Influence of Print Orientation on the Dynamic Fracture Behavior of Two Additive Thermosets

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Abstract
This study investigates the quasi-static and dynamic fracture behavior of two thermosetting polymer resins used in additive manufacturing (AM). DA-3 resin, printed using digital light processing (DLP), and PM-EM828 resin, printed using stereolithography (SLA), were evaluated to determine the effect of print orientation on fracture properties. Dynamic experiments used a long-bar impact apparatus with ultra-high-speed imaging and digital image correlation (DIC) to capture displacement fields and calculate the resulting stress intensity factor (SIF) ahead of the crack tip. Quasi-static tests of the same materials and orientations were conducted using a standard load frame. DA-3 exhibited higher quasi-static fracture toughness compared to dynamic conditions, with a 54.8% and 58.3% reduction in the X and Y-orientations, respectively, while PM-EM828 demonstrated a 21.0% and 25.5% reduction. Overprinting the final layers of DA-3 improved fracture toughness and reduced anisotropy, whereas SLA-printed PM-EM828 showed negligible print orientation effects. The implications of additive fabrication methods on rate-dependent fracture behavior will be discussed, offering insights into optimizing mechanical performance for thermosetting polymers.

1 Introduction

Additive manufacturing (AM) processes such as stereolithography (SLA) and digital light processing (DLP) build three-dimensional (3D) shapes by curing photopolymer layers [1]. These processes create complex parts at low cost with minimal material waste. However, print orientation influences mechanical properties due to the layered nature of AM parts. Despite the ever-increasing prevalence of and interest in AM methods, limited study has been performed specifically to determine the effects of build orientation on fracture properties of additively manufactured thermosets. This study evaluates the print orientation dependency of fracture behavior under quasi-static and stress-wave loading conditions in DA-3 (DLP) and PM-EM828 (SLA).

2 Materials Methods

DA-3 specimens were printed using an ELEGOO Mars DLP printer and postcured at 120°C, provided by Professor Giuseppe Palmese's research team (Drexel/Rowan University). PM-EM828 specimens were printed using a Formlabs Form 2 SLA printer and postcured at 180°C, provided by Professor Joesph Stanzione's research team (Rowan University) [2]. Both materials were printed in X, Y, and Z-orientations and prepared for quasi-static and dynamic fracture tests.

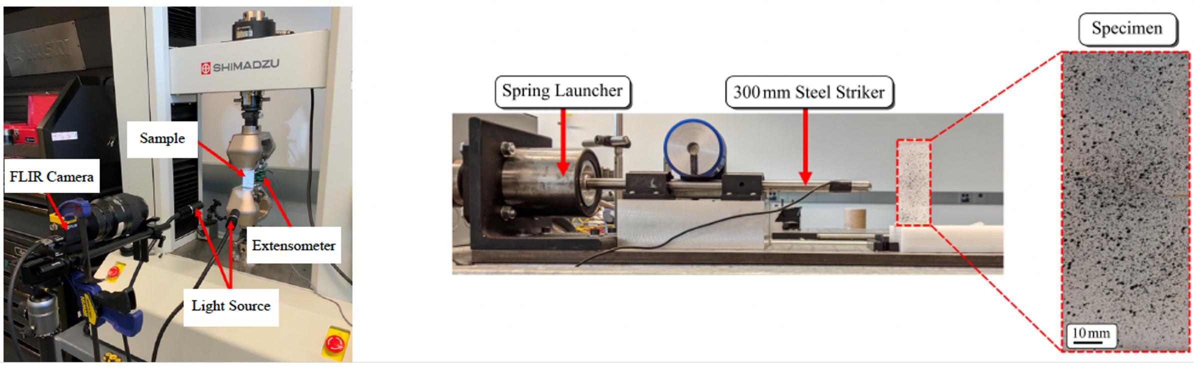

Figure 1: (Left) Quasi-static fracture experimental setup. (Right) Dynamic fracture experimental setup.

Quasi-static tests followed ASTM D638 guidelines, while dynamic experiments of nominally the same coupon size used a long-bar impact device with ultra-high-speed imaging for DIC analysis to determine crack tip displacement fields in-situ. The elastodynamic solution for a stationary crack was used to determine the critical SIF, and the asymptotic steady-state dynamic crack solution was used to examine crack propagation behavior. Ultrasonic pulse-echo measurements of the longitudinal and shear wave speeds confirmed that bulk elastic properties showed no statistically significant differences between print orientations, allowing the use of an isotropic stress intensity factor (SIF) in a bulk sense to assess how print orientation of additive thermosets influenced the initiation of and evolving front.

3 Results

Quasi-static tests revealed higher SIF values for DA-3 and PM-EM828 compared to dynamic conditions. The X and Y-orientations of DA-3 demonstrated higher fracture toughness than the Z-orientation, which exhibited lower fracture toughness due to residual stress and warpage [3]. Overprinting the last two layers of Z-orientation DA-3 specimens increased quasi-static fracture toughness by 28.6%, reducing anisotropy. Dynamic experiments showed a 54.8% and 58.3% reduction in SIF for DA-3 X and Y-orientations, while PM-EM828 demonstrated a lesser rate dependency, with 21.0% and 25.5% reductions. The results of all the critical stress intensity factors are shown in the Figure 2 below.

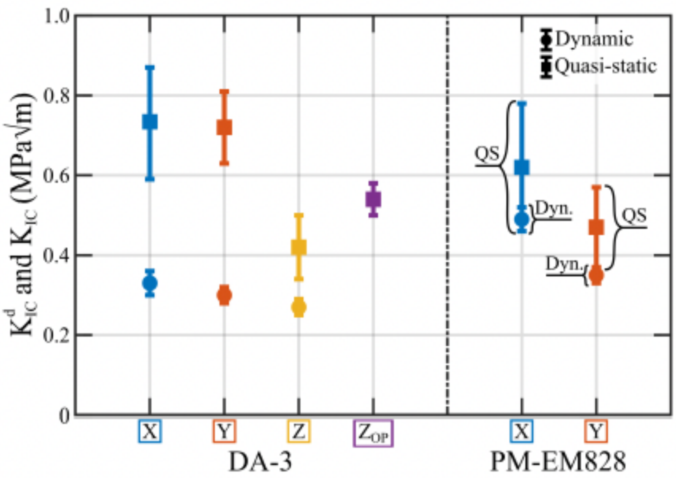

Figure 2: Critical stress intensity factors of all orientations and loading rates for DA-3 and PM-EM828, including standard error bars, from [4].

While SLA-printed parts generally support the assumption of isotropy at the bulk scale, fracture behavior at lower length scales appear to be influenced by the additive layer structure.

4. Conclusion

Overall, results indicate the influence of print orientation is both material and loading condition dependent. This study highlights the influence of print orientation on the fracture behavior of DLP and SLA printed thermosetting resins. Overprinting mitigated warpage and residual stress effects in DA-3, improving fracture toughness and reducing anisotropy. PM-EM828 showed less print orientation dependency and demonstrated better rate insensitivity. These findings underscore the importance of optimizing print parameters to enhance mechanical performance in AM-processed materials.

References

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