Mechanical properties of Polymer Matrix Composites produced by Fused Deposition Modelling (FDM) method

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Introduction

3D printing, notably Fused Deposition Modelling (FDM), revolutionizes manufacturing with high-strength fiber-reinforced polymer parts across aerospace, medical, automotive, and construction sectors. The FDM process offers advantages such flexibility to adjust interior infill patterns to save manufacturing time, cost, and materials [1,2,3].

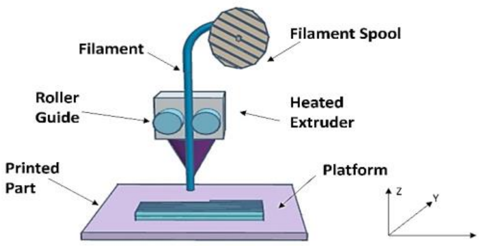

Fig 1: Typical Fused Deposition Modelling (FDM)

Aims

This research aims to evaluate mechanical properties by examining infill pattern and density variations to enhance the capacity of 3D-printed composite parts for engineering applications.

Methods

This study utilizes an Ultimaker S3 3D printer to create specimens from Nylon matrix and Chopped Carbon Fibers, by adhering to ASTM D3039 standards. The specimens are filled with chopped carbon fiber reinforced composite at different infill patterns and densities as shown in Fig 2 for comparison in mechanical test results using a design of experiments approach. An average of eight tensile tests conducted for each combination of infill density and pattern investigated (Honeycomb, Triangle, and Grid) at various infill densities (30, 40, 50, 60%). Tensile testing is conducted on an Instron tension machine with a constant cross head displacement of 2mm/min

One Way ANOVA statistically to compare tensile strength, modulus, and toughness means to discern significant differences or chance disparities. Utilizing a significance level of $p=0.05$, ANOVA tested four infill density groups (30, 40, 50, 60%) with eight observations each, where $P \leq 0.05$ denotes statistically significant results, leading to null hypothesis rejection and indicating mean differences. Tukey's HSD post hoc test further identifies specific infill density groups with significant mean disparities, enhancing understanding of infill level impacts on mechanical properties.

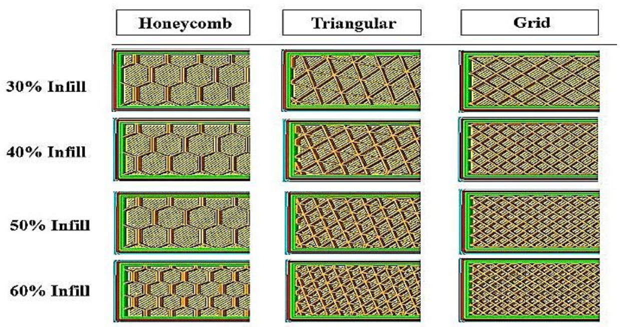

Fig 2: Types of Infill and respective Infill density

Results

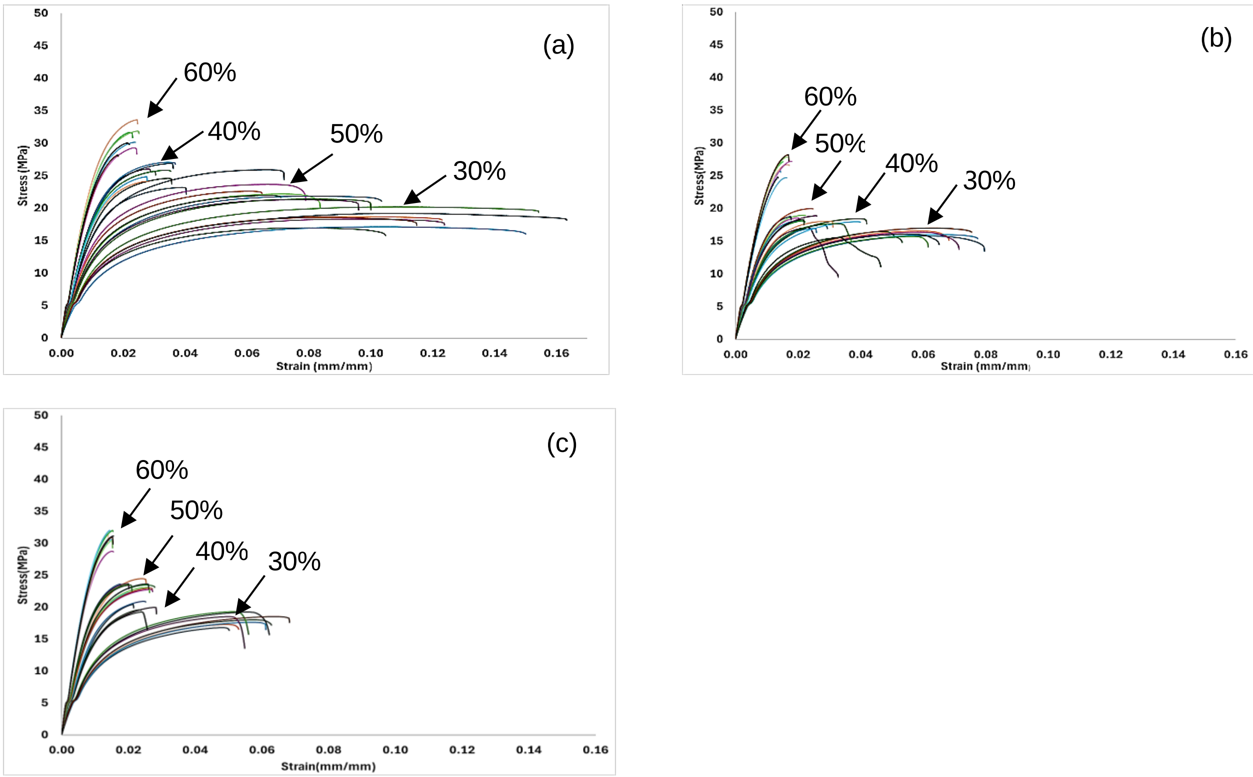

Fig 3. Stress Strain Curve (a) Grid Pattern (b) Honeycomb (c) Triangle Pattern

The Triangle infill pattern demonstrates superior tensile strength and modulus, possibly due to its geometric stability, with increasing infill percentages consistently boosting these properties. Meanwhile, the Grid pattern exhibits the highest toughness, indicating good fracture resistance, while the Line pattern maintains consistent performance. Higher infill percentages generally lead to reduced toughness due to increased rigidity. ANOVA results indicate significant differences with $P \leq 0.05$ across infill densities for all patterns, with density primarily influencing strength. However, unexpected variations in toughness are observed in the Grid pattern, challenging conventional expectations. Conversely, the Honeycomb pattern displays a decreasing trend, hinting at a potential inverse relationship between infill percentage and toughness.

Conclusion

In summary, the experiment unveils distinctive trends in tensile strength, modulus, and toughness across various infill patterns and percentages, illustrated in Fig 3. The Triangle infill pattern demonstrates superior tensile strength, potentially due to its geometric stability, with increasing infill percentages leading to higher strength. Similarly, the Triangle pattern exhibits the highest modulus, suggesting structural rigidity benefits. However, further investigation into geometric arrangements is needed. The Grid pattern stands out for its high toughness, while the Line pattern consistently performs well. ANOVA results reveal significant differences across infill densities for all patterns, with higher infill percentages correlating with increased strength. Future studies could include impact testing, two-way ANOVA, and flexural testing to explore these findings further.

References

[1]. F. Górski, W. Kuczko, R. Wichniarek, and A. Hamrol, "Mechanical properties of composite parts manufactured in FDM technology," *Rapid Prototyp. J.*, vol. 24, no. 8, pp. 1281–1287, 2018, doi: 10.1108/rpj-11-2016-0197.

[2]. S. C. Joshi and A. A. Sheikh, "3D printing in aerospace and its long-term sustainability," *Virtual Phys. Prototyp.*, vol. 10, no. 4, pp. 175–185, 2015, doi: 10.1080/17452759.2015.1111519.

[3]. S. K. Moon, Y. E. Tan, J. Hwang, and Y.-J. Yoon, "Application of 3D printing technology for designing light-weight unmanned aerial vehicle wing structures," *Int. J. Precis. Eng. Manuf.-Green Technol.*, vol. 1, no. 3, pp. 223–228, 2014, doi: 10.1007/s40684-014-0028-x.

This participation at BSSM's 18th International Conference on Advances in Experimental Mechanics is sponsored by the Lim Boon Heng funds.