Designation: F3522 – 22

Standard Guide for Additive Manufacturing of Metals — Feedstock Materials — Assessment of Powder Spreadability[1]

This standard is issued under the fixed designation F3522; 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 guide provides definitions of the spreading behavior or spreadability of metal powder feedstock used in powder bed additive manufacturing (AM) – Powder Bed Fusion and Metal Binder Jetting. Definitions are made in terms of powder bed characteristic parameters, and suggests measurement methods that could be used to measure these parameters.

1.2 This standard is intended for the producers and users of powder feedstock used in powder bed AM to provide a common understanding of spreadability parameters. These parameters can be used as the basis for developing powder specifications that ensure proper powder spreadability.

1.3 This guide provides guidance to manufacturers and users of AM machines by providing possible techniques to quantify powder bed spreadability, and highlighting possible process parameters that may affect this spreadability. These parameters can be used as the basis for developing process specifications and for developing measures to improve the quality of spreadability in AM processes.

1.4 The values stated in SI units are to be regarded as the standard units. 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]

B243 Terminology of Powder Metallurgy

2.2 *ISO/ASTM Standard:*[2]

52900 Additive manufacturing – General principles – Fundamentals and vocabulary

2.3 *ISO Standard:*[3]

ISO 25178-2 Geometrical product specifications (GPS) – Surface texture: Areal – Part 2: Terms, definitions and surface texture parameters

3. Terminology

3.1 *Definitions*—Powder metallurgy terms can be found in Terminology B243 and AM processes and terms can be found in Terminology ISO/ASTM 52900.

4. Significance and Use

4.1 The overall aim of this guide is to provide a common understanding of spreadability in relation to powder bed AM. This guide provides an overview of spreadability parameters and measurement methods that could be used to measure these parameters. These parameters could be used as the basis to develop process specifications for the powder bed.

5. Introduction/Background

5.1 Understanding of powder spreading behavior or spreadability is essential for ensuring that powder feedstock material can be processed in powder bed AM machines. Desirable spreadability is the one that results in a powder bed with a uniform layer thickness and powder bed density, a smooth even surface, an equal particle size distribution across the bed, and with an absence of defects.

5.2 There are a range of test methods that can measure powder flow properties; however, it is not clear if these tests adequately address the requirement for spreadability in the

[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 Nov. 15, 2022. Published January 2023. DOI: 10.1520/F3522-22.

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

powder bed AM process. This challenge is exacerbated by the wide range of powder bed AM machine designs available.

5.3 There is a need to define standardized spreadability parameters, which are physical characteristics of the powder bed. This is essential to help end users understand what good spreading powder means in terms of part quality, so that appropriate limits on spreadability parameters can be defined. These limits would be specific to the design of the powder bed AM machine.

5.4 Guidelines will help powder feedstock manufacturers to develop appropriate powder specifications that guarantee their powders will be processable to an acceptable level in powder bed AM machines. These specifications will ultimately enable AM users to optimize the powder-process property relationship for powder bed AM, and enable end users to understand when to accept powder batches from suppliers, when to refresh powders for re-use, and when to quarantine powder batches.

6. Powder Processing with Powder Bed AM Machines

6.1 There are many powder bed AM machines available commercially, which have slightly different architecture set-ups and parameters. However, many features of these powder bed AM machines are similar, allowing a generalized powder bed AM machine design to be described for *(1)* piston-fed (Fig. 1) and *(2)* gravity-fed machine designs (Fig. 2). There are other emerging systems too, for example, utilizing a non-contact recoater, or a cartridge system for material deposition.

6.2 Many powder bed AM machines operate with heated build platforms and are typically back-filled with inert gas or evacuated, which might be essential for keeping powder oxidation levels low during the build. A generalized powder bed AM machine consists of the following elements:

1. *Feed region*—Please refer to ISO/ASTM 52900.
2. *Powder delivery system*—A batch powder feeding system. The powder can either be delivered and metered by a hopper, or supplied by a dosing platform working in the opposite direction to the build platform.
3. *Powder spreading device*—A device which moves powder uniaxially across the build chamber to spread powder in a thin and even layer.
4. *Build platform*—Refer to ISO/ASTM 52900.

6.3 The scope of spreadability relates to the process of transferring powder (see Fig. 1 and Fig. 2) from the 1. Feed region to the 4. Build platform, and includes the powder processing stages of dosing and spreading, performed by the 2. Powder delivery system and the 3. Powder spreading device.

7. Powder Bed Spreadability Characteristic Parameters

7.1 The terminology definition of spreadability is given in ISO/ASTM 52900. Consequently, spreadability depends on evaluation of properties of the spread layer. The layer thickness in question is approximately 20 µm to 300 µm, and the resultant powder bed should have a uniform surface texture, uniform layer density, an absence of segregation and an absence of defects. A two dimensional schematic diagram of the cross-section through a powder layer is given in Fig. 3. The powder layer quality could be defined in terms of the following six powder bed characteristic parameters, described in Table 1 alongside potential methods of their determination. It is recommended that users characterize powder feedstock in terms of the defined powder bed characteristic parameters and assess whether powder is spreading properly in the process, in order to understand when a powder should not be used in the process.

7.2 *Measurement Methods of Powder Layer Characteristic Parameters*—This section outlines potential assessment methods of powder bed characteristic parameters. The techniques described currently are ex-situ unless manufacturers of AM systems integrate those system into AM machines. Most of the described techniques can include both in-situ and ex-situ measurements. A summary of the measurement methods are given in Table 2. For each assessment method, a basic rating system (low to high) was used to score five key areas; namely Resolution, Cost, Data Complexity and Analysis Time, Data Variability, and Suitability. A 'high' rating denotes a higher value of the factor, while footnote[B] in Table 2 denotes how favorable the factor is.

7.2.1 *Laser Line Scanning*—Laser line scanning is a non-contact method used for capturing the shape of a three-dimensional (3D) object. The operating principle of a laser line scanner is based on the laser triangulation technique for two-dimensional detection. A laser line scanner projects a laser line onto the surface of an object, and the reflection of that line on the object's surface is captured by a camera. A type of

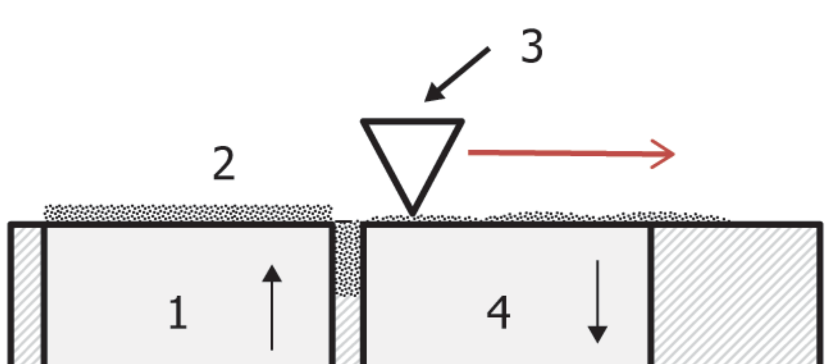

FIG. 1 Schematic of a Generalized Piston-fed Powder Bed Additive Manufacturing (AM) Machine – 1. Feed Region, 2. Powder Delivery System, 3. Powder Spreading Device, 4. Build Platform

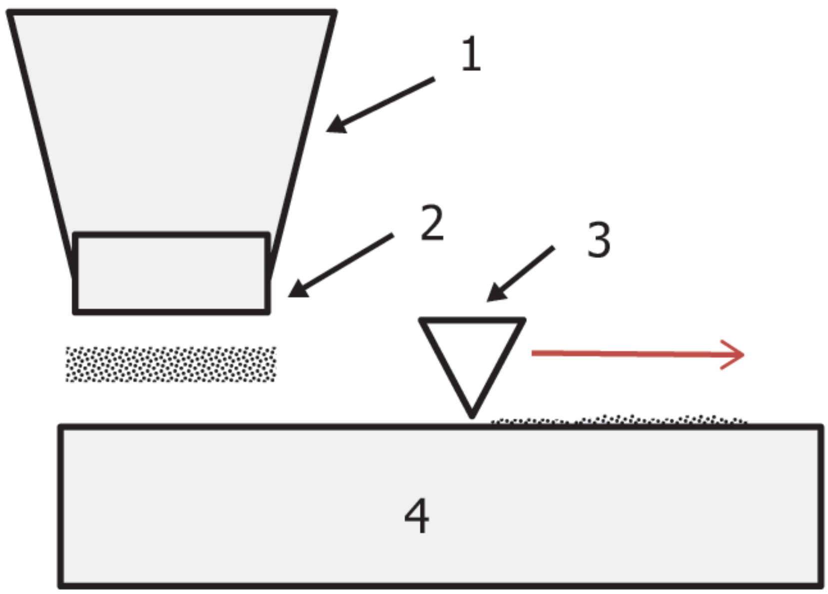

FIG. 2 Schematic of a Generalized Gravity-fed Powder Bed Additive Manufacturing (AM) Machine – 1. Feed Region, 2. Powder Delivery System, 3. Powder Spreading Device, 4. Build Platform

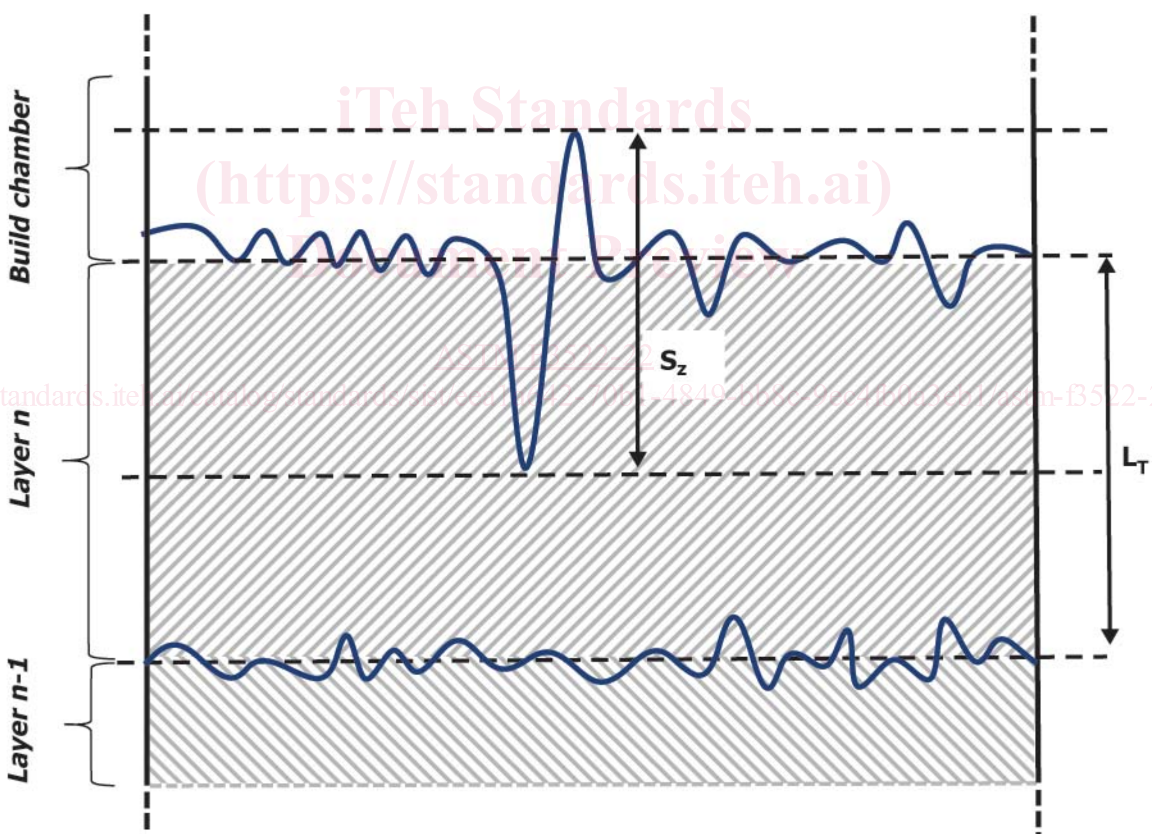

FIG. 3 Schematic Diagram of a Powder Layer (2D Representation)

information captured depends on the direction of lines. Lines parallel to the movement of the powder spreading device provide information on waviness, while, lines perpendicular to the movement of the powder spreading device provide information on line defects. The frequency of the signal varies, depending on the direction of the scanning. The distance of each surface point is computed to obtain a 3D profile or a contour of the object's shape through a triangulation process. The laser line scanner could be mounted to the back of the powder spreading device, and captures data as the powder spreading device moves across the bed. A height map is generated by the comparison of two split laser light beams; one

TABLE 1 Potential Powder Bed Layer Characteristic Parameters

Parameter	Description	Comments	Potential Measurement Methods	Target Resolution
Powder layer thickness, L_T	Distance between the least squares mean plane of the top surface of the deposited layer, to the least squares mean plane of the previously deposited layer	Influenced by rebound and packing	• Laser line scanner • Fringe projection system (structured illumination pattern scanner) • Laser scanning microscope • X-ray Computed Tomography • High resolution camera • Optical Profilometry • Optical Coherence Tomography (OCT)	Ideally at least equal to one third of the powder layer thickness (for example, 10 µm for a 30 µm layer thickness)
Powder layer thickness uniformity across the entire powder bed, L_U	The standard deviation of the powder layer thickness, throughout the build	Accounts for insufficient powder coverage		
Maximum height of the scale-limited surface, S_z	See ISO 25178-2 A sum of the maximum peak height and the maximum pit height value within a definition area	Accounts for track lines in the powder bed surface		Ideally at least equal to one third of the powder layer thickness (for example, 10 µm for a 30 µm layer thickness) N/A
Root mean square (RMS) height of the scale-limited surface, S_q	See ISO 25178-2 S_q is a root square value of the ordinate values within a definition area	This parameter does not account for track lines		
Powder bed density, D_B	The powder bed density (powder bed mass divided by the volume it occupies) measured over a specified area	Found to not strongly influence part density, although there will be a limit where low bed density will influence mechanical properties negatively	• X-ray Computed Tomography • Load cell under the build platform • Recover powder and weight externally (that is, capsules)	Ideally 0.1 g for mass measurement and 0.1 cm^3 for volume measurement
Powder bed density homogeneity, D_H	The standard deviation of the powder bed density over multiple areas within one layer	This parameter account for powder particle size segregation. Likely to impact part properties	• X-ray Computed Tomography • Sample known volume of powder and weight externally (that is, capsules)	N/A

TABLE 2 Summary of Potential Measurement Methods Used to Assess Powder Bed Spreadability Characteristic Parameters[A,B]

Measurement Method	Resolution	Cost	Data Complexity and Analysis Time	Data Variability	Suitability
Surface Topography Measurement Methods					
Laser Line Scanning	High$^+$	Moderate	High$^-$	Moderate	Moderate
Fringe Projection	High$^+$	Moderate	High$^-$	Moderate	High$^+$
Laser Scanning Microscopy	High$^+$	Moderate	High$^-$	Moderate	High$^+$
X-Ray Computed Tomography	High$^+$	High$^-$	High$^-$	Moderate	High$^+$
Camera Image	Moderate	Low$^+$	High$^-$	Moderate	High$^+$
Optical Profilometry	High$^+$	Moderate	Moderate	Moderate	High$^+$
Optical Coherence Tomography	High$^+$	High$^-$	Moderate	Moderate	High$^+$
Density Measurement Methods					
Load Cell	Low$^-$	Low$^+$	Low$^+$	Low$^+$	Moderate
AM Capsules	High$^+$	Moderate	Low$^+$	Low$^+$	High$^+$

[A] A ‘High’ rating denotes a higher value of the factor.
[B] The $^+$ denotes the factor is positive. $^-$ denotes the factor is negative.

to the inspection surface and one to a reference geometry at a known distance. By comparing the data from each beam, the surface height can be inferred and plotted. Laser line scanning allows detailed features and roughness to be measured due to high depth resolution using a single camera. However, the resolution can decrease considerably if the field of view is trapezium with sharply inclined edges.

7.2.2 *Fringe Projection*—Fringe projection is a non-contact method to generate a 3D measurement of component's surfaces from the digitization of the projected patterns onto these surfaces. The structured illumination pattern is projected onto a sample from a certain angle and reflected light is captured by a camera. The 3D image can be obtained by correlating the change of fringe pattern to the changes in height of a surface. A digital 3D profile of the target is calculated via a mathematical calculation. The projected image is distorted due to varying height of the surface from a reference plane, and the image distortion allows measurement of the surface profile. Cameras can be positioned around the build platform, and layer-by-layer images and data points can be taken to create a 3D point cloud system which can be evaluated by the 3D metrology software and used to measure the selected powder bed characteristic parameters. The whole surface of the sample is acquired at once by a camera perpendicular to the surface. The technique exhibits a high resolution (up to 50 times smaller than the fringe width) with a small measurement duration.

7.2.3 *Laser Scanning Microscopy (LSM)*—Laser scanning microscopy uses the confocal principle and a laser as the light source, to measure the asperity of the target's surface. The target surface is scanned by the laser beam and the microscope records the laser intensity of the received reflection and the height position of the lens. The laser intensity and the lens height is recorded for each measured point. Once the scan of one surface is complete, the objective lens move in the Z direction by the specified pitch and the same surface scan is performed again. The reflected light intensity of each pixel is compared with the reflected light intensity recorded for the previously measured surface. If the new reflected light intensity is higher, the reflected light intensity and lens height position data are overwritten. The reflected light intensity and lens position data of each measured point are recorded for the strongest laser light reflection received. It is assumed that the image is in focus when the reflected light intensity is at maximum and this assumption allows a 3D image in the observation area of the microscope to be obtained by stitching together the lens height positions from the times when the reflected light intensity was at its maximum. LSM is not capable of measuring high aspect ratios and slopes with large angles as these features do not reflect the laser beam. LSM can achieve very high resolutions, however it is only capable to measure materials that do not absorb the laser beam wavelength.

7.2.4 *X-Ray Computed Tomography (XCT)*—X-Ray Computed Tomography allows the visualization of interior features within solid objects, to obtain digital information on their 3D geometries and properties. The tomographic imaging consists of directing X-rays at the object from multiple orientations and measuring the decrease in intensity along a series of linear paths. A specialized algorithm is used to reconstruct the distribution of X-ray attenuations in the volume being imaged. The technique exhibits a high resolution up to about 1000–2000× the object diameter. Higher resolution can usually be obtained with small objects. A limitation of the technique is the size of the analyzed objects that is determined by the field of view for CT.

7.2.5 *Camera Image*—The camera can be mounted directly above the build platform to capture images of the build area. Cameras can capture an entire target with a single operation. Images can be converted into 3D maps of the powder surface by software. Raised particles generate more light and display a higher pixel intensity, whereas troughs in the bed appear as darker regions with a lower pixel intensity. With this information, the images can be converted into height maps and selected powder bed characteristic parameters can be calculated thereafter. The lens resolution determines the minimum interval in which observation is possible.

7.2.6 *Optical Profilometry*—Optical profilometry is a surface metrology technique based on coherence scanning interferometry and uses an optical profiler, which is a type of microscope in which light from a lamp is split into two paths by a beam splitter. The light from the test path is directed onto the analyzed surface, while light from the reference path is directed onto a reference mirror. Reflections from both surfaces are combined and projected onto an array detector. Interference might occur if the difference between recombined beams is of the order of few wavelengths of light or less. The analysis provides information about the surface contours. The profiler is capable of detecting a height difference between peaks and valleys in a range from 25 µm to 50 µm.

7.2.7 *Optical Coherence Tomography (OCT)*—Optical Coherence Tomography uses reflected near-infrared light to obtain micron-scale, depth-resolved images. The technique can be used to capture cross sectional or 3-D volume images and can provide quantitative measurements. OCT uses different localization techniques to obtain information in the axial direction and the transverse direction. The information in the axial direction is obtained by estimating the time delay of light reflected from structures or layers in a sample using low-coherence interferometry. The axial (depth) resolution is related to the bandwidth or the coherence length of the source. The imaging depth of OCT is limited by the depth of penetration of the light source in the sample. OCT is a non-destructive and highly sensitive method, therefore, it can be used for in situ measurements of low contrast or highly scattering objects, or both. OCT provides information on surface profiles, subsurface structure and uniformity.

7.2.8 *Mass Measurement Using a Load Cell*—The base plate sits atop a balance which can measure the mass of powder on the base plate. The bed density is calculated by dividing the powder mass as measured by the balance, and the volume of the material on the base plate calculated accounting for the area of the base plate and the base plate displacement.

7.2.9 *Mass Measurement of the Powder Enclosed in the Capsules*—Powder bed density can be determined by measuring the mass of powder enclosed in capsules (Fig. 3). Capsules are built in the AM process, and are hollow structures that capture a specific volume of unmelted powder. The capsule needs to be removed from the build plate and the powder first removed from the capsule. The mass of the powder is weighted by using a precision scale. The actual internal volume of the capsule needs to be determined. This method isn't applicable for binder jetting processes.

8. Process Failure Modes

8.1 Potential key powder spreading process failure modes within the powder bed AM process, including their possible causes and effects on parts, are listed in Table 3. This is a list of factors within the powder bed AM process that may result in a flawed spread powder bed. Images showing examples of some of these failure modes are shown in Fig. 4.

9. Key Process Variables

9.1 Potential key process variables and factors that could influence powder spreading behavior are given in Table 4. It is recommended that powder bed AM users gain an appreciation of how the following spreadability process variables, influence the performance of their feedstock materials within their powder bed AM process.

9.2 Most of the spreadability test methods presented in Section 7 could be used to characterize the spreading behavior of a particular powder bed machine platform. However, these test methods are most likely to be unsuited to testing in