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Standard Specification for Powder Bed Fusion of Plastic Materials[1]

This standard is issued under the fixed designation F3091/F3091M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification describes a method for defining requirements and ensuring component integrity for plastic parts created using powder bed fusion processes. Materials include unfilled formulations and formulations containing fillers, functional additives (for example, flame retardant), and reinforcements or combinations thereof. Processes include all powder bed fusion processes as defined in Terminology F2792.

1.2 This specification is intended for use by manufacturers of plastic parts using powder bed fusion and for customers procuring such parts.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D638 Test Method for Tensile Properties of Plastics
D4000 Classification System for Specifying Plastic Materials
D6779 Classification System for and Basis of Specification for Polyamide Molding and Extrusion Materials (PA)
D6980 Test Method for Determination of Moisture in Plastics by Loss in Weight
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
F2792 Terminology for Additive Manufacturing Technologies (Withdrawn 2015)[3]

2.2 *ISO/ASTM Standard:*[2]

ISO/ASTM 52921 Standard Terminology for Additive Manufacturing – Coordinate Systems and Test Methodologies

2.3 *ISO Standards:*[4]

ISO 527-1 Determination of tensile products – Part 1: General principles
ISO 3310-1 Test Sieves – Technical Requirements and Testing – Part 1: Test Sieves of Metal Wire Cloth
ISO 9001 Quality management systems – Requirements
ISO 13485 Medical Devices – Quality Management System
ISO 15512 Plastics – Determination of Water Content - Second Edition

2.4 *Other Standards:*

AS9100 Quality Systems – Aerospace – Model for Quality Assurance in Design, Development, Production, Installation and Servicing[5]
ASQC C1 Standard C1 Specification of General Requirements for a Quality Program[6]

3. Terminology

3.1 Additional definitions are listed in Terminology F2792.

3.2 *Definitions:*

3.2.1 *batch processing, n*—powder preparation and delivery process in which a powder batch is blended using specific quantities of virgin and used powder for use as feedstock, sometimes in quantities larger than the machine build volume or feed region(s) or both.

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[1] This specification is under the jurisdiction of ASTM Committee F42 on Additive Manufacturing Technologies and is the direct responsibility of Subcommittee F42.05 on Materials and Processes.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[5] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, http://www.sae.org.

[6] Available from American Society for Quality (ASQ), 600 N. Plankinton Ave., Milwaukee, WI 53203, http://www.asq.org.

3.2.2 *build cycle, n*—single cycle in which one or more components are built up in layers in the process chamber of the machine.

3.2.3 *build volume, n*—total usable volume available in the machine for building parts.

3.2.4 *continuous feed processing, n*—powder preparation and delivery process in which a powder batch is dynamically blended in a steady state process to deliver feedstock as needed to the powder bed.

3.2.5 *customer, n*—entity that receives end use parts from a part manufacturer.

3.2.6 *feed region, n—in batch processing*, the lcoation(s) in the machine where feedstock is stored and from which a portion of the feedstock is repeatedly conveyed to the part bed during the build cycle.

3.2.7 *feedstock, n*—the bulk raw material supplied to the additive manufacturing building process.

3.2.8 *master bounding box, n*—the orthogonally oriented minimum perimeter bounding box which encloses all of the parts in a single build.

3.2.9 *nesting, n*—parts that are made in one build cycle and are located such that their arbitrarily oriented minimum bounding boxes will overlap.

3.2.9.1 *Discussion*—For a definition of the arbitrarily oriented minimum bounding boxes, see ISO/ASTM 52921.

3.2.10 *overflow region, n*—the location(s) in the machine where excess powder is stored during a build cycle.

3.2.10.1 *Discussion*—Feedstock is usually conveyed to the powder bed in excess of the volume needed.

3.2.11 *part cake, n*—powder remaining in the powder bed at the end of a build cycle surrounding the fabricated components.

3.2.12 *part manufacturer, n*—entity that processes materials and produces parts using additive manufacturing equipment.

3.2.13 *powder batch, n*—powder used as feedstock that may be used powder, virgin powder or a blend of the two.

3.2.14 *powder lot, n*—quantity of virgin powder produced under traceable, controlled conditions from a single unifying manufacturing process cycle and provided with source documentation as described in 6.2.2.

3.2.14.1 *Discussion*—Source documentation is also referred to as a "certificate of conformance", "factory certificate", or "certificate of analysis".

3.2.15 *powder vendor, n*—entity that supplies or distributes virgin powder.

3.2.16 *used powder, n*—powder that has been processed in at least one previous build cycle.

3.2.16.1 *Discussion*—Subcategories may include powder from the part cake, feed, and overflow region.

3.2.17 *virgin powder, n*—unused powder from a single powder lot.

4. Process Classification

4.1 *Class I*—Most rigorous process classification intended for use in producing the highest quality parts with the highest degree of confidence through detailed traceability required in quality documents.

4.2 *Class II*—A rigorous process classification intended for use in producing high-quality parts with less traceability than Class I.

4.3 *Class III*—A general process classification intended for use as a guideline in processing quality parts using best practices with minimum traceability.

4.4 Specific class-dependent recommendations and requirements are described regarding fabrication of test specimens (7.1), mechanical property testing (7.4.2, Table 1), powder batch identification (8.5.4 – 8.5.6), multiple laser systems (8.7.3.1), part certification (13.3 – 13.5) and quality program requirements (S3). Additional requirements may be negotiated between the customer and part manufacturer.

5. Part Ordering Information

5.1 Orders for parts to this specification shall include the following information:

5.1.1 Reference to this ASTM International standard, process classification (Section 4), materials classification (Section 6), material and process certification requirements, number of test specimens as needed (Section 7), post-processing requirements (8.8), definition of general dimensional characteristics and tolerance (Section 9), part marking requirements (Section 14), packaging requirements (Section 15), digital product definition (CAD model), customer purchase order number and quantity in pieces.

5.2 Orders for parts may include the following information:

5.2.1 Engineering drawings, bill of materials, assembly instructions, manufacturing plan and special engineering requirements (Section 7).

FIG. 1 Specifications for Mechanical Testing of Powder Bed Fusion Polymer Parts[A]

Specification	Class I	Class II	Class III
Build certification	A minimum of three *XY* or *YX* tension specimens with at least one specimen above and below the build envelope and *ZX* or *ZY* tension specimens staggered at edges of the master bounding box such that all layers of the build envelope fall within a tension specimen gage length.	A minimum of three *ZX* or *ZY* tension specimens at the edge of the master bounding box. If the build height is less than 57 mm [2.25 in.], use instead two *XZ* and two *YZ* specimens outside the build envelope.[B]	No tension specimens needed unless requested by customer.

[A] For part orientation notation, see ISO/ASTM 52921. For multiple laser systems, see 8.7.3.1.
[B] For Test Method D638 or ISO 527, subsized tension specimens may be used for *ZX* or *ZY* samples for build heights less than 57 mm [2.25 in.].

6. Materials

6.1 *Material Specification—*This specification is intended to facilitate communication between part manufacturer and customer and to establish a condition for acceptance. Material composition of the part(s) shall be defined as the brand name of the powder to be supplied by the powder vendor or in accordance with a standard classification system. Required material properties of fabricated parts and test specimens and test methods, if any, shall be stated in the order. For parts with direction-dependent or direction-independent properties, the specification of test specimens and directionality are addressed in 7.1 through 7.4.

6.1.1 Plastic materials and testing requirements may alternatively be specified by composition in accordance with Classification D4000. These standard classification systems may be applied to virgin powder, powder batches, and feedstock. Use of Classification D4000 is intended to be a means of identifying plastic materials and associated test methods used to support fabrication of end items or parts. It is not intended to be a method for selection of materials.

6.1.2 Several nomenclature examples are listed. This listing is not meant to be complete or to be used as an endorsement of any specific material or material composition.

6.1.2.1 *Unreinforced polyamide 12 powder*—Classification D6779 PA0400 or PA0410.

6.1.2.2 *Polyamide 12 powder with 15 % by weight glass spheres added*—Classification D6779 PA0400 GE15 A00000.

6.1.2.3 *LS processed unfilled polyaryletherketone test part with a tensile strength at break of 90 MPa, tensile modulus of 4250 MPa, and elongation at break of 3 % (ISO 527-1)*—Classification D4000 PAEK0000 KD090 KN042 LD003.

6.2 *Virgin Powder:*

6.2.1 The composition, particle size, particle size distribution, powder morphology, viscosity, thermal characteristics and bulk density shall be acceptable for the powder bed fusion process, as certified by the powder vendor before or at delivery.

6.2.2 Each powder lot shall be accompanied by documentation to include, at a minimum, powder vendor name or classification as in 6.1.1 or 6.1.2, material identification (including a material safety data sheet(s) (SDS) and Chemical Abstracts Service (CAS) registry number(s)), lot number, mean particle size, particle size distribution, and rheological and thermal characteristics such as those obtained by melt flow or differential scanning calorimetry.

7. Fabrication of Test Specimens

7.1 Unless otherwise specified, all test specimens shall be additive manufactured parts that are neither finished nor post-processed. Redundant test specimens may be produced during the same build in the event retesting becomes necessary per 8.7.3.2 and 11.2. Test specimens shall be included in the same build with the parts for which test specimens are required. An exception for tension specimens for Class 1 and Class II parts may be made at the direction of the customer when production runs involve two or more separate builds. The frequency of test specimen production across two or more builds shall be clearly specified by the customer in the order.

7.2 *Direction-Independent Properties*—Test specimens used to assess direction-independent properties may be built with associated parts anywhere in the build at the part manufacturer's discretion. Unless otherwise specified by the customer or otherwise stated in the specific test method to be used, a minimum of three test specimens per build shall be evaluated. The specimen may be aligned to any direction axis (*X*, *Y*, or *Z*) chosen by the part manufacturer.

7.3 *Nonmechanical Direction-Dependent Properties*—Test specimens used to assess nonmechanical, potentially direction-dependent properties such as electrical resistance shall be built in a location deemed by the part manufacturer to be the least favorable orientation within the master bounding box for measurement of the property in question. This would typically be in the *Z* direction and on a surface of the master bounding box. Unless otherwise specified by the customer or otherwise specified in the specific test method to be used, a minimum of three test specimens per build shall be evaluated.

7.4 *Mechanical Direction-Dependent Properties:*

7.4.1 *All Mechanical Property Testing Except Tension Testing*—Test specimens other than tension testing specimens used to assess mechanical properties such as flexural modulus, impact strength, and shear modulus shall be built in a location and direction deemed by the part manufacturer to be the least favorable orientation within the master bounding box for measurement of the property in question. This would typically be in the *Z* direction and on a surface of the master bounding box. Three test specimens per build shall be evaluated using Test Method D638 or ISO 527 unless otherwise specified by the customer or otherwise specified within a specific test method required for part acceptance. Unless otherwise specified, the specimen type, tensile strength and percent elongation at break shall be recorded.

7.4.2 *Tension Testing*—The number, orientation, and location of test specimens for evaluation of tensile mechanical properties are tabulated in Table 1. Every build containing Class I or Class II parts shall include test specimens as described in Table 1.

8. Material Processing

8.1 Virgin powder shall be supplied with an accompanying certificate of conformance from the powder vendor and shall be segregated based on virgin powder lot number in preparation for creation of powder batches and feedstock.

8.2 Virgin and used powder shall be stored using containers and methods to minimize contamination, cross contamination between lots and, for atmosphere-sensitive plastics, air exposure.

8.3 All powders shall be stored according to the powder vendor's specifications.

8.4 Used powder shall be sieved using sieves complying with Specification E11 or ISO 3310-1 before blending to eliminate foreign objects and limit the maximum particle size.

8.5 *Powder Batch/Powder Mixing:*

8.5.1 Powder for batch processing shall be blended such that the resulting powder batch is uniformly mixed.

8.5.2 Virgin powder for processing may be a blend from several powder lots unless otherwise specified by the customer as communicated through the purchase order or a customer-specified manufacturing plan.

8.5.3 All powder batches shall be stored in an environment complying with 8.3. Some polymeric powders are prone to absorption of moisture that may adversely influence their processing by laser sintering. In this case, the use of dryers is recommended to control powder moisture content as needed. Moisture content of polymeric materials shall be assessed using Test Method D6980, ISO 15512 or an equivalent method.

8.5.4 The powder batch (batch processing) or powder blend (continuous feed processing) shall be formulated based on the manufacturing plan (Class I required, Class II and Class III optional).

8.5.5 For batch processing, the powder batch shall have a unique identifier (batch number) to facilitate traceability (Class I required, Class II and Class III optional).

8.5.6 For each powder batch (batch processing) or powder blend (continuous feed processing), virgin powder lot number(s) and the blend ratio of virgin and used powder shall be documented. Additional documentation may include used powder sieve size, blend parameters, resultant viscosity, and operator name (Class I and Class II required, Class III optional).

8.6 *Feedstock:*

8.6.1 Feedstock materials are divided into two categories: virgin powder and used powder. Used powder may be categorized further as overflow powder or part cake powder.

8.6.2 For both batch processing and continuous feed processing, feedstock is mixed before being processed in the powder bed. For batch processing, mixing is performed before feedstock loading into the machine. In the case of continuous feed processing, mixing is a component of the process of delivering powder to the machine.

8.6.3 All feedstock shall conform to requirements stated in 8.5. If applicable, feedstock shall comply with additional customer-specified requirements.

8.7 *Production Build:*

8.7.1 A production build shall have a part or multiple parts that may be nested in the recommended build volume, sintering parameters, tension specimens, warm-up layer, and cool-down layer. Sacrificial geometries may be used when a part may be susceptible to curl in the build.

8.7.2 The part manufacturer shall record build layout, sintering parameters, and material batch for each build.

8.7.3 Test specimens shall be positioned to represent all parts that are in the build per Section 7.

8.7.3.1 In multiple laser systems, for Class I and Class II part builds, at least two tension specimens in addition to those specified in 7.4 shall be placed in the build such that the laser overlap region falls within the gage length of the tension specimen if production parts cross through a beam overlap region. The specimens shall be located at opposite extents of the master bounding box, oriented perpendicular to and spanning the overlap plane, and represent the maximum extents of all parts in the build layout.

8.7.3.2 Redundant tension specimens may be produced to resolve tension test anomalies such as failure outside the gage length. Redundant specimen builds shall be positioned in close proximity to primary tension specimens so as to duplicate them.

8.7.3.3 Tension specimens shall be identified by their location and orientation in the build layout. Identification shall not be in the gage section of the tension specimen.

8.7.4 The additive manufacturing equipment shall be cleaned per the original equipment manufacturer's instructions or recommendations or both along with the part manufacturer's best practices before each build.

8.7.5 After build completion, part breakout shall be performed. Heated builds shall be cooled in a manner to control post-build part distortion as a result of temperature gradient formation. The powder and part temperature at breakout shall be low enough to control discoloration as a result of atmospheric effects if appearance is a factor. Excess material shall be removed without damage to the parts and test specimens. Tools or methods that avoid damage to the part should be part of the manufacturing plan. Residual material that can be removed by compressed air shall be removed before post processing.

8.7.6 All parts shall be identified as soon as possible after part breakout is completed if parts are not already self-identified.

8.7.7 Production builds shall comply with all customer-specified requirements. When explicitly stated in an order, customer specifications may exceed or waive the specification requirements contained in this standard.

8.8 *Post Processing:*

8.8.1 Parts may be finished (for example, drilled, holes reamed, deburred, or hand sanded) to remove excess material from the part to meet requirements. A tumbler may also be used if the part geometry allows.

8.8.2 Parts shall be visually examined for defects and anomalies (for example, curl, growth, nodules, discoloration, distortion, layer lines, and so forth). Parts may be scrapped if visual defects are present.

8.8.3 High-intensity light may be required to check internal features. The light source shall be sufficient to yield penetration of the part structure requiring inspection.

8.8.4 If applicable, post-processing methods shall comply with all customer-specified requirements. Customer specification may supersede the methods listed.

9. Dimensional Tolerances

9.1 Tolerance, given in absolute or relative format, shall be defined by the customer in consultation with the part manufacturer. As a general rule, tolerance may be specified to be the larger of ±0.3 % of an associated length measurement or ±0.1 mm [0.004 in.].

10. Source Inspection

10.1 If the customer desires that a representative inspect or witness the inspection to the requirements stated in the purchase order or purchase contract and testing of the material