

Optical photopolymers for additive manufacturing: reporting practices and cross-study comparability

Juan Seguro

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

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Abstract

The optical performance of photopolymers used in additive manufacturing is characterised through multiple parameters, including refractive index and dispersion, transmittance and absorption, surface quality, birefringence and scattering. Reported values are obtained from samples that have passed through specific fabrication and post-processing workflows and are measured under configurations that document wavelength, geometry, sample state and method with varying degrees of completeness. This focused review examines reporting practices in a bounded corpus of optical-additive-manufacturing studies. Three observations emerge. First, the surveyed corpus shows recurrent partial completeness rather than a uniform reporting deficit: different studies emphasise different subsets of the optical parameter space according to their methodological objective. Second, some studies provide either explicit qualification of what a reported quantity does and does not characterise or reusable parameters that permit downstream reconstruction by an independent reader. Third, standards and reference conventions relevant to refractive index, transmittance, haze, colour and additive-manufacturing terminology are available, but they are not used uniformly across the surveyed studies. Within the limits of this focused corpus, cross-study comparability therefore depends strongly on the measurement context co-reported with each optical value.

Keywords: additive manufacturing photopolymers; optical characterisation; refractive index; optical transmittance; reporting practices; cross-study comparability

1. Introduction

Additive-manufacturing photopolymers are used in optical and photonic applications including lenses, waveguides, gratings, resonators, sensors and micro-optical components. Vat-photopolymerisation platforms represented in the recent review literature include stereolithography, digital light processing, liquid-crystal-display printing, continuous liquid-interface approaches and two-photon polymerisation [1]. Other additive routes, including material-jetting approaches, have also been used to fabricate centimetre-scale optical components [2].

The optical requirements imposed on these systems are application dependent. Refractive index and dispersion are central to lens design and chromatic-aberration control; bulk absorption and transmittance constrain thick optical elements and waveguides; birefringence affects polarisation-sensitive and imaging applications; and surface form and roughness are critical when printed or post-processed surfaces function directly as optical interfaces [1-6]. Recent material-development work has also demonstrated high-refractive-index photopolymers with low birefringence and low near-infrared absorption in millimetre- to centimetre-scale specimens [3].

The reporting practices surrounding these measurements have received less direct attention than the materials and devices themselves. Reynoso et al. [4], for example, explicitly motivated their refractive-index study by the limited wavelength-resolved data then available for 3D-printing photoresins. They measured three resins across multiple visible wavelengths and published dispersion parameters that can be reused by other researchers [4].

This review therefore focuses on how optical parameters are reported, rather than attempting an exhaustive review of optical additive manufacturing. Particular attention is given to wavelength range, sample geometry, post-cure or post-processing state, measurement method and sample condition. The discussion is observational. It does not propose a mandatory reporting framework, and claims about the wider field are limited to what can reasonably be inferred from the cited corpus.

2. Optical parameters and measurement approaches

Optical characterisation of additively manufactured photopolymers occupies a multi-parameter measurement space. The studies considered here report refractive index and dispersion, transmittance or absorption, surface quality and, in selected cases, birefringence [2-6]. These quantities are not interchangeable: each describes a different aspect of optical behaviour, and each depends on its measurement conditions.

2.1 Refractive index and dispersion

Refractive index is among the most directly reusable quantities in optical design, provided that wavelength and sample state are specified. Reynoso et al. [4] measured three transparent photoresins at multiple wavelengths between 405 and 670 nm using a modified Pulfrich refractometer, fitted Cauchy dispersion relations and derived Abbe numbers. Publishing the fitted dispersion coefficients allows the refractive index to be reconstructed within the measured spectral interval rather than restricting reuse to a single reported wavelength.

Olikagu et al. [3] developed a sulfur-containing photopolymer for plastic optics and reported a visible-range refractive index of approximately 1.57-1.59. The same work reported birefringence below 10^{-4} and very low optical absorption at 1310 nm for thick samples. These data illustrate why a single refractive-index value is insufficient to describe bulk optical suitability: dispersion, birefringence, absorption, specimen thickness and post-processing state can all be relevant to the intended optical function [3].

Academic measurements can also differ from manufacturer-supplied single-point values because wavelength, cure state and measurement geometry are not necessarily matched. Reynoso et al. [4] explicitly compared their wavelength-resolved measurements with earlier

peer-reviewed measurements, including Berglund and Tkaczyk [5], illustrating the value of reporting enough context to identify whether numerical differences are methodological or material in origin.

2.2 Transmittance and absorption

Bulk transparency cannot be interpreted independently of wavelength and specimen thickness. Olikagu et al. [3] reported optical absorption below 0.05 cm^{-1} at 1310 nm for specimens spanning approximately 1-30 mm in thickness. Reporting thickness alongside absorption makes the measurement more transferable than a transparency statement without a defined optical path length.

For transparent plastics more generally, standards distinguish among concepts such as luminous transmittance, haze and spectrophotometric transmittance. ASTM D1003 defines procedures for haze and luminous transmittance of transparent plastics [9], while ASTM E1348 specifies spectrophotometric transmittance and colour measurements using hemispherical geometry [12]. These standards do not make measurements from different printed samples automatically equivalent, but they illustrate the contextual information required for meaningful comparison, including specimen geometry and measurement configuration.

2.3 Surface quality and birefringence

Optical fabrication studies report surface quality using metrics such as form accuracy and roughness, with the appropriate metric depending on the scale and function of the component. Pekkarinen et al. [2] demonstrated additive manufacturing of double-sided centimetre-scale optics and reported both surface roughness and form-accuracy data for the fabricated components. Berglund and Tkaczyk [5] and Assefa et al. [6] likewise demonstrate that the optical performance of printed lenses depends on fabrication and finishing as well as on bulk material properties.

Birefringence is a separate material or process-sensitive quantity. Olikagu et al. [3] reported birefringence below 10^{-4} for their optical photopolymer under the stated measurement conditions. A report of a detection limit or instrument sensitivity is particularly important when the result is expressed as an upper bound rather than as a resolved numerical value.

3. Photopolymer chemistries and process platforms

The cited literature spans several photopolymer chemistries and additive-manufacturing routes. Acrylate- and methacrylate-based systems are represented in studies of commercial and custom photoresins [4,5]. Sulfur-containing methacrylate chemistry has been developed specifically to increase refractive index while retaining manufacturability for optical components [3]. Review literature further documents a broad set of photopolymer formulations and vat-photopolymerisation processes used for photonic-device fabrication [1].

The fabrication route is part of the measurement context because it affects attainable geometry, surface state and post-processing requirements. The corpus includes vat photopolymerisation, consumer-grade lithographic printing, centimetre-scale additive optical fabrication, high-area rapid-printing DLP, and 3D direct laser writing for micro-optics [1-7]. These processes should not be treated as metrologically interchangeable merely because they all produce photopolymer optical components.

4. Optical application classes represented in the corpus

Four application classes are sufficiently supported by the cited corpus to be used here without extending beyond the evidence base.

Bulk optical elements and plastic optics. Olikagu et al. [3] demonstrated thick optical photopolymer specimens and precision optical components based on a high-refractive-index sulfur-containing resin. The study combines bulk optical measurements with manufacturing by moulding, diamond turning and vat photopolymerisation.

Imaging and lens systems. Berglund and Tkaczyk [5] demonstrated optical-component fabrication using a consumer-grade lithographic printer, while Assefa et al. [6] reported an imaging-quality centimetre-scale 3D-printed lens. These studies show why refractive index, geometry and surface quality need to be considered together when comparing printed optical elements.

Micro-optical and photonic devices. The vat-photopolymerisation review by Chekkaramkodi et al. [1] documents lenses, waveguides, gratings, resonators, sensors and related photonic structures across multiple vat-photopolymerisation technologies.

Hybrid refractive-diffractive micro-optics. Schmid et al. [7] demonstrated 3D direct-laser-written achromatic and apochromatic micro-optics combining refractive and diffractive surfaces and two different photoresists. This example is retained because it directly supports the hybrid refractive-diffractive category; it replaces the earlier attribution of this function to the Pekkarinen et al. study, which concerns double-sided centimetre-scale optics rather than the claimed inkjet hybrid refractive-diffractive architecture.

5. Operational workflows and sample state

Optical measurements apply to the sample state that actually enters the instrument. That state can differ materially from the as-printed state because of post-cure, thermal treatment, cleaning, machining, polishing or mould replication. Consequently, a reported optical value should not be interpreted as an intrinsic formulation constant unless the measurement and sample state justify that interpretation.

In the Olikagu et al. study [3], bulk optical properties are evaluated together with manufacturing routes that include moulding, diamond-turn machining and vat photopolymerisation. In the lens-fabrication studies [2,5,6], surface generation and finishing are central to the achieved optical performance. These examples support treating post-processing route and sample geometry as part of the reporting context rather than as incidental procedural detail.

The same principle applies to thin-film versus bulk measurements. A dispersion relation obtained from a thin or optically homogeneous specimen can be highly useful for optical design, but it does not by itself establish the absorption, scattering, internal homogeneity or surface quality of a thick printed component. Cross-study comparison therefore benefits from distinguishing the property being measured from the broader performance of the final optical part.

6. Reporting configurations, practices and standards uptake

6.1 Reporting configurations in the surveyed corpus

The surveyed studies do not show a single uniform reporting pattern. Instead, different contributions provide different combinations of wavelength, sample thickness, fabrication state, measurement geometry and fitted parameters. This is better described as partial co-reporting than as a universal reporting deficiency.

Reynoso et al. [4] provide an example of a highly reusable refractive-index report because the wavelength-dependent measurements are accompanied by fitted Cauchy coefficients. Olikagu et al. [3] combine refractive index, birefringence and bulk absorption with specimen-thickness information and manufacturing demonstrations. Pekkarinen et al. [2], Berglund and Tkaczyk [5], and Assefa et al. [6] place optical measurements in the context of fabricated components, where surface form, roughness and processing route become central to interpretation.

These studies answer different technical questions, so their reporting structures are not expected to be identical. The cross-study problem arises when a numerical value is transferred from one context to another without preserving the conditions that define what that value represents.

6.2 Standards and reference conventions

Several standards and reference resources are relevant to optical measurements on transparent polymeric materials. ASTM D542-22 specifies refractive-index measurement for transparent organic plastics and notes technical equivalence with ISO 489 [11]. ISO 489:2022 specifies refractometric and immersion methods for determining the refractive index of plastics [13]. ASTM D1003-21 addresses haze and luminous transmittance of transparent plastics [9]. ASTM E1348-22 covers transmittance and colour measurements by spectrophotometry using hemispherical geometry [12]. ASTM E313-20(2025) provides procedures for calculating yellowness and whiteness indices from measured colour coordinates [10]. ISO/ASTM 52900:2021 provides the general terminology used for additive manufacturing [14].

The refractiveindex.info database described by Polyanskiy [8] is a reference-data resource rather than a measurement standard. Its value lies in traceable optical-constant data and explicit source attribution. It should therefore be described as reference infrastructure, not as an ASTM- or ISO-equivalent measurement convention.

Two standards cited in the original manuscript, ASTM E168 and ASTM E1252, have been removed from this section. They concern general techniques for infrared quantitative analysis and acquisition of infrared spectra for qualitative analysis, respectively. They do not support the original manuscript's characterisation of them as general standards for visible or UV-visible spectrophotometric transmission measurement.

6.3 Reporting practices that support cross-study comparison

Two practices in the cited corpus are particularly useful for comparison without requiring a new normative framework.

First, publishing wavelength-resolved data or a reusable dispersion parametrisation allows an independent reader to reconstruct the optical quantity within the validated range. Reynoso et al. [4] exemplify this by publishing Cauchy coefficients alongside their measured refractive-index values.

Second, reporting complementary quantities under clearly stated specimen conditions reduces the risk of over-interpreting any single metric. Olikagu et al. [3] report refractive index together with birefringence, absorption and specimen-thickness information. This does not make the study a universal template, but it demonstrates how multi-parameter reporting can preserve distinctions between dispersion, bulk loss and anisotropy.

7. Implications for cross-study comparison

Within this focused corpus, optical-value comparability depends on the measurement context that accompanies each reported value. Refractive-index values are more interpretable across studies when wavelength, measurement method, sample state and dispersion parametrisation are specified. Transmittance and absorption data are more interpretable when wavelength range, optical path length and measurement geometry are reported. Surface-quality data require an explicit metric, instrument or method, and post-processing state. Birefringence upper bounds require the associated measurement sensitivity or detection limit.

This conclusion should not be read as evidence that the wider optical-additive-manufacturing literature is globally under-reported. The cited corpus is intentionally bounded and is not a systematic review with exhaustive search, screening and risk-of-bias procedures. It supports a narrower observation: optical properties that share the same label can remain only partially comparable when the conditions defining those properties are not aligned.

The practical implication is therefore methodological rather than prescriptive. Cross-study comparison should retain the context in which each optical quantity was obtained. Where studies publish reusable dispersion parameters, thickness-dependent loss measurements, explicit sample-state descriptions or traceable measurement conventions, downstream comparison becomes more defensible. Where those dimensions differ, numerical agreement or disagreement should be interpreted with corresponding caution.

Declarations

Competing interests

Juan Segurola is the founder and Scientific Director of 3Dresyns by Resyner Technologies S.L., a company active in photopolymer materials for additive manufacturing. No 3Dresyns product, proprietary formulation or unpublished company dataset is evaluated in this manuscript.

Data availability

No new primary dataset was generated for this focused literature review. The publications and standards discussed are identified in the reference list.

Ethics statement

This work is a literature-based review and does not involve human participants, animals or newly collected personal data.

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