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NCAMP Process Specification

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Polymer Additive Manufacturing Materials, Machine, Processing and Quality Requirements Specification for Onyx FR-A w/ Carbon Fiber FR-A and Markforged X7 System

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TABLE OF CONTENTS

1. SCOPE 4
1.1. Purpose 4
1.2. Health and Safety 4
2. APPLICABLE DOCUMENTS 4
2.1. Markforged Documents 4
2.2. NCAMP Documents 5
2.3. Industry Standards 5
2.4. US Government Publication 6
2.5. Abbreviations and Acronyms 6
2.6. Terms and Definitions 6
3. ENVIRONMENTAL CONTROL 8
4. EQUIPMENT CONTROL 8
4.1. Continuous Fiber Reinforcement (CFR) Equipment 9
4.2. Machine Maintenance and Control 9
4.2.1. Preventative Maintenance 9
4.2.2. Maintenance Record 10
5. SOFTWARE CONTROL 10
5.1. 3D Geometry Preparation 11
5.2. Pre-Processing 11
5.3. Device Application Parameters 11
5.4. CFR Preprocessing Methodology 11
5.4.1. Type I Material Properties 12
5.4.1.1. Fiber Placement 12
5.4.1.2. Resin Base Material Placement 13
6. MATERIALS CONTROL 15
6.1. Consumable and Expendable Materials 15
6.2. Adhesive Build Layer 15
6.3. Receiving Material Lot Release 15
6.3.1. As-Printed Specimen Mechanical Testing 15
6.4. Material Storage Control 16
6.4.1. Onyx FR-A (Un-verified) 16
6.4.2. Carbon Fiber FR-A (Un-verified) 16

7. BUILD PROCESS 16
7.1. Start-up 16
7.2. Fabrication 17
7.3. Part Removal 17
7.4. Support Removal 17
7.5. Fabricated Parts Identification & Storage 17
8. QUALITY ASSURANCE & INSPECTION CONTROL 17
8.1. General 17
8.2. Quality Testing & Control 18
8.3. Dimensional Inspection 18
8.4. Visual Inspection 18
8.4.1. Acceptable Part Quality Anomalies 18
8.4.2. Unacceptable Part Quality Defects 27
9. RETENTION OF QUALIFICATION 30
10. USER QUALITY ASSURANCE 30
10.1. Process Control 30
10.2. X-Ray Computed Tomography & Non-Destructive Inspection 30
10.3. Visual Inspection 30
APPENDIX A: NCAMP COUPON BUILD INFORMATION 31
APPENDIX B: NCAMP COUPON-SPECIFIC REINFORCEMENT SETTINGS 34
REVISION HISTORY 42

1. SCOPE

This process specification describes the methods of fabricating parts using Continuous Fiber Reinforcement (CFR), Markforged's patented process consisting of traditional FFF printing combined with continuous fiber reinforcement. Coupons will be made using Markforged Onyx FR-A and Carbon Fiber FR-A (T300 1K tow) on a Markforged X7 (Gen 2 - No WiFi) printer. Specifically, this specification covers the constituent material, the configuration of the machine, operating software, machine calibration, build parameters, and acceptance criteria. This specification does not contain all the necessary information typically required for the fabrication of CFR parts, such as personnel qualification, facility requirements or any part acceptance criteria. Users should refer to their existing company process specification for such information.

1.1. Purpose

This specification establishes the requirements for the CFR process using Markforged Onyx FR-A thermoplastic with Carbon Fiber FR-A on a Markforged X7 printer, herein referred to as the “CFR capable platform”. This specification requires qualified operators.

1.2. 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 form a part of this document to the extent specified herein.

2.1. Markforged Documents

Table 1. Markforged Document List

Document Title	Full Link	Version(s)
Markforged Composite Design Guide	https://s3.amazonaws.com/mf.product.doc.images/NCAMP/Composites_Design_Guide_v1.2.pdf	1.2
Markforged Composites Facilities Guide	https://s3.amazonaws.com/mf.product.doc.images/NCAMP/Composites_Facilities_Guide_v1.0.2.pdf	1.0.2
Markforged Industrial Printer Service Manual	https://s3.amazonaws.com/mf.product.doc.images/NCAMP/Industrial_Printer_Service_Manual_v1.2.pdf	1.2
Markforged Industrial Printer User Guide	https://s3.amazonaws.com/mf.product.doc.images/NCAMP/Industrial_Printer_UserGuide_v1.4.1.pdf	1.4.1

2.2. NCAMP Documents

Table 2. NCAMP Document List

Document No.	Document Title	Version(s)
NMS 754	Filament Specification (Onyx FR)	Rev B
NMS 755	Filament Specification (Carbon Fiber FR-A)	Rev B
NMS 754/1	NCAMP Material Specification Slash Sheet (OFRA with CFRA)	Rev B

2.3. Industry Standards

Table 3. Relevant Standards

Document No.	Document Title
ASTM D256-10	Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics
ASTM D638-14	Standard Test Method for Tensile Properties of Plastics
ASTM D790-17	Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
ASTM D792-13	Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
ASTM D1238	Standard Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer
ASTM D2344/D2344M-16	Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates
ASTM D3039/D3039M-17	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials
ASTM D3418-15	Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry (DSC)
ASTM D3518/D3518M-18	Standard Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a ±45° Laminate
ASTM D5766/D5766M-11	Standard Test Method for Open-Hole Tensile Strength of Polymer Matrix Composite Laminates
ASTM D5961/D5961M-17	Standard Test Method for Bearing Response of Polymer Matrix Composite Laminates
ASTM D6484/D6484M-14	Standard Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates
ASTM D6641/D6641M-16e1	Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture

ASTM D6742/D6742M-12	Standard Practice for Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates
ASTM D7028-07(2015)	Standard Test Method for Glass Transition Temperature (DMA Tg) of Polymer Matrix Composites by Dynamic Mechanical Analysis (DMA)
ASTM E228-17	Standard Test Method for Linear Thermal Expansion of Solid Materials With a Push-Rod Dilatometer
IEC 60947-1	Low-voltage switchgear and controlgear - Part 1: General rules
IEC 60664-1	Insulation coordination for equipment within low-voltage supply systems - Part 1: Principles, requirements and tests

2.4. US Government Publication

Table 4. Relevant Government Publications

Document No.	Document Title
14 CFR 25.853	Vertical Flammability Test - Fire Test to Aircraft Material

2.5. Abbreviations and Acronyms

BOM	Bill of Material
CEO	Cognizant Engineering Organization
CFR	Continuous Fiber Reinforcement
FFF	Fused Filament Fabrication
FR	Flame Retardant
LTS	Long Term Support
OEM	Original Equipment Manufacturer
PPE	Personal Protective Equipment
QA	Quality Assurance (Department)

2.6. Terms and Definitions

- **Bead** - A single line of extrudate material from an FFF nozzle.
- **Build** - The physical activities the machine takes in producing a single or set of parts within a unique start and stop of the machine.
- **Build Envelope** - The three-dimensional space within the CFR capable platform that can be utilized to produce a part or sets of parts.
- **Carbon Fiber FR-A** - When the Fiber Spool is processed and procured to NMS 755, “Filament Specification (Carbon Fiber FR-A)”.
- **Cognizant Engineering Organization (CEO)** - The person(s) with the authority and

technical knowledge to approve any deviation from this Process Specification.

- **Continuous Fiber Reinforcement (CFR)** - An augmented FFF process that works in addition to an FFF printer to lay continuous fiber in a part. In this process, a printer utilizes a second nozzle to lay continuous strands of composite fibers inside a conventional FFF thermoplastic part.
- **Coupon** – A set of basic geometries used to generate physical or mechanical data.
- **CFR capable platform** – Refers to the combination of equipment and software used to process Type I or Type II Material, configured, calibrated, and maintained outlined per this Process Specification**.**
- **Device ID** - A series of characters uniquely identifying the Markforged X7 printer.
- **Eiger** - The Markforged proprietary, version-controlled software that manages, configures, stores, and distributes printer and build data.
- **Fill Pattern** - Preset methods of different ways or lattice structures used to complete the interior of a part. The fill pattern is made up of infill.
- **Filament Spool** - A single unit of FFF feedstock wound around a plastic core.
- **Fiber Spool** - A single unit of continuous fiber feedstock wound around a plastic core.
- **Fused Filament Fabrication (FFF)** - A type of extrusion based additive manufacturing technology that enables the construction of three-dimensional objects, prototypes, and products through a computer-aided process.
- **Infill** - The beads that make up the internal lattice structure of the part (defined here as fill pattern), bounded by the shell(s).
- **Onyx FR-A** – When the Filament Spool is processed and procured to NMS 754, “Filament Specification (Onyx FR-A)”.
- **Lattice** - Recurring pattern of geometries.
- **Markforged X7 Printer** - A machine supplied by Markforged, identified by device ID, at a specific location where Type I and Type II Material are manufactured to this Process Specification.
- **Must** - Expresses a binding requirement.
- **Operator** - The person(s) trained to set up, run, and maintain Markforged X7 printer(s).
- **Part** - Physical object produced by the CFR capable platform.
- **Print bed** - The platform of the CFR capable platform on which the parts are built.
- **Raw Feedstock** – Raw material usually in pellet form.
- **Raw Feedstock Lot or Batch** - Total quantity of a unique lot or batch identifier as defined by original feedstock manufacturer.
- **Roof** - The final, top layer of a part.
- **Seam** - The start and stop location of a contour for each perimeter for every part layers.
- **Shell** - The exterior beads, setting the perimeter of a given layer.
- **Should/May** - Expresses a recommended or allowed action.
- **Slicer** - The version-controlled software that converts three-dimensional part geometry into layers, predetermined XYZ coordinates, and other information required to print a part.
- **Type I Material** - The combination of Onyx FR-A and CF FR-A (CF30) processed to the requirements in this Process Specification.

- **Type II Material** - Onyx FR-A processed to the requirements in this Process Specification.
- **Verification** - Identifies that the implementation has been evaluated to determine that all design requirements have been met.
- **Wall** - See definition for shell. Used interchangeably in user-facing documentation.
- **Will** - Expresses a declaration of intent.

3. ENVIRONMENTAL CONTROL

Refer to Markforged Composites Facilities Guide for full requirements. The summary is shown in Table 5.

Table 5: Environmental Requirements

Condition	Description	Limits
Room Temperature (Operation)	Temperature of the environment in which the printer is operated, measured by local thermometer	66°F – 95°F (18.8°C – 35°C)
Relative Humidity Requirement (Operation)	Humidity of the environment in which the printer is located and operated	0% - 90%, non-condensing
Room Temperature (Idle)	Temperature of the environment in which the printer must be stored when not processing	66°F – 95°F (18.8°C – 35°C)
Relative Humidity Requirement (Idle)	Humidity of the environment in which the printer must be stored when not processing	0% - 90%, non-condensing
Altitude	Altitude of the environment in which the printer is located and operated	< 9842ft (3000m)
Pollution Degree	Pollution degree of environment conditions as per IEC 60947-1 and IEC 60664-1	2

4. EQUIPMENT CONTROL

a) Once approved, unless otherwise specified, this document is the primary reference source for the operating and performance standards for all Type I Material and Type II Material parts fabricated with the CFR capable platform (manufactured by Markforged, Inc.).
b) This document is to cover all Markforged X7 Printers identified by SKU number 21451 on the machine label located on the rear of the device.
c) The Markforged X7 Printer must be installed in accordance with all Markforged installation manuals and guidance.

4.1. Continuous Fiber Reinforcement (CFR) Equipment

a) CFR capable platforms must be identified by names or numbers for setup and traceability.
b) All CFR capable platforms must be calibrated in accordance with the procedures outlined in the Markforged Industrial Printer User Guide.
c) All CFR machines must have a maintenance plan based on the manufacturer's recommended procedures.
d) 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 subsystem equipment may demonstrate significant changes in build quality and are noted in Table 6. Any changes made and communicated by the Printer OEM or replacement of these components must be reviewed and dispositioned by the CEO and approved by NCAMP that may require requalification per Section 9, repeated Equivalency, or even full certification based on the change classification. The proprietary revision controlled Markforged Process Control Document PCD-003 contains calibration steps and tests to be performed after routine and non-routine maintenance procedures to these subsystems.

Table 6: Critical Subsystems

Subsystem	Description
Continuous Fiber System	The components responsible for moving fiber from the Fiber Spool to the print head.
Print Bed and Z Stage	The platform of the Markforged X7 Printer on which the parts are built.
Print Head	The print head heats and deposits Type I or Type II Material to produce a CFR or FFF part.
Composite Base System	The components responsible for moving filament from the Filament Spool to the print head.
Gantry	The subsystem responsible for positioning the print head in the machine.

4.2.1. Preventative Maintenance

Preventive maintenance will be performed on each Markforged X7 Printer used to fabricate production parts. This maintenance will verify proper operation of the CFR Capable Platform.

Preventive maintenance procedures will be performed as prompted by the Markforged X7 Printer’s preventative maintenance utility and as recommended in the Preventive Maintenance Schedule outlined in the Markforged Industrial Printer User Guide, except where explicitly overridden in Table 7.

All maintenance activities will be performed in accordance with the Markforged standard procedures found in documents outlined in Section 2.1 using Markforged X7 Printer replacement

parts as needed. Replacement parts must be approved identical parts and not upgrades or obsolescent components that have not been approved through an Advanced Change Notice (ACN).

Table 7: Preventative Maintenance Intervals

Procedure	Frequency
Replace Fiber Nozzle	Every 150cc of Carbon Fiber FR-A printed.
Replace Fiber Bowden Tube	Every 450cc of Carbon Fiber FR-A printed.
Replace Fiber Feed Tube	Every 450cc of Carbon Fiber FR-A printed.
Replace Plastic Nozzle	Every 1600cc of Onyx FR-A printed.
Replace Plastic Bowden Tube	Every 1600cc of Onyx FR-A printed.
Replace Plastic Feed Tube	Every 1600cc of Onyx FR-A printed.

4.2.2. Maintenance Record

A record of all machine maintenance activities, calibrations, and repairs will be maintained for each Markforged X7 Printer 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 will be controlled for that material. Any changes to software critical to this process must be approved via ACN through NCAMP.

Type I Material must be built in accordance with the approved software version in Table 8.

Table 8: Software Revisions

Component	Number
Offline Eiger	1.0.7
LAN Connector	1.0.2
Slicer	3.27.3
Device Application	61defc3 LTS
Motherboard Firmware	3edb53dc39ca81dc36c97899eb9245bb7309e6ca
Printhead Firmware	d8a5c97de913ec01517d746becdf2dfe454c2be3

5.1. 3D Geometry Preparation

3D geometry preparation is performed using industry standard CAD software. The required output of this process is a .STL file that can be imported into Markforged's Eiger pre-processing software (see Table 8 for approved version). The control and verification of the model preparation and CAD packages is at the discretion of the user.

5.2. Pre-Processing

The Slicer software (see Table 8 for approved version), provided by Markforged and managed through Eiger, has a release version designation that must be recorded and maintained for any certified production.

5.3. Device Application Parameters

The X7 printer exposes a number of parameters to the user that will impact the results of the build through the touchscreen under the Preferences menu. The settings for these parameters used for Type I Material are listed in Table 9.

Table 9: Device Application Parameter Settings

Parameter	Type I	Notes
Plastic Issue Detection	Enabled	
Fiber Jam Detection	Enabled	
Wet Plastic Purge	Enabled	
Scan Bed Before Prints	Enabled	

5.4. CFR Preprocessing Methodology

In preprocessing parts using CFR technology, including the coupons discussed in Appendices A and B, the proper approach must be taken to ensure expected part performance. The mechanical performance of a CFR part comes primarily from fiber, and as such fiber placement must be considered based on orientation and load conditions to meet part functionality or requirements (this includes coupons). A general overview of design considerations can be found in the Markforged Design Guide.

Appendices A and B cover the complete set of parameters used in the printing of coupons used in this qualification. The coupons were designed to characterize the anisotropic properties of Type I and Type II Material as completely as possible, and not necessarily to maximize their performance in testing.

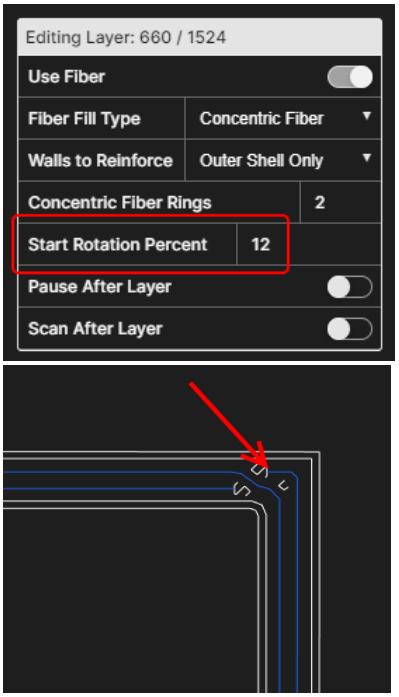
5.4.1. Type I Material Properties

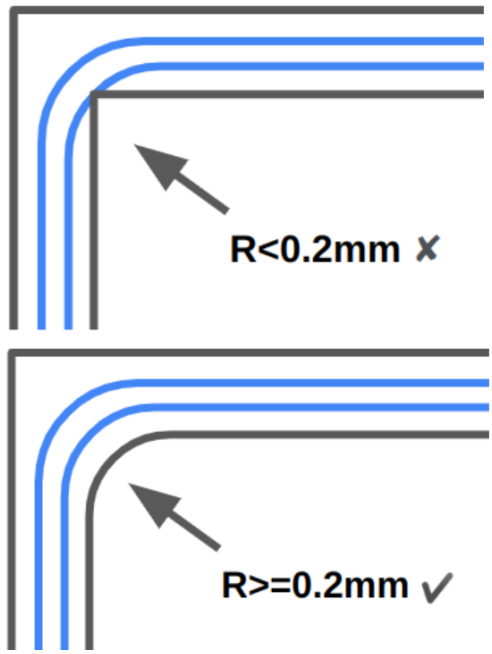
Type I parts are inherently anisotropic which is why multiple orientations are needed to characterize the material system. Parts must be preprocessed with load condition(s) in mind such that fiber is deliberately oriented under these load(s).

5.4.1.1. Fiber Placement

Proper placement of fiber directly correlates to the performance of a coupon or part. Fiber must be placed where the maximum stresses in the part will occur under expected load conditions, as fiber is much stronger than the resin base material. Furthermore, it is recommended to be aligned such that it is placed in tension under said load conditions as discussed in section 5.4.1. Guidance for fiber placement is described in Table 10 below.

Table 10: Fiber Placement Recommendation

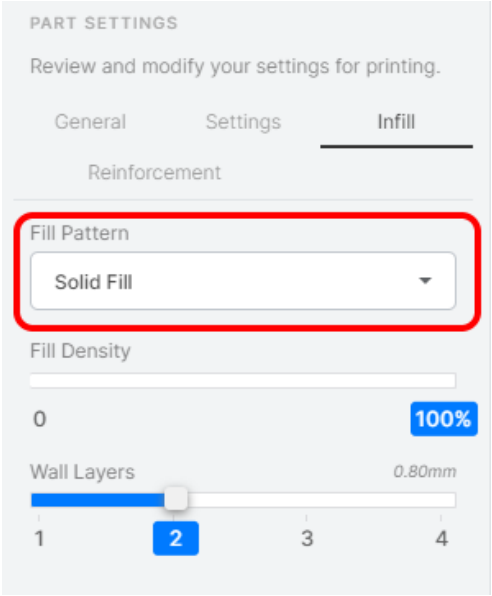
Recommended Settings	Image
Use at least 2 rings of fiber. This means a minimum wall thickness of 3.57mm where fiber placement is required.	
Fiber start location can be controlled through the Start Rotation Percent parameter available within Eiger's Internal View. Start location must not be placed in critical load locations. *Note that the photo to the lower right displays an area containing a fiber start/stop location. Assume that corner is not an area bearing a critical load.*	

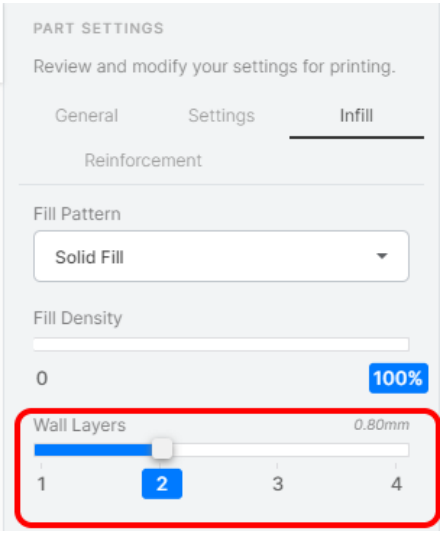
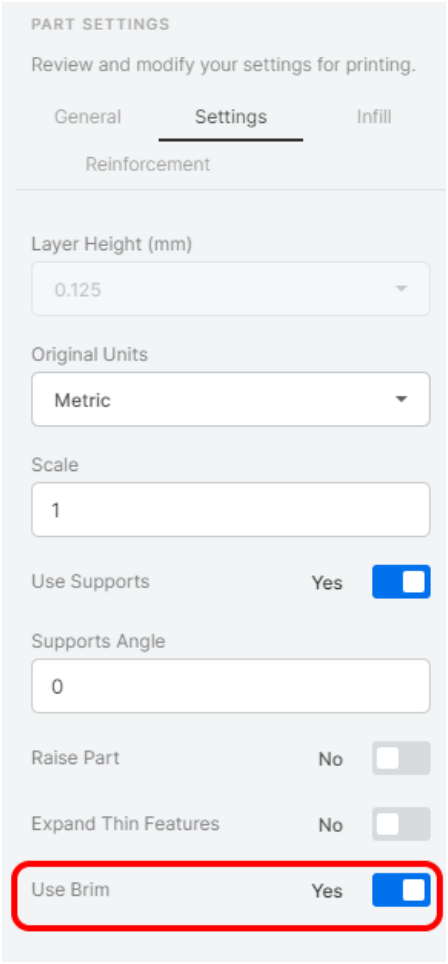
Recommended Settings	Image
Fiber has a minimum bend radius. Internal corners must have a radius of 0.2mm or greater to allow the maximum fiber density in the part.	

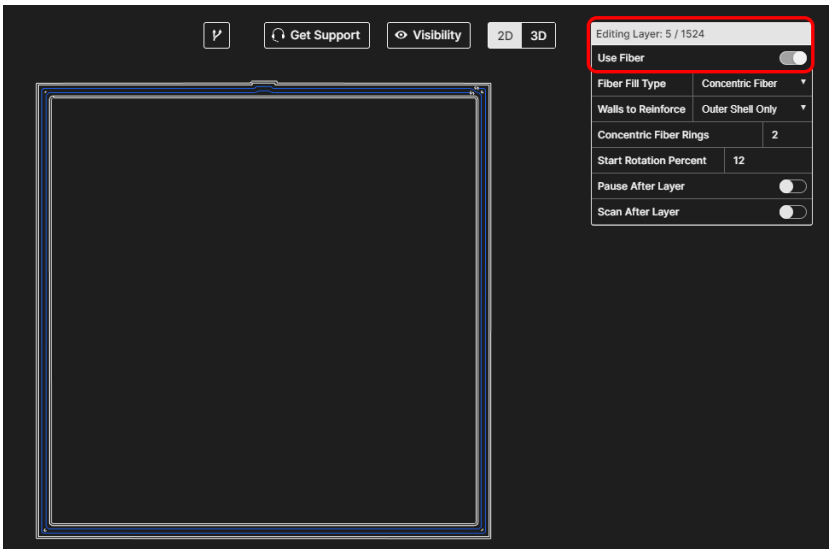
5.4.1.2. Resin Base Material Placement

Settings for resin base material placement can be found in Table 11 below and should be considered to achieve expected performance results.

Table 11. Resin Base Placement Settings

Recommended Settings	Image
Solid fill must be used under Infill settings.	

Recommended Settings	Image
Wall layers must be set to 2 under Infill settings.	
Brim must be enabled to minimize the likelihood of warp.	

Recommended Settings	Image
Fiber may be used in the bottom layers of the part to minimize the likelihood of warp.	

6. MATERIALS CONTROL

6.1. Consumable and Expendable Materials

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

6.2. Adhesive Build Layer

A layer of adhesive material in the form of a glue stick is applied to the print bed to assist the model material's adherence to the bed. The print bed adhesion glue stick provided by Markforged should be used to create a thin layer over the complete area of the print bed where the parts will be built as detailed in Preparing the Print Bed in the Markforged Industrial Printer User Guide.

6.3. Receiving Material Lot Release

a) Markforged must provide a Certificate of Analysis for each Markforged Filament Lot and/or Markforged Fiber Lot.
b) Markforged must provide a Certificate of Conformance for each Markforged Filament Lot and/or Markforged Fiber Lot.
c) Markforged must provide a Certificate of Analysis for each Raw Feedstock Lot or Batch.

6.3.1. As-Printed Specimen Mechanical Testing

a) User must document Markforged Filament Lot, Fiber Lot, and Raw Feedstock Lot or Batch per user's designated Job Tracking system.
b) The NMS 754/1 outlines the as-printed specimen testing and properties for Markforged Onyx FR-A and Markforged Carbon Fiber FR-A. Both materials are tested as a

combination.

6.4. Material Storage Control

6.4.1. Onyx FR-A

Sealed and unopened Filament Spools must have a minimum shelf life of 2 years from date of manufacture when stored in their original sealed packaging at temperatures between 55°F – 90°F (13°C – 33°C) and 0-90 %RH.

Once unsealed, Filament Spools must be stored in a Markforged Dry Box or another similarly sized air-tight container at temperatures between 55°F – 90°F (13°C – 33°C) and 0-90 %RH. Filament Spools must be stored in this manner for up to 1 year, but no more than 2 years total from manufacture date.

Filament Spools must spend no more than 15 minutes outside of either the original sealed packaging, a Markforged Dry Box, or a similarly sized air-tight container.

Filament Spools must be stored with the desiccant pack(s) they shipped with at all times.

6.4.2. Carbon Fiber FR-A

Sealed and unopened Fiber Spools must have a minimum shelf life of 2 years from date of manufacture when stored in their original sealed packaging at temperatures between 55°F – 90°F (13°C – 33°C) and 0-90 %RH.

Once unsealed, Fiber Spools can be stored at these temperatures and humidity for up to 1 year, but no more than 2 years total from manufacture date.

7. BUILD PROCESS

7.1. Start-up

a) The Markforged X7 Printer must be properly calibrated and maintained as covered in Section 4.2 of this Process Specification.
b) Eiger: Parts must stay in the same location as set by the software; no part relocation is acceptable. If a part is moved by the operator, the job must be restarted so that the part is re-centered to the original location.
c) Both nozzles must be checked for built up material prior to the start of any builds. If there is any built up material, it must be removed by the use of filament snips and/or brass brush. To aid in the material removal, the nozzles may be heated.
d) Prior to starting a build, the bed must be prepared as detailed in Preparing the Print Bed in the Markforged Industrial Printer User Guide. This involves cleaning the bed of previous glue and applying additional glue over the complete area of the print bed where the parts will be built.
e) Material volume must be sufficient to complete the entire build without depleting the material on a single spool. If material quantity is insufficient, the spool must be replaced with a spool that can meet this criterion. The system may alert the user if there is insufficient material available on the spool.
f) The material must be loaded as detailed in sections Loading Plastic and Loading Fiber in the Markforged Industrial Printer User Guide. Filament Lot and Raw Feedstock Lot or

Batch of loaded material should be recorded per user's designated Job Tracking system.

g) Once the build has been submitted to the X7, the machine will run through an auto-startup process. This process will include a purge routine, bed scan, and nozzle offset routine.

7.2. Fabrication

a) Prior to build removal confirm the build is finished via machine display screen. Builds removed prior to finishing will be invalidated.
b) Builds will not contain any Unacceptable Part Quality Defects as defined in Section 8.4.2. Builds with any of these conditions must result in disposition by the CEO.
c) Builds will not encounter a resume status at any point throughout the build. Builds with this condition must be documented and dispositioned by the CEO.
d) Builds will not encounter any errors at any point throughout the build. Builds with this condition must be documented and dispositioned by the CEO.

7.3. Part Removal

Parts or coupons must be removed using the Markforged scraper, making sure to always pry with the scraper in a direction away from your body. Glue must be removed from the bottom of the part with warm water.

For a fully detailed explanation of this process see section Safely Removing Printed Parts in the Markforged Industrial Printer User Guide.

7.4. Support Removal

See section Removing Support Material in the Markforged Industrial Printer User Guide.

7.5. Fabricated Parts Identification & Storage

a) Completed Type I and Type II Material parts exhibit a chemical compatibility typical of polyamide (nylon) materials. Although resistant to most solvents, use with halogens and peroxides is not recommended for extended periods. As such, parts are compatible with most major inks and markers and can be directly labeled.
b) Coupons should be stored in a sealed bag, at temperatures between 66°F – 95°F (18.8°C – 35°C) and relative humidity between 0% - 90%, non-condensing.
c) Sealed bags should be properly labeled according to the user's preferred part identification methods. Parts in bags with no label must be dispositioned by the CEO.

8. QUALITY ASSURANCE & INSPECTION CONTROL

8.1. General

Quality Assurance must ensure that the Markforged X7 Printer is adequately controlled per this Process Specification and the user's internal quality control procedures.

8.2. Quality Testing & Control

Type I Material must be inspected in accordance with this specification.

- All requirements of the applicable Engineering Drawing must be met.
- All non-conforming conditions must be submitted on the appropriate rejection documentation.
- All parts must be individually weighed and part weight should be recorded per user's designated Job Tracking system.

8.3. Dimensional Inspection

Dimensional requirements should be specified on the engineering drawing. Parts produced by the Markforged X7 Printer in the as-built condition are 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 and any support material removed.

Highest Accuracy (XY plane):	+/- 150µm or 0.15% of the measured length (Whichever is greater)
Highest Accuracy (Z):	+/- the layer height of the build
Minimum Wall Thickness:	1.6mm

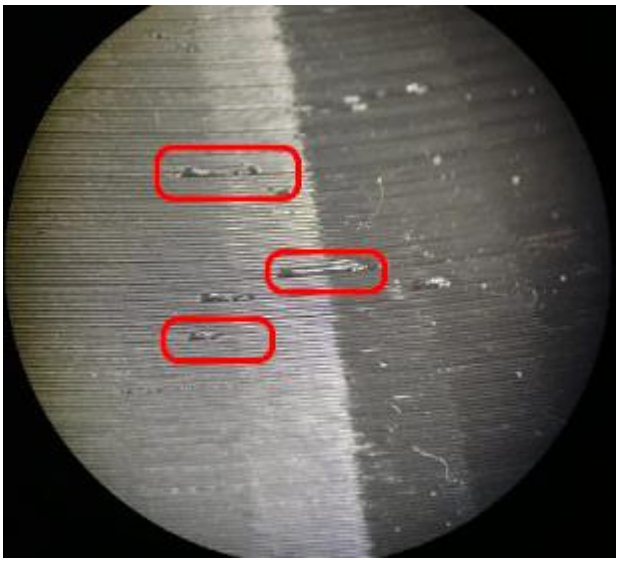
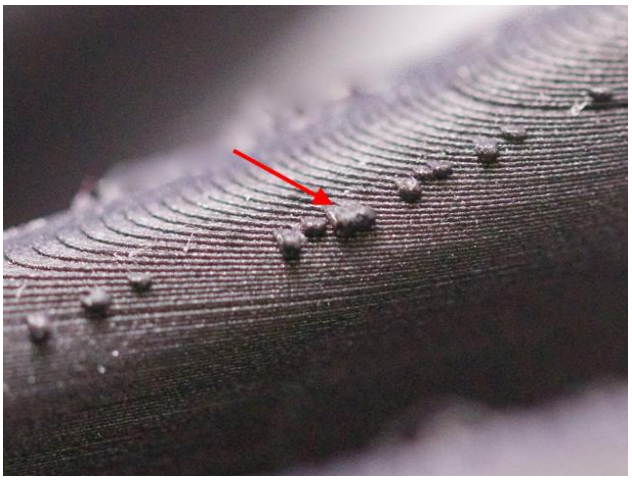
8.4. Visual Inspection

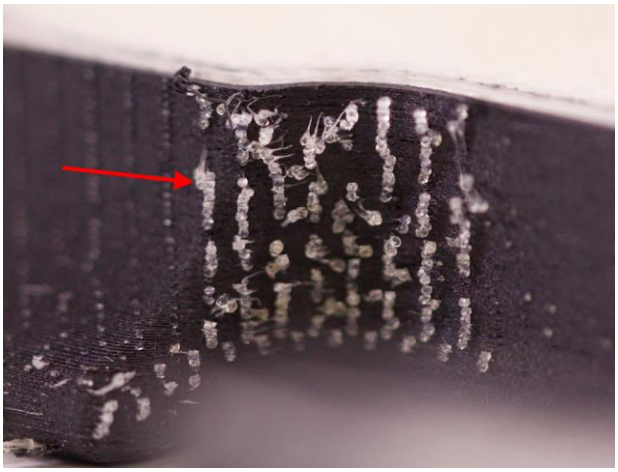
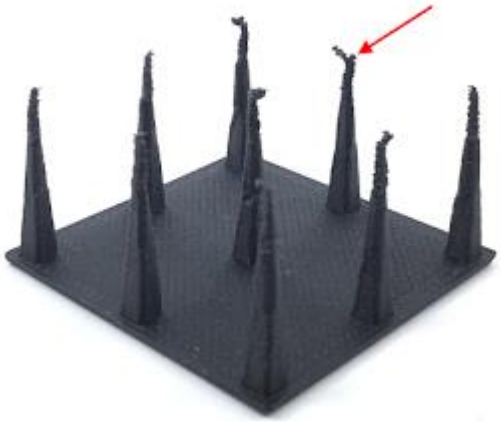
A visual inspection procedure must be conducted on each part post build completion and compared to the descriptions of acceptable anomalies outlined in Section 8.4.1. and unacceptable defects outlined in Section 8.4.2. for disposition by the CEO.

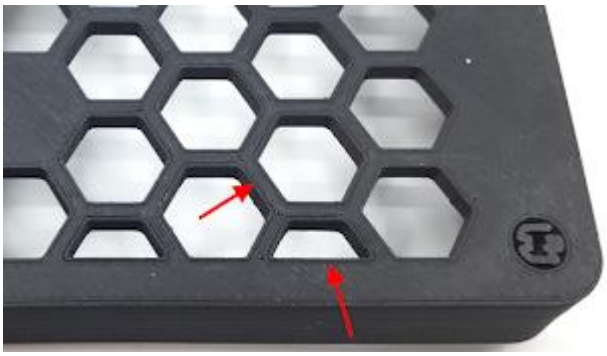
8.4.1. Acceptable Part Quality Anomalies

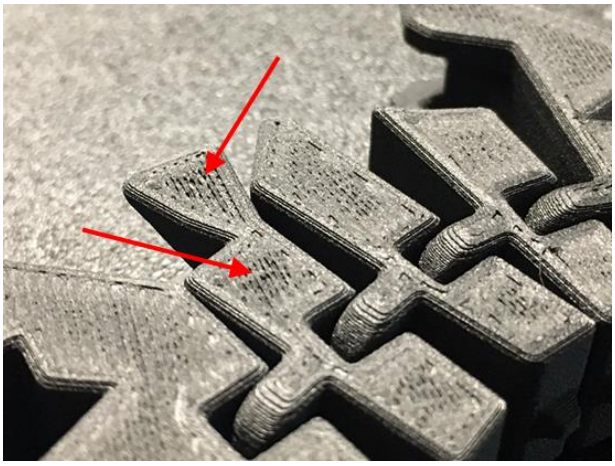
Table 12 describes typical acceptable aesthetic anomalies that may present themselves in the finished CFR part, along with their allowable limit(s).

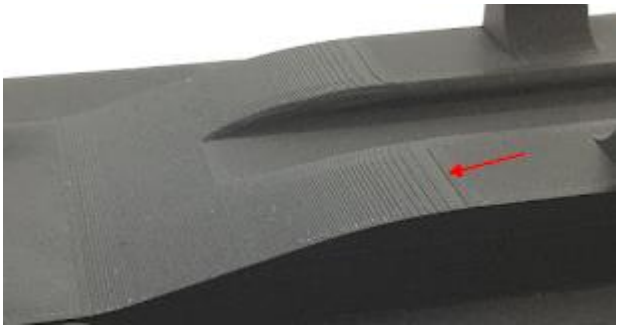
Table 12. Acceptable Part Quality Anomalies

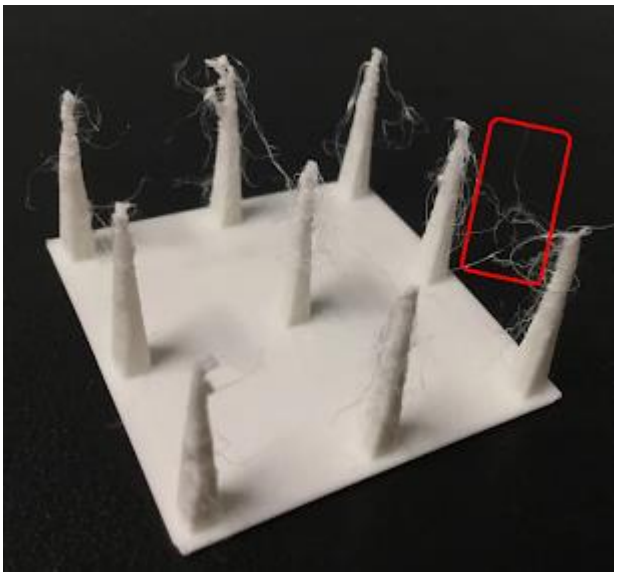
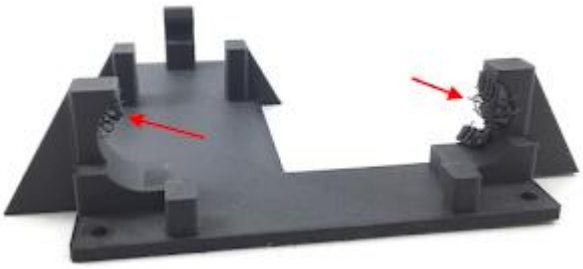
Anomaly	Image	Definition	Allowable Limit
Blip		Small negative feature of missing material on the outer shell of the part.	Blips must not extend beyond a single layer thickness, nor should they extend further than 20 times the layer height, or 2.5mm for Type I or Type II Material.
Blop		Extra material particles present on the outer surface of the part. Blops may be sanded to be removed.	Blops must not extend beyond a single layer thickness.

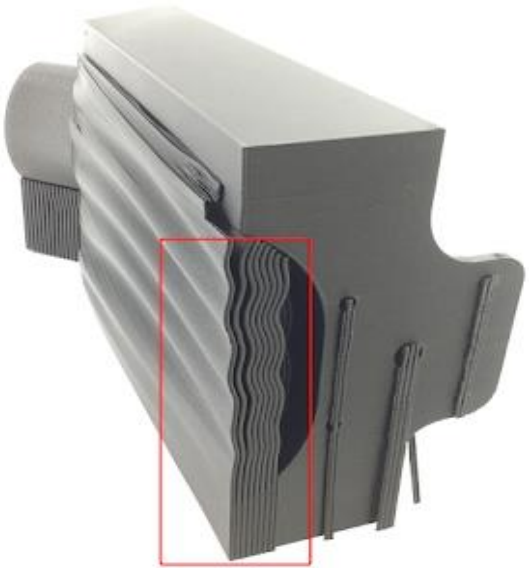
Anomaly	Image	Definition	Allowable Limit
Fiber Residue		Milky white or clear material particles present on the outer surface of the part. Residue may be removed by hand or trimmed.	Fiber residue is cosmetic in nature and is allowed.
Fine Feature Melt		Small fine features outside of the recommended feature size may melt due to nozzle dwell time re-melting material deposited on previous layers. Melted features may be removed by hand or trimmed.	The minimum post diameter must not be less than 0.079” when printing up in the Z direction (vertical) and not less than 0.063” in the XY direction (horizontal).

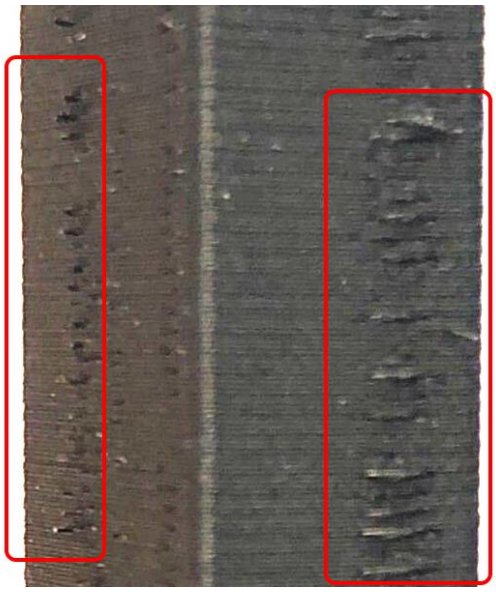
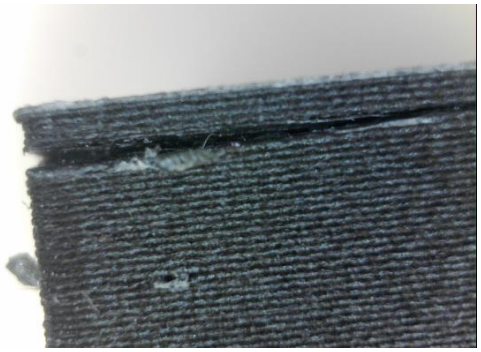
Anomaly	Image	Definition	Allowable Limit
First Layer Gaps		Shells or infill don't fully touch on the bottom (first layer) of your part.	Gaps in beads must not exceed a single bead width, which is 0.5mm for Type I and Type II Material.
Horizontal Banding		Regular or irregular indentations or protrusions in the outer shell.	Banding size must not exceed the layer thickness.

Anomaly	Image	Definition	Allowable Limit
Path Gap		Small holes in roof fill that are inherent to FFF technology and bead geometry.	Path gaps are inherent to the FFF process and are allowed. Path gaps must be under 1 mm^2 in total area, or must not exceed 0.5 mm in width.
Roof Underfill		Incomplete fill visible on the roof layers of the part. Beads do not fully connect with parallel beads.	Gaps in beads must not exceed a single bead width.
Rough Supported Surface		Faces of a part that interface with support structures may have a rougher surface finish which can be post processed to improve quality via sanding or other smoothing methods.	Rough supported surfaces are allowable, given that the tolerances imposed on the feature(s) of the part are met.

Anomaly	Image	Definition	Allowable Limit
Seam		The location where extrusion process starts or stops on the outer shell of the part.	Seams are inherent to the FFF process and are acceptable.
Stairstepping		Visible, perceptible lines or ridges between successive layers.	Ridges must not exceed the part layer height.

Anomaly	Image	Definition	Allowable Limit
Stringing		Wispy strands of material attached to the part. Material may be trimmed or removed by hand.	Wisps of material that can be removed without damaging the part are acceptable. If removing the wisps damages the part then the part must be dispositioned according to MRB processes.
Support Structures not Adhering		Support sections may not fully adhere to part and sections are left behind. Support structured embedded in the part may be removed by trimming, sanding, or other mechanical processing methods.	Issues with the support structure(s) are allowable, given that the tolerances imposed on the feature(s) of the part are met.

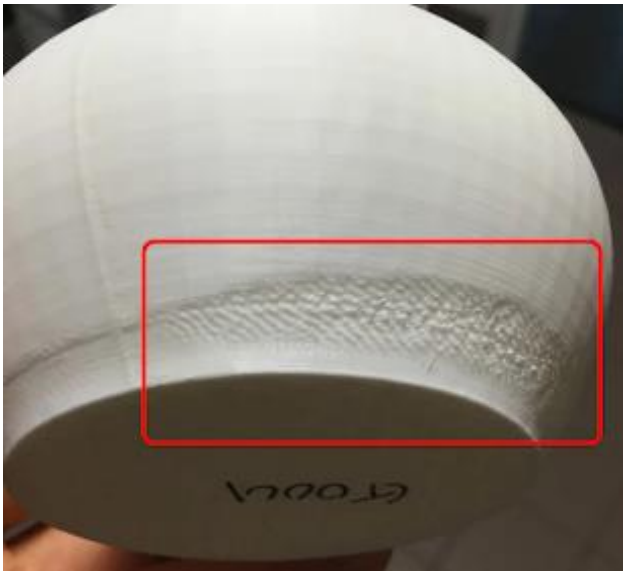
Anomaly	Image	Definition	Allowable Limit
Warp (after removal from bed)		Deformation of the base of the part upwards in the z direction.	Acceptable levels of warp after removal from the print bed should be defined by the tolerances imposed on the feature of the part by the responsible engineering authority.
Wavy Supports		Tall accordion support structures show waviness along their height.	Wavy support structure(s) are allowable, given that the tolerances imposed on the feature(s) of the part are met.

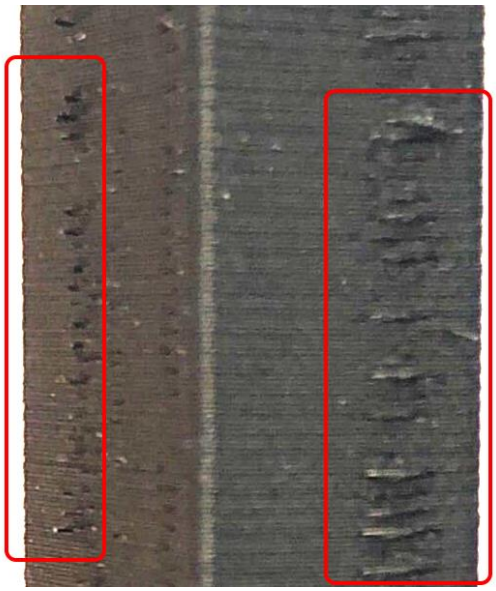
Anomaly	Image	Definition	Allowable Limit
Fiber Tracks Outside of Part		Fiber reinforcement material extending past the outer shell to the exterior of the part.	A discrete portion of fiber that extends beyond & re-enters the outer shell of the part for less than 4mm. *Note: The intent of measuring the material that exits the part is to have a non-destructive measurement that correlates to internal void size. It's not 1-to-1 – the void will typically be smaller, as plastic from neighboring layers will flow to fill in the gap.*
Part Removal Damage	 	Indentation from scraper during part removal	A material review board (MRB) disposition process will be carried out to decide whether the damage prevents use as a test coupon or influences results of test coupon.

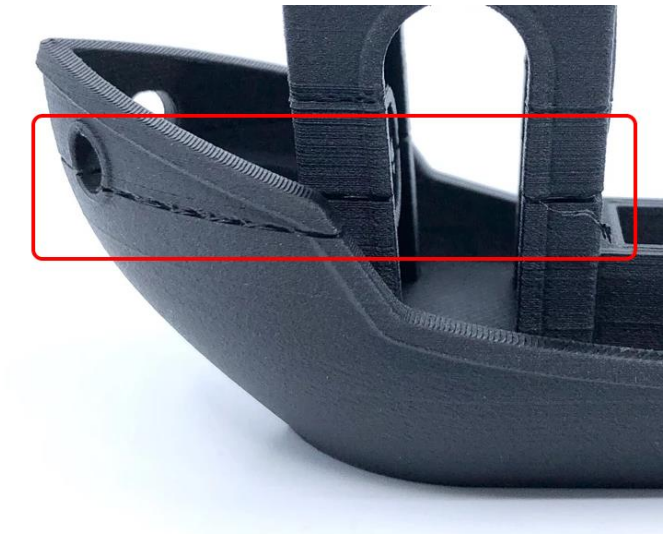
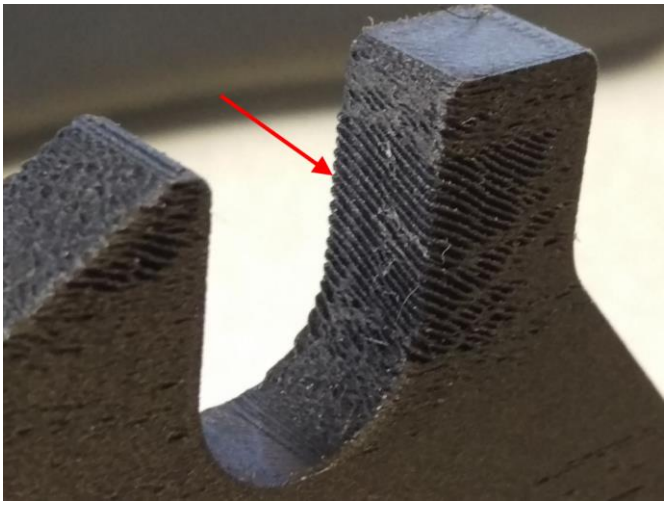
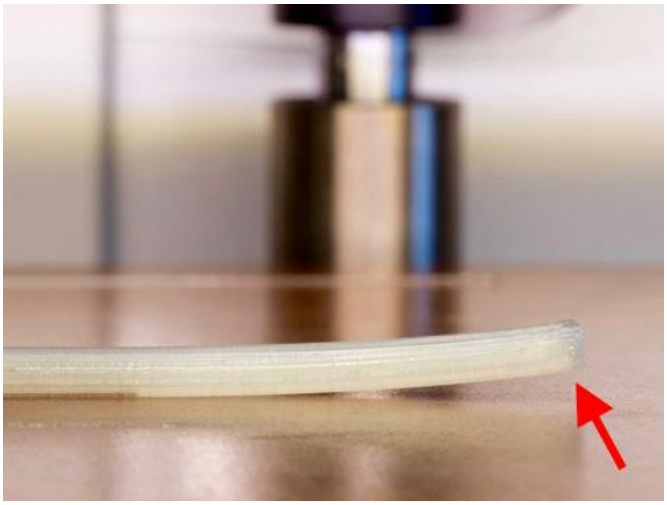
8.4.2. Unacceptable Part Quality Defects

Table 13 describes defects that may present themselves in the finished CFR part. Parts with the following defects must be rejected unless it is dispositioned by the CEO following the company's appropriate MRB processes.

Table 13. Unacceptable Part Quality Defects

Anomaly	Image	Definition
Curling Damage		Mottled, potentially burned, uneven vertical surface finish on an overhang.
Fiber Nozzle Drag		A pair of depressions on the outer shell of the part that continues between layers.

Anomaly	Image	Definition
Fiber Tails		A discrete tow of fiber that extends beyond the outer shell of the part by 2mm or more. A tow of fiber is 0.3mm or more in width. Portions of fiber either less than 0.3mm in width or shorter than 2mm are not fiber tails.
Fiber Tracks Outside of Part		A discrete portion of fiber that extends beyond & re-enters the outer shell of the part for 4mm or more. *Note: The intent of measuring the material that exits the part is to have a non-destructive measurement that correlates to internal void size. It's not 1-to-1 – the void will typically be smaller, as plastic from neighboring layers will flow to fill in the gap.*

Anomaly	Image	Definition
Layer Pause Line		In-plane gap or line visible on the outer surface of the part.
Shell Ribbing		Missing material on the outer shell of the part that progresses through several layers.
Warp (during printing)		Deformation of the base of the part upwards in the z direction prior to removal from the print bed.

9. RETENTION OF QUALIFICATION

The Qualification of Type I 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 must be submitted to the CEO 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; version control defined in section 2.1. Any deviation to the prescribed maintenance must be considered as a non-conformance and must be dispositioned by the CEO. Equipment repair, as defined by any action not outlined in the maintenance manual for normal maintenance, is considered to be a change to the system and must be submitted to the CEO for review and disposition.

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

10. USER QUALITY ASSURANCE

10.1. Process Control

In-process monitoring data should be in accordance with the user's applicable company process specification or an approved shop practice. For material qualification and equivalency purposes, the in-process monitoring data should be provided to the appropriate organizations in accordance with the applicable test plan. Process control testing is not required for the fabrication of finished parts.

10.2. X-Ray Computed Tomography & Non-Destructive Inspection

X-Ray CT inspection can be performed on fabricated parts to determine internal defects such as porosity, foreign inclusions, voids, cracks, etc. These internal defects are presented as a percentage of the total part volume along with minimum and maximum defect lengths. Inspection criteria such as scan type, energy, current, and detector location vary depending on material type, fabrication method, sample size, designated area of interest, and required resolution.

10.3. Visual Inspection

Finished products for material qualification and equivalency purposes must be labeled in accordance with the applicable test plan for identification purposes. Identification of anomalies and defects should be documented per Section 8.4 associated with all coupons for future performance verification and validation.

APPENDIX A: NCAMP COUPON BUILD INFORMATION

The slicer software available through Eiger provides the user with the option to change a number of parameters that will impact the results of a build. Settings are available through several tabs on the part page of Eiger. This appendix outlines the impact levels of each parameter, as well as the settings used for Type I and Type II Material.

Low impact parameters within the slicer software can be changed to improve build quality and print reliability and are not critical to part performance. The default settings for Type I and Type II Material are provided in Table 14.

Table 14. Low Impact Parameter Settings

Parameter	Tab	Type I	Type II	Notes
Raise Part	Settings	No	No	This feature may make the removal of small support sections beneath a part easier.
Use Brim	Settings	Yes	Yes	Enabling this feature may help to reduce warping during printing.

Medium impact parameters within the slicer software can be changed to improve build quality and print reliability but may also impact part performance. The default settings for Type I and Type II Material are provided in Table 15.

Table 15. Medium Impact Parameter Settings

Parameter	Tab	Type I	Type II	Notes
Supports Angle	Settings	0	0	

High impact parameters within the slicer software can improve build quality and print reliability but require specific understanding of performance implications as they will affect part performance. The default settings for Type I and Type II Material are provided in Table 16.

Table 16. High Impact Parameter Settings

Parameter	Tab	Type I	Type II	Notes
Material	General	Onyx FR	Onyx FR	

Parameter	Tab	Type I	Type II	Notes
Reinforcement Material	General	Carbon Fiber FR	None	
Printer Type	General	Industrial Series (X3, X5, X7)	Industrial Series (X3, X5, X7)	A qualified Markforged X7 Printer must be used.
Layer Height (mm)	Settings	.125	.125	Using Carbon Fiber FR will automatically set layer height to 0.125mm.
Original Units	Settings	Metric, Imperial	Metric, Imperial	Units must match the units that the STL was generated with.
Scale	Settings	1	1	Scale changes should be unnecessary with the proper STL.
Use Supports	Settings	Yes	Yes	
Expand Thin Features	Settings	No	No	
Turbo Infill (Beta)	Settings	No	No	
Turbo Supports (Beta)	Settings	No	No	
Fill Pattern	Infill	Solid	Solid	
Fill Density	Infill	100%	100%	This parameter is unavailable for change when Solid fill is selected
Roof and Floor Layers	Infill	4	4	This parameter is unavailable for change when Solid fill is selected
Wall Layers	Infill	2	2	
Total Fiber Layers	Reinforcement	See Appendix B	N/A	By default, fiber layers are placed as a sandwich panel where half are in the bottom of the part and half are in the top. Total Fiber Layers vary based on coupon type. See Appendix A for specific settings used.
Fiber Fill Type	Reinforcement	See Appendix B	N/A	
Concentric Fiber Rings	Reinforcement	See Appendix	N/A	Concentric rings follow the perimeter of parts sliced with isotropic fill.

Parameter	Tab	Type I	Type II	Notes
		B		They help to ensure a smoothly reinforced external surface where the outermost fibers are always continuous.
Walls to Reinforce	Reinforcement	See Appendix B	N/A	This field is only available when Fiber Fill Type is set to Concentric Fiber.
Fiber Angles	Reinforcement	See Appendix B	N/A	This field is only available when Fiber Fill Type is set to Isotropic Fiber. Any values in this field should be entered numerically and separated by commas. The Slicer will repeat this list if the part has more fiber layers than values specified. Fiber Angles vary based on coupon type. See Appendix B for specific settings used.

APPENDIX B: NCAMP COUPON-SPECIFIC REINFORCEMENT SETTINGS

The following appendix describes the specific fiber reinforcement layouts used for the printing of each coupon. In combination with Appendix A of this document, this fully defines the build parameters used for the qualification. This information is provided as a supplement to the NCAMP test plan and does not replace it.

OFRA and CFRA volumes are reported below for all utilized test types, orientations, and fiber fills within the qualification test matrix as the expectation of specimen composition calculated by the slicing software. Volumes of both OFRA and CFRA will be recorded for all test geometries, orientations, and fiber volumes utilized as qualification test samples.

Table 17. Part Slicer Settings

Title	Layers	Use Fiber	Fiber Pattern Type	Fiber Fill Type	Walls to Reinforce	Concentric Fiber Rings	Start Rotation Percent	Fiber Angles	Plastic Volume [cc]	Fiber Volume [cc]
D2344-XY-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	1.6	1.73
	4->45	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	46+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D2344-XY-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	3.01	0.33
	4->7	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	8->41	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	42->45	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	46+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D2344-XZ-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	1.24	1.79
	4->97	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	98+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D2344-XZ-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	2.86	0.44
	4->12	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	13->83	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	84->97	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	98+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D2344-ZX-PF-TUBE	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	14.1	34.01
	4->300	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	5	12	N/A		
	301+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D256-XY-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	2.66	3.9
	4->32	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,0,-45,90		
	33->60	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	-45,0,45,90		
	61+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D256-XY-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	6.35	0.55
	4->7	TRUE	Entire	Isotropic	N/A	0	0	45,0,-		

Title	Layers	Use Fiber	Fiber Pattern Type	Fiber Fill Type	Walls to Reinforce	Concentric Fiber Rings	Start Rotation Percent	Fiber Angles	Plastic Volume [cc]	Fiber Volume [cc]
			Group	Fiber				45,90		
	8->56	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	57->64	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	90,-45,0,45		
	65+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D256-XZ-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	2.73	3.59
	4->50	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,0,-45,90		
	51->97	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	-45,0,45,90		
	98+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D256-XZ-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	6.39	0.53
	4->10	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,0,-45,90		
	11->90	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	91->97	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	-45,0,45,90		
	98+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D256-ZX-PF-TUBE	0->199	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	155.38	30.08
	200->307	TRUE	Entire Group	Concentric Fiber	Inner Holes Only	12	0	N/A		
	308+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D3039-XY-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	7.45	9.62
	4->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D3039-XY-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	13.61	3.66
	4->7	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	8->20	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	21->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D3039-XZ-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	8.47	7.66
	4->198	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	199+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D3039-XZ-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	13.35	3.69
	4->50	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	51->151	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	152->198	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	199+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D3039-ZX-PF-TUBE	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	132.8	17.97
	4->7	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	2	12	N/A		

Title	Layers	Use Fiber	Fiber Pattern Type	Fiber Fill Type	Walls to Reinforce	Concentric Fiber Rings	Start Rotation Percent	Fiber Angles	Plastic Volume [cc]	Fiber Volume [cc]
	8->539	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	540->881	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	2	12	N/A		
	882+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D3418-XY-FF	0->0	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	0.28	0.07
	1->6	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	7+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D3418-XY-NF	0+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	0.36	0
D3418-XY-PF	0->0	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	0.33	0.02
	1->1	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	2->5	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	6->6	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	7+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D3518-XY-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	6.97	9.62
	4->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,-45		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D3518-XY-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	13.42	3.66
	4->7	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,-45		
	8->20	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	21->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	-45,45		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D5766-D6484-D6742-XY-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	10.32	16.43
	4->14	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,0,-45,90		
	15->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0,45,90,-45		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D5766-D6484-D6742-XY-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	21.17	6.26
	4->7	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,0,-45,90		
	8->20	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	21->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	90,-45,0,45		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D5766-D6484-D6742-XZ-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	13.14	12.75
	4->300	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	301+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D5766-D6484-D6742-XZ-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	20.89	6.44
	4->78	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	79->225	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		

Title	Layers	Use Fiber	Fiber Pattern Type	Fiber Fill Type	Walls to Reinforce	Concentric Fiber Rings	Start Rotation Percent	Fiber Angles	Plastic Volume [cc]	Fiber Volume [cc]
	226->300	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	301+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D5766-D6484-D6742-ZX-PF-TUBE	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	128.91	10.75
	4->7	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	2	12	N/A		
	8->655	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	656->897	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	2	12	N/A		
	898+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D5961C-XY-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	7.52	11.76
	4->14	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,0,-45,90		
	15->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0,45,90,-45		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D5961C-XY-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	15.31	4.48
	4->7	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,0,-45,90		
	8->20	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	21->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	90,-45,0,45		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D5961C-XZ-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	9.41	9.15
	4->300	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	301+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D5961C-XZ-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	15.16	4.5
	4->76	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	77->227	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	228+	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
D5961C-ZX-PF-TUBE	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	74.95	22.73
	4->7	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	2	12	N/A		
	8->46	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	47->304	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	2	12	N/A		
	305->812	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	813->1070	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	2	12	N/A		
	1071+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D638DF-ZX-NF	0+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	4.38	0

Title	Layers	Use Fiber	Fiber Pattern Type	Fiber Fill Type	Walls to Reinforce	Concentric Fiber Rings	Start Rotation Percent	Fiber Angles	Plastic Volume [cc]	Fiber Volume [cc]
D6641-XY-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	3.98	3.33
	4->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D6641-XY-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	6.05	1.27
	4->7	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	8->20	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	21->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D6641-XZ-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	3.9	2.9
	4->97	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	98+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D6641-XZ-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	5.96	1.23
	4->23	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	24->77	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	78->97	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	98+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D6641-ZX-PF-TUBE	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	53.85	40.3
	4->7	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	2	12	N/A		
	8->99	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	100->1017	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	2	12	N/A		
	1018+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D7028-XY-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	1.76	1.36
	4->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D7028-XY-NF	0+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	3.15	0
D7028-XY-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	2.61	0.52
	4->7	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	8->20	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	21->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D7028-XZ-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	1.63	1.2
	4->97	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	98+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D7028-XZ-NF	0+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	3.3	0

Title	Layers	Use Fiber	Fiber Pattern Type	Fiber Fill Type	Walls to Reinforce	Concentric Fiber Rings	Start Rotation Percent	Fiber Angles	Plastic Volume [cc]	Fiber Volume [cc]
D7028-XZ-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	2.71	0.36
	4->17	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	18->83	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	84->97	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	98+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D7028-ZX-PF-TUBE	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	18.99	20.06
	4->462	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	2	12	N/A		
	463+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D790-XY-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	2.18	1.73
	4->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D790-XY-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	3.26	0.66
	4->7	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	8->20	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	21->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D790-XZ-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	2.06	1.52
	4->97	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	98+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D790-XZ-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	3.16	0.65
	4->23	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	24->77	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	78->97	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	0	N/A		
	98+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
D790-ZX-PF-TUBE	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	23.68	25.39
	4->584	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	2	12	N/A		
	585+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
E831-XY-FF00	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	0.62	0.3
	4->56	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	90		
	57+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
E831-XY-FF45	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	0.64	0.27
	4->30	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,-45		
	31->56	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	-45,45		

Title	Layers	Use Fiber	Fiber Pattern Type	Fiber Fill Type	Walls to Reinforce	Concentric Fiber Rings	Start Rotation Percent	Fiber Angles	Plastic Volume [cc]	Fiber Volume [cc]
	57+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
E831-XY-FF90	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	0.49	0.32
	4->56	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	57+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
E831-XY-FFQI	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	0.59	0.29
	4->30	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,0,-45,90		
	31->56	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	-45,0,45,90		
	57+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
E831-XY-NF	0+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	0.94	0
E831-XY-PF00	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	0.82	0.09
	4->11	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	90		
	12->48	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	49->56	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	90		
	57+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
E831-XY-PF45	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	0.83	0.08
	4->11	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,-45		
	12->48	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	49->56	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	-45,45		
	57+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
E831-XY-PF90	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	0.78	0.1
	4->11	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	12->48	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	49->56	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	0		
	57+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
E831-XY-PFQI	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	0.81	0.09
	4->11	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,0,-45,90		
	12->48	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	49->56	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	90,-45,0,45		
	57+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
E831-ZX-FF90	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	0.82	0.47
	4->86	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	90		
	87+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
E831-ZX-NF	0+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	1.33	0
E831-ZX-PF90	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	1.14	0.13
	4->15	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	90		
	16->74	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	75->86	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	90		

Title	Layers	Use Fiber	Fiber Pattern Type	Fiber Fill Type	Walls to Reinforce	Concentric Fiber Rings	Start Rotation Percent	Fiber Angles	Plastic Volume [cc]	Fiber Volume [cc]
	87+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
FARHR-XY-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	60.89	20.09
	4->7	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,0,-45,90		
	8->20	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	21->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	90,-45,0,45		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
FARHR-XZ/ZX-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	45.11	48.34
	4->1214	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	3	N/A		
	1215+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
FARSM-XY-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	16.37	4.98
	4->7	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,0,-45,90		
	8->20	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	21->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	90,-45,0,45		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
FARSM-XZ/ZX-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	13.9	14.38
	4->605	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	6	N/A		
	606+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
FARVB-XY-PF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	63.37	20.51
	4->7	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	45,0,-45,90		
	8->20	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
	21->24	TRUE	Entire Group	Isotropic Fiber	N/A	0	0	90,-45,0,45		
	25+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
FARVB-XZ-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	41.65	44.91
	4->605	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	2	N/A		
	606+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		
FARVB-ZX-FF	0->3	FALSE	N/A	N/A	N/A	N/A	N/A	N/A	34.03	36.91
	4->1549	TRUE	Entire Group	Concentric Fiber	Outer Shell Only	1	6	N/A		
	1550+	FALSE	N/A	N/A	N/A	N/A	N/A	N/A		

REVISION HISTORY

Revision	By	Date	Description
-	NCAMP	4/21/2021	Initial Release
A	Royal Lovingfoss	8/19/2022	1. Inclusion of "Part Removal Damage" in Table 12 2. Inclusion of "Fiber Tracks Outside of Part" in Table 12 & Table 13 3. Table 18 was included to provide part configuration transparency.
B	Neville Tay	8/9/2023	1. Table 1 document links were all updated. 2. Table 10 graphic for fiber minimum bend radius was updated to better reflect the setting. 3. Section 6.3.1: b) Table 12 changed to the NMS 754/1. As-printed specimen properties table (formerly Table 12) was removed. 4. The Faceting anomaly was removed from Table 12. 5. In Table 12, path gap allowable limit is now specified: Path gaps must be under 1 mm^2 in total area, or must not exceed 0.5 mm in width. 6. In Table 12, Fine feature melt allowable limit was edited to: The minimum post diameter must not be less than 0.079" when printing up in the Z direction (vertical) and not less than 0.063" in the XY direction (horizontal). 7. A note was added to the anomaly "Fiber tracks outside of parts" in both Table 12 and 13 to note the correlation to void size. 8. Part removal damage's allowable limit was edited in Table 12 to reflect: A material review board (MRB) disposition process will be carried out to decide whether the damage prevents use as a test coupon or influences results of test coupon 9. Section 8.4.2 paragraph was edited to: defects must be rejected unless it is dispositioned by the CEO. 10. Updated the software version strings in Table 8 to their latest LTS versions.

C	Neville Tay	11/13/2023	1. Removed hyperlinks to google document locations throughout the document. 2. Updated the material specification versions in Table 2 to Rev B. 3. Class “CF30” was added to Section 2.6 for Type I Material definition. 4. “Un-verified” was removed from the titles of section 6.4.1 and 6.4.2.
D	Neville Tay	3/4/2024	1. The Offline Eiger, LAN Connector, and Device application values in Table 8 were updated.