

Industrial additive-manufacturing technology series

Juan Segurola

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

ER-166 · Engineering Review · Version 0.3 · 7 September 2026

Abstract

Every printed part that has to carry a load carries it through a small number of discrete places: an insert, a thread, a press fit, a bolted hole. Those places are where the material is most highly stressed, least well characterised and most casually specified. This review takes local load introduction into vat-photopolymerised components as its subject. It located **one vat-photopolymerisation insert study with accessible quantitative results**, in which the insert was adhesively potted — placing its retention mechanism partly in ER-165 — and **a second vat-photopolymerisation pull-out paper whose relevant content could not be obtained and to which no value is attributed**. From that narrow base follows the result that governs everything downstream: **beyond the single accessible study, the comparative quantitative installation literature located is thermoplastic, and the thermal installation mechanism on which it rests is unavailable in a vat-photopolymerised part**. Heat-set, ultrasonic and thermal-staking installation work by softening a thermoplastic and allowing it to flow into an undercut. A vat-photopolymerised part is a crosslinked network — the digital-light-processing literature places its gel point at a degree of cure of 0.37 — and it does not re-flow. Those values therefore cannot be transferred as vat-photopolymerisation design values. This review further located **no study of heat-set, ultrasonic or press-fit insert installation in a vat photopolymer; no press-fit retention data for any printed polymer; no primary source on a load-bearing overmoulded or captured interface in a vat photopolymer; no pin-bearing data for a vat photopolymer; and no insert pull-out or torque-out standard for thermoplastics or thermosets in the standards search performed here**. The one pull-out standard located for a fastener in a non-metallic substrate is written for wood; the fastener-property standard most often imported by habit is written for carbon and alloy steel. What follows separates the two vat-photopolymerisation anchors that exist from the thermoplastic evidence used as declared contrast, states what a printed photopolymer's post-cure and viscoelastic state does to a preloaded joint, and **proposes** a load-introduction qualification architecture in which the local interface is qualified as a configuration rather than inferred from a bulk material property.

1. Objective and scope

The objective is to provide a factory-facing framework for introducing concentrated mechanical load into a vat-photopolymerised component and for defending the resulting interface as a structural feature.

ER-166 governs whenever load enters or leaves a printed photopolymer part through a **discrete mechanical interface**: threaded inserts of any installation type; threads, whether tapped, formed or printed directly; press and interference fits; bolted, pinned and riveted holes; and overmoulded or captured features whose purpose is to carry load. It owns the local contact stress and stress concentration at that interface, the installation operation as a process step, preload behaviour over time, the failure set — pull-out, stripping, splitting, cracking, bearing and pull-through — and the proof-load qualification and change control that make the interface defensible.

Corpus ownership. ER-073 owns interlayer cohesion and mechanical anisotropy [25]; the directional property field an insert bears against is its subject, and ER-166 cites it rather than re-deriving it. ER-039 owns fatigue and time-dependent deformation in vat-printed thermosets [26]; bulk creep is its subject, and ER-166 owns preload decay only as a joint-level consequence of it. ER-069 owns fatigue-crack growth and subcritical fracture [27] and ER-070 owns fracture toughness and damage tolerance [28]; the cracking behaviour of the bulk network is theirs, and ER-166 owns the local interface that initiates the crack. ER-163 owns support strategies for internal channels and sacrificial geometries [29] and is excluded. ER-043 owns multimaterial interfaces and functionally graded networks [30] and is excluded. ER-164 owns non-destructive evaluation [31]; where this review calls for inspection of an insert region it defers method selection and detectability to ER-164. ER-139 owns the corpus-level qualification

record and decision-gate architecture [33]; ER-166 supplies the load-introduction evidence that feeds a gate and does not redefine the gate structure.

Shared boundary with ER-165. ER-165 owns adhesive bonding and structural joining of printed photopolymers [32]. The boundary is the load path: ER-165 governs when load crosses an **adhesive layer of area**; ER-166 governs when load crosses a **discrete mechanical interface**. The only vat-photopolymer insert study located anywhere in the literature uses an adhesively potted insert, so both papers apply to it and both say so. ER-166 owns the insert's pull-out behaviour and the resulting failure set; ER-165 owns the potting adhesive's bond to the printed wall.

Two forward boundaries are stated because the papers do not yet exist. **ER-169 will own embedded components and hybrid functional assemblies.** The split proposed here is by purpose of the embedded element: an overmoulded metal boss loaded in tension is ER-166; an embedded sensor, conductor or optical element is ER-169. That split is asserted by this batch, not by ER-169, and should be confirmed when ER-169 is drafted. **ER-181 will own post-cure process engineering;** ER-166 treats post-cure state as an input variable, not as a process to design.

Excluded: adhesive joining as the principal subject; multimaterial gradient chemistry; printer support strategy.

The review covers the process category defined as vat photopolymerization in ISO/ASTM 52900:2021 [7]. Evidence from other additive processes is used only as declared contrast and is labelled as such at every occurrence.

2. The load path is the ownership boundary, and it is also the engineering one

A joining decision is usually made by naming a part: “use an M4 heat-set insert.” That names a component and hides the question. The question is where the load goes and what carries it.

Three load paths are available in a printed polymer, and they fail differently.

Load path	Load is carried by	Governing failure set	Owner
Area-distributed adhesion	Shear over a bonded area	Cohesive, interfacial, adherend	ER-165 [32]
Discrete mechanical interface	Contact stress over a small bearing area, with a geometric undercut or thread	Pull-out, stripping, splitting, bearing, pull-through	ER-166
Hybrid	Both simultaneously — an adhesively potted insert, a bonded-and-bolted joint	The set of both, and their interaction	Both, jointly

The engineering consequence of the second row is the reason this review exists. A discrete interface concentrates the load into a volume of material a few millimetres across. In that volume the printed part's anisotropy, its post-cure gradient, its residual stress and its layer boundaries are not averaged out by a large gauge length — they are the local property field. **A load-introduction feature is therefore not qualified by a bulk material property; it is qualified as a configuration.** That statement is the organising principle of §14.

3. The vat-photopolymerisation evidence: two anchors, and what they actually test

This review located **two** primary sources that place a mechanical load-introduction feature in a vat-photopolymerised part. Both are stated in full, including their limits, because everything else in this review is declared contrast from another process.

3.1 Lohuis, Traub and Hühne: the only insert pull-out data on a vat-photopolymerised structure

Lohuis and co-workers tested threaded inserts in additively manufactured sandwich panels with gyroid core structures [9]. The panels were printed by stereolithography on a Form 3L in Clear resin v4. The insert was a NAS1836-08-11 potted insert, installed with a two-part structural adhesive (3M Scotch-Weld 9300 B/A FST). Pull-out force was reported for four core configurations:

Core configuration	Pull-out force (N)
Honeycomb	2057.35 ± 272.96
Gyroid, restricted	1354.43 ± 287.31
Gyroid, unrestricted	1612.11 ± 359.65
Graded	2088.24 ± 285.45

Two observations, and one caution.

The first observation is qualitative and is the more useful of the two: **the failure character differed by core**. The gyroid cores failed progressively; the honeycomb failed instantaneously. For a structure whose insert is a safety-relevant load path, a progressive failure that gives warning and a sudden one that does not are different engineering objects even at the same peak force.

The second observation is arithmetic on the stated values. Taking the $\pm$ figures at face value, and without asserting what statistic they represent — this review did not record the sample count or the dispersion basis, so no significance test is performed or implied — **the honeycomb, graded and unrestricted-gyroid means are not separated by their own quoted dispersions**. Only the restricted-gyroid configuration is separated from the honeycomb and graded configurations on that arithmetic. A specification that selects the graded core over the honeycomb core on a 1.5 % difference in mean pull-out force is selecting on noise.

The caution is the scope one. **This study does not tell you what a threaded insert does in a solid printed photopolymer wall**. It tests a sandwich panel with a lattice core, and the insert is adhesively potted, so a share of the retention is the adhesive's — which is ER-165's subject [32]. No standard is named for the pull-out test. It is, nonetheless, the only vat-photopolymerisation insert result located, and it is reported here in full rather than paraphrased so that a reviewer can see exactly how narrow it is.

3.2 Ipek and co-workers: a vat-photopolymerisation pull-out study whose content was not obtained

Ipek and co-workers report pull-out test performance of a hydroxyapatite-reinforced vat-polymerised bone mimic [10]. Only the abstract was obtainable. The source is recorded as resolved-not-read, is cited for topic only, and **no finding and no number is attributed to it**. It is listed here because a reviewer should know it exists and because its subject — a filled vat-photopolymer under pull-out load, in a biomedical rather than a structural frame — is the nearest located neighbour to the gap this review reports.

3.3 What the two anchors establish, and what they do not

Together they establish that pull-out testing of vat-photopolymerised features has been done at least twice, in two unrelated application domains, with no shared method. They establish **no** design value, no geometry rule, no installation procedure and no acceptance criterion for a threaded insert in a solid vat-photopolymerised wall. That is the state of the evidence.

4. The quantitative insert base is thermoplastic, and its mechanism is thermal

Everything else that is quantitative about inserts in printed polymers comes from powder-bed fusion or material extrusion. It is used here only as declared contrast, and the label appears at every occurrence.

4.1 What the thermoplastic literature establishes

Śliwka and Wójcik (declared contrast: SLS PA12) compared load-bearing thread solutions at M8 [14]. Directly printed threads carried 3.41 kN. A heat-set insert raised this to 3.83 kN, a 12 % increase. A wire thread insert raised it to 4.78 kN, a 40 % increase. The ranking — printed thread < heat-set insert < wire insert — is the clearest single statement of relative capability in the located literature.

Kuettner, Fischer and Laumer (declared contrast: SLS PA12) characterised heat-staked joints [15] and reported the mechanism explicitly in the material's structure: joint strength of 33.6 MPa against 39.9 MPa for a turned reference, with porosity in the staked region falling from 3.9 % to 1.56 % under a 300 N staking force and from 4.29 % to 0.81 % under 1000 N. **The process consolidates the polymer by melting and compacting it**. That is the mechanism, stated in the source, and §4.2 turns on it.

Fürst and Göhlich (declared contrast: material extrusion) report that thermal installation of screw connections produced an increase exceeding 100 % over the baseline [18]. The exact values appear only in bar charts in that publication and are therefore **not quoted here**; only the stated ">100 %" figure is used.

Kastner and co-workers (declared contrast: fused-layer modelling) investigated pull-out of metal threaded inserts and identified the failure as **interlaminar, between wall lines** [17]. The numerical results are presented as box plots from which values can only be read approximately, so **no number from this source is quoted**; the failure-locus finding is used, because it is stated in the text rather than read off a plot.

Severson, Lutz and Elhajjar (declared contrast: FDM, ULTEM 9085) measured pull-through of additively manufactured sandwich composite inserts and reported improvements of 7.1 % in stiffness, 53.0 % in maximum force and 62.3 % in energy absorption for their novel insert against the reference [19]. **No ASTM or ISO standard was used for the test.** For a pull-through measurement this is a material limitation on the result's transferability, because a standard for exactly this measurement exists (§11).

Omidvarkarjan and co-workers (declared contrast: SLS PA2200) developed an insert for integrating threads into additively manufactured polymer components [16]. The only pull-out value this review recorded from that source with confidence is **5600 N for a 3/8"-16 UNC configuration**. Values for smaller metric sizes were obtained by interpolation during source discovery and are therefore **not stated here at all**.

4.2 Why that evidence does not transfer to a vat-photopolymerised part

The thermoplastic insert literature rests on one mechanism. Heat-set, ultrasonic and heat-staked installation soften a thermoplastic above its transition, allow it to flow around a knurl or into an undercut, and let it re-solidify. Kuettner and co-workers document this directly in the consolidated, densified polymer around the stake [15] (declared contrast: SLS PA12).

A vat-photopolymerised part is a crosslinked network. Rehbein and co-workers, working on digital-light-processing photopolymer resins, place the gel point at a degree of cure of **$q_{\text{gel}} = 0.37$** and characterise the cured material as a temperature- and cure-dependent viscoelastic solid, reporting $G_{\infty} = 1900$ MPa at 20 °C and a degree of cure of 0.96, with Williams–Landel–Ferry constants $C_1 = 32.73$ and $C_2 = 448.62$ °C, and a critical exposure $E_c = 0.89$ J/cm² [11]. A material described by that constitutive framework has a glass transition; it does not have a melt.

The claim this review makes is therefore precise, and it is narrower than the claim usually made informally:

Heat-set, ultrasonic and heat-staking installation cannot work in a vat-photopolymerised part by the mechanism that the thermoplastic literature documents, because that mechanism requires viscous re-flow of the matrix and a crosslinked network does not provide it.

This review does **not** claim that a thermal installation is impossible in every photopolymer formulation, that no other retention mechanism could be found, or that a particular commercial insert will fail. It claims that **the evidence does not transfer**, that no located source has tested the transfer, and that a specification which installs a heat-set insert into a printed photopolymer is running an unqualified process whose supporting literature is about a different material class. Whether some other mechanism — mechanical keying into an as-printed cavity, local softening near T_g without flow, chemical bonding to residual reactive species — can produce a defensible retention force is an open experimental question, and §13 states it as one.

4.3 The one thing that does transfer

Kastner's failure-locus finding [17] (declared contrast: fused-layer modelling) transfers as a **question**, not as a value: the insert failed at the interfaces the process created, not through the bulk. A vat-photopolymerised part also has process-created interfaces — layer boundaries whose cure overlap is ER-073's subject [25]. The transferable statement is that an insert in an additively manufactured polymer tends to fail at the process's own interfaces, and that the qualification must therefore be run in the orientation the part will actually be built in. The FLM number does not transfer; the requirement to test in the build orientation does.

5. Threads: printed, tapped and inserted

For threads in a vat-photopolymerised part, the located evidence is thinner than for inserts.

Printed threads. The only direct comparison of a printed thread against insert alternatives is Śliwka and Wójcik's M8 data [14] (declared contrast: SLS PA12), in which the printed thread was the weakest of the three options at 3.41 kN. That ranking is plausible for vat photopolymerisation on geometric grounds — a printed thread reproduces the thread form only to the process's own resolution, and the resulting flank geometry determines how load distributes across the engaged threads — but **no vat-photopolymerisation printed-thread strength data was located**, and this review states no expected value.

Tapped threads. No located source tests a tapped thread in a vat-photopolymerised part. Tapping cuts through the cured layer structure, which means the thread flanks intersect layer boundaries at an angle set by the feature's orientation. Whether that matters, and how much, is unmeasured.

Inserted threads. Covered by §4. The wire thread insert was the strongest option in the only located ranking [14] (declared contrast: SLS PA12), and its installation is mechanical rather than thermal — which is the reason it is the most plausible candidate for transfer to a thermoset network, and the reason §13 lists it first among the experiments worth running.

The rule this review will not state. It is common practice to specify a minimum thread engagement as a multiple of nominal diameter, carried over from metal practice. **No located source establishes such a rule for any printed polymer**, and §12 explains why importing it from ISO 898-1 [4] is not a conservative simplification but an untested one.

6. Press fits, overmoulding and captured interfaces: practice with no located primary evidence

Two of this review's three remaining load paths share a single property: they are used in production and neither has a primary source behind it. They are treated together for that reason.

6.1 Press and interference fits

Press fits are used routinely in printed parts — bearing seats, dowel pins, captured nuts, snap-in bushings. This review therefore searched specifically for retention-force data.

No primary source establishing press-fit retention force in a printed polymer, of any process family, was located in this review. Not for vat photopolymerisation, not for material extrusion, not for powder-bed fusion.

The gap is worth stating carefully, because a press fit in a photopolymer is the configuration in which the material's viscoelasticity acts most directly against the designer's intent. An interference fit holds by a sustained radial strain, and a sustained strain in a viscoelastic solid relaxes. Rehbein's constitutive characterisation [11] establishes that a digital-light-processing photopolymer is such a solid and that its response is both temperature- and cure-dependent. ER-039 owns the bulk time-dependent deformation [26]. **What is missing is the joint-level measurement: how much retention force a printed-photopolymer press fit has at installation, and how much of it remains after a defined hold at a defined temperature.** That is a straightforward experiment and nobody located has run it.

Until it is run, a press fit in a vat-photopolymerised part should be treated as an interface with an unknown time-dependent retention, and either designed out of the load path, backed by a secondary retention feature, or qualified locally under the sustained-load protocol in §14.

6.2 Overmoulded and captured interfaces

An element is **captured** when the build is paused, the element is placed, and printing resumes around it; it is **overmoulded** when material is formed around an already-made part. Both create a load-bearing interface that no post-build installation step could produce, and both are used.

No primary source on a load-bearing overmoulded or captured interface in a vat-photopolymerised part was located in this review. The nearest located work is an insert designed for integration into additively manufactured polymer components [16] (declared contrast: SLS PA2200), and that insert is installed into a finished part rather than captured during the build.

Two constraints follow from the definition of the process rather than from any source, and are stated as such.

The captured element is in the light path. Vat photopolymerisation cures each layer by projected radiation, so an opaque or strongly absorbing inclusion shadows the region behind it for every layer in which it sits. That is optics, not a finding: it is stated here because it makes the cure state of the shadowed region a design variable rather than a process constant, and because §14's evidence item 9 — inspection of the feature region, with method selection and detectability deferred to ER-164 [31] — applies to that region with more force than to any other in this review.

The element's surface becomes an interface cured against a foreign solid. The cure state at a free or interfacial surface is ER-030's subject [34]. Whether the network that forms against a metal inclusion differs from the bulk, and by how much, is not established for this configuration by any located source.

The consequence is not a design rule, because there is nothing to build one from. It is a status: **an overmoulded or captured load-bearing interface in a vat-photopolymerised part is an unqualified configuration.** The architecture in §14 applies to it unchanged, with the shadowed region added to the inspection requirement, and every value in it must be generated locally.

Where the embedded element's purpose is functional rather than structural — a sensor, a conductor, an optical element — the subject is ER-169's, on the boundary asserted in §1.

7. Bearing and pull-through: two standards exist, and the data contradict each other

Bearing is the one part of this subject with mature test standards, and the one where the printed-polymer data are in open conflict.

The standards exist. ASTM D5961/D5961M-23 covers bearing response of polymer matrix composite laminates [2]; ASTM D7332/D7332M-23 covers fastener pull-through resistance of a fibre-reinforced polymer matrix composite [3]. They were written for laminated composites, but they are the closest applicable methods and — unlike the insert case — they are usable without inventing a procedure.

They are used, sometimes. Khosravani and co-workers (declared contrast: FDM, PLA and ABS) tested pin-bearing strength to ASTM D5961-13 [20]. The largest force reported was 3646 ± 143 N, in ABS at a width-to-diameter ratio of 3 and an edge-distance-to-diameter ratio of 1.5, and the largest bearing strength 189 ± 5 MPa. The engineering finding is the geometric one: **a bearing failure mode — rather than net-tension or shear-out — was obtained at $e/D \geq 3$** . That is the same qualitative geometry dependence the composites literature reports, obtained on a printed polymer with a named standard.

Severson and co-workers' pull-through work [19] (declared contrast: FDM, ULTEM 9085), by contrast, used no standard at all, although D7332 covers exactly that measurement. The two studies together show that the standards are available and that their use is inconsistent.

And the hole-preparation data contradict. Two sources compare a printed hole against a drilled one and disagree in sign:

Source	Process (declared contrast)	Result
Yu and co-workers [21]	Continuous-fibre fabrication	Drilled holes up to 23 % stronger than printed holes
Mazarbhuiya and Veeman [22]	FDM, PLA	Printed 22.3 MPa against drilled 20.8 MPa — printed 7.21 % stronger

This review does not resolve the contradiction and does not choose a side. The two studies use different materials, different reinforcement states and different measurands, and either result could be correct in its own frame. The point for a vat-photopolymerisation specification is the one that survives the disagreement: **whether a hole should be printed or machined is an open question even within material extrusion, and this review located no vat-photopolymerisation data on it at all**. A specification that asserts either practice is asserting something the literature does not support.

No pin-bearing or pull-through data on a vat-photopolymerised part was located. The standards apply; nobody located has run them on this process family.

8. Preload should not be expected to stay where it was set

A bolted or threaded interface is only a load path while it retains preload. Two located results bound the problem, both as declared contrast.

Eraliev, Lee and Lee (declared contrast: FDM printed M12 bolts, three materials) studied self-loosening under cyclical temperature change [23]. Two findings are relevant here. Bolts printed in the horizontal orientation achieved approximately **three times** the preload of vertically printed bolts — an orientation effect on the joint, not on a coupon. And preload losses under thermal cycling between 10 °C and 80 °C were **severe in the first cycle**, which is the practically important shape: the loss is not a slow drift that a maintenance interval catches, it is a step that happens the first time the assembly sees its service temperature.

Rehbein and co-workers [11] supply the vat-photopolymerisation-side constitutive reason to expect the same behaviour class: a temperature- and cure-dependent viscoelastic solid under sustained strain relaxes, and its relaxation is a function of both temperature and degree of cure. **This is the transfer this review does make**, and it is a mechanism transfer rather than a value transfer: the FDM bolt numbers do not apply to a photopolymer, but the requirement to measure preload retention after a thermal excursion does, because the constitutive characterisation of the photopolymer predicts a loss and no located source has measured its size.

The design consequence is stated as a requirement, not a value: **a preloaded interface in a vat-photopolymerised part must have its retained preload measured after the first thermal excursion of its service envelope, not only at installation.** ER-039 owns the underlying bulk creep and relaxation [26]; ER-166 owns this joint-level requirement.

9. Post-cure sets the failure mode, not only the strength

Post-cure produces three property changes in a stereolithography network, and for a load-introduction feature the governing one is the change usually treated as a footnote. Measured across twelve methacrylate resins before and after post-cure, elongation at break fell by up to **90 %**, while Young's modulus rose by **88 % on average** — maximum +215 %, minimum +33 % — and tensile strength by **89 % on average** [12]. It is the ductility loss that matters here, and it runs against the other two.

ER-165 draws a different consequence from this same measurement: a stiffer, less ductile adherend concentrates load at the ends of a bonded overlap instead of yielding to spread it [32]. That consequence is about load distribution along an area. ER-166's is about which failure mode remains available at a discrete interface, and the two do not substitute for each other.

An insert or a press fit loads its surroundings in a stress state with a high local peak. A material with ductility accommodates that peak by yielding locally and redistributing load along the engagement. A material whose elongation at break has fallen by an order of magnitude does not: the peak stays a peak, and the failure mode available to it is **splitting or cracking rather than progressive bearing**. Post-cure therefore raises the strength of the material while removing the mechanism by which a load-introduction feature survives its own stress concentration.

This is a hypothesis, not a measured result. It is derived from measured bulk property changes [12] and from the failure set that those changes make available. No located source measures insert retention or splitting resistance in a vat-photopolymerised part as a function of post-cure state. It is listed as a research priority in §17 and stated as an inference in §16, and it is the single most consequential untested claim in this review.

The practical corollary is nonetheless actionable now: **post-cure state is a controlled variable of a load-introduction qualification, and a change to the post-cure route invalidates it** (§15).

10. Orientation and anisotropy at the interface

Build orientation is a controlled variable for every claim in this review, for three separate reasons.

It changes the direction of the layer boundaries relative to the insert's pull-out axis, and therefore which interfaces the load must cross — the transferable lesson from Kastner's interlaminar failure locus [17] (declared contrast: fused-layer modelling).

It changes the strength of the printed part in the loading direction, which is ER-073's subject [25]. Li and Teng address printing orientation and mechanical properties of stereolithography-printed photopolymer [13]; that source is recorded as resolved-not-read, is cited for topic only, and **no value from it is stated or relied on**.

And it changes the joint itself, not only the coupon: the three-fold preload difference between horizontally and vertically printed bolts [23] (declared contrast: FDM) is an orientation effect measured at the joint level.

Reporting requirement. Orientation must be reported per ISO 17295:2023 [5]. ISO/ASTM 52921:2013, still cited in parts of the additive-manufacturing literature for coordinate systems and test methodologies, was **withdrawn and replaced by ISO 17295:2023** [6]. A qualification record that specifies orientation by reference to the withdrawn document should be re-expressed.

11. Standards position

This is the shortest section in this review and the most consequential, because what it reports is mostly absence.

Standard	Covers	Status for this subject
ASTM D1761-20(2025) [1]	Mechanical fasteners in wood and wood-based materials	The only located pull-out standard for a fastener in a non-metallic substrate. Written for wood. Not applicable to a printed polymer without a documented justification that

Standard	Covers	Status for this subject
		this review cannot supply.
ISO 898-1:2013 [4]	Mechanical properties of fasteners made of carbon steel and alloy steel	Frequently the unstated source of “standard practice” thread rules. Written for steel. See §12.
ASTM D5961/D5961M-23 [2]	Bearing response of polymer matrix composite laminates	Applicable and usable. Already used on printed polymers [20] (declared contrast: FDM).
ASTM D7332/D7332M-23 [3]	Fastener pull-through resistance of fibre-reinforced polymer matrix composites	Applicable and usable. Available but not used in the located pull-through work [19] (declared contrast: FDM).
ISO 17295:2023 [5]	Part positioning, coordinates and orientation	Controls orientation reporting.
ISO/ASTM 52921:2013 [6]	Coordinate systems and test methodologies	Withdrawn , replaced by ISO 17295:2023.
ISO/ASTM 52900:2021 [7]	Fundamentals and vocabulary	Defines the process category.
ASTM WK78224 [8]	Vat photopolymerization — next-generation tensile test method	A work item registered under ASTM Subcommittee F42.05. Its page does not state a current ballot status, and no ballot status is asserted here.

Two conclusions follow.

No published insert pull-out or torque-out standard for thermoplastics or thermosets was located in the standards search performed for this review. Every insert result cited in this review was obtained under a procedure the authors defined themselves. That is why the values in §4 cannot be pooled, compared or used as design allowables, and why §14 proposes that an insert qualification declare its own procedure in full rather than name a standard this review was unable to locate.

Vat photopolymerisation is only now acquiring a standardised tensile test [8]. A process family whose basic coupon method is still a work item does not have a standardised local-load-introduction method, and will not have one soon. Qualification must therefore be local, and it must be documented well enough to survive the arrival of a standard that will not match it.

12. Why classical metal fastener rules do not transfer

Croccolo and co-workers reviewed the failure of threaded connections [24]. It is a thorough treatment and it is **about metals**. It is cited here for exactly one purpose: to mark the boundary explicitly rather than leave it implicit.

The rules that engineers carry across without noticing — a minimum thread engagement of one to one and a half diameters, a torque-tension relationship with a nut factor, a preload target as a fraction of proof load, a re-torque interval — all rest on properties a printed photopolymer does not have. They assume a material that yields before it fractures, whose modulus is effectively time-independent over the service life, whose proof strength is classified by a standard [4], and whose thread form is manufactured to a controlled tolerance. A vat-photopolymerised part meets none of those four assumptions: its ductility depends on the post-cure route and can collapse [12], its response is viscoelastic and both temperature- and cure-dependent [11], this review located no property class for it, and its thread form is limited by process resolution.

The importation is not conservative. A rule calibrated for steel does not become safe when applied to a weaker material; it becomes a rule of unknown validity applied to a material with a different failure set. A metal thread strips; a photopolymer boss can split. Those are not the same failure, and a rule that prevents the first does not address the second.

13. Evidence gaps, stated as gaps

Recorded so that a reviewer can test them and a specification writer can see what is not there.

No study of heat-set, ultrasonic or press-fit insert installation in a vat-photopolymerised part was located. Zero. This is the central absence of this review.

No press-fit retention-force data for any printed polymer was located, in any process family.

No primary source on a load-bearing overmoulded or captured interface in a vat-photopolymerised part was located. An element captured during the build also shadows the light path, which no located source addresses either.

No pin-bearing or fastener pull-through data on a vat-photopolymerised part was located, although two applicable standards exist [2,3].

No printed-thread or tapped-thread strength data on a vat-photopolymerised part was located.

No published insert pull-out or torque-out standard for thermoplastics or thermosets was located in the standards search performed for this review. The only located pull-out standard is for wood [1].

No study measures preload retention in a vat-photopolymerised threaded interface. The constitutive basis to expect a loss exists [11]; the joint-level measurement does not.

No study measures insert retention or splitting resistance as a function of post-cure state, although post-cure changes modulus, strength and ductility substantially [12].

The printed-versus-drilled hole question is unresolved even within material extrusion, where two located sources disagree in sign [21,22].

The only located vat-photopolymerisation insert result is on a lattice-cored sandwich panel with an adhesively potted insert [9], not a solid wall with a mechanically retained insert.

14. A proposed load-introduction qualification architecture

This architecture is a proposed engineering qualification framework, offered for use where no application-specific validated procedure exists. No standard establishes it and none is claimed for it. Within that framing it follows from §2: a load-introduction feature is qualified as a **configuration**, not inferred from a material property.

14.1 The configuration is the unit of qualification

A qualified configuration is the complete set:

resin and lot · printer and process parameters · build orientation of the feature, per ISO 17295:2023 [5] · wash route · post-cure route · feature geometry, including wall thickness and boss geometry around the feature · insert or fastener type and part number · installation method and its settings · any adhesive, with its own qualification under ER-165 [32] · service temperature envelope · service load spectrum, distinguishing sustained from cyclic.

A change to any element places the configuration outside the demonstrated qualification envelope until equivalence or requalification is established through a documented change-control assessment, of the kind §15 describes. The envelope is drawn tightly here because the evidence base offers no property from which a changed configuration's behaviour could be predicted — not because any standard requires it.

14.2 Required evidence

#	Evidence item	Why it is required	What it must not be
1	Installation-process record for every specimen: force, temperature, time,	The insert literature shows installation parameters determine the result [15]	An insert part number with no installation record

#	Evidence item	Why it is required	What it must not be
	torque as applicable	(declared contrast: SLS PA12)	
2	Quasi-static capability in the actual load direction, on the actual configuration, n declared	No applicable standard was located (§11), so the procedure must be self-documenting	A value transferred from another process family
3	Declared failure mode on every specimen — pull-out, thread stripping, boss splitting, bearing, pull-through, adhesive failure	The failure mode determines whether the result is about the interface or the part	A peak force with no failure description
4	Build-orientation matrix: at minimum the intended orientation and one orthogonal alternative	Orientation is a joint-level variable [23] (declared contrast: FDM) and an interface-crossing variable [17] (declared contrast: FLM)	A single orientation assumed to be worst-case
5	Sustained-load retention: preload or retention force re-measured after a declared hold at the maximum service temperature	The constitutive characterisation predicts relaxation [11]; the size is unmeasured (§8)	An installation-time value presented as a service value
6	First-thermal-cycle check across the full service temperature envelope	The located evidence shows the loss is concentrated in the first cycle [23] (declared contrast: FDM)	A room-temperature-only qualification
7	Post-cure state as a declared, controlled variable , with the route recorded	Post-cure changes ductility by up to an order of magnitude [12] and therefore the available failure mode (§9)	“Post-cured” with no route
8	A production control against undetected configuration drift — proof loading is one option, selected against failure consequence, detectability and the risk of damaging the	A type test alone does not detect drift the qualification did not see	A one-off type test treated as ongoing evidence, or proof loading applied universally without regard to the damage it can do

#	Evidence item	Why it is required	What it must not be
	article; sampling, in-process monitoring or increased inspection are others		
9	Inspection of the feature region where the consequence of failure justifies it, with method selection and detectability deferred to ER-164 [31]	An insert region is a stress concentration and a plausible defect site	An inspection claim without a detectability basis

14.3 Where a hybrid interface is used

An adhesively potted or bonded-and-bolted interface requires **both** qualifications: this one for the mechanical interface, and ER-165's [32] for the adhesive bond, including its own failure-locus determination. Neither substitutes for the other, and the combined interface's failure mode must be declared for the assembly as built, not inferred from the two separately.

15. Failure modes of the qualification programme itself

These are the ways a load-introduction qualification goes wrong while looking complete.

Naming an insert instead of qualifying an installation. A drawing that calls out a heat-set insert has specified a component and left the process — which determines the result — unspecified and, in a photopolymer, unsupported by any located evidence (§4.2).

Transferring a thermoplastic value. The pull-out figures in §4 are the most quotable numbers in this review and the most dangerous. Each is labelled as declared contrast at every occurrence for that reason.

Qualifying at room temperature only. The located evidence puts the largest preload loss in the first thermal cycle [23] (declared contrast: FDM), and the constitutive basis for expecting relaxation in a photopolymer is established [11]. A room-temperature qualification does not see the governing loss.

Treating post-cure as a finishing step. Post-cure is a controlled variable of the qualification (§9). Changing the lamp, the time or the temperature changes the ductility of the material around the feature and therefore the failure mode available to it.

Reporting a peak force without a failure mode. A pull-out force with no declared failure mode cannot be interpreted: it may be a property of the insert, of the boss, of the adhesive or of the layer boundary. This is the same error ER-165 identifies for bonded joints [32], in a different geometry.

Selecting on differences inside the scatter. The §3.1 arithmetic is the worked example: three of four configurations in the only vat-photopolymerisation insert study are not separated by their own quoted dispersions.

Citing a withdrawn standard for orientation. ISO/ASTM 52921:2013 is withdrawn [6]; ISO 17295:2023 replaces it [5].

Assuming a metal rule is the conservative choice. §12.

16. Limitations of this review

This review qualifies no insert, no thread, no press fit and no fastener for any resin or duty, and states no design allowable.

Findings are attributed only to sources whose content was read. **Ipek and co-workers** [10] and **Li and Teng** [13] are recorded as resolved-not-read, are cited for topic only, and no finding or value is attributed to either.

Three sources are cited with their numerical content deliberately withheld. **Kastner and co-workers** [17]: the results are box plots from which values can only be read approximately, so only the stated failure-locus finding is used. **Fürst and Göhlich** [18]: exact values appear only in bar charts, so only the stated “>100 %” figure is used. **Omidvarkarjan and co-workers** [16]: only the 3/8"-16 UNC value is stated, because the smaller-size figures available to this review were obtained by interpolation.

For **Lohuis and co-workers** [9] the sample count and the statistical basis of the $\pm$ figures were not recorded during source discovery. The comparison in §3.1 is arithmetic on the stated values and is explicitly not a significance test.

The §9 argument is an inference. That post-cure changes which failure mode governs a load-introduction feature is derived from measured bulk property changes [12] and from the failure set those changes make available. It is not a measured joint result, and no located source tests it.

The §4.2 argument is a mechanism argument. It establishes that the documented thermoplastic installation mechanism is unavailable in a crosslinked network, using that literature's own account of the mechanism [15] and a constitutive characterisation of a digital-light-processing photopolymer [11]. It does not establish that no thermal installation of any kind can be made to work in any photopolymer formulation, and it is not offered as such.

The search behind §6 and §13 was conducted for this review and returned nothing; “no source was located” is a statement about that search, not a proof of non-existence. A reviewer who locates one of these sources is correcting a finding of this review, and the finding is written to make that correction easy.

17. Conclusions and research priorities

A load-introduction feature is qualified as a **configuration**, not inferred from a bulk material property. The stress concentration is small enough that the printed part's anisotropy, post-cure gradient and layer boundaries are the local property field rather than an averaged one.

One vat-photopolymerisation insert study with accessible quantitative results was located [9], on a lattice-cored sandwich panel with an adhesively potted insert; it supplies no design value for a solid printed wall, and three of its four configurations are not separated by their own quoted dispersions. **A second vat-photopolymerisation pull-out paper was located** [10]; its relevant content was not obtained and no value is attributed to it.

Beyond [9], the comparative quantitative installation literature located is thermoplastic, and its installation mechanism — softening and re-flow — is unavailable in a crosslinked photopolymer network [11,15]. Heat-set, ultrasonic and heat-staking installation therefore cannot work in a vat-photopolymerised part by the mechanism that literature documents, and its values cannot be transferred as vat-photopolymerisation design values. Whether another mechanism can be made to work is untested.

This review located no press-fit retention data for any printed polymer, and a press fit is precisely the configuration in which the material's measured viscoelasticity [11] acts against the designer's intent.

This review located no evidence for an overmoulded or captured load-bearing interface in a vat photopolymer, which is therefore an unqualified configuration on the evidence found; a captured element additionally shadows the light path during the build, making the cure state of the shadowed region a design variable.

This review located no pin-bearing or pull-through data for a vat-photopolymerised part, although two applicable standards exist [2,3] and the located printed-polymer bearing work shows they are usable [20].

Whether a hole should be printed or machined is unresolved even within material extrusion, where two located sources disagree in sign [21,22].

There is a strong basis to expect preload relaxation, and no measurement of it. The constitutive evidence for a temperature- and cure-dependent viscoelastic solid is direct and vat-photopolymerisation-specific [11]; the first-cycle concentration of the loss is FDM contrast [23]; **the magnitude and cycle dependence in a vat-photopolymerised threaded interface are unmeasured.** The requirement to measure retained preload is therefore proposed as a qualification control, not transferred as a numerical result.

Post-cure raises strength while removing ductility [12], and therefore plausibly moves the failure mode from progressive bearing towards splitting. Stated as this review's central untested hypothesis.

No insert pull-out or torque-out standard for thermoplastics or thermosets was located in the standards search performed for this review, which enumerated the relevant publisher catalogues rather than relying on keyword query. The only located pull-out standard for a fastener in a non-metallic substrate is written for wood [1]; the fastener-property standard most often imported by habit is written for steel [4].

Classical metal fastener rules are not a conservative default. They are rules of unknown validity applied to a material with a different failure set [24].

Research priorities, in order of value

Pull-out capability of a mechanically retained insert in a solid vat-photopolymerised wall, across at least two insert types whose installation is mechanical rather than thermal, with declared failure mode on every specimen and a declared procedure in the absence of a standard. **The central absence.**

Press-fit retention force at installation and after a defined sustained hold at service temperature, on a vat-photopolymerised part. The cheapest experiment in this list and the one closing the widest gap.

Preload retention through the first thermal cycle of a declared service envelope, in a threaded vat-photopolymerised interface.

Insert retention and boss splitting resistance as a function of post-cure route, testing the §9 hypothesis directly.

Pin-bearing to ASTM D5961/D5961M and pull-through to ASTM D7332/D7332M on a vat-photopolymerised laminate-equivalent, printed and drilled holes both, to place this process family into a standardised frame and to address the [21] / [22] contradiction on a third process.

Printed against tapped thread capability in a vat-photopolymerised part, reported per ISO 17295:2023 orientation conventions.

References

- [1] ASTM D1761-20(2025). *Standard Test Methods for Mechanical Fasteners in Wood and Wood-Based Materials*. <https://store.astm.org/d1761-20r25.html>
- [2] ASTM D5961/D5961M-23. *Standard Test Method for Bearing Response of Polymer Matrix Composite Laminates*. https://store.astm.org/d5961_d5961m-23.html
- [3] ASTM D7332/D7332M-23. *Standard Test Method for Measuring the Fastener Pull-Through Resistance of a Fiber-Reinforced Polymer Matrix Composite*. https://store.astm.org/d7332_d7332m-23.html
- [4] ISO 898-1:2013. *Mechanical properties of fasteners made of carbon steel and alloy steel — Part 1: Bolts, screws and studs with specified property classes — Coarse thread and fine pitch thread*. Edition 5. <https://www.iso.org/standard/60610.html>
- [5] ISO 17295:2023. *Additive manufacturing — General principles — Part positioning, coordinates and orientation*. Edition 1. <https://www.iso.org/standard/76471.html>
- [6] ISO/ASTM 52921:2013. *Standard terminology for additive manufacturing — Coordinate systems and test methodologies*. **WITHDRAWN**; replaced by ISO 17295:2023. <https://www.iso.org/standard/62794.html>
- [7] ISO/ASTM 52900:2021. *Additive manufacturing — General principles — Fundamentals and vocabulary*. Edition 2. <https://www.iso.org/standard/74514.html>
- [8] ASTM WK78224. *New Test Method for Additive Manufacturing — Vat Photopolymerization — Next Generation Tensile Test Method*. ASTM Committee F42, Subcommittee F42.05. Work item. <https://www.astm.org/workitem-wk78224>
- [9] Lohuis, D., Traub, H. and Hühne, C. Mechanical testing of threaded inserts for additively manufactured sandwich panels with Gyroid core structures. *Results in Materials* 21 (2024) 100543. <https://doi.org/10.1016/j.rinma.2024.100543>
- [10] Ipek, H., Aslan, M., Elmas, E. and Terzi, Y. The Pull-Out Test Performance of the Hydroxyapatite (HAP) Reinforced VAT Polymerized Bone Mimic. In: *Digitalization in Additive Manufacturing* (Springer Tracts in Additive Manufacturing). Springer Nature Switzerland (2025) 379–392. https://doi.org/10.1007/978-3-031-84873-5_30
- [11] Rehbein, T., Johlitz, M., Lion, A., Sekmen, K. and Constantinescu, A. Temperature- and degree of cure-dependent viscoelastic properties of photopolymer resins used in digital light processing. *Progress in Additive Manufacturing* 6(4) (2021) 743–756. <https://doi.org/10.1007/s40964-021-00194-2>
- [12] Riccio, C., Civera, M., Grimaldo Ruiz, O., Pedullà, P., Rodriguez Reinoso, M., Tommasi, G., Vollaro, M., Burgio, V. and Surace, C. Effects of Curing on Photosensitive Resins in SLA Additive Manufacturing. *Applied Mechanics* 2(4) (2021) 942–955. <https://doi.org/10.3390/applmech2040055>
- [13] Li, Y. and Teng, Z. Effect of printing orientation on mechanical properties of SLA 3D-printed photopolymer. *Fatigue & Fracture of Engineering Materials & Structures* 47(5) (2024) 1531–1545. <https://doi.org/10.1111/ffe.14265>
- [14] Śliwka, M. and Wójcik, B. Load-Bearing Assessment of Threads in 3D-Printed Polymer Elements. *Polymers* 18(1) (2026) 112. Published online 30 December 2025. <https://doi.org/10.3390/polym18010112>

- [15] Kuettner, A., Fischer, S. and Laumer, T. Mechanical and structural characterization of heat-staked parts realized by selective laser sintering of polyamide 12. *The International Journal of Advanced Manufacturing Technology* 142(7–8) (2026) 3751–3770. <https://doi.org/10.1007/s00170-025-17319-4>
- [16] Omidvarkarjan, D., Balicki, P., Baumgartner, H., Rosenbauer, R., Fontana, F. and Meboldt, M. The AM Dowel – A Novel Insert for the Integration of Threads into Additive Manufactured Polymer Components. In: *Industrializing Additive Manufacturing*. Springer International Publishing (2020) 391–398. https://doi.org/10.1007/978-3-030-54334-1_27
- [17] Kastner, T., Troschitz, J., Vogel, C., Behnisch, T., Gude, M. and Modler, N. Investigation of the Pull-Out Behaviour of Metal Threaded Inserts in Thermoplastic Fused-Layer Modelling (FLM) Components. *Journal of Manufacturing and Materials Processing* 7(1) (2023) 42. <https://doi.org/10.3390/jmmp7010042>
- [18] Fürst, T. and Göhlich, D. Innovative high-strength screw connections for additive manufactured thermoplastic components. *The International Journal of Advanced Manufacturing Technology* 135(9–10) (2024) 4669–4682. <https://doi.org/10.1007/s00170-024-14746-7>
- [19] Severson, P., Lutz, A. and Elhajjar, R. Pull-Through Behavior of Novel Additively Manufactured Sandwich Composite Inserts. *Materials* 17(8) (2024) 1884. <https://doi.org/10.3390/ma17081884>
- [20] Khosravani, M.R., Sadeghian, H., Ayatollahi, M.R. and Reinicke, T. On the Pin-Bearing Strength of Additively Manufactured Polymer Parts. *Polymers* 15(7) (2023) 1660. <https://doi.org/10.3390/polym15071660>
- [21] Yu, Y.-H., Kim, D.-H., Cho, K.R. and Seo, H.-S. Effects of Pre- and Post-Processing on Pin-Bearing Strength of 3D-Printed Composite Specimens with Circular Notches. *Polymers* 17(19) (2025) 2609. <https://doi.org/10.3390/polym17192609>
- [22] Mazarbhuiya, R.M. and Veeman, D. Tensile performance of 3D-printed PLA material with conventionally drilled and additively fabricated holes. *Progress in Additive Manufacturing* 11(3) (2026) 2579–2590. <https://doi.org/10.1007/s40964-025-01483-w>
- [23] Eraliev, O., Lee, K.-H. and Lee, C.-H. Self-Loosening of a 3D-Printed Bolt by Using Three Different Materials under Cyclical Temperature Changes. *Applied Sciences* 12(6) (2022) 3001. <https://doi.org/10.3390/app12063001>
- [24] Croccolo, D., De Agostinis, M., Fini, S., Mele, M., Olmi, G., Scapecchi, C. and Bin Tariq, M.H. Failure of Threaded Connections: A Literature Review. *Machines* 11(2) (2023) 212. <https://doi.org/10.3390/machines11020212>
- [25] Segurola, J. Interlayer Cohesion and Mechanical Anisotropy in Vat-Photopolymerised Thermosets: Cure Overlap, Network Continuity and Qualification. ER-073 (2026). Controlled corpus reference.
- [26] Segurola, J. Fatigue and Time-Dependent Deformation in Vat-Printed Thermosets: A Qualification and Evidence-Gap Note. ER-039 (2026). Controlled corpus reference.
- [27] Segurola, J. Fatigue-Crack Growth and Subcritical Fracture in Vat-Photopolymerised Thermosets: Crack Preparation, Cyclic Driving Force, Environment and Qualification. ER-069 (2026). Controlled corpus reference.
- [28] Segurola, J. Fracture Toughness and Damage Tolerance in Vat-Photopolymerised Thermosets: Crack Preparation, Cure State, Anisotropy and Qualification. ER-070 (2026). Controlled corpus reference.
- [29] Segurola, J. Support Strategies for Internal Channels and Sacrificial Geometries. ER-163 (2026). Controlled corpus reference.
- [30] Segurola, J. Multimaterial Vat Photopolymerisation Interfaces and Functionally Graded Networks: Qualification and Failure-Mode Control. ER-043 (2026). Controlled corpus reference.
- [31] Segurola, J. Non-Destructive Evaluation of Vat-Photopolymerised Parts. ER-164 (2026). Controlled corpus reference.
- [32] Segurola, J. Adhesive Bonding and Structural Joining of Printed Photopolymers. ER-165 (2026). Controlled corpus reference.
- [33] Segurola, J. A State-Resolved Framework for Industrial Additive-Manufacturing Technology Selection Across Polymers, Metals, Ceramics and Advanced Materials: Process Chains, Invalidation Gates, Factory Constraints and Qualification. ER-139 (2026). Controlled corpus reference.
- [34] Segurola, J. Oxygen Inhibition and Free-Surface/Interfacial Cure in VPP: A Qualification and Minimum-Reporting Note. ER-030 (2026). Controlled corpus reference.