

Design Values for Printed Photopolymers

Why Classical Allowables Methodology Does Not Transfer, and What Does

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Statement of Significance

A mean property value is not a design value, and a conservative multiplier does not convert a small research dataset into an allowable. Printed photopolymers add state variables that classical material tables often hold fixed: formulation lot, optical system, position, build, wash, post-cure, orientation, environment and elapsed time. ER-171 separates the transferable statistical logic of population coverage and confidence from the non-transferable assumption that a resin name identifies one stable material population.

Abstract

Statistically based material design values are intended to bound population variability with declared confidence, production representativeness and environmental applicability [1,2]. Classical A-basis and B-basis terminology provides a useful model for distinguishing a population-bound value from a mean, but its labels and tabulated values cannot be copied automatically to vat-photopolymerised materials. An interlaboratory study using aliquots from one photopolymer-resin batch found large scatter in working-curve parameters when procedures, light engines and measurement capability varied [3]. This demonstrates that even a nominally common material can produce incompatible parameter populations when state and method are not controlled. ER-171 defines a bounded path from state-resolved test data to a usable design value: declare the material-process population, preserve independent sampling levels, control method capability, select and justify a distribution or nonparametric approach, calculate a one-sided population bound with declared confidence, apply environmental and process knockdowns separately, and requalify when the population definition changes. It does not prescribe a universal sample size, distribution, allowable, safety factor or regulatory route.

Keywords: design values; material allowables; vat photopolymerisation; statistical tolerance bounds; A-basis; B-basis; process variability; qualification

1. Scope and ownership

ER-171 owns derivation of usable design values from state-dependent printed-photopolymer data and the conditions under which a basis value may or may not be claimed. It addresses population definition, sampling hierarchy, statistical tolerance bounds, method capability, environmental conditioning, process-state restrictions, bridging and change control.

ER-010 retains dimensional capability and dimensional metrology. ER-001 retains reporting and cross-study comparison. ER-100 retains corpus evidence architecture. ER-171 does not provide material-specific allowables, structural safety factors or regulatory approval.

The evidence core comprises an FAA advisory circular on material strength properties and design values, a NASA technical paper describing A-basis and B-basis allowable logic for structural composites, and a complete primary interlaboratory study of a vat-photopolymerisation working-curve method [1-3]. The aerospace sources supply a formal statistical model, not direct qualification of printed photopolymers.

2. Property measurement and design value are different objects

A measured property describes the specimens and conditions tested. A design value is intended for a declared population and use. It must incorporate population variability, confidence in the estimate, production representativeness and relevant environmental state.

FAA guidance describes material design values as statistically determined from sufficient data to reduce the probability of structural failure arising from material variability [1]. The same guidance requires statistical analysis and specimens made using production processes [1]. These principles transfer. The regulatory applicability and any listed values do not.

A supplier mean, a best result, a minimum in a small sample or a selected percentile without confidence control is not equivalent to a design value.

3. What A-basis and B-basis mean

The NASA technical paper describes A-basis as a value exceeded by 99 percent of the population with 95 percent confidence, and B-basis as a value exceeded by 90 percent of the population with 95 percent confidence [2]. These are one-sided population-coverage statements, not fixed percentages of the sample mean.

The important transferable element is the structure of the claim:

1. a defined property and failure direction;
2. a defined population;
3. a stated population coverage;
4. a stated confidence level;
5. a statistical method appropriate to the data and sampling design.

Using the words A-basis or B-basis without these elements is not a statistical qualification.

4. Why the classical material identity does not transfer automatically

Traditional allowables can rely on a mature material specification and controlled production population. A printed photopolymer part is produced by a coupled material-process route. Resin identity alone does not fix the final network state.

Relevant state variables include raw-material and resin lot, age and reuse, temperature, dissolved oxygen, printer, optical spectrum and field, exposure strategy, layer thickness, build position, orientation, geometry, wash, drying, post-cure, conditioning and test time. If uncontrolled, these variables can create several populations hidden beneath one product name.

The statistical method cannot repair an undefined population. More specimens from mixed states may estimate the mixture precisely while producing a value that applies to none of the constituent states.

5. Direct VPP evidence for method-defined variability

Kolibaba et al. distributed aliquots from one photopolymer-resin batch to multiple laboratories for working-curve measurement [3]. The reported fit parameters showed large interlaboratory scatter associated with non-uniform procedure, light-engine characteristics, measurement precision and model uncertainty [3].

The study concerned working-curve parameters rather than mechanical allowables. Its relevance is methodological: same-batch material identity did not ensure a common measurement population when the excitation and measurement systems differed.

A design-value programme must therefore control the measurement chain and the manufacturing chain. Otherwise the observed tail combines material variability with preventable method incompatibility.

6. Define the qualification population first

The population statement should identify, at minimum:

1. formulation and controlled specification;
2. raw-material and resin lot policy;
3. printer family and qualified optical configuration;
4. layer, exposure and build strategy;
5. geometry and orientation domain;
6. wash, drying and post-cure state;
7. environmental conditioning and test temperature;
8. ageing or time-since-cure interval;
9. property method and specimen definition;
10. production period or change-control envelope.

A design value is valid only inside this population unless a bridging study demonstrates equivalence.

7. Preserve the sampling hierarchy

Independent information can arise at raw-material lot, resin batch, printer, build, position, part and specimen levels. Repeated instrument readings on one specimen estimate repeatability but do not increase knowledge of lot-to-lot or build-to-build variation.

The experimental design should allocate replication across the population levels that matter to the claim. A nested or mixed-effects analysis may be required when several levels contribute variance. Pooling all readings as independent can narrow confidence intervals falsely and raise a lower bound without adding production evidence.

The report should state the experimental unit for every calculation and show how nested observations were handled.

8. Sample count follows the claim and variability

There is no universal minimum sample count for ER-171. Required information depends on target coverage and confidence, distribution shape, censoring, batch structure, variance and the consequence of error.

The NASA paper shows why small samples produce severe tolerance penalties and why a fixed fraction of the mean is not a substitute for a correctly calculated basis value [2]. It also notes that identifiable batch variability requires analysis that retains that structure [2].

A programme should justify sample size before testing using the intended method and plausible variability. Testing should not stop merely because an attractive bound has appeared.

9. Distribution choice is an evidence decision

Parametric tolerance bounds require a defensible distribution. Candidate normal, lognormal, Weibull or other models should be selected on physical and statistical grounds, not by choosing the model that returns the highest allowable.

The NASA paper describes distribution checks and nonparametric alternatives when candidate models do not fit [2]. For printed photopolymers, multimodality may signal mixed process states rather than an exotic single distribution. Outliers require investigation of specimen, process and measurement history before exclusion.

The report should retain the raw distribution, model diagnostics, exclusion rules and sensitivity of the bound to plausible analytical choices.

10. Censoring, failures and missing data

Run-outs, instrument limits, invalid specimens, print failures and unreadable results are not ordinary missing values. Their treatment can move a lower bound materially.

Predeclared rules should distinguish manufacturing nonconformance, test invalidity, right or left censoring, and legitimate extreme results. A specimen should not be removed because it weakens the design value. If a process failure belongs to the qualified population, excluding it can misrepresent that population.

Sensitivity analysis should show how disputed classifications affect the result.

11. Measurement uncertainty and guard bands

A statistical tolerance bound describes population sampling uncertainty under the chosen model. It does not automatically include calibration uncertainty, method bias or resolution limits.

Kolibaba et al. showed that light-engine characterisation and thickness measurement contributed strongly to incompatible working-curve results [3]. A property programme should therefore establish method repeatability, reproducibility, calibration, resolution and uncertainty at the decision boundary.

Where measurement uncertainty is material, a documented guard-band or integrated uncertainty treatment is required. It must not be counted twice with an environmental or process knockdown.

12. Environmental and temporal state

FAA guidance requires relevant temperature and moisture effects to be considered for affected non-metallic materials [1]. For printed photopolymers, the declared state may also depend on post-cure completion, continuing dark reactions, physical ageing, absorbed chemicals and service conditioning.

Environmental evidence can be incorporated by defining separate conditioned populations, using an approved adjustment model or selecting a demonstrated worst case. A dry-room-temperature value should not be relabelled as a service-environment design value.

The time origin and conditioning sequence must be controlled because a property that continues to evolve does not represent a stationary population.

13. Orientation, geometry and process interaction

Orientation and position are not automatically random noise. They may define systematic populations. Geometry can change exposure, heat flow, support interaction, wash access and post-cure penetration.

The qualification plan should decide whether to establish separate values, bound a family with a representative worst case, or use a validated model. Combining orientations or geometries is acceptable only when the combined population matches the intended design use.

Coupon evidence may require component-relevant confirmation when the manufacturing state cannot be reproduced adequately in the coupon.

14. From statistical bound to design use

A population tolerance bound is one input to design. It is not automatically a permissible stress, fatigue limit, life prediction or acceptance criterion. Structural analysis, load uncertainty, failure mode, environment, ageing, geometry and regulatory factors remain separate.

The report should distinguish:

- measured property distribution;
- statistical basis value;
- environmental or process adjustment;
- design factor or safety factor;

- final design input.

This separation prevents hidden double conservatism and, more importantly, hidden omission of necessary adjustments.

15. Bridging and lot equivalence

A new resin lot, printer, exposure profile or post-cure condition may be bridged to an existing database only when the affected variables and comparison method are predeclared. Equality of means is not sufficient if variance or lower-tail behaviour changes.

Bridging should include reference controls from the qualified state, adequate method sensitivity and acceptance logic tied to the design claim. A failed bridge does not necessarily reject the material; it means the old design value does not transfer without new qualification.

Historical data may be pooled only after compatibility of definitions, methods and populations has been demonstrated.

16. Change control and requalification

Requalification triggers include changes in formulation, supplier, inhibitor state, pigment or filler, resin ageing policy, printer or light engine, exposure strategy, layer thickness, build orientation, wash, post-cure, specimen method, test laboratory, environmental envelope or analysis method.

Not every change requires rebuilding the entire database. A tiered assessment can use screening, targeted bridging or full requalification according to the affected variance component and failure consequence.

Change control should protect the identity of the population to which the design value belongs.

17. Minimum design-value record

The controlled record should contain:

1. the exact population and property definition;
2. production and conditioning specifications;
3. sampling hierarchy and experimental units;
4. raw data, exclusions, censoring and failure records;
5. method validation and uncertainty;
6. distribution selection and diagnostics;
7. tolerance-bound method, coverage and confidence;
8. environmental and process adjustments;
9. sensitivity analysis;
10. bridging and requalification rules;
11. the final permitted design use and its boundaries.

Without this chain, a numerical value should remain a reported test result rather than a design value.

18. Evidence limitations

The FAA circular applies to transport-airplane certification and does not regulate printed photopolymer products generally [1]. The NASA paper addresses structural composites and illustrates allowables methodology rather than VPP qualification [2]. Their statistical logic is used as an explicit model, not imported as universal law.

The VPP interlaboratory study measures working curves, not mechanical strength or lower-tail design properties [3]. It directly demonstrates method and equipment sensitivity but does not provide a VPP allowable.

No universal distribution, sample count, coverage level, confidence level or acceptance rule is established by ER-171. The applicable requirement must come from the actual product, failure consequence and regulatory context.

19. Conclusions

Classical allowables methodology contributes an essential discipline: a design value is a population statement with declared coverage, confidence, production basis and environmental applicability. What does not transfer automatically is the assumption that a printed resin name defines one stable material population or that an aerospace label can be attached without its evidence structure.

Vat-photopolymerisation data must be state-resolved across material, printer, optical field, build, position, post-processing, environment and time. Sampling must preserve independent population levels, and measurement uncertainty must remain separate from process variability.

The defensible result is not the largest statistically obtainable number. It is a traceable lower bound for a declared population, calculated by a justified method and used only inside its qualified state envelope.

Related Engineering Review boundaries

ER-171 owns design-value methodology for printed photopolymers. ER-010 retains dimensional capability and metrology. ER-001 retains reporting and cross-study comparison. ER-100 retains corpus evidence architecture. ER-172 retains incoming photoresin raw-material and lot-equivalence qualification. ER-174 retains longitudinal optical-equipment and consumable drift.

References

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Competing interests

The author is Founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L. This review does not claim that any 3Dresyns material, process or property value is qualified as a design allowable.

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Data availability

No new experimental dataset was generated for this review.