

Poly(trimethylene carbonate) Photoresins for Stereolithography: Macromer Identity, Non-Reactive Diluent, Elastic Networks, Perfusable Channels, β -TCP Composites and Qualification

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Statement of Significance

Poly(trimethylene carbonate) (PTMC) macromers have enabled flexible, elastic stereolithography structures ranging from porous scaffolds to branched microchannels and β -tricalcium-phosphate composites. Their apparent simplicity hides critical controls: macromer molecular mass, terminal photoreactive functionality, large non-reactive-diluent fractions, extraction, network conversion, architecture and filler gradients. ER-116 separates polymer identity, printable resin, washed network and biological article so performance is not transferred between materially different states.

Keywords: vat photopolymerisation; stereolithography; poly(trimethylene carbonate); PTMC macromer; propylene carbonate; elastic network; perfusable channels; β -tricalcium phosphate; micro-CT; qualification.

Abstract

Photo-crosslinkable PTMC macromers support flexible and elastic stereolithography networks. Direct studies report tensile moduli from about 3.8 to 7.9 MPa in different formulations, elongation above 900% in selected films, porous structures, five-generation branched channels and PTMC/ β -TCP builds. Up to 45 wt% propylene carbonate was used as a non-reactive viscosity reducer in one platform, making extraction and residual-solvent closure integral to identity. Water flow through approximately 224 μ m channels and HUVEC attachment demonstrate platform capability, not haemocompatibility or implantation readiness. Filler contents up to 60 wt% were printed in smaller structures, while 51 wt% enabled a large prototype and surface enrichment showed composition nonuniformity. Qualification must close macromer functionality, diluent mass balance, spatial cure, geometry, deformation, filler profile, degradation products and biological risk.

1. Scope and boundaries

ER-116 owns photo-crosslinkable PTMC macromers, non-reactive propylene-carbonate dilution, flexible stereolithography networks, PTMC-specific channel/scaffold behaviour and PTMC/ β -TCP composition gradients. It does not own generic silicone-like materials, all hydrophobic elastomers, microfluidic leak qualification, every filled resin or medical-device approval.

ER-06 retains biological response; ER-12 organ-on-chip qualification; ER-15 tissue-scaffold degradation; ER-24 soft robotics; ER-26 cellular architectures; ER-33 washing/drying; ER-36 rheology/recoating; ER-41 liquid exposure; ER-69 fatigue-crack growth; ER-76 filled-resin optics; ER-86 extractables; ER-89 leak/seal testing; ER-97 capillary flow; ER-100 corpus architecture; and ER-102 silicone/silicone-like elastomers [C1-C15]. ER-116 is the PTMC macromer-to-final-network gate.

PTMC is not trimethylene carbonate monomer, propylene carbonate diluent or polycarbonate generically. Propylene carbonate is non-reactive in the cited resin, while terminal (meth)acrylate functionality fixes the network. These species require independent mass balance.

2. Material-state gate

State	Controlled identity	Release risk
Macromer	PTMC molar mass, dispersity, end groups, photofunctionality and catalyst residues	Class name substitutes for batch identity
Vat	Macromer, propylene carbonate, initiator, absorber, temperature and ageing	Non-reactive diluent or drift is hidden
Green/washed network	Conversion, extractables, swelling, dry mass and geometry	Printed and final states are conflated
Functional article	Architecture, filler profile, perfusion, deformation and biological exposure	Material coupon is treated as device evidence

Table 1. PTMC material-state controls.

3. Direct primary evidence

3.1 Flexible PTMC stereolithography

Schüller-Ravoo et al. prepared porous and non-porous structures from photo-crosslinkable PTMC macromers [1]. Selected network films had tensile modulus about 3.8 MPa, tensile strength about 4.2 MPa and elongation above 900%; properties increased with macromer molecular mass. Solid compression moduli were 3.1–4.2 MPa. Porous structures had 53–66% porosity and average pore sizes of 309–407 μm , with lower compression modulus than solid specimens. These values are formulation- and architecture-specific [S1-S3].

3.2 Non-reactive diluent boundary

The same platform used up to 45 wt% propylene carbonate to reach processable viscosity [1]. Because the diluent was non-reactive, printed-object identity depended on washing, diffusion path, geometry, drying and residual analysis. A dry-looking structure is not evidence of complete removal; mass balance and extractables must close every architecture [S4-S6].

3.3 Branched microvascular structure

A later study used a PTMC macromer of 3150 g mol⁻¹ and reported modulus 7.9 ± 0.1 MPa, tensile strength 3.5 ± 0.1 MPa and elongation $76.7 \pm 0.7\%$ [2]. A five-generation design branched each channel into four, keeping overall cross-sectional area constant. The smallest built channels were approximately 224 μm wide with approximately 152 μm walls. Water flow was 0.279 ± 0.006 mL s⁻¹ at 80 mmHg and 0.335 ± 0.009 mL s⁻¹ at 120 mmHg. This validates open water-perfusable geometry, not blood flow, haemocompatibility, leak lifetime or physiological shear.

3.4 Cell-evidence boundary

HUVECs attached and proliferated on the studied PTMC surfaces [2]. That evidence is relevant but narrow. It does not close extractables, degradation products, thrombogenicity, immune response, sterilisation, chronic perfusion or implantation. Biological claims must follow the final material state and a risk-management plan [S7-S10].

3.5 Internal deformation by μCT

Narra et al. imaged stereolithography PTMC scaffolds during compression using 12.25 μm isotropic voxels [3]. Local deformation was approximately linear along the compression axis, while planes perpendicular to it varied by 150–200 μm . The work demonstrates why bulk modulus or finite-element input alone cannot validate realised struts, pores and local deformation fields [S3].

3.6 PTMC/ β -TCP composites

Dienel et al. stereolithographically built PTMC structures containing up to 60 wt% β -TCP and a large patient-specific prototype at 51 wt% [4]. β -TCP increased tensile properties, but the printed scaffolds showed more ceramic at the surface. Surface availability may be useful, yet it is also evidence of a spatial composition gradient requiring top/bottom, surface/core and lot-specific measurement; nominal vat loading is not article composition.

4. Geometry, flow and filler qualification

Gate	Minimum evidence	Claim withheld
Channels	Target/measured width, wall, roughness, occlusion and build orientation	Resolution or perfusion equivalence
Flow	Fluid, pressure, flow, temperature, leakage, compliance and duration	Blood compatibility or service lifetime
Scaffold	Porosity, pore distribution, strut geometry and full-field deformation	Bulk-coupon mechanics transfer
Composite	Vat dispersion, optical profile, surface/core β -TCP and cure conversion	Uniform filler or bioactivity

Table 2. PTMC article-level qualification gates.

5. Degradation and service boundary

PTMC is commonly described as bioresorbable, but a printed crosslinked network has its own molar mass, crosslink density, residual diluent, geometry and degradation pathway. Release requires medium, temperature, pH, swelling, dry mass, molar-mass change, mechanical retention and identified products [S5,S9,S10,S11]. Hydrolysis or surface erosion cannot be assumed from the polymer name.

Flexible does not mean fatigue-resistant, and water perfusion does not prove long-term channel integrity. Cyclic pressure, creep, sterilisation, ageing, biological media and particle exposure from β -TCP composites require separate endpoints. ER-69 retains fatigue-crack ownership; ER-89 retains leak qualification [C9,C12].

6. Failure-mode interpretation

- The vat flows after adding propylene carbonate: close extraction and residual solvent for the thickest article.
- A film reaches >900% elongation: do not transfer that result to a porous scaffold or another macromer molar mass.
- A channel passes water: record leakage, compliance and duration; do not call it vascularly qualified.
- HUVECs proliferate: retain the final washed network and withhold haemocompatibility or implantation claims.
- The nominal β -TCP fraction is known: measure article surface/core composition and local conversion.
- Compression modulus matches a coupon: verify realised strut deformation by imaging or equivalent full-field evidence.
- PTMC is called resorbable: identify products and time-resolved properties in the relevant environment.

7. Minimum workflow

- Freeze PTMC molar mass, dispersity, end groups, photofunctionality, catalyst residues and batch.
- Freeze propylene carbonate, initiator, absorber, temperature, water and open-vat history.
- Measure rheology and optics before printing; record exposure, conversion and spatial growth.
- Close wash/dry by input-output mass, extractables, residual diluent, swelling and geometry.
- Validate pores/channels by 3D metrology, full-field deformation, leakage and duration-specific flow.
- Map β -TCP from vat through article surface/core and requalify optics, conversion and particles.
- Close degradation products and biological risk on the exact final article before medical claims.

8. Conclusions

PTMC macromers support unusually flexible stereolithography networks and demonstrators with porous, perfusable and composite architectures. Direct studies show that macromer molecular mass, non-reactive dilution, geometry and ceramic distribution govern performance.

The evidence also establishes strict limits: propylene carbonate extraction is part of material identity; coupon mechanics do not transfer to pores; water flow is not vascular qualification; cell attachment is not device biocompatibility; and nominal β -TCP content is not spatially uniform article composition.

ER-116 therefore releases no universal PTMC formulation, elongation, channel size, perfusion, bioresorption, bioactivity or medical safety claim. Qualification must follow the exact macromer, vat, washed network and functional article.

Limitations

This qualitative engineering review is not a systematic meta-analysis. Direct evidence covers several related PTMC stereolithography platforms with different macromers, formulations and architectures; numerical values are not pooled. No proprietary recipe, universal exposure, complete extraction process, haemocompatibility, long-term perfusion, sterilisation validation, in-vivo degradation, toxicological qualification, regulatory approval or clinical-performance claim is supplied.

Author contributions

Juan Seguro: conceptualisation, evidence synthesis, boundary definition, engineering interpretation, manuscript preparation and final author verification.

Competing interests

The author is founder and CEO of 3Dresyns by Resyner Technologies S.L. No comparative product recommendation is made.

Data availability

No new experimental dataset was generated. Scientific statements derive from cited primary literature and official standards. The review package includes QA and source-boundary records for independent review.

Company information

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Related Engineering Review boundaries

- [C1] Segurola, J. Biological Response in Photopolymer Additive Manufacturing. ER-06. Zenodo (2026).
- [C2] Segurola, J. Engineering Qualification of Vat-Printed Organ-on-Chip Materials. ER-12. Zenodo (2026). o or controlled
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- [C7] Segurola, J. Rheology, Recoating and Dispersion Control of Highly Filled VPP Suspensions. ER-36. Zenodo (2026).
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- [C9] Segurola, J. Fatigue-Crack Growth and Subcritical Fracture in Vat-Photopolymerised Thermosets. ER-69. Zenodo
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- [C13] Segurola, J. Wettability and Capillary Flow in Vat-Printed Microfluidic Channels. ER-97. Zenodo (2026).
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Version note

v0.2 closes the applicable partial-gate findings in the frozen ER architecture and records author-side primary-source completion. Author: Juan Segurola, without degree suffix