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Processing of Flexible Dielectric Nanocomposites Using Nanocellulose and Recycled Alum Sludge for Wearable Technology Applications

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Abstract : With the rapid development of wearable technology (e.g., smartwatch, activity trackers and health monitor devices), flexible dielectric materials with environmental-friendly, low-cost and high-energy efficiency characteristics are in increasing demand. In this work, a flexible dielectric nanocomposite was processed by incorporating two components: cellulose nanofibrils and alum sludge in a polymer matrix. The two components were used in the reinforcement phase as well as for enhancing the dielectric properties; they were processed using waste materials that would otherwise be disposed to landfills. Alum sludge is a by-product of the water treatment process in which aluminum sulfate is prevalently used as the primary coagulant. According to the data from a project partner-Scottish Water: there are approximately 10k tons of alum sludge generated as a waste from the water treatment work to be landfilled every year in Scotland. The industry has been facing escalating financial and environmental pressure to develop more sustainable strategies to deal with alum sludge wastes. In the available literature, some work on reusing alum sludge has been reported (e.g., aluminum recovery or agriculture and land reclamation). However, little work can be found in applying it to processing energy materials (e.g., dielectrics) for enhanced energy density and efficiency. The alum sludge was collected directly from a water treatment plant of Scottish Water and heat-treated and refined before being used in preparing composites. Cellulose nanofibrils were derived from water hyacinth, an invasive aquatic weed that causes significant ecological issues in tropical regions. The harvested water hyacinth was dried and processed using a cost-effective method, including a chemical extraction followed by a homogenization process in order to extract cellulose nanofibrils. Biodegradable elastomer polydimethylsiloxane (PDMS) was used as the polymer matrix and the nanocomposites were processed by casting raw materials in Petri dishes. The processed composites were characterized using various methods, including scanning electron microscopy (SEM), rheological analysis, thermogravimetric and X-ray diffraction analysis. The SEM result showed that cellulose nanofibrils of approximately 20nm in diameter and 100nm in length were obtained and the alum sludge particles were of approximately 200um in diameters. The TGA/DSC analysis result showed that a weight loss of up to 48% can be seen in the raw material of alum sludge and its crystallization process has been started at approximately 800°C. This observation coincides with the XRD result. Other experiments also showed that the composites exhibit comprehensive mechanical and dielectric performances. This work depicts that it is a sustainable practice of reusing such waste materials in preparing flexible, lightweight and miniature dielectric materials for wearable technology applications.

Keywords : cellulose, biodegradable, sustainable, alum sludge, nanocomposite, wearable technology, dielectric
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