



Investigation of 3D-Printed ABS Anisotropy as a Laminated Composite

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Introduction

The motivation for this project stems from the transition of Fused Deposition Modelling (FDM) from a tool for rapid prototyping to its increasing use in end-use applications. It's crucial that this type of material is accurately understood.

A primary shortcoming is the practise of modelling as orthotropic, which stems from a desire to apply known FEA techniques (Zheng et al., 2021). Inherent in the FDM layup process is a weakened structure between deposited filaments, which drives anisotropic behaviour. This project explores how this gap might be closed.

Experimental Results

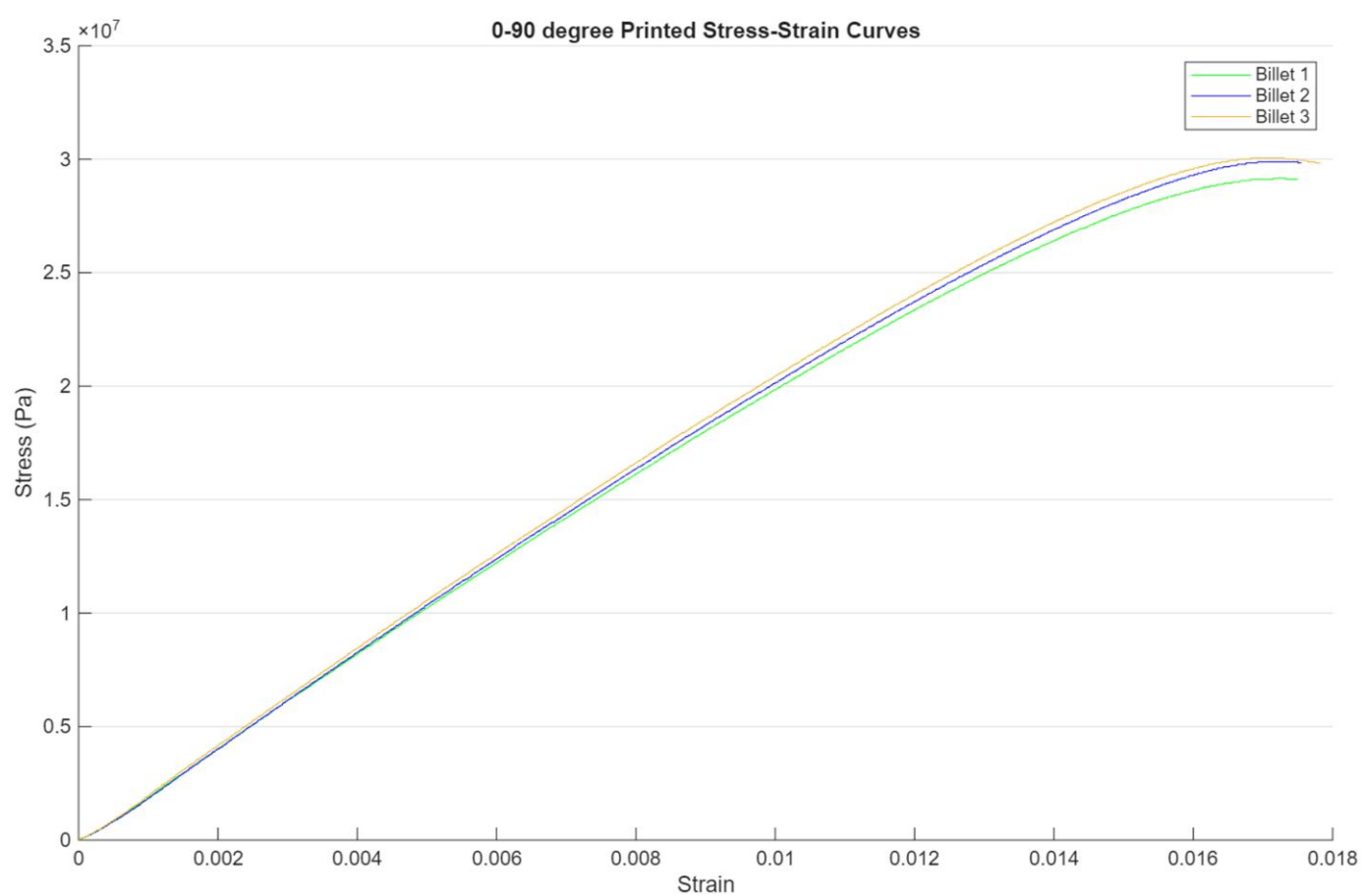


Figure 3 Stress-strain curve for 45 ° fibre orientation under UTS test

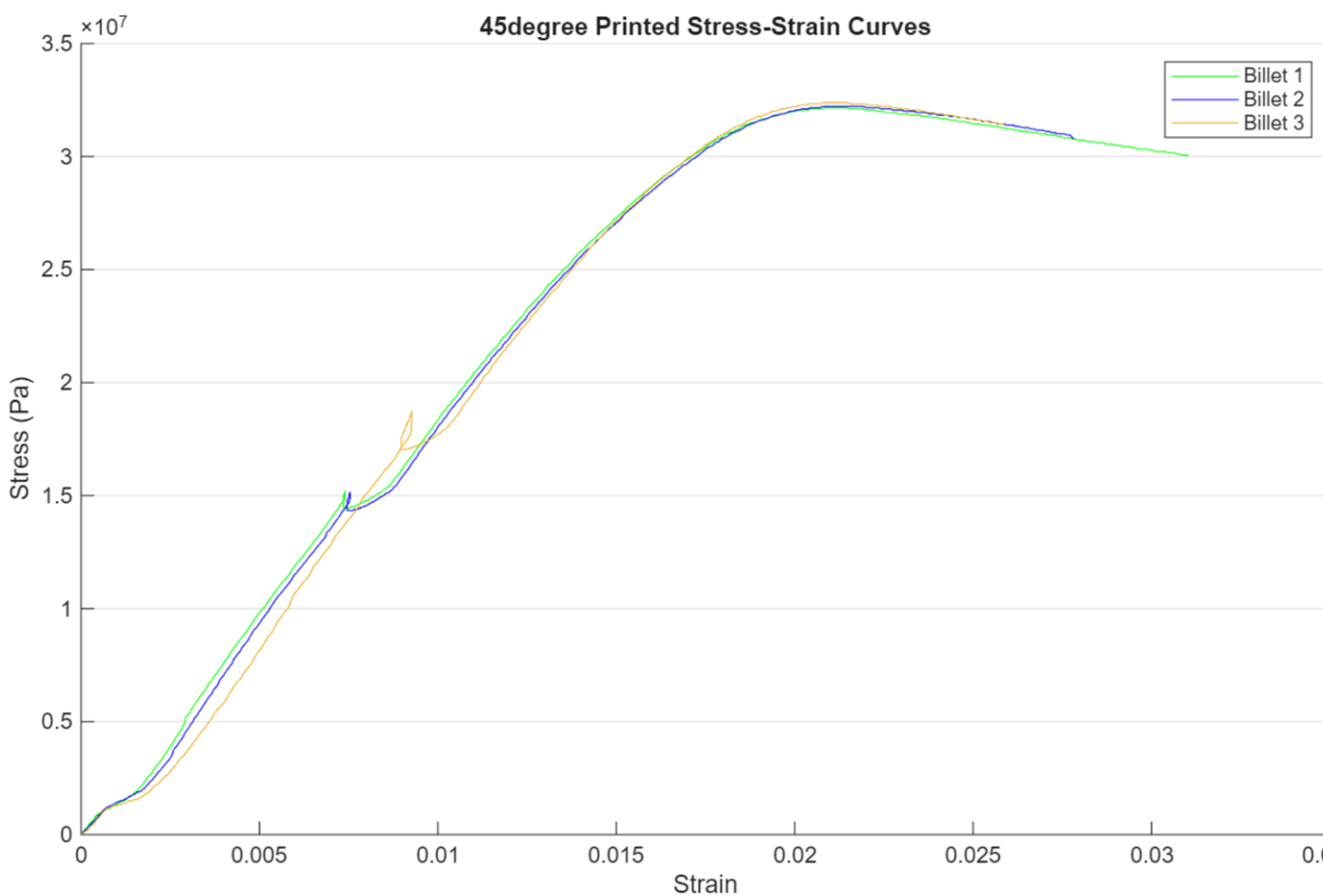


Figure 4 Stress-strain curve for perpendicular fibre orientation under UTS test

The data from these two figures confirm the conflict with traditional orthotropic methods. At 45° (Figure 4), the ABS behaviour is significantly different to perpendicular or out of plane, both of which have a similar profile to Figure 3. While the 45° direction displayed a traditional plastic region, perpendicular to the filament polymers, are able to displace non-characteristic brittle failures.

Equation & Modelling

This Equation (Equation 1) is a modified Halpin-Tsai equation (Fuchs et.al., 2006), adapted to predict the mechanical properties of Fused Deposition Modelling (FDM) materials. While the Halpin-Tsai model is traditionally used to predict properties of composite materials, consisting of a filler and a polymer matrix, this is adapted for the bond (z) and 'true' (xy) strength of an FDM material.

$$\sigma = \sigma_z \cdot \frac{1 + \xi \cdot n \cdot V_{xy}}{1 - n \cdot V_{xy}}$$

Equation 1 Modified Halpin-Tsai equation for ABS FDM material

where:

$$n = \frac{\sigma_z / \sigma_{xy} - 1}{\sigma_z / \sigma_{xy} + \xi}$$

and:

$$\xi = 2 \frac{L_f}{\phi_f}$$

Figure 5 Graph of UTS in-plane at angle theta ensile Stress X-Y Plane Graph

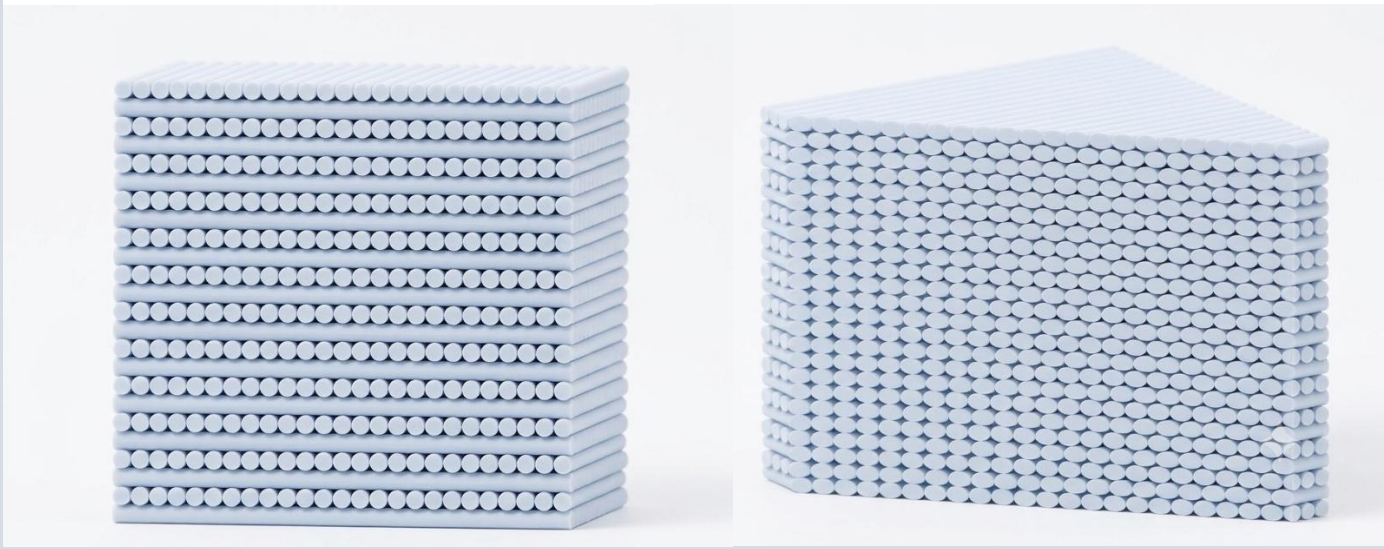
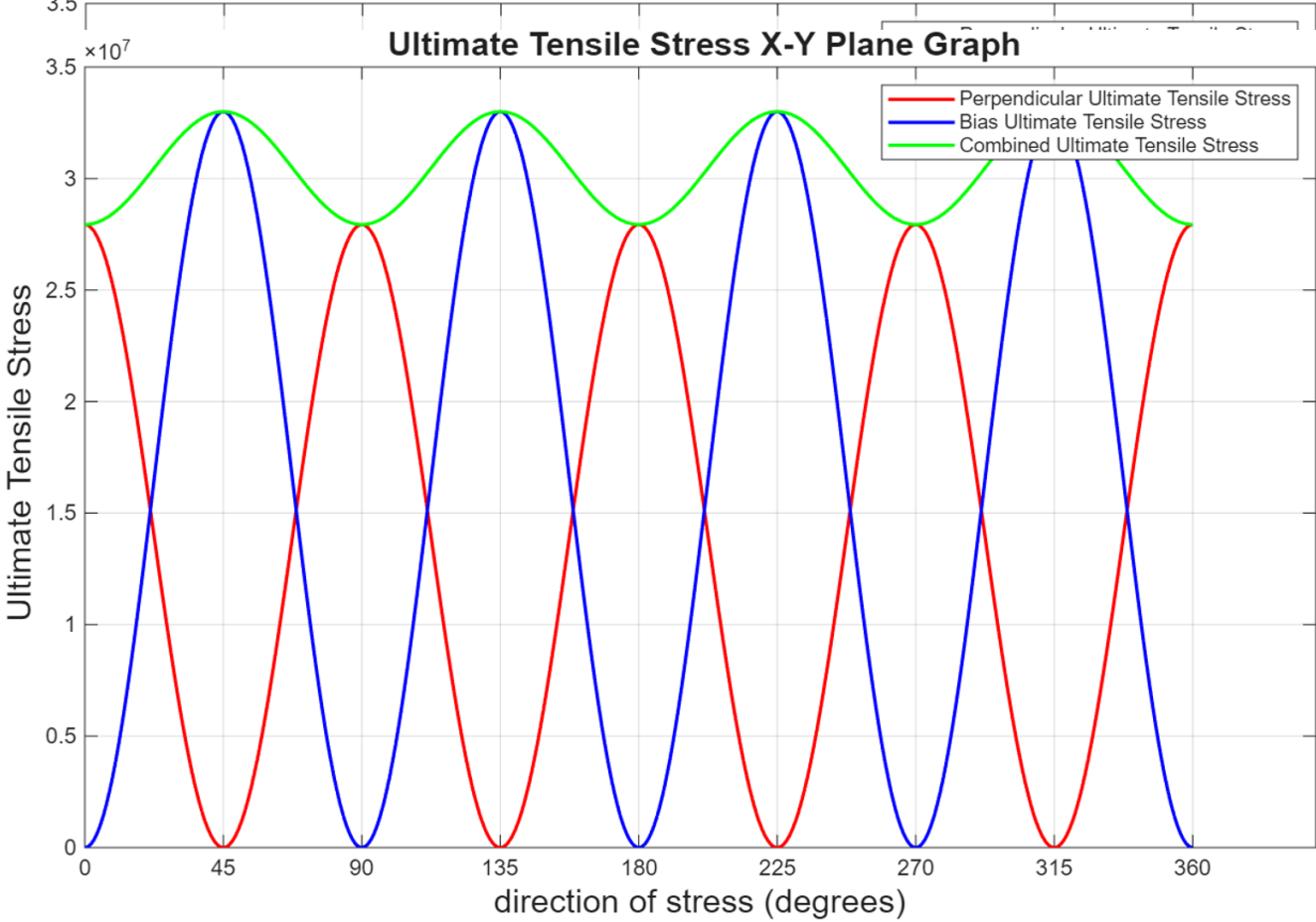


Figure 1&2 Cross-sections of modelled filament layup, perpendicular and 45 °

Case Study

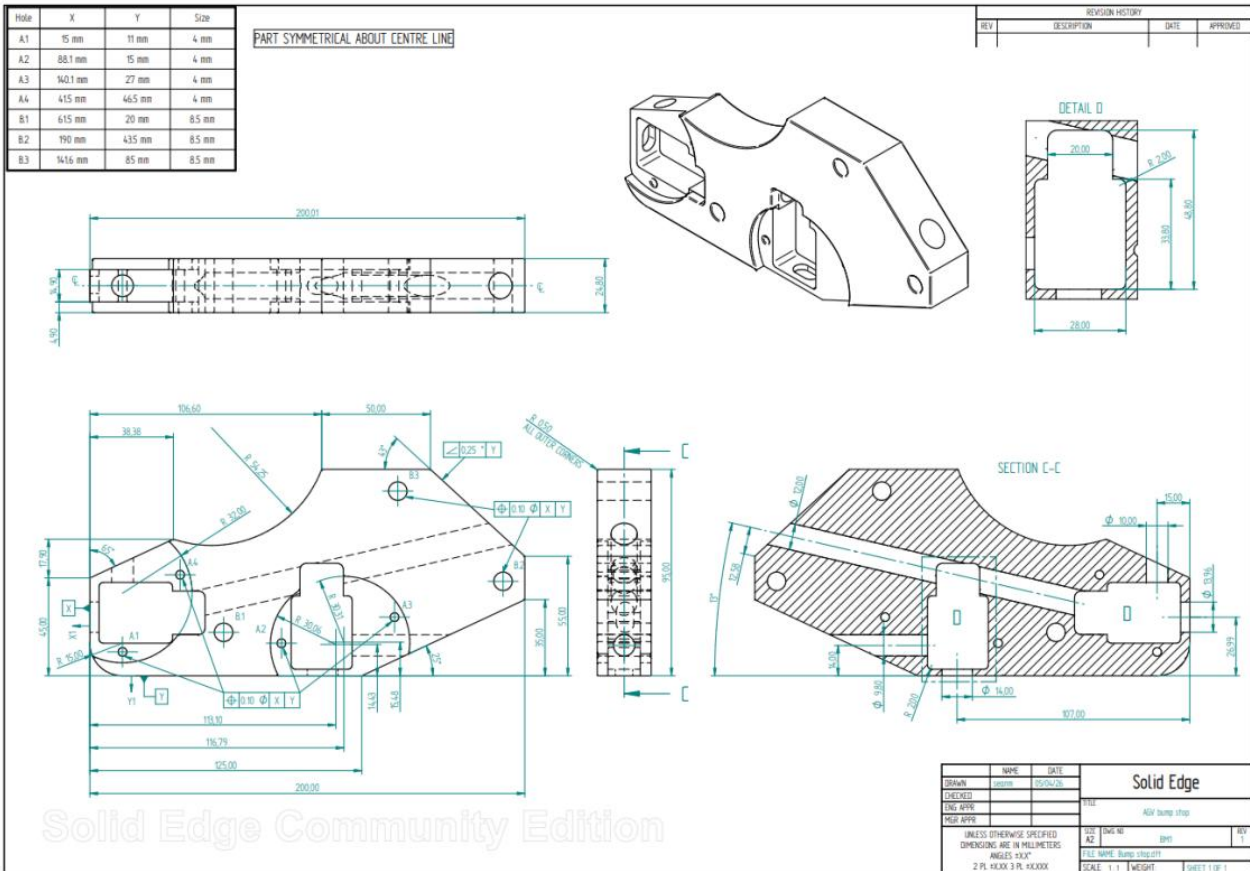


Figure 6 Figure 33 Engineering drawing of the 'bump-stop' component

The case study presented an industrial application where Fused Deposition Modelling (FDM) was used to reproduce the part shown to reduce cost.

A Quality Function Deployment (QFD) was used to demonstrate how the filament orientation was the main design aspect which could be used to improve the design without increasing costs.

Design recommendations were informed by the project's research into loaded material at a 45° bias, where the impact energy could improve from (0.169 mJ/mm³) to (0.206 mJ/mm³).

Acknowledgements

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Kelvin Lake – General Guidance

References

Fuchs, C. et al. (2006) 'Application of Halpin-Tsai equation to microfibril reinforced poly-propylene/poly (ethylene terephthalate) composites', Compos. Interfaces, 13, pp. 331-344

Zheng, A. et al. (2021) 'Optimized Unidirectional and Bidirectional Stiffened Objects for Minimum Material Consumption of 3D Printing', *Mathematics*, 9(21), 2835. DOI: 10.3390/math9212835.