

Outgassing and Vacuum Qualification of Photopolymer Materials and Vat-Printed Parts

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Statement of Significance

Liquid-resin vacuum screening, cured-coupon outgassing, volatile-emission identification and qualification of a finished vacuum assembly are different evidence layers. ASTM E595 quantities support material screening, but acceptance belongs to a named programme and frozen processed article. TML, WVR, RML and CVCM must not be conflated.

Keywords: outgassing; vacuum; TML; WVR; RML; CVCM; photopolymer; contamination; qualification.

Abstract

This targeted engineering review separates three questions often collapsed under “low outgassing”: behaviour of liquid photopolymers under vacuum, volatile compounds emitted from cured stereolithography parts and standardized thermal-vacuum mass-loss screening. Primary studies confirm that liquid and cured states require different evidence and that processing operations can emit identifiable volatile compounds. ASTM E595 measures total mass loss and collected volatile condensable material under a defined accelerated condition; ECSS applies retained mass loss and CVCM criteria where its programme governs. Neither method alone establishes long-duration mission compatibility, optical contamination, mechanical retention or lot-to-lot equivalence. The paper defines the minimum material-process-specimen record, conditioning and bakeout controls, witness/functional tests and claim boundaries required for a finished vat-printed article. RP-02 supplies the shared evidence-to-decision method.

1. Scope and evidence boundary

Kringer et al. screened liquid photopolymer resins under high vacuum [1]. Pham et al. identified volatile compound emissions from cured SLA resin models [2]. Zisook et al. measured emissions associated with several additive-manufacturing operations [3]. These studies answer different questions: liquid stability and bubble/volatile behaviour, cured-part chemical emissions, and workplace exposure during production. None substitutes for thermal-vacuum qualification of a finished spacecraft or high-vacuum component.

A vacuum claim must remain bound to exact resin lot, printer, exposure, wash, dry, post-cure, age, specimen geometry, surface-to-volume ratio and any bakeout. Pigments, fillers, residual monomer, trapped cleaner, absorbed water, supports and internal channels can change the result. A database entry for a similarly named material is not evidence for an untested formulation or production state.

2. Evidence layers and what they support

- Liquid-state screening can identify foaming, mass transport, contamination or cure-related risks before printing, but it does not quantify emissions from the final crosslinked network [1].
- Cured printed parts can emit volatile compounds whose identity and amount depend on resin and post-processing [2]. Chemical identification adds information that gravimetric loss alone cannot provide.
- Operational emission measurements are relevant to worker and facility exposure controls, not to spacecraft material acceptance [3].
- Standard outgassing screening is necessary when required by the governing programme, but the test specimen must reproduce the approved cure, cleaning, conditioning and bakeout state.

3. TML, WVR, RML and CVCM

In ASTM E595-type testing, total mass loss (TML) is the specimen mass fraction lost during the prescribed thermal-vacuum exposure. Collected volatile condensable material (CVCM) is the fraction collected on the controlled-temperature collector. Water-vapour regained (WVR) is the mass fraction recovered during the specified reconditioning step. Retained mass loss (RML) corrects TML for regained water, commonly expressed as $RML = TML - WVR$. TML and RML are therefore not synonyms, and neither is a chemical identification of the evolved species.

NASA's outgassing database documents cure conditions with TML, CVCM and, where available, WVR, and warns that material formulations and manufacturing lots can change over time [4]. Historical screening values of 1.0% TML and 0.10% CVCM are useful context, not universal acceptance limits. ECSS-Q-ST-70-02C applies RML below 1.0% and CVCM below 0.10% where that standard governs. Project-specific requirements may be stricter or add contamination, optical or electrical controls.

4. Minimum qualification and reporting set

Control	Minimum record	Required interpretation
Article state	Formulation/lot, printer, orientation, layer, wash, dry, post-cure, age, coating and assembly	The claim belongs to the frozen finished state
Preconditioning	Temperature, humidity, duration, storage and starting mass method	Water history can dominate TML/WVR interpretation
Test	Standard/edition, vacuum, specimen/collector temperatures, duration, mass, geometry and replicates	Do not compare results from unmatched methods or states
Outputs	TML, WVR, calculated RML, CVCM and uncertainty; evolved-species analysis when needed	Keep gravimetric and chemical evidence distinct
Bakeout	Temperature, pressure, ramp, duration, load, post-bake storage and repeat measurement	Bakeout is a controlled process change, not data deletion
Contamination	Witness plates, optical transmission/reflectance or surface analysis at representative view factor	Low bulk loss does not prove absence of critical deposition
Function	Dimensions, leakage, electrical/optical response and mechanics before/after vacuum and thermal cycling	Coupon screening cannot replace assembly performance
Change control	Lot, supplier formulation, pigment/filler and process-revision triggers	Critical uses may require lot or change-specific retest

5. Bakeout, geometry and mission interpretation

Bakeout can reduce removable volatiles, but it can also advance cure, relax stress, oxidize the network, embrittle a part or alter dimensions. The pre-bake and post-bake article are different states. A qualification report must retain both the bakeout recipe and evidence that required mechanical, dimensional, optical or sealing functions remain acceptable afterward.

Small coupons may not represent internal channels, blind volumes, adhesive interfaces or high surface-area lattices. Conversely, mass-loss screening does not reproduce every mission temperature, radiation exposure, view factor or long-duration desorption process. Where contamination of optics, sensors or electronics is critical, witness surfaces and functional testing in a representative thermal-vacuum configuration are necessary additions.

6. 3Dresyns implementation boundary

The Microfluidic 3Dresyn MF HDT LV1 Clear page describes “extremely low outgassing” and vacuum-oriented uses as manufacturer product information. ER-46 does not treat that wording as independent qualification or as an ASTM/ECSS result. Any project use must identify the exact controlled grade and TDS/IFU revision, reproduce its printer, cleaning, post-cure and bakeout state, and test the finished article under the governing acceptance plan. Source: <https://www.3dresyns.com/products/microfluidic-3dresyn-mf-hdt-lv1-clear-high-deflection-temperature-with-low-viscosity>

7. Limitations and research priorities

Direct peer-reviewed outgassing data for named vat-printed formulations remain limited. Existing studies use different resin states, analytical methods and exposure purposes. Priorities are matched liquid/cured/printed comparisons; post-cure and bakeout dose-response; evolved-species identification alongside TML/RML/CVCM; high-surface-area and channel geometries; witness contamination; thermal cycling; and lot-to-lot repeatability. Public claims should expose the exact method, specimen state and acceptance authority.

8. Conclusions

- Liquid-resin screening, cured-part emissions and finished-assembly vacuum qualification are distinct evidence layers.
- TML, WVR, RML and CVCM must be reported and interpreted separately.
- ASTM E595 is a test method; acceptance limits come from the governing programme and application.
- Bakeout and post-cure define a new material state whose function must be revalidated.
- No 3Dresyns product is presented here as space-qualified; qualification belongs to the tested article and project authority.

Declarations

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Standards

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