Piezoelectric Composite Sensors for Artificial Arteries: Toward Realistic Simulation of Vascular Mechanics

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Abstract

Flexible sensors have gained significant interest in the biomedical field due to their potential for application in medical diagnostics, human health monitoring, and artificial organ systems (1, 2). Their unique ability to adapt to complex geometries and respond to dynamic mechanical stimuli offers a critical tool for accurately monitoring and replicating physiological conditions. This feature is crucial in medical simulation and therapeutic devices, where precise detection of mechanical deformations contributes significantly in understanding organ function and optimizing medical device performances.
In this context, this study aims to develop piezoelectric flexible sensors made of silicone matrix (polydimethylsiloxane, PDMS) filled with ceramic particles (Barium Titanate, $BaTiO3$). The obtained piezoelectric composites are engineered to be integrated into an experimental vascular network model, allowing advanced monitoring of mechanical deformations in artificial arteries designed with unfilled silicone matrix (3). Combining the inherent flexibility of silicone with the piezoelectric response of ceramic fillers, these sensors are expected to enhance the detection of mechanical deformations within artificial arteries as well as the additional stress applied by the deployment of a medical device, such as vascular stents.

To achieve an optimized piezoelectric sensitivity and still be able to maintain a mechanical behavior comparable to that of human arteries, several processing parameters were investigated. These include the ceramic filler content, the configuration of particles (random or oriented), and the curing conditions (temperature and duration) (4). This investigation revealed that processing parameters significantly influence the composite's mechanical properties, with the incorporation of BaTiO notably enhancing the piezoelectric performance yet substantially altering the material's mechanical response. For the unfilled silicone matrix, modifying the curing temperature and duration enabled tailoring its mechanical behavior

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to mimic the trend of non linear elasticity of human arteries, characterized by a transition from a supersoft behavior at low strain to a superstiff behavior at higher strain. These findings underscore the crucial role of filler content, particle orientation and curing conditions in modulating the overall performance of the composite and in achieving application-specific properties.

Furthermore, ongoing cyclic tensile tests are being conducted to assess the durability and reliability of the sensor under repeated deformation cycles, simulating physiological conditions. These tests will provide crucial data for optimizing the integration of sensors within the vascular simulator, ensuring their long-term performance.

In regard to the incorporation of the sensor within the simulator, tests are being first carried out on flat silicone substrates to evaluate sensor performance and adhesion. The piezoelectric and mechanical responses under cyclic deformation of the sensor-substrate assembly are also being investigated. After these preliminary tests, the sensors will be adapted for integration onto a tubular model that more closely replicates the geometry of a human artery. This progression is crucial for developing a realistic vascular simulator capable of accurately mimicking physiological conditions.

These findings provide valuable insights into the fundamental mechanisms that govern the mechanical and piezoelectric behavior of silicone/ceramic composites, offering a pathway to tailoring their properties to mimic closely the mechanical characteristics of arterial tissues. This approach aims to upgrade the vascular simulator, improving the testing and validation of medical devices in a controlled environment.

References

(1) G. D'Ambrogio *et al.*, " Piezoelectric biosensor for smart cardiovascular grafts based on NaNbO3 fibers/PDMS structured composite ", *Materials & Design*, vol. 223, p. 111195, nov. 2022.

(2) W. Xu *et al.*, " High-sensitivity piezoelectric pressure/stress sensors based on LiNbO3 for minuscule pressure/stress detection ", *Ceramics International*, vol. 50, no 13, p. 23500-23508, juill. 2024.

(3) A. Moravia *et al.*, " In vitro flow study in a compliant abdominal aorta phantom with a non-Newtonian blood-mimicking fluid ", *Journal of Biomechanics*, vol. 130, p. 110899, janv. 2022.

(4) I. D. Johnston *et al.* , " Mechanical characterization of bulk Sylgard 184 for microfluidics and microengineering ", *J. Micromech. Microeng.*, vol. 24, no 3, p. 035017, mars 2014.