Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

Multifunctional Triboelectric Mechanical Metamaterials with Sustainable Electric Output

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Abstract

Conventional triboelectric generators (TEGs) have been developed to mainly harvest electricity from linear mechanical motions. However, conventional TEGs cannot continuously transfer charges from the positive electrode to the negative electrode (i.e., generating sustainable electrical output) under a compression-tension reciprocal motion, which hinders their application in charging power-storing devices or driving direct current electronics. Traditional electrostatic generators, such as the Van de Graaff generators and Wilmshurst generators, generate sustainable voltage or charge output, but they work under rotational motions and consist of numerous components. In this paper, novel unidirectional charge transfer mechanisms are introduced to develop triboelectric mechanical metamaterials (TMMs) converting linear mechanical motions into a sustainable electrical output. Density Functional Theory (DFT) and experimental analyses demonstrate the minimum necessary components for sustainable electrical output fabricated by only two triboelectric materials (i.e., PTFE and copper). Our TMMs exhibit maximum open-circuit voltage, short-circuit current, and volumetric power density of 3860 V, 8 μA, and 365.3 kW m^{-3}, respectively, under a wide range of compression-tension strain of ±50%. Compared to conventional cellular materials with a plastic deforming energy dissipating mechanism, TMMs developed here utilize friction mechanisms to achieve extreme mechanical energy dissipating performance while keeping excellent resilience. Counterintuitive electromechanical behaviors are experimentally unraveled that the mechanical energy dissipation in the TMMs increases quadratically with the number of unit cells under the same cyclic loading strain. In contrast, the mechanical energy dissipation of conventional cellular materials is usually proportional to the number of unit cells. The open-circuit voltage, short-circuit charge transfer amount, and energy dissipation per unit volume are inversely proportional to the length of unit cells, which reveals the exciting potential for reducing unit cell size to achieve extraordinarily high specific electric output. A vehicle suspension system with a TMM as an intelligent damper is constructed to demonstrate three electromechanical functions including energy harvesting, mechanical energy dissipating, and displacement sensing. The displacement of the TMM damper is sensed by counting the number of distinctive peaks in the short-circuit charge transfer or reaction force versus time curves of the TMM. The excellent electromechanical performance of the multifunctional TMMs facilitates their applications in all-in-one self-powered and self-sensing suspension systems.