Biomechanical role of thin reinforcements layers in woodcells: field study and transfer to artificial helicoidal composited composites

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The arrangement of stiff helicoidal fibers into a soft matrix is a strategy used by nature to finely tune local mechanical behavior. Common examples of helicoidal reinforcement in biological load-bearing materials are the spiral pattern of mineralized collagen fibrils in osteonal bone and the twisted motif of cellulose microfibrils inside wood cell wall [1]. These biological materials feature multiple layers combining different fiber winding angles. Inspired by this biological construction principle, we developed synthetic helicoidal composites using multi-material 3-dimensional polyjet printing. We fabricated cylindrical shells having an elastomeric matrix reinforced by spiral fibers of a rigid glassy polymer and we explored the range of properties that can be achieved by varying fiber winding angle. Firstly, we characterized the mechanical behavior of cylindrical shells (height 24 mm, diameter 10.2 mm and shell thickness 1.8 mm) with a single layer of 20 helicoidal fibers, having spiral angles from 0 to 45 degree. Similarly to wood cells, by varying fiber angle we could modulate both stiffness and failure strains up to almost 2 orders of magnitude with the stiffer configuration being also the less deformable. Finite element simulations indicated that such response is due to a switching in failure mechanism from fiber buckling to matrix shear, when going from straight to tilted fibers. Furthermore, we fabricated double-layered configurations with different combinations of winding angles, keeping constant overall dimensions and volume fractions of the two phases. Double-layered cylindrical shells containing both straight and helical fibers led to an amplification of failure strength of 200% with no loss in stiffness when compared to straight fibers only. This solution seems a promising route to combine both high stiffness and high strength in bio-inspired helicoidal composites.

[1] P. Fratzl and R. Weinkamer, “Nature’s hierarchical materials,” *Prog. Mater. Sci.*, vol. 52, no. 8, pp. 1263–1334, Nov. 2007.