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NCAMP Process Specification
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Polymer Additive Manufacturing Materials, Machine, Processing and Quality Requirements Specification for fabrication of NMS 800 thermoplastic powder using Laser Powder Bed Fusion on EOS P800 printer

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Table of Contents

Revisions:

Rev	By	Date	Description
-	Michelle Man	10/25/2021	Document Initial Release
A	Jonathan John	11/3/2023	-Page 11, Table 2. Added the new software update for the Materialise Magic and EOS RP-Tools
B	Jonathan John	10/4/2024	-Page 5, section 2.2. Updated the document numbers to reflect the right numbers -Page 11, section 5.2 and page 24. Added a description "Derivatives of these .SLI files will be printed per the controlled dataset procedures in the PCD." to clarify the process -Page 12, section 6.4. Updated the CoC document number to AERO QAL FRM-0048 -Page 18,22, Chip. Added note [1] to show a mitigation process, if necessary -Page 25-27. Updated appendix B with some new coupon print locations -Page 28-41. Updated Build Layouts -Page 42. Added a note "Note: All dimensions are reference only. Width, length, and radius to read and record only."

1. Scope

This process specification describes the methods of coupon and part fabrication using a Laser Powder Bed Fusion (LPBF) process using thermoplastic powder materials described in NMS 800 on an EOS P800 printer. Specifically, this specification covers the constituent material, the configuration of the machine, operating software, machine calibration, and machine and build parameters and acceptance criteria. In addition to the instructions contained in this specification, users are advised to obtain hands-on guidance directly from the machine manufacturer for the setup of the machine, establishing the build and slice files as well as determination of the correct build parameters.

This specification does not contain all the necessary information typically required for the fabrication of LPBF parts, such as personnel qualification or facility requirements. Users should refer to their existing company process specification for such information.

1.1. Purpose

The purpose of this process specification is to provide processing information for the fabrication of test coupons for use in material qualification, equivalency and acceptance testing. This process specification may also be used as a baseline by material users to develop a process specification for the fabrication of aerospace advanced material parts.

Specifically, this specification establishes the requirements for the Laser Powder Bed Fusion (LPBF) process using materials in NMS 800 on the EOS P800 printer, herein referred to as “LPBF System”.

1.2. Classification

a) Powder – When the Raw Flake is processed and procured to NMS 800 and NMS 800/1.

b) EOS P800 - A machine supplied by EOS, identified by Serial number at a specific location. For the purpose of Qualification and/or Equivalency, this machine is used according to this Process Specification to manufacture material produced per NMS 800.

c) LPBF System – Is representative of the combination of LPBF equipment and software, configured, calibrated, and maintained as outlined per this Process Specification.

1.3. Health and Safety

While the materials, methods, hardware, applications, and processes described or referenced in this specification may involve the use of hazardous materials and hazardous environments, this specification does not address the hazards which may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials or processes and to take necessary

precautionary measures to ensure the health and safety of all personnel involved.

2. Applicable Documents

The following specifications, drawings, and publications, of latest issue when not specified, form a part of this document to the extent specified herein.

2.1. NCAMP Documents:

Document No.	Document Title
NMS 800	Hexcel Corporation HexPEKK®-100 powder for Laser Powder Bed Fusion
NMS 800/1	NCAMP Material Specification, Hexcel Corporation HexPEKK®-100 (Virgin material only) HexPEKK®-100 is a registered trademark of Hexcel Corp. or affiliates

2.2. Hexcel Documents:

Document No.	Document Title
AERO ENG DOC-0027	Process Control Document
9256-0011	Installation Conditions
9256-0101	Operation

2.3. Industry Standards:

Document No.	Document Title
ASTM D638	Standard Test Method for Tensile Properties of Plastics
ASTM D792	Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
ASTM D695	Standard Test Method for Compressive Properties of Rigid Plastics
ASTM D790	Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
ASTM D3418	Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry

2.4. US Government Publication:

Not Used

2.5. Abbreviations and Acronyms:

ACN	Advanced Change Notice
AM	Additive Manufacturing
CAD	Computer-aided Design
DSC	Differential Scanning Calorimetry
BOM	Bill of Material
°F	Degrees Fahrenheit
Hz	Hertz
KPV	Key Process Variable
LPBF	Laser Powder Bed Fusion
OEM	Original Equipment Manufacture
PEKK	Polyetherketoneketone
PPE	Personal Protective Equipment
RH	Relative Humidity
SLI	Slice Layer Interface File
STL	Standard Tessellation Language File
QA	Quality Assurance (Department)
QMS	Quality Management System
VAC	Volts Alternating Current

2.6. Terms and Definitions:

- Additive Manufacturing – Process of joining materials to make parts from 3D model data, usually layer upon layer.
- Auditing Body – Entity responsible for certifying the performance of a user to the qualification requirements of a specification and slash sheet.
- Batch – A batch of carbon fiber combined to produce a Lot of manufacturing material that is fed/used in the LPBF System.
- Build – The physical activities the machine takes to fabricate one or more parts within a unique start and stop of the machine.
- Build Chamber – The “in-oven” portion of the LPBF System hardware that includes the platen and heating elements.
- Build Cycle – A single process cycle in which one or more parts are built by successive layer fusion of material within the machine.
- Build Envelope – The volume within the laser sintering system that can be utilized to produce a part or sets of parts.
- Container – Packaging used to house polymer powder material.
- EOS P800 – A specific model of 3D printer, trademarked by EOS, denoting the build volume and grade of printer.
- Feedstock – Bulk raw material supplied to the additive manufacturing process.
- Key Process Variable (KPV) - Variable in the manufacturing process determined to have the most critical impact on fit, form, and function of the resultant printed part(s).
- Laser Powder Bed Fusion (LPBF) – A type of consolidation-based additive manufacturing technology that utilizes one or more lasers to combine polymer powder particles into three-dimensional objects, prototypes, and products through a computer-aided process.
- Lot (Powder Lot) - The quantity of Hexcel consumables manufactured at one time to a single set of defined properties.
- Machine – The computer guided apparatus that is used to create the manufactured 3D part.
- Machine Controlling Software – Software that controls motion and fusion during the laser sintering process workflow, manipulation of location and orientation.
- Manufacturer – The organization which designed/built the laser sintering system.

- Material – The polymer powder that is fed into the laser sintering machine to be fabricated.

- Material Supplier – The organization that manufactures the polymer powder material.

- Part – A physical fabricated 3D object created through the laser sintering system including but not limited to production articles, coupons, and specimens.

- Part Cake – The unsintered powder material surrounding parts after a Build.

- Pre-processing Software – Software that converts part models from CAD or .STL files into machine processable files.

- Qualification —The implementation of set parameters to establish the requirements and its suitability for operation.

- Qualified Processor – A processor demonstrating the ability to meet the requirements defined herein and approved by the Auditing Body.

- Recycled material– Unsintered powder material that has been previously used in at least one build. This is not sintered pieces which have been reground (regrind)

- Refresh material – A powder batch consisting of a mix of virgin and recycled powder. Refresh material is not available for materials governed in NMS 800.

- Shall — Expresses a binding requirement.

- Should/May — Expresses a recommended or allowed action.

- Software – The combination of pre-processing software and machine controlling software which is necessary to guide the laser sintering machine.

- System – Refers to the combination of equipment, material, and software used to create the laser sintering parts.

- User – The organization responsible for part fabrication

- User designated authority – a person(s) with authority to disposition unsatisfactory or non-conformance issues. This may be a person(s) appointed by a governing agency/authority, an engineer appointed by the user, or a material disposition board acting under the guidance of the appropriate company documents.

- Validation — Identifies that the requirements for a product are sufficiently correct and complete.

- Verification — Identifies that the implementation has been evaluated to determine that all design requirements have been met.

- Virgin Material – Feedstock from a material supplier that has not been used in the LS process.

- Will — Expresses a declaration of intent.

3. Environmental Control

3.1. Fabrication Facility Conditions

The LPBF System is for indoor use only:

a) Operating temperature: 60°F (15.5°C) to 90°F (32°C)
b) Humidity: 0% RH to 60% RH non-condensing

Operation of the LPBF System outside this range is not recommended.

3.2. Fabrication Facility Electrical Requirements

Facility power is required to meet the following power quality and nominal voltage requirements:

a) Voltage: 400VAC nominal 3-phase service with 10% regulation
b) Frequency: 50 Hz or 60 Hz
c) Current: 32 Amp circuit

Operation of the LPBF System outside this range is not recommended and degradation of the LPBF System performance and shortened component life expectancy will be experienced. The LPBF System is to be operated on a 3-phase service meeting the recommendations for power quality given in IEEE Standard 141-1976. Facilities who are unsure of their power quality should contact their service provider.

3.3. Compressed Air Requirements

The LPBF System has an onboard pressure regulator, onboard particle filtration, water, and oil separation. Air-lines must be used in conjunction with the following:

a) Supply pressure at the LPBF System:
    a. 80-145 PSI with a minimum flow of 12 CFM
    b. Non-lubricated
    c. Non-condensing
b) DIN ISO 8573-1 Quality Class 5 or better is recommended to improve onboard filter life
c) Connection: Dimensional standard A-A-59439

4. Equipment Control

a) Once approved, unless otherwise specified, this document is the primary reference source for the operating and performance standards for all parts fabricated with the LPBF System (manufactured by EOS.).
b) The LPBF System shall be installed in accordance with EOS Installation Conditions and Operation manuals for guidance. It is recommended that installation be completed by a certified EOS representative or trained personnel.

4.1. Laser Powder Bed Fusion (LPBF) Equipment

a) LPBF Systems must be identified by names or numbers for setup and traceability.
b) All LPBF machines must have a maintenance plan based on the manufactures' recommended procedures.
c) Record of calibration and machine maintenance must be retained as QA records and must comply with Section 4.2.2.

4.2. Machine Maintenance and Control

Modifications or repairs to major sub-system equipment may demonstrate significant changes in build quality and are noted in Table 1. Any changes made and communicated by EOS or replacement of these components must be reviewed and dispositioned by designated authority and may require requalification per Section 8, repeated Equivalency, or even full certification based on the change classification.

Table 1. Critical Sub-System Components

Sub-System	Description
Laser Generation	Critical sub-components fundamental to creating and controlling the sintering area.
Recoater System	Mechanism that dispenses powder onto the build platform
Vertical Drive Motor	Mechanism that drives belt controlling vertical (Z) motion or platform location. Observed faults, shifts, and motion failures will result in replacing these motors and requiring revalidation of system through appropriate ACN process.
Master Computer	On-board computing system
Universal Power Supply	Critical component of the electrical system to regulate incoming power to all electronics on an LPBF System

4.2.1. Preventative Maintenance

a) Preventive maintenance will be performed on each LPBF System used to fabricate production parts. This maintenance will verify proper operation of the LPBF System.
b) Preventive maintenance will be performed per EOS' recommend maintenance procedures on an annual or bi-annual basis.
c) All maintenance activities will be performed in accordance with the EOS

standard procedure using EOS replacement parts as needed.

d) After maintenance has been performed on a LPBF System, the LPBF System shall be verified by the Qualified Processor

4.2.2. Maintenance Record

A record of all machine maintenance activities, calibrations, and repairs will be maintained for each LPBF System and stored per the user's applicable quality management system procedures.

5. Software Control

Software for additive manufacturing systems is an essential part of the process and must be defined and be under configuration control. Specific software versions utilized for the qualification of the material are controlled for that material through the controlled internal PCD that governs the manufacturing process. Any changes to software listed in the PCD at the time of qualification and used as part of this process must be approved via ACN through NCAMP.

Table 2: Software Revisions

Revision Number	Revision Description
3.7	3D Printing Software - EOS P800
22.0.1.27 or newer	Materialise Magics version update
6.2.7 or newer	EOS RP-Tool model prepration software update

5.1. Model Preparation

Model preparation is performed using industry standard CAD and .STL modification software. The required output of this process is a .SLI file that can be imported into EOS' software. The control and verification of these software packages is at the discretion of the user.

5.2. Job File Creation

Pre-loaded .SLI files for all coupon geometries and orientations shall be used for Qualification and Equivalency and should be retrieved by contacting NCAMP. Derivatives of these .SLI files will be printed per the controlled dataset procedures in the PCD. For a list of all Pack Files and .SLIs for each test and coupon see Appendix A: NCAMP SLI file Coupon Build information.

6. Materials Control

6.1. Deliverable Material

a) All parts shall be fabricated in accordance with material governed by NMS 800.

Refresh material is not allowed for use.

6.2. Consumable and Expendable Materials

a) Consumable and expendable materials are necessary for part production and shall not be part of bill of material (BOM) or used in the part assembly.

6.3. Miscellaneous Contact Materials

a) Gloves and other PPE for handling parts, tools for support removal, shall be utilized as required when handling material

6.4. Material Receiving Inspection

a) Hexcel shall provide a Certificate of Compliance (AERO QAL FRM-0048) for each Powder Batch or Lot in conformance with NMS 800.
b) Document Hexcel Powder Lot # per user's designated Job Tracking system.

6.5. Material Storage Control

Recommended storage conditions are to maintain temperature between 60 – 90°F and a relative humidity of 0% - 60%.

LPBF Materials shall be stored in the original containers until ready for use in the LPBF System in accordance to Section 4.0. Powder bags shall be properly stored per manufacturer's recommendations as stated above. The material called out in NMS 800 does not have a shelf life when stored per manufacturer's recommendations.

a) If drying is needed, drying time and conditions shall be recorded per user's PCD.
b) Any unused powder shall be returned to inventory or storage.
c) Once the container is open, the allowable work time is the time it takes to place material into the printer system. Upon completion of that task any unused powder should be resealed and follow steps 6.5b above.

7. Build Process

7.1. Start-up

a) Machine Readiness values fall within the following limits
   i. Ensure equipment is on, that the approved machine software version is in place, and sufficient material allocated.
   ii. Ensure preventative maintenance records are up to date and the machine is within calibration.
   iii. Visually verify the build chamber, powder supply bin, exchangeable frame and platform are clean and free from adhering powder or any other foreign object debris (FOD).
   iv. Verify cooling system is in operation.
   v. Verify external extraction fans are ON and in operation.
   vi. Verify temperature and humidity meet requirements in Section 3.1
b) Load the exchangeable frame into the P800
c) Material preparation must be conducted using the following guidelines.
   i. Remove the top cap from each container
   ii. Carefully pour powder into each container
   iii. Ensure the containers are at least a quarter full of powder before starting. Continual monitoring of material level may be necessary depending on build size. Material may be added as needed.
   iv. Replace top cap
d) Machine heat up time and stabilization must be the minimum time prompted by the machine and documented for each build.
e) Coat the bed with powder and visually check even powder distribution

7.2. Fabrication

a) No part files shall be manipulated during fabrication
b) Prior to build removal confirm the build is a 100% complete.
c) Builds shall not contain any unacceptable defects (Table 6) regardless of location within the build. Builds with this incident shall result in disposition by user designated authority.
d) Builds will not encounter any errors at any point throughout the build. Builds with this incident shall result in disposition by user designated authority.
e) Refill canisters with adequate powder as-needed.

7.3. Part Removal

a) Parts shall be removed after the platform has reached its end of the build position and temperature. It is recommended to remove parts from powder cake once it is cool enough to handle.
b) If the part is unable to be removed on the same day of manufacture, it should be removed within 3 days of build completion.
c) Remove excess part (powder) cake. Excess part (powder) cake may be discarded at the discretion of the user. Alternately the part cake may be reused as recycled material but this is outside the scope of this document until equivalency of recycled material is met.
d) Parts shall be removed manually from powder cake without damaging the parts.

NOTE: Care should be taken on fine feature geometries to not distort or damage parts on removal.

NOTE: Wear heat resistant glove and proper PPE while removing parts from build cake.

NOTE: Use special care when removing powder cake from thin sections of the part, as to not puncture the part

7.4. Part Clean-up

a) Remove powder cake using a flat workspace.
b) Vibratory and/or glass bead pressurized material removal methods are recommended to remove residual cake and shall not have an adverse effect on dimensional criteria.
c) As necessary, use probes or a pick to remove the powder cake from the part.
d) The use of hand sanding, reaming and/or deburring for rework to meet engineering drawing requirements is permitted.

NOTE: Wear glove and eye protection while attempting to clean up parts.

NOTE: Care must be taken when removing powder cake to prevent breaking of features and gouging of part(s).

7.5. Fabricated Parts Identification & Storage

a) Completed parts must be labeled per the user's preferred part identification method.
b) Parts should be stored in a sealed bag (bag material is at discretion of user), at temperatures between 60°F and 90°F.
c) Sealed bags should be properly labeled according to user's preferred part identification methods. Parts in bags with no label shall be dispositioned by user designated authority.

8. Quality Assurance & Inspection Control

8.1. General

Quality Assurance must ensure that the LPBF System is adequately controlled to consistently produce quality parts that meet the requirements of this specification.

8.2. Quality Testing & Control

Each build shall have witness coupons fabricated along with the part(s) and shall meet the requirements shown in Table 3. Witness coupons shall be fabricated with the identical build parameters as the part(s).

Table 3. Witness Coupon Requirements

Property	Section	Standard	Minimum No. of Coupons	Test Conditions	Requirement
Tension Strength	8.2.1	ASTM D638 DF2 ZX Orientation	5	RTA	8.4 ksi Note I
Tension Modulus					0.6569 to 0.7658 msi Note II
Glass Transition	8.2.2	ASTM D3418	1	RTA	152°C Note I
Density	8.2.3	ASTM D792	5	RTA	1.30 – 1.36 Note II
Surface Resistivity	8.2.4	ASTM D257	1	RTA	$< 1 \times 10^{9}$
Volume Resistivity			1	RTA	$< 1 \times 10^{11}$

NOTE I: No single test coupon result can be lower than the listed value (min. individual)
NOTE II: Minimum and maximum average value

8.2.1. Tension

Tension coupons shall be fabricated and data recorded in accordance with Appendix C: Coupon Geometry. A minimum of five coupons shall be oriented with the largest dimension in the Z direction and second largest dimension in the X direction (ZX). Coupons shall be well distributed throughout the build volume. Tension coupons shall be tested at room temperature ambient (RTA) and as-received condition. Prior to test, light sanding may be necessary to remove any surface anomalies in tab sections as defined in Table 4. If a tensile coupon fails the Table 3 requirement or breaks outside of the gage length, a duplicate coupon may be tested in lieu of the original coupon. Duplicate coupons must be printed in close proximity to the original coupon.

8.2.2. Glass Transition

The glass transition temperature shall be measured with differential scanning calorimetry (DSC) in accordance with ASTM D3418. A minimum of one test coupons shall be fabricated or excised from existing fabricated coupon or part. The coupon length of each coupon shall be parallel to the XY plane of the build volume.

8.2.3. Density

Density of the coupon shall be measured in accordance with ASTM D792.

8.2.4. Electrical Resistivity

The testing for compliance will be the fabrication of a set of four 3 inch nominal diameter disks of 0.110 inch nominal in thickness. Two electrical tests shall be performed to meet the requirements of Table 3; one for XY orientation, and one for Z orientation. Surface and volume resistivity shall be verified as specified in ASTM D257.

8.3. Visual Inspection

8.3.1. Anomaly Acceptance Limits

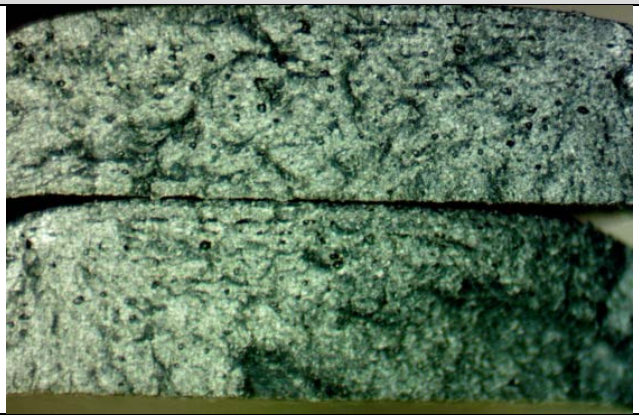
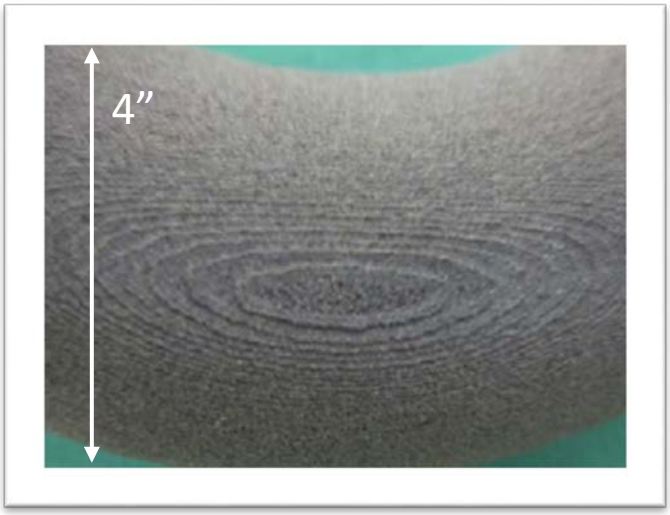
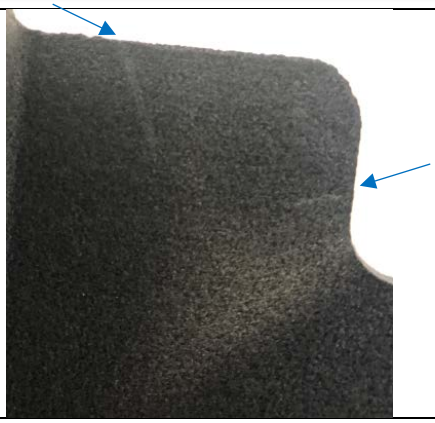
The following anomalies are inherent to the LPBF process, are deemed aesthetic, and are acceptable to the extent specified herein. Table 4 Acceptance Limits is for reference only and requirements shall be defined in the Engineering Drawing of the user/part manufacturer.

Table 4 Acceptance Criteria for Visually Detected Anomalies

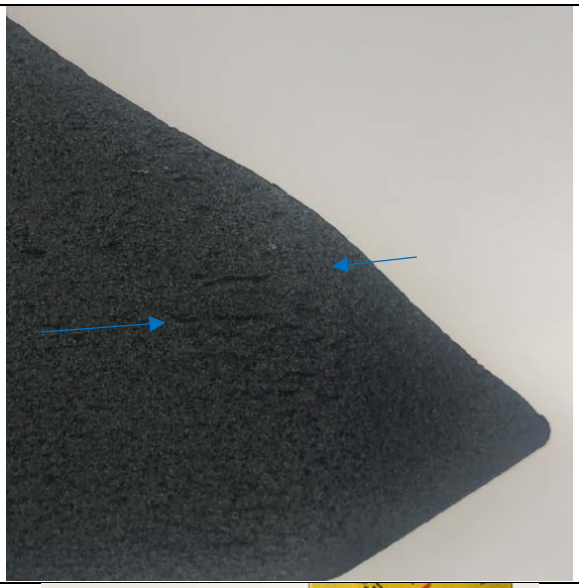
Item	Anomalies	Definition	Acceptance Limit	Optional Rework
a	Within Part Porosity	Incomplete part fill inherent to the LPBF process	Porosity shall be less than or equal to 2% averaged over the entire part as measured by Xray/CT Scan when called out in engineering drawing.	None
b	Stairstepping	Visible, perceptible lines or ridges between successive build layers that are typical on highly curved surfaces. See Table 5	Ridges less than or equal to one LPBF powder layer deposition in height	May be removed or smoothed without damaging the part
c	Scratches	Shallow cut or scrape on the surface of a part occurring from routine handling, such as cake removal.	Scratches less than one deposition layer deep	May be removed or smoothed without damaging the part – surface may be sanded down.
d	Raised Edge	Uneven surfaces that occur at the part edge due to residual sintering. Most common on thin features. See Table 5	No limit	May be removed or smoothed without damaging the part

Item	Anomalies	Definition	Acceptance Limit	Optional Rework
e	Knitline Seam	The central start/stop location of a laser in a dual laser system. See Table 5	No Limit (Note: Seams are inherent to multiple laser LPBF machines and are acceptable, as long as the seam meets the engineering drawing requirements)	None
f	Color Striation	Gradual change from dark to light color. See Table 5	Any pigmentation variation.	None
g	Surface Porosity	Small voids in surface, typically seen around vertical surfaces. See Table 5	Each individual void less than or equal to 0.080 inch in maximum dimension or as required by engineering drawing.	May be removed or smoothed without damaging the part – surface may be sanded down
h	Striping	Uneven surface typically seen in vertical surfaces.	< 3” total area. Dimensional value must meet minimum thickness.	May be removed or smoothed without damaging the part
i	Banding	Uneven thickness typically seen in vertical surfaces. See Table 5	No limit	May be removed or smoothed without damaging the part
j	Chips	See Table 6	Not acceptable [1]	None [1]
k	Cracks	See Table 6	Not acceptable	None

Table 5 Representative Illustrations of Acceptable Anomalies

Anomalies	Picture / Figure
Within Part Porosity (cross section of tension coupon taken with microscope)	
Stairstepping	
Scratches	

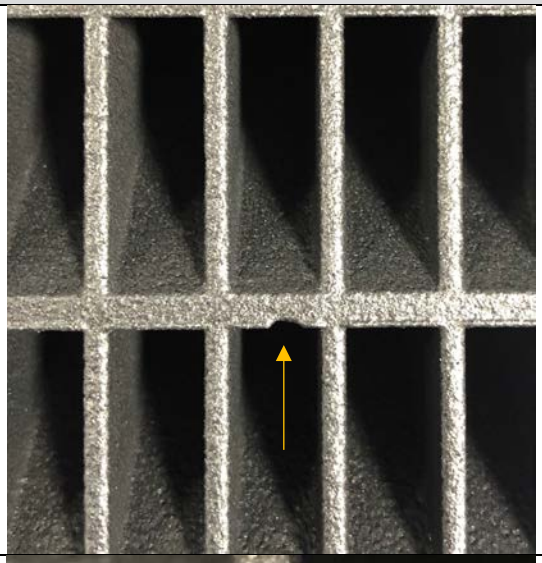
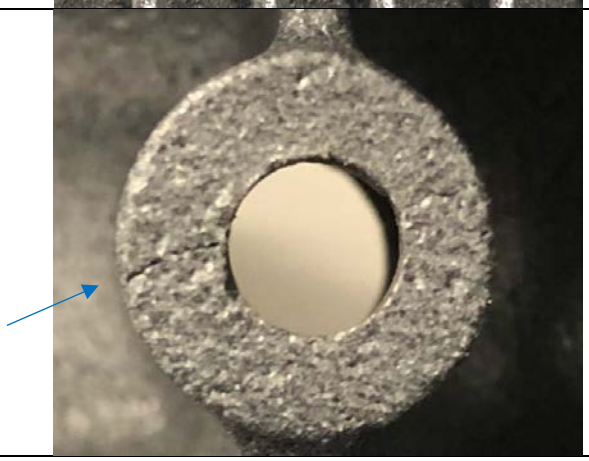
Anomalies	Picture / Figure
Raised Edge	
Knitline Seam	
Color Striation	

Anomalies	Picture / Figure
Surface Porosity	
Striping	
Banding	

8.3.2. Unacceptable Defects

Any parts with defects that fall outside of the requirements defined herein shall be rejected and dispositioned by user designated authority.

Table 6 Representative Illustrations of Unacceptable Anomalies

Anomalies	Picture / Figure
Chip [1]	
Crack	

[1] Depending on the feature, severity, and location of the chip, a rework may be possible. This should be discussed with affected parties and reviewed by the user designated authority.

9. Additional Dimensional Tolerance Guidelines

This is intended to provide additional information for dimensional tolerances. Dimensional requirements are specified on the engineering drawing or test specification. Parts produced by the LPBF process in the as built condition, would be limited to the accuracy defined below. Accuracy greater than those specified below may require additional post processing to achieve. To remove any thermal effects, dimensional inspections should occur at room temperature after the part has been removed:

Minimum Wall Thickness:	0.100 (reference only)
Global Profile Tolerance:	± 0.0075 inch * [Max Part Distance] + 0.04 inch (reference only)
Geometric Tolerance:	ASME Y14.5
Surface Roughness:	560 RMS (touch comparator)

NOTE: Measurements may be taken in the free or restrained state inspection. Maximum part distance should be rounded up to the nearest 0.01in.

10. Retention of Qualification

The Qualification of material was based on the system and processes outlined within this specification. Any changes to the material, machine, software including physical location is considered to be a change to the process. All changes to the system shall be submitted to the cognizant design authority for review and disposition via Advanced Change Notice (ACN).

It is up to the manufacturer to maintain the system to the requirements outlined in the Maintenance manual. Any deviation to the prescribed maintenance shall be considered as a non-conformance and shall be dispositioned by the cognizant design authority. Repair, as defined by any action not outlined in the maintenance manual for normal maintenance, shall be considered to be a change to the system and submitted to the cognizant design authority for review and disposition.

The software utilized in the manufacture of the material is specified in Section 5 of this document are the only approved versions for making the Material. Newer versions of the software will need to be submitted to cognizant design authority for review and disposition. Once a newer version of the software is approved, this specification will be updated to list all approved versions.

11. Shipping

For material qualification and equivalency purposes, it may be necessary to send the finished parts to a designated test lab as specified in the applicable test plan. The finished parts shipping instruction should also be included in the applicable test plan.

Accomplish packaging in such a manner that will prevent damage and distortion during normal handling, shipment and storage. Parts shall be protected from dust, and contamination by placing in sealed plastic bags or other suitable containers.

Appendix A: NCAMP SLI file Coupon Build information

The following information shall be utilized for any NCAMP mechanical testing. Any deviation to the build definitions provided will result in non-conforming coupons which may not be acceptable. For a more complete definition of the test requirements please refer to the NCAMP test plan. Derivatives of these .SLI files will be printed per the controlled dataset procedures within the PCD.

Table 7 .SLI Files for Coupon Fabrication

Test	Properties	Method	Type	ASTM 52921 Orientation	.SLI Name
Tensile	Modulus, UTS, EAB, Poisson, Yield	ASTM D638	DF2 T = 0.130”	XY, YX, XZ, ZX, ZX45	• ASTM-D638-DF2
Compression	Yield, Modulus	ASTM D695	1” Prism	XY, YX, ZX, ZX45	• ASTM-D695-COMPRESSION PRISM
Flex	Modulus, UFS	ASTM D790	Span = 16T	XY, YX, XZ, ZX, ZX45	• ASTM-D790-FLEX
Punch Shear	Modulus, UTS	ASTM D732	2 x 2 Plate	XY, YX, ZX, ZX45	• ASTM-D732-SHEAR
Open Hole Tension	Modulus, UTS	ASTM D5766	L = 8”	XY, YX, XZ, ZX, ZX45	• ASTM-D5766-OPEN-HOLE-TENSION
Filled Hole Tension	Modulus, UTS	ASTM D6742	L = 8”	XY, YX, XZ, ZX, ZX45	• ASTM-D6742-FILLED-HOLE-TENSION
Open Hole Compression	UCS, Yield	ASTM D6484	L = 12”	XY, YX, XZ, ZX, ZX45	• ASTM-D6484-OPEN-HOLE-COMPRESSION
Filled Hole Compression	Modulus, UTS	ASTM D6742	L = 12”	XY, YX, XZ, ZX, ZX45	• ASTM-D6742-FILLED-HOLE-COMPRESSION
Single Shear Bearing	UTS, Deformation	ASTM D5961	L = 5.5”	XY, YX, XZ, ZX, ZX45	• ASTM-D5961-BEARING

Appendix B: Coupon Locations for Qualification Build

Locations: Number 1-5 indicate the different zones in the print chamber. Letters “B” and “T” indicate if it’s the top or bottom half of the build chamber.

Build Layout ID	.SLIs Contained	Quantity	Locations	Orientations
1	ASTM-D638-DF2	20	1B,2B,3B,4B,5B,1T,2T,3T,4T,5T	XY, YX, ZX
	ASTM-D695-COMPRESSION PRISM	12	5B,1T,2T,3T	XY, ZX
	ASTM-D790-FLEX	20	1B,2B,3B,4B,5B,1T,2T,4T,5T	XY, YX, ZX
	ASTM-D732-SHEAR	12	1B,5B,2T,4T,5T	XY, ZX
	ASTM-D5766-OPEN-HOLE (TENSION)	20	1B,2B,3B,4B,1T,2T,3T,4T,5T, 5B	XY, ZX, Z45
	ASTM-D6742-FILLED-HOLE-TENSION	12	1B,2B,5B,1T,3T,4T, 5T	XY, ZX
	ASTM-D6484-OPEN-HOLE (COMPRESSION)	6	4B,5B,1T,2T,5T	XY, YX
	ASTM-D6742-FILLED-HOLE-COMPRESSION	6	1B,2B,3T,4T	XY, ZX
	ASTM-D5961-BEARING	18	1B,3B,4B,5B,1T,2T,5T	XY, ZX, Z45

Build Layout ID	.SLIs Contained	Quantity	Locations	Orientations
2	ASTM-D638-DF2	20	1B,2B,3B,4B,1T,2T,3T,4T,5T	XY, XZ, ZX
	ASTM-D695-COMPRESSION PRISM	12	2B,5B,1T,3T,4T, 5T	XY, ZX
	ASTM-D790-FLEX	20	1B,3B,4B,5B,1T,4T,5T	XY, XZ, ZX
	ASTM-D732-SHEAR	12	1B,2B,5B,3T,4T,5T	XY, ZX
	ASTM-D5766-OPEN-HOLE (TENSION)	12	1B,3B,1T,2T,4T	XY, ZX
	ASTM-D6742-FILLED-HOLE-TENSION	20	2B,3B,4B, 5B,1T,2T,4T,5T	XY, YX, ZX
	ASTM-D6484-OPEN-HOLE (COMPRESSION)	6	2B, 4B,5B,1T,3T	XY, YX
	ASTM-D6742-FILLED-HOLE-COMPRESSION	6	5B,1T,3T,4T	XY, YX
	ASTM-D5961-BEARING	12	1B,2B,3B,5B,1T,3T,4T,5T	XY, ZX

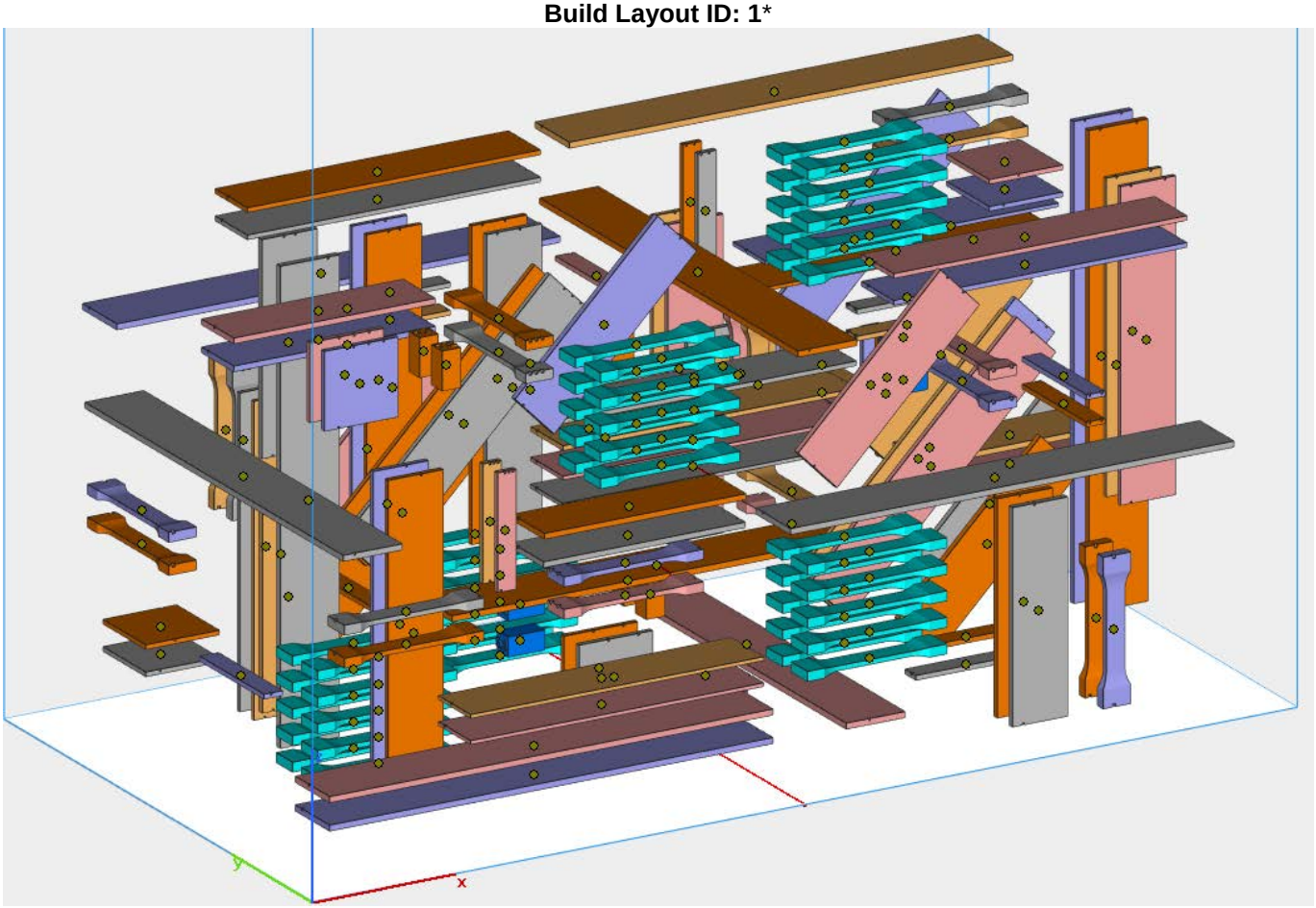
Build Layout ID	.SLIs Contained	Quantity	Locations	Orientations
3	ASTM-D638-DF2	20	1B,2B,3B,4B,5B,1T,2T,3T,5T	XY, ZX, Z45
	ASTM-D695-COMPRESSION PRISM	12	2B,4B,1T,3T	XY, ZX
	ASTM-D790-FLEX	20	1B,2B,3B,4B,4T,5T	XY, ZX, Z45
	ASTM-D732-SHEAR	12	1B,2B,3B,4T,5T	XY, ZX
	ASTM-D5766-OPEN-HOLE (TENSION)	12	3B,4B,5B,1T,2T	XY, ZX
	ASTM-D6742-FILLED-HOLE-TENSION	20	1B,2B,3B,5B,2T,3T,4T	XY, XZ, ZX
	ASTM-D6484-OPEN-HOLE (COMPRESSION)	6	1B,2B,3B,5B,4T,5T	XZ, ZX
	ASTM-D6742-FILLED-HOLE-COMPRESSION	6	3B,4B,1T,2T,4T	YX, XZ
	ASTM-D5961-BEARING	12	4B, 5B,1T,3T,4T,5T	XY, ZX

Build Layout ID	.SLIs Contained	Quantity	Locations	Orientations
4	ASTM-D638-DF2	12	3B,4B,5B,1T,2T,5T	XY, ZX
	ASTM-D695-COMPRESSION PRISM	20	2B,3B,4B,5B,1T,3T, 5T	XY, YX, ZX
	ASTM-D790-FLEX	12	1B,5B,2T,4T,5T	XY, ZX
	ASTM-D732-SHEAR	20	1B,2B,3B,5B,1T,2T,3T,4T	XY, ZX, Z45
	ASTM-D5766-OPEN-HOLE (TENSION)	12	1B,2B,3B,5B,3T,4T	XY, ZX
	ASTM-D6742-FILLED-HOLE-TENSION	20	2B,3B,4B,5B,1T,2T,3T	XY, ZX, Z45
	ASTM-D6484-OPEN-HOLE (COMPRESSION)	6	1B,3B,5B,2T,4T	XZ, ZX
	ASTM-D6742-FILLED-HOLE-COMPRESSION	6	1B,3B,4T,5T	XZ ZX
	ASTM-D5961-BEARING	12	3B,4B,5B,1T,4T,5T	XY, ZX

Build Layout ID	.SLIs Contained	Quantity	Locations	Orientations
5	ASTM-D638-DF2	12	1B,4B,5B,3T,4T,5T	XY, ZX
	ASTM-D695-COMPRESSION PRISM	12	3B,4B,5B,1T,2T,3T, 5T	XY, ZX
	ASTM-D790-FLEX	12	4B,5B,1T,2T,3T	XY, ZX
	ASTM-D732-SHEAR	12	1B,2B,3B,1T,2T,4T	XY, ZX
	ASTM-D5766-OPEN-HOLE (TENSION)	20	1B,2B,4B,5B,1T,2T,3T,4T	XY, YX, ZX
	ASTM-D6742-FILLED-HOLE-TENSION	12	3B,4B,5B,1T,2T	XY, ZX
	ASTM-D6484-OPEN-HOLE (COMPRESSION)	3	1B,3B,2T	Z45
	ASTM-D6742-FILLED-HOLE-COMPRESSION	3	4B,1T	Z45
	ASTM-D5961-BEARING	18	1B,2B,3B,5B,2T,3T,4T,5T	XY, YX, ZX

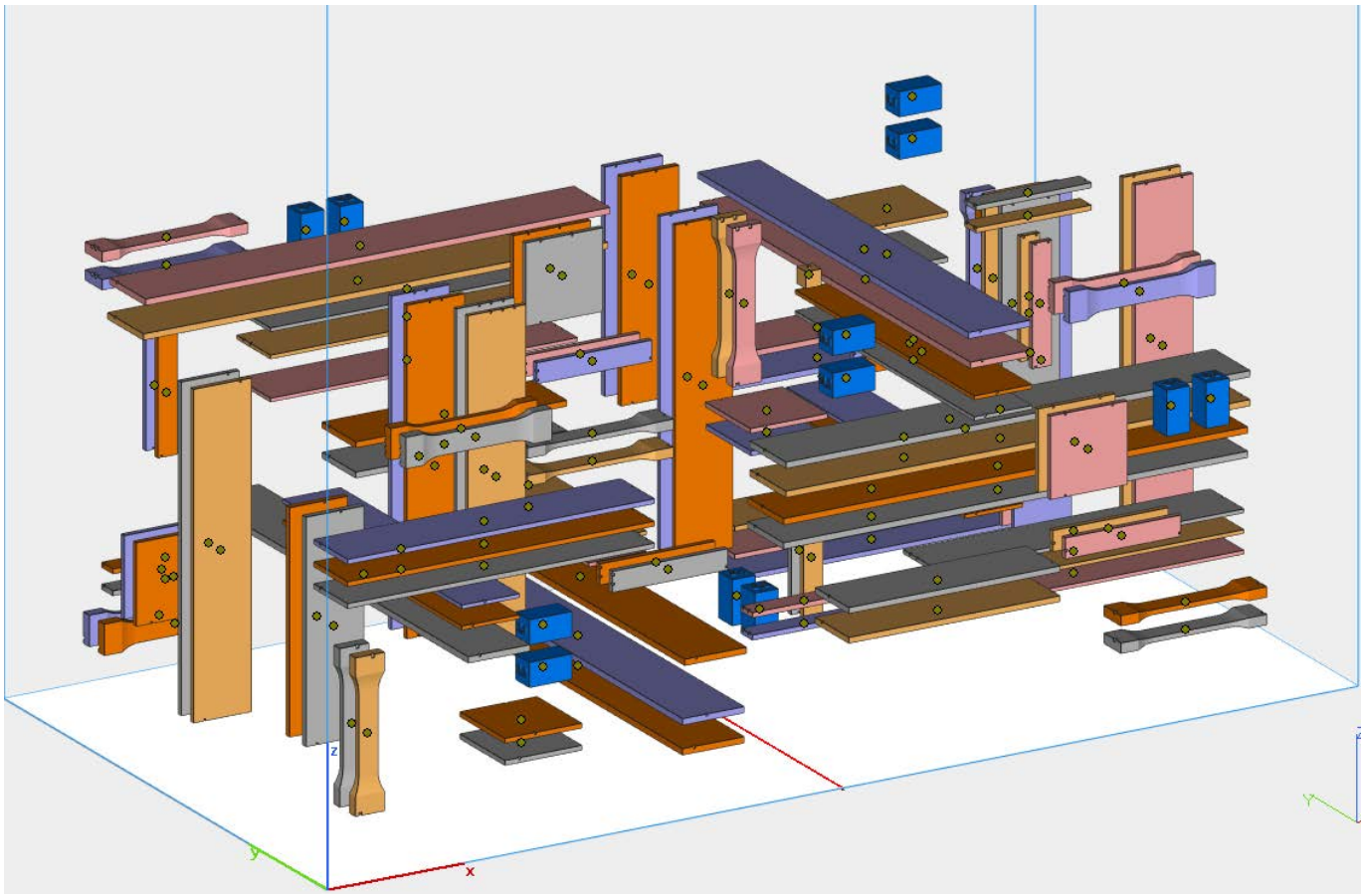
Build Layout ID	.SLIs Contained	Quantity	Locations	Orientations
6	ASTM-D638-DF2	12	1B,3B,5B,2T,4T,	XY, ZX
	ASTM-D695-COMPRESSION PRISM	20	1B,3B, 5B,2T, 4T, 5T	XY, ZX, Z45
	ASTM-D790-FLEX	12	1B,3B,4B,5B,1T,2T	XY, ZX
	ASTM-D732-SHEAR	12	2B,3B,1T,2T,4T,5T	XY, ZX
	ASTM-D5766-OPEN-HOLE (TENSION)	18	2B,4B,5B,1T,3T,5T	XY, XZ, ZX
	ASTM-D6742-FILLED-HOLE-TENSION	12	1B,2B,5B,3T,5T	XY, ZX
	ASTM-D6484-OPEN-HOLE (COMPRESSION)	3	3B,1T,2T	Z45
	ASTM-D6742-FILLED-HOLE-COMPRESSION	3	3B,2T	Z45
	ASTM-D5961-BEARING	18	1B,2B,3B,1T,3T,4T,5T	XY, XZ, ZX

Build Layout ID: 1*

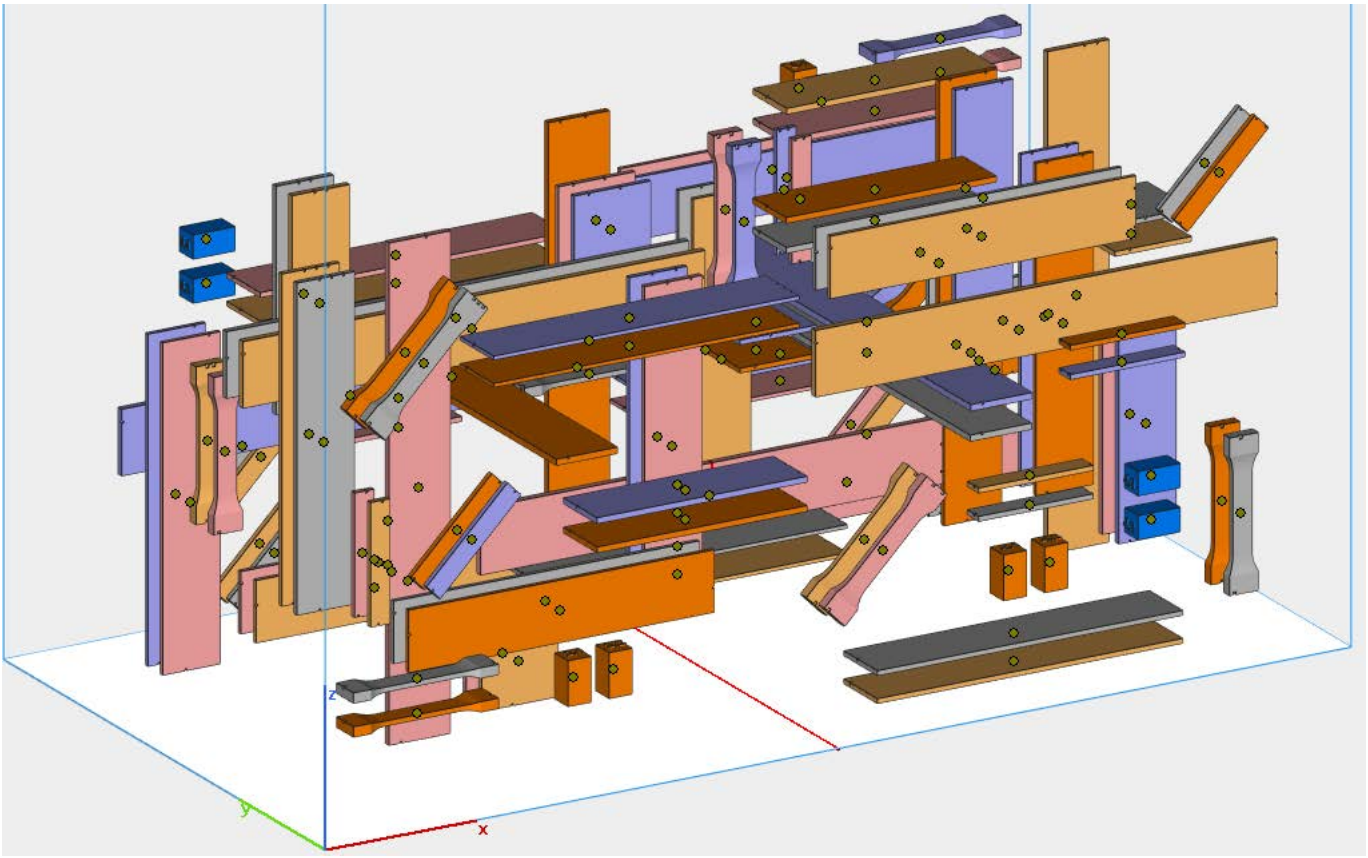


*In Build Layout ID: 1, the grouped specimens in teal color are sampled for fluid screening. The randomized distribution of these samples within the build chamber is less critical and have been printed in a manner to optimize distribution of other mechanical test coupons.

Build Layout ID: 2



Build Layout ID: 3



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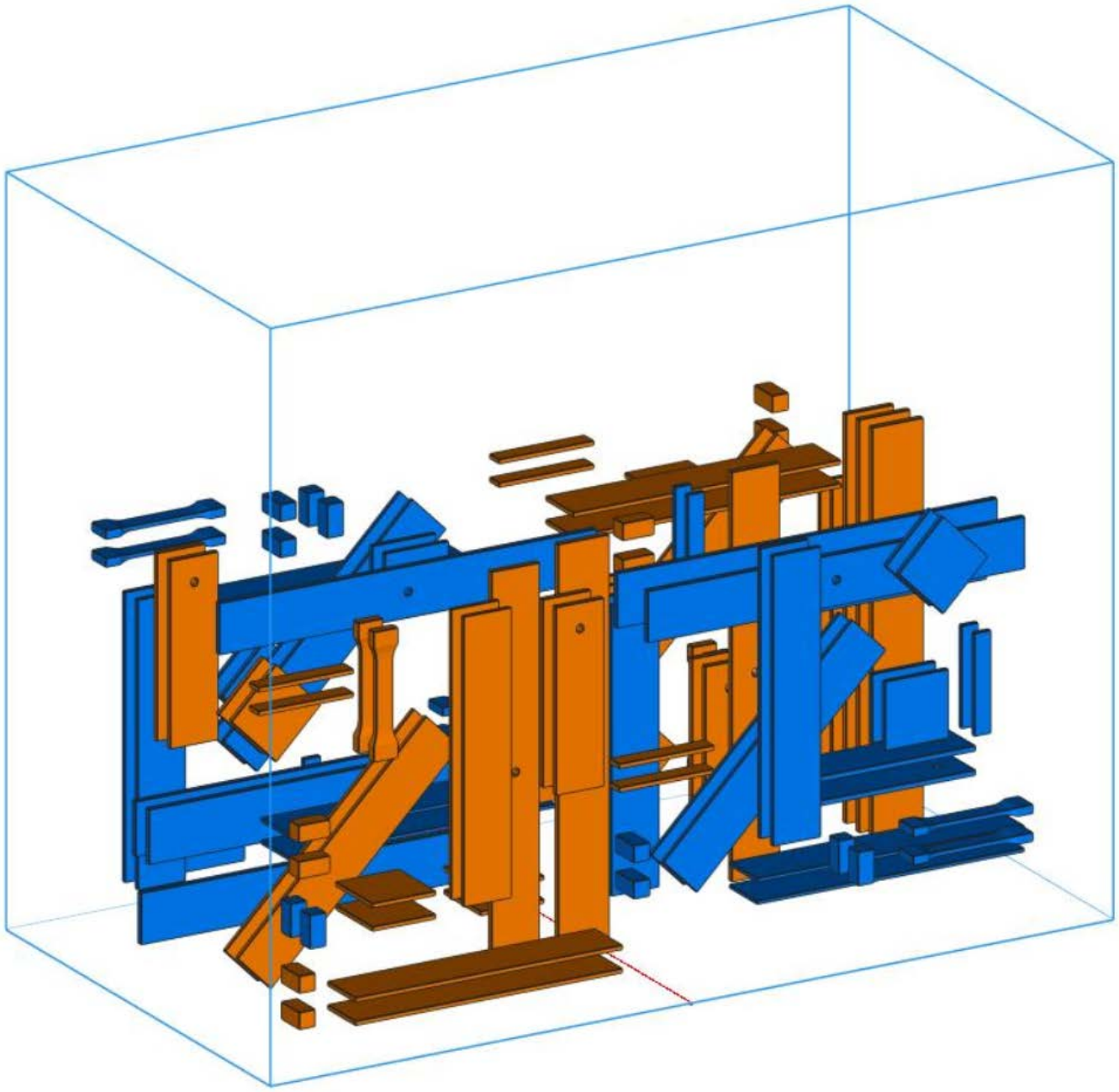

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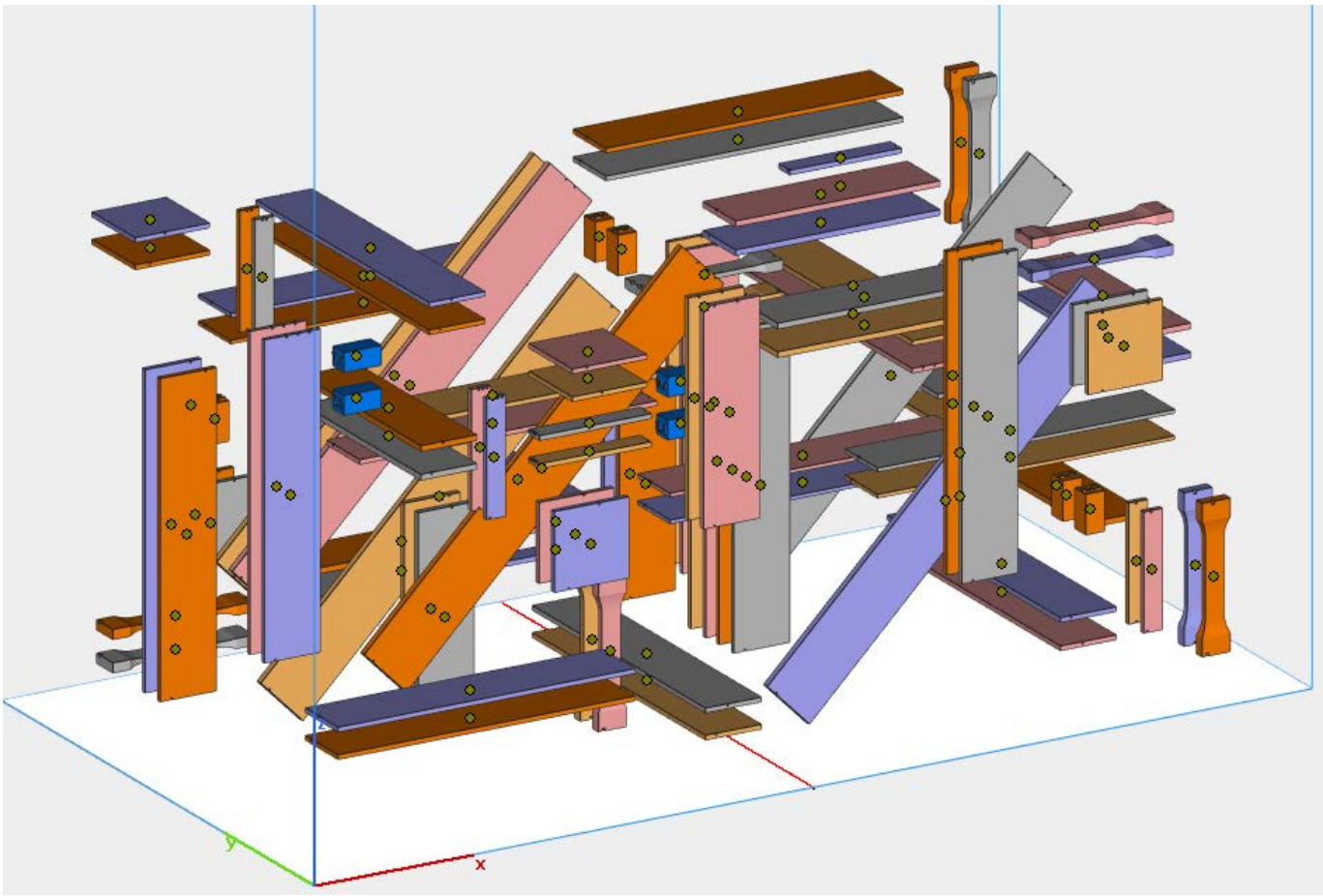
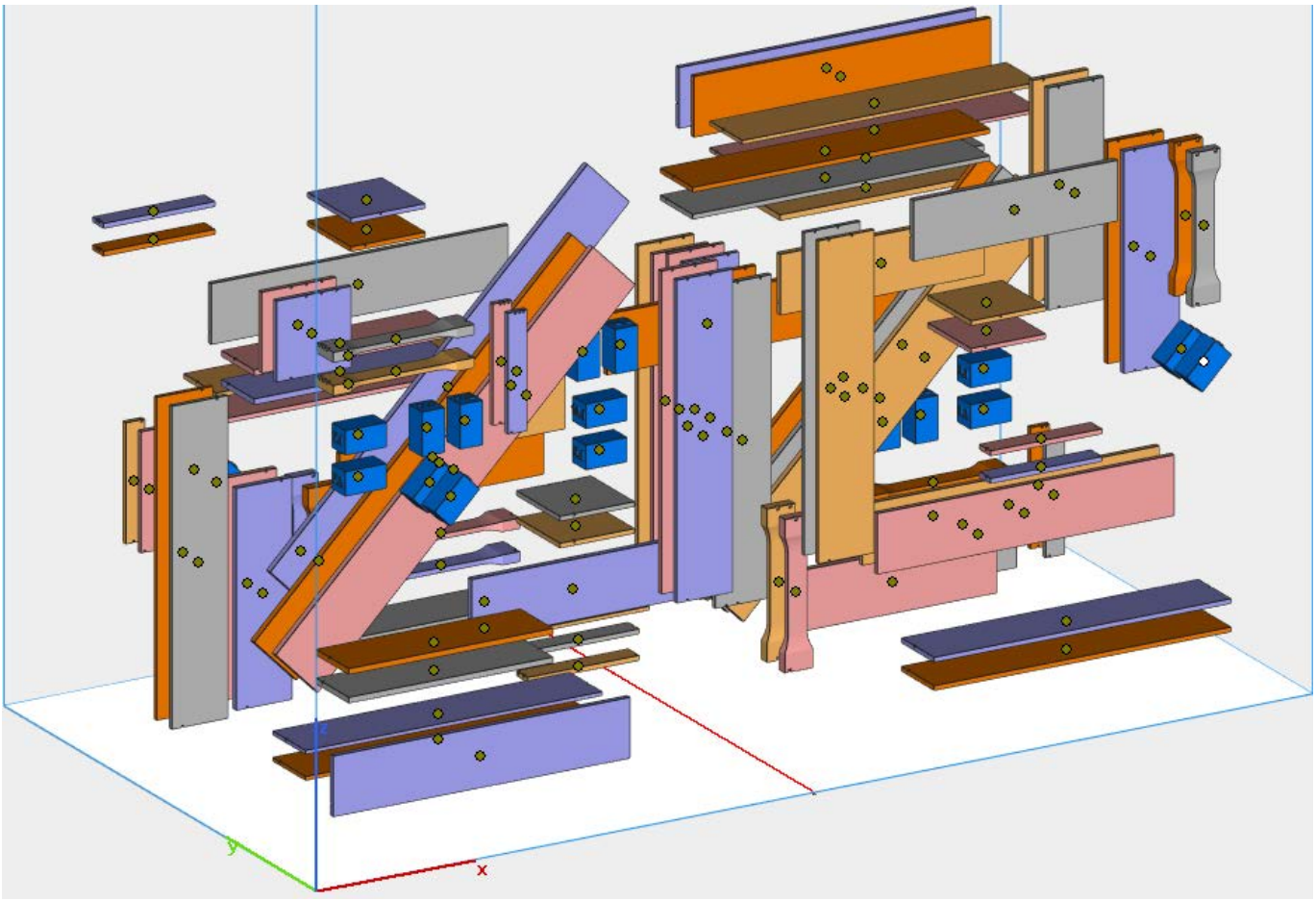


Build Layout ID: 6



Appendix C: Coupon Geometry

Note: All dimensions are reference only. Width, length, and radius to read and record only.