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Three-dimensional printing of hierarchical liquid crystal polymer structures

Fibre-reinforced polymer composites are stiff and strong materials but require energy- and labour-intensive fabrication processes, exhibit typically brittle fracture and are difficult to shape and recycle. Biological materials rely on hierarchical architectures to achieve their excellent mechanical properties while minimizing their weight. Here, we demonstrate a bioinspired 3D printing approach to create lightweight structures with hierarchical architectures, complex geometries and unprecedented stiffness and toughness. By orienting liquid crystal polymers along the print path, we can reinforce the structure according to the predicted mechanical stresses and utilize the material more efficiently, which enables us to reduce the weight of structures in mobility.

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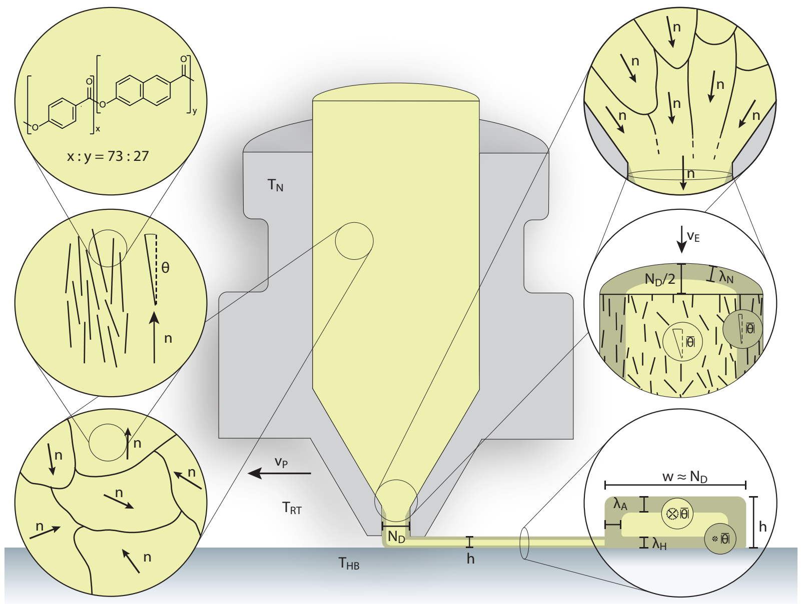
1 Introduction

Fused deposition modelling is a technique that makes it possible to produce complex parts. However, the available polymers are relatively weak and thus methods have been developed to incorporate fibres, such as glass or carbon, into the print path. This increase in mechanical properties comes at the price of recyclability and ease of processing.

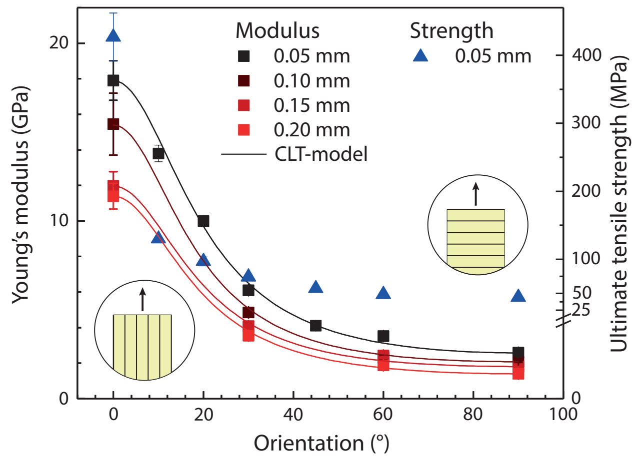
It is well known that liquid crystal polymers (LCPs) can be aligned along shear and elongational stress fields[1] and that those fibres can be used to create monolithic composites[2]. These recyclable structures exhibit high stiffness and strength but are limited to simple geometries and orientations. Here, we combine the shaping freedom of 3D Printing and LCPs to create complex structures with excellent mechanical properties.

2 3D Printing

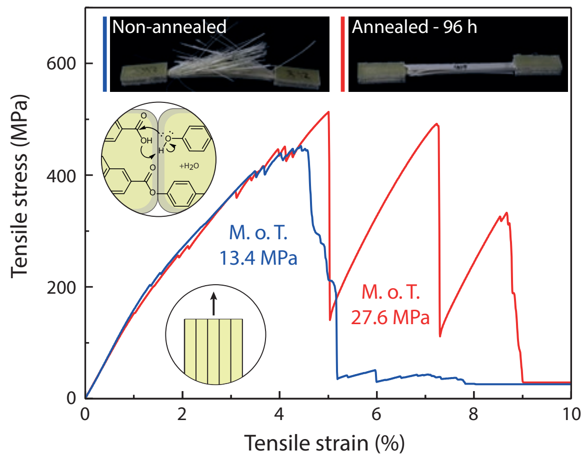


Thermotropic LCPs form nematic liquid crystalline domains when melted. These domains can be aligned in the FDM nozzle along the extrusion direction. Due to thermal motion of the polymer chains, the alignment of the polymer decreases as soon as it exits the nozzle and the shear and elongational forces cease to act on it. At the same time, the extrudate starts to cool and solidify starting from the surface. This solidification front freezes the orientation and thus the extruded filaments form a skin-core morphology.

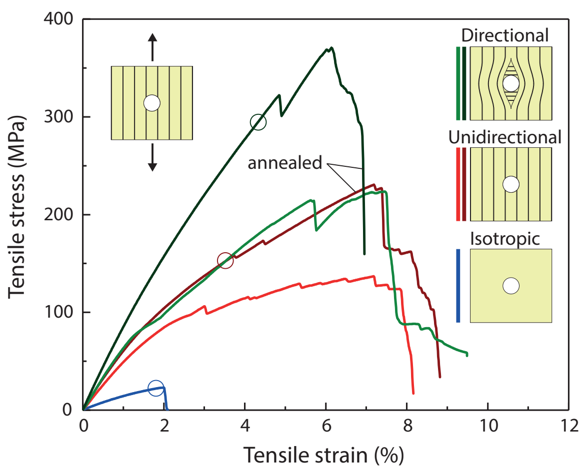
3 Tensile properties

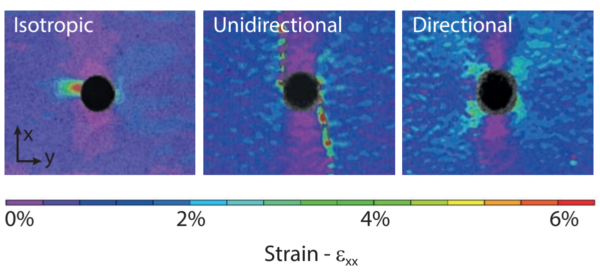


4 Thermal annealing



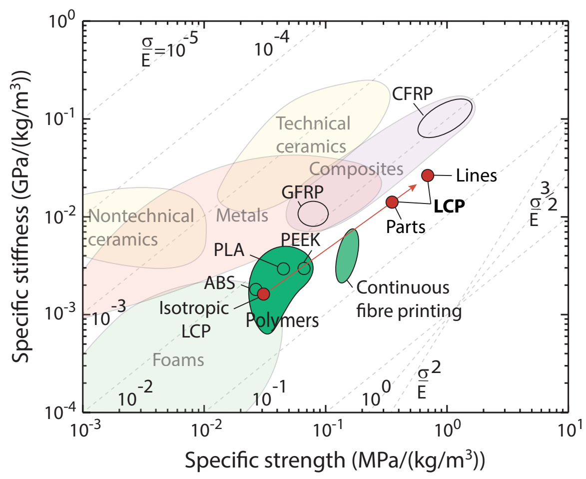
5 Stress adapted microstructure

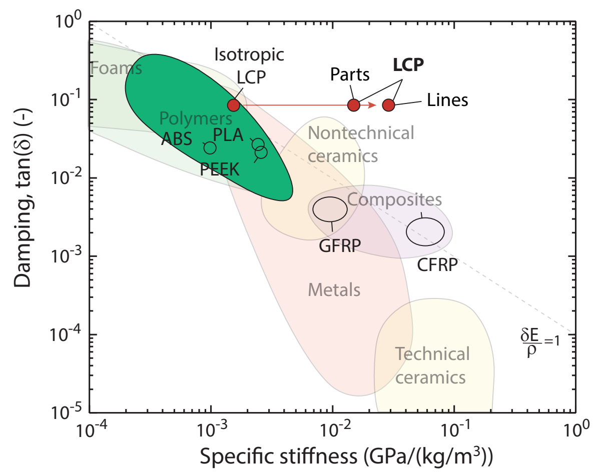




6 Expected impact

We show 3D printed objects with stress-adapted print line architecture with mechanical properties that are much stronger than state-of-the-art 3D printed polymers and rival the highest performance lightweight materials using a readily available polymer and a commercial desktop printer. Thus, the technology is expected to be a game-changer in several structural, biomedical and energy-harvesting applications, where lightweight materials have been used to reduce fuel consumption.





References

[1] Lefèvre, J., et al. *J. of Polymer Science Part B: Polymer Physics* 50.24 (2012): 1713-1727.
[2] Schaller, R., et al. *Composites Part A: Applied Science and Manufacturing* 81 (2016): 296-304.

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