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Standard Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes[1]

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1. Scope

1.1 This guide introduces the reader to techniques for metal powder characterization that may be useful for powder-based additive manufacturing processes including binder jetting, directed energy deposition, and powder bed fusion. It refers the reader to other, existing standards that may be applicable for the characterization of virgin and used metal powders processed in additive manufacturing systems.[2]

1.2 The values stated in SI units are to be regarded as 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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

B212 Test Method for Apparent Density of Free-Flowing Metal Powders Using the Hall Flowmeter Funnel
B213 Test Methods for Flow Rate of Metal Powders Using the Hall Flowmeter Funnel
B214 Test Method for Sieve Analysis of Metal Powders
B215 Practices for Sampling Metal Powders
B243 Terminology of Powder Metallurgy
B329 Test Method for Apparent Density of Metal Powders and Compounds Using the Scott Volumeter
B417 Test Method for Apparent Density of Non-Free-Flowing Metal Powders Using the Carney Funnel
B527 Test Method for Determination of Tap Density of Metallic Powders and Compounds
B703 Test Method for Apparent Density of Metal Powders and Related Compounds Using the Arnold Meter
B783 Specification for Materials for Ferrous Powder Metallurgy (PM) Structural Parts
B822 Test Method for Particle Size Distribution of Metal Powders and Related Compounds by Light Scattering
B855 Test Method for Volumetric Flow Rate of Metal Powders Using the Arnold Meter and Hall Flowmeter Funnel
B923 Test Method for Metal Powder Skeletal Density by Helium or Nitrogen Pycnometry
B964 Test Methods for Flow Rate of Metal Powders Using the Carney Funnel
E539 Test Method for Analysis of Titanium Alloys by X-Ray Fluorescence Spectrometry
E572 Test Method for Analysis of Stainless and Alloy Steels by Wavelength Dispersive X-Ray Fluorescence Spectrometry
E1447 Test Method for Determination of Hydrogen in Titanium and Titanium Alloys by Inert Gas Fusion Thermal Conductivity/Infrared Detection Method
E1569 Test Method for Determination of Oxygen in Tantalum Powder by Inert Gas Fusion Technique
E1638 Terminology Relating to Sieves, Sieving Methods, and Screening Media
E1941 Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys by Combustion Analysis
E2371 Test Method for Analysis of Titanium and Titanium Alloys by Direct Current Plasma and Inductively Coupled Plasma Atomic Emission Spectrometry (Performance-Based Test Methodology)
E2465 Test Method for Analysis of Ni-Base Alloys by Wavelength Dispersive X-Ray Fluorescence Spectrometry
E2594 Test Method for Analysis of Nickel Alloys by Inductively Coupled Plasma Atomic Emission Spectrometry (Performance-Based Method)
E2626 Guide for Spectrometric Analysis of Reactive and Refractory Metals

[1] This test method 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] Cooke, A. L., Slotwinski, J. A., "Properties of Metal Powders for Additive Manufacturing: A Review of the State of the Art of Metal Powder Property Testing," NIST IR 7873, July, 2012. Available at http://www.nist.gov/manuscript-publication-search.cfm?pub_id=911339

[3] 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.

E2792 Test Method for Determination of Hydrogen in Aluminum and Aluminum Alloys by Inert Gas Fusion
F2792 Terminology for Additive Manufacturing Technologies

2.2 *ISO Standards:*[4]
ISO 3923-1, ISO 3923-2 Metallic Powders, Determination of Apparent Density
ISO 4497 Metallic Powders, Determination of Particle Size by Dry Sieving
ISO 8302 Thermal Insulation – Determination of Steady-State Areal Thermal Resistance and Related Properties – Guarded-Hot-Plate Apparatus
ISO 13320-1 Particle Size Analysis – Laser Diffraction Methods – Part 1: General Principles

2.3 *Metal Powder Industries Federation (MPIF) Standards:*[5]
MPIF Standard 01 Sampling Metal Powders
MPIF Standard 03 Flow Rate of Free-Flowing Metal Powders Using the Hall Apparatus
MPIF Standard 04 Apparent Density of Free-Flowing Metal Powders Using the Hall Apparatus
MPIF Standard 05 Sieve Analysis of Metal Powders
MPIF Standard 28 Apparent Density of Non-Free Flowing Metal Powders Using the Carney Apparatus
MPIF Standard 46 Tap Density of Metal Powders
MPIF Standard 48 Apparent Density of Metal Powders Using the Arnold Meter

3. Terminology

3.1 *Definitions:*

3.1.1 Terminology relating to powder metallurgy in Terminology B243 shall apply.

3.1.2 Terminology relating to sieve analysis in Terminology E1638 shall apply.

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

4. Significance and Use

4.1 Determining the properties of the feedstock powder used in these processes is a necessary condition for industry's confidence in powder selection and ability to produce consistent components with known and predictable properties. The intention of this guide is to provide purchasers, vendors, or producers of metal powder to be used in additive manufacturing processes with a reference for existing standards or variations of existing standards that may be used to characterize properties of metal powders used for additive manufacturing processes. It will serve as a starting point for the future development of a suite of specific standard test methods that will address each individual property or property type that is important to the performance of metal-based additive manufacturing systems and the components produced by them. While the focus of this standard is on metal powder, some of the referenced methods may also be appropriate for non-metal powders.

5. Tests for Measuring Powder Properties

5.1 *Sampling:*

5.1.1 Practice B215 outlines procedures for sampling metal powders transferred from blenders or storage tanks, as well as metal powders already package in containers such as bags. The techniques in this standard are readily applicable to metal powders used in additive manufacturing. MPIF Standard 01 provides similar procedures.

5.2 *Size Determination:*

5.2.1 The procedures outlined in Test Method B214 give detailed specifications for determining powder particle sizes through a sieving process. This process is applicable for sieves with openings from 45 to 1000 µm, and therefore not suitable for powders with particles smaller than 45 µm. MPIF Standard 05 gives similar procedures, as does ISO 4497.

5.2.2 Test Method B822 describes the use of light scattering to measure the particle size distribution. This test method describes the limitations of this technique, which may be used as agreed upon by user and manufacturer to measure particle size distribution for metal powders for additive manufacturing since the allowable particle diameters for this technique range from 0.4 µm to 2 mm.

5.2.3 Non-standardized methods such as image analysis may also be applicable for measuring the size distribution of a collection of metal particles.

5.3 *Morphology Characterization:*

5.3.1 Terminology B243 establishes qualitative definitions for many powder shapes. However, no standards describe a means of quantifying the morphology of metal powder particles. Morphology can be determined via light scattering and image analysis methods.

5.4 *Chemical Composition:*

5.4.1 Several standards describe the inert gas fusion technique, and they are highly specific.

5.4.1.1 Test Method E1447 describes the procedure for determining the hydrogen content in solid specimens of titanium and titanium alloys by using the inert gas fusion technique combined with measuring the water created by passing the hydrogen released through the inert gas fusion over heated copper oxide in an infrared cell.

5.4.1.2 Test Method E1569 describes using inert gas fusion for determining the oxygen content in tantalum powder.

5.4.1.3 Test Method E1941 describes the procedure using combustion analysis to determine carbon content in refractory and reactive metals.

5.4.1.4 Test Method E2371 describes the procedure using atomic emission plasma spectrometry to determine the content of elements other than oxygen, nitrogen, hydrogen and carbon in titanium and titanium alloys.

5.4.1.5 Test Method E2792 outlines the procedure for using inert gas fusion to determine the hydrogen content in solid aluminum and aluminum alloy specimens.

[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 Metal Powder Industries Federation (MPIF), 105 College Rd. East, Princeton, NJ 08540-6692, http://www.mpif.org.

5.4.2 Test Methods for relevant X-ray Fluorescence or Optical Emissions Spectroscopy include E539, E572, E2465, E2594, and E2626.

5.5 *Flow Characteristics:*

5.5.1 Methods of determining the mass flow rate of powders using two types of flowmeters, the Hall flowmeter funnel and the Carney funnel, are described in Test Method B213 and B964, respectively. These procedures are readily applicable for metal powders used for additive manufacturing. Methods for using the Hall flowmeter are also described in MPIF Standard 03.

5.5.2 The process of timing powder as it flows through a Hall flowmeter, which would determine the powder's flow by volume instead of the flow by mass, is described in Test Method B855. This standard is readily applicable for metal powders used for additive manufacturing. MPIF Standard 03 provides similar procedures.

5.5.3 Note that powder samples with a significant fraction of small particles or irregularly shaped particles may have inconsistent or greatly reduced flow rates, or both. The methods listed in 5.5.1 and 5.5.2 may not be suitable for these powders.

5.6 *Density:*

5.6.1 Methods for determining the apparent density of metal powder through the use of a Hall flowmeter funnel, a Carney funnel, a Scott volumeter, and and Arnold meter are described in Test Methods B212, B417, B329, and B703, respectively. Each of these standards is readily applicable to metal powders for additive manufacturing. The specification of Test Method B417 for the measurement of "non-free-flowing powders" does not mean that the powders will not flow at all. It is to be used for powders that will not freely flow through the circular orifice of the Hall flowmeter, wich is 2.54 mm in diameter. The Carney funnel used in this standard has an opening that is twice the diameter of the Hall flowmeter's opening, at 5.08 mm. The flowability of metal powder is likely to differ with different alloys and powder manufacturing techniques. Powder density measurement using a Hall Apparatus is also described in MPIF Standard 04. Powder density measurement using a Carney Apparatus is also described in MPIF Standard 28. Apparent density of metal powders using an Arnold Meter is also described in MPIF Standard 48. The ISO standards for determining the apparent density of metallic powders are ISO 3923-1 and ISO 3923-2.

5.6.2 Test Method B527 describes the method of determining the tap density of metallic powders and compounds. This standard is readily applicable for metal powders for additive manufacturing. MPIF Standard 46 describes methods for measuring the tap density of metal powders.

5.6.3 The method of obtaining the skeletal density of metal powders by helium or nitrogen pycnometry is described in Test Method B923. This standard is readily applicable for metal powders for additive manufacturing.

5.6.3.1 *Discussion*—Contamination of the original metal powder may occur at any stage of processing and handling, starting from metal powder production. The contaminants may be organic (such as oil, grease, lubricants, hair, plastics and glue) or metallic (such as wear debris or other powders) or inorganic compounds. Various standard methods used in the production and quality assurance of powders, such as scalping with sieves to remove oversize contaminant, visual inspection, and analytical methods to detect foreign materials, can be used to ensure that the final powder product is free of contamination.

6. Keywords

6.1 apparent density; Arnold Meter; Carney funnel; density; flash method; flow rate; flowmeter funnel; guarded-hot-plate; Hall flowmeter funnel; heat flow; inert gas fusion; light scattering; metal powder flow; metal powders; particle size; particle size distribution; powder flow; powder metallurgy; pycnometry; Scott density; Scott Volumeter; sieves; skeletal density; tap density