Stochastic Fracture of Additively Manufactured Composites

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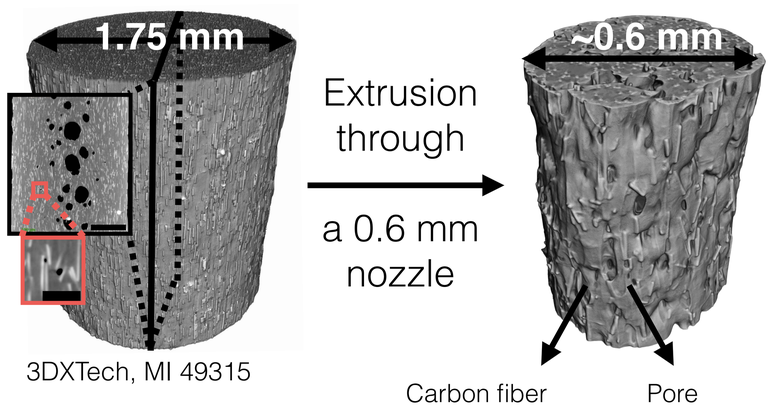
Abstract: Additive manufacturing (AM) is increasingly used to produce parts from composites, polymers, metals, and ceramics. Among various AM techniques, fused filament fabrication (FFF) can use relatively cheap short-fiber-reinforced composites, making FFF accessible for industrial and consumer-level production. Despite the increasing use of FFF to produce parts from composites, mechanical behavior of fused filament fabricated (FFFed) porous short-carbon-fiber-reinforced acrylonitrile butadiene styrene (SCFR-ABS) and the variations in their mechanical properties are unclear. In this study, we investigated the effects of porosity, raster orientation, and extrusion tip vibrations on the stochastic fracture of FFFed composites. We used Weibull statistics to quantify mechanical reliability, i.e., to quantify the variations in fracture strength. A total of 243 tensile tests revealed that the Weibull modulus of fracture strength was between 17 and 56 for a porosity level between 10 and 52 vol. %. The change in raster orientation from 45˚/-45˚ to 0˚ increased the Weibull modulus from 25 to 50. Vibrations at the extrusion head more than doubled the mechanical reliability. The extrusion process decreased the average fiber length by 33 %. We also used X-ray computed tomography to investigate as-received and extruded filaments. Finally, we performed micromechanical simulations on two-dimensional lattice structures to understand the effects of heterogeneous materials and size on the stochastic fracture of FFFed materials.

Fused filament fabrication of SCFR-ABS



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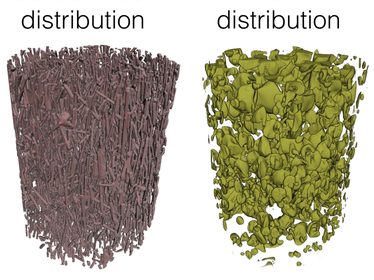
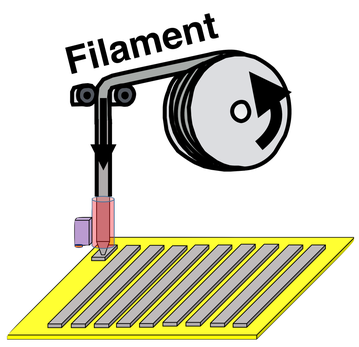
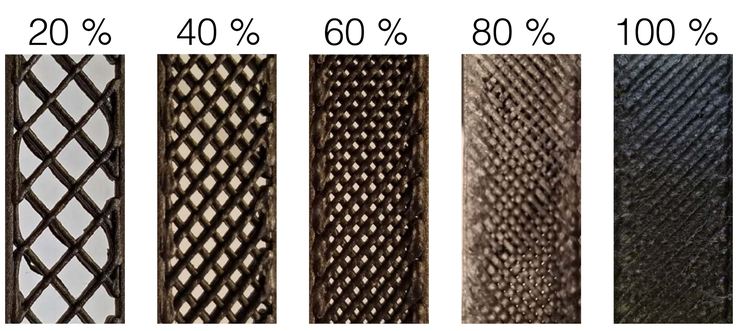
Average fiber length decreased from 170±70 μm to 110±70 μm after extrusion.





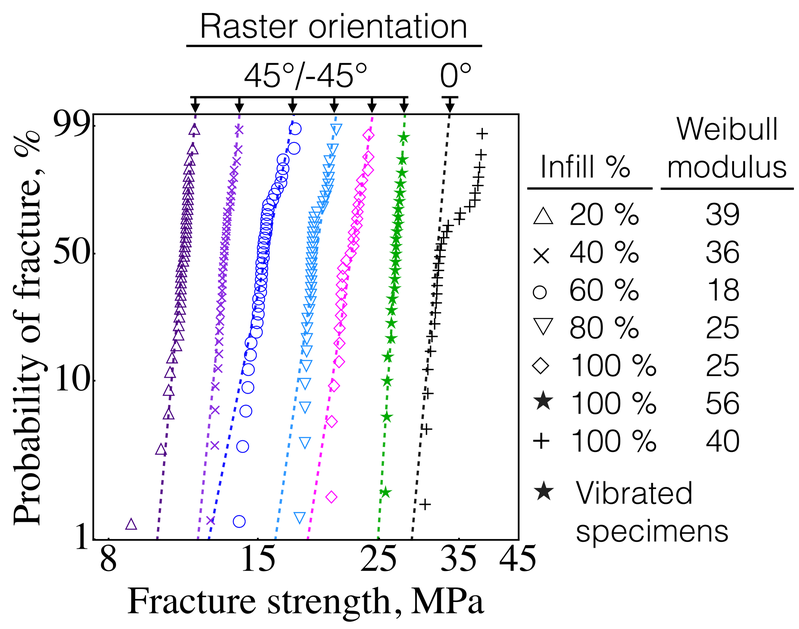
Produce tensile test specimens with infills ranging from 20 % to 100 % at 45°/-45° raster orientation, and at 0° with 100 % infill using a consumer-level FFF system.

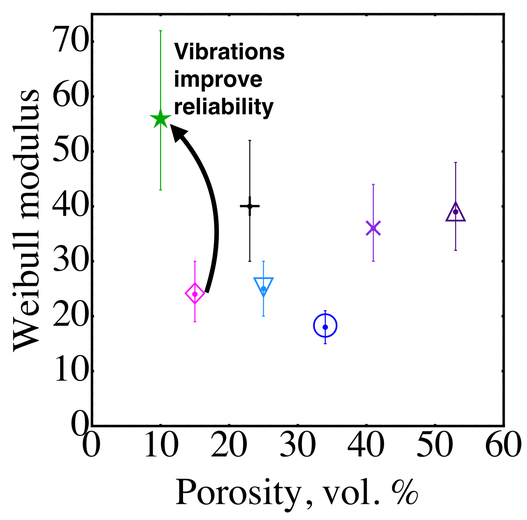
Internal structure, infill %



Effect of infill % on stochastic fracture

We performed 243 tensile tests and used Weibull analysis to quantify the variations in fracture strength.

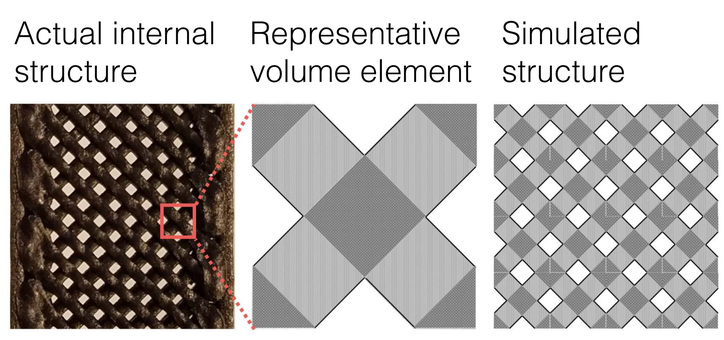




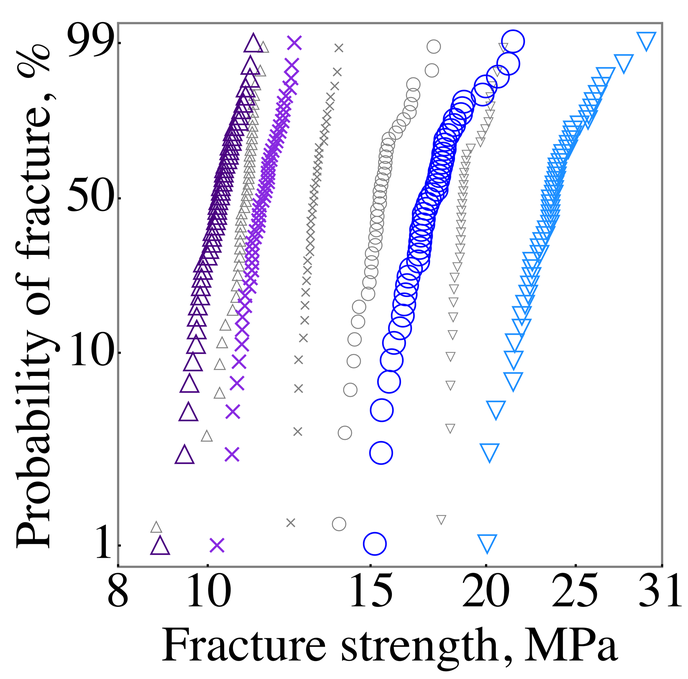
Vibrations decreased variations in fracture strength.

Lower infill %-lower porosity specimens have higher Weibull modulus.

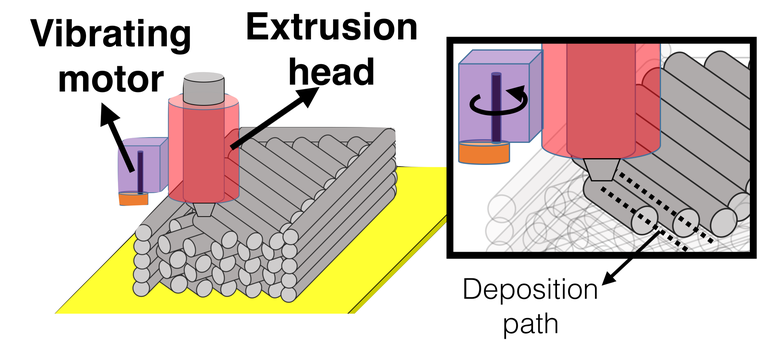
Modeling variations in mechanical properties using a hierarchical lattice model

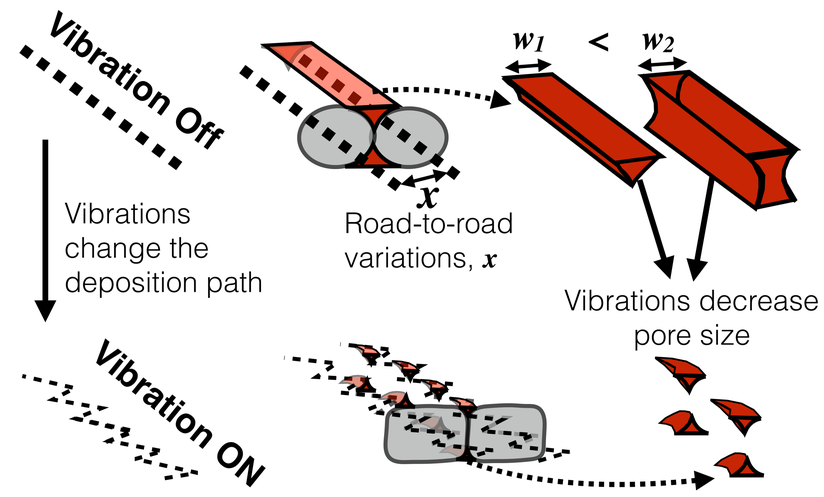


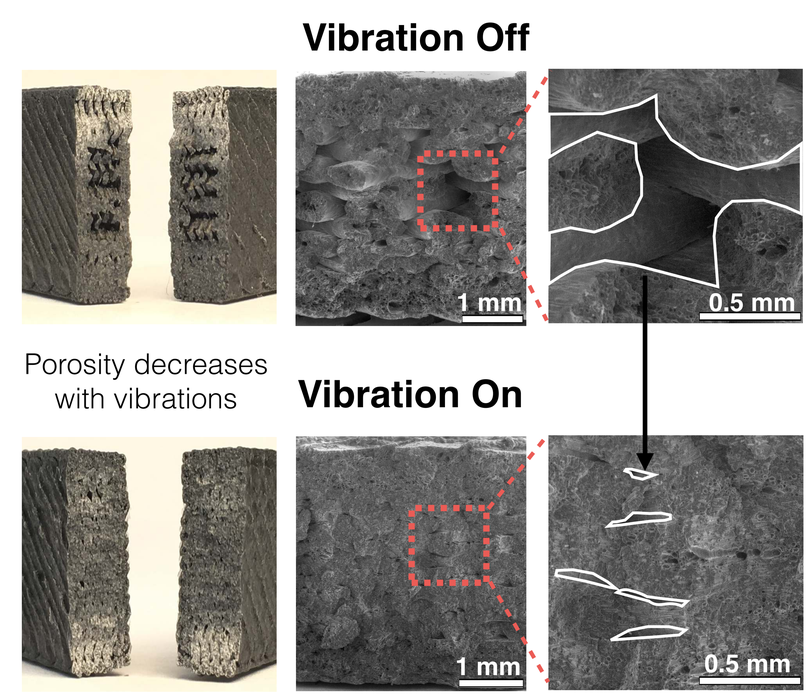
Simulated strength distributions (colored markers) capture experimental deviations from Weibull statistics and trend in decreasing strength with increasing porosity. Grey markers represent experimental results.



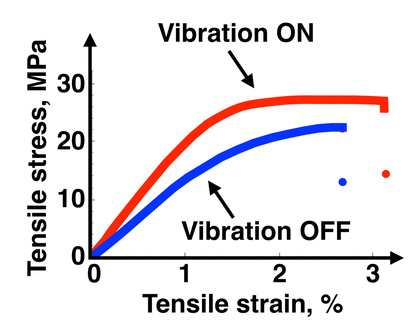
Patent in process technique
Vibration assisted fused filament fabrication







Vibrations increase:
- **Fracture strength**
- **Tensile strength**
- **Toughness**
- **Elastic modulus**
- **Mechanical reliability**



Conclusions

- Fused filament fabricated composites contain various sizes of pores that account for variations in mechanical properties.
- Hierarchical micromechanics simulations capture the effect of porosity on the stochastic fracture of FFFed composites.
- A simple and cost effective vibration technique was shown to decrease porosity and increase elastic modulus, fracture strength, strain at break, reliability, and toughness of SCFR-ABS.

References

- Keleş, Özgür, et al. "Effect of Build Orientation on the Mechanical Reliability of 3D Printed ABS." Rapid Prototyping Journal 23.2 (2017): 320-328.
- Keleş, Özgür, et al. "Effect of Porosity on Stochastic Fracture of Additively Manufactured Composites." Scientific Reports, *to be submitted*.

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