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Standard Guide for Evaluating Mechanical Properties of Metal Materials Made via Additive Manufacturing Processes¹

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1. Scope

1.1 This standard serves as a guide to existing standards or variations of existing standards that may be applicable to determine specific mechanical properties of materials made with an additive manufacturing process.

1.2 As noted in many of these referenced standards, there are several factors that may influence the reported properties, including material, material anisotropy, method of material preparation, porosity, method of specimen preparation, testing environment, specimen alignment and gripping, testing speed, and testing temperature. These factors should be recorded, to the extent that they are known, according to Practice F2971 and the guidelines of the referenced standards.

1.3 The following standards are not referred to directly in the guide but also have information that may be useful in the testing of metal test specimens made via additive manufacturing: A370, A1058, B211, B348, B557, B565, B724, B769, E3, E6, E7, E290, E467, E468, E837, E915, E1049, E1823, E1942.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *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.*

1.6 *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

- A370 Test Methods and Definitions for Mechanical Testing of Steel Products
- A1058 Test Methods for Mechanical Testing of Steel Products—Metric
- B211 Specification for Aluminum and Aluminum-Alloy Rolled or Cold-Finished Bar, Rod, and Wire (Metric) B0211_B0211M
- B348 Specification for Titanium and Titanium Alloy Bars and Billets
- B557 Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products
- B565 Test Method for Shear Testing of Aluminum and Aluminum-Alloy Rivets and Cold-Heading Wire and Rods
- B645 Practice for Linear-Elastic Plane-Strain Fracture Toughness Testing of Aluminum Alloys
- B646 Practice for Fracture Toughness Testing of Aluminum Alloys
- B647 Test Method for Indentation Hardness of Aluminum Alloys by Means of a Webster Hardness Gage
- B648 Test Method for Indentation Hardness of Aluminum Alloys by Means of a Barcol Impressor
- B724 Test Method for Indentation Hardness of Aluminum Alloys by Means of a Newage, Portable, Non-Caliper-Type Instrument (Withdrawn 2013)³
- B769 Test Method for Shear Testing of Aluminum Alloys
- B909 Guide for Plane Strain Fracture Toughness Testing of Non-Stress Relieved Aluminum Products
- E3 Guide for Preparation of Metallographic Specimens
- E6 Terminology Relating to Methods of Mechanical Testing
- E7 Terminology Relating to Metallography

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.

- E8/E8M Test Methods for Tension Testing of Metallic Materials
- E9 Test Methods of Compression Testing of Metallic Materials at Room Temperature
- E10 Test Method for Brinell Hardness of Metallic Materials
- E18 Test Methods for Rockwell Hardness of Metallic Materials
- E21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials
- E23 Test Methods for Notched Bar Impact Testing of Metallic Materials
- E111 Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus
- E132 Test Method for Poisson's Ratio at Room Temperature
- E140 Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness
- E143 Test Method for Shear Modulus at Room Temperature
- E209 Practice for Compression Tests of Metallic Materials at Elevated Temperatures with Conventional or Rapid Heating Rates and Strain Rates
- E238 Test Method for Pin-Type Bearing Test of Metallic Materials
- E290 Test Methods for Bend Testing of Material for Ductility
- E292 Test Methods for Conducting Time-for-Rupture Notch Tension Tests of Materials
- E384 Test Method for Microindentation Hardness of Materials
- E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness of Metallic Materials
- E448 Practice for Scleroscope Hardness Testing of Metallic Materials (Withdrawn 2017)³
- E466 Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials
- E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System
- E468 Practice for Presentation of Constant Amplitude Fatigue Test Results for Metallic Materials
- E606 Test Method for Strain-Controlled Fatigue Testing
- E647 Test Method for Measurement of Fatigue Crack Growth Rates
- E740 Practice for Fracture Testing with Surface-Crack Tension Specimens
- E837 Test Method for Determining Residual Stresses by the Hole-Drilling Strain-Gage Method
- E915 Practice for Verifying the Alignment of X-Ray Diffraction Instruments for Residual Stress Measurement
- E1049 Practices for Cycle Counting in Fatigue Analysis
- E1221 Test Method for Determining Plane-Strain Crack-Arrest Fracture Toughness, K_{Ia} , of Ferritic Steels
- E1290 Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness Measurement (Withdrawn 2013)³
- E1304 Test Method for Plane-Strain (Chevron-Notch) Fracture Toughness of Metallic Materials
- E1450 Test Method for Tension Testing of Structural Alloys in Liquid Helium
- E1457 Test Method for Measurement of Creep Crack Growth Times in Metals
- E1681 Test Method for Determining Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials
- E1820 Test Method for Measurement of Fracture Toughness
- E1823 Terminology Relating to Fatigue and Fracture Testing
- E1875 Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio by Sonic Resonance
- E1876 Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio by Impulse Excitation of Vibration
- E1942 Guide for Evaluating Data Acquisition Systems Used in Cyclic Fatigue and Fracture Mechanics Testing
- E2368 Practice for Strain Controlled Thermomechanical Fatigue Testing
- E2472 Test Method for Determination of Resistance to Stable Crack Extension under Low-Constraint Conditions
- E2714 Test Method for Creep-Fatigue Testing
- E2760 Test Method for Creep-Fatigue Crack Growth Testing
- E2789 Guide for Fretting Fatigue Testing
- F2971 Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing
- F2792 Terminology for Additive Manufacturing Technologies (Withdrawn 2015)³
- ISO/ASTM 52921 Terminology for Additive Manufacturing—Coordinate Systems and Test Methodologies
- 2.2 ISO Standards:⁴
- EN ISO 148-1 Metallic materials—Charpy pendulum impact test—Part 1: Test method
- ISO 148-3 Metallic materials—Charpy pendulum impact test—Part 3: Preparation and characterization of Charpy V-notch test pieces for indirect verification of pendulum impact machines
- ISO 377 Steel and steel products—Location and preparation of samples and test pieces for mechanical testing
- ISO 1099 Metallic materials—Fatigue testing—Axial force-controlled method
- ISO 1143 Metallic materials—Rotating bar bending fatigue testing
- ISO 1352 Metallic materials—Torque-controlled fatigue testing
- EN ISO 4545-1 Metallic materials—Knoop hardness test—Part 1: Test method
- ISO/DIS 5173 Destructive tests on welds in metallic materials—Bend tests
- EN ISO 6506-1 Metallic materials—Brinell hardness test—Part 1: Test method
- EN ISO 6507-1 Metallic materials—Vickers hardness test—Part 1: Test method
- EN ISO 6508 Metallic materials—Rockwell hardness test—Part 1: Test method (scales A, B, C, D, E, F, G, H, K, N, T)

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

- ISO 6892-1 Metallic materials—Tensile testing—Part 1: Method of test at room temperature
- ISO 6892-2 Metallic materials—Tensile testing—Part 2: Method of test at elevated temperature
- EN ISO 7438 Metallic materials—Bend test
- ISO 11531 Metallic materials—Earing test
- ISO 12106 Metallic materials—Fatigue testing—Axial-strain-controlled method
- ISO 12108 Metallic materials—Fatigue testing—Fatigue crack growth method
- ISO 12111 Metallic materials—Fatigue testing—Strain-controlled thermomechanical fatigue testing method
- ISO 12135 Metallic materials—Unified method of test for the determination of quasistatic fracture toughness
- ISO 12737 Metallic materials—Determination of plane-strain fracture toughness
- ISO 14556 Steel—Charpy V-notch pendulum impact test—Instrumented test method
- EN ISO 14577 Metallic materials—Instrumented indentation test for hardness and materials parameters—Part 1: Test method
- ISO/TR 14936 Metallic materials—Strain analysis report
- ISO 15579 Metallic materials—Tensile testing at low temperature
- ISO 19819 Metallic materials—Tensile testing in liquid helium
- ISO 22889 Metallic materials—Method of test for the determination of resistance to stable crack extension using specimens of low constraint
- ISO 26203-1 Metallic materials—Tensile testing at high strain rates—Part 1: Elastic-bar-type systems
- ISO 26203-2 Metallic materials—Tensile testing at high strain rates—Part 2: Servo-hydraulic and other test systems
- ISO 27306 Metallic materials—Method of constraint loss correction of CTOD fracture toughness for fracture assessment of steel components
- ISO/TR 29381 Metallic materials—Measurement of mechanical properties by an instrumented indentation test—Indentation tensile properties
- ISO 3369 Impermeable sintered metal materials and hardmetals—Determination of density
- ISO 3452-1 Non-destructive-testing—Penetration testing—Part 1: General principles

3. Terminology

3.1 Definitions:

3.1.1 Terminology relating to additive manufacturing in Terminology F2792 shall apply.

3.1.2 Terminology relating to additive manufacturing in ISO/ASTM 52921 shall apply.

4. Measuring Deformation Properties

4.1 Tension:

4.1.1 The procedures outlined in Test Methods E8/E8M, E21, E1450, ISO 6892-1, ISO 6892-2, ISO 15579, and ISO 19819 explain guidelines for tension testing under various conditions to determine a material's yield and tensile strengths. All are applicable to materials made additively, but sheet-,

wire-, and rod-shaped specimens with small diameters are difficult to build through an additive process.

4.1.2 In the tension testing procedures outlined in Test Methods E292 (for determining a material's rupture strength) and Practice E740 (for determining metal plate yield strength), Test Methods E8/E8M's methods are followed, but the samples are first prepared with a notch or surface-crack before subjecting them to tension. While Test Method E292 is applicable to materials made additively, it must be noted that thin specimens made according to Practice E740 may be challenging to make in some additive manufacturing processes.

4.1.3 Two ISO Standards, ISO 26203-1 and ISO 26203-2, describe testing sheet metal, such as the material used for automotive bodies, at high strain rates. These standards are not applicable to materials made additively, because sheet material would not be made with such a process.

4.2 Compression:

4.2.1 The procedures outlined in Test Methods E9 and Practice E209 describe the basic method for uniaxial compression testing of metallic samples at various temperatures. The procedures are used in determining a material's compressive yield strength and compression strength. These standards are applicable to materials made additively, but not all of the sample types (thin sheets) can be successfully built through an additive process.

4.3 Bearing:

4.3.1 The procedures outlined in Test Method E238 describe the method used to determine bearing yield strength and bearing strength for a rectangular metal specimen containing a hole for a bearing pin. This standard is applicable to materials made additively, but the surface finish requirements and some thickness requirements for the specimen may be problematic for some additive manufacturing processes.

4.4 Bend:

4.4.1 Practice E209 describes the methods that determine the limit of plastic deformation allowed in a metallic material during bending. The criterion used to evaluate the quality of materials includes their ability to resist cracking or other surface irregularities. ISO 7438 includes plastic deformation methods to evaluate a material's ability to resist cracking. ISO 7438 also includes the methodology behind measuring the bending strength, the limit of elasticity bending, bending moments and the bending angle using plastic deformation methods. These standards are also applicable for metal based additive manufactured parts.

4.5 Modulus:

4.5.1 The following section includes standard test methods to evaluate elastic moduli and Poisson's Ratio. These test methods could be used in the determination of elastic properties of metal based AM materials.

4.5.2 Tension tests, as described by Test Methods E8/E8M, can be used to determine the Young's modulus, tangent modulus and chord modulus of AM structural materials. Test Method E111 describes how to determine the elastic material property based on the tension test (E8/E8M) or compression test (E9). This standard also can be used to determine the