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Recycled carbon fibres into hierarchical natural fibre composites with high stiffness and damping

Continuous fibre-reinforced composites are lightweight and stiff, but show clear limitations in terms of vibration damping[1]. Natural fibre composites have excellent damping characteristics[2] and can be produced at much lower environmental cost[3], yet their properties cannot rival those of their synthetic counterparts, limiting their design freedom. We combine natural and recycled carbon fibres in multi-directional composites to overcome design constraints and to enhance the sustainability of lightweight components.

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1 Introduction

Continuous fibre-reinforced composites (CFRC) are lightweight materials with high stiffness and strength. The microstructure lending the material its low mass and the high modulus reduces the ability to suppress mechanical vibrations and has a high environmental cost to produce.

Natural fibre composites are not only very sustainable but have also a hierarchical structure across multiple length scales, which is key for energy dissipation when the component is subjected to dynamic mechanical loading[4], but demonstrate lower performance than CFRC.

In this study, we developed a 3D printing process in which stiff recycled carbon fibres (CF) are used to create multi-directional hybrid natural fibre composites with high stiffness and damping.

2 Hierarchical structuring

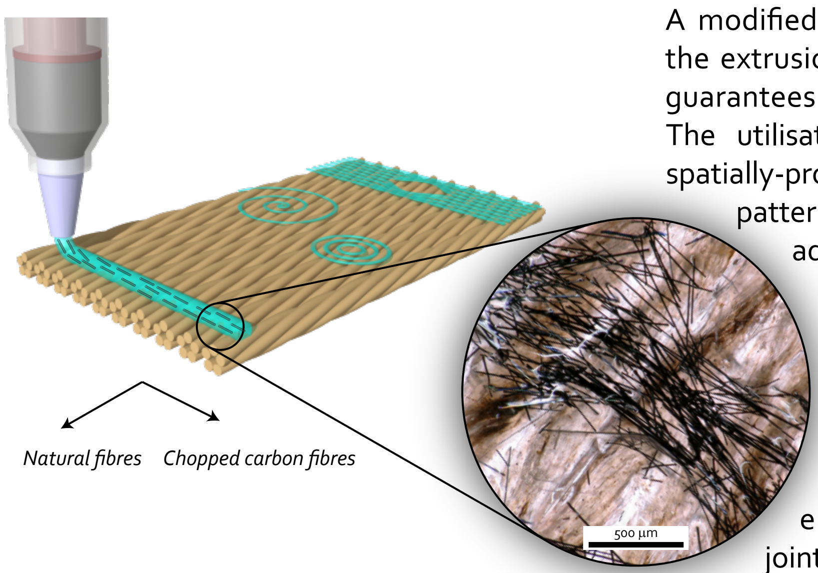

Fig. 1: 3D printing of chopped CF onto natural fibre fabrics

A modified 3D printing setup was developed for the extrusion of liquid inks with chopped CF that guarantees elongational alignment (Fig. 1).

The utilisation of extrusion printers allows for spatially-programmed deposition and vast printing patterns on flax fibre laminates, which can be adjusted in accordance with structural design requirements. The natural fibres absorb the resin and deposit CFs in prescribed directions through capillary forces. Local reinforcements can change the elastic properties and how stress is guided through the structure, e.g. for open holes and location for joints, or to stiffen the compliant transverse direction of unidirectional composites.

3 Mechanics of printing process

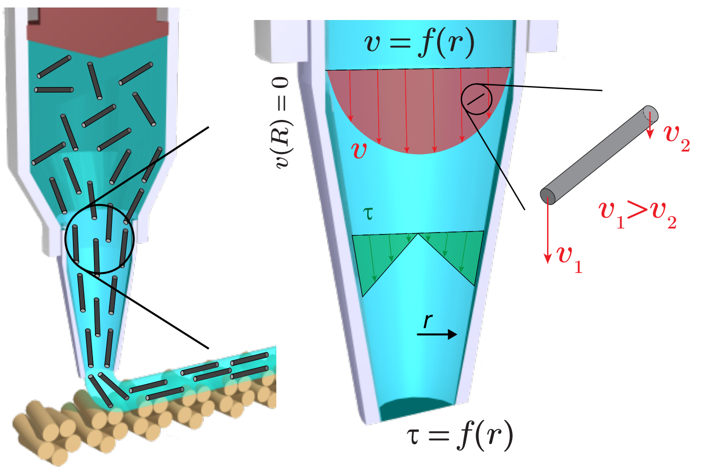

Fig. 2: Schematic cross-section of print head and alignment affecting parameters

Elongational flow and viscous forces acting inside the syringe must be balanced to bring the CF in a vertical position prior to entering the nozzle (Fig 2.). Therefore, the ink viscosity needs to be high to avoid liquid phase migration but low enough to allow extrusion. This processing window was determined by analysing the rheological properties during curing of the ink (Fig. 3).

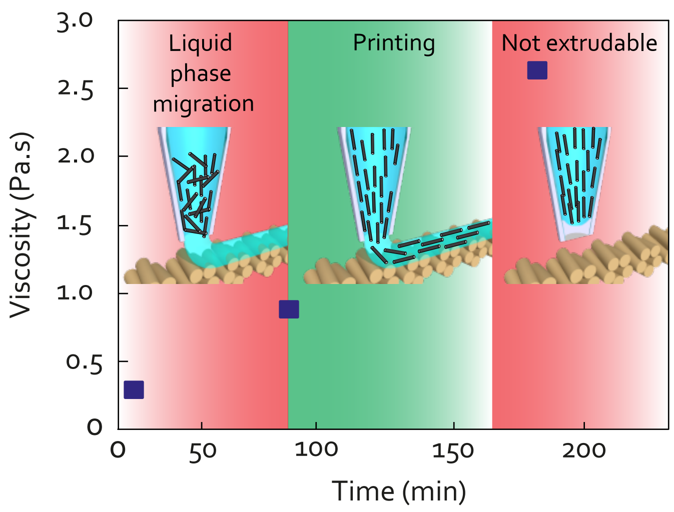

Fig. 3: Viscosity-time diagram illustrating the processing conditions

4 Mechanical properties

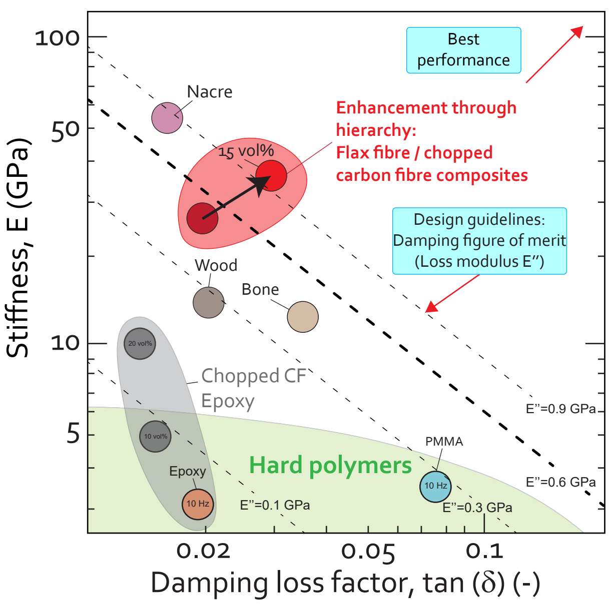

Fig. 4: Comparison of in-plane stiffness and damping loss factor

5 Expected impact

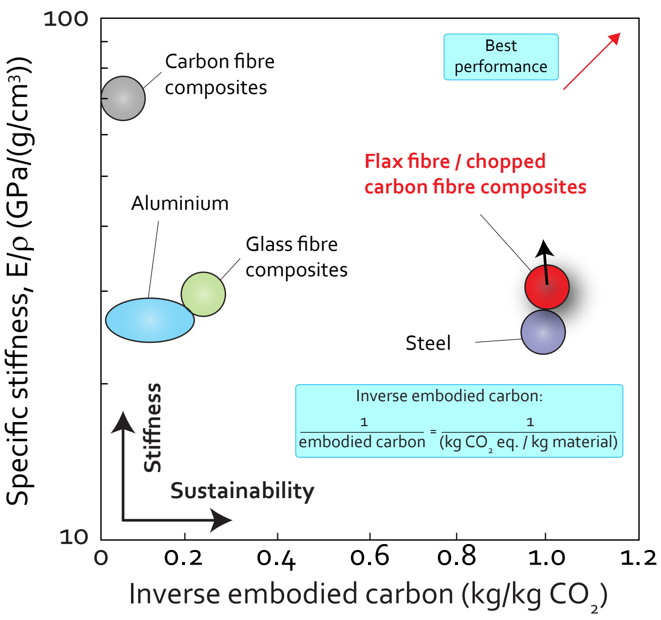

Fig. 5: Comparison of specific stiffness and inverse embodied carbon

The additive integration of chopped carbon fibres as additional detail has shown to enhance the damping figure of merit, E'', of natural fibre composites (Fig. 4). The increased energy dissipation is generated by shear stress transfer between the discontinuous fibres. The implementation of such materials promotes composites that perform dynamically better and are less susceptible to vibrational failure as well as demonstrating low embodied carbon.

The integration of recycled carbon fibres not only increase the property design freedom but allow for the production of environmentally friendly material with a low carbon footprint (Fig. 5).

Specific applications may be automotive body parts, robot and gripper arms, where lightweight components with low oscillation amplitudes and higher resonant frequencies are required.

References

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