



ZONMED

Shenzhen Zhongchuang 3D Technology Co., Ltd.

Dental 3D Printing Process Stability White Paper

Process Stability Whitepaper

Version: V1.0

Release Date: 2026.06.08

Scope of Application: Dental 3D Printing and Related Industries

Compiled by: ZONMED

Shenzhen ZONMED 3D Technology Co., Ltd.

Shenzhen Zhongchuang 3D Technology Co., Ltd

Web: www.zonmedtech.com E-mail: info@zonmedtech.com

Tel: +86 15959299121



Abstract

In the dental 3D printing production process, the consistency of printing results is influenced by multiple factors such as materials, equipment, environment, printing parameters, and post-processing. This white paper focuses on the key variables affecting process stability, establishing systematic testing and data analysis methods to help technicians build repeatable, monitorable, and optimizable printing processes.

Keywords

Dental 3D Printing | Printing Stability | Process Control | Resin | Printing Parameters | Data Analysis | Quality Control

1 Introduction

1.1 What is Printing Process Stability

- Consistent printing results: The same model can be stably reproduced at different times and in different batches.
- Process stability: The ability to maintain consistent output results within a controllable range of variation.
- Successful printing in the lab $\neq$ long-term production stability.
- Even with the same equipment and material, variations can occur—differences arise from the superposition of multiple variables.

1.2 General Factors Affecting Printing Results

Material $\times$ Equipment $\times$ Environment $\times$ Printing Parameters $\times$ Post-processing $\rightarrow$ Final Printing Result

1.3 Why Data-Driven Management is Needed

Transition from 'experience-based adjustments' to: standard testing $\rightarrow$ data recording $\rightarrow$ trend analysis $\rightarrow$ process optimization. Replace personal experience with data to reduce human variability.

2 Key Factors Affecting Process Stability

2.0 Factor Priority Matrix (Impact Weight $\times$ Controllability)

Not every variable has the same priority for control. Score based on 'Impact Weight (1–5)' and 'Controllability (1–5)'; Composite Score = Impact $\times$ Controllability; P0 (≥ 16) requires immediate standardized control, P1 (9–15) requires focused monitoring and compensation.

Factor	Impact	Controllable	Comprehensive	Priority	Control Strategy
Printing Parameters (Exposure/Layer Thickness/Speed)	5	5	25	P0	Parameter Locking + Window Control
Light Source / LCD and Light Intensity	5	4	20	P0	Light Intensity Calibration /



Attenuation					Consumable Part Replacement
Post-processing (Cleaning / Secondary Curing)	4	5	20	P0	Cleaning and Curing SOP
Model Layout / Placement / Supports	4	5	20	P0	Slicing Template + Slice Review
Ambient Temperature	4	4	16	P0	Temperature Control + Recording
Operator Consistency	4	4	16	P0	SOP + Training Certification
Equipment Z-axis Stability / Wear	4	4	16	P0	Z-axis Accuracy Check + Regular Maintenance
Resin Tank Resin Status	3	5	15	P1	Filtration / Recycling Rules
Material Batch Variation	4	3	12	P1	Batch Sampling + Release
Release Film / Resin Tank Wear	4	3	12	P1	Lifetime Log + Regular Replacement
Ambient Humidity	3	3	9	P1	Dehumidification + Recording

Interpretation: Quadrant I (High Impact-High Controllability, P0) is prioritized for investment; Quadrant II (High Impact-Low Controllability, P1) is 'contained' through sampling, lifespan management, and trend monitoring.

2.1 Ambient Temperature

Impact Mechanism

Temperature primarily affects printing results through two pathways: 'resin viscosity → curing reaction rate.' As temperature increases, viscosity decreases, flowability improves, and the curing reaction accelerates (curing depth increases under the same exposure). As temperature decreases, viscosity increases, resistance during layer spreading and release rises, leading to under-curing, loss of detail, and brittle support breakage. Sudden changes in ambient temperature can also cause thermal expansion and contraction of the platform and resin tank, affecting interlayer bonding and dimensional reproducibility.

Test Design

Keep equipment, material, model, layer thickness, parameters, and post-processing fixed, only change the ambient temperature; it is recommended to set temperature points such as 18 / 22 / — / 30 °C, with no less than 3 repetitions per point.

Recorded Items (Example Conditions)

Item	Condition
Ambient Temperature	25 °C
Ambient Humidity	50 %RH



Printer	LCD 405 nm
Resin Model	Dental Model Resin
Layer Thickness	50 μm
Exposure Time	2.5 s

Data Analysis

Analyze the relationship between temperature and ① dimensional accuracy, ② surface quality, ③ print success rate, ④ support stability (recommended presentation via line or scatter charts).

Process Control Recommendations

- Set a constant temperature range (e.g., 22–26 °C) and record throughout; alarm when deviating from thresholds.
- Allow materials to return to room temperature before opening packaging to avoid sudden viscosity changes.
- Avoid direct airflow from air conditioning onto the equipment; maintain stable ambient temperature around the device.

2.2 Environmental Humidity

Influencing Factors

In high-humidity environments, resin is prone to moisture absorption, leading to changes in viscosity and curing behavior, manifesting as surface whitening, bubbles, and uneven curing, thereby affecting dimensions and appearance.

Testing Method

Control humidity ranges (e.g., 30% / 50% / 70% RH) with other conditions fixed; record printing performance under each humidity range.

Data Recording

Record items same as 2.1 (environmental temperature, humidity, equipment, material, layer thickness, exposure time, results).

Result Analysis

Analyze the relationship between humidity and surface quality, dimensional deviation, and print success rate.

Process Control Recommendations

- Dehumidify the workshop; it is recommended to control relative humidity within 40–60% RH.
- Store resin sealed; after opening, use as needed and finish within a limited time.
- Add desiccant to the resin vat; seal before long-term inactivity.

2.3 Printing Equipment Status

Influencing Factors

- LCD / DLP Light Source Brightness and Uniformity Degradation



- Release Film Wear, Scratches, Contamination
- Resin Vat Aging, Scratches
- Print Platform Leveling and Adhesion Status
- Equipment Cumulative Usage Time
- Calibration State Drift

Equipment Aging Test (Example)

Cumulative Usage	Light Intensity Measured	Print Success Rate
0 h	2.8 mW/cm ²	99%
200 h	2.5 mW/cm ²	98%
400 h	2.1 mW/cm ²	96%
600 h	1.7 mW/cm ²	92%

Data Analysis

Determine at what level of light intensity degradation and component wear recalibration or part replacement is required.

Process Control Recommendations

- Establish light intensity logs and replacement cycles for consumable parts (light source, release film, resin vat).
- Perform regular calibration based on printing hours; re-validate parameters after part replacement.
- Perform daily checks for platform cleaning and leveling.

2.4 Material Batch Variation

Comparison Items (Example Values)

Test Item	Batch A	Batch B	Batch C
Viscosity (mPa·s)	320	335	350
Cure Depth (μm)	180	175	168
Dimensional Deviation (mm)	+0.02	+0.05	+0.09
Strength (MPa)	62	60	57
Print Success Rate (%)	99	97	95

Data Analysis

Analyze the variation range between different batches and its impact on printing results to determine if parameter fine-tuning per batch is necessary.

Process Control Recommendations

- Batch sampling + release upon storage, register batch numbers and key indicators.
- First-in-first-out to avoid using beyond shelf life.
- Fine-tune exposure parameters per batch and archive records when necessary.

2.5 Printing Parameters



Key Parameters

- Exposure Time, Bottom Exposure
- Layer Thickness
- Lift speed, retract speed
- Number of Bottom Layers
- Other device-related parameters

Impact Mechanism

Insufficient exposure → under-curing, loss of detail; excessive exposure → dimensional expansion, blurred details, rough surface. Layer thickness affects detail and efficiency; lift and retract speeds affect release force and interlayer bonding; number of base layers and base exposure affect first-layer adhesion and overall success rate.

Recommended parameter range (example / reference)

Parameters	Recommended Range / Example Value
Layer Thickness	30–100 μm (Conventional 50 μm)
Exposure Time	1.5–3.5 s (Calibrated per Resin and Machine Model)
Bottom Exposure	20–40 s
Number of Bottom Layers	4–6 Layers
Lift Speed	30–80 mm/min
Retract Speed	60–120 mm/min
Lift Height	5–8 mm
Rest Time	1–8 s
Light Intensity	Calibrated per Machine Model (LCD approx. 1–3 mW/cm ²)

Process Control Recommendations

- Parameter version management; changes must be validated through testing before taking effect.
- Lock validated parameters into SOP, prohibiting arbitrary modifications.

2.6 Post-processing

Steps

- Cleaning (solvent, time, cycles)
- Drying
- Post-curing (time, temperature, wavelength, equipment status)

Impact Mechanism

Insufficient cleaning → residual liquid, affecting dimensions, surface, and compatibility; excessive cleaning → deformation, cracking. Insufficient post-curing → inadequate mechanical properties and long-term stability; excessive → brittleness, discoloration.

Process Control Recommendations

- Standardize cleaning and post-curing SOP (time / temperature / process fixed and recorded).
- Monitor post-processing equipment status (light source power, timing, temperature).



2.7 Device Z-axis stability and wear

Impact Mechanism

Z-axis (lead screw / guide rail / stepper motor) determines the lift and positioning accuracy of each layer. Z-axis wear, gap, looseness, insufficient lubrication, or missed steps can lead to uneven layer thickness, Z-axis banding, Z-axis dimensional deviation, layer misalignment, and in severe cases, direct print failure. The longer the cumulative usage time of the device, the more pronounced the lead screw wear, guide rail contamination, and lubrication degradation become, amplifying errors.

Testing Method

Print Z-axis step / columnar test pieces, measure Z-axis dimensions and layer thickness consistency; regularly check platform homing accuracy and Z-axis repeat positioning accuracy (multiple lifts / homing to measure deviation); observe model surface for Z-axis banding.

Record items

Item	Record Content
Cumulative Usage Time	___ h
Z-axis repeat positioning deviation	___ mm
Measured layer thickness	___ μm
Z-direction dimensional deviation	___ mm
Surface Z-direction streaks	Present / Absent

Data Analysis

Analyze the relationship between Z-axis deviation / wear and layer thickness consistency, Z-axis dimensional accuracy, surface quality, print success rate; determine when cleaning, lubrication, lead screw replacement, or recalibration is needed.

Process Control Recommendations

- Regularly clean and lubricate lead screws and guide rails to maintain smooth movement.
- Periodically test Z-axis repeat positioning accuracy and include it in equipment records.
- When Z-axis banding, abnormal layer thickness, or Z-axis dimensional deviation occurs, prioritize troubleshooting the Z-axis.
- After replacing or overhauling Z-axis components, revalidate print parameters.

3 Standardized testing methods

3.1 Test objectives

Clearly define validation targets: print success rate, dimensional stability, surface quality, detail reproduction, mechanical properties, long-term stability.

3.2 Standardization of test conditions

Fixed: device → material → model → parameters → environment → post-processing. Principle: change only one main variable per test as much as possible.



3.3 Test models

Use test models containing key features: small holes, thin walls, edges, details, dimensions, curved surfaces.

3.4 Data collection

Record fields: date, temperature, humidity, device, material batch, parameters, results (corresponding to Appendix A table).

3.5 Data analysis methods

Mean, maximum, minimum, standard deviation, coefficient of variation (CV), dimensional deviation, success rate, failure rate, trend changes.

4 Experimental data and result analysis

This chapter provides a data template and analysis framework; actual data will be filled in by the laboratory according to standard tests and analyzed uniformly.

4.1 Temperature variation experiment

[Data table] + [Line chart] → Analysis: temperature variation → material state → print performance.

4.2 Exposure parameter experiment

Parameters A→B→C→D, compare dimensions, surface, details, supports, success rate.

4.3 Batch-to-Batch Material Testing

[Data Sheet] + [Comparison Chart] → Analyze the variation range between batches.

4.4 Equipment Usage Time and Printing Results

[Trend Chart] → Determine if equipment status changes require recalibration.

5 Parameter Optimization and Best Practices

5.1 Establishing a Parameter Window (Operating Window)

Instead of defining a single fixed value, provide a 'recommended parameter range.' The following figure uses exposure parameters as the horizontal axis and pass rate as the vertical axis to illustrate the under-cured zone, stable window, and over-cured zone; the stable window is the interval where the SOP is locked and operates.

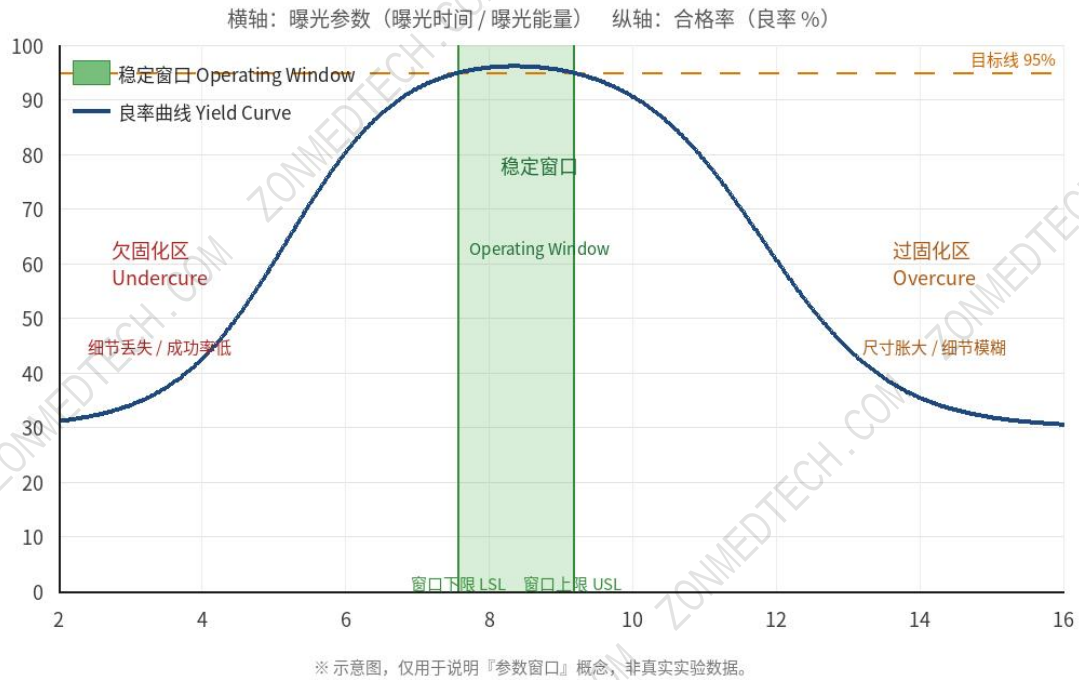


Figure 5-1 Schematic Diagram of Exposure Parameter Window (Operating Window)

Note: The above figure is a schematic diagram, used only to illustrate the concept of a 'parameter window'; replace it with the factory's 'parameter-yield' fitting curve during actual testing.

5.2 Parameter Adjustment Logic

Identify problem → Determine variable → Adjust parameter → Test again → Data confirmation.

5.3 Long-term Printing Stability Verification

30-day / 60-day / 90-day testing, recording date, environment, equipment, material batch, printing parameters, printing results, outputting long-term trend charts.

6 Process Stability Management

- 6.1 Daily Inspection
- 6.2 Equipment Maintenance
- 6.3 Material Management
- 6.4 Parameter Management
- 6.5 Exception Handling: Exception → Root cause analysis → Parameter adjustment → Verification → Recording

7 Technician Daily Inspection Checklist

Inspection item	Frequency	Inspection content	Status
-----------------	-----------	--------------------	--------



Ambient Temperature	Daily	Record and confirm within range	☐
Ambient Humidity	Daily	Record and confirm within range	☐
Resin status	Each print	Appearance / Viscosity / Impurities	☐
Resin batch	Per batch	Batch number registration, sampling inspection release	☐
Printing platform	Daily	Cleaning / Leveling confirmation	☐
Release Film	Periodically	Appearance / Scratches / Replacement	☐
Light source / LCD	Periodically	Light intensity and uniformity calibration	☐
Parameter calibration	Periodically	Cross-check with parameter version	☐
Z-axis / Lead screw	Periodically	Cleaning lubrication + repeat positioning accuracy	☐
Cleaning	Each print	Cleaning solution / Process compliance	☐
Post-Curing	Per batch	Time / Temperature / Equipment status	☐

8 Conclusions and Recommendations

- Process stability is not determined by a single parameter.
- Materials, equipment, environment, and parameters require systematic management.
- Standardized testing can reduce differences due to individual experience.
- Continuous data recording can reveal process trends.
- Establishing a parameter window is more suitable for long-term production than pursuing a single fixed parameter.

Appendix A–G Unified Record Form Templates

Seven record forms align fields according to a unified specification: unified 'Record Number · Date · Operator' starting columns; unified 'Ambient Temperature · Humidity'; unified 'Judgment / Status · Remarks' ending columns; forms cross-reference via record numbers to form a traceable closed loop.

Appendix	Name	Key fields
A	Test data record sheet	Dimensional deviation, surface quality, judgment, layer thickness, exposure time
B	Printing parameter record sheet	Exposure / Bottom exposure / Layer thickness / Lift retract / Light intensity / Parameter version
C	Material batch record sheet	Batch number, viscosity, curing depth, inspection conclusion
D	Equipment maintenance record sheet	Measured light intensity, release film / resin tank, calibration, next maintenance
E	Abnormal analysis record sheet	Abnormal phenomenon, 5Why root cause,



		correction / prevention, closed-loop status
F	Test Model Description	Test Features (Small Holes / Thin Walls / Edges / Curved Surfaces), Printing Angle
G	Data Analysis Method Description	Calculation and Thresholds for Mean / Standard Deviation / CV / Deviation / Success Rate

White Paper Core Logic

Variable identification → Standardized testing → Data collection → Result analysis → Parameter optimization → Long-term verification → Establishing a stable process → Forming an SOP

SEO Keywords / Long-tail Terms

- dental 3D printing process stability whitepaper
- dental lab 3D print consistency guide
- dental 3D printer process control parameters
- resin selection for stable dental 3D prints
- dental 3D printing quality control whitepaper
- optimizing dental 3D print parameters whitepaper
- dental 3D printing data analysis for consistency
- ensuring dental 3D print process stability
- dental lab 3D printing QC protocols whitepaper
- dental 3D printing resin stability factors
- process control in dental additive manufacturing
- dental 3D printing repeatability and consistency
- dental distributor 3D printing process whitepaper
- dental 3D printing parameter optimization guide
- achieving consistent dental 3D printed restorations
- dental lab 3D printing workflow stability
- monitoring dental 3D printing process stability
- dental 3D printing material data analysis whitepaper



ZONMED

Shenzhen Zhongchuang 3D Technology Co., Ltd.

- dental 3D printing calibration for consistency
- dental 3D printing process validation whitepaper
- dental 3D printing environmental control parameters
- dental 3D printing statistical process control SPC