



AEROSPACE MATERIAL SPECIFICATION

AMS7101™**REV. A**Issued 2019-10
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Superseding AMS7101

Fused Filament Fabrication, Material for

RATIONALE

Add key process variables (KPVs), statistical process control to monitor KPVs, and feedstock manufacturer requirements for a PCD.

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1. SCOPE

This specification establishes the minimum requirements for fused filament fabrication (FFF) feedstock.

1.1 Slash Sheet

This specification outlines the basic requirements for a FFF feedstock. A separate slash sheet shall contain the product specific FFF technical requirements for each FFF feedstock. This specification is in addition to and in no way limits, supersedes, or abrogates any contractual obligation as required by the applicable procurement documents. In the event of conflict in requirements, the order of precedence shall be:

- Specifications referenced on the drawing,
- Slash sheet associated with this specification,
- This specification, and
- All specifications referenced in this document.

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

1.3 FFF Feedstock Classification

The FFF feedstock shall have a slash sheet associated with it and shall be classified as outlined in this section. Additional types, classes, forms, grades, and colors will be added to this section as new materials are available. A current list of released slash sheets can be found at <http://www.sae.org>. The entity qualifying the FFF feedstock shall work with SAE to provide the statistically valid data to generate the slash sheet and have the material added to this specification.

1.3.1 Type

The type shall specify the predominant resin used in the feedstock. Currently defined types are listed in Table 1. The resin type shall use ASTM D4000 abbreviations (aka, standard symbols); if the resin type is not listed in ASTM D4000, abbreviations known in the industry shall be used. If the base resin is mixed with an amount of another resin, the name shall include "blend" to indicate a mixture of the blended component.

Table 1 - Material types

Type	Base Resin
Type 1	Polyetherimide (PEI) blend
Type 2	Polyetherimide (PEI)

1.3.2 Class

The class specifies polymer thermal characteristics (indicated by Tg) to further identify the material resin type. Currently defined classes are listed in Table 2.

Table 2 - Material classes

Class	Thermal Characteristic Indicated by Glass Transition Temperature⁽¹⁾
Class 1	150 °C ≤ Tg ≤ 200 °C (302 °F ≤ Tg ≤ 392 °F)
Class 2	Tg > 200 °C (Tg > 392 °F)

⁽¹⁾ Glass transition temperature shall be in accordance with ASTM D3418.

1.3.3 Form

The form specifies polymer rheological characteristics (indicated by melt flow rate) to further identify the material resin type. Currently defined forms are listed in Table 3.

Table 3 - Material forms

Form	Rheological Characteristic Indicated by Melt Flow Rate⁽¹⁾
Form 1	5 g/10 min ≤ Melt flow rate ≤ 15 g/10 min
Form 2	15 g/10 min ≤ Melt flow rate ≤ 25 g/10 min

⁽¹⁾ Melt flow rate measured in accordance with 3.5.4.

1.3.4 Grade

The grade specifies quantity and type of fillers or reinforcements such as glass beads, carbon fibers, or carbon nanotubes. Currently defined grades are listed in Table 4. The grade shall be identified by the weight of additive to the closest one weight percent, followed by an abbreviation of filler type (e.g., GB, CF, or CNT) to further define the material. In the case of Grade 0, neat material, no abbreviation shall follow.

Table 4 - Material grades

Grade	Filler Material
Grade 0	Neat, no filler

1.3.5 Color

The color specifies the overall color of the material. Any colorant added to the material that may affect the material properties shall be tested as described herein. If multiple colors are shown to be equivalent through testing, "multiple colors" may be used as the classification with the specific colors tested listed in the slash sheet. A qualitative determination of the color may be used as this descriptor is only used as an identification of a certain composition and not as a color requirement.

2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D3418 Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry

ASTM D4000 Standard Classification System for Specifying Plastic Materials

2.2 Definitions and Acronyms

ADDITIVE MANUFACTURING (AM): Process of joining materials to make parts from 3D model data, usually layer upon layer.

BATCH: Defined quantity of feedstock with uniform properties and composition.

CONSTITUENT MATERIAL: Raw components that will be compounded to produce the final filament feedstock. Each raw material should possess a unique lot or batch identifier as defined by the raw components manufacturer.

FEEDSTOCK LOT: Quantity of feedstock produced under traceable controlled conditions from a single feedstock manufacturing process cycle.

FFF FEEDSTOCK: Bulk raw material supplied to the additive manufacturing building process.

FFF FEEDSTOCK MANUFACTURER: Entity that produces the feedstock.

FFF SYSTEM: Refers to the combination of equipment, material, and software used to create the parts.

FILAMENT: Feedstock characterized by extreme length relative to its uniform cross section.

FILLER: A relatively inert material added to the resin to modify its strength, permanence, working properties, cost, or other qualities.

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.

KEY PROCESS VARIABLE (KPV): Variable in the manufacturing process determined to have the most critical impact on fit, form, and function of the resultant feedstock material.

PART: A physical 3D object created through the fused filament fabrication system.

RECYCLED RESIN: Thermoplastic material that has been reclaimed through additional heat histories from the supplier after polymerization.

VIRGIN RESIN MATERIAL: Thermoplastic material that has no other heat history other than the initial polymerization, compounding, and pelletization performed by the resin supplier.

3. TECHNICAL REQUIREMENTS

3.1 Process Control Document

The manufacturer shall prepare a process control document (PCD). The PCD shall describe the raw materials, manufacturing processes, in-process test methods, and alternate test methods used to document and to control the variation of the product. Once established, the PCD shall be configuration controlled within the feedstock manufacturer's quality management system. Changes to the PCD shall be substantiated and shall be approved by the cognizant engineering organization (CEO). All product shall be produced in accordance with an approved PCD.

3.2 Key Process Variables

The feedstock manufacturer shall establish values, tolerances, measurement methods and measurement frequency for all key process variables (KPVs) of the feedstock production process including but not limited to the variables defined in Appendix A. The KPVs shall be controlled within the PCD. Any changes to the KPVs in the PCD once qualified shall require requalification unless authorized by the CEO.

Process parameters may be omitted from the PCD when substantiated by the feedstock manufacturer and authorized by the CEO.

The values of any KPVs considered proprietary by the feedstock manufacturer may be assigned a code designation and recorded by the feedstock manufacturer in an internal document. Each variation in such variable value shall be assigned a modified code designation.

3.3 Statistical Process Control

The feedstock manufacturer shall establish and maintain procedures and requirements for a statistical process control (SPC) system based on KPVs and FFF feedstock requirements defined in the applicable slash sheets and PCDs. The monitoring, typically using control charts, shall be available to material users upon request, but proprietary information may be coded or normalized.

3.4 Composition

The FFF feedstock composition shall consist of constituent material (including base resin, fillers, etc.) evaluated and controlled by the feedstock manufacturer's quality management system. The feedstock composition shall not be altered following qualification to this specification, except in accordance with Section 4. Each constituent material lot shall be uniquely identified, tested, supplied, and processed in accordance with the feedstock manufacturer's quality management system. Virgin resin shall be used as the constituent unless specifically indicated by the applicable slash sheet. If recycled resin is used for any constituents, the amount and quality of recycled material must be defined and strictly bounded by the feedstock's manufacturer's quality system. Virgin resin and recycled resin are not considered interchangeable and constitute unique entities within the overall composition. The purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that processing conforms to specified requirements.

3.5 Compounding

Material supplied in accordance with this specification shall be processed as controlled by the feedstock manufacturer's quality management system. The feedstock manufacturer shall establish procedures to mitigate contamination during processing.

3.6 FFF Feedstock Requirements

FFF feedstock shall, at a minimum, conform with the requirements listed in Table 5 when tested in accordance with the test methods contained in 3.8.

Table 5 - FFF feedstock requirements

Property	Requirement
Diameter average	±0.05 mm (±0.002 inch) of specified diameter
99.73% of diameter readings in range	±0.1 mm (±0.004 inch) of specified diameter
Diameter min	95% of specified diameter
Diameter max	105% of specified diameter
Ovality	Shall be defined in slash sheet
Diameter exceptions - max local flaws	Shall be defined in slash sheet
Moisture	Shall be defined in slash sheet
Melt flow rate	Shall be defined in slash sheet

3.6.1 Storage and Handling

FFF feedstock, after fabrication and testing, shall be stored in containers according to the feedstock manufacturer's instructions which should include the shelf life at specified storage conditions. Procedures shall be established to prevent contamination of the filament during handling.

3.7 Traceability

Each material container shall be given a unique serial number that is tied to a specific manufacturing lot. That manufacturing lot number shall be tied to individual raw components lots and manufacturing processes. The recording and retention of this data shall be defined by the feedstock manufacturer's quality system. The feedstock manufacturer shall present evidence of the material traceability upon request.

3.8 Test Methods

3.8.1 General Requirements

All tests shall be performed in a controlled environment, as follows: the temperature shall be maintained at $23\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ ($74\text{ }^{\circ}\text{F} \pm 9\text{ }^{\circ}\text{F}$) and relative humidity maintained below 60% unless otherwise specified by the individual test method.

3.8.2 Diameter and Ovality Testing

Diameter testing shall be performed post process, once the material is in its final form and after it has reached room temperature. Diameter and ovality testing shall be performed with calipers, micrometer, laser micrometer, or other industry accepted measurement techniques. In-line diameter measurements during the production run may be used instead of testing after processing if the results are correlated to the post processing testing.

3.8.3 Moisture Testing

Moisture testing shall be performed in accordance with the test method defined in the applicable slash sheet. Moisture testing shall be performed once the material is in its final form, prior to shipping. If moisture content fails to meet the requirement, then the entire lot of product shall be dried in accordance with the drying method defined in the applicable slash sheet and moisture shall be retested. Once an acceptable moisture content measurement is achieved, the entire lot of material is released.

The moisture requirement in the slash sheet may be listed as "no requirement" if the material is known to be not affected by moisture. If "no requirement" is listed, moisture testing is not required by this specification.

3.8.4 Melt Flow Rate

The melt flow rate shall be tested in accordance with the test method defined in the slash sheet.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The feedstock manufacturer is responsible for the development and manufacture of any material submitted in accordance with this specification. The FFF feedstock manufacturer shall supply all samples and shall be responsible for all required tests. The purchaser reserves the right to sample and to perform additional testing deemed necessary to ensure that the quality of the FFF feedstock conforms to the requirements of this specification and the applicable slash sheet.

Quality control by the feedstock manufacturer shall be in accordance with this specification.

Any minor changes in the material manufacturing such as spool length, changes to cleaning process, etc., shall be verified through the testing described in this specification. Any major changes such as raw material suppliers, manufacturing location, etc., that can affect filament properties controlled by this specification shall be tested in accordance with this specification. Filament properties and/or resin properties not controlled by this specification but which could be affected by the major change shall also be evaluated. Specific test methods and acceptance criteria shall be authorized by the CEO.

4.2 Classification of Tests

4.2.1 Lot Acceptance Tests

Tests to determine conformance to the requirements of this specification and the applicable slash sheet shall be performed on every lot of material in accordance with the sampling plan defined by Table 6. Tests shall be conducted in accordance with the test methods defined in 3.8. The test results shall meet the criteria defined by Table 5.

Table 6 - Acceptance test sampling plan

Property	Sampling Plan
Diameter average	Continuous or every spool/container
99.73% of diameter readings in range	Continuous or every spool/container
Diameter min	Continuous or every spool/container
Diameter max	Continuous or every spool/container
Ovality	Continuous or every spool/container
Diameter exceptions - max local flaws	Continuous or every spool/container
Moisture	Every lot
Melt flow rate	Every lot

4.3 Test Report

The feedstock manufacturer shall furnish with each shipment a report showing the results of tests to determine conformance to the acceptance requirements of the slash sheet, and stating that the product conforms to the other technical requirements of this specification. This report shall include the purchase order number, lot number, AMS7101 and the applicable slash sheet (e.g., AMS7101/1) and its revision letter, feedstock manufacturer's identification, value to be reported, form or part number, and quantity.

5. PREPARATION FOR DELIVERY

5.1 Identification and Packaging

Each material shall be packaged in accordance with 3.6.1. The material shall be packaged in such a way that the feedstock can dispense with a uniform force. The container shall be labeled with following information at a minimum. This label and information shall be visible and easily read.

- Name, part number, or product designation
- Lot number
- Date of manufacture
- Feedstock manufacturer location
- AMS7101 and revision and applicable slash sheet and revision

6. ACKNOWLEDGEMENTS

A feedstock manufacturer shall mention this specification number and the applicable slash sheet number and their revision letters, if any, in all quotations and when acknowledging purchase orders.

7. REJECTIONS

Material that does not conform to this specification and the applicable slash sheet will be subject to rejection.