

Cryogenic Service of Printed Photopolymers: Glass Transition, Thermal Shock, Permeation, Fracture and Repeated Cycling

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Abstract

Cryogenic Service of Printed Photopolymers is evaluated as the bounded decision of whether a printed photopolymer retains geometry, integrity and assigned function through cooling, dwell and rewarming at the declared cryogenic condition. The controlled state comprises resin and cure state, orientation, moisture/conditioning, temperature trajectory, dwell, constraint, pressure/fluid environment and number of cycles. ER-287 uses its single direct source only for the bounded proposition described in section 3. ER-287 defines measurements, transfer logic, failure modes and release gates specific to this subject; no universal process window, product recipe or compliance conclusion is inferred.

Keywords: cryogenic; photopolymer; DLP; thermal contraction; brittle fracture; cycling; permeability

1. Significance, scope and ownership

ER-287 owns whether a printed photopolymer retains geometry, integrity and assigned function through cooling, dwell and rewarming at the declared cryogenic condition. The review is organised around the decision-specific evidence chain and leaves neighbouring ownership intact.

1.1. Corpus boundary

The cryogenic boundary is the printed article after cooling, exposure and cycling. ER-54 retains gas-permeation physics, ER-70 fracture-toughness methods, ER-72 general environmental ageing, and ER-283 vacuum components. ER-287 does not generalise room-temperature properties or one 77 K test into service-life equivalence.

2. Subject-specific state model and causal chain

For ER-287, causal interpretation begins by freezing resin and cure state, orientation, moisture/conditioning, temperature trajectory, dwell, constraint, pressure/fluid environment and number of cycles. Cooling changes modulus, contraction, fracture response and seal geometry simultaneously; a single low-temperature strength value cannot stand in for repeated cryogenic service.

3. Direct evidence and point-of-use source map

Pascua, Dullas, Lee and Shin directly tested a DLP photopolymer resin at room temperature and 77 K and reported embrittlement/failure associated with thermal contraction under their tensile-test conditions. ER-287 treats that result as a material-specific warning against room-temperature transfer, not as a class-wide failure rule. Reference [1] is used for direct DLP photopolymer mechanical/thermal-contraction evidence at 77 K.

4. Measurement architecture

The measurement architecture for ER-287 is built around thermal contraction/CTE across the relevant range, modulus/strength/strain or fracture response at temperature, dimensional recovery, crack inspection, seal/permeation endpoints where functional and repeated-cycle drift. Contraction, transition behaviour, fracture response and leak or permeation measurements are assigned to the actual thermal cycle and geometry used in service.

5. Qualification and transfer

Cryogenic transfer requires the proposed temperature excursion, dwell and cycle count to be represented, together with the geometry that governs contraction and stress concentration. Room-temperature similarity is not accepted as the bridge.

6. Failure modes and interpretation traps

The central interpretation trap in ER-287 is that room-temperature properties are used at cryogenic temperature; one cool-down is called cycle life; fixture constraint and differential contraction are omitted. The cryogenic gates deliberately separate contraction, transition, thermal shock, fracture, permeation and cycling because improvement or survival in one endpoint cannot erase failure in another.

7. Non-compensatory release gates

Gate	Minimum evidence	Blocking failure
Material state	Resin/print/cure/conditioning fixed	Generic photopolymer
Contraction	Thermal strain/contraction measured	Room-temperature dimensions used
Thermal transition	Relevant Tg/transition margin known	Nominal datasheet alone
Thermal shock	Cooling/rewarming rate and dwell represented	Slow single cool generalized
Fracture	Strength/strain or fracture evidence at cryogenic state	Room-temperature mechanics substituted
Permeation/leak	Function-specific low-temperature integrity checked	Mechanical coupon only
Cycling	Repeated thermal cycles represented	One excursion called service life
Functional geometry	Post-cycle dimensions/function verified	Survival without function

8. Minimum verification experiment

Measure dimensions and mechanical reference state at ambient conditions, cool specimens and representative geometry under a controlled rate to the target temperature, test at temperature, rewarm, inspect and repeat for a predeclared cycle count. Couple permeability or sealing tests only where they belong to the actual function.

9. Knowledge boundary

One bibliographically resolved DLP study demonstrates severe low-temperature embrittlement under its material and test conditions, but there is insufficient basis for a universal photopolymer cryogenic limit, cycle-life law or permeation prediction.

10. Conclusions

ER-287 restricts cryogenic-service claims to the demonstrated temperature history, geometry and cycle count and withholds equivalence based solely on room-temperature properties or a single cold test.

References

1. Richard G. Pascua, Gellieca Dullas, SangHeon Lee, Hyung-Seop Shin. Evaluation of mechanical properties of polylactic acid and photopolymer resin processed by 3D printer fused deposition modeling and digital light processing at cryogenic temperature. Progress in Superconductivity and Cryogenics. 2024;26(2):19-23. <https://doi.org/10.9714/psac.2024.26.2.019>

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