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Advances in Fundamental Materials Research

Cactus-based Solids for Energy Dissipation in Defence Applications for Protection and Burden Optimization.

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The availability, cost effectiveness and manufacturability of natural fibres in tandem with their energy absorbing capacity, high specific mechanical properties and lightweight fibrous structure has attracted significant industrial and research interest while leading to their classification as a futuristic design concept for ballistic armour and other defence energy dissipating applications[1]. Cactus fibres, specifically, demonstrate interesting deformation mechanisms and energy dissipation properties under cyclic flexural loading as a fibre reinforcement of a polyester matrix yielding, a significantly high flexural to axial stiffness ratio, a 7-fold increase in the flexural stiffness and a 4.2-fold increase in the energy dissipation per volume of the matrix[2].

The distinctive feature that separates the cactus fibres from their homologues is their cellular structure, hence a multiscale materials characterization methodology was established to assess their morphological traits on a macro, meso, micro and nano scale through optical microscopy, X-Ray CT and SEM. The analysis revealed the existence of a unique fractal structure with a fractal order of 1.8 with self-similarity across scales, that was assessed by a fractal box-counting algorithm developed[3], providing one explanation for the interesting structural properties demonstrated. Additionally, the natural fibres were ball-milled into a fine powder and were characterized using the above protocol revealing the conservation of the fractal order at 1.8. The morphological information obtained provided an intriguing insight in instituting cactus fibres as a novel biological material to be implemented as a matrix structural reinforcement in a new class of composite materials with unusual energy dissipation properties for defence applications.

Through their self-similarity across scales, cactus fibres enable the production of a multiscale composite reinforcement, both in sheet and micro-powder formats, and prototype composite manufacturing methods were developed using the thermoplastic bio-polymer Polylactic acid (PLA) to evaluate the multiscale reinforcement potential of this biological material. Lastly, the morphological data obtained, enabled the generation of 3D rendered models and 3D printed analogues of the cacti structures that were assessed in terms of their mechanical properties to produce a novel cactus based, bioinspired, multi-material, structural reinforcement paradigm for energy dissipation applications. Cactus fibres can be a novel synthetic biology block and bio-inspirational tool in the development of innovative energy dissipating and protecting materials for defence applications.

1. David, N. V., Gao, X. L. & Zheng, J. Q. Ballistic Resistant Body Armor: Contemporary and Prospective Materials and Related Protection Mechanisms. Applied Mechanics Reviews **62**, 050802-050802, doi:10.1115/1.3124644 (2009).

2. M. Bouakba, A. Bezazi, K. Boba, F. Scarpa, and S. Bellamy: Cactus fibre/polyester biocomposites: Manufacturing, quasi-static mechanical and fatigue characterisation. *Composites Science and Technology.* **74**, 150-159 (2013).

3. K. Billon, I. Zampetakis, F. Scarpa, M. Ouisse, E. Sadoulet-Reboul, M. Collet, A. Perriman, & A. Hetherington: Mechanics and band gaps in hierarchical auxetic rectangular perforated composite metamaterials. *Composite Structures*, **160**, 1042-1050 (2017).

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