

Standardised Failure Reporting for Photopolymer Parts: Taxonomy, Minimum Evidence, Root Cause and Learning

A proposed reporting architecture that separates observed failure, classification and causal inference

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Abstract

Failure reports are most useful when they preserve the difference between what was observed, how it was characterized, how the event was classified and what cause is only inferred. Direct reviews of defects in ceramic vat photopolymerisation show that VPP has process-specific defect types, characterization methods, mechanisms and control strategies [1,2], but those reviews do not establish a universal taxonomy across photopolymer materials. Current additive-manufacturing standardisation also separates common failure-mode and risk-mapping concepts from technology-specific treatment, while the published classification standard for metallic powder-bed fusion demonstrates that imperfection classification and probable-cause information can be distinct layers [3,4]. On that bounded evidence, this review proposes a photopolymer failure-reporting architecture and a minimum failure record for use within the Engineering Review corpus. The record is an author-proposed framework, not an externally established universal standard. It captures observed signature, location, characterization evidence, classification status, causal hypothesis, uncertainty and learning linkage while preventing a suspected mechanism from being recorded as an observed fact. ISO/ASTM DIS 52954-1 remains a Draft International Standard under development and may change before publication. No acceptance criterion, operational threshold or universal VPP cause list is proposed. A worked hypothetical failure record and an independent-coder exercise make the proposed taxonomy testable on evidence preservation and classification consistency.

Keywords: vat photopolymerisation; failure reporting; defect taxonomy; minimum evidence; root cause; classification; learning; uncertainty

1. Scope and ownership

ER-484 owns the general failure taxonomy and the minimum failure record for photopolymer parts, including the separation of observed failure from inferred cause and the evidential status of root-cause attribution. It does not own warranty or returned-product lifecycle evidence, exposure reconstruction or feedback tied specifically to returns; those belong to ER-483. Cost-of-quality consequences remain with ER-472.

The purpose is not to declare a universal industry standard. It is to define a disciplined reporting architecture that can be reviewed, compared and improved without collapsing observation, classification and causation into a single label.

2. Failure reporting has distinct evidential layers

A failure record begins with an event or condition that has been observed. Classification is a subsequent act that groups the observation according to a defined taxonomy. Root-cause attribution is a further inference that links the observation to a mechanism, process state or service condition. These layers can agree, but they are not interchangeable.

When the layers are collapsed, a visually plausible cause can become encoded as fact and then propagate into trend analyses, corrective actions and later reviews. ER-484 therefore requires the reporting structure to preserve the path from observation to classification to causal hypothesis, including the evidence used and the uncertainty that remains.

3. What direct VPP defect literature can support

Reviews by Zhang and colleagues and by Wu and colleagues describe defects in ceramic vat photopolymerisation together with characterization, mechanisms, detection or control considerations [1,2]. The available publisher abstracts support the existence of VPP-specific defect classes and the need to connect defect description with characterization and control.

Their scope is ceramic VPP. ER-484 therefore does not promote the categories in those reviews into a universal cross-material photopolymer taxonomy. A classification useful for one feedstock, geometry or process state may need to be refined or qualified in another. The reporting architecture must be stable enough for comparison while allowing technology-specific classes to evolve under change control.

4. Standardisation direction and its limits

ISO/ASTM DIS 52954-1 addresses common failure modes used for process risk mapping across additive manufacturing [3]. It remains a Draft International Standard under development and can change before publication. ER-484 uses it only as evidence that failure-mode and risk-mapping concepts are being standardized at a cross-AM level, not as a published or VPP-specific taxonomy.

ISO/ASTM 52948:2026 addresses classification of imperfections in metallic powder-bed-fusion parts [4]. Its relevance here is methodological: a classification standard can define imperfection classes while keeping probable causes process-specific. The metal classification is not transferred to VPP, and no metal-specific class or acceptance concept is reused as a photopolymer rule.

5. Proposed taxonomy architecture

The proposed ER-484 taxonomy is layered rather than exhaustive. A report first records the observable signature, then places it in a controlled failure class suitable for aggregation, and only then records candidate causes and their evidential status. This allows different analytical methods to converge on the same observation without requiring immediate agreement on mechanism.

Taxonomy terms should be defined by observable or measurable features wherever practical. Cause-oriented labels should be reserved for cases where the causal evidence is separately stated. When a failure could plausibly belong to several classes, the record should preserve that ambiguity instead of forcing an apparently precise category.

Layer	Question answered	Reporting rule
Observed signature	What is present or what function failed?	Describe the condition before assigning a mechanism.
Location and distribution	Where is the condition and how is it distributed?	Preserve spatial information relevant to comparison and characterization.
Characterization evidence	How was the condition detected or measured?	Record the evidence type so the classification can be audited.
Failure class	How is the observation grouped for comparison?	Use controlled terminology and retain taxonomy-version identity.
Cause hypothesis	What mechanism or process state may explain it?	Keep hypothesis separate from observation and classification.
Causal evidence status	How strongly is the cause supported?	State support, competing explanations and unresolved evidence.
Learning linkage	What investigation or control change follows?	Link action to the evidence that motivated it without treating action as proof.

6. The proposed minimum failure record

The minimum failure record below is an author-proposed corpus framework derived from the reporting needs supported by the bounded sources [1-4]. It is not claimed to be an externally established universal VPP record. Its purpose is to prevent loss of the evidence needed to understand what happened, how it was classified and how far causal interpretation can legitimately go.

Record element	Why it is retained	Evidence boundary
Record and object identity	Keeps the report traceable to the physical or digital object under investigation.	Identity does not itself establish cause.
Observed failure signature	Preserves the condition or functional failure before interpretation.	Observation must not be rewritten as mechanism.
Location and distribution	Allows comparison of localized, distributed or geometry-linked manifestations.	Spatial pattern may suggest but does not prove cause.
Characterization evidence	Identifies how the observation was detected or measured.	Method capability must be evaluated separately when it matters.
Controlled failure class and taxonomy version	Supports aggregation while making category definitions auditable over time.	No universal VPP class list is asserted.
Cause hypothesis and evidential status	Separates suspected mechanism from established observation.	Competing explanations remain visible.
Relevant context available to the investigation	Preserves manufacturing, storage, service or test context when known.	Missing context is not imputed.
Learning and disposition linkage	Connects the report to investigation, control or corrective learning.	Action taken is not proof of causal correctness.

7. Root-cause attribution

Root-cause analysis should begin from the failure record rather than replace it. A cause statement is strongest when it explains the observed signature, is compatible with location and characterization evidence, and distinguishes competing explanations. When the evidence does not discriminate among mechanisms, the correct record is an unresolved or provisional attribution, not a forced single cause.

This separation also protects corpus learning. If later evidence changes the causal interpretation, the original observation and classification remain available for reanalysis. The system can therefore learn from revised hypotheses without rewriting the historical event itself.

8. Learning without taxonomy drift

Failure reporting becomes a learning system when repeated events can be compared under controlled definitions. Taxonomy changes may be necessary as new materials, process modes or analytical methods expose previously hidden distinctions. Such changes should be versioned so that a trend is not created merely by renaming categories.

Learning can occur at several levels: a recurring observed signature can trigger deeper characterization; an unresolved class can motivate a new discriminating test; a supported mechanism can motivate a process-control change; and a corrected interpretation can refine the taxonomy. The record should preserve these transitions rather than presenting the latest interpretation as though it had always been known.

9. Relationship to ER-483 and ER-472

ER-484 provides the failure taxonomy and minimum failure record that can be used whether a failure is discovered during production, testing, service or return. ER-483 adds the warranty and returned-product context, return-linked coding, constrained exposure reconstruction and feedback workflow for events that reach those channels.

ER-472 retains only the cost-of-quality consequences associated with failures. Cost classification is therefore downstream from the failure record and does not redefine the technical taxonomy or the evidence required to support causal attribution.

10. A worked failure record without premature cause assignment

Consider a hypothetical printed component found with a crack near a supported region after a functional test. The initial observation is the crack and the loss of the specified function. The record would preserve photographs, location, examination method, the state at which the crack was first observed and the test history. The proximity to a supported region is contextual evidence; it does not by itself establish support removal as the cause.

A proposed classification could describe the visible crack by a defined observable category and retain the taxonomy version. Candidate causes would be entered separately, each with supporting evidence and alternatives. If the crack was not examined before the functional test, the time of initiation would remain uncertain. The record should not silently convert first detection into the time of formation.

A later examination might identify an additional feature or reject an earlier hypothesis. The original observation should remain accessible, with the new interpretation linked as a revision. This allows the same event to support learning without creating two apparent failures or losing the history of the investigation.

11. Evaluate whether the taxonomy improves reporting

The proposed architecture can be tested rather than accepted only because its fields appear sensible. Independent coders could classify the same set of sufficiently documented cases using a fixed version of the taxonomy. The evaluation would report agreement, unresolved assignments and the reasons for disagreement. A consensus reached after discussion should be distinguished from initial independent agreement.

The test set should include ambiguous and incompletely documented cases. A taxonomy that forces every case into a precise cause category may produce apparent completeness while degrading inference. An explicit unresolved category is useful when it preserves the actual evidence limit. Its frequency should be interpreted with the case mix and documentation depth, not automatically as poor reporting performance.

When a category is split, the change record should state whether old cases can be recoded from retained evidence. If the required distinction was never captured, historical cases should not be assigned by guesswork. Trends across versions can then either use a justified mapping or remain separated. This makes the proposed minimum record assessable on consistency and preservation of evidence while leaving universal acceptance limits and consensus terminology unclaimed.

Supplementary critical engineering analysis: Failure taxonomy and causal confidence: Observed failure morphology, mechanism hypotheses and confirmed root causes must occupy separate fields. A surface crack, for example, can be recorded reproducibly without immediately classifying the mechanism as overcuring, cleaning damage, brittle geometry or ageing. A useful record must preserve inspection method, image scale, orientation, feature location and the time at which the failure was first observed. Causal confidence should be explicitly graded against alternative explanations and the discriminating tests actually performed.

Inter-laboratory comparability and learning: An apparently common defect code does not make measurements comparable when exposure settings, layer geometry, conditioning and acceptance thresholds differ. A controlled vocabulary should therefore be paired with defined observation procedures, controlled revisions and links to raw evidence. Proposed root causes should be updated only through a documented adjudication step, without overwriting the first observation. This section describes an engineering reporting proposal rather than a validated universal failure-classification standard.

Additional critical synthesis: evidence, applicability and qualification: Distinguishing reproducible observation from causal diagnosis: The minimum failure record should be useful even before a root cause is known. It should capture article identity, geometry, build orientation, failure feature location, inspection method, scale, time of first observation and the current evidence status. Description of fracture, distortion, incomplete cure or dimensional drift is not itself proof of the underlying mechanism. This separation permits analysts at different sites to code the same observed feature while disagreeing, legitimately, about its cause. Competing explanations should remain visible until a discriminating test supports their rejection.

Testing whether a taxonomy improves learning: Taxonomic quality can be evaluated with a blinded coding exercise in which independent reviewers classify a common set of records. Agreement should be measured by category and by severity of disagreement, not merely by an aggregate percentage. A category with poor agreement may need clearer definition or a mandatory image standard. A second

test should assess whether using the record leads to faster or more accurate discrimination of causes compared with unstructured narratives. Neither a long defect list nor a well-presented diagram validates a reporting standard without such testing.

Boundaries relative to returns and economics: ER-484 defines the observation language and minimum failure evidence applicable to production and field observations. ER-483 uses that language for the selected subset of warranty and returned products, including exposure reconstruction and reporting bias. ER-472 addresses the costs that failures generate. The three articles can share controlled codes without claiming that all observations have the same denominator, evidence quality or economic significance.

Critical evidence synthesis: Failure-taxonomy validation: repeatability before causal inference: Failure coding should distinguish observable morphology, functional consequence and proposed cause as separate fields. Two reviewers may agree that an object contains delamination yet disagree on whether incomplete cure or mechanical overload initiated it. Collapsing those fields into a single failure code prevents reliable comparison and encourages a taxonomy to become an untested causal theory. A practical validation exercise would present blinded failure records to independent assessors and measure agreement first on observations and only then on causal categories.

Classification performance must be assessed on difficult cases as well as clear exemplars, including insufficient-evidence and multiple-mechanism outcomes. An apparent improvement in agreement can arise simply because a scheme permits very broad codes; this must be balanced against its ability to support actionable root-cause investigations. The minimum failure record should preserve geometry, process history, condition at examination, applicable test conditions and chain of evidence, while avoiding forced diagnoses where the data are inadequate. Warranty return reconstruction remains with ER-483.

Failure-code validation and inter-reviewer agreement: A minimum failure record should separate observation from causal attribution. Crack location, geometry, surface condition and the operating stage are observable variables; insufficient washing, oxygen inhibition or resin ageing are hypotheses unless supported by discriminating evidence. A multilevel code can preserve both dimensions, preventing a plausible mechanism from being recorded as an established fact. The same photograph may support more than one candidate cause, so the coding system must include an explicit unresolved category.

To test taxonomy reproducibility, multiple trained reviewers should independently assign codes to a shared blinded case set, then adjudicate differences by documented rules. Agreement should be reported by code family, because overall accuracy can conceal poor performance for rare but consequential mechanisms. Longitudinal review should identify codes used inconsistently or requiring excessive “other” entries. ER-484 owns the generic failure classification and the minimum record; evidence from returned products and exposure reconstruction is treated separately in ER-483.

12. Evidence limitations

The direct VPP evidence supporting this review consists of ceramic-VPP defect reviews available only at abstract level [1,2]. The standards evidence consists of an unpublished draft for common AM failure modes and a published metal-PBF imperfection-classification standard used only as a methodological analogue [3,4]. These sources do not establish a universal cross-material VPP taxonomy or a universal minimum failure record.

The framework in this review is therefore explicitly proposed rather than claimed as consensus. No operational threshold, numerical acceptance criterion, universal root-cause list or defect-frequency claim is introduced. Future validation should test whether the proposed record preserves sufficient evidence across different photopolymer materials and failure contexts without encouraging false causal certainty.

13. Conclusions

Standardised failure reporting is primarily an evidential discipline. The report must preserve what was observed, how it was characterized, how it was classified, what cause is hypothesized and what remains uncertain. A taxonomy that does not preserve those distinctions can make aggregation easier while making engineering inference less reliable.

ER-484 therefore proposes a layered taxonomy and a minimum failure record for the Engineering Review corpus, while explicitly declining to present either as an externally established universal VPP standard. The architecture is designed to support comparison, root-cause learning and future refinement while keeping warranty-return workflows with ER-483 and failure-cost consequences with ER-472.

References

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Competing interests

The author is Founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L. The company develops and supplies photoresins and related process materials. No proprietary formulation, manufacturing sequence, process window or comparative product recommendation is disclosed.

Data availability

No new experimental dataset was generated.

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