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NCAMP Material Specification

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Filament Specification (Onyx FR-A™)

(Markforged - MFD)

Prepared by: John Tomblin (NCAMP/NIAR), Cole Daharsh (NCAMP/NIAR), Neville Tay (NCAMP/NIAR), Thomas Muscolo (Markforged), Patrick Dunham (Markforged), Vinay Rodriguez (Markforged)

Reviewed by: Royal Lovingfoss (NCAMP/NIAR), Vinsensius Tanoto (NCAMP/NIAR)

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National Center for Advanced Materials Performance

Wichita State University – NIAR

1845 Fairmount Ave., Wichita, KS 67260-0093, USA

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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.

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 Onyx FR-A™, a Type 1 Form 1 PACF15FR15 filament.

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. Melt compounding is method by which the additive and polymer were combined in the manufacturing of the final material form performed via MF-PCD-000, Section 6.

Table 1 – Material Types

Type	Resin Type
Type 1	Polyamide 6 (PA-6) Copolymer

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% are of 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
MIL–D–3464	Desiccants, Activated, Bagged, Packaging Use and Static Dehumidification
ASTM D1603	Test Method for Carbon Black Content in Olefin Plastics
ASTM D5630	Standard Test Method for Ash Content in Plastics
ASTM D638	Standard Test Method for Tensile Properties of Plastics

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 755	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-001	Printer Backpressure Testing

3. DEFINITIONS

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

Filament Lot	The quantity of Markforged Filament Spools manufactured at one time to a set of defined properties in compliance with this specification using a single Raw Feedstock Lot
Filament Lot Supplier	The supplier responsible for producing Filament Lots. Equivalent to Markforged
Filament Spool	A single unit of thermoplastic filament feedstock wound around a plastic spool
Must	Expresses a binding requirement
Process Control Document (PCD)	Proprietary revision-controlled document documenting the process of producing a Filament Lot. Owned by Filament Lot Supplier and further defined in Section 4
Qualification	The process of validation of a Filament Lot complying to this specification

Raw Feedstock Lot	Total quantity of a unique lot identifier incoming to the Filament Lot Supplier as defined by the Raw Feedstock Supplier. Incoming Raw Feedstock Lots are in the form of pellets with polyamide, carbon fiber, and FR pre-compounded.
Raw Feedstock Supplier	The supplier responsible for providing a Raw Feedstock Lot to the Filament Lot Supplier. Identified in the PCD
Should/May	Expresses a recommended or allowed action
Will	Expresses a declaration of intent

For definitions that are not provided in this specification, 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 PCD. This PCD must contain all process parameters, steps & controls needed to produce a Filament Lot.

The PCD must be considered proprietary and must be protected in accordance with disclosure agreements signed by the supplier and NCAMP. The established 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 Onyx FR-A and are controlled by the PCD.

Table 3 - Approved Production Lines

Line ID	Location
EX01 - Labtech Engineering 30 mm x 30:1 L/D Extrusion Workstation	Markforged located at 4 Suburban Park Drive, Billerica, MA 01821

5. QUALIFICATION

All requests for qualification must be directed to NCAMP.

6. FILAMENT FEEDSTOCK REQUIREMENTS

The testing defined in this section is the responsibilities of the Filament Lot Supplier's and need not to be repeated by the purchaser. Filament Lot Supplier will submit a test report/Certificate of Conformance (COC) that demonstrates the candidate material's ability to meet the specifications in Table 4 - Table 6. The report will include the following information:

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

Table 4 - Incoming Raw Feedstock Lot Property Requirements(1)

Properties	Test Method(2)	Requirements
Extrusion Force (7.1)	MF WI-001	≤ 1.8 kg
Moisture (7.2)	ASTM D7191	≤ 0.10 %
Nitrogen Burnout – Carbon Content (7.4)	ASTM D1603 / WI-0824	15.3 – 18.7%
Air Burnout – Ash Content (7.5)	ASTM D5630 / WI-0816	2.5 – 3.1%
Tensile Strength (7.6)	ASTM D638 / WI-0812	≥ 8.9 ksi

Table 5 - In-Process Filament Material Property Requirements(1)

Properties	Test Method(2)	Requirements
Cross-sectional Area (7.3)	PCD-000A Onyx FR-A	2.3000 – 2.5000 mm²
Single-axis Diameter (7.3)	PCD-000A Onyx FR-A	1.6925 – 1.8019 mm

Table 6 - Outgoing Filament Lot Property Requirements

Properties	Test Method(1)	Requirements
Moisture (7.2)	ASTM D7191	≤ 0.10 %

6.1. RETENTION OF QUALIFICATION STATUS

No changes in approved product formulation, raw materials, and basic methods of manufacture, 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. PRINTER EXTRUSION FORCE

Filament Printer Extrusion Force must be tested according to MF WI-001 Printer Extrusion Force Testing. This test must examine the force developed by a Filament Spool when fed into a proprietary test fixture representing a Markforged print head. Note that this has no relation to extruder backpressure developed when manufacturing Filament Spools.

7.2. MOISTURE

Moisture testing must be performed on every Raw Material Lot prior to pre-impregnation in compliance to ASTM D7191. Moisture testing must again be performed on a representative sample of each Filament 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 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.

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

7.4. NITROGEN BURNOUT (Carbon Content)

Incoming Raw Feedstock Lots must meet carbon content requirement as specified in Table 4. This test must be carried out per ASTM D1603/WI-0824 by the Raw Feedstock Supplier prior to shipping. The Certificate of Analysis (COA) provided by the Raw Feedstock Supplier must then be supplied by Markforged with each Filament Spool.

7.5. AIR BURNOUT (Ash Content)

Incoming Raw Feedstock Lots must meet ash content requirement as specified in Table 4. This test must be carried out per ASTM D5630/WI-0816 by the Raw Feedstock Supplier prior to shipping. The COA provided by the Raw Feedstock Supplier must then be supplied by Markforged with each Filament Spool.

7.6. TENSILE STRENGTH

Incoming Raw Feedstock Lots must meet the tensile strength requirement as specified in Table 4. Tensile strength testing on injection molded specimens must be carried out per ASTM D638/WI-0812 by the Raw Feedstock Supplier prior to shipping. The COA provided by the Raw Feedstock Supplier must then be supplied by Markforged with each Filament Spool.

8. TEST FAILURE

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

9. SPOOL IDENTIFICATION

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

9.1. TRACEABILITY

Filament Spools must be traceable to date of manufacture and Filament Lot. Filament Lots must be traceable to extruder and Raw Feedstock Lot.

10. STORAGE AND HANDLING OF FILAMENT

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 always be stored with the desiccant pack(s) they are shipped with.

11. SAFETY – HAZARDOUS MATERIALS

The materials, methods, applications, and processes described or referenced in this specification may involve the use of hazardous materials. As with any new industrial process, it is recommended that a hazard assessment is performed, taking into consideration the specifics of each location, personnel, and facility.

Equipment, materials, solutions, and emissions (if applicable) must be controlled, handled, used, and disposed of in accordance with all local, State, and Federal Government Safety, Health, and Environmental Affairs. It must be the sole responsibility of the user to ensure familiarity with, and practice, the safe and proper use of any materials and to take necessary precautionary measures to ensure the health and safety of personnel involved.

The Material Safety Data Sheet (SDS) 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 PCD.

The KPV monitoring must also 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
Rev A	1. Filament class, glass transition, melt temperature and composition requirements for outgoing filament testing were removed from section 6, section 7, and Appendix A. 2. Nitrogen burn out, air burn out and tensile strength of raw incoming feedstock requirements was included in section 6 and section 7.	8/9/2023	Neville Tay
Rev B	1. Table 2: Composition lead in was removed from the front of CF and FR. 2. Added "and the remaining 70% are of Type 1 and FR blend" to the end of the sentence in Section 1.3. 3. 14 CFR 25.853 reference was removed from Section 2. 4. MMPDS reference was removed from Section 2. 5. MF WI-001-Printer Backpressure Testing was added as reference in Section 2. 6. MMPDS (formerly MIL-HDBK-5) reference removed from Section 3. 7. "Units" header in Table 4 through 6 was changed to "Requirements". 8. "Markforged Proprietary" test method in Table 5 was changed to "PCD-000A Onyx FR-A". 9. "Un-verified" was removed from the title of 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 Filament 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 7 – Key Process Variables

Variable	Description	Control Type	SPC Required
Moisture	Moisture of Raw Feedstock Lot, Filament Lot, or Filament Spool sample measured in accordance to ASTM D7191	Range	N/A
Extruder Head Temperature	Temperature of the die head on the filament extruder	Range	Yes
Extruder Melt Temperature	Temperature of the molten filament as measured within the die of the filament extruder	Range	Yes
Extruder Filtration	Presence, design, and orientation of filtering mechanism as required	Discrete	N/A
Extruder Barrel Temperature(s)	Temperature of various zones on the barrel of the filament extruder	Range	Yes
Extruder Die Diameter	Diameter of the die orifice used on the filament extruder	Range	N/A
XX/YY Cross-Sectional Area	Cross-sectional area of the Filament Spool calculated using a single-axis non-contact micrometer	Range	Yes
XY Cross-Sectional Area	Cross-sectional area of the Filament Spool calculated using a 2-axis non-contact micrometer	Range	Yes