strain curve: at low strains, the soft and compliant base elastomeric material dominates the material response, while at higher strains, the fibers provide a strong strain-stiffening effect. These behaviors are often biomimetic – for example, human aorta displays a similar ‘J-shaped’ stress-strain curve and may be thought of as a reliable elastomeric (elastin) tube with helically oriented ‘families’ of stiff fibers (collagen) in its outermost layers that passively initiate strain-stiffening to prevent aneurysm at high pressures. Synthetic, aorta-inspired elastomeric tubes with fibrous reinforcement were originally hypothesized for use in ex-vivo heart perfusion devices (an innovative technology in which a donor heart is kept alive and beating outside the human body), but their applicability has since been recognized to be far more diverse. Here, we present a design for RTV silicone elastomer tubes jacketed by a ‘free-standing’ (adhesive-free) sleeve of knitted fabric. We used a custom-built flow loop to pump fluid into sections of compliant tubing at known pressures and measured the deformation response. Our main finding was that the jacketed tubes deform rapidly as pressure initially increases, but eventually display ‘self-regulation’ behavior where their continued distension is tempered by the stiffening of fibers in the fabric; this is in marked contrast to pure elastomer tubes without fibrous reinforcement, which experience severe asymmetric distension at much lower pressure magnitudes. Additionally, 3-dimensional finite element simulations were developed in ABAQUS using material coefficients obtained from uniaxial tensile tests of the tubing materials and were highly successful in predicting distensions of all tested tubes over the entire pressure range. Ultimately, the experimental results illustrate a highly useful property of fabric-jacketed elastomer tubing, while our established simulation methodologies offer a versatile pathway to predicting deformation behavior in more complex contexts (i.e. fabric jackets with cut relief patterns). The applications of the self-regulating compliant tubes are widespread; they can be essential in biomedical ‘exomuscles’, compression garments, and soft robotic actuators for a variety of industrial purposes.

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