

Inkjet Jetting Physics for Photopolymer Materials: Rheology, Waveform, Satellite Formation and Cure Timing

Juan Seguro

3Dresyns by Resyner Technologies S.L.

© 2026 Juan Seguro. All Rights Reserved.

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

ER-028 · Engineering Review · Version 1.1 · 2026

Statement of Significance

Photopolymer inkjet printability cannot be defined by one viscosity value. Droplet formation occurs under high shear rates and sub-millisecond surface ages, while the piezoelectric waveform, nozzle acoustics, viscoelastic relaxation, dynamic surface tension and jet velocity jointly determine ligament breakup and satellite formation. After impact, wetting and photopolymerisation introduce a second coupled time-scale problem. This review therefore separates material characterisation from waveform optimisation and from post-impact curing, and proposes a reporting chain in which a resin is described as jettable only under a defined printhead, temperature, waveform and droplet-state measurement.

Keywords: inkjet; material jetting; photopolymer; rheology; viscoelasticity; waveform; satellite droplets; dynamic surface tension; droplet impact; UV curing

Abstract

Drop-on-demand material jetting converts a liquid photopolymer into a train of discrete droplets before solidification. The governing material state differs sharply from a low-shear benchtop viscosity measurement: the fluid experiences rapid deformation in the nozzle, a newly created interface with microsecond-to-millisecond age, ligament extension, pinch-off, flight, impact and then curing. Recent work with UV-curable acrylate inks shows that high-frequency rheology and dynamic surface tension can be combined with jetting temperature and waveform variables to predict satellite-free operating conditions. Independent studies of viscoelastic inks demonstrate multiple droplet-formation regimes under different excitation waveforms, while photopolymer material-jetting studies show that UV dose history also changes final conversion and properties. This Engineering Review organises those phenomena into a qualification framework spanning material rheology, nozzle/waveform dynamics, droplet breakup, impact/wetting and cure timing. 3Dresyns Inkjet products are included only as commercial implementation examples; no waveform, satellite-free window or jet velocity is inferred from product positioning.

1. Introduction

Inkjet photopolymer engineering is often reduced to a viscosity range and a nominal printhead temperature. That simplification misses the physics that occurs between the reservoir and the cured voxel. During drop-on-demand ejection, the ink is accelerated through a small nozzle by a pressure waveform, stretched into a ligament, pinched into one or more droplets and decelerated on impact. Every stage is time-dependent, and the relevant rheology and interfacial properties may differ from equilibrium values [1-3].

Chen, Hagenmeyer and Elkaseer recently demonstrated this directly for UV-curable acrylate inks. Their workflow measured complex viscosity, viscoelastic relaxation, dynamic surface tension and density across temperature, extrapolated those properties to inkjet-relevant time scales and linked them to driving voltage, droplet velocity and satellite regimes [1]. The result is important because it shows why a static printability window cannot replace waveform- and time-scale-specific observation.

2. Five coupled states in a jetted photopolymer

State	Primary observables	Dominant variables	Claim boundary
Reservoir / feed	Temperature, viscosity, stability	Composition, temperature, residence time	Does not establish nozzle dynamics
Nozzle deformation	High-rate viscosity, elasticity, pressure response	Waveform, nozzle, frequency, temperature	Low-shear viscosity alone is insufficient
Ligament / pinch-off	Ligament length, breakup time, satellites	Velocity, relaxation, surface tension, waveform	One stable drop is condition-specific
Flight / impact	Velocity, trajectory, spread, contact angle	Droplet size, substrate, surface state	Jetting does not establish final feature
Cure / build	Conversion, shape retention, interlayer state	UV timing/dose, overlap, layer strategy	Cure cannot be inferred from droplet quality

Table 1. Distinct states in photopolymer jetting.

3. High-rate rheology and viscoelasticity

A fluid can appear Newtonian at the shear rates available to a rotational viscometer yet respond differently during rapid nozzle deformation. For polymeric or oligomeric inks, extensional response and relaxation time are particularly important because the ligament must retract before it fragments. Zhao et al. observed no-drop, single-drop, one-satellite and multi-satellite regimes when waveform conditions were varied for a viscoelastic conductive ink [2]. The useful reporting question is therefore not only “what is the viscosity?”, but “what rheological model and time scale describe the deformation experienced during ejection?”

Chen et al. further showed that temperature changes several coupled properties, not viscosity alone [1]. Heating can reduce viscous resistance while also changing surface tension, relaxation and acoustic damping. A jetting temperature should therefore be reported as part of the measured material state rather than treated as a universal correction factor.

4. Dynamic surface tension and new interfaces

The surface of a droplet formed in less than a millisecond is newly created. Surfactant or surface-active species may not have reached equilibrium coverage, so equilibrium surface tension can misrepresent pinch-off and impact behaviour. High-frequency or dynamic methods are preferable when a formulation contains components whose interfacial adsorption is time-dependent. The relevant surface age and method should accompany the value [1].

5. Waveform, velocity and satellite formation

The electrical waveform is not a printer-only setting independent of formulation. It creates the pressure history that accelerates the fluid and controls the timing of ligament formation and retraction. Chen et al. identified droplet velocity as a strong discriminator of satellite regimes for their UV-curable materials and developed a rheology-driven route to waveform selection [1]. Zhao et al. independently showed strong coupling between bipolar waveform parameters and droplet morphology [2]. These studies support an engineering rule: waveform transfer between inks should be demonstrated, not assumed.

Dimensionless groups such as Reynolds, Weber and Ohnesorge numbers remain useful for organising inertia, viscosity and capillarity, but they collapse details of viscoelastic relaxation, nozzle acoustics and waveform shape. They are therefore screening descriptors rather than sufficient qualification of a photopolymer ink.

6. Impact, wetting and cure timing

A correctly formed droplet can still produce a poor feature after impact. Substrate surface energy, drop velocity, temperature and previously deposited material determine spreading and coalescence. For a photocurable ink, polymerisation begins to compete with spreading once UV exposure is introduced. Sivasankar et al. described this as a competition between spreading and photopolymerisation time scales in microdroplet curing: when curing becomes comparable to spreading, the evolving viscosity can arrest the droplet at a smaller radius [3].

For inkjet-based 3D printing, UV strategy also accumulates across passes and layers. Zhao et al. developed a model linking UV source pathway, intensity, printing strategy and interlayer attenuation to degree of conversion within the printed object [4]. Bezek and Williams later connected the UV exposure history of material-jetted photopolymers to final process-structure-property response [5]. Jetting and curing should therefore be qualified as sequentially coupled processes, not independent optimisation exercises.

7. Minimum reporting framework

Block	Minimum information	Reason	Claim limit
Material state	Batch/composition class, temperature, age, filtration	Defines tested liquid state	No transfer across states
Rheology	Method, shear/frequency range, model, relaxation if relevant	Captures nozzle-relevant response	One viscosity value is not jettability
Interface	Equilibrium/dynamic surface tension and surface age	Defines pinch-off/impact context	Static value may not represent fresh surface
Printhead	Nozzle, native drop volume, frequency/back pressure	Defines acoustic geometry	Printer family alone is insufficient
Waveform	Pulse shape, width, voltage and timing	Controls pressure history	No waveform transfer without validation
Drop watch	Velocity, diameter, ligament, satellites, trajectory	Directly measures ejection state	Visual single drop supports only tested condition
Impact	Substrate, temperature, spacing, spread/contact metric	Defines deposited geometry	Flight quality is not feature quality
Cure	Wavelength/dose/timing and conversion or property endpoint	Links liquid drop to solid state	No final-property inference from jetting alone

Table 2. Minimum reporting set for photopolymer inkjet physics.

8. 3Dresyns implementation examples

3Dresyn IJ ENG2 is a current manufacturer-documented engineering photopolymer for Inkjet printing. It illustrates the feedstock side of the framework, but the product description does not establish a universal waveform, droplet velocity, satellite-free regime or printhead-specific operating window [M1].

NG 3Dresyn IJ TFD70 is a tough-foldable Inkjet photopolymer representing a mechanically different cured-material target. Its final flexibility does not predict high-rate liquid rheology or nozzle behaviour; jetting must still be characterised at the intended temperature and printhead conditions. [M2]

Source basis: current 3Dresyns controlled product documentation, August 2026. These examples connect commercial material classes to the qualification workflow and are not independent evidence of jetting performance.

9. Conclusions

- Inkjet jettability is a coupled material-printhead-waveform state, not a viscosity specification.
- High-rate rheology, viscoelastic relaxation and dynamic surface tension are more relevant to ejection than isolated equilibrium measurements.
- Satellite formation must be measured under a defined waveform and droplet velocity; dimensionless printability maps are screening tools rather than proof.
- A satellite-free droplet can still fail at impact, wetting, coalescence or curing.
- UV timing creates a second time-scale competition and can change shape retention, conversion and final properties.
- The defensible qualification chain runs from liquid state to nozzle dynamics to droplet observation to impact and finally cured-part validation.

Limitations

This review is a focused engineering synthesis rather than a systematic review. Jetting behaviour is printhead- and waveform-specific, so quantitative operating windows are not pooled across systems. Product examples do not disclose proprietary formulation composition, waveform settings or printer-specific dosage guidance.

Author contributions

Juan Segurola: conceptualisation, literature synthesis, engineering framework, writing and critical review.

Competing interests

The author is affiliated with 3Dresyns by Resyner Technologies S.L. Commercial 3Dresyns materials are identified only as implementation examples supported by controlled product documentation. They are not treated as independent peer-reviewed evidence and no proprietary formulation composition is disclosed.

Data availability

No new experimental dataset was generated for this review. Scientific statements are attributed to the cited literature; commercial examples are separated from the independent evidence base.

Company information

Legal company name: 3Dresyns by Resyner Technologies S.L. Registered tax address: General Etxague 15B, 20003 Donostia / San Sebastián, Gipuzkoa, Spain VAT number: ESB24827511 Contact email: info@3Dresyns.com Company website: www.3Dresyns.com

References

- [1] K.J. Chen, V. Hagenmeyer, A. Elkaseer, Satellite-free droplet formation in material jetting via rheology-driven waveform modelling approach, *Materials & Design* 260 (2025) 115252. DOI: 10.1016/j.matdes.2025.115252.
- [2] D. Zhao, H. Zhou, Y. Wang, J. Yin, Y. Huang, Drop-on-demand (DOD) inkjet dynamics of printing viscoelastic conductive ink, *Additive Manufacturing* 48 (2021) 102451. DOI: 10.1016/j.addma.2021.102451.
- [3] V.S. Sivasankar, H.S. Sachar, S. Sinha, D.R. Hines, S. Das, 3D Printed Microdroplet Curing: Unravelling the Physics of On-Spot Photopolymerization, *ACS Applied Polymer Materials* 2 (2020) 966-976. DOI: 10.1021/acsapm.9b01181.
- [4] P. Zhao, Y. He, G.F. Trindade, M. Baumer, D.J. Irvine, R.J.M. Hague, I.A. Ashcroft, R.D. Wildman, Modelling the influence of UV curing strategies for optimisation of inkjet based 3D printing, *Materials & Design* 208 (2021) 109889. DOI: 10.1016/j.matdes.2021.109889.
- [5] L.B. Bezek, C.B. Williams, Process-structure-property effects of ultraviolet curing in multi-material jetting additive manufacturing, *Additive Manufacturing* 73 (2023) 103640. DOI: 10.1016/j.addma.2023.103640.

Manufacturer documentation

- [M1] 3Dresyns, 3Dresyn IJ ENG2, TDS-IJ-ENG2-EN v1.1, manufacturer product documentation, accessed 20 August 2026. <https://www.3dresyns.com/products/3dresyn-ij-eng2-tough-functional-resin>
- [M2] 3Dresyns, NG 3Dresyn IJ TFD70, manufacturer product documentation, accessed 20 August 2026. <https://www.3dresyns.com/products/ng-3dresyn-ij-tfd70-tough-foldable-d70>

Copyright

© 2026 Juan Segurola. All Rights Reserved.