

Impact and High-Rate Response of Printed Photopolymers: Strain Rate, Temperature, Specimen Geometry and Failure Mode

A state-resolved framework for dynamic characterization and bounded design transfer

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Abstract

Impact resistance and high-rate response are not single properties of a printed photopolymer. Pendulum impact energy, drop-weight force history, rapid servo-hydraulic stress-strain response and split-Hopkinson measurements interrogate different geometries, rate histories and failure processes. Their results depend on resin chemistry, print orientation, exposure, wash, post-cure, conditioning, specimen dimensions, notch state, temperature, stress state and data-reduction assumptions. A higher response at rapid loading does not establish a universal dynamic increase factor, and absorbed impact energy is not interchangeable with a constitutive law.

This review defines a non-compensatory qualification framework for printed photopolymers under impact and rapid loading. It requires the loading device and specimen rate history to be identified, separates apparatus response from specimen response, and treats dynamic equilibrium, wave dispersion, pulse shaping, inertia and adiabatic heating as validity questions rather than reporting details. Rate and temperature are coupled, while build and cure state can change both failure stress and morphology. Constitutive calibration must be separated from prediction and validated at an additional rate or temperature. The primary corpus supports this state-resolved approach but does not establish universal impact strengths, strain-rate exponents, failure thresholds or transferable crashworthiness values.

Keywords: printed photopolymer; impact; high strain rate; strain-rate sensitivity; temperature; split Hopkinson pressure bar; failure mode; dynamic qualification

1. Significance and scope

Printed photopolymers can respond more stiffly or strongly when loaded rapidly because molecular relaxation has less time to occur. The same rapid loading can reduce deformability, alter crack initiation, change the balance between matrix fracture and layer-related failure, and produce self-heating. Whether that response is beneficial depends on the service event and on which quantity is measured.

ER-233 addresses monotonic impact and rapid-loading response of already printed and post-processed photopolymers. It does not convert one test family into another or treat the word “impact” as a complete loading specification.

1.1 Corpus boundary

ER-039 retains fatigue, creep, repeated impact and time-dependent deformation. ER-069 retains crack-growth kinetics. ER-070 retains general fracture toughness and damage tolerance. ER-073 retains general anisotropy. ER-090 retains dynamic-mechanical damping and viscoelastic frequency-temperature response. ER-170 retains accelerated-ageing design. ER-184 retains diagnostic discrimination between competing defect mechanisms under uncertainty; it does not own constitutive inverse inference in general. ER-207 retains residual-stress measurement. ER-231 and ER-232 are forward references to the planned statistical-size and notch-sensitivity reviews, not published incumbents. ER-234 retains quasi-static compression, buckling and crushing. ER-235 retains general multiaxial failure criteria. ER-233 uses those domains only where needed to define the dynamic state and failure event.

2. Define the dynamic claim before selecting a test

At least four claim families must be separated. Pendulum impact tests report energy absorbed by a specified notched or unnotched specimen and machine configuration. Drop-weight tests provide force, displacement or energy histories for a particular support and impactor. Servo-hydraulic or actuator-based tests can generate controlled rapid tension or compression over an intermediate rate range. Split-Hopkinson systems infer specimen response from propagating waves at much higher rates.

These tests do not measure one universal impact property. The SLA study spanning quasi-static to rapid tension demonstrates rate-dependent stress response and failure morphology for an oriented, post-cured methacrylate system [1]. Hopkinson-bar research determines dynamic elastic response of specific printing resins in compression [4]. Charpy work evaluates absorbed pendulum energy as a function of hardness and process variables [7]. Their endpoints are complementary, not interchangeable.

3. Freeze the printed material state

Record resin and batch, printer, wavelength and exposure state, build location, orientation, layer thickness, support and removal, washing, drying, post-cure spectrum, irradiance or validated dose, temperature, storage and conditioning. State the time between post-cure and test. Rapid response can be particularly sensitive to degree of conversion, free volume, glass-transition region and residual solvent.

Orientation and post-cure were controlled variables in SLA specimens tested from quasi-static to rapid loading [1], while cure time interacted with strength measured at different rates [6]. The abstract of [1] establishes the study design and rate-dependent response but

does not independently resolve the magnitude of the orientation or post-cure effects. High-rate stereolithographic composite evidence also shows that reinforcement and printing direction must remain attached to the result [8]. These studies support state-specific qualification. They do not provide universal cure corrections.

4. Report specimen geometry and notch state

Report dimensions, gauge length, thickness, cross-section, grips or supports, impact span, striker geometry and the complete notch or crack preparation. Measure critical as-built dimensions after post-processing. A printed notch, machined notch and razor precrack are distinct discontinuities under ER-232, even when used in an impact specimen.

Geometry governs wave transit, stress concentration, inertia and the volume sampled for defects. A pendulum result normalized by nominal section remains a structural test result. It is not automatically intrinsic toughness. If geometry changes with rate or device, the observed difference includes both rate and configuration effects.

5. Distinguish machine speed from specimen strain rate

Crosshead velocity is not strain rate unless specimen kinematics justify the conversion. Under rapid loading, grip compliance, fixture motion, wave travel and local deformation can make strain nonuniform. Report the measured strain history and method, such as extensometry, digital image correlation, strain gauges or validated wave analysis.

For a test with changing strain rate, provide the relevant interval or instantaneous history rather than one nominal number. The experimental SLA framework emphasizes characterization across loading regimes and process states [3]. Low- and high-rate comparisons likewise require the rate actually experienced by the specimen to remain attached to the result.

6. Establish dynamic equilibrium and valid wave reduction

In a split-Hopkinson test, input and output waves must support force equilibrium over the interval used to calculate stress-strain response. Report bar materials, diameters, wave speed, gauges, striker, pulse shaper, sampling, dispersion correction and the criterion used to identify equilibrium. Low-impedance polymer specimens can require polymeric or otherwise impedance-matched bars.

The two-bar study demonstrates that bar selection changes signal quality for printing resins and that numerical support can be needed [4]. A smooth curve does not prove equilibrium. Results before equilibrium, after severe wave overlap or during uncontrolled interface slip must not be reported as validated material response.

7. Control inertia, friction and apparatus energy

Apparatus compliance, ringing, striker rebound, fixture friction and specimen inertia can distort force or energy. In compression, interface friction can create confinement and barreling. In drop-weight or pendulum tests, measured machine energy includes contributions from specimen fracture, deformation, vibration and fixture motion according to the instrument method.

Document machine calibration, empty-fixture or compliance correction where applicable, contact conditions and discarded transients. Compare force signals from both specimen interfaces when the method permits. Numerical correction is acceptable only when the model and parameters are independently supported.

8. Couple strain rate and temperature

Rate sensitivity and temperature dependence are not separable by assumption. Higher temperature can permit relaxation and reduce stress, while rapid deformation can approach adiabatic conditions and heat the specimen. The dynamic photosensitive-resin study across several temperatures shows systematic temperature softening and rate dependence [5]. Although that source does not establish a fully controlled printed-part history, it defines a necessary coupling boundary.

Measure initial specimen temperature, ambient condition and, when material heating may matter, temperature evolution or a justified thermal estimate. Report proximity to glass transition or other relevant transition using the tested cure and conditioning state. A rate law calibrated at one temperature should not be transported across a transition without new data.

9. Separate response quantities

Dynamic modulus, yield or peak stress, strain at failure, absorbed energy, resilience, toughness-like area and crack-initiation time describe different parts of the event. Define the calculation interval and smoothing or filtering. Do not infer fracture toughness from total pendulum energy without a validated method, or service survivability from peak stress alone.

The rapid-tension study resolved stress and failure-surface changes with rate [1]. The Hopkinson study focused on dynamic modulus [4]. Charpy testing measured impact energy in printed polymers [7]. The different endpoints show why a single ranking cannot represent every dynamic decision.

10. Resolve failure mode and morphology

Record whether failure is brittle, ductile, layer-associated, notch-initiated, grip-initiated, interface-controlled or accompanied by extensive deformation. Use high-speed imaging, digital image correlation and post-test fractography where appropriate. Report whether the intended gauge or impact region controlled failure.

Rate-dependent fracture surfaces in SLA specimens provide direct evidence that morphology can change with loading history [1]. Graphene-filled stereolithographic composites demonstrate additional reinforcement and anisotropy mechanisms [8]. Such evidence can structure the inspection plan but cannot be transferred to an unfilled resin.

11. Treat orientation and cure as possible rate interactions

An orientation that performs similarly under slow loading may diverge under rapid loading if layer interfaces, cure gradients or flaw populations respond differently. Likewise, post-cure may increase stiffness while reducing deformation capacity. Test factorial or otherwise balanced combinations when claiming an interaction.

The cure-time study and the orientation/post-cure rapid-loading study support explicit interaction testing [1,6]. Do not derive a universal “more cure is better” rule. Each response must retain its failure mode and the degree to which conversion, embrittlement or thermal history was actually characterized.

12. Calibrate and validate constitutive models separately

State whether the model represents elasticity, viscoelasticity, viscoplasticity, damage or failure. Define the stress and strain measures, rate and temperature dependence, parameter-identification method and data used. A model fitted to every available curve has no independent prediction test.

Reserve at least one rate, temperature or loading path for holdout validation. Compare the full curve and failure-relevant quantities, not only peak stress. Temperature-dependent dynamic compression work illustrates constitutive calibration over a bounded domain [5]. Its parameters remain specific to that resin and specimen state.

13. Connect coupons to component events

Component impact can combine bending, contact, multiaxial stress, local notches and changing rate. Transfer requires an analysis that maps the component event onto the calibrated material domain and confirms that the failure mode remains represented. Component geometry and contact should be validated at an intermediate or full scale.

No coupon source in the corpus establishes general crashworthiness. Charpy performance does not directly predict a drop, collision or ballistic event. A dynamic increase factor derived from one specimen does not replace a validated component model.

14. Build a non-compensatory qualification matrix

Gate	Required evidence	Unsupported shortcut prevented
Printed state	Resin, orientation, wash, post-cure and conditioning	Treating rate response as formulation-only
Test identity	Device, specimen, fixture, rate history and temperature	Combining unlike impact methods
Dynamic validity	Equilibrium, signal quality, inertia and friction controls	Accepting an attractive transient curve
Response separation	Stress, strain, energy and morphology reported distinctly	Calling every endpoint impact strength
Model validity	Constitutive domain, calibration and holdout test	Extrapolating a fitted rate law
Component transfer	Event mapping, contact and failure-mode confirmation	Converting coupon data into crashworthiness

The gates do not compensate for one another. Correct geometry cannot repair invalid wave reduction, and good equilibrium cannot repair a mismatched printed state.

15. Minimum reporting set

Report resin, batch, printer, exposure, orientation, layer, wash, post-cure, storage and conditioning; specimen design and measured dimensions; notch state; apparatus, fixtures, sensors and calibration; loading speed and measured strain-rate history; temperature history; raw signal processing and filters; Hopkinson bars, pulse shaping, dispersion and equilibrium where relevant; friction and inertia controls; stress and strain definitions; modulus, strength, failure strain and energy calculations; replicate structure and exclusions; failure location and morphology; constitutive equations and fitting data; validation rate or temperature; component-transfer limits; and uncertainty.

Every numerical value must remain tied to the complete state and method. No impact energy, dynamic modulus, rate exponent, dynamic increase factor or failure threshold becomes universal.

16. Knowledge boundary

The corpus directly supports rate-dependent SLA tension, SLA strength at low and high rates, process-resolved characterization, Hopkinson compression, temperature-dependent dynamic response, cure-rate interaction, Charpy impact and high-rate printed composites [1–8]. No common resin, geometry, temperature, cure or device spans the studies. ER-232 retains notch design, ER-234 retains quasi-static crushing and ER-235 retains general multiaxial failure.

17. Limitations

Evidence is distributed across tension, compression and pendulum impact. References [1], [5] and [8] were used at publisher-abstract depth; references [3], [4], [6] and [7] were read at full-text depth. Reference [2] was verified only at bibliographic-record depth and is retained for corpus identity, not as support for a technical claim. In [5], stereolithographic manufacture is identified, but build orientation and post-cure conditions are not fully reported for transfer. Charpy evidence does not provide a constitutive curve [7], and composite evidence adds mechanisms absent from neat networks [8]. The review therefore establishes a qualification architecture, not numerical design values.

18. Conclusions

Impact and high-rate response of printed photopolymers must be qualified by test family, actual strain-rate history, temperature, geometry, print state and failure mode. Dynamic equilibrium, wave quality, inertia, friction and apparatus energy are validity gates. Stress, strain and absorbed energy remain distinct. Rate and temperature must be coupled, and orientation and cure may alter the rate response. Constitutive calibration requires independent validation, while component impact requires event-specific transfer. The defensible result is bounded to the tested state and apparatus, not a universal dynamic factor.

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