INTERNATIONAL

Designation: F3122 − 14 (Reapproved 2022)

Standard Guide for Evaluating Mechanical Properties of Metal Materials Made via Additive Manufacturing Processes[1]

This standard is issued under the fixed designation F3122; 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 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.*

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

[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.

Current edition approved April 1, 2022. Published April 2022. Originally approved in 2014 as F3122–14. DOI: 10.1520/F3122-14R22.

[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

Young's modulus, tangent modulus and chord modulus using the stress-strain behavior.

4.5.3 Poisson's ratio is the ratio of transverse strain to the corresponding axial strain, and is an intrinsic material property. This ratio can be useful to further describe any anisotropic behavior of additively produced bulk materials. Test Method E132 describes the method to determine Poisson's ratio based on the results of a tension test on a rectangular specimen.

4.5.4 Test Method E143 describes the procedure for calculating the Shear modulus on specimens with a round shape, such as a solid cylinder or a tube. This standard describes the use of an externally applied torque, and subsequent calculation and determination of the Shear modulus. Shear modulus is a helpful property used in the design of rotating technical parts, such as, rotating shafts, springs or screws.

4.5.5 Two alternative methods to determine the dynamic Young's modulus, Shear modulus and Poisson's ratio are described in Test Methods E1875 and E1876. These test methods include guidelines for making measurements at temperatures between -195 to 1200°C. Additionally, formulas can also be found that are used to calculate the dynamic elastic properties based on the elastic resonance of the specimens. Both Test Methods E1875 and E1876 require specimens that possess specific mechanical resonant frequencies. The difference between these two standards is the application of a transducer, which transforms a cyclic electrical signal from the oscillator into a mechanical force on the specimen.

4.6 *Hardness:*

4.6.1 The following indentation tests may help to define the hardness of additive manufactured parts. Hardness is not a fundamental material property, but the wide variety of hardness test methods in use today help predict a material's resistance to plastic deformation or wear resistance, or both against abrasive stress. Due to the subjective nature of the present hardness tests, the desired hardness test and loading size must be specified prior to testing. Regardless of the hardness test specified, all methods require preparation of the material's surface before testing. Prior to testing, the sample thickness size must also be considered, because if the sample is too thin, the hardness value measured can be inaccurate.

4.6.2 Brinell hardness testing defines the determination of the hardness of a material, using a spherical shaped indenter at room temperature. Test Method E10 and ISO 6506-1 provide guidance on the Brinell hardness test, which is based on the measurement of the diameter from the impact of a removed indenter.

4.6.3 Vickers and Knoop are hardness test methods that both use pyramidal shaped indenters, but have different face angles on the indentations, and also specify different ranges of the loading force. Knoop (0.098 N to 19.614 N) could be helpful to determine the micro-hardness of separate inclusions in the structure of additive metals. Test Method E384 and ISO 4545-1 describe the Knoop hardness test. Vickers (0.098 N to 980.07 N) may be helpful in evaluating both the micro- and macro-hardness of additive manufactured metal parts. The Vickers hardness test is described in Test Method E384 and ISO 6507-1. The evaluation of the hardness by Vickers and Knoop is based on the measurement of the diagonal lengths from the impact of the removed indenter.

4.6.4 Test Methods E18 and ISO 6508-1 provide information on the Rockwell hardness test. Both tungsten carbide balls (HRB) and diamond sphero-conical indenters (HRC) can be used for the Rockwell hardness test, which is done at room temperature. One main advantage of this hardness test in comparison to the previously described test methods is Rockwell's ability to measure the indention depth directly.

4.6.5 The Scleroscope hardness test method, which is a dynamic measurement, is described in Practice E448. This dynamic indentation hardness test uses a calibrated instrument which then drops a diamond-tipped hammer from a fixed height onto the surface of the test material. The height of the rebound of the hammer is used to measure the hardness of the material. An additional dynamic hardness test is described in ISO 14577-1. One benefit of this test method is its ability to not only determine the plastic hardness, but also the elastic hardness and the indention modulus, which cannot be determined using the previously mentioned methods.

4.6.6 There are also a wide range of mobile hardness measurement instruments with many potential applications. These instruments are used to determine the hardness when the previously mentioned test methods are not practical (such as due to an inability to take sample to the test instrumentation), or when it isn't possible to make a sample out of the original part. These mobile hardness test instruments are only described in ASTM Standards. Test Methods B647 and B648 cover the mobile Hardness tests by Webster, Barcol and Newage. These techniques have limited applicability and can only be used on aluminum materials.

4.6.7 Approximate conversions between the different hardness tests and indenter shapes are provided in ASTM E140.

4.6.8 ISO TR 29381 summarizes the state of the art in deriving bulk material tensile properties from the indentation response of the material. It describes three techniques: representative stress-strain, inverse finite element analysis methods and the use of statistical approaches. However, all of these techniques assume a test piece that is free of residual stresses.

5. Tests for Measuring Fatigue Properties

5.1 *Fatigue:*

5.1.1 Both Practice E466 and ISO 1099 can be used for fatigue testing of metals at room temperature. Both standards provide guidelines for an axial force-controlled fatigue test, which is continued until the specimen fails or until a predetermined number of stress cycles has been exceeded. ISO 12106 covers fatigue testing of metal samples where the axial-strain is controlled. This differs from ISO 1099, which is a low-cycle fatigue test that is performed until specimen failure.

5.1.2 Test Method E606 is intended for primarily strain-controlled fatigue tests, in which the magnitude of time-dependent inelastic strains are on the same order or less than the magnitudes of time-independent inelastic strains. In addition, Test Method E606 determines the cyclic stresses and strains any time during the tests and provides guidance to determine the fatigue life.

5.1.3 The method to determine the rate of crack growth on notched specimens is described in Test Method E647 and ISO