

Mycelium–Photopolymer Hybrid Materials: Interface Formation, Growth, Moisture and Structural Performance

Engineering fungal colonisation, hydrogel interfaces and evolving mechanics in living mycelium hybrids

Juan Seguro

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

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Abstract

Mycelium-based living materials derive function from fungal growth through and across a shaped matrix. In printed hybrids, colonisation, moisture and nutrient transport, interfacial bridging and the evolving mechanical state are inseparable. This review treats the fungal phase as an active structural constituent whose morphology changes after fabrication, and it distinguishes printing fidelity from the later material state produced by growth. A qualification framework is proposed for species identity, growth conditions, interface formation, moisture dependence, mechanical development, contamination and regenerative behaviour.

Keywords: mycelium; fungal living material; 3D printing; hydrogel; interface; moisture; colonisation; mechanical performance

1. Significance and scope

Mycelium hybrids differ from inert fibre composites because the reinforcing or connecting phase develops after printing. Gantenbein and co-workers printed *Ganoderma lucidum*-laden hydrogels into lattices and showed that fungal growth could colonise the gel, bridge gaps and enable regenerative material behaviour [1]. The printed geometry is therefore an initial condition, not the final microstructure. Macroscopic fungal-bacterial living structures also show that regenerative and sensing functions can emerge from a biological phase that continues to develop after shaping, but those results belong to a different matrix/feedstock class and therefore provide a boundary rather than direct transfer evidence [2].

A mycelium–photopolymer hybrid can be fabricated by embedding fungal material before crosslinking, inoculating a preformed scaffold, or combining printed hydrogel domains with later colonisation. These routes create different interfaces and exposure histories. In particular, direct exposure of spores or hyphae to photocure chemistry cannot be treated as equivalent to post-print inoculation, and the chosen route should be explicit in any comparison of growth or mechanics.

2. Interface formation is an evolving process

The relevant interface is not only the adhesion between a cured matrix and a fungal filament at time zero. Hyphae grow, branch, penetrate accessible pores and bridge neighbouring regions. Qualification should distinguish interfacial contact, penetration depth, bridge density and the mechanical consequence of those features.

Surface chemistry and crosslink density can change wetting and nutrient transport, thereby changing apparent adhesion indirectly. Interfacial evolution should be tracked at more than one time point. Early wetting and adhesion may control whether hyphae establish contact, whereas later penetration and branching determine the load-bearing network.

Microscopy that resolves hyphae relative to pores or printed struts can distinguish true interpenetration from superficial overgrowth. Mechanical tests should then be interpreted against this morphology rather than credited to 'mycelium content' alone.

3. Moisture controls both biology and mechanics

Fungal growth requires water, while hydrogel swelling and drying change dimensional stability and modulus. Mechanical tests performed at different water activities cannot be compared directly. The intended service state must specify humidity or hydration, and drying or rehydration cycles should be included where relevant.

A mechanically strong dried state is not evidence of a robust living wet state, and vice versa. Water content also changes fracture mode and friction at the hybrid interface. A specimen tested immediately after culture can be highly compliant and tough in a way that disappears on drying; conversely, drying can increase apparent stiffness while killing the living component.

If the intended product is ultimately inactivated or dried, that transition defines a different material state and should be qualified separately from the living-growth stage.

4. Growth and feeding define structural development

Nutrient concentration, temperature and oxygen access set the colonisation rate and final morphology. Excess nutrient can favour rapid biomass accumulation but can also change porosity, contamination risk and long-term dimensional stability. The growth interval should therefore be treated as a manufacturing stage with controlled endpoint criteria rather than as uncontrolled ageing.

Growth endpoint control is a manufacturing problem. Mass gain, image-derived coverage, respiration or another quantitative proxy can be used to define when a part leaves the biological growth stage. Without an endpoint criterion, two nominally identical prints can enter service with different hyphal density and connectivity.

Batch qualification should therefore include both initial inoculum statistics and final colonisation statistics.

5. Regeneration claims require damage-and-recovery testing

Self-repair or regeneration should be demonstrated through a defined damage geometry, recovery environment and restored functional metric. Visual re-colonisation alone is insufficient if the claimed function is mechanical. The recovered stiffness, strength or integrity should be compared with the undamaged state and with an abiotic matrix control.

Regeneration tests should include a no-growth control and should distinguish recovery of geometry from recovery of load capacity. If hyphae simply cover a crack without restoring tensile or flexural transfer, the visual repair has not restored the claimed structural function. Repeated damage-recovery cycles are more informative than a single demonstration because nutrient depletion and ageing can reduce the available regenerative reserve.

Axis	Measurement	Failure mode
Fungal state	species, inoculum, growth interval	uncontrolled biological variability
Interface	penetration/bridging morphology	visual colonisation without load transfer
Moisture	water activity or hydration state	mechanical comparison across different states
Growth endpoint	biomass/spatial colonisation criterion	open-ended post-print evolution
Structure	stiffness/strength before and after growth	growth that weakens geometry or causes cracking

Table 1. Domain-specific qualification matrix for mycelium–photopolymer hybrid materials.

6. Device-level verification

Qualification should include fungal species and strain, inoculum state, matrix composition, cure or crosslink conditions, growth medium, geometry, moisture history, contamination controls and mechanical testing at a defined hydration state. For structures that rely on bridging across gaps, the gap scale and orientation must be part of the test because growth across open space is geometry-dependent. The central boundary is with conventional mycelium composites: this review concerns hybrids in which a photocurable or crosslinkable printed matrix remains an engineered constituent.

Results from loose agricultural-fibre/mycelium composites cannot be transferred without showing that the printed matrix permits comparable growth, moisture exchange and load transfer. Quantitative moisture control should accompany mechanical testing. Gravimetric water content, equilibrium relative humidity or a validated hydration protocol should be recorded so that modulus and strength can be compared on a common state basis. Conventional lignocellulosic mycelium composites show strong dependence of mechanical response on fibre processing and hydration-related state, supporting treatment of substrate architecture and moisture as explicit comparability variables rather than assuming one generic mycelium mechanical envelope [3].

Dimensional change during growth and drying should also be tracked because a structure can gain biological connectivity while simultaneously accumulating residual strain or warp.

7. Minimum qualification framework

At minimum, report print fidelity at fabrication, spatial colonisation after growth, water content or humidity, interface morphology, a mechanical metric before and after growth, leakage or spore release where relevant, and a defined endpoint for the living phase. If the material is later dried or inactivated, that transition should be reported because it changes the claim from a living material to a biologically fabricated material. Acceptance criteria should distinguish three stages: as-printed scaffold, actively colonised living hybrid and any final dried or inactivated product.

Each stage has different hazards and functional metrics. If the claimed service state is living, viability and ongoing growth control belong beside structural performance; if the claimed service state is inactivated, evidence of biological activity during manufacture does not substitute for final mechanical and environmental qualification.

8. Engineering conclusions

Mycelium–photopolymer hybrids should be viewed as staged materials: printing establishes the scaffold, growth creates a second structural architecture, and moisture determines the operating state. The engineering challenge is to control that evolution so that biological development improves rather than destabilises the intended structure. Qualification must therefore follow the material through growth and environmental cycling, not freeze the assessment at the moment of printing.

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.