

Returned-Part Analysis for Printed Photopolymers

Reconstructing Cure State, Exposure History and Contamination from a Failed Component

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Treatment: Identifiability limits in reconstructing cure state, exposure history and contamination.

Statement of significance

A returned photopolymer part provides a present material state, not a recording of one unique manufacturing and service history. Post-cure, environmental ageing and depletion of mobile species allow different histories to converge on similar measurements. This review defines the resulting identifiability limits and the known-history evidence required before a historical reconstruction can be licensed.

Abstract

Post-hoc measurements of a failed vat-photopolymerised component may reveal conversion, thermal transitions, mechanical state, gradients, extractables, contamination or damage at the time of examination. They do not automatically identify the original cure dose, exact exposure history or contamination event. The limitation follows positively from established forward mechanisms: reaction can continue after printing, environmental and thermal ageing can change conversion and network response, and extractable species can deplete during washing, conditioning and service. The mapping from history to measured returned state is therefore potentially many-to-one. ER-180 presents an identifiability-limits framework that separates observation, candidate histories, discriminating measurements and independent validation. It reports separately that no controlled known-history forensic VPP dataset was recovered. This absence is an evidence gap, not proof of impossibility. No attribution rule, confidence figure or universal method-capability threshold is proposed.

Keywords: vat photopolymerisation; returned part; forensic analysis; identifiability; cure state; exposure history; contamination; ageing; extractables; uncertainty

1. Scope and ownership

ER-180 addresses what can and cannot be determined about manufacturing and service history from post-hoc measurement of an already-failed printed photopolymer part, and what independent validation would be required to support a reconstruction claim.

ER-027 retains controlled-specimen conversion metrology. ER-072 retains ageing mechanisms. ER-086 retains extractables method design. ER-184 retains general cross-mechanism diagnostic inference. Complaint handling, trending and corrective-action workflow are outside ER-180.

2. Observation is not history

A returned part contains measurable consequences of formulation, printing, washing, post-cure, storage, use, environment and failure. The same measurement can be compatible with several histories. A low present conversion could reflect low initial cure, spatial attenuation, inhibition, later chemical change or a measurement limited to a nonrepresentative location. A reduced extractable concentration could reflect high initial conversion, effective washing, diffusion during service or prior leaching.

The analyst should therefore state observations before assigning causes. Instrument output, derived material state and historical attribution are different evidential levels.

3. The positive many-to-one argument

Non-unique reconstruction is not inferred from a lack of studies. It follows from independently established forward processes.

First, cure state can evolve after the build through post-cure, gelation, vitrification and continuing reaction [1]. Second, thermal, photochemical, chemical and environmental ageing can further change conversion, network mobility, stiffness and chemical signatures [2]. Third, mobile and extractable species can be removed progressively by washing, conditioning and service exposure [5]. Consequently, distinct combinations of initial exposure and later history can converge on similar present measurements.

This many-to-one mapping means that inversion requires additional information. It does not mean reconstruction is impossible in principle. A sufficiently discriminating set of measurements and known-history validation could separate defined candidate histories.

4. Define the claim before choosing the method

“Reconstruct the history” is too broad to validate. A claim should identify the variable to be inferred, its range and resolution, the formulation and geometry domain, permitted service histories, specimen locations, measurement methods and decision output. Distinguishing two declared cure states is a different claim from estimating continuous dose, identifying a contaminant source or assigning root cause.

5. Preserve the returned state and provenance

The investigation should record part identity, location and orientation, receipt condition, packaging, known service information, storage after return, sampling and every destructive or cleaning step. Measurements should distinguish exposed surfaces, fracture surfaces, interior material, interfaces and retained liquid where present.

Preservation matters because washing, cutting, heating and solvent extraction can change the very quantities being used to infer prior state. A destructive sequence should be planned so that one method does not erase evidence needed by another.

6. Measurement families and their limits

FTIR or Raman measurements can provide spatially resolved information about chemical groups or reaction state when validated for the actual material [1,4]. DSC and DMA can probe thermal or network response [1,2]. Extraction and chromatographic or spectrometric methods can detect mobile species [5]. Microscopy and dimensional or fracture examination can localise damage and interfaces. These citations identify the controlled method owners; they do not constitute a validated forensic reconstruction dataset.

Each family measures a present attribute. No single result is automatically a historical timestamp or dose meter. Method penetration, spatial averaging, calibration, detection limits, sample preparation and ageing sensitivity must be recorded.

7. Cure-state reconstruction

Conversion measurements can compare a returned specimen with reference specimens, but equivalence depends on formulation identity, spectral and thermal history, sampling location and method response [4]. A post-cured initially underexposed part may approach the measured conversion of a differently exposed part while retaining a different network or gradient. Reconstruction therefore needs multiple observables chosen to separate the candidate paths.

8. Exposure-history reconstruction

Exposure includes more than printer dose. It can include wavelength distribution, irradiance-time history, repeated layer exposure, scattered or transmitted light, post-cure and environmental radiation. A present state

may integrate these contributions without retaining a unique signature for each. Any claimed inference of original printer settings must be validated against later histories capable of producing similar measurements.

9. Contamination attribution

Detecting a compound does not by itself identify when or where it entered. Candidate sources may include raw materials, processing aids, wash media, packaging, service contact, degradation products and analytical handling. Source attribution requires discriminating markers, blanks, controls and a chain of custody. Depletion or transformation can make a prior event undetectable; a nondetect is bounded by sampling and method capability.

10. Candidate-set discipline

Before interpretation, the analyst should list plausible histories and the observations each predicts [3]. Measurements should be selected for their ability to discriminate between candidates, not simply because they are available. An eliminated candidate needs a test capable of observing its expected consequence in the relevant location and state.

If several histories remain compatible, the result should remain unresolved. Selecting the most familiar explanation does not increase identifiability.

11. Known-history validation

A reconstruction claim requires specimens whose relevant histories are independently known and deliberately varied. The validation set should include competing histories expected to converge on similar present states, not only extreme positive and negative controls. The analytical and interpretive procedure should be prespecified and applied without access to the assigned history where practical.

Performance reporting must match the claim. Classification between defined states, numerical estimation and contaminant-source attribution require different statistics and controls. ER-180 supplies no confidence value or universal acceptance criterion.

12. Evidence gap

No controlled known-history forensic VPP dataset was recovered that combines declared manufacture, later ageing or contamination histories, post-hoc measurements and independently verified historical labels across the ER-180 scope. This is reported separately from the many-to-one mechanism argument. It does not establish that no such dataset exists and does not prove that reconstruction is impossible.

The most valuable study would publish paired or factorial histories designed specifically to test confounding: for example, different initial cure states followed by different post-cure or ageing routes that produce overlapping present conversion, mechanical or extractables measurements. The study would then test whether additional observables recover the known labels.

13. What cannot presently be claimed

The evidence does not support universal reconstruction of cure dose, exposure history, contamination event or manufacturing cause from a returned part. It does not support an attribution rule, confidence figure, method-capability threshold or claim of impossibility in principle. A successful case study does not validate transfer to another formulation, geometry, history or failure mode.

14. Conclusions

Returned-part analysis can characterise present state and narrow candidate histories, but it does not automatically invert state into one cause. Continuing cure, ageing and depletion of mobile species provide a positive many-to-one reason for caution. Historical reconstruction becomes defensible only for a defined

claim validated with known-history specimens and relevant competing paths. Until then, unresolved attribution is a legitimate technical result.

Related Engineering Review boundaries

ER-180 owns identifiability limits in returned-part historical reconstruction. ER-027 retains controlled conversion metrology; ER-061 gelation, vitrification and mobility arrest; ER-072 ageing mechanisms; ER-086 extractables method design; and ER-184 general diagnostic inference under uncertainty. ER-160 is not a mechanism owner for this article: the controlling register assigns ER-160 to *Extreme-Service Specialty Resins*.

References

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Competing interests

The author is Founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L. No comparative product recommendation is made.

Data availability

No new experimental dataset was generated. The controlled copies of ER-027, ER-061, ER-072 and ER-086 used for the bounded mechanism and method-owner statements are included in the independent-review package with their SHA-256 identities recorded in the source ledger. ER-184 remains directly resolvable by DOI. The absence of a recovered known-history dataset is reported as an evidence gap, not as proof of absence.

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