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NCAMP Material Specification

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Standard Operating Procedures, NSP 100*

Filament Specification (Carbon Fiber FR-A™)

(Markforged - MFD)

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1. SCOPE

This specification establishes the requirements for the manufacturing of a Finished Goods Feedstock from receipt of Raw Feedstock Lot and Raw Resin Lot.

This specification does not cover the process of NCAMP Qualification and is limited to establishing requirements only. It does not establish implementation.

The Finished Goods Feedstock detailed in this document is Carbon Fiber FR-A™ (T300 1K tow), a Type 1 Form 1 PACF50FR05 filament. Carbon Fiber FR-A™ cannot be used on its own and is intended to be used with Onyx FR-A™.

1.1. TYPE

The type must specify the predominant resin used in the feedstock. The resin type must use ASTM D4000 abbreviations (a.k.a. standard symbols); if the resin type is not listed in ASTM D4000, abbreviations known in the industry must be used. All material must be Type 1. The resin is placed in and around the fiber. Melt compounding is method by which the additive and polymer were combined in the manufacturing of the final material form performed via MF-PCD-001, Section 6. Melt compounding is also the process of including polyamide in and around the carbon fiber.

Table 1 – Material Types

Type	Resin Type
Type 1	Polyamide

1.2. COMPOSITION

The composition must specify the type of fillers and/or reinforcements.

Table 2 – Material Composition

Composition	Filler / Reinforcement Material
CF	Carbon Fiber
FR	Flame Retardant

1.3. CLASS

The Class must specify the amount, to the nearest weight percent, of the filler or reinforcement. The value for the Class must be immediately appended to the Composition abbreviation (e.g. CF30 for 30% carbon fiber and the remaining 70% is a Type 1 and FR blend).

2. REFERENCES

29 CFR 1910.1200	Hazard Communication, Occupational Safety and Health Standards
MIL-PRF-131	Barrier Materials, Watervaporproof, Greaseproof, Flexible, Heat-Sealable
ASTM D3878	Standard Terminology for Composite Materials
ASTM D4000	Standard Classification System for Specifying Plastic Materials
ASTM D7191	Standard Test Method for Determination of Moisture in Plastics by

	Relative Humidity Sensor
ASTM E29	Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
CMH-17	Composite Materials Handbook (formerly MIL-HDBK-17)
DOT/FAA/AR-06/10	Guidelines and Recommended Criteria for the Development of a Material Specification for Carbon Fiber/Epoxy Fabric Prepregs
DOT/FAA/AR-07/3	Guidelines and Recommended Criteria for the Development of a Material Specification for Carbon Fiber/Epoxy Unidirectional Prepregs Update
ISO 9000	Quality Management Systems
NSP 100	NCAMP Standard Operating Procedures
NMS 754	NCAMP Materials Specification Onyx FR-A
NMS 754/1 Slash	NCAMP Materials Specification Slash Sheet
NTP AM-6754Q1	NCAMP Test Plan
NPS 86754	NCAMP Process Specification – Markforged X7
MF WI-213	Line Weight Test

3. DEFINITIONS

The following definitions apply to terms that have special meaning as used in this material specification:

Continuous Fiber Reinforcement	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. Abbreviated as CFR
Raw Resin Lot	Total quantity of a unique lot or batch identifier as defined by original resin supplier
Fiber Lot	The quantity of Markforged Fiber Spools manufactured at one time to a single set of defined properties in compliance with the material specification using a minimal set of Raw Resin and Raw Feedstock Lots
Fiber Lot Supplier	The supplier responsible for producing Fiber Lots
Fiber Spool	A single unit of fiber feedstock with resin in and around the fiber wrapped around a plastic spool.
Fused Filament Fabrication	A type of extrusion based additive manufacturing technology that enables the construction of three-dimensional objects, prototypes and products through a computer-aided process. Abbreviated as FFF
Batch Release Testing	The process of validation of a Fiber Lot complying to this

	specification
Raw Feedstock Lot	Total quantity of a unique lot of feedstock incoming to the Fiber Lot Supplier as defined by the Raw Feedstock Supplier
Must	Expresses a binding requirement
Should/May	Expresses a recommended or allowed action
Will	Expresses a declaration of intent

For definitions that are not provided in this specification or other applicable NCAMP specifications, the definitions in DOT/FAA/AR-06/10 and DOT/FAA/AR-07/3 must apply. For definitions not provided in DOT/FAA/AR-06/10 and DOT/FAA/AR-07/3, the definitions in ASTM D3878 must apply. For definitions not provided in ASTM D3878, the definitions in CMH-17 (formerly MIL-HDBK-17) must apply.

4. PROCESS CONTROL DOCUMENT

The supplier must prepare and control a Process Control Document (PCD). This PCD must contain all process parameters, steps & controls needed to produce a Fiber Lot.

The PCD must be considered proprietary and must be protected in accordance with disclosure agreements signed by the supplier and NCAMP. The established Process Control Document (PCD) must be presented to NCAMP upon request. NCAMP must treat any information contained in the PCD as proprietary. Formal change notification and approval must be required before a change may be implemented. NCAMP approval must be required for major changes, and must be granted through Advance Change notices (ACN).

Changes to the PCD of a qualified material (as defined by DOT/FAA/AR-06/10, DOT/FAA/AR-07/3) are subject to the written approval of NCAMP. Such changes may require substantial testing to demonstrate equivalency.

4.1. MATERIAL REQUIREMENTS

Feedstock materials must meet a controlled specification. Approved Raw Feedstock Suppliers must be controlled by the PCD.

4.2. APPROVED MACHINES

The following production lines are approved to produce Carbon Fiber FR-A and are controlled by the PCD.

Table 3 – Approved Production Lines

Line ID	Location
FP25	Markforged located at 4 Suburban Park Drive, Billerica, MA 01821
FP26	
FP27	
FP28	

5. QUALIFICATION

All requests for qualification must be directed to NCAMP.

6. FIBER FEEDSTOCK REQUIREMENTS

The testing defined in this section is the responsibilities of the Fiber Lot Supplier's and need not to be repeated by the purchaser. Fiber Lot Supplier will submit a test report with a Certificate of Conformance (COC) that demonstrates the candidate material's ability to meet the specifications in Table 4 -

Table 7. The report will include the following information:

- Supplier name and product designation
- Test Inspection Records, including individual specimen values, to prove material conforms with this specification
- Fiber Lot number
- Date of Manufacture
- Raw Resin Lot or batch number
- Raw Feedstock Lot number
- A statement of conformity with this specification

Table 4 – Incoming Fiber Raw Feedstock Lot Property Requirements

Properties	Test Method	Requirements
Line weight (7.1)	MF WI-213	0.0610 - 0.0694 g/m
Fiber Density (7.4)	Raw Feedstock Supplier COA	1.757 - 1.765 g/cc
Tensile Strength (7.4)	Raw Feedstock Supplier COA	475 – 643 ksi
Young's Modulus (7.4)	Raw Feedstock Supplier COA	33.3 - 35.4 Msi

Table 5 – Incoming Prepreg-FR (PFR) Raw Resin Lot Property Requirements

Properties	Test Method	Requirements
Moisture (7.2)	ASTM D7191	<0.01%

Table 6 – In-Process Fiber Material Property Requirements

Properties	Test Method	Requirements
Cross-sectional Area (7.3)	PCD-000A Onyx FR-A	0.102 - 0.119 mm ²
Single-axis Diameter (7.3)	PCD-000A Onyx FR-A	0.3514 - 0.4070 mm

Table 7 – Outgoing (coated) Fiber Lot Property Requirements

Properties	Test Method	Requirements
Line weight (7.1) (Coated)	MF WI-213	0.1424 - 0.1560 g/m

6.1. RETENTION OF QUALIFICATION STATUS

No changes in approved product formulation, raw materials, and basic methods of manufacture, production lines or plant site, for a material qualified to this specification must be made without

approval from NCAMP via the ACN process.

7. MATERIAL TEST METHODS

All in-process monitoring requirements must be met as stated in the PCD. Any changes made to the in-process monitoring requirements must be reported to NCAMP via the ACN process.

7.1. LINE WEIGHT

Line weight must be measured on each incoming lot of fiber, and each outgoing Fiber Lot in accordance with MF WI-213 Line Weight Testing.

7.2. MOISTURE

Moisture testing must be performed on every Raw Feedstock Lot prior to coating in compliance to ASTM D7191. Moisture testing must again be performed on a representative sample of each Fiber Lot prior to shipping in compliance to ASTM D7191.

7.3. LINE DIAMETER & CROSS-SECTIONAL AREA

Line diameter & cross-sectional area must be held to a specification defined in the material PCD. Each must be evaluated at a minimum rate of 1 measurement per meter of material using an in-process noncontact measurement device.

Cross-sectional area must be calculated using at least two off-axis diameter measurements. All diameter measurements used in the calculation of cross-sectional area must be individually checked against the specification.

Fiber Spools with missing diameter or cross-sectional area data must be segregated and handled via the Filament Lot Supplier's MRB process.

7.4. FIBER DENSITY, TENSILE STRENGTH, & YOUNG'S MODULUS

The fiber density, tensile strength, and Young's modulus must be held to the Raw Feedstock Lot supplier's specification requirements per Table 4. These tests must be carried out by the Raw Feedstock Lot supplier prior to shipping. The Certificate of Analysis (COA) provided by the Raw Feedstock Lot supplier must then be supplied by Markforged with each Fiber Spool.

8. TEST FAILURE

Material (either Raw Feedstock Lot, Fiber Lot, or Fiber Spool) that does not meet specifications must be segregated and handled via the Fiber Lot Supplier's MRB process.

9. SPOOL IDENTIFICATION

Each Fiber Spool must be labeled with a unique Spool ID and the corresponding Fiber Lot ID. This labeling must additionally be affixed to the outside of the Fiber Spool packaging.

9.1. TRACEABILITY

Fiber Spools must be traceable to date of manufacture, and Fiber Lot. Fiber Lots must be traceable to fiber line, Raw Resin Lot, and Raw Feedstock Lot.

10. STORAGE AND HANDLING OF FIBER

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.

11. SAFETY – HAZARDOUS MATERIALS

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

The Material Safety Data Sheet (MSDS) must be made available to the purchaser.

12. ROUNDING OF VALUES

The following applies to all specified limits or requirements in this specification. For purposes of determining conformance with this specification, an observed value or a calculated value must be rounded “to the nearest unit” in the last right-hand digit used in expressing the specification limit, in accordance with the rounding method of ASTM E29.

13. QUALITY MANAGEMENT SYSTEM

The manufacturer’s quality system must be approved as defined in ISO 9000 or equivalent.

14. STATISTICAL PROCESS CONTROL

The supplier must establish and maintain procedures and requirements for an SPC system based on Key Process Variables (KPV). The KPV are the material properties required for batch release, and must be fully defined in the material PCD.

The KPV monitoring must be provided to material users, certification agencies, and NCAMP staff upon request, but proprietary information may be coded or normalized. Alternatively, the supplier may send the KPV data to NCAMP for inclusion in NCAMP’s control charts which are available to the public.

15. ACKNOWLEDGEMENT

A vendor must mention this specification number and the applicable detail specification number and their revision letters, if any, in all quotations and when acknowledging purchase orders.

16. REVISION HISTORY

REV	DESCRIPTION	DATE	WHO
-	Initial release	4/21/2021	NCAMP
A	<ol style="list-style-type: none"> Added "Section 6" to referred MF-PCD-001 in section 1.1. Added Line weight requirements of "0.0610 - 0.0694" in Table 4 and Table 7. (Values provided by Markfroged) Incorporated fiber density, tensile strength, and Young's modulus requirements in Table 4 Removed filament class, melt and glass transition temperature, and composition requirements was removed from Table 7, Table 8, Section 7, and Appendix A. Section 7.4 "Fiber density, tensile strength, & Young's modulus was added for further definition 	8/9/23	Neville Tay
B	<ol style="list-style-type: none"> Table 2: Composition lead in was removed from CF and FR. Added "and the remaining 70% are of Type 1 and FR blend" to the end of the sentence in section 1.3. 14 CFR 25.853 reference was removed from Section 2. MMPDS reference was removed from Section 2. MF WI-213 – Line Weight Test was added as reference in Section 2. "MMPDS (formerly MIL-HDBK-5)" reference removed from Section 3. The "Units" column was deleted from Table 4 through 7 to align table formats across material specification documents. "Raw Feedstock Supplier Proprietary" test method was changed to "Raw Feedstock Supplier COA" in Table 4. "Markforged Proprietary" test method in Table 6 was changed to "PCD-000A Onyx FR-A". "Un-verified" was removed from the title for Section 10. 	11/13/2023	Neville Tay

APPENDIX A - KEY PROCESS VARIABLES

The following table outlines parameters and characteristics determined to be critical to the quality of a Fiber Spool. A brief description of each parameter, along with SPC requirements, is also included. “Discrete” parameters are a specific value, and do not deviate. “Range” parameters may fall within an allowable range.

Table 8 – Key Process Variables

Variable	Description	Control Type	SPC Required
Fiber Line Die Design Parameters	Conformance to design of the die used on the fiber line	Range	N/A
Fiber Line Temperature(s)	Temperature of various zones in the fiber line die	Range	Yes
Melt Flow Ratio	Ratio of coating material to raw fiber	Discrete	N/A
Moisture	Moisture of Raw Feedstock Lot, Fiber Lot, or Fiber Spool sample measured in accordance to ASTM D7191	Range	N/A
XX/YY Cross-Sectional Area	Cross-sectional area of the Fiber Spool calculated using a single-axis non-contact micrometer	Range	Yes
XY Cross-Sectional Area	Cross-sectional area of the Fiber Spool calculated using a 2-axis non-contact micrometer	Range	Yes