

ER-85

Vat-Photopolymerised Water-Soluble Sacrificial Tooling for Ceramic and Metal Powder Injection Moulding: Process-Class Boundaries, Intricate Geometry, Aqueous Removal and Qualification Requirements

Juan Seguro, PhD

3Dresyns by Resyner Technologies S.L.

Registered tax address: General Etxague 15B, 20003 Donostia / San Sebastián, Gipuzkoa, Spain

VAT number: ESB24827511

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

3Dresyns Engineering Review ER-85 · Version 0.5 · 26 August 2026 · No proprietary formulation composition disclosed

Statement of significance

Water-soluble VPP sacrificial tooling is valuable when it enables geometric feature classes that cannot be demoulded, or can be produced only through costly multipart tooling. ER-85 separates that geometric opportunity from process validation. Direct evidence supports defined CIM and low or near-zero-pressure metal-powder routes; it does not support transfer to conventional high-pressure or POM-bound MIM. ER-85 retains the geometry-class evidence matrix and the explicit manufacturer-context distinction between binder-built feedstock slurries and ready ceramic or metal slurry routes.

Abstract

Water-soluble sacrificial tooling can extend ceramic and metal powder injection moulding to enclosed cavities, undercuts, tortuous channels and freeform negative geometries that are difficult to realise with conventional demouldable tooling. The evidence base, however, contains process classes that must not be merged. Direct studies support ceramic injection moulding, a complete near-zero-pressure metal-powder process chain, low-pressure injection of a 316L suspension into a complex helix mould, and thermoplastic micro-injection lost-core manufacturing. Separate material studies support hydrolysable vat-photopolymerised cavity tools, while adjacent reviews describe sacrificial removal without closing the PIM-specific removal-kinetics gap. ER-85 therefore classifies geometric advantage classes, feedstock/process classes, binder-built versus ready-slurry preparation routes, stage-resolved evidence and failure-discrimination requirements. Conventional high-pressure or POM-bound systems such as Catamold remain an explicit upper-boundary case because no retained source demonstrates injection into a water-soluble VPP mould followed by aqueous tool removal and the complete downstream chain. Manufacturer documentation identifies candidate implementation routes only. Exact compositions are not inferred, and no product-specific superiority, universal compatibility or universal feature-size claim is made.

Keywords: vat photopolymerisation; sacrificial tooling; water-soluble mould; ceramic injection moulding; powder injection moulding; metal injection moulding; low-pressure powder injection moulding; intricate geometry; internal channel; aqueous removal; green part; debinding; sintering; qualification framework

1. Scope and evidence boundary

ER-85 is restricted to evidence needed to qualify vat-photopolymerised water-removable sacrificial moulds or cores in ceramic injection moulding and metal-powder injection-moulding process chains. Durable tooling, investment-casting patterns removed by melting or burnout, and generic support-removal applications remain outside the technical core. The evidence-to-decision rules follow the shared RP-02 framework [F1].

Table 1. Included and excluded scope.

Included	Excluded or not established
SLA, DLP, LCD/MSLA and volumetric printing of sacrificial moulds or cores	Durable or reusable rigid tooling
Ceramic injection moulding	Investment casting and heat-removable patterns
Metal-powder injection moulding under directly demonstrated low or near-zero pressure conditions	Conventional high-pressure or POM-bound metal injection moulding as a validated application
Tool survival, feedstock compatibility, aqueous removal, residue and green-part recovery	Universal temperature, pressure, cycle-time or dissolution windows
Debinding and sintering interfaces after tool removal	Product superiority or universal compatibility
FDM/PVA comparisons as external reference cases	Inference of proprietary resin chemistry

2. Terminology and process-class separation

The acronym MIM is ambiguous in the retained literature. It can refer to metal injection moulding or to micro-injection moulding of thermoplastics. ER-85 requires the full term at every first use and whenever the process class could be misunderstood. Section 6 separately classifies the geometric advantages that may justify a single-use water-soluble mould; those advantages do not erase the process-class boundaries below.

Table 2. Process classes and prohibited evidence transfer.

Process class	Direct evidence retained	Permitted conclusion	Prohibited transfer
Ceramic injection moulding	Wick-Joliat et al. [1]	Water-soluble sacrificial moulds can enable complex CIM geometries in the reported FDM and DLP workflows	No validation of a 3Dresyns grade or of all ceramic feedstocks
Near-zero-pressure metal-powder injection moulding	Zhang et al. [2]	A complete VPP mould -> metal-feedstock injection -> aqueous removal -> debinding -> sintering chain was demonstrated with a specially developed feedstock	No transfer to conventional high-pressure or POM-bound MIM
Low-pressure metal-powder injection moulding of intricate geometry	Basso et al. [13]	A 316L suspension was injected into a VPP water-soluble helix mould; the study directly exposes geometry and cleaning failure modes	No general feature-size threshold; debinding and sintering were outside that study
Thermoplastic micro-injection moulding	Farrugia et al. [3]	IM-HDT-WS has direct peer-reviewed lost-core evidence in a PMMA micro-injection process	Not evidence for metal powder, debinding or sintering
Lost-form powder injection moulding with thermal tool removal	Hein [4]	DLP sacrificial inserts can support a PIM chain when the polymer is thermally degraded	Not evidence for aqueous removal
Conventional high-pressure or POM-bound MIM	No direct retained process-chain source; Catamold [M6] is a boundary reference	Remains an excluded qualification target	Must not be presented as compatible or validated

3. Corrected and expanded source map

The controlled CIM reference is Wick-Joliat et al., Additive Manufacturing 48, 102408 [1]. Zhang et al. directly support a specially developed metal feedstock, near-zero-pressure injection, aqueous tool removal, debinding and sintering [2]. Basso et al. add a geometry-resolved low-pressure 316L helix case and, importantly, a direct failure example [13]. Hein is the sole author of the 2018 thermal lost-form conference paper [4].

Table 3. Source map and evidence boundaries.

Source	What it establishes	What it does not establish
Wick-Joliat et al. 2021 [1]	FDM PVA and laboratory DLP water-soluble moulds for CIM	3Dresyns product validation; metal-powder PIM
Zhang et al. 2020 [2]	VPP water-soluble mould, specially developed metal feedstock, near-zero injection pressure, aqueous removal, debinding and sintering	Conventional high-pressure/POM MIM; any 3Dresyns grade
Farrugia et al. 2024 [3]	Direct IM-HDT-WS evidence in thermoplastic micro-injection lost-core manufacturing	Metal injection moulding or sintered metal parts
Hein 2018 [4]	Lost-form PIM with DLP tool and thermal polymer degradation	Water dissolution
Zhang et al. 2022 [5]	Adjacent inspection architecture for mould and part quality	Sacrificial-tool material validation
Liz-Basteiro et al. 2023 [6]	Aqueous-sacrificial VPP chemistry used with molten PCL and silicone	CIM or metal-powder PIM
Rafalko et al. 2023 [11]	Base-triggered dissolution of a hydrolysable VPP thermoset and fabrication of intricate parts	PIM tool survival, green-part compatibility or removal kinetics inside injected bodies
Wang and Zhou 2024 [12]	Adjacent review of sacrificial biomaterials in tissue-engineering scaffold fabrication	PIM-specific removal kinetics; CIM or metal-powder PIM process-chain evidence
Basso et al. 2021 [13]	Direct geometry-resolved low-pressure PIM helix study using a VPP water-soluble mould and 316L suspension	A universal helix diameter or process window
PIM books and reviews [7-10]	Feedstock, binder, pressure-class, debinding and sintering context	Product-specific sacrificial-tool performance

4. Distinction from ER-09 and neighbouring papers

ER-09 remains the broad cross-application review of water-removable sacrificial photopolymers and their removal pathways [E1]. ER-85 is narrower: it asks what evidence is required before a defined CIM or metal-powder injection-moulding process chain can be released. ER-85 adds stage-resolved qualification, process-class separation, intricate-geometry evidence and failure discrimination. ER-74 addresses cleavage or depolymerisation as an end-of-life or circular-material operation. ER-85 treats intentional tool loss as an in-process demoulding step. ER-31 controls shrinkage, residual stress and warpage; ER-33 controls washing, extraction and drying; ER-43 controls intentionally different material interfaces; ER-73 controls native printed-layer cohesion; and ER-13 controls repair. ER-85 uses those topics only where they determine sacrificial-tool survival or the state of the injected green part.

5. Stage-resolved process-chain model

A successful print, a soluble coupon or one filled cavity does not validate an injection-moulding process chain. The minimum evidence sequence is shown in Table 4.

Table 4. Eleven-stage evidence chain.

	Minimum record	Required interpretation
1. Material control	Resin version, batch, storage history and cure state	The tool material is reproducible
2. Tool fabrication	Complete printed geometry, wall thickness, channels, gates, vents and cleaning access	The tested cavity is known before injection
3. Conditioning	Declared thermal, moisture and surface state	The tool enters injection in a controlled condition
4. Feedstock formulation and definition	Declare ready-slurry or binder-built route; powder identity and lot, binder version, solids loading, mixing history, rheology and process class	The injected material and its preparation history are not described only by a trade name
5. Injection	Temperature, pressure, rate, time, packing, tool temperature and cooling	The load history is reproducible
6. Tool-survival check	Deformation, fracture, leakage, cavity shift and flow evidence	Adequate filling is not mistaken for tool integrity
7. Assembly recovery	Cooling and handling protocol	Pre-removal damage is separated from bath-induced damage
8. Aqueous removal	Bath chemistry, temperature, agitation, renewal, access and endpoint	Removal is controlled and complete
9. Released green part	Residue, cracks, density, dimensions and failure location	The part is suitable for downstream processing
10. Debinding and sintering	Feedstock-specific schedules, supports, atmosphere and shrinkage	The downstream chain remains valid
11. Final qualification	Dimensions, defects, density, properties, replicates and uncertainty	The result is more than a one-off demonstration

6. Geometric advantages of water-soluble VPP sacrificial moulds for intricate CIM and low-pressure MPIM designs

The rationale for a water-soluble VPP sacrificial mould is not that it replaces metal tooling generically, but that it enables feature classes that cannot be demoulded or require prohibitive multipart assembly with durable tooling. Table 5 enumerates those candidate advantage classes, anchors them to the retained evidence and states the failure modes that remain to be excluded before the advantage becomes a qualified capability.

The evidence also shows why geometry must be treated as an experimental variable. In the direct low-pressure 316L helix study, the straight 2 mm pillar survived but the 2 mm helix failed at its turning points. Pre-injection CT identified necking and deviations exceeding 0.3 mm, linked in part to incomplete removal of uncured resin; the study did not establish a universal minimum channel or helix diameter [13]. This is not evidence against intricate tooling. It is evidence that nominal CAD complexity, printed cavity fidelity, cleaning access, local shear and removal handling must be measured separately.

Rafalko et al. support a complementary material boundary: an acrylate VPP thermoset containing a hydrolysable cross-linker could be formulated for complete base-triggered dissolution and used to print intricate cavity tools [11]. That study does not validate a PIM chain, but it strengthens the material-level premise that dissolution behaviour can be engineered rather than treated as a product adjective.

Table 5. Candidate geometric advantage classes enabled by water-soluble VPP sacrificial moulds.

ID	Candidate geometric advantage	Constraint reduced	Evidence status	Boundary / failure to rule out
A	Enclosed cavities and hollow parts	Physical demoulding or multipart tool assembly	Supported as an enabling use by CIM, near-zero-pressure PIM, thermoplastic micro-injection and water-soluble-cavity sources [1-3,11]	Green strength after removal, trapped residue and dimensional support remain process-specific
B	Zero-draft or low-draft walls	Draft-driven ejection constraint	Candidate advantage consistent with sacrificial demoulding logic in [1,2]	No universal zero-draft tolerance or dimensional accuracy is established
C	Complex internal channels and tortuous paths	Slides, side cores or straight pull-out paths	Direct internal hollow-feature and aqueous-sacrificial context [3,6,11]; helix failure case [13]	Removal time and residue depend on diameter, tortuosity, access and bath renewal; quantitative PIM kinetics remain a gap
D	Undercuts without slides or side cores	Mechanical tool retraction and parting-line complexity	Candidate advantage within the design-flexibility logic of [1,2,10]	Thin tool walls may deflect, crack or leak under the filling history
E	Mesoscale porosity, lattices and TPMS-like cavities	Continuous negative geometry that cannot be pulled from a durable tool	Research-gap class only; adjacent sacrificial-material literature [12]	No direct retained CIM or metal-PIM end-to-end validation
F	Freeform and conformal cavities	Machining and multipart assembly of complex negative surfaces	Near-zero/low-pressure PIM evidence [2,13]	Printer, cleaning and injection errors can accumulate before demoulding

ID	Candidate geometric advantage	Constraint reduced	Evidence status	Boundary / failure to rule out
G	One-piece parts without a persistent parting line	Split-tool assembly, flash and seam imprint	Candidate benefit supported by the single-use sacrificial-tool concept [1-3]	Removal access and downstream binder transport still require qualification

Every advantage class above is a candidate contribution of the water-soluble VPP pathway. None is validated end-to-end across the complete stage chain for every geometry. The conversion from candidate advantage to qualified capability requires the same material, injection, removal, green-part and final-part evidence applied to the intended feature set.

7. Feedstock-class compatibility and the Catamold boundary

The term metal feedstock does not define one pressure, binder, viscosity or debinding class. Table 6 separates the retained feedstock classes. Conventional POM-bound systems such as BASF Catamold are retained solely as an upper-boundary reference. BASF identifies Catamold as a ready-to-mould catalytic-debiding MIM feedstock [M6]. No retained source demonstrates the chain water-soluble VPP mould -> Catamold injection -> aqueous mould removal -> catalytic debinding -> sintering. ER-85 therefore does not describe Catamold as compatible, recommended or validated.

Manufacturer documentation also identifies a separate preparation route. The 3Dresyns ceramic, metal and polymer powder-feedstock collection groups eco binders and ready ceramic or metal slurries for injection in 3D printed molds [M7]. Within that portfolio, 3Dresyn EB1 is positioned as a binder to be mixed with selected ceramic or metal powders to prepare feedstock slurries for injection in durable or sacrificial 3D printed molds, followed by water and thermal debinding and sintering [M8]. ER-85 retains this only as manufacturer-defined implementation context. It does not establish universal powder compatibility, solids loading, mixing conditions, rheology, injection pressure or temperature, mould survival, debinding or sintering schedules, or final-part performance.

Table 6. Feedstock and process classes relevant to the sacrificial-mould pathway.

Feedstock / process class	Representative source	Status in ER-85	Boundary
Ceramic injection feedstocks	CIM workflows represented by [1]	Directly within scope under the reported process conditions	Tool water sensitivity, ceramic binder chemistry and drying remain coupled
Specially developed near-zero-pressure metal feedstock	Zhang et al. [2]	Directly demonstrated with a VPP water-soluble mould, aqueous removal, debinding and sintering	No transfer to conventional high-pressure feedstocks
Low-pressure 316L suspension with LDPE/paraffin binder	Basso et al. [13]	Direct low-pressure intricate-geometry evidence	Helix damage and >0.3 mm cavity deviation demonstrate that geometric capability is not automatic
Thermoplastic micro-injection feedstock	PMMA process in [3]	Direct lost-core evidence for a separate process class	Not metal-powder PIM
Binder-built ceramic or metal feedstock slurry	3Dresyns collection and 3Dresyn EB1 [M7,M8]	Manufacturer implementation context: EB1 is positioned as a binder to mix with selected ceramic or metal powders to prepare injectable feedstock slurries	No independent validation of powder family, loading, mixing, rheology, injection window, mould compatibility, debinding, sintering or final-part performance
Conventional POM-bound Catamold-class feedstock	BASF Catamold [M6]	Upper-boundary reference only	No retained source demonstrates VPP water-soluble mould -> Catamold injection -> aqueous mould removal -> catalytic debinding -> sintering
Low-viscosity solvent-based slurry	No retained direct PIM source	Context only; do not present as included	Solvent compatibility and removal pathway unverified

8. Thermal-mechanical survival is process-specific

A static HDT or flexural-modulus value does not define tool survival during injection. The realised load depends on feedstock temperature and viscosity, pressure class, filling rate, cavity geometry, local wall thickness, support condition, cure state, contact time and cooling history. Near-zero or low-pressure evidence must not be transferred to high-pressure PIM merely because both workflows contain metal powder. The release question is not “is the resin high-temperature?” but “does the printed tool preserve the required cavity and surface under the complete declared injection history?”

9. Aqueous removal, access and residue

Water removal can involve direct molecular dissolution, swelling-dominated breakup or hydrolytic disintegration. ER-09 controls the broad mechanistic taxonomy [E1]. ER-85 requires the removal pathway to be reported only to the level supported by direct evidence for the exact tool and cure state. Rafalko et al. provide direct base-triggered hydrolysis evidence for a defined VPP thermoset [11], whereas Wang and Zhou review sacrificial removal across tissue-engineering fabrication routes and remain adjacent rather than PIM-specific evidence [12].

At minimum, record water composition, pH, temperature, agitation, bath-to-tool ratio, wall thickness, exposed area, internal flow access, duration, solution refresh, mass change and the physical endpoint used to declare completion. For internal channels, tortuosity and restricted access can make the local removal path differ from an exposed coupon; no directly on-scope 2023-2026 review identified in the reviewed corpus supplies a transferable kinetic model for hydrolysable VPP moulds inside PIM assemblies. The gap remains explicit. Tool disappearance alone does not establish chemical cleavage, low residue or green-part integrity.

10. Green-part recovery, debinding and sintering

The injected body must be evaluated immediately after tool removal and again after debinding and sintering. Required observations include cracks, edge loss, distortion, surface imprint, binder migration, residue, local density, dimensional change and failure location. A clean-looking green part can still carry soluble residues or density gradients that become consequential during debinding or sintering. Zhang et al. [2] support a complete process chain under their own near-zero-pressure conditions. Basso et al. [13] stop after demoulding and therefore support geometric failure analysis but not downstream debinding or sintering.

11. Manufacturer implementation boundary

Public manufacturer documentation identifies two distinct 3Dresyns implementation families: sacrificial tooling materials and feedstock/slurry preparation materials, together with Catamold as an upper-boundary reference. The collection page [M7] groups eco binders and ready ceramic or metal slurries; 3Dresyn EB1 [M8] is the specific binder route for mixing with selected ceramic or metal powders to formulate injectable feedstock slurries. Exact compositions are not inferred. Descriptors such as hard and tough, ultra tough, high deflection temperature, ultra rigid, water-soluble, eco binder and ready slurry define manufacturer positioning only. They are not independent evidence of powder compatibility, process windows, defect-free debinding or final-part performance.

Table 7. Manufacturer implementation context and evidence boundaries.

Candidate route	Public positioning retained	Evidence boundary
IM-HT-WS [M1]	Hard/tough water-removable tooling	Candidate for process-specific qualification; no universal window
IM-UHT-WS [M2]	Ultra-tough water-removable tooling	Toughness label does not establish injection survival
IM-HDT-WS [M3]	High-deflection-temperature water-removable tooling	Direct thermoplastic micro-injection evidence exists [3]; metal-PIM transfer is not established
IM-UHR-WS [M4]	Ultra-rigid water-removable tooling	Rigidity label does not establish pressure resistance in a printed cavity
VAM IM-UHT-WS [M5]	Volumetric-printing implementation context	No independent CIM or metal-PIM process-chain validation inferred
Catamold [M6]	Commercial catalytic-debinding MIM feedstock	Boundary reference only; no water-soluble VPP mould compatibility claim
3Dresyns powder-feedstock collection [M7]	Portfolio of eco binders and ready ceramic or metal slurries for injection in 3D printed molds and downstream debinding/sintering workflows	Manufacturer portfolio identity only; no independent validation of a complete CIM or metal-PIM process chain
3Dresyn EB1 binder [M8]	Binder route for mixing with selected ceramic or metal powders to prepare feedstock slurries for injection in durable or sacrificial 3D printed molds	Manufacturer workflow only; exact powder, loading, mixing, rheology, injection, mould, removal, debinding and sintering must be qualified

12. Minimum qualification matrix

Table 8. Minimum evidence architecture for process release.

Domain	Minimum record or measurement	Release question
Material identity	Controlled resin version, batch, age, storage and permitted composition disclosure	Can the tool material be reproduced?
Printing state	Printer, wavelength, irradiance/exposure, layer or voxel conditions, post-cure and conditioning	Is the realised cure state defined?
Tool geometry	CAD, wall thickness, gates, vents, unsupported spans, surface and dimensional map	Is the tested tool representative?
Intricate-feature preservation	Feature-class-specific metrology before injection, after injection, after removal and after sintering; report resolution and uncertainty rather than a universal tolerance	Did channels, undercuts, helix turns or freeform surfaces retain their intended geometry?
Feedstock identity and preparation	Ready slurry or binder-built route; powder identity and lot, particle distribution, binder version, solids loading, mixing temperature/time, dispersion and rheology	Is the injected material and its preparation history fully defined?
Injection history	Machine, temperature, pressure, rate, time, mould temperature and cooling	Is the load history reproducible?
Tool response	Deformation, fracture, leakage, surface damage and cavity fidelity	Did the tool survive without corrupting filling?
Aqueous removal	Bath chemistry, temperature, agitation, duration, refresh, access and endpoint	Was removal controlled and complete?
Residue and contamination	Tool residue, bath residue, surface chemistry and binder compatibility	Did removal preserve the green material state?
Green-part fidelity	Dimensions, cracks, surface, density and failure location	Is the released part suitable for debinding?
Debinding and sintering	Complete schedules, supports, atmosphere and shrinkage	Does the downstream process remain valid?
Final part	Dimensions, defects, density and application-relevant properties	Does the whole chain meet the predefined criterion?

Domain	Minimum record or measurement	Release question
Reproducibility	Replicates, batches, failed runs and uncertainty	Is the result more than a one-off demonstration?

13. Failure-mode and discrimination matrix

Table 9. Failure observations, competing causes and discrimination evidence.

Observed failure	Competing causes	Discriminating evidence
Tool deforms during filling	Temperature softening; pressure; thin wall; undercure	In-situ or staged geometry, thermal history, matched wall-thickness controls
Thin-wall detail region collapses	Local pressure, insufficient support, cure gradient, cleaning damage	CT or sectioned comparison before/after injection; local pressure or flow simulation; rigid-control geometry
Tool fractures or leaks	Brittleness; interlayer weakness; stress concentration; impact	Failure-location images, orientation controls, cure-state verification
Short shot or incomplete cavity fill	Feedstock rheology; gate design; premature cooling; tool deflection	Pressure/temperature trace, flow-front evidence, rigid-tool control
Internal channel or helix breaks	Printed necking, trapped uncured resin, shear concentration, removal handling	Pre-injection CT, cleaning record, post-injection CT and model comparison [13]
Tool adheres to feedstock	Surface chemistry; roughness; binder interaction; incomplete cure	Surface analysis, contact controls, matched release protocol
Removal is incomplete	Insufficient access; thick wall; weak bath; swelling without disintegration	Sectioned residue, mass change, bath refresh, geometry controls
Green part cracks after removal	Tool swelling; capillary stress; binder extraction; handling	Immediate and recovered-state imaging, binder-content control
Binder-built slurry is non-uniform or not injectable	Insufficient powder wetting or dispersion; excessive solids loading; incomplete mixing; binder-powder incompatibility	Mixing log, rheology, solids-distribution mapping, sedimentation/segregation check and injection pressure trace
Binder or powder segregates	Feedstock instability; injection history; removal-bath interaction	Composition or density mapping before and after removal
Final part drifts dimensionally	Tool error; green-part damage; debinding or sintering shrinkage	Stage-by-stage metrology and error budget
One demonstration succeeds	Uncontrolled batch or geometry dependence	Replicates, batches, declared failures and uncertainty

14. Standards and method gate

No retained source establishes a single ISO, ASTM or DIN standard that directly qualifies a vat-printed water-soluble sacrificial mould through injection, aqueous removal, green-part recovery, debinding and sintering. Conventional methods for thermal deflection, tensile/flexural properties, water uptake, dimensions and powder-injection-moulding process control may provide adjacent measurements only. They do not validate the complete process chain or create a universal intricate-feature acceptance threshold.

15. Verification record and residual evidence items

- Full-text proposition pinning for source-specific numerical and process claims.
- Current controlled product-page and TDS verification for every manufacturer descriptor used.
- Exact standards search and gap statement.
- Proposition-level duplication analysis against ER-09 and neighbouring ER papers.
- Bounded search for direct high-pressure or Catamold-class MIM evidence with a VPP water-soluble sacrificial mould; no such chain is present in the reviewed corpus.
- Dedicated removal-kinetics evidence for tortuous internal geometry; the adjacent review [12] does not close this gap.
- Complete file, link, accessibility and page-by-page visual QA.

16. Research priorities

1. Direct comparison of the same tool geometry across ceramic and metal feedstocks, including ready-slurry and binder-built preparation routes.
2. Stage-resolved measurement of tool deformation during filling and cooling.
3. Removal kinetics as a function of wall thickness, internal access, tortuosity, cure state and bath renewal.
4. Residue and binder-compatibility analysis before debinding.
5. Error budgets separating tool printing, cleaning, injection, removal, debinding and sintering.
6. Direct evidence for or against conventional high-pressure/POM-bound metal injection moulding.
7. Geometry-class qualification using CT or equivalent metrology before and after every critical stage.

17. Conclusions

ER-85 presents a narrow, qualification-led review. Direct evidence exists for water-soluble sacrificial tooling in CIM, near-zero-pressure metal-powder injection moulding, low-pressure 316L helix tooling and thermoplastic micro-injection moulding, but those process classes are

not interchangeable. The geometric advantage matrix clarifies why single-use soluble moulds are enabling for selected cavities, channels, undercuts and freeform negative geometries, while the Basso helix case demonstrates that complexity can expose printing, cleaning and flow-related failure rather than guarantee success. Catamold remains an excluded boundary reference, not an application example. The 3Dresyns binder-built and ready-slurry routes remain manufacturer implementation context, and no proprietary chemistry, universal powder compatibility or universal process window is inferred.

Limitations

This review is literature-based and is not a systematic review. It reports no new experimental data. The search for a recent review specifically quantifying aqueous-removal kinetics of hydrolysable VPP moulds in PIM assemblies did not identify a directly on-scope source; [12] is adjacent. Candidate advantage classes B, D, E and G include engineering hypotheses that require direct end-to-end validation. No universal process window, feature-size threshold, compatibility claim, commercial superiority or freedom-to-operate conclusion is made.

Declarations

Author contributions: Juan Segurola: industrial question definition, scope architecture, evidence-boundary design, geometric qualification framework and critical review.

Competing interests: Juan Segurola is founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L., which develops sacrificial photopolymer tooling and powder-feedstock binder/slurry materials discussed as manufacturer implementation context.

Data availability: No new experimental dataset was generated.

References

- [1] Wick-Joliat, R.; Tschamper, M.; Kontic, R.; Penner, D. Water-Soluble Sacrificial 3D Printed Molds for Fast Prototyping in Ceramic Injection Molding. *Additive Manufacturing* 2021, 48, 102408. <https://doi.org/10.1016/j.addma.2021.102408>
- [2] Zhang, Y.; Basso, A.; Christensen, S. E.; Pedersen, D. B.; Staal, L.; Valler, P.; Hansen, H. N. Characterization of Near-Zero Pressure Powder Injection Moulding with Sacrificial Mould by Using Fingerprint Geometries. *CIRP Annals* 2020, 69(1), 185-188. <https://doi.org/10.1016/j.cirp.2020.04.052>
- [3] Farrugia, J.; Vella, P.; Rochman, A. Combining 3D Printing and Injection Moulding for the Fabrication of Polymer Micro-Components with Internal Hollow Features. *Progress in Additive Manufacturing* 2024, 9, 1353-1364. <https://doi.org/10.1007/s40964-024-00616-x>
- [4] Hein, S. B. Lost-Form Powder Injection Moulding - Combining Additive Manufacturing and PIM. In *Euro PM2018 Proceedings; European Powder Metallurgy Association, Bilbao, 14-18 October 2018*. <https://publica.fraunhofer.de/entities/publication/9f98be14-835b-46f6-8778-ae7cece445be>
- [5] Zhang, Y.; Shan, S.; Frumosu, F. D.; Calao, M.; Yang, W.; Liu, Y.; Hansen, H. N. Automated Vision-Based Inspection of Mould and Part Quality in Soft Tooling Injection Moulding Using Imaging and Deep Learning. *CIRP Annals* 2022, 71(1), 429-432. <https://doi.org/10.1016/j.cirp.2022.04.022>
- [6] Liz-Basteiro, P.; Sanz-Horta, R.; Reviriego, F.; Martínez-Campos, E.; Reinecke, H.; Elvira, C.; Rodríguez-Hernández, J.; Gallardo, A. High Resolution Molds, Sacrificial in Aqueous Media, Obtained by Vat Photopolymerization 3D Printing. *Additive Manufacturing* 2023, 75, 103758. <https://doi.org/10.1016/j.addma.2023.103758>
- [7] German, R. M.; Bose, A. *Injection Molding of Metals and Ceramics*. Metal Powder Industries Federation, 1997. ISBN 978-1-878954-61-9.
- [8] González-Gutiérrez, J.; Stringari, G. B.; Emri, I. Powder Injection Molding of Metal and Ceramic Parts. In *Some Critical Issues for Injection Molding*; 2012; pp 65-88. <https://doi.org/10.5772/38070>
- [9] Pottier, V. *Powder Injection Molding*. Wiley Encyclopedia of Composites, 2nd ed., 2012. <https://doi.org/10.1002/9781118097298.weoc193>
- [10] Momeni, V.; Hufnagl, M.; Shahroodi, Z.; González-Gutiérrez, J.; Schuschnigg, S.; Kukla, C.; Holzer, C. Research Progress on Low-Pressure Powder Injection Molding. *Materials* 2023, 16(1), 379. <https://doi.org/10.3390/ma16010379>
- [11] Rafalko, C.; Stovall, B. J.; Zimudzi, T.; Hickner, M. A. Tunable Stereolithography Photopolymerization Resin for Molding Water-Soluble Cavities. *ACS Applied Polymer Materials* 2023, 5(12), 10097-10104. <https://doi.org/10.1021/acsapm.3c01965>
- [12] Wang, C.; Zhou, Y. Sacrificial Biomaterials in 3D Fabrication of Scaffolds for Tissue Engineering Applications. *Journal of Biomedical Materials Research Part B: Applied Biomaterials* 2024, 112(1), e35312. <https://doi.org/10.1002/jbm.b.35312>
- [13] Basso, A.; Zhang, Y.; Kjeldahl Pløger, J.; Spangenberg, J.; Hansen, H. N. Analysing Powder Injection Moulding of a Helix Geometry Using Soft Tooling. *Polymers* 2021, 13(23), 4183. <https://doi.org/10.3390/polym13234183>

Engineering Review framework and neighbouring paper

[E1] Segurola, J. ER-09 - Water-Removable Sacrificial Photopolymers for Indirect Additive Manufacturing: Mechanistic Frameworks, Process Coupling and Emerging Applications. Version 2.6, 2026. <https://doi.org/10.5281/zenodo.21996998>

[F1] Segurola, J. RP-02 - Evidence-to-Decision Qualification Framework for Vat Photopolymerisation. Version-independent concept record, 2026. <https://doi.org/10.5281/zenodo.22048032>

Manufacturer documentation

- [M1] 3Dresyn IM-HT-WS Hard and Tough Water-Soluble Sacrificial Resin. Public product page; accessed 26 August 2026. <https://www.3dresyns.com/products/3dresyn-im-ht-ws-hard-and-tough-and-water-soluble-for-sacrificial-low-medium-temperature-sacrificial-injection-molding>
- [M2] 3Dresyn IM-UHT-WS Ultra-Tough Water-Soluble Sacrificial Resin. Public product page; accessed 26 August 2026. <https://www.3dresyns.com/products/3dresyn-im-uht-ws-ultra-tough-and-water-soluble-for-sacrificial-medium-temperature-sacrificial-injection-molding>
- [M3] 3Dresyn IM-HDT-WS High-Deflection-Temperature Water-Soluble Sacrificial Resin. Public product page; accessed 26 August 2026. <https://www.3dresyns.com/products/3dresyn-im-hdt-ws-high-deflection-temperature-and-water-soluble-for-very-high-temperature-sacrificial-injection-molding>
- [M4] 3Dresyn IM-UHR-WS Ultra-Rigid Water-Soluble Sacrificial Resin. Public product page; accessed 26 August 2026. <https://www.3dresyns.com/products/3dresyn-im-uhr-ws-ultra-rigid-and-water-soluble-for-high-temperature-sacrificial-injection-molding>
- [M5] 3Dresyn VAM IM-UHT-WS Water-Soluble Sacrificial Resin for Volumetric Additive Manufacturing. Public product page; accessed 26 August 2026. <https://www.3dresyns.com/products/3dresyn-vam-im-uht-ws-ultra-tough-and-water-soluble-sacrificial-resin-for-vam-3d-printers>
- [M6] BASF. Catamold - Ready-to-Mould Catalytic-Debinding Metal Injection Moulding Feedstocks. Public manufacturer page; accessed 26 August 2026. https://electronics-electric.basf.com/global/en/electronics/metal_systems/catamold
- [M7] 3Dresyns by Resyner Technologies S.L. Ceramic, metal & polymer powder feedstock slurries for injection in 3D printed molds. Public collection page; accessed 26 August 2026. <https://www.3dresyns.com/collections/ceramic-metal-polymer-powder-feedstock-slurries-for-injection-in-3d-printed-molds>
- [M8] 3Dresyns by Resyner Technologies S.L. 3Dresyn EB1, Eco Binder for water debinding and sintering of Ceramic, Metal & Polymer powder slurries. Public product page; accessed 26 August 2026. <https://www.3dresyns.com/products/3dresyn-eb1-eco-binder-for-water-debinding-and-sintering-of-ceramic-metal-polymer-powder-slurries>