

Flame-Retardant Vat-Photopolymer Composites: Evidence Limits and Test Architecture

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Statement of Significance

A flame-retardant claim has no meaning without a named test, specimen thickness, orientation, conditioning state and acceptance criterion. A coated printed lattice and a flame-retarded bulk SLA formulation demonstrate different control routes. Neither establishes a transferable fire rating, smoke/toxicity performance or durability for another formulation or geometry.

Keywords: flame retardancy; vat photopolymerisation; coating; composite; UL 94; cone calorimetry; heat release; smoke; durability.

Abstract

This targeted engineering note examines direct evidence for two flame-resistance strategies in vat-photopolymerisation: a nanobrick-wall coating on printed lattices and a flame-retarded SLA resin for printed-circuit-board manufacture. It then builds a method-specific qualification architecture. Small-flame classification, oxygen-consumption calorimetry, smoke/effluent measurements and sector-specific tests answer different questions and cannot be converted into one another. Fire performance must remain bound to formulation, additive or coating state, print and post-cure history, specimen geometry, exposure and conditioning. Durability requires ageing followed by the same fire test. The note assigns no rating to a 3Dresyns product; 3Dresyn FR1 is treated only as a manufacturer-controlled candidate requiring finished-part validation. RP-02 supplies the shared evidence-to-decision method.

1. Scope and evidence boundary

The retained direct VPP evidence is narrow. Kolibaba et al. studied a multilayer nanobrick-wall coating applied to printed photopolymer lattices [1]. Reinšteinová et al. studied a flame-retarded SLA formulation for PCB manufacture [2]. These are distinct architectures: the first modifies a surface and the second modifies a bulk resin. Their specimens, loading, cure state and fire methods are not interchangeable. Numerical results are not pooled and no universal threshold is inferred.

A fire test result belongs to the tested assembly. Resin chemistry, flame-retardant identity and loading, dispersion, pigments, residual conversion, build orientation, surface area, thickness, porosity, supports and post-cure can all change ignition, melt/drip behaviour, char continuity and heat or smoke release. A formulation label or ingredient statement is therefore screening information, not a classification.

2. Evidence-supported route distinctions

- Coating route. Kolibaba et al. showed synergistic fire resistance for the coated lattice system they manufactured [1]. The evidence applies to the coating chemistry, layer architecture, coverage and lattice used. Damage, abrasion, cut edges or incomplete coverage can create failure paths, so coating adhesion and aged coverage are part of qualification.
- Bulk-formulation route. Reinšteinová et al. demonstrated that a flame-retarded stereolithography resin can be formulated and assessed for a PCB workflow [2]. The result supports feasibility, not automatic transfer to another photoinitiator, resin matrix, additive concentration, printer or final thickness.
- Geometry route. Lattices, plaques, vertical bars and enclosed electronic components experience different heat flux, oxygen access, dripping, edge ignition and heat-sink conditions. A rating on one geometry cannot be reworded as an intrinsic resin property.

3. Test methods answer different questions

UL 94 vertical or horizontal classifications describe small-flame behaviour of specified specimens, including afterflame, afterglow, dripping and ignition of indicator material under the selected procedure. They do not quantify heat-release rate, smoke density or toxic effluent. A thickness-specific classification must retain the tested thickness and conditioning.

ASTM E1354 and ISO 5660-1 use oxygen-consumption calorimetry to measure quantities such as time to ignition, heat-release rate, total heat release, mass loss and smoke-related outputs at a declared incident heat flux. Heat flux, orientation, backing, edge condition and specimen construction must accompany every value. NIST has shown that fire-effluent yields can be sensitive to oxygen concentration and apparatus conditions, which limits attempts to infer full-scale hazard from a single bench result [3].

Sector-specific requirements such as aircraft-interior flammability use their own specimen preparation, exposure and acceptance rules. Passing a screening method cannot be converted into compliance with another standard, code or finished-product requirement. Smoke and toxicity require separately named methods and analytes; 'low smoke' or 'low toxicity' must not be inferred from self-extinguishing behaviour.

4. Minimum qualification and reporting set

Control	Minimum record	Required interpretation
Material state	Exact formulation/lot, additive or coating, dispersion, colour, conversion and moisture	No transfer across unnamed or differently processed materials
Print state	Printer, wavelength, layer, orientation, supports, wash, dry and post-cure	Fire response belongs to the complete production state
Specimen	Geometry, thickness, mass, density/voids, edges, coating coverage and substrate	Retain the tested configuration with the result
Method	Standard/edition, apparatus, ignition, heat flux, orientation, atmosphere and calibration	Do not convert results between methods
Outputs	Afterflame/drip class or HRR, pHRR, THR, ignition, mass loss, smoke and analytes as applicable	Report measured outputs, uncertainty and replicates
Conditioning	Temperature/humidity plus wet, thermal, UV, chemical or mechanical ageing	Durability requires ageing and repetition of the same fire test
Trade-offs	Mechanical, thermal, electrical, dimensional and printability properties after FR modification	A fire improvement cannot hide loss of intended function
Claim gate	Named authority, application, criterion, thickness and configuration	A screening result is not a certification or product approval

5. Failure interpretation and durability

A shorter afterflame time can coexist with greater smoke, different dripping or reduced mechanical integrity. A lower peak heat-release rate can coexist with a longer burning duration or different total heat release. Intumescent or barrier coatings may crack, delaminate or lose coverage after service. Filled bulk systems can sediment before printing, agglomerate, attenuate cure light or create anisotropic char and mechanical response. These competing outcomes require a predefined decision table rather than a single 'flame-retardant' pass/fail label.

Durability claims require the intended ageing exposure followed by the identical fire test on conditioned and control specimens. At minimum, the protocol should consider moisture, temperature cycling, UV where relevant, solvent/cleaning exposure and abrasion or impact for exposed coatings. Visual retention alone is insufficient; coating continuity, adhesion and thickness should be measured before retest.

6. 3Dresyns implementation boundary

The 3Dresyn FR1 product page identifies a vat-photopolymer candidate and explicitly requires user validation of final fire performance, mechanics and printability. This manufacturer information is useful for route selection but is not independent evidence and no fire classification is asserted here. Implementation must freeze the exact controlled grade and TDS/IFU revision, including any high-viscosity variant, colour, printer, thermal control and post-cure, then test the finished geometry by the governing method. Source: <https://www.3dresyns.com/products/3dresyn-fr1-for-fire-and-flame-resistance>

7. Limitations and research priorities

Direct peer-reviewed evidence for fire-retarded VPP systems remains sparse and heterogeneous. The retained studies do not establish cross-formulation ranking, long-term durability, full-scale fire behaviour or a general relationship

between small-flame classification and calorimetry. Priority work is a matched matrix of neat and flame-retarded formulations printed in both orientations and multiple thicknesses, with rheology/cure-depth/dispersion control, small-flame and cone-calorimeter outputs, smoke/effluent analysis where required, mechanical trade-offs and post-ageing retest.

8. Conclusions

- Coated and bulk-modified VPP systems are separate evidence routes.
- Every claim must retain its method, specimen thickness, orientation, conditioning and complete material-process state.
- UL 94-type classification, cone-calorimeter outputs, smoke/toxicity measurements and sector tests are not interchangeable.
- Durability requires controlled ageing followed by repetition of the same fire test.
- No 3Dresyns product receives a public fire rating from this review; qualification belongs to the tested finished part and governing authority.

Declarations

References

- [1] Kolibaba TJ, Iverson ET, Legendre H, Higgins CI, Buck ZN, Weeks TS, Grunlan JC, Killgore JP. Synergistic Fire Resistance of Nanobrick Wall Coated 3D Printed Photopolymer Lattices. *ACS Applied Materials & Interfaces*. 2023;15(12):16046–16054. <https://doi.org/10.1021/acsami.3c00177>
- [2] Reinšteinová L, Zdráhal J, Uříčář J, Chodounská A, Veselý P. Flame-Retarded and Sustainable Stereolithography Resin for Printed Circuit Boards. 49th International Spring Seminar on Electronics Technology. 2026:1–6. <https://doi.org/10.1109/ISSE70010.2026.11600933>
- [3] Marsh ND, Gann RG. Smoke Component Yields from Bench-scale Fire Tests: 3. ISO 5660-1/ASTM E1354 with Enclosure and Variable Oxygen Concentration. NIST Technical Note 1762. 2013. <https://doi.org/10.6028/NIST.TN.1762>

Standards and regulatory methods

ASTM E1354-26. Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter. <https://store.astm.org/e1354-26.html>

ISO 5660-1:2015/Amd 1:2019. Reaction-to-fire tests—Heat release, smoke production and mass loss rate—Part 1: Heat release rate (cone calorimeter method) and smoke production rate (dynamic measurement). <https://www.iso.org/standard/57957.html>

14 CFR Part 25, Appendix F. Test Criteria and Procedures for Showing Compliance with §25.853 or §25.855. <https://www.ecfr.gov/current/title-14/chapter-I/subchapter-C/part-25/appendix-Appendix%20F%20to%20Part%2025>