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Standard Guide for Additive Manufacturing of Polymers — Material Extrusion — Recommendation for Material Handling and Evaluation of Static Mechanical Properties¹

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1. Scope

1.1 This guide covers existing standards or variations of existing standards that may be applicable to determine specific static mechanical properties of polymeric specimens fabricated with the material extrusion (MEX) additive manufacturing (AM) process. The test methods covered within this document are recommendations supplied coming from the experience previous material qualification programs have provided. Additional test methods may be considered as well depending when evaluating material performance for specific applications. Recommendations for material handling prior to testing and characterization are included as they can greatly affect material properties. It is for the end user to determine if the recommended tests adequately evaluate the material performance for the intended application.

1.2 *Units*—The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.3 *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.*

1.4 *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.*

¹ This guide is under the jurisdiction of ASTM Committee F42 on Additive Manufacturing Technologies and is the direct responsibility of Subcommittee F42.01 on Test Methods.

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2. Referenced Documents

2.1 ASTM Standards:²

- D638 Test Method for Tensile Properties of Plastics
- D695 Test Method for Compressive Properties of Rigid Plastics
- D790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
- D3039 Test Method for Tensile Properties of Polymer Matrix Composite Materials
- D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
- D5379 Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method
- D5766 Test Method for Open-Hole Tensile Strength of Polymer Matrix Composite Laminates
- D5961 Test Method for Bearing Response of Polymer Matrix Composite Laminates
- D6484 Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates
- D6641 Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture
- D6742 Practice for Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates
- D7191 Test Method for Determination of Moisture in Plastics by Relative Humidity Sensor
- F2971 Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing

2.2 ISO/ASTM Standards:²

- ISO/ASTM 52900 Additive manufacturing — General principles — Terminology
- ISO/ASTM 52921 Standard terminology for additive manufacturing — Coordinate systems and test methodologies

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. Terminology

3.1 *Definitions*—Terminology relating to additive manufacturing (AM) in Terminologies ISO/ASTM 52900 and ISO/ASTM 52921 shall apply.

4. Significance and Use

4.1 As noted in many of the standards in Section 2, there are multiple factors that may influence the reported properties, including material choice, material anisotropy, methods of material storage and preparation, porosity, methods of specimen storage and preparation, orientation and specimen build plate location during fabrication, testing environment, specimen alignment and gripping during testing, testing speed, and testing temperature. These factors should be recorded according to Practice F2971 and the guidelines of the referenced standards. This guide is intended to inform users of best practices for static mechanical testing of additive manufactured polymer specimens fabricated using material extrusion (MEX).

5. Material Handling Considerations

5.1 All material exposure conditions pre- and post-fabrication should be clearly defined and documented to minimize environmental effects on material properties.

5.2 *Inherent Material Properties*—There is a large selection of polymer materials available for MEX fabrication, each material having their own inherent characteristics that can greatly affect both fabrication capability and performance after fabrication. Filament materials are recommended to be stored in a controlled environment to mitigate effects of exposure to temperature, humidity, and UV exposure, among other exposures that may degrade performance of fabricated parts.

5.3 Two material characteristics that can significantly affect tested material properties include a material's moisture absorption and thermal history. Hygroscopic materials are very susceptible to moisture absorption even when located in ambient environments with moderate humidity. For this reason, moisture content of materials under investigation shall be controlled. Nylon is one such material type that readily absorbs moisture from the surrounding air and the rate of absorption is increased in higher humidity environments and even more so when submerged. Other materials such as PLA are much less susceptible to moisture absorption and therefore require less monitoring regarding storage and filament moisture content during fabrication. Secondly, a material's thermal history at both elevated and cold temperatures prior to fabrication can significantly affect fabrication and mechanical performance. A material's glass transition temperature (T_g) is the point at which a material begins to change from a glassy to a rubbery state. It is important to avoid exposing filament materials to temperatures near its inherent T_g to minimize thermal cycling effects on material properties. Some studies have shown that extended exposure to elevated and cold temperatures before fabrication can result in variation or degradation in mechanical performance of fabricated specimens. Moisture absorption and thermal history are not the only conditions that should be controlled but each is known to be a major contributor to material performance variation.

5.4 *Filament Material Conditioning*—Environment control should be in place for both pre- and post-fabrication states (filament and fabricated specimens), as material performance for both fabrication and testing mechanical performance can be altered if environmental exposure occurs in either state. Testing of polymer filament for moisture content before fabrication is recommended to follow Test Method D7191. Recommended acceptable values may be defined per material manufacturer recommendations. If material moisture content exceeds the recommended passing limit, material drying should be required at a predetermined temperature and duration to reduce the material moisture content to a passing level. Temperature, duration, and process for drying is specific to the material being used and it is commonly recommended to use a temperature at least 14 °C (25 °F) below the material's T_g unless otherwise stated by the manufacturer. Moisture testing should occur after the drying procedure to verify that the material drying sufficiently reduced the material moisture content before fabrication.

5.5 *Specimen Material Conditioning*—Post-fabrication specimen conditioning also plays a significant role in physical and mechanical performance. Investigations of material performance as a result of various specimen conditioning effects is a typical area of interest for end users depending on the expected application for the materials. Some standard specimen and testing conditions that are of interest in most cases include, but are not limited to, room temperature dry (RTD), cold temperature dry (CTD), elevated temperature dry (ETD), and elevated temperature wet (ETW). To achieve a dry or wet (saturated) material state or both before mechanical testing it is recommended to use Test Method D5229/D5229M to validate when a material has stabilized its moisture content via periodic weight measurements. Test temperatures are specific to the material under investigation and should be determined by the end user based on end-use application.

5.6 *Specimen Handling*—If available, follow specimen handling conditions provided within each available ASTM test standard. In the absence of specified material handling conditions, appropriate methods can be used to minimize effects of ambient environment on conditioned specimens. One potential way to accomplish this is to store specimens properly in between conditioning and testing. For wet conditioned specimens, a small moist fabric towel should be placed in a sealed bag with the specimens after the specimen has reached saturation from conditioning. The moist towel should not introduce excess moisture within the bag during specimen storage prior to testing. The goal of this is to keep the specimen at a saturated steady state prior to testing. Similarly, dried specimens should be placed in a sealed bag with a desiccant pack to maintain a dried specimen state. It is recommended that specimens in a sealed bag be tested within two weeks from the end of conditioning or within 8 h if specimens are not stored in the sealed bag environment.

6. Fabrication Considerations

6.1 *Fabrication Orientation Overview*—It is an inherent property within the MEX process that the same geometry specimen fabricated in different orientations will have different