

Micro-Computed-Tomography Qualification of Printed Photopolymers

Porosity, internal defects, segmentation and detection limits

Juan Seguro

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Correspondence: info@3Dresyns.com · www.3Dresyns.com

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Abstract

X-ray micro-computed tomography can reveal pores, inclusions, channels and internal geometric departures in printed photopolymers without sectioning the part. Its three-dimensional output is attractive for qualification, but a reconstructed volume is not a direct map of physical truth. Detectability depends on attenuation contrast, source spot, magnification, detector sampling, acquisition noise, reconstruction, artefact correction and the orientation and morphology of each indication. Quantitative porosity additionally depends on the segmentation rule, region of interest and treatment of partial-volume voxels.

This review defines a bounded qualification architecture for micro-CT examination of vat-photopolymerised and related printed photopolymers. It distinguishes nominal voxel size from spatial resolution, visible indication from validated defect, and repeatable segmentation from metrologically supported volume fraction. It develops controls for specimen geometry, scan setup, reconstruction, threshold selection, detectability experiments and uncertainty. Porosity analysis, dimensional comparison and defect localisation are treated as different measurement tasks that require separate validation. The central conclusion is that micro-CT supports qualification only when the complete measurement chain and its task-specific detection limit are demonstrated on representative material and geometry. The review does not select among non-destructive evaluation modalities and does not prescribe universal acceptance criteria.

Keywords: micro-computed tomography; X-ray CT; photopolymer; porosity; internal defects; segmentation; spatial resolution; detection limit; uncertainty; additive manufacturing

1. Significance and scope

Internal voids and geometric discontinuities can control leakage, optical performance, fatigue initiation or local stiffness even when an external inspection is satisfactory. Micro-CT offers a volumetric record and preserves the specimen for subsequent testing. However, low-density polymers often provide limited X-ray attenuation contrast, while thick sections, fillers and high-aspect-ratio features can create different imaging constraints within one part.

Qualification therefore requires more than obtaining a visually plausible volume. The method must show which indications it can detect and measure under the declared scan, reconstruction and analysis conditions.

1.1 Corpus boundary

ER-206 owns metrological performance and detection limits of micro-CT applied to printed photopolymers. ER-164 owns comparison and selection among non-destructive evaluation routes. ER-075 and WP-034 concern tomographic printing processes rather than post-manufacture X-ray inspection. Cross-method dimensional metrology has no dedicated owner in the controlling registers, so this review limits dimensional treatment to CT-specific surface determination and alignment. ER-484 owns standardised failure reporting, taxonomy, minimum evidence and root-cause learning. This review uses defect classes only to define CT measurement tasks and does not create general accept/reject rules.

2. Measurement chain

An industrial CT result is produced by an interacting chain:

- 1 X-ray generation and focal-spot behaviour;
- 2 specimen positioning, magnification and angular sampling;
- 3 detector response, exposure and corrections;
- 4 projection preprocessing and reconstruction;
- 5 artefact suppression and volume calibration;
- 6 region-of-interest definition and segmentation; and
- 7 calculation, classification and reporting.

ASTM E1441 describes CT as a radiographic reconstruction method that locates and sizes three-dimensional detail and explicitly separates general system guidance from object-specific scan parameters and acceptance criteria [1]. A result is thus traceable to a declared chain, not merely to the scanner model.

3. Voxel size is not spatial resolution

For a reconstructed isotropic voxel pitch v , a feature may occupy several voxels while still being blurred by the system point-spread function. Nominal voxel size is a sampling interval. Spatial resolution is the ability of the complete system to distinguish neighbouring structures or reproduce an edge, and it depends on focal spot, magnification, detector, motion, reconstruction and contrast.

A task-specific resolution metric may be obtained from an edge-spread or modulation-transfer measurement. If $LSF(x)$ is the derivative of an edge-spread function, the modulation transfer function is:

$$|MTF(f)| = \left| \frac{F}{LSF(x)} \right|$$

The frequency at a declared MTF level is meaningful only for the contrast, direction and processing used. It should not be converted automatically into a universal minimum pore diameter.

ASTM E1695 provides a dedicated system-performance test-method framework [2]. Its presence does not remove the need to validate the object-specific detection task.

4. Attenuation contrast and specimen design

For a monochromatic idealisation, transmitted intensity follows:

$$I = I_0 \exp\left(-\int \mu(s) ds\right)$$

where μ is the linear attenuation coefficient along the ray path. Real sources are polychromatic, so beam hardening and scatter can invalidate the simple model. A void within neat resin usually provides strong material-air contrast, but thin walls, resin-filled channels, low-density inclusions and boundaries next to exterior air can be more difficult.

Specimen diameter, path length and orientation should be chosen so that projections neither saturate nor become photon starved. A coupon can support process monitoring, but its detectability does not automatically transfer to a larger production part. If a region is cut from a part, the sampling decision and any cutting-induced damage must be documented.

5. Acquisition and reconstruction

Tube voltage and filtration set spectral penetration; current, exposure time and projection count influence noise; magnification connects detector pitch to object sampling. Averaging can improve signal-to-noise ratio at the cost of time and possibly drift. Rotation-axis errors, specimen movement and detector defects propagate into the reconstruction.

Reconstruction settings are part of the method. Filter choice, ring correction, beam-hardening correction, smoothing and resampling can change boundary location and small-feature visibility. Raw projections or lossless reconstructed data should be retained when feasible so that a later analysis is not limited to screenshots or an irreversibly processed surface.

6. Artefacts and false indications

Ring artefacts can resemble cylindrical defects; beam hardening can create centre-to-edge gradients; insufficient angular sampling can generate streaks; motion can duplicate edges; and partial-volume averaging can create intermediate grey levels at every boundary. Filled or pigmented resins can add local high-attenuation regions and streaking.

An indication should be checked across adjacent slices and orthogonal views. Artefact controls can include repeat scans after specimen rotation, a known homogeneous reference, reconstruction with a predeclared alternative setting and comparison with a destructive section for selected validation specimens. An algorithmic component count is not automatically a physical pore count.

Published microtomography work on printed photopolymer-resin scaffolds confirms direct applicability to this material class [4], while leaving task-specific resolution and acceptance to the individual measurement design.

7. Segmentation and porosity

Let Ω be a declared material region and $P(T)$ the set of voxels assigned to pores under threshold or classifier T . A simple segmented porosity estimate is:

$$\phi_T = \frac{\sum_{i \in P(T)} V_i}{\sum_{i \in \Omega} V_i}$$

The subscript is essential because threshold selection changes the result. Global thresholding can be biased by grey-level drift, while local methods can convert noise into small pores. Surface-adjacent voxels require special treatment so that external air is not counted as internal porosity.

Du Plessis and co-workers published a reproducible micro-CT porosity workflow for additive-manufacturing quality control and emphasised scan quality, region selection, thresholding and partial-volume limitations [3]. Their settings and minimum object rules are method examples, not universal values for photopolymers.

8. Detection probability and minimum detectable defect

The smallest visually observed indication in one volume is not a validated detection limit. A defensible study introduces or selects reference features spanning size, contrast, morphology, orientation and location, then performs blinded repeated evaluations. For defect class c , a probability-of-detection model can be expressed as:

$$P_{\{a,c\}} = P(\text{reported} \mid a, c, M)$$

where a is a size descriptor and M is the complete method. False-call probability must be evaluated alongside detection probability. Cramer and co-workers examined CT resolution of critical flaws in a stereolithography-derived alumina system, illustrating why flaw detectability must be tied to material, process and reference evidence rather than nominal voxel size [5]. The filled ceramic system is adjacent evidence and is not transferred quantitatively to neat photopolymers.

9. Ground truth and validation hierarchy

A useful hierarchy is:

- 1 dimensional or density reference objects for system checks;
- 2 representative polymer artefacts with manufactured channels or inclusions;
- 3 repeated scans with repositioning and independent analysts;
- 4 destructive sectioning, microscopy or serial preparation of selected regions; and
- 5 correlation with a relevant functional test such as leakage.

Ground truth has its own uncertainty. A section may miss the maximum pore diameter, smear a soft polymer or open a closed pore. Registration between CT and sectioned images should be stated. Functional correlation can establish relevance but not the geometric truth of every indication.

10. Dimensional and surface determination tasks

Internal dimensional measurement uses the material boundary, whereas porosity measurement classifies enclosed low-attenuation regions. These tasks should not silently share a segmentation method. Surface determination can depend on local wall thickness, orientation and beam path; a threshold validated for a thick wall may shift a thin channel boundary.

For comparison with a nominal model, alignment method, excluded surfaces, smoothing, datum choice and signed-distance convention must be fixed before interpreting a colour map. ER-206 states only the CT-specific controls and does not claim ownership of cross-method dimensional qualification.

11. Uncertainty and reproducibility

Contributors include scale calibration, focal-spot variation, geometric magnification, detector correction, thermal drift, specimen motion, reconstruction, surface determination, threshold choice, region selection and analyst decisions. Repeatability from one reconstruction underestimates uncertainty when preprocessing and segmentation are fixed.

A reproducibility study should vary at least repositioning and analyst or automated-analysis initialisation. If different thresholds are plausible, sensitivity should be reported rather than hiding the spread inside one selected result. Common systematic components should not be reduced by averaging multiple pores from the same volume.

12. Interpretation matrix

Observation	Supported interpretation	Unsupported leap
A void-like indication persists across adjacent slices	A three-dimensional low-attenuation feature is present in the reconstruction	Its composition and cause are known
A calibrated artefact is resolved	The system resolves that artefact under the declared conditions	Every pore of the same nominal diameter will be detected
Segmented porosity is repeatable	The analysis is stable under the repeated workflow	The value is unbiased relative to physical porosity
No indication exceeds the validated limit	No qualifying feature was detected within the demonstrated method capability	The part is defect free
CT geometry agrees with a nominal model	Reconstructed boundaries agree under the declared alignment and surface rule	All functional dimensions meet specification

13. Minimum reporting set

Report specimen identity, material class, age and conditioning; scan region and orientation; scanner, source, voltage, current, filtration and focal-spot mode; detector and magnification; nominal voxel pitch; projections, exposure and averaging; corrections and reconstruction settings; spatial-resolution or task reference; artefact checks; region of interest; segmentation algorithm and parameters; object-connectivity and surface rules; detection-limit evidence; repeats, analyst controls and uncertainty; data-retention format; and the exact acceptance rule if one is applied.

14. Knowledge boundary

Micro-CT cannot identify chemical composition uniquely from grey level, and low contrast can make a resin-rich inclusion indistinguishable from its matrix. Closed pores below the validated detection capability can remain invisible. Resolution and detectability established in a small coupon may fail in a full part with a longer or heterogeneous beam path. Automated classifiers may be repeatable outside their validated domain while being systematically wrong.

15. Limitations

This review does not compare micro-CT with ultrasound, thermography or other non-destructive routes, prescribe radiation-safety controls, define scanner purchasing criteria or set universal pore limits. The cited studies include general CT standards and adjacent additive-manufacturing materials; quantitative transfer requires validation on the actual photopolymer, geometry and task.

16. Conclusions

Micro-CT is a powerful volumetric measurement route for printed photopolymers, but the result is conditional on acquisition, reconstruction and analysis. Voxel pitch is not a detection limit; segmentation is a measurement model; and absence of a visible indication is meaningful only within demonstrated probability of detection. Representative artefacts, repeat scans, declared algorithms and independent ground truth convert a persuasive image into qualification evidence. Acceptance criteria remain product specific and outside the scope of this review.

References

- 1 ASTM International. *ASTM E1441-19(2026), Standard Guide for Computed Tomography (CT)*. West Conshohocken, PA; 2026. <https://doi.org/10.1520/E1441-19R26>
- 2 ASTM International. *ASTM E1695-20e1, Standard Test Method for Measurement of Computed Tomography (CT) System Performance*. West Conshohocken, PA; 2020. <https://doi.org/10.1520/E1695-20E01>
- 3 du Plessis A, Sperling P, Beerlink A, Tshabalala L, Hoosain S, Mathe N, le Roux SG. Standard method for microCT-based additive manufacturing quality control 1: Porosity analysis. *MethodsX*. 2018;5:1102-1110. <https://doi.org/10.1016/j.mex.2018.09.005>
- 4 Sadyrin EV, Nikolaev AL, Chapek SV, et al. Manufacturing Quality Evaluation of Photopolymer Resin 3D-Printed Scaffolds Using Microtomography. In: *Proceedings of the 9th International Conference on Industrial Engineering*. 2023:619-630. https://doi.org/10.1007/978-3-031-26186-2_38
- 5 Cramer CL, Rossy AM, Dehoff R, Nelson A. Ability of X-ray computed tomography to resolve critical flaw size in laser-based, paste stereolithography ceramic printing of alumina. *International Journal of Ceramic Engineering & Science*. 2024;6:e10233. <https://doi.org/10.1002/ces2.10233>

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