

# Thermal Conductivity in Vat-Photopolymerised Composites: Formulation, Anisotropy and Measurement

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## Statement of Significance

“Thermally stable”, “heat resistant” and “thermally conductive” are different claims. In vat-photopolymerised composites, conductivity belongs to a defined formulation–process–microstructure–direction–temperature state and to a stated measurement model. A filler loading or a thermogravimetric result cannot replace a measured conductivity value.

Keywords: thermal conductivity; VPP composite; anisotropy; laser flash; transient plane source; filler network; qualification.

## Abstract

This targeted engineering review evaluates the evidence needed to claim thermal conductivity in vat-photopolymerised (VPP) composites. Direct studies of boron-nitride and hybrid boron-nitride/graphite systems show that filler loading, connectivity, dispersion, viscosity, conversion, porosity and print direction are coupled. A high-viscosity VPP study demonstrates process enablement but does not by itself prove thermal transport, while a ZnO study based on thermogravimetry and calorimetry supports thermal-stability claims rather than a conductivity value. The review separates diffusivity from conductivity, explains the relation  $k = \rho c_p \alpha$ , distinguishes flash and transient-plane-source methods, and defines a minimum qualification record for printed articles. Manufacturer descriptions are treated as screening information unless the exact grade and processed state have traceable, direction- and temperature-specific test data. RP-02 supplies the shared evidence-to-decision method.

## 1. Scope and evidence boundary

Thermal conductivity  $k$  describes heat-flow response under defined conditions; thermal diffusivity  $\alpha$  describes the rate of temperature equalisation; heat capacity  $c_p$  and density  $\rho$  complete the common relation  $k = \rho c_p \alpha$ . Glass-transition temperature, heat-deflection temperature, decomposition onset and mass loss answer other questions. Consequently, “thermal properties” in a paper title cannot be read as evidence of conductivity unless conductivity or the required inputs were actually measured and reported.

The evidence considered here covers photocurable polymer composites processed by DLP or related VPP routes. The reported values belong to the named resin, filler identity and surface state, loading, dispersion route, specimen geometry, print orientation, exposure, post-cure, conditioning, temperature and measurement method. They cannot be transferred automatically to another filler grade, commercial resin, printed feature or assembly.

## 2. What the direct literature supports

Fortunato et al. studied h-BN/graphite hybrid fillers in a UV-curable DLP composite and reported conductivity improvement for that formulation [1]. The study supports the importance of hybrid connectivity and microstructure; it does not establish a universal loading–conductivity law.

Bagatella et al. directly studied VPP composites containing unmodified h-BN up to 20 wt% [2]. Conductivity reached about  $0.8 \text{ W m}^{-1} \text{ K}^{-1}$ , approximately 270% above the unfilled system, in the reported state. The authors measured thermal diffusivity in two directions by laser flash and combined it with density and heat capacity. Increasing filler content also increased viscosity and reduced conversion, illustrating why transport gain, cure quality and printability must be qualified together [2].

Lamiri et al. examined ZnO-filled DLP specimens using thermal analysis and mechanical testing [3]. Its TGA/DSC evidence addresses thermal transitions and degradation behaviour, not a measured thermal-conductivity value. ER-47 therefore does not use that paper to support a conductivity claim.

Weng et al. demonstrated a linear-scan VPP route for ultra-high-viscosity resin [4]. This is relevant process-enablement evidence for highly loaded systems, but it is not proof that a candidate composite has a particular conductivity. Processability, homogeneous dispersion and thermal transport remain separate gates.

### 3. Measurement model and comparability

In a flash experiment, the primary measured transport quantity is thermal diffusivity. Conductivity is normally calculated as  $k = \rho c p \alpha$ , so uncertainty and state mismatch in density or heat capacity propagate into  $k$ . Density,  $c_p$  and  $\alpha$  should therefore be measured or justified for the same composition, conditioning state and temperature range. Values calculated with supplier constants or unmatched specimens must be identified as estimates.

ASTM E1461 provides a flash-method framework for thermal diffusivity. ISO 22007-2 specifies the transient plane heat source method for thermal conductivity and diffusivity of plastics. These routes use different specimen, contact and analysis assumptions and should not be treated as interchangeable without method validation. Surface coatings used for optical absorption in flash testing, thermal contact resistance, specimen thickness, sensor size, anisotropy model and heat-loss correction can materially influence results.

A single scalar value is inadequate where print orientation or filler alignment creates anisotropy. At minimum, in-plane and through-thickness directions should be tested when either is relevant. Test temperature and humidity matter because polymer mobility, absorbed water and interfacial resistance can change transport. Replicates and an uncertainty statement are required before small differences are interpreted as formulation effects.

### 4. Minimum qualification and reporting set

| Control      | Minimum record                                                                               | Required interpretation                                                 |
|--------------|----------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Material     | Resin and lot; filler chemistry, grade, morphology, surface treatment and wt/vol fraction    | The claim belongs to the exact formulation                              |
| Dispersion   | Mixing energy/time, degassing, sedimentation window and sampling position                    | A nominal loading does not prove a connected homogeneous network        |
| Print/cure   | Printer, wavelength, exposure, layer, orientation, wash, dry, post-cure and conversion proxy | Transport must be tied to the achieved network state                    |
| Specimen     | Dimensions, porosity/density, surface preparation and measurement axes                       | Bulk plaques may not represent thin walls or lattices                   |
| Conditioning | Temperature, humidity, duration and test temperature range                                   | Do not compare unmatched thermal/moisture states                        |
| Flash route  | $\alpha$ , $\rho$ and $c_p$ with source/method, coating, pulse/model and uncertainty         | Report components of $k = \rho c p \alpha$ , not only the derived value |
| TPS route    | Standard/edition, sensor, power/time, geometry, contact pressure and model                   | Contact and model suitability must be demonstrated                      |
| Function     | Cycling plus dimensions, mechanics, dielectric/electrical performance and ageing as relevant | Conductivity alone is not application qualification                     |
| Statistics   | Independent specimens, repeats, dispersion and uncertainty                                   | Resolve real effects from measurement scatter                           |

### 5. Anisotropy and process-function trade-offs

Conductive paths form through particle contact, aspect ratio, orientation and interfacial thermal resistance. VPP can impose gradients through sedimentation, recoating shear, cure-depth attenuation and layer interfaces. A formulation can therefore show different in-plane and through-thickness transport even at constant nominal loading.

Microstructure and direction should accompany the numerical result.

More filler is not automatically better. Higher loading can increase viscosity, scattering and sedimentation risk, narrow the processing window, reduce conversion, create voids and compromise interlayer bonding. Bagatella et al. provide a direct example of simultaneous conductivity gain, viscosity increase and conversion loss [2]. Selection should maximise required system performance, not conductivity in isolation.

### 6. 3Dresyns implementation boundary

The 3Dresyns GrapSEK1-MWCNT Bio product page describes the material as electrically and thermally conductive but publishes electrical, not thermal-conductivity, values. That wording is manufacturer screening information; it is not an independent  $k$  result and ER-47 assigns no thermal value to the product. A project claim requires the exact controlled

grade and TDS/IFU revision, dispersion state, printer and cure record, followed by temperature- and direction-specific thermal testing in representative geometry. Source: <https://www.3dresyns.com/products/3dresyn-grapsek1-mwcnt-bio-compatible-multi-wall-carbon-nanotubes-based-electrically-conductive-water-soluble-3d-resin>

## 7. Limitations and research priorities

Direct peer-reviewed conductivity datasets for VPP composites remain sparse and formulation-specific. Priorities include round-robin comparisons between flash and transient-plane-source methods; matched in-plane/through-thickness microstructure; sedimentation and reuse history; conversion and porosity mapping; temperature-dependent  $\kappa$ ; thin-feature and lattice validation; thermal cycling; and simultaneous mechanical, dielectric and ageing evidence. Product values should be published with uncertainty and complete state metadata.

## 8. Conclusions

- Thermal stability, heat resistance, diffusivity and conductivity are distinct claims.
- A conductivity value requires formulation, processing, direction, temperature, method and uncertainty.
- Flash-derived conductivity requires traceable  $\alpha$ ,  $\rho$  and  $c_p$  for compatible states.
- High filler loading or high-viscosity printability does not independently prove thermal performance.
- No 3Dresyns product is assigned a universal conductivity value here; qualification belongs to the tested article.

## Declarations

## References

- [1] Fortunato M, Stifani C, Fava A, Mancini MR, De Angelis U, De Santis G, Corallo G, Mirabile Gattia D. Improvement in Thermal Conductivity in UV-Curable Polymer Composites via h-BN and Graphite Hybrid Fillers for DLP 3D Printing. *Materials*. 2026;19(11):2304. <https://doi.org/10.3390/ma19112304>
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## Standards

ASTM E1461-13(2022). Standard Test Method for Thermal Diffusivity by the Flash Method. <https://store.astm.org/e1461-13r22.html>

ISO 22007-2:2022. Plastics—Determination of thermal conductivity and thermal diffusivity—Part 2: Transient plane heat source (hot disc) method. <https://www.iso.org/standard/81836.html>