Phase-field modeling of fracture in additively manufactured parts

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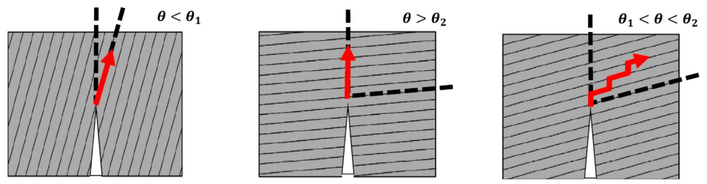
Additive manufacturing for structural applications

- **Fused Filament Fabrication (FFF): Layer-by-layer deposition of a semi-molten filament.**
- **Partial weld → Weak interfaces → Anisotropic behavior:**



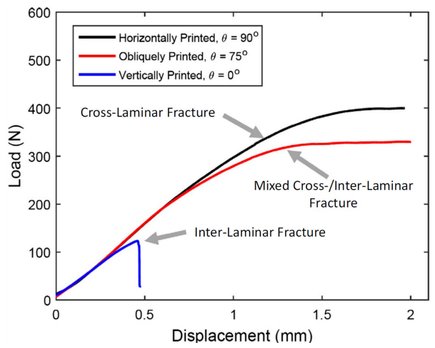


Figure 1: Fracture behavior of FFF parts under three-point bending. Modified from [1].

Objectives

1. **Characterize the anisotropic behavior of FFF parts.**
2. **Develop a phase-field fracture model (PFM) for FFF parts.**
3. **Minimize the computational cost of the PFM.**

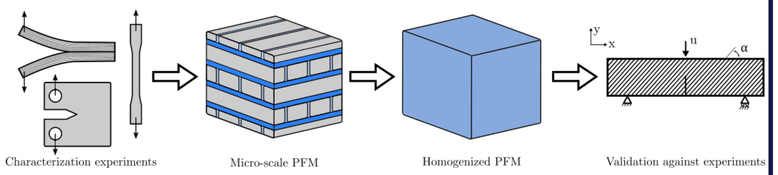


Figure 2: Multi-scale phase-field approach to fracture modeling in FFF parts.

Characterization methodology

Fracture tests on Single Edge Notch Bending (SENB) and tensile tests on dogbone specimens printed at multiple build angles.

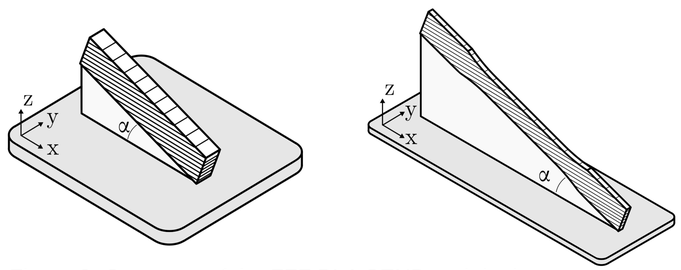


Figure 3: Geometry of the FFF PLA SENB and dogbone specimens. [2]

Characterization results

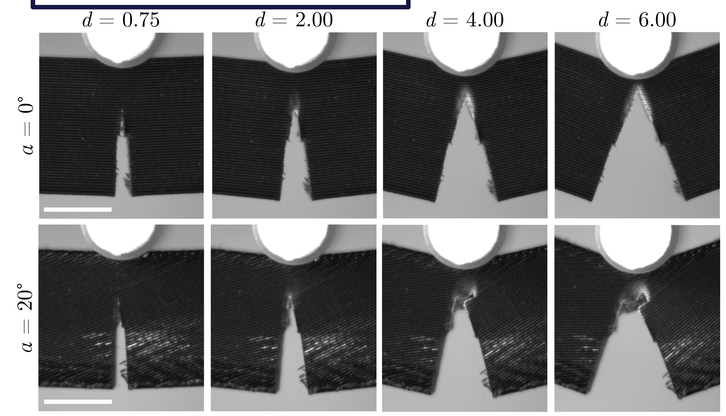


Figure 4: Fracture process under three-point bending of the SENB specimens for 0° and 20° build angles at four applied displacement. Scale bar is 5 mm. [2]

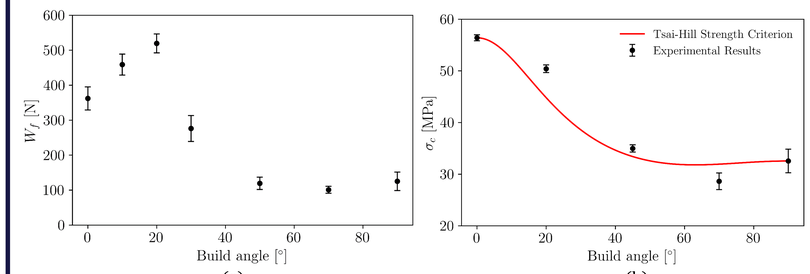


Figure 5: (a) Average work required to fracture the SENB specimens as a function of the build angle. (b) Average strength as a function of the build angle of the dogbone specimens. The bars indicate a 95% confidence interval. [2]

PFM for FFF parts

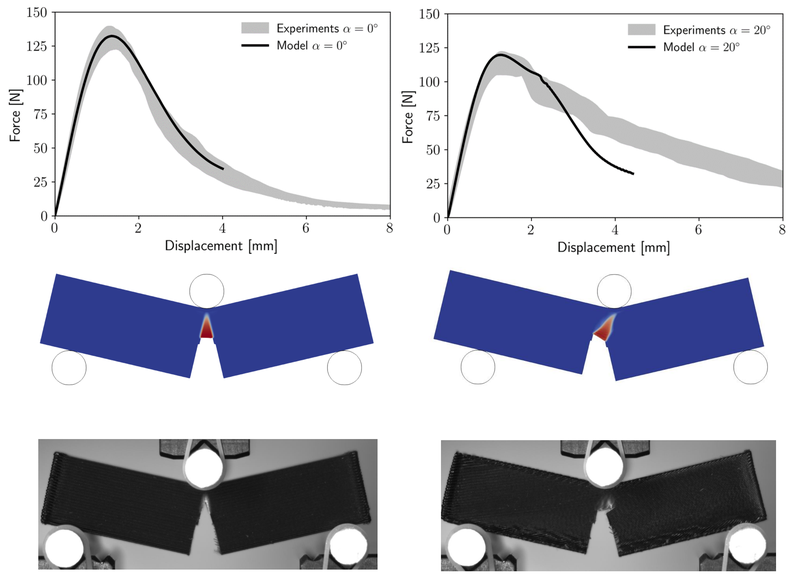


Figure 6: Comparison of experimental and model predicted force-displacement responses and crack paths.

Experimental Validation

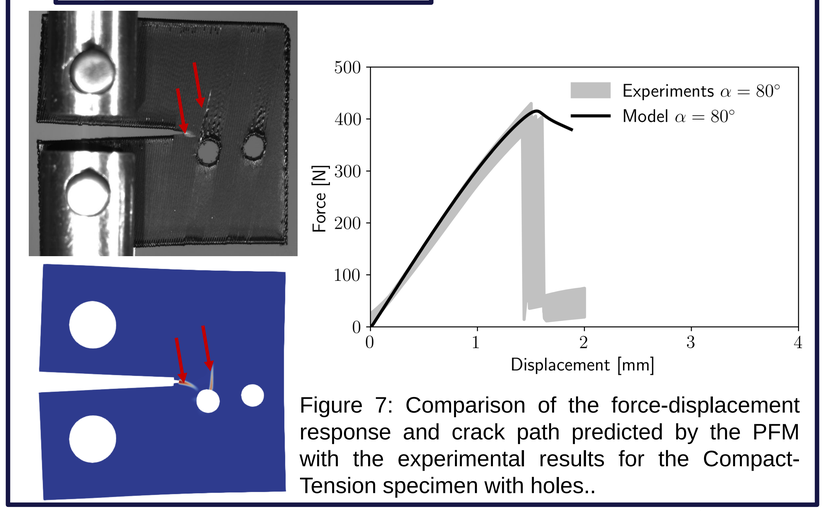


Figure 7: Comparison of the force-displacement response and crack path predicted by the PFM with the experimental results for the Compact-Tension specimen with holes..

Computational cost minimization results

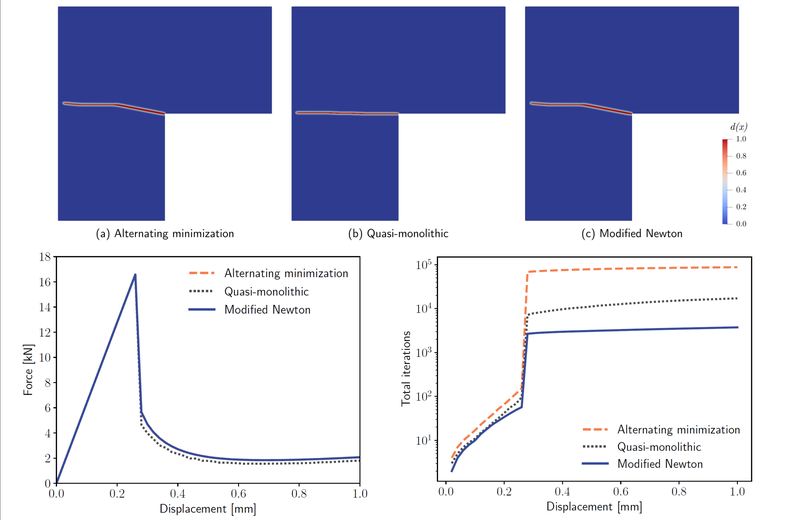


Figure 8: Comparison of the predicted cracks, force-displacement responses and number of iterations of the three solvers. The proposed modified Newton solver yielded an acceleration of the computation time by a factor of 12. [3]

Conclusions

- The failure behavior of unidirectional FFF PLA was characterized.
- A PFM for FFF parts was proposed and evaluated against experiments.
- The computational cost was reduced by a factor of 12.

References

[1] K. R. Hart and E. D. Wetzel, Engineering Fracture Mechanics, 2017.
[2] O. Lampron, A. Lingua, D. Therriault, and M. Lévesque, Additive Manufacturing, 2023.
[3] O. Lampron, D. Therriault, and M. Lévesque, CMAME, 2021.

ACKNOWLEDGMENTS

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