

In-Space Vat Photopolymerisation: Containment, Optics, Heat, Motion and Part Release in Microgravity

Qualification of liquid-resin handling and light-based additive manufacturing outside terrestrial gravity and pressure conditions

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Abstract

In-space vat photopolymerisation is not terrestrial VPP placed in a spacecraft. Reduced gravity suppresses buoyancy-driven flow, pressure reduction expands trapped gases and promotes volatile loss, heat rejection changes, free surfaces become capillary-dominated and part release cannot rely on weight. Recent photopolymer manufacturing experiments under microgravity and reduced pressure provide direct evidence for several of these effects. This review converts that evidence into a qualification framework for containment, resin preparation, optics, thermal control, motion, interfaces and part release, while separating true VPP requirements from adjacent extrusion demonstrations.

Keywords: in-space manufacturing; vat photopolymerisation; microgravity; vacuum; containment; thermal control; bubbles; optics; part release

1. Significance and scope

Photopolymer processing is attractive for in-space manufacturing because curing energy can be localized and the feedstock is compact before use. The same liquid state that makes the process versatile creates mission-specific hazards: uncontrolled free surfaces, gas expansion, volatile loss and contamination [1-3].

ER-444 owns the physics of how microgravity changes photopolymer cure and network uniformity. The present review owns the machine-level VPP problem: keeping resin where it belongs, delivering light and motion predictably, and separating the finished part without relying on terrestrial gravity.

2. Containment, gas state and optical boundary

A terrestrial vat can assume a stable gravitational free surface and passive drainage. In microgravity, containment must be established by walls, capillarity, compliant reservoirs, membranes or another engineered boundary. Every fill, vent and return path becomes part of the process definition.

Reduced-pressure and microgravity experiments with photopolymer specimens show that gas expansion and interface instability can create severe morphological artefacts, making degassing and controlled filling central process steps rather than optional preparation [1].

The optical path must remain defined even when the resin interface is curved, displaced or bubble-contaminated. Window wetting, meniscus geometry, particle or pigment settling and bubble occlusion can all alter local exposure.

3. Optics and free surfaces are coupled

Qualification should couple optical calibration to the actual containment geometry. An irradiance map measured through a dry window is not equivalent to the dose field delivered through a mission resin layer with evolving interfaces.

Photopolymerisation is exothermic. Recent ISS and parabolic-flight work shows that suppressed natural convection in microgravity can increase thermal buildup and produce surface blistering or deformation in some formulations [2].

4. Heat rejection changes in microgravity

Thermal qualification should measure temperature at the curing region, not only chamber temperature. Exposure strategy, absorber concentration, build size and conductive paths to the machine can all shift local peak temperature.

Cooling concepts that are effective on Earth may fail when buoyancy-driven air or liquid flow disappears. Forced convection, conduction to a controlled fixture or staged exposure should be qualified as part of the process rather than assumed from terrestrial printer behaviour.

Stage motion can disturb a capillary-held liquid even when the nominal acceleration is small. Start-stop profiles, vibration, spacecraft manoeuvres and recoater motion should therefore be included in interface-stability tests.

Gas management must include dissolved gas as well as visible bubbles. A resin that is bubble-free at ambient pressure may nucleate or expand gas after pressure reduction; vacuum screening of liquid photopolymers confirms that formulation volatility and pre-degassing materially affect behaviour [3].

5. Motion, gas management and device-level verification

Contamination control must also consider condensable volatiles on optics, radiators and spacecraft surfaces. A process can print successfully and still be unacceptable if it deposits contamination elsewhere.

Part release in bottom-up or constrained VPP requires a reaction force path. Weight cannot be relied upon to hold the vat, drain the part or move debris away. Release films, peel kinematics and capture features should be verified under the intended acceleration environment.

Device-level testing should run a complete sequence: storage, fill, degas or condition, expose, reposition/recoat, release, remove and secure the part, and recover unused resin. Demonstrating only cure is not demonstrating an in-space manufacturing system.

Axis	Measurement	Failure mode
Containment	free-surface and leak control	gravity-dependent vat assumed
Optics	dose through actual interface	dry optical calibration over-transferred
Thermal	local cure temperature and heat path	chamber temperature used as proxy
Gas/motion	degassing, bubbles, acceleration profile	ambient bubble-free state assumed stable
Release	peel/release and part capture	weight-dependent separation or drainage

Table 1. Domain-specific qualification matrix for in-space vat photopolymerisation.

6. Transfer limits and minimum reporting dataset

Failure containment should be explicit. A ruptured film, bubble burst or mis-release must not create free-floating liquid or uncured contamination beyond the manufacturing enclosure.

Report resin identity and conditioning, pressure, acceleration environment, containment geometry, interface state, optical path, dose, thermal history, motion profile, gas observations and contamination controls.

For VPP qualification, add dimensional fidelity, cure completeness, release force or success criteria, retained resin recovery and post-process handling under the same environmental sequence.

7. Minimum qualification framework

A minimum in-space VPP qualification programme should instrument the resin containment system, optical exposure, thermal state and separation event as one coupled process. Reservoir pressure, free-surface location, gas inventory, temperature, dose and part-release force should be logged on the same build so that anomalies can be assigned to a physical mechanism.

Verification should progress from contained fluid handling to single-layer exposure, multilayer build, release and post-cure under the intended gravity/pressure envelope. Ground controls and reduced-gravity tests should use matched resin state and thermal history; otherwise differences attributed to gravity may actually arise from temperature, trapped gas or hardware configuration.

8. Engineering conclusions

In-space vat photopolymerisation is therefore a spacecraft process as much as a materials process. Qualification succeeds when resin containment, heat rejection, optical delivery, motion and part release remain controlled together; a resin that prints well on Earth is only one component of that evidence chain.

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Competing interest

Juan Segurola is founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L., which develops and commercialises photopolymer materials and related additive-manufacturing technologies. This review is an engineering analysis and does not constitute a product-performance claim or a device qualification.