

Gravity and Build Orientation as Material-State Variables: Sedimentation, Buoyancy, Drainage and Cure Asymmetry

Treating the gravity vector relative to the vat and part as a declared process variable in filled and unfilled resins

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Abstract

Gravity and build orientation are treated here as material-state variables because they alter composition, drainage and resin retention before and during cure. In the dilute creeping-flow limit, settling grows with density mismatch and particle size squared and falls with viscosity; at higher loading, yield stress and particle interactions change that scaling. Orientation also changes drainage paths and trapped-resin volumes even when optical settings are unchanged. The evidence chain combines time-resolved vertical concentration profiles, mass or CT-based through-height analysis, rheology after controlled aging and drainage/refill imaging in representative orientations. A pre-print dwell series then provides a direct basis for setting the maximum allowable vat dwell between remixing events and for deciding when orientation-specific controls are required.

Keywords: gravity; sedimentation; build orientation; drainage; resin stability; cure asymmetry

1. Qualification problem: gravity-driven material state

The qualification problem posed by gravity-driven material state is a transfer problem across geometry, history, or environment. The required decisions are the decision criterion, whether orientation-specific supports/drainage are required, and whether cure calibration remains valid over long jobs; evidence is stratified by settling Peclet number, Bond number, and Stokes number. [1,6]

1.1 Scope boundary.

ER-359 owns gravity/orientation response, including sedimentation, buoyancy, drainage and orientation-dependent cure asymmetry. ER-353 owns natural convection, ER-354 shrinkage-fed flow, ER-358 shear alignment, and ER-360 validation; those topics set the competing transport pathways.

2. Governing balances for gravity-driven material state

Gravity-driven state changes are bounded with the following relations for settling, capillary competition, and inertial response.

Stokes settling velocity scales with density mismatch, particle size squared and inverse viscosity in the dilute creeping-flow limit

hindered settling and non-Newtonian rheology modify that scaling at realistic loadings

drainage and refill are gravity-dependent free-surface flows whose characteristic pressure is $\rho g L$

The three descriptors distinguish slow settling from gravity-capillary distortion and from transient particle lag.

3. Regime boundaries for gravity-driven material state

The gravity map below determines when remixing interval, support orientation, or long-job calibration must be reconsidered.

Table 1. Regime indicators for gravity/orientation response.

Indicator	Engineering meaning	Use
settling Peclet number	gravitational transport relative to Brownian diffusion	Qualification of 'maximum allowable vat dwell between remixing events' should be indexed by settling Peclet number, since that variable condenses gravitational transport relative to Brownian diffusion into a transferable regime coordinate.
Bond number	gravity relative to capillarity	Qualification of 'whether orientation-specific supports/drainage are required' should be indexed by Bond number, since that variable condenses gravity relative to capillarity into a transferable regime coordinate.
Stokes number	particle transient response relative to recoating or other imposed accelerations	Qualification of 'whether cure calibration remains valid over long jobs' should be indexed by Stokes number, since that variable condenses particle transient response relative to recoating or other imposed accelerations into a transferable regime coordinate.

Long-build claims remain bounded by the sampled settling, gravity-capillary, and particle-response conditions.

4. Couplings that move the gravity-driven material state

Sedimentation changes local composition and viscosity even when cure-depth tests appear unchanged.

Orientation changes drainage paths and trapped-resin retention.

Buoyant thermal flow can oppose or reinforce particle settling.

5. Failure signatures and false diagnoses

Defect interpretation begins by distinguishing vertical composition gradients across long jobs from bottom-heavy filler content and top-layer underfill and orientation-dependent trapped resin or drainage marks. The corresponding evidence channels are time-resolved vertical concentration profiles, mass/CT or elemental analysis through height and rheology before and after controlled aging; agreement in only one channel is not sufficient to collapse the three mechanisms into one. The Table 2 programme separates causality from correlation by requiring a different intervention for each candidate mechanism.

Table 2. Failure-mode discrimination for gravity/orientation response.

Failure mode	Observable signature	Discriminating evidence
vertical composition gradients across long jobs	time-resolved vertical concentration profiles	controlled pre-print dwell series
bottom-heavy filler content and top-layer underfill	mass/CT or elemental analysis through height	rotate specimen or vat relative to gravity while maintaining optics
orientation-dependent trapped resin or drainage marks	rheology before and after controlled aging	compare matched formulations with altered density contrast
apparent optical asymmetry caused by composition history	drainage/refill imaging for representative orientations	interrupt builds and sample resin at multiple depths

6. Measuring gravity-driven material state with traceable uncertainty

Traceability requires the three Table 2 measurement channels to be linked to the same material and process state, with separate uncertainty estimates for each. Three independent checks structure the gravity-driven material state assessment; during metrology of gravity-driven material state, capillary pressure is resolved against refill dynamics. Independent resolution of Stokes settling and hindered sedimentation establishes the primary state, separate monitoring of refill dynamics tests whether that state survives transfer, and an uncertainty-controlled perturbation of capillary pressure is the perturbation used when the two disagree; the uncertainty record for gravity-driven material state keeps refill dynamics separate from Stokes settling.

7. Experiments that discriminate competing mechanisms

For the gravity-driven material state problem, a replicate test of refill dynamics defines the independent cross-check rather than a tuning variable; during the causal challenge for gravity-driven material state, refill dynamics is tested against Stokes settling. The main inference uses a causal contrast between Stokes settling and capillary pressure, whereas a boundary challenge involving hindered sedimentation is reserved for the boundary test that can overturn the proposed interpretation; the experiment for gravity-driven material state separates Stokes settling from hindered sedimentation.

8. Model identification and validation for gravity-driven material state

No parameter adjustment is allowed during those checks. [1,6] [3,5] [2,4] The model-to-decision step propagates uncertainty independently to every Table 3 row, preserving which mechanism dominates each margin. Rather than reduce gravity-driven material state to one surrogate, the analysis combines an uncertainty-bounded check on refill dynamics with parameter estimation for Stokes settling and hindered sedimentation; within model identification for gravity-driven material state, Stokes settling is not fitted through hindered sedimentation. A separate prediction against capillary pressure is used to challenge that interpretation, making disagreement between the two routes visible instead of averaging it away; prediction for gravity-driven material state keeps hindered sedimentation independent of capillary pressure.

9. Qualification envelope and technology decisions

Table 3. Technology-decision matrix for gravity/orientation response.

Decision	Minimum evidence	Acceptance logic
maximum allowable vat dwell between remixing events	Use calibrated time-resolved vertical concentration profiles measurements across the reference and candidate states to justify maximum allowable vat dwell between remixing events, with uncertainty propagated to the decision threshold.	Keep the claim only if 'controlled pre-print dwell series' does not drive time-resolved vertical concentration profiles outside its demonstrated range and no evidence of vertical composition gradients across long jobs emerges.
whether orientation-specific supports/drainage are required	The evidence floor for whether orientation-specific supports/drainage are required is a repeatable mass/CT or elemental analysis through height trend that spans the claimed envelope and includes the first departure from baseline behaviour.	Accept the transfer when repeated 'rotate specimen or vat relative to gravity while maintaining optics' tests keep mass/CT or elemental analysis through height on the qualified trend and bottom-heavy filler content and top-layer underfill is absent from the boundary state.
whether cure calibration remains valid over long jobs	Quantify whether cure calibration remains valid over long jobs with rheology before and after controlled aging at multiple states, including the boundary condition where the response first becomes decision-relevant.	Passing requires rheology before and after controlled aging to remain consistent across repeated 'compare matched formulations with altered density contrast' challenges while orientation-dependent trapped resin or drainage marks stays below the diagnostic threshold.

An acceptable record for gravity-driven material state must show an explicit transfer limit on refill dynamics without inferring it from tested ranges in Stokes settling and hindered sedimentation; inside the gravity-driven material state envelope, hindered sedimentation and capillary pressure define different transfer limits. In parallel, a separate boundary for capillary pressure probes the boundary condition

most likely to change the interpretation, and the resulting uncertainty is carried forward explicitly; qualification of gravity-driven material state bounds capillary pressure separately from refill dynamics.

10. Design consequences for gravity-driven material state

Implementation is separated into a design change governed by Stokes settling and an implementation check on capillary pressure; while maximum allowable vat dwell between remixing events is controlled independently, a change in a requalification trigger tied to refill dynamics prevents the new setting from being called equivalent; during design implementation for gravity-driven material state, capillary pressure is constrained by refill dynamics. The consequence is a bounded design decision with a defined route back to validation; the gravity-driven material state design record separates refill dynamics from Stokes settling.

11. Evidence gaps for gravity-driven material state

The largest uncertainty lies beyond the states represented by the third diagnostic pathway. Uncertainty in hindered sedimentation versus capillary pressure is the first stress test for gravity-driven material state; only after that result is bounded is scale transfer of Stokes settling interpreted; for unresolved gravity-driven material state transfer, refill dynamics is studied separately from Stokes settling. The record keeps independent replication of refill dynamics outside that inference and reports it as an independent line of evidence; the evidence gap in gravity-driven material state distinguishes Stokes settling from hindered sedimentation.

12. Qualification outcome for gravity-driven material state

The final qualification statement remains conditional on the state space represented in Table 3 and its associated uncertainty. Qualification of gravity-driven material state treats agreement between measurement and prediction for Stokes settling as one axis and a renewed-evidence trigger when refill dynamics changes as another; at final qualification of gravity-driven material state, Stokes settling is reconciled with hindered sedimentation. Between them, causal evidence that separates hindered sedimentation from capillary pressure supplies the deliberate challenge that determines whether the apparent transfer is mechanistic or merely coincidental; the closing gravity-driven material state claim keeps hindered sedimentation distinct from capillary pressure.

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Competing interests

The author is Founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L. No comparative product recommendation is made.

Data availability

No new experimental dataset was generated for this review.