

Recovery and Requalification of Functional Fillers from Cured Photopolymer Composites: Separation, Surface State and Performance

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Abstract

Recovering a particulate phase from a cured photopolymer composite is materially different from recycling the polymer network. A primary stereolithography study demonstrated chemically triggered degradation of thioester composite networks with 91% recovery of the composite filler [1], establishing direct feasibility of selective filler recovery. Separate studies show that mechanically recycled cured DLP resin particles [2] and diverse recycled polymer powders [3] can be reincorporated into photocurable matrices, but these are reuse-as-filler routes rather than recovery of an original functional filler. ER-276 therefore defines the evidence needed to claim recovery and requalification of a functional filler: close the filler mass balance, separate residual polymer and process chemicals, measure particle-size and morphology change, characterise surface chemistry and agglomeration, demonstrate dispersion and optical/rheological compatibility in the new resin, and verify the property that made the filler functional. A recovered mass percentage alone cannot establish preserved filler identity, surface state or performance, and no universal recovery chemistry, acceptable surface contamination or reincorporation fraction is prescribed.

Keywords: functional filler; photopolymer composite; filler recovery; surface state; requalification; particle size; interface; vat photopolymerisation; circularity

1. Significance, scope and ownership

ER-276 owns recovery and requalification of a particulate functional phase originally embedded in a cured photopolymer composite. The filler can be electrical, thermal, dielectric, magnetic, optical, mechanical, ceramic or otherwise functional. ER-74 retains the chemistry of deliberately cleavable networks that may enable release [5]. ER-183 retains mechanical size reduction of cured photopolymer waste and reincorporation of that polymer as filler [4]. ER-198 retains end-to-end material circularity. ER-276 begins when a distinct filler population is recovered and asks whether that population still has the identity, surface and performance required for reuse.

1.1 Corpus boundary

ER-74 retains cleavable-network chemistry, ER-183 retains mechanical recycling of cured photopolymer waste, and ER-198 retains end-to-end material-circularity evidence. ER-276 does not count removal of the matrix as proof that the recovered filler is unchanged, and it does not treat ordinary ground cured-resin particles as recovered functional filler. Its decision problem is preservation or controlled change of a pre-existing filler population across separation and reuse.

2. Direct evidence proves feasibility, not universality

Hernandez and co-workers formed thioester-based composite materials by stereolithography and then chemically degraded the network, reporting 91% recovery of the composite filler [1]. The study demonstrates that a designed network can release an embedded filler with high gravimetric recovery in a defined system. It does not establish that every filler survives the trigger, that recovered surfaces are chemically identical to virgin filler, or that 91% is a transferable acceptance limit.

3. Filler recovery needs its own denominator

The filler-recovery denominator is the filler mass initially present in the article or controlled feed, not total composite mass. The numerator is chemically or physically identified filler recovered after separation. Matrix fragments, adsorbed oligomer, solvent, salts and bound process chemicals must not inflate the numerator. Losses to filters, vessel walls, fines, dissolved species or uncollected fractions should be retained in the balance. Where the filler can dissolve or react, elemental or phase-resolved accounting may be more informative than dry mass alone.

4. Particle population can change during release

Crushing, swelling, dissolution, filtration, centrifugation and drying can change particle-size distribution, break agglomerates, create fines or promote hard agglomeration. These changes affect sedimentation, resin viscosity, optical scattering and interfacial area. Requalification therefore measures particle-size distribution under a declared dispersion protocol plus morphology and agglomeration state. A nominal supplier size cannot be carried forward after recovery without measurement.

5. Surface state is part of filler identity

Functional fillers frequently carry native oxides, silanes, dispersants, polymer-grafted layers or adsorbed species that control compatibility with the resin and the final interface. A depolymerisation trigger or wash can remove, hydrolyse, oxidise or replace those layers while leaving the particle core apparently intact. Surface-sensitive evidence may include XPS, infrared spectroscopy, thermogravimetry, contact/wetting measurements or another chemistry-specific method. The selected measurement must address the interface mechanism relevant to reuse rather than merely confirming bulk elemental identity.

6. Mechanical recycled-particle studies define an adjacent boundary

Rooney, Dong, Basak and Pramanik mechanically recycled cured epoxy-acrylate DLP resin into particulate filler and characterised rheology, dispersion and tensile response [2]. Gholami and co-workers incorporated multiple recycled polymer powders, including 3D-printed thermoset waste, into photocurable resin and showed that particle addition couples strongly to viscosity and UV attenuation [3]. These studies are valuable process analogues: they demonstrate how particle size, loading and optical/rheological effects can control a filled VPP formulation. They do not demonstrate recovery of an original functional filler from a composite.

7. Reincorporation creates a new dispersion state

Recovered particles must be redispersed into a declared resin using a controlled history. The resulting state should be tested for sedimentation or separation, viscosity/rheology, optical attenuation or working curve, and spatial distribution in the printed part. A recovered filler that retains intrinsic conductivity or dielectric constant can still fail because aggregation or interface contamination prevents a percolated or mechanically integrated structure. Requalification therefore couples filler-level and composite-level evidence.

8. The original function must be retested

The acceptance endpoint is the function for which the filler was selected. Electrical fillers require conductivity/contact/percolation evidence; thermal fillers require thermal transport under a defined geometry; dielectric or ferroelectric fillers require the appropriate frequency/field-dependent response; optical fillers require spectral behaviour; reinforcing particles require mechanical and interfacial evidence. Bulk chemistry and recovery yield cannot substitute for the property that the reused filler must deliver.

9. Non-compensatory release gates

Gate	Minimum evidence	Blocking failure
Initial filler inventory	Measured filler mass/fraction and identity	No recovery denominator
Recovery balance	Recovered filler plus all losses/residues accounted	Composite mass called filler yield
Particle state	Size distribution, morphology and agglomeration	Supplier size carried forward
Bulk identity	Phase/element/composition appropriate to filler	Recovered solid assumed to be filler
Surface state	Interface-relevant chemistry or justified proxy	Core identity substitutes for surface
Dispersion state	Stability, rheology and spatial distribution	Recovered powder simply mixed in
Cure compatibility	Optical/working-curve response of filled resin	Neat-resin settings reused blindly
Functional performance	Property that defines filler function	Recovery percentage called performance

10. Minimum experiment

A minimum study uses one composite with a measured initial filler content and one declared release route. The recovered solids are collected across every process fraction. Filler recovery is quantified against the initial filler denominator, then particle size, morphology, bulk identity and at least one surface-state measurement are compared with virgin filler. Recovered and virgin filler are each incorporated at matched loading into the same controlled resin. The comparison measures dispersion stability, rheology, optical/cure response, print quality and the filler's defining functional property. At least one repeated recovery or ageing challenge is required before claiming reusable filler rather than one-time salvage.

11. Knowledge boundary

Direct VPP evidence demonstrates selective filler recovery from a designed thioester composite network [1]. Adjacent studies demonstrate reincorporation of recycled polymer particles into photocurable resins and expose rheological, optical and dispersion penalties [2,3]. The evidence does not establish that all functional fillers preserve surface chemistry or performance through chemical release, nor does it supply a universal recovered-filler specification. ER-276 therefore defines requalification requirements rather than a recovery recipe.

12. Conclusions

Filler recovery is credible only when the recovered population is accounted independently from the matrix and when its particle and surface state are measured after separation. Reuse then requires a second bridge: from recovered filler to a new dispersion and finally to the function delivered by the printed composite. High gravimetric recovery can coexist with unacceptable surface contamination, agglomeration or functional loss. The claim should therefore remain filler-specific, process-specific and cycle-specific.

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