ABSTRACT

In contemporary engineering practice, membrane structures are widely used in applications such as inflatable space habitats, aerostats, and tunnel sealing because of their lightweight nature and ease of deployment. However, these structures undergo large deformations, creating challenges in stress control and structural health monitoring. This research focuses on developing finite element models of membrane structures incorporating cable stiffeners to reduce stress accumulation. It also aims to develop and characterize strain-sensing materials suitable for such structures and to simulate their behavior.

Finite element modeling of cable-stiffened membranes was performed using the updated Lagrangian method. For inflatable structures, the inclusion of cable stiffeners effectively controlled the inflation process and minimized stress buildup. Textile-based strain-sensing materials were fabricated using a bar coating technique with polyester knitted fabric, carbon nanotubes, and polydimethylsiloxane. The polyester fabric served as the base, carbon nanotubes as conductive fillers, and polydimethylsiloxane as the matrix material.

Piezoresistive characterization showed that the textile base increased composite stiffness, which is undesirable for sensing applications. The electrical response was also time-dependent. Although this behavior was initially considered due to inherent electrical components within the nanostructure, further numerical and experimental studies revealed that viscoelastic effects play the dominant role in governing the time-dependent electrical response.

Subsequent finite element simulations were conducted on strain-sensing materials without the fabric base. Incorporating viscoelastic behavior under large deformation using a total Lagrangian formulation, the analysis demonstrated that the developed materials can detect instantaneous responses at very low strain rates, below 1% strain per minute.