

Interpreting Critical Exposure and Penetration Depth in Vat Photopolymerization

Photochemistry, gelation, exposure history and dimensional verification

Juan Seguro

3Dresyns by Resyner Technologies S.L.

© 2026 Juan Seguro. All Rights Reserved.

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

ER-035 · Engineering Review · Version 0.2 · 13 September 2026

Abstract

Critical exposure, E_c , and penetration depth, D_p , are widely used to characterize photopolymerizable resins and select exposure conditions in stereolithography, digital light processing and masked stereolithography. Their compact representation in the Jacobs working curve is useful, but it can encourage an interpretation that is physically broader than the measurement supports. An experimentally fitted E_c is not necessarily the dose of the first molecular initiation event, while a fitted D_p is not necessarily an invariant optical attenuation length. Both values depend on formulation, wavelength, irradiance, exposure time, specimen preparation, oxygen history, cleaning, dimensional metrology and the criterion used to identify cured material. Interlaboratory results demonstrate that procedural variability can dominate the reported values even when the same resin is tested.

This review proposes a layered interpretation connecting incident and absorbed light, formation of initiating reactive species, inhibitor consumption, functional-group conversion, gelation, dimensional survival and layer-by-layer exposure history. It distinguishes the quantum yield of initiating-species formation from the efficiency with which a liquid formulation becomes a dimensionally persistent solid. Functionality, reactive-group equivalent weight, viscosity, molecular mobility, backbone structure, photobleaching, absorption and scattering are treated as coupled variables rather than independent predictors. The analysis is extended to thin layers, retained resin and enclosed microfluidic channels, where repeated sub-threshold exposures can produce delayed gelation outside the intended geometry. A verification framework is proposed that combines working curves with chemical conversion, rheological or mechanical gelation, spatial test artifacts and channel-retention measurements. The objective is not to replace E_c and D_p , but to define what they measure, what they omit and how they can be used without confusing cure speed with dimensional fidelity.

Keywords: vat photopolymerization; critical exposure; penetration depth; working curve; gelation; oxygen inhibition; microfluidics; dimensional accuracy; exposure history; scattering

1. Significance and scope

The Jacobs working curve remains one of the most practical tools in vat photopolymerization. It reduces a series of cured-thickness measurements to two parameters [13]:

$$C_d = D_p \ln \left(\frac{E}{E_c} \right)$$

where C_d is measured cure depth and E is nominal exposure dose. The model supports process comparison and initial parameter selection, but its apparent simplicity can obscure the sequence of physical and chemical events between photon delivery and a measurable solid.

This review is limited to layerwise vat photopolymerization, including SLA, DLP and LCD or MSLA systems. It does not propose a universal kinetic model, a formulation recipe or an automatic transfer rule between printers. Its purpose is methodological: to identify the conditions under which E_c and D_p are useful observables, the conditions under which they become protocol-specific effective parameters, and the additional measurements required when dimensional fidelity matters.

1.1 Corpus boundary

ER-035 owns the cross-stage interpretation of E_c and D_p as protocol-bound observables and connects the individually owned stages into one measurement and verification methodology. It does not replace the focused scopes retained by ER-002 on cross-platform process equivalence; ER-027 on conversion metrology and spatial cure heterogeneity; ER-030 on oxygen inhibition and interfacial cure; ER-061 on gelation, vitrification and mobility arrest; ER-076 on optical attenuation and feature broadening in particle-filled systems; ER-034 on separation and peel mechanics; ER-033 on washing-, drying- and extraction-induced dimensional response; or ER-012 and ER-097 on microfluidic fidelity, wettability and capillary flow. These neighboring reviews remain the controlling locations for their respective mechanisms and applications. ER-035 integrates them only to explain why a working curve alone cannot establish dimensional selectivity.

Microfluidic channels are used as a demanding example. They reveal a central limitation of single-exposure characterization: the intended walls must solidify reliably while the liquid inside narrow or poorly renewed cavities must remain removable after many neighboring exposures. A resin can therefore appear fast in a working-curve experiment and still perform poorly in a device containing negative features.

2. What E_c and D_p operationally represent

In an ideal absorbing medium with invariant chemistry, D_p is associated with exponential attenuation and E_c with the surface dose at which the cured depth extrapolates to zero. Real working-curve tests add several operational decisions: the exposure geometry, spectral distribution, irradiance, resin thickness, substrate, delay before cleaning, cleaning force, measurement technique and minimum mechanically surviving thickness. Consequently, the fitted parameters should be reported as conditional values attached to a complete protocol.

An initiating reaction can occur below the fitted E_c . The resulting conversion may remain too small to form a spanning network or may be removed during cleaning. Thus, E_c is better described as an operational threshold associated with detectable and persistent solidification under the stated protocol. It should not be defined as the first molecular polymerization event.

Similarly, a fitted D_p is the slope of a working-curve relationship over the tested range. It may approximate an optical attenuation length when absorption dominates and material properties remain stationary. It can deviate when photobleaching, changing refractive index, scattering, conversion-dependent absorption, thermal effects or nonlinear kinetics alter the field. The symbol may be retained for engineering continuity, but the measurement should not be promoted to an intrinsic material constant without independent optical support.

The distinction is experimentally important. A recent interlaboratory study using material from the same resin batch reported large differences in working-curve parameters across laboratories, including variations of up to approximately sevenfold in D_p and approximately seventyfold in E_c [2]. These results do not make working curves useless. They show that the protocol is part of the measurand.

3. A layered causal model

Dimensional solidification can be separated into linked but non-equivalent stages:

1. delivery of an incident spectral irradiance field;
2. absorption, transmission and scattering within the formulation;
3. formation of initiating reactive species;
4. competition with oxygen, inhibitors and termination pathways;
5. reaction of functional groups and growth of active chains or networks;
6. gelation or another mechanically relevant transition;
7. survival during separation, cleaning and measurement;
8. further conversion, shrinkage or accretion during subsequent exposures and post-curing.

The initiating species may be radicals, cationic species, photoacids or other reactive intermediates. The propagating centre can differ from the initially generated species. Terminology limited to radical production is therefore valid only for radical systems and should not be generalized to cationic or hybrid formulations.

For the same reason, a quantum yield of radical formation is not a quantum yield of liquid-to-solid conversion. Allonas and co-workers established, for the radical systems and conditions they investigated, a relationship among inhibition time, radical-generation quantum yield and E_c [1]. The study provides a valuable mechanistic bridge, but it does not establish that radical yield alone predicts dimensional solidification across other resins or mechanisms. The transition from absorbed photon to persistent solid also depends on inhibitor concentration, propagation and termination, reactive-group concentration, gel criterion, mobility and the measurement window.

A useful conceptual sequence is:

absorbed photons → initiating species → reacted groups → gel or network → persistent dimension

Each arrow has its own efficiency and boundary conditions. Collapsing the sequence into a single number risks mistaking one efficient step for an efficient process.

4. Oxygen, induction and resin history

Oxygen can intercept carbon-centred radicals and extend the induction period of many free-radical systems. Its effect depends on the initiating system, reaction mechanism, oxygen concentration and replenishment, sample thickness, viscosity, temperature and exposure rate [8,9]. Removing dissolved oxygen can accelerate the onset of polymerization and reduce an operational E_c in systems dominated by oxygen inhibition. It can also reduce the dose margin separating intended cure from cure outside the intended geometry. Degassing is therefore a change in both kinetics and dimensional risk, not simply an improvement in speed.

The quantity of resin placed in a vat cannot by itself be used to infer the oxygen concentration at the build interface. Fill depth can change the diffusion path, convective renewal, mixing behaviour, thermal mass and surface-area-to-volume ratio, but the local oxygen state also depends on equilibration time, headspace, vat materials, membrane permeability, recoating and motion. Claims about a bottom oxygen concentration require direct measurement or a validated transport model.

In layerwise printing, the relevant initial state may change during a build. Freshly renewed resin, resin held in a thin confined gap and resin retained in a cavity can have different oxygen and reaction histories. A working curve measured on a static specimen should therefore not automatically be interpreted as the state present at every layer of a dynamic print.

Oxygen effects are also mechanism-specific. Higher nominal functionality does not universally mean that a formulation is immune to oxygen. In thiol-acrylate systems, for example, rate and inhibition can vary with thiol chemistry, concentration and viscosity; an observed functionality effect can partly arise from restricted oxygen diffusion rather than functionality alone [9]. General statements such as “a hexafunctional molecule remains reactive after one group is inhibited” are useful as intuition about redundant reactive groups, but they are not a complete kinetic law because inhibition acts on active species and pathways, not by permanently assigning one oxygen molecule to one functional group.

5. Functionality, equivalent weight, mobility and gelation

Nominal functionality, the number of reactive groups on a molecule, must be distinguished from reactive-group concentration in the formulation. For a component of mass fraction w , molar mass M and functionality f , an idealized reactive-group concentration scales with wf/M . The corresponding reactive-group equivalent weight scales with M/f . A highly functional oligomer of high molar mass can therefore supply fewer reactive groups per unit mass than a lower-molar-mass material of lower nominal functionality.

Functionality influences the probability of network formation and can reduce the conversion required to reach gelation in an idealized network. Real photopolymers depart from ideal network statistics through unequal reactivity, cyclization, pendant groups, chain transfer, vitrification, phase behaviour and mobility loss. Allonas and co-workers found that a Stockmayer-based gel estimate substantially overpredicted the operational E_c in their investigated acrylate formulation [1]. Goldbach and co-workers later reported top-of-pillar conversions of approximately 20 to 25% for four formulations under their specific protocol, interpreting these results as compatible with gel-point-controlled pillar formation while also noting that gel conversions reported in the literature span a much wider range [7]. These values are evidence of system dependence, not a universal solidification conversion.

Molecular structure also affects rheology and mobility. Segurola and co-workers reported relationships among molecular structure, branching, molecular weight, functionality and thixotropic behaviour for UV-curable reactive diluents [10]. Those observations support inclusion of rheology in a formulation-to-printability model, but they do not establish a universal ordering of cure speed by functionality. Low-functionality monomers can react rapidly, while highly functional oligomers can become mobility-limited. Conversely, early network formation can produce rapid dimensional survival even when final conversion is incomplete.

Equivalent weight, functionality, backbone and viscosity must therefore be reported or controlled together. None determines E_c , D_p or resolution independently. In particular, a higher reactive-group equivalent weight does not necessarily lower optical D_p . It may change the chemical conversion profile or gelation threshold, while D_p also depends on absorption, scattering and the fitting protocol.

6. Initiating efficiency is not printing selectivity

Increasing the rate of initiating-species formation can shorten induction and accelerate conversion, but the same change may reduce spatial selectivity. A high density of active species can allow locations receiving weak stray or cumulative light to cross the gel threshold. The engineering objective is therefore not maximum initiation efficiency in isolation. It is adequate solidification in the intended voxel while preserving a margin against gelation elsewhere.

Photoinitiator identity and concentration also change spectral absorption. At low concentration, increasing initiator can raise the absorbed fraction and accelerate cure. At higher concentration, absorption close to the illuminated surface can reduce transmission to depth. Photobleaching and secondary absorption can further change the response during exposure. An apparent improvement in E_c may occur together with a change in D_p , conversion uniformity or lateral growth. Published studies based on controlled photoinitiator and absorber series demonstrate that these parameters are coupled [1,3,4].

Consequently, comparisons between initiating systems require, at minimum, the same reactive matrix, wavelength distribution, irradiance, temperature, specimen thickness, oxygen history, absorbed-light basis and dimensional criterion. Comparisons based only on equal mass percentage are not mechanistically equivalent because molar concentration, extinction coefficient and number of generated active species can differ.

The identities and proportions that produce a useful balance of initiation, propagation, inhibition and optical confinement constitute formulation-specific engineering knowledge. A general methodology can identify the variables and tests without publishing the combinations that optimize them.

7. Absorption, scattering and dimensional propagation

In a homogeneous, unfilled resin, light propagation is primarily axial but remains affected by the projection optics, pixel aperture, reflections and the resin's wavelength-dependent absorption. Filled and multiphase systems require an additional scattering description. High-refractive-index pigments, ceramic particles and metal-containing suspensions can redistribute light laterally and axially. Particle size, size distribution, concentration, aggregation, surface treatment, refractive-index contrast and wavelength all influence the result [11]. Metals can add strong reflection and absorption; they should not be treated as optically equivalent to transparent ceramics.

The term scattering is preferable to diffraction for random particulate formulations unless an ordered structure or aperture effect is specifically being analysed. Scattering can broaden the effective point-spread function and cure material outside the projected boundary. A reduced axial working-curve slope does not guarantee improved lateral resolution because a formulation may attenuate strongly while redistributing a fraction of the light sideways.

Optical blockers and absorbers can reduce penetration or stray-light consequences, but their effect is not necessarily independent of kinetics. By changing the spatial distribution of absorbed photons, they can alter both the fitted D_p and the operational E_c . Their concentration can be used to tune dimensional bias only within a defined formulation, wavelength, printer and exposure regime. The required identities, concentrations and compensation rules are not transferable universal constants.

8. Layer thickness and exposure history

Layer height changes more than geometric sampling. For an object of height H , the number of exposures is approximately $N = H/h$, where h is nominal layer thickness. A 2 mm feature contains 20 layers at 100 micrometres, 40 layers at 50 micrometres and 200 layers at 10 micrometres. Decreasing h increases the number of optical and mechanical cycles, although the exposure assigned to each cycle may be reduced.

The local nominal exposure in cycle i can be written as:

$$E_i(x, y, z) = I_i(x, y, z) t_i$$

and a formal exposure history as:

$$E_{hist}(x, y, z) = \sum_i E_i(x, y, z)$$

However, final conversion cannot generally be written as a unique function of the summed dose. Oxygen transport, termination, dark reactions, photobleaching, temperature, delay between layers, mobility and resin renewal can make two exposure schedules with equal

total nominal dose produce different results. Allonas and co-workers observed irradiance-dependent departures from reciprocity in less reactive systems [1]. Dose, irradiance and temporal distribution must therefore be reported separately.

At fixed blocker concentration, changing layer height can shift the balance between negative dimensional change from polymerization shrinkage and positive dimensional change from cure outside the intended boundary. Thin layers may create more opportunities for retained resin to receive repeated stray exposures. Thick layers may require a larger cure depth or dose to ensure interlayer attachment. Neither direction guarantees better Z fidelity.

A nominally correct final thickness can result from cancellation:

$$\Delta Z_{net} = \Delta Z_{shrinkage} + \Delta Z_{secondarycure} + \Delta Z_{machineandprocess}$$

where the shrinkage contribution is normally negative and secondary cure or accretion is positive. Dimensional agreement alone does not show that either error has been eliminated.

9. Retained resin and negative features

The statement that resin “accumulates photons” is physically misleading. Photons are absorbed, transmitted or scattered. What may persist between exposures is chemical state: consumed inhibitor, partial conversion, oligomer or microgel formation, photoproducts, changed viscosity, changed absorption and network development. Short-lived active species need not survive between layers for successive exposures to have a cumulative consequence.

Retained resin is particularly important behind supported horizontal features, between closely spaced supports and inside poorly drained cavities. Resin that is refreshed after each separation cycle may repeatedly return toward its initial state. Resin that remains confined can experience a different sequence of oxygen replenishment, conversion and viscosity. Once its local state reaches an effective gel criterion, it can adhere to the intended solid and produce progressive thickening.

An unsupported coupon printed directly on the platform and a supported coupon with a retained-resin region therefore answer different questions. The unsupported coupon can assess initial printability, XY feature transfer and net Z thickness. A thickness deficit can be consistent with accumulated constrained shrinkage, but it can also include machine zero, platform calibration, compression, cleaning, swelling and measurement effects. Because it lacks a comparable retained-resin region behind the part, it should not be treated as a direct measure of that specific accretion mechanism.

The supported coupon is more sensitive to resin retention, repeated stray exposure and support-related effects. Its net Z deviation can be represented as:

$$\Delta Z_{supported} = \Delta Z_{shrinkage} + \Delta Z_{secondarycure} + \Delta Z_{support} + \Delta Z_{machineandprocess}$$

The two coupons should not be subtracted as if they were identical experiments. Their different orientation, support, base exposure, resin flow and mechanics prevent a uniquely causal difference. They are complementary diagnostic geometries.

10. Microfluidic channels as a selectivity test

Vat photopolymerization is attractive for microfluidic devices because it can produce integrated three-dimensional paths. Transparent resins, however, can have a cure depth substantially larger than the required channel height. Xu and co-workers showed that accumulated dose in the build direction can cure residual resin inside small channels and cause clogging, motivating a process designed specifically to avoid that exposure history [12].

For microfluidics, a low E_c is not sufficient evidence of suitability. Fast wall formation can coexist with premature gelation of confined liquid. The useful operating window lies between two conditions:

$$E_{intended} \geq E_{persistentwall}$$

and

$$E_{unintended,history} < E_{confinedresingel}$$

These are local and protocol-dependent inequalities rather than universal thresholds. The second term incorporates the complete exposure history, not only the dose used for the nominal channel layer.

Channel retention can be expressed by a geometric ratio such as:

$$R_A = \frac{A_{measuredopen}}{A_{designed}}$$

provided that the measurement method, channel location, orientation and uncertainty are reported. Hydraulic resistance or flow can add functional information because a small deposit may strongly affect a narrow channel even when the exterior dimensions remain acceptable.

Channel closure also depends on orientation, length, drainage, resin viscosity, wetting, access for cleaning, layer height, number of exposures and the spatial light field. Positive features and negative features must therefore be qualified separately. A system that reproduces a thin free-standing wall does not necessarily preserve a void of the same nominal width.

11. A combined measurement methodology

No single measurement resolves all stages of the causal chain. A defensible characterization combines complementary methods.

11.1 Working curve

Measure cured depth over an exposure range that is wide enough to test linearity rather than merely force a two-parameter fit. Report the individual points, regression interval, residuals and uncertainty. Repeat at more than one irradiance when reciprocity is assumed. Record

wavelength or spectrum, irradiance at the resin plane, temperature, specimen geometry, delay before cleaning, cleaning method and thickness instrument.

11.2 Chemical conversion

Use RT-FTIR, Raman spectroscopy or another suitable method to measure functional-group conversion with defined optical and geometric conditions. Conversion profiles at depth are more informative than a single surface value [3,5]. Chemical conversion should not be labelled gelation unless the mechanical transition has been independently established.

11.3 Gelation or mechanical transition

Use photorheology, rheometry coupled to spectroscopy, dynamic mechanical methods or a validated network criterion to locate the mechanically relevant transition. Simultaneous rheological and spectroscopic measurements can distinguish functional-group conversion from the onset of a load-bearing network [6]. The criterion must be defined because different rheological gel indicators need not coincide in non-ideal networks.

11.4 Spatial artifacts

Use at least one unsupported artifact for platform adhesion, feature transfer and baseline net thickness, and one supported or cavity-containing artifact designed to retain resin. Map where material is added or lost rather than reducing the result to a single external dimension. Inspect both lateral boundaries and build-direction surfaces.

11.5 Negative-feature verification

For microfluidic or enclosed geometries, print channels across a controlled matrix of height, width, orientation and length. Measure open cross-section and, where relevant, flow resistance. Document resin evacuation and cleaning. The smallest visibly open channel is insufficient if its cross-section or hydraulic performance is not stable along its length.

12. Interpretation matrix

Observation	Plausible causes	Discriminating measurements
Working-curve parameters change with irradiance	reciprocity failure, oxygen replenishment, thermal or kinetic effects	repeat at fixed dose with different irradiance and time; conversion-time profiles
Low fitted E_c but poor negative-feature fidelity	narrow inhibition margin, rapid gelation outside target, cumulative exposure	channel matrix; retained-resin artifact; spatial conversion or sectioning
Low fitted D_p but broad XY features	scattering or broad optical point-spread function	lateral edge profile; optical imaging; filled/unfilled comparison
Correct exterior Z but internal channel closure	cancellation of shrinkage and secondary cure; exposure history	separate surface map and internal cross-section; flow measurement
Supported feature thicker than unsupported baseline	retained-resin cure, support exposure, orientation or mechanics	spatial localization; support-free and retained-resin controls
Performance worsens at smaller layer height	increased cycle count or accumulated stray exposure	hold geometry and total height fixed; record dose schedule and number of cycles

This matrix is hypothesis-generating, not a direct assignment of cause. A causal study should change one variable at a time where possible, predict the direction and location of the response, and repeat the measurement.

13. Minimum reporting set

A working-curve or dimensional-selectivity result should report at least the following information. This interpretive set complements, but does not replace, the standardized-method framework developed in the second interlaboratory working-curve study [14]. No threshold, acceptance criterion or mandatory procedure from that study is imported here; adoption requires validation against its full protocol and the intended application.

1. resin identity or controlled batch identifier and conditioning history;
2. wavelength or spectral distribution and calibrated irradiance at the resin plane;
3. exposure times and doses without assuming reciprocity;
4. resin temperature, specimen thickness and exposure geometry;
5. oxygen or atmosphere conditioning, including equilibration and degassing when used;
6. formulation-level optical state, including whether the resin is clear, absorbing, scattering or filled;
7. working-curve raw points, fitted interval, regression statistics and uncertainty;
8. cleaning, delay and thickness-measurement procedures;
9. layer height, number of layers and base-layer strategy for printed artifacts;
10. dimensional results separated into XY, exterior Z and negative-feature retention;
11. post-print and post-cure history;
12. deviations from the protocol used for comparison.

When formulation confidentiality prevents disclosure of identities or proportions, the report should still describe the controlled functional categories and preserve a confidential internal record. Confidentiality does not justify omitting the process conditions required to interpret the measurement.

14. Knowledge boundary

The scientific framework can be published without disclosing competitive formulation knowledge. Publicly useful content includes the distinction among initiation, conversion, gelation and dimensional persistence; the role of exposure history; the need to assess negative features; and the minimum reporting requirements.

The following remain formulation-specific and need not be disclosed: selected initiator and blocker identities, component ratios, equivalent-weight targets, degassing conditions, exposure windows, wavelength-specific compensation factors and decision rules that convert diagnostic artifacts into formulation changes. Their omission should be explicit as a scope boundary rather than disguised as a universal claim.

15. Limitations

The proposed framework is not a closed predictive model. Several terms, including spatial exposure history and effective gel threshold, require experimental definition for each system. The treatment of oxygen is principally relevant to oxygen-sensitive radical chemistry; cationic and hybrid systems can exhibit different initiation, inhibition and dark-reaction behaviour. The channel analysis does not replace fluid-dynamic, cleaning or biocompatibility qualification. Finally, dimensional outcomes depend on machine mechanics and image formation as well as resin chemistry.

16. Conclusions

E_c and D_p remain valuable engineering parameters when they are attached to a complete measurement protocol and used within their demonstrated range. They should not be treated automatically as intrinsic constants or as complete predictors of printing performance.

The decisive quantity for high-fidelity vat photopolymerization is not maximum generation of radicals, cations or other initiating species. It is selective liquid-to-solid conversion within the intended volume, with sufficient interlayer survival and without unintended gelation or solidification outside the designed boundary. That selectivity depends on photochemistry, reactive-group concentration, gelation, rheology, optical transport, oxygen and the temporal history of every location.

Layer height and optical attenuation can tune net dimensional bias, including partial cancellation between shrinkage and secondary cure. Such cancellation is conditional and can conceal opposing errors. Microfluidic channels make this visible: acceptable exterior dimensions can coexist with loss of the internal void. Working curves should therefore be combined with chemical, mechanical and spatial verification whenever the application depends on thin walls, retained resin or enclosed negative features.

References

- Allonas X, Métal B, Villarroel-Marquez A, Ley C, Croutxé-Barghorn C. Predicting 3D printing critical parameters from basic photochemical principles in vat photopolymerization. *Journal of Photochemistry and Photobiology A Chemistry*. 2025;469:116572. <https://doi.org/10.1016/j.jphotochem.2025.116572>
- Kolibaba TJ, Killgore JP, Caplins BW, et al. Results of an interlaboratory study on the working curve in vat photopolymerization. *Additive Manufacturing*. 2024;84:104082. <https://doi.org/10.1016/j.addma.2024.104082>
- Allonas X, Hammouda B, Métal B, et al. Controlling photopolymerization reaction in layer-by-layer photopolymerization in 3D printing. *Applied Research*. 2024;3:e202400004. <https://doi.org/10.1002/appl.202400004>
- Champion A, Métal B, Schuller AS, et al. A simple and efficient model to determine the photonic parameters of a photopolymerizable resin usable in 3D printing. *ChemPhotoChem*. 2021;5:839-846. <https://doi.org/10.1002/cptc.202100002>
- Tu J, Kashcooli Y, Alvarez NJ, Palmese GR. A practical framework for predicting conversion profiles in vat photopolymerizations. *Additive Manufacturing*. 2022;59:103102. <https://doi.org/10.1016/j.addma.2022.103102>
- Gorsche C, Reghunathan H, Baudis S, Knaack P, Husar B, Laeuger J, Hoffmann H, Liska R. Real Time-NIR/MIR-Photorheology: A Versatile Tool for the in Situ Characterization of Photopolymerization Reactions. *Analytical Chemistry*. 2017;89(9):4958-4968. <https://doi.org/10.1021/acs.analchem.7b00272>
- Goldbach E, Villarroel-Marquez A, Halbardier L, et al. Assessing the validity of Jacobs' model through conversion measurements in photopolymerized resins. *Monatshefte für Chemie*. 2026;157:519-524. <https://doi.org/10.1007/s00706-025-03417-2>
- Pynaert R, Buguet J, Croutxé-Barghorn C, Moireau P, Allonas X. Effect of reactive oxygen species on the kinetics of free radical photopolymerization. *Polymer Chemistry*. 2013;4:2475-2479. <https://doi.org/10.1039/C3PY21163K>
- O'Brien AK, Cramer NB, Bowman CN. Oxygen inhibition in thiol-acrylate photopolymerizations. *Journal of Polymer Science Part A Polymer Chemistry*. 2006;44:2007-2014. <https://doi.org/10.1002/pola.21304>
- Segurola J, Allen NS, Edge M, McMahon A, Roberts I. Comparative study of the relationship between structure and rheology properties of UV-curable reactive diluent monomers. *Polymers Paint Colour Journal*. 1999;(4413):XII-XIII. <https://research.manchester.ac.uk/en/publications/comparative-study-of-the-relationship-between-structure-and-rheol/>
- Griffith ML, Halloran JW. Scattering of ultraviolet radiation in turbid suspensions. *Journal of Applied Physics*. 1997;81:2538-2546. <https://doi.org/10.1063/1.364311>
- Xu Y, Qi F, Mao H, et al. In-situ transfer vat photopolymerization for transparent microfluidic device fabrication. *Nature Communications*. 2022;13:918. <https://doi.org/10.1038/s41467-022-28579-z>
- Jacobs PF. *Rapid Prototyping and Manufacturing: Fundamentals of Stereolithography*. Society of Manufacturing Engineers; 1992.
- Kolibaba TJ, Killgore JP, Caplins BW, et al. Results of an interlaboratory study on the working curve in vat photopolymerization II: Towards a standardized method. *Additive Manufacturing*. 2025;104919. <https://doi.org/10.1016/j.addma.2025.104919>

Copyright

© 2026 Juan Segurola. All Rights Reserved.