

Variability Management for Recovered Fillers in Photocurable Composites: Contamination, Surface State and Lot Control

Qualifying reclaimed fibres and particulate fillers as variable manufacturing inputs rather than assuming virgin equivalence

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Abstract

Recovered fillers can reduce virgin-material demand in photocurable composites, but thermal, chemical or mechanical recovery changes surface chemistry, sizing, morphology and contamination. Those changes affect dispersion, wetting, optical attenuation, viscosity, interfacial adhesion and cure. This review defines a qualification framework for reclaimed fibres and particulate fillers in photopolymer formulations, centred on source traceability, recovery history, contamination, particle or fibre geometry, surface state, optical/rheological effects, lot acceptance and blending strategies.

Keywords: recovered filler; recycled carbon fibre; photopolymer composite; contamination; surface chemistry; lot variability; dispersion; qualification

1. Significance and scope

Reclaimed fibres and fillers can preserve significant material value, but recovery processes modify the state that made the virgin reinforcement predictable. Studies of recycled carbon fibre repeatedly identify surface condition and variability as central to second-life performance [1].

This review owns qualification of recovered filler before and during its use in photocurable composite formulations. ER-454 owns thermochemical recovery itself; here the recovered solid becomes a manufacturing input.

2. Recovered fillers are not virgin fillers by default

A recovered filler should be identified by source stream, recovery route and post-treatment. Mixing production scrap, end-of-life composite and thermally reclaimed fibre under one grade can conceal very different contamination histories.

Geometry matters: fibre length, aspect ratio, particle-size distribution and fines content affect both mechanical reinforcement and slurry rheology. Recovery and milling can shift these distributions from lot to lot.

Incoming material should be sampled with a plan that captures heterogeneity. Recovered-filler drums can stratify by particle size or contamination, so a single top-sample can give a false impression of lot uniformity.

Optical effects should be measured on the formulated composite rather than inferred from filler colour. Scattering and absorption depend on particle size, refractive-index contrast, agglomeration and wavelength, so the same recovered solid can alter cure differently after a change in dispersion state.

3. Recovery history changes surface state

Surface sizing and oxidation affect adhesion and can also influence recycling damage. Work on recycled carbon fibre shows that surface treatment history can alter defects and tensile retention after recycling [1].

Surface-state measurements should therefore include chemistry or wetting proxies appropriate to the filler, not just bulk composition. A clean-looking fibre can still have changed interfacial energy.

4. Contamination affects both interface and cure

Residual char, matrix fragments, metals, salts or cleaning agents can alter photopolymer cure. In optically cured composites, even small changes in filler absorption or scattering can shift exposure requirements.

Thermal recovery may preserve reinforcement while changing surface chemistry; fully recycled composite demonstrations show that useful strength can be recovered but that interface and impact behaviour remain sensitive to the recycled constituents [2].

Recovered fillers from different routes should not be blended until their acceptance variables are known. Blending can reduce variability, but it can also hide an out-of-control source if only the final average is measured.

Surface modification applied after recovery should be treated as a new process step with its own lot controls. Coupling-agent dose and drying history can reduce one source of variability while introducing another.

Lot-release rules should distinguish within-lot sampling variation from between-lot process variation. Control charts or retained-sample comparisons are useful only when the sampling plan is capable of detecting segregation and contamination at the scale that reaches formulation.

5. Lot variability requires acceptance and blending

Lot control should define mean and distribution limits for geometry, contamination, moisture and optical/rheological effect. Retained samples allow later investigation of cure or property drift.

Dispersion qualification should use the actual recycled filler fraction and production mixing route. A laboratory sonication result may not transfer to scalable mixing or high-solids formulations.

The recovered-filler fraction should be reported on a dry, defined basis. Virgin make-up, coupling agents and additional dispersants should be included so environmental or circularity claims are not based on filler mass alone.

Axis	Measurement	Failure mode
Source	waste stream and recovery history	all recycled filler treated as one grade
Geometry	size/aspect ratio and fines	mean value hides distribution
Surface	sizing, oxidation, wetting	clean appearance treated as interface quality
Contamination	char, matrix, metals, moisture	residuals ignored in cure
Lot control	acceptance, blending, retained sample	one research batch treated as production

Table 1. Domain-specific qualification matrix for recovered fillers in photocurable composites.

6. Device-level verification in photocurable composites

Device-level verification should compare representative printed geometry made with virgin and recovered filler under controlled exposure. Record cure, dimensions, defects and properties relevant to the application.

Interface-sensitive properties such as fatigue, impact or fracture may reveal recovery damage that tensile stiffness misses. Qualification should select tests based on the failure mode the filler is intended to improve.

Broader thermoset-recycling literature reinforces that recovered reinforcements require quality assessment rather than assuming that surviving solid material retains original performance [3].

Device-level qualification should include a failure mode that is interface-sensitive. If the application relies on crack resistance, fatigue or impact, acceptance based only on modulus can miss deterioration caused by a damaged or poorly wetted recovered-filler surface.

7. Minimum qualification framework

Report source stream, recovery process, lot identity, geometry distribution, moisture, ash/char or other contamination, surface treatment and storage history.

Report filler fraction, mixing/dispersant route, viscosity, optical attenuation, cure response, print settings, final dispersion and application-relevant properties.

8. Engineering conclusions

Recovered fillers should enter photocurable production as controlled variable inputs. Source, surface and contamination must be bounded before lot-to-lot variation can be separated from formulation or printer variation.

References

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Competing interest

Juan Segurola is founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L., which develops and commercialises photopolymer materials and related additive-manufacturing technologies. This review is an engineering analysis and does not constitute a product-performance claim or a device qualification.