Meta-compliance and energy dissipation in cactus-based solids
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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 interests. These fibres inspire futuristic designs for ballistic armour and other defence-related energy dissipation applications\textsuperscript{1}. Here we present a novel multiscale materials characterization methodology for the evaluation of the morphological characteristics on a macro, meso, micro and nano scale through optical microscopy, X-Ray CT and SEM, revealing a fractal structure with a fractal order of 1.8 across scales and formats determined via a fractal box counting algorithm developed. The self-similarity across scale enabled the production of a multiscale composite reinforcement, both in sheet and micro-powder formats. Prototype composite materials were developed using thermoplastic polymers Polylactic acid-PLA and Polypropylene (PP) as matrices, and cactus fibre powders obtained via ball milling, as the reinforcement. Under compression loading a 33% increase in the compressive modulus for PP composites at a 0.4% by weight and a 23% increase for the PLA composites at 1% by weight was observed while a 25% bending modulus increase at 3.3% by weight was also observed for the PLA composites. These values demonstrate the potential of this biological material as a lightweight reinforcement. The morphological data obtained enabled the generation of 3D rendered models and 3D printed analogues of the cacti structures, which were tested under three point bending and tensile loading, while compared to their bulk material analogues. The analysis revealed that the specific bending modulus of the cactus biomimetic structures is 45% higher than that of their bulk material analogues, and that the cactus bioinspired 3D printed.

- Multiscale fractal geometry analytical methodology developed.
- Fractal Order of 1.8 maintained across scales and formats.

Cactus Composites Manufacture

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<th>Bending Stiffness (MPa)</th>
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3D Modelling and Rendering-Biomimicry

![Graph showing specific chord modulus comparison](image)

Specific Chord Modulus= 2831.2 (MPa/g/cm\textsuperscript{3})
Specific Chord Modulus= 1958.7(MPa/g/cm\textsuperscript{3})

Conclusions and Future Work

- Cactus Fibres demonstrate unusual energy dissipating properties due to their fractal structure determined via a novel multiscale fractal characterization method.
- Multiscale cactus fibre thermoplastic composites developed show increased mechanical properties making the cactus fibres a very lightweight matrix reinforcement.
- 3D Printed cactus structure analogues show significantly improved specific flexural properties while maintaining the unusual properties observed in nature making them ideal candidates for energy dissipation applications in defence.

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