

Fretting and Repeated-Contact Damage in Printed Photopolymers: Contact Pressure, Slip Amplitude, Debris and Surface Evolution

A state-resolved framework for small-amplitude contact qualification

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ER-239 · Engineering Review · Version 0.3 · 21 September 2026

Abstract

Fretting is repeated small-amplitude relative motion between loaded contacts. It is not ordinary sliding wear at reduced stroke. Partial slip can nucleate edge cracks while gross slip can generate a broader wear scar, debris and progressive conformity; transitions depend on pressure, tangential force, displacement amplitude, frequency, surface state, environment and counterface. Printed photopolymers add cure gradients, orientation, pixel or layer texture, residual washing products and viscoelastic time dependence. A friction coefficient or wear volume measured in another polymer cannot therefore be transferred safely.

This review defines a non-compensatory qualification framework for fretting and repeated-contact damage. It requires measured normal load and local contact geometry, actual rather than commanded slip, loop-resolved tangential force, thermal monitoring, debris accounting and failure-mode attribution. Surface polishing can alter both geometry and near-surface network state; debris can be expelled, retained or transformed into a third body. Qualification must distinguish running-in, stable response and transition, and must reserve a prospective condition for validation. Direct fretting evidence for vat-printed photopolymers remains sparse. Polymer and printed-material studies support the architecture but not universal coefficients. The defensible output is a bounded contact map for a defined printed state, counterface and environment.

Keywords: printed photopolymer; fretting; repeated contact; partial slip; gross slip; wear debris; contact pressure; surface evolution

1. Significance and scope

Small oscillatory motion occurs in press fits, bolted joints, clips, guides, seals and vibration-loaded interfaces. Damage can accumulate before gross sliding is visible and can reduce subsequent fatigue or fracture resistance.

ER-239 addresses repeated contact with small tangential displacement under normal load. ER-010 retains dimensional metrology; ER-039 retains general fatigue; ER-040 retains general tribology and wear; ER-070 retains fracture toughness; ER-088 retains surface topography and finishing; ER-171 retains design values and allowables; and ER-184 retains uncertainty. ER-239 owns only the contact-state, debris and surface-evolution qualification problem. Rolling-contact fatigue remains outside this review and is treated under the general fatigue framework of ER-039 together with the tribology boundary of ER-040.

1.1 Corpus boundary

ER-207 (residual stress), ER-232 (notch sensitivity), ER-236 (environmental stress cracking), ER-238 (system vibration qualification) and ER-241 (exposure-pattern compensation) are planned forward references, not published incumbents. They do not supply authority for this review. ER-239 retains the bounded small-amplitude repeated-contact architecture and does not displace the general tribology and wear remit of ER-040. Future dedicated reviews may narrow adjacent domains but cannot be treated as current corpus authority.

2. Define the contact claim

Declare whether the endpoint is first crack, specified scar size, wear volume, debris release, friction instability, loss of fit, electrical interruption or residual strength. A contact can meet one endpoint and fail another. Fix acceptance limits before examining results.

State whether the claim concerns running-in, steady operation or a transition. A single averaged friction coefficient can conceal stick-slip, changing contact area and progressive damage.

3. Freeze the printed and counterface states

Record resin and lot, printer, exposure, build location and orientation, layer thickness, supports, wash, drying, post-cure, storage, conditioning, age and surface preparation. Record counterface material, hardness, coating, roughness, geometry and cleaning.

Orientation-sensitive printed response [3] and fatigue sensitivity to surface finish in material-jetted photopolymers [2] show why contact parameters must remain state-bound. They do not provide fretting coefficients for vat-printed systems.

4. Resolve real contact geometry

Measure as-built radii, flatness, roughness and alignment. Nominal Hertzian geometry is only a starting point when roughness, compliance, plasticity or wear changes the contact. Use pressure-sensitive methods, validated contact models or in situ field measurements where necessary.

Contact pressure, tangential force and slip must be resolved together. Machine displacement is not interface slip because fixture and specimen compliance absorb motion.

5. Distinguish partial slip and gross slip

In partial slip, a central stick region can coexist with slipping edges. In gross slip, most of the contact slides during each cycle. The transition is identified from tangential force-displacement loops, not from commanded amplitude alone.

Polymer contact studies show strong dependence on material, load and displacement amplitude [1,4]. These adjacent systems demonstrate variables and diagnostic logic; their transition boundaries are not transferable to a printed photocured network.

6. Measure the loop and dissipated energy

Record tangential force and relative displacement with adequate bandwidth. The energy dissipated per cycle is the enclosed loop area:

$$E_d = \text{area}(Q-\delta \text{ loop})$$

where Q is tangential force and δ is interface displacement. Energy can correlate with damage in a bounded regime, but equal cumulative energy does not prove equal mechanism when pressure, temperature or debris state differs.

7. Control viscoelastic heating and rate

Photopolymer modulus and damping depend on temperature and frequency. Measure contact or near-contact temperature and distinguish frictional heating from chamber conditions. A rising temperature can change conformity, slip and debris production during the test.

Frequency acceleration is valid only if the contact regime, temperature and morphology remain equivalent. Otherwise a faster test is a different test.

8. Track debris as a third body

Collect and characterise debris where feasible. Report mass, size distribution, morphology and chemistry, together with the recovery efficiency. Debris retained in the contact can abrade, lubricate, compact or shield the surfaces; expelled debris changes the interface again.

Epoxy-composite and engineering-polymer studies show formulation-specific friction and wear behaviour [1,4]. No generic filler or hardness correction is released for printed photopolymers.

9. Separate surface damage from subsurface cracking

Use profilometry and microscopy to map scar depth, volume, pile-up, transfer film and crack location. Section selected contacts to identify subsurface cracks, layer-associated paths and interface damage. Report detection limits.

A smoother initial surface may reduce asperity damage but may also change contact area and adhesion. Polishing, coating and machining are material-state changes, not merely cosmetic preparation.

10. Control environment and cleaning

Humidity, liquids, lubricants and residual wash solvent can change friction, sorption and crack resistance. Define atmosphere, temperature, humidity, lubricant identity and replenishment. Control cleaning because a film introduced before the test may dominate running-in.

ER-041 retains chemical resistance and solvent uptake. Planned ER-236 will address environmental stress cracking but is not a current incumbent. ER-239 uses those domains only when they alter repeated-contact damage.

11. Use an informative test matrix

Vary normal load and displacement amplitude independently across the intended regime. Include frequency or temperature only after the contact map is established. Use replicates and randomise order where ageing or machine drift could bias results.

Reserve at least one combined condition as a holdout. Validate predicted loop shape, regime, scar metric and morphology, not only final friction.

12. Prevent fixture and alignment artefacts

Characterise fixture stiffness, parasitic rotation, backlash and resonance. Verify contact position and normal load throughout the cycle. Edge loading caused by misalignment is not a material property.

Use controls to distinguish specimen wear from counterface or fixture wear. Replace or requalify counterfaces under declared rules.

13. Measure residual function

After fretting, measure the property linked to service: fit, sealing, electrical continuity, stiffness, strength or fatigue resistance. A small wear volume can coexist with a critical crack, while a large shallow scar may retain structural function.

Do not infer residual strength from surface images alone. Preserve uncoupled controls and identical conditioning.

14. Build a non-compensatory qualification matrix

Gate	Required evidence	Unsupported shortcut prevented
Printed state	Resin, orientation, cure, age and surface	Pooling unlike contact materials
Contact	Geometry, alignment, pressure and normal load	Treating nominal geometry as local stress
Motion	Measured slip and force-displacement loops	Using actuator stroke as interface slip
Mechanism	Regime, debris, scar and crack morphology	Reducing damage to friction coefficient
Environment	Temperature, humidity, films and cleaning	Hidden chemical or thermal coupling
Validation	Holdout condition and residual function	Calling curve fitting qualification

15. Minimum reporting set

Report printed and counterface identities; processing and conditioning; surface preparation and topography; contact geometry and alignment; normal load and pressure model; commanded and measured slip; frequency and cycle count; force-displacement loops; temperature and environment; debris collection; scar and crack metrics; microscopy and detection limits; exclusions; replicates and uncertainty; residual function; acceptance criteria; and transfer boundaries.

16. Knowledge boundary

Direct studies establish material-, load-, amplitude- and surface-dependent repeated-contact behaviour in epoxy composites and reinforced polyamide [1,4]. Printed-polymer evidence establishes orientation and surface sensitivity [2,3]. Direct replicated fretting maps for neat vat-printed photopolymers remain sparse. The evidence supports a qualification architecture, not universal friction, wear or endurance values.

17. Limitations

References [1], [2] and [4] were used at publisher-abstract depth; reference [3] was read at full-text depth. The adjacent polymer systems differ from crosslinked vat-printed networks in chemistry, microstructure and surface evolution. This review supplies no universal pressure, slip amplitude, friction coefficient, wear law or allowable.

18. Conclusions

Fretting qualification must resolve the actual contact, slip regime, loop response, temperature, debris and damage morphology. Printed state and surface preparation are inseparable from the result. Acceleration and transfer require mechanism equivalence and prospective validation. The defensible outcome is a bounded contact map for one printed state, counterface, environment and endpoint.

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