National Center for Advanced Materials Performance

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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	

2.2.   NCAMP Documents

Table 2. NCAMP Document List

Document No.	Document Title	Version(s)
NMS 754	Filament Specification (Onyx FR)	

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 -

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

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

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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)

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)

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Table 12. Acceptable Part Quality Anomalies
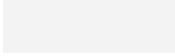
Anomaly	Image	Definition	Allowable Limit
Fiber Residue		Milky white or clear material particles present on the outer surface of the part. Residue may be removed by hand or trimmed.	Fiber residue is cosmetic in nature and is allowed.
Fine Feature Melt		Small fine features outside of the recommended feature 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

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
Seam		The location where extrusion p 1 50.4 39.	
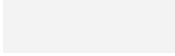
8.4.2. Unacceptable Part Quality Defects

Table 13

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		

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	

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.

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]
				N/A	N/A	N/A	N/A	N/A		
				Concentric Fiber	Outer Shell Only	2	12	N/A		
				N/A	N/A	N/A	N/A	N/A		
				N/A	N/A	N/A	N/A	N/A		
				Isotropic Fiber	N/A	0	0	0	0.28	0.07

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					

Title	Layers	Use Fiber	Fiber Pattern Type	Fiber Fill Type	Walls to Reinforce

Title	Layers	Use Fiber	Fiber Pattern Type	Fiber Fill Type	Walls to Reinforce

Title	Layers	Use Fiber	Fiber Pattern Type	Fiber Fill Type	Walls to Reinforce	Concentric Fiber Rings	Start Rotation

Title	Layers	Use Fiber	Fiber Pattern Type	Fiber Fill Type	Walls to Reinforce	Concentric Fiber Rings	Start Rotation

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

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.