



Fiber Orientation Effects in 3D-Printed Composites

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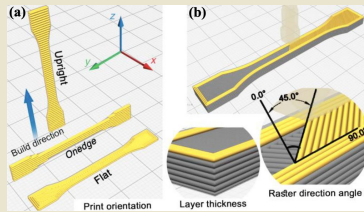


Introduction

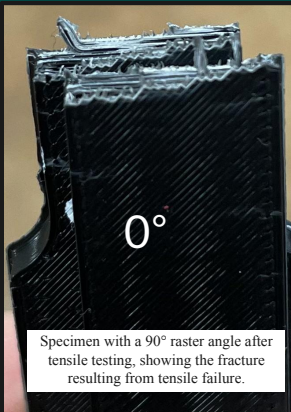
Composite materials are made by combining strong fibers with polymers to create lightweight, durable parts with improved mechanical properties [2, 19]. Additive manufacturing (AM), also known as 3D printing, is a process that builds objects layer by layer from digital models, allowing rapid and customizable production [15, 16]. These technologies are especially valuable in industries like aerospace and automotive, where strength and weight reduction are essential [4, 24]. While many studies have looked at how fiber orientation affects mechanical properties in traditional composites, there is limited information about 3D-printed fiber-reinforced composites made with affordable, consumer-grade printers like Prusa [1, 3, 17]. Also, most existing models predict mechanical behavior are complex or tied to commercial software, making them hard to access for students and researchers [13]. This project addressed these gaps by experimentally studying how fiber orientation influenced stiffness in 3D-printed composites and developing an easy-to-use Mathematica simulation to predict mechanical properties. The goal was to provide open-source data and tools to support both education and composite design [1, 3, 7, 8, 10, 11, 13, 22, 23].

Hypothesis

Specimens with fibers aligned closer to the tensile loading direction (e.g., 90°) will demonstrate significantly higher stiffness than those with transverse or off-axis orientations.



Overview of 3D printing and fiber direction. [23]



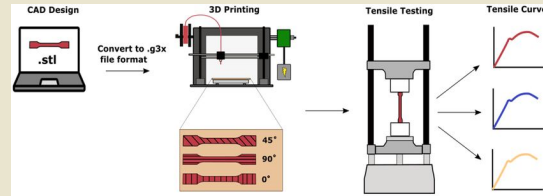
Specimen with a 90° raster angle after tensile testing, showing the fracture resulting from tensile failure.



Specimen with a 45° raster angle after tensile testing, showing the fracture resulting from tensile failure.

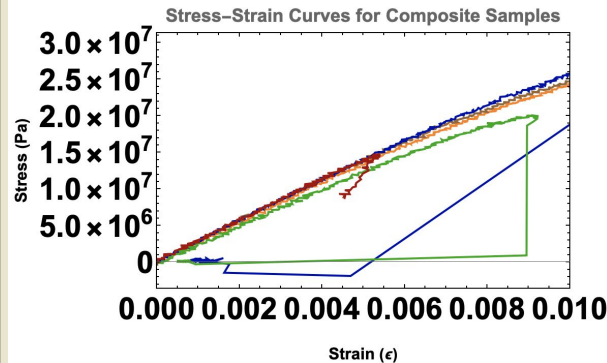
Methods

Tensile specimens were designed according to ASTM D638 Type V standards and printed using a Prusa i3 MK3S+ printer [1, 3]. The matrix materials used were PLA or nylon, with fibers embedded either manually or through composite filaments, depending on availability [2, 3, 23]. Fiber alignments were set at 0°, 45°, and 90° relative to the tensile loading direction, based on established findings that orientation significantly influences mechanical performance [1, 8, 17, 23]. Mechanical testing was conducted on a Shimadzu universal testing machine. Young's modulus was calculated from the linear elastic region of each curve, consistent with standard characterization methods [11, 22]. Micromechanical models, including the Rule of Mixtures and Halpin-Tsai equations, were used to predict modulus values, which were then compared with experimental data to evaluate model accuracy [13, 17]. A Mathematica interactive model was developed to simulate and visualize how fiber angle affected composite stiffness, supporting both theoretical understanding and practical design [13, 22].



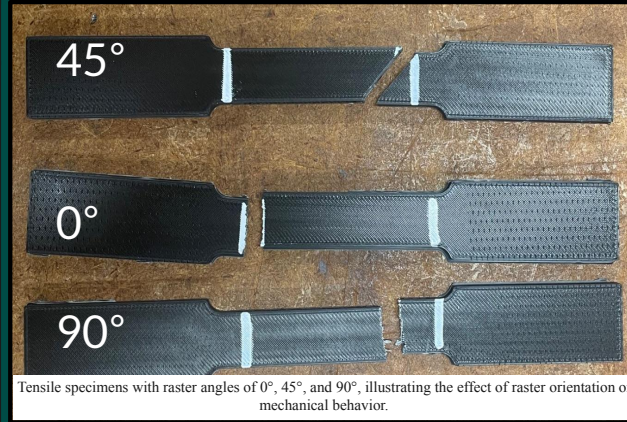
Overview of 3D printing and testing procedure. [14]

Results



Orientation	45° Run 1	45° Run 2	45° Run 3	90° Run 1	0° Run 1
YM (GPa)	2.76	2.88	2.88	2.56	2.78

Young's modulus was calculated from the initial linear elastic region, with higher stiffness observed when fibers were more closely aligned with the loading direction.



Tensile specimens with raster angles of 0°, 45°, and 90°, illustrating the effect of raster orientation on mechanical behavior.

Conclusion

This study confirms that fiber alignment significantly affects stiffness in 3D printed composites, supporting the thesis that specimens with fibers aligned closer to the tensile loading direction (90°) show higher stiffness than those with off-axis orientations [1, 3, 17]. The 90° specimen (2.77 GPa) outperformed the 0° (2.31 GPa), aligning with predictions from micromechanical models like the Rule of Mixtures and Halpin-Tsai [13, 17]. Although 45° specimens had slightly higher average stiffness (2.26 GPa), this likely reflects non-uniform load transfer due to gaps between fiber layers rather than optimal load alignment [13, 23]. The Mathematica simulation developed offers an accessible tool for predicting stiffness based on fiber angle, supporting future design and educational efforts [13, 22].

Acknowledgements, Contacts, Demonstration, & Citations

Acknowledgements

MathematicaContacts
 Demonstration



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