Nonlinear Fiber Reinforced Membranes with Activated Fibers

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Materials reinforced with activated fibers are ubiquitous. In biological systems, active muscle fibers in soft tissues exhibit the ability to contract and relax when they are subjected to biochemical signals [1]. Engineered fibers such as azobenzene - a photoresponsive material - change their stress free or natural reference length in response to ultraviolet light [2,3]. This work focuses on the mechanics of a plane annular membrane formed from a homogenous incompressible nonlinear elastic material reinforced by an axisymmetric distribution of activated fibers lying in a plane parallel to the mid surface [4-7]. The lengths of these fibers can be triggered to change by non-mechanical influences such as changes in temperature or radiation from an ultraviolet light source [2,3]. Each fiber has the shape of a plane spiral curve that extends from the inner to the outer radius [6,7]. The membrane is attached to a rigid circular disc at the inner boundary. Boundary value problems that combine twist with radial expansion are formulated and solved analytically. Corresponding finite element models are also developed. Results show that the contraction of the spiral fibers will lead to a shape change, a shearing deformation within the membrane, and a distribution of shear stresses. The resulting shear deformation may cause a principal stress to become negative indicating wrinkling. We consider conditions where wrinkling may be avoided by imposing a radial prestretch. We also investigate the regimes of instability due to the compressive stress in the membrane using finite element methods. Such understanding is critical to multiple applications including designing soft robotic devices that can be actuated by active fibers and biomechanical modeling of biological phenomena such as vasoconstriction and vasodilation in blood vessels.

References:

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