ASME Y14.46-2022

Product Definition for Additive Manufacturing

Engineering Product Definition and Related Documentation Practices

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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This Standard will be revised when the Society approves the issuance of a new edition.

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Errata to codes and standards may be posted on the ASME website under the Committee Pages to provide corrections to incorrectly published items, or to correct typographical or grammatical errors in codes and standards. Such errata shall be used on the date posted.

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The American Society of Mechanical Engineers
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FOREWORD

The Charter of the ASME Y14.46 Subcommittee was approved by the ASME Y14 Standards Committee on October 10, 2014, with the task to develop requirements in geometric dimensioning and tolerancing for additive manufacturing (AM). The goal of the Subcommittee was to create a broadly accepted standard that incorporates, expands, or refines international practices and symbology to enable AM product definition data to be created, interpreted, and consumed on a global basis. The Y14.46 Subcommittee has brought together subject matter experts (SMEs) who have generously volunteered a significant amount of time and resources to this effort over the last 5 years.

The Subcommittee approved the ASME Y14.46 Draft Standard for Trial Use on June 19, 2017. The Subcommittee welcomed comments and/or proposals for revisions to the Draft Standard, as submitted through the provided forms and additional balloting process. Since the initial release of the Draft Standard for Trial Use, the Subcommittee has received important feedback from the additive manufacturing and product definition communities. The Subcommittee has incorporated the feedback into this document to make it a released Standard.

Some appendices are introduced in this Standard because the Subcommittee is aware of the need to address these topics. Work to enhance these appendices is ongoing, and feedback from the public is welcome (see Correspondence With the Y14 Committee). The following appendices are identified as "forward work":

(a) Nonmandatory Appendix C, Reference Documents to Test for Conformance

(b) Nonmandatory Appendix D, Complex Geometry and Forward Work

This Standard has been created and edited to be distributed in the pdf format. It was approved as an American National Standard by the American National Standards Institute on May 19, 2022.

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Engineering Product Definition and Related Documentation Practices

(The following is the roster of the Committee at the time of approval of this Standard.)

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General. ASME Standards are developed and maintained with the intent to represent the consensus of concerned interests. As such, users of this Standard may interact with the Committee by proposing revisions or a case and attending Committee meetings. Correspondence should be addressed to:

Secretary, Y14 Standards Committee
The American Society of Mechanical Engineers
Two Park Avenue
New York, NY 10016-5990
http://go.asme.org/Inquiry

Proposing Revisions. Revisions are made periodically to the Standard to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the Standard. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this Standard. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

Proposing a Case. Cases may be issued to provide alternative rules when justified, to permit early implementation of an approved revision when the need is urgent, or to provide rules not covered by existing provisions. Cases are effective immediately upon ASME approval and shall be posted on the ASME Committee web page.

Requests for Cases shall provide a Statement of Need and Background Information. The request should identify the Standard and the paragraph, figure, or table number(s), and be written as a Question and Reply in the same format as existing Cases. Requests for Cases should also indicate the applicable edition(s) of the Standard to which the proposed Case applies.

Attending Committee Meetings. The Y14 Standards Committee regularly holds meetings and/or telephone conferences that are open to the public. Persons wishing to attend any meeting and/or telephone conference should contact the Secretary of the Y14 Standards Committee. Future Committee meeting dates and locations can be found on the Committee Page at http://go.asme.org/Y14committee.

PRODUCT DEFINITION FOR ADDITIVE MANUFACTURING

1 GENERAL

1.1 Scope

This Standard covers the definitions of terms and features unique to additive manufacturing (AM) technologies with recommendations for their uniform specification in product definition data and in related documents. Unless otherwise specified, any reference to features, parts, or processes shall be interpreted as applying to parts or assemblies manufactured using an AM process. Additively manufactured parts or assemblies are referred to as "parts" throughout the Standard. The Standard extends to capturing relevant AM detail from design, manufacturing, and quality engineering.

1.2 ASME Y14 Series Conventions

The conventions in paras. 1.2.1 through 1.2.12 are used in this and other ASME Y14 standards.

1.2.1 Mandatory, Recommended, Guidance, and Optional Words

(a) The word "shall" establishes a requirement.
(b) The word "will" establishes a declaration of purpose on the part of the design activity.
(c) The word "should" establishes a recommended practice.
(d) The word "may" establishes an allowed practice.
(e) The words "typical," "example," "for reference," and the Latin abbreviation "e.g." indicate suggestions given for guidance only.
(f) The word "or" used in conjunction with a requirement or a recommended practice indicates that there are two or more options for complying with the stated requirement or practice.
(g) The phrase "unless otherwise specified" or the abbreviation "UOS" shall be used to indicate a default requirement. The phrase is used when the default is a generally applied requirement and an exception may be provided by another document or requirement.

1.2.2 Cross-Reference of Standards. Cross-reference of standards in text with or without a date following the standard designator shall be interpreted as follows:
(a) Reference to other ASME Y14 standards in the text without a date following the standard designator indicates that the edition of the standard identified in the References section (para. 1.5) shall be used to meet the requirement.
(b) Reference to other ASME Y14 standards in the text with a date following the standard designator indicates that only that edition of the standard shall be used to meet the requirement.

1.2.3 Invocation of Referenced Standards. The following examples define the invocation of a standard when specified in para. 1.5 and referenced in the text of this Standard:
(a) When a referenced standard is cited in the text with no limitations to a specific subject or paragraphs of the standard, the entire standard is invoked. For example, "Dimensioning and tolerancing shall be in accordance with ASME Y14.5" is invoking the complete standard because the subject of the standard is dimensioning and tolerancing and no specific subject or paragraphs within the standard are invoked.
(b) When a referenced standard is cited in the text with limitations to a specific subject or paragraphs of the standard, only the paragraphs on that subject are invoked. For example, "Assign part or identifying numbers in accordance with ASME Y14.100" is invoking only the paragraphs on part or identifying numbers because the subject of the standard is engineering drawing practices and part or identifying numbers is a specific subject within the standard.
(c) When a referenced standard is cited in the text without an invoking statement such as "in accordance with," the standard is invoked for guidance only. For example, "For gaging principles, see ASME Y14.43" is only for guidance and no portion of the standard is invoked.

1.2.4 Definitions. Section 2 provides definitions specific to this Standard. For definitions of words used in but not defined in this Standard, see Merriam-Webster's Unabridged Dictionary at https://www.merriam-webster.com/.

1.2.5 Parentheses Following a Definition. When a definition is followed by a standard referenced in parentheses, the standard referenced in parentheses is the source for the definition.

1.2.6 Notes. Notes depicted in this Standard in ALL UPPERCASE letters are intended to reflect actual product definition entries. Notes depicted in initial uppercase or lowercase letters are to be considered supporting data to the contents of this Standard and are not intended for literal entry on the product definition. A statement requiring the addition of a note with the qualifier "such as" is a requirement to add a note, and the content of the note is allowed to vary to suit the application.

1.2.7 Acronyms and Abbreviations. Acronyms and abbreviations are spelled out the first time used in this Standard, followed by the acronym or abbreviation in parentheses. The acronym is used thereafter throughout the text.

1.2.8 Units. The International System of Units (SI) is featured in this Standard. It should be understood that U.S. Customary units could equally have been used without prejudice to the principles established.

1.2.9 Figures. The figures in this Standard are intended only as illustrations to aid the user in understanding the practices described in the text. In some cases, figures show a level of detail as needed for emphasis. In other cases, figures are incomplete by intent so as to illustrate a concept or facet thereof. The absence of figures has no bearing on the applicability of the stated requirements or practice. To comply with the requirements of this Standard, actual data sets shall meet the content requirements set forth in the text. To assist the user of this Standard, a list of paragraphs that refer to an illustration appears in the lower right-hand corner of each figure. This list may not be all inclusive. The absence of a paragraph reference is not a reason to assume inapplicability. Some figures are illustrations of models in a three-dimensional (3D) environment. The absence of dimensioning and tolerancing annotations in a view may indicate that the product definition is defined in three dimensions. Dimensions that locate or orient and are not shown are considered basic and shall be queried to determine the intended requirement. When the letter "h" is used in figures for letter heights or for symbol proportions, select the applicable letter height in accordance with ASME Y14.2. Multiview drawings contained within figures are third-angle projection.

1.2.10 Precedence of Standards. The following are ASME Y14 standards that are basic engineering drawing standards:

ASME Y14.1, Drawing Sheet Size and Format
ASME Y14.2, Line Conventions and Lettering
ASME Y14.3, Orthographic and Pictorial Views
ASME Y14.5, Dimensioning and Tolerancing
ASME Y14.24, Types and Applications of Engineering Drawings
ASME Y14.34, Associated Lists
ASME Y14.35, Revision of Engineering Drawings and Associated Documents
ASME Y14.36, Surface Texture Symbols
ASME Y14.38, Abbreviations and Acronyms for Use on Drawings and Related Documents
ASME Y14.41, Digital Product Definition Data Practices
ASME Y14.100, Engineering Drawing Practices

All other ASME Y14 standards are considered specialty types of standards and contain additional requirements or make exceptions to the basic standards as required to support a process or type of drawing.

1.2.11 Use of an ASME Y14 Case. Where product definition and engineering documentation are based on an ASME Y14 Case, this fact shall be noted on the documentation or in a referenced document.

1.2.12 Product Definition Without Reference to a Standard. When a product definition is created without a reference document (company, regional, national, or international) or contractually imposed documents, the product definition shall be interpreted in accordance with ASME PDS-1.1–2013.

1.3 Dimensioning and Tolerancing

The methods of dimensioning and tolerancing shall be in accordance with ASME Y14.5, ASME Y14.41, and this Standard. Unless otherwise specified, datums shall not be defined (or redefined) by this Standard, thus avoiding definition overlap or conflict with ASME Y14.5 or ASME Y14.41.

1.4 Examples

Where examples are provided, such lists are not exhaustive and other examples could be equally applicable.

1.5 References

The following editions of national and international standards and practices form a part of this Standard to the extent specified herein. A more recent revision may be used, provided there is no conflict with the text of this Standard. In the event of a conflict between the text of this Standard and the references cited herein, the text of this Standard shall take precedence.

ASME B46.1-2019, Surface Texture (Surface Roughness, Waviness, and Lay)
ASME B89.7 series, Measurement Uncertainty
ASME Y14.2-2014, Line Conventions and Lettering
ASME Y14.5-2018, Dimensioning and Tolerancing
ASME Y14.24-2012, Types and Applications of Engineering Drawings
ASME Y14.36-2018, Surface Texture Symbols
ASME Y14.41-2019, Digital Product Definition Data Practices
ASME Y14.47-2019, Model Organization Practices
ASME Y14.100-2017, Engineering Drawing Practices
Publisher: The American Society of Mechanical Engineers (ASME), Two Park Avenue, New York, NY 10016-5990 (www.asme.org)

ASTM A1067/A1067M-12a(2018), Standard Specification for Test Coupons for Steel Castings
ASTM F2971-13, Standard Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing
Publisher: American Society for Testing and Materials (ASTM International), 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959 (www.astm.org)

ISO/ASTM 52900:2015, Standard Terminology for Additive Manufacturing — General Principles — Terminology
ISO/ASTM 52915:2020, Standard Specification for Additive Manufacturing File Format (AMF) Version 1.2
ISO/ASTM 52921:2013, Standard Terminology for Additive Manufacturing — Coordinate Systems and Test Methodologies
Publisher: International Organization for Standardization (ISO), Central Secretariat, Chemin de Blandonnet 8, Case Postale 401, 1214 Vernier, Geneva, Switzerland (www.iso.org)

2 DEFINITIONS

The following terms are defined as their use applies in this Standard. Additionally, throughout the Standard, definitions of italicized terms are given in subsections describing their application. Some definitions from ISO/ASTM and ASME standards are reproduced here, and the ownership of those definitions is indicated by the name of the standard after the term being defined.

additive manufacturing process: any process of additive manufacturing (AM), such as those defined by ISO/ASTM 52900.

bounded surface region: a surface subset within a part or on a part surface that bounds a set of connected or intersecting edges.

bounded volume region: a subset of 3D space within a part that bounds a set of connected or intersecting surfaces.

bounding box (ISO/ASTM 52900[1]): orthogonally oriented minimum perimeter cuboid that can span the maximum extents of the points on the surface of a 3D part.

build cycle (ISO/ASTM 52900[1]): single process cycle in which one or more components are built up in layers in the process chamber of the additive manufacturing system.

build direction: the line or course in which layers are added in an AM process to produce a part.

build environment: the conditions in which a part is created.

build location: identification of the site where the part will be produced relative to the build platform.

build platform (ISO/ASTM 52900[1]): of a machine, base which provides a surface upon which the building of the part/s is started and supported throughout the build process.

[1] Reprinted, with permission, from ISO/ASTM 52900:2015, Standard Terminology for Additive Manufacturing — General Principles — Terminology, copyright © ISO/ASTM International.

build surface (ISO/ASTM 52900[1]*):* area where material is added, normally on the last deposited layer, which becomes the foundation upon which the next layer is formed. Discussion: For the first layer, the build surface is often the build platform.

build volume (ISO/ASTM 52900[1]*):* total usable volume available in the machine for building parts.

complex geometry: a combination of features that cannot easily be characterized by concise equations or algorithms (e.g., nonlinear, nonrepeating, random).

coordinate system (ASME Y14.41): a representation of a Cartesian coordinate system in a product definition data set.

datum (ASME Y14.5): a theoretically exact point, axis, line, plane, or combination thereof derived from the true geometric counterpart.

datum feature (ASME Y14.5): a feature that is identified with either a datum feature symbol or a datum target symbol.

end product (ASME Y14.24): an item, such as an individual part or assembly, in its final or completed state. Also called *end item*.

fill pattern: a geometry pattern, usually not fully dense, used between solid surfaces to reduce material usage when building a part.

free zone: a type of bounded volume region that encloses the entire part and in which other parts cannot be located or intersected.

gradient control: specifies, with tolerance, how physical characteristics are varied spatially (e.g., changes in material composition, color, density, porosity, or unit cell size).

item (ASME Y14.100): a nonspecific term used to denote any unit or product, including materials, parts, assemblies, equipment, accessories, and computer software.

lattice structures (ISO/ASTM 52900[1]*):* three-dimensional geometric arrangement composed of connective links between vertices (points) creating a functional structure.

nesting (ISO/ASTM 52900[1]*):* situation when parts are made in one build cycle and are located such that their bounding boxes, arbitrarily oriented or otherwise, will overlap.

part (ASME Y14.100): one item, or two or more items joined together, that is not normally subject to disassembly without destruction or impairment of designed use, e.g., transistor, composition resistor, screw, transformer, and gear.

product definition data (ASME Y14.41): denotes the totality of data elements required to completely define a product. Product definition data includes geometry, topology, relationships, tolerances, attributes, and features necessary to completely define a component part or an assembly of parts for the purpose of design, analysis, manufacture, test, and inspection.

product definition data set (ASME Y14.41): a collection of one or more data files that discloses, directly or by reference, by means of graphic or textual presentations or combinations of both, the physical or functional requirements of an item.

product definition data set type: a specific product definition data set designation that defines a particular stage of manufacturing and conformance to specification.

roughness (ASME B46.1): the finer spaced irregularities of the surface texture that usually result from the inherent action of the production process or material condition. These might be characteristic marks left by the processes listed in ASME B46.1, Nonmandatory Appendix B, Figure B-1.

shell thickness: volume defined by the normal offset from the outer bounding surface toward the inside of the item and excludes infill.

support (ISO/ASTM 52900[1]*):* structure separate from the part geometry that is created in order to provide a base and anchor for the part during the building process.

surface texture (ASME B46.1): the composite of certain deviations that are typical of the real surface. Surface texture includes roughness and waviness.

test coupon (ASTM A1067/A1067M[1]*):* a test specimen defined by a standard, produced for the purpose of obtaining test results that comply with the requirements of the applicable product standard, sometimes built at the same time as the part for additive manufacturing processes.

theoretical supplemental surface (TSS): supplemental geometry, explicitly defined in the design model and similar to true profile, that may be used to control the form, size, orientation, or location of a functional collection of points, lines, surfaces, or any combination thereof.

track path: the additive manufacturing machine-material interface path through space for producing the desired geometry of the layer.

transition region: a bounded region where gradient control applies.

waviness (ASME B46.1): the more widely spaced component of the surface texture. Waviness may be caused by such factors as machine or workpiece deflections, vibration, and chatter. Roughness may be considered as superimposed on a wavy surface.

Other terms related to AM, general product definition practices, and tolerances not defined in this Standard can be found in ASME Y14.5, ASME Y14.41, ISO/ASTM 52900, and ISO/ASTM 52921.

3 SUPPLEMENTAL GEOMETRY

Supplemental geometry, such as coordinate systems, unit vectors, and surfaces, may be needed to support product definition data for AM.

3.1 Coordinate System Identification

Coordinate systems and associativity shall be identified and labeled per ASME Y14.41. Single (see Figure 3-1) or multiple coordinate systems (see Figure 3-2) may be used.

NOTE: Alternative coordinate systems may be user defined.

3.2 Unit Vector Identification

When used, a unit vector shall be identified and may be related to a coordinate system or otherwise defined mathematically. Associativity and representation of unit vectors shall follow coordinate system guidelines per ASME Y14.41.

Examples of unit vectors include the following:

(a) indication of build direction identified as “B DIR” (see Figure 3-3)
(b) indication of gravity direction identified as “G DIR” (see Figure 3-4)

3.3 Surface Identification

When used, a surface shall be identified.

An example of an identified build surface (B SURF) is shown in Figure 3-5. Additional examples of surface identifications can be found in para. 4.1.

Figure 3-1
Single Coordinate System Related to the Model

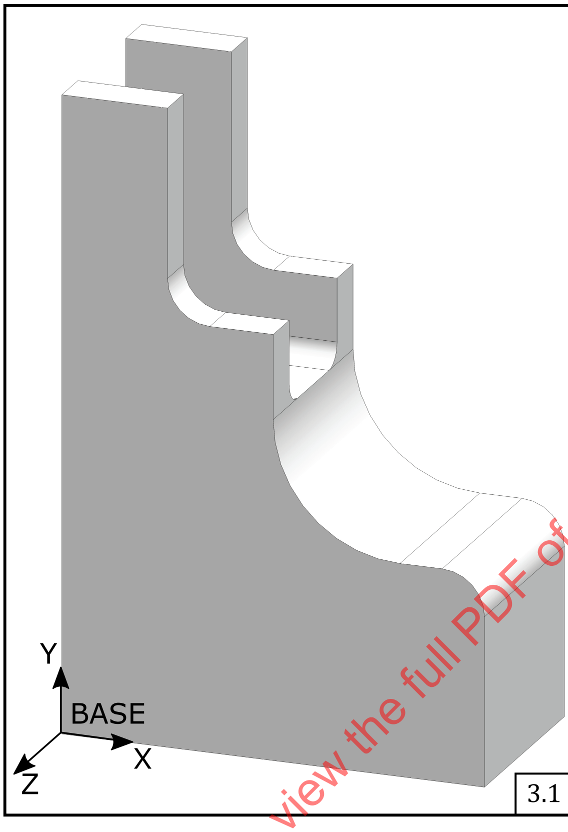


Figure 3-2
Multiple Coordinate Systems

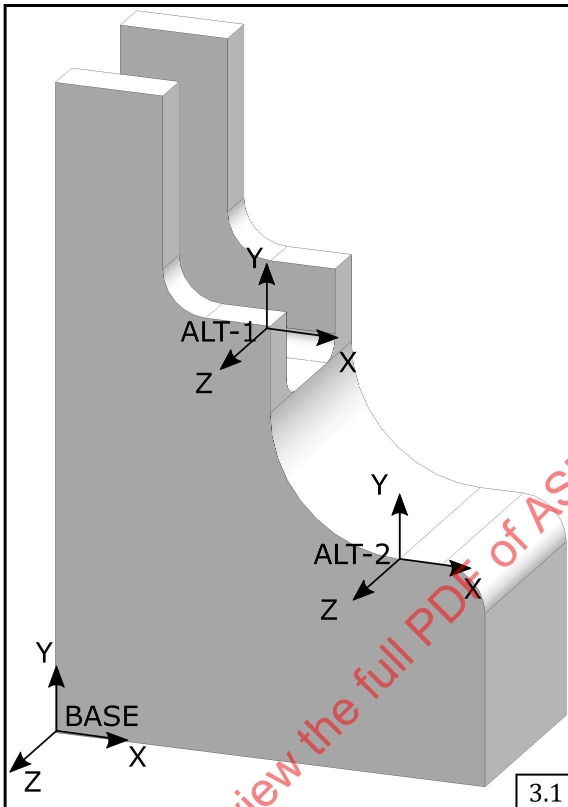


Figure 3-3
Unit Vector Indicating Build Direction

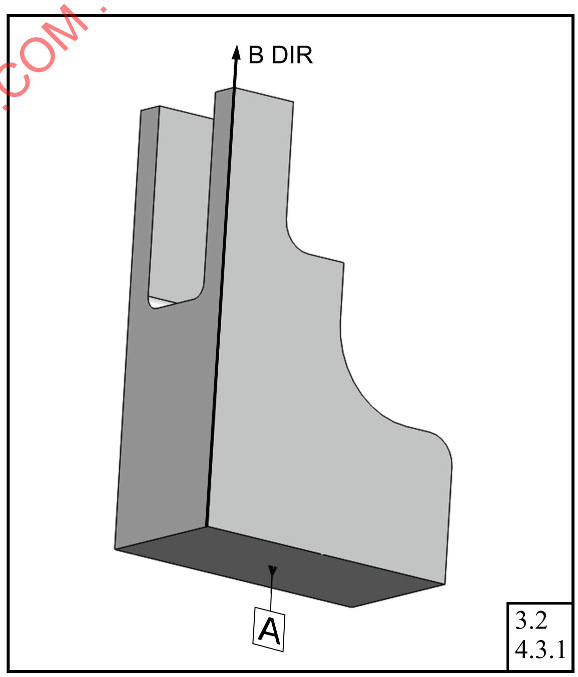


Figure 3-4
Unit Vector Indicating Gravity Direction

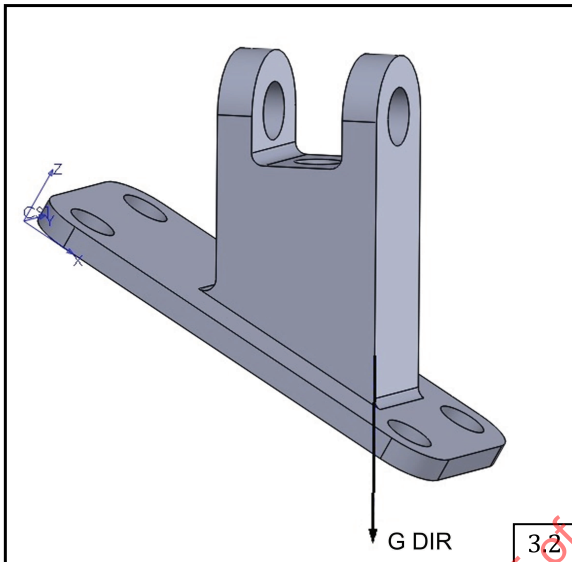
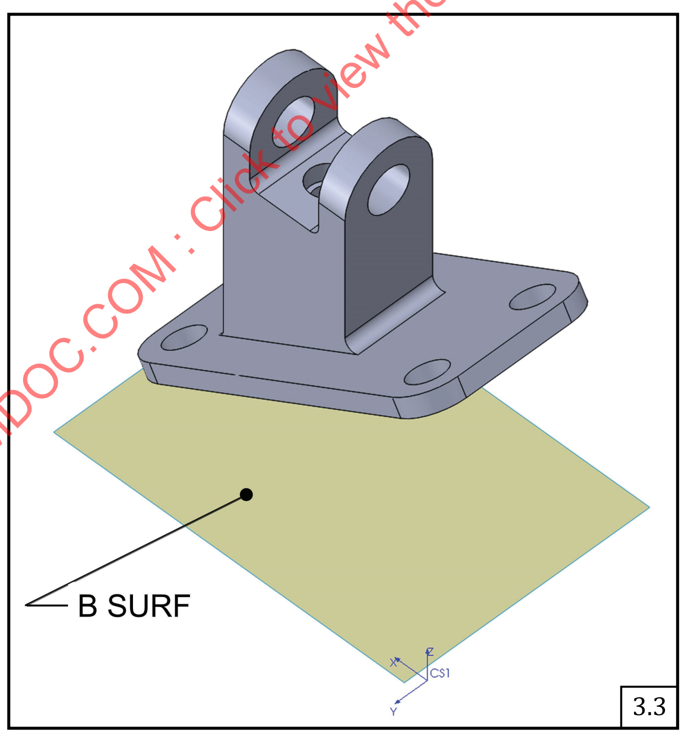


Figure 3-5
A Surface Representing a Build Surface



4 PRODUCT AND PROCESS DEFINITION

The nature of AM parts is such that a complete product definition may be achieved only by the communication of both design-related and process-related characteristics.

4.1 Geometry Characteristics

4.1.1 Surfaces and Tolerance

4.1.1.1 Defining a Theoretical Supplemental Surface (TSS). When used, theoretical supplemental surfaces shall be indicated with "TSS," as shown in Figures 4-1 through 4-3. Any point, line, or geometric element within the model that coincides with a TSS shall be allowed to vary within the applicable geometric tolerance zone applied to the TSS. The TSS may be an external surface or a surface that defines transitional boundaries between dissimilar characteristics of material. Such boundaries may be associated with changes in material composition, properties, porosity, or any other controllable characteristic that might be specified to achieve the product design intent. A TSS is differentiated from the traditional interpretation of a surface in that a TSS need not be a continuous surface. The TSS shall be identified in the part model in order to derive its topology. When partitioning volumes, if boundary interfaces must be controlled, a single TSS is used to define the interface.

4.1.1.2 Defining Surface Texture. Surface texture, where specified, shall be defined using the requirements from ASME B46.1 and ASME Y14.36.

4.1.2 Bounded Regions and Tolerances. Bounded regions may be used to indicate a subset of requirements such as materials, application of geometric tolerances, support structure volumes, allowable attachment areas, and other properties. A bounded region may be represented as a bounded volume region or a bounded surface region.

The bounded region shall be represented as a separate volume or surface region in the specification for the part. See Figure 4-4 for an example of bounded regions representing surface regions in a part.

4.1.2.1 Bounded Volume Region Identification. When used, a bounded volume region shall be indicated by "VOL*X*" where *X* is a unique label. The bounded volume region indicator may also be coupled with a feature control frame to specify a geometric tolerance as shown in Figures 4-5 and 4-6.

4.1.2.2 Bounded Surface Region Identification. When used, a bounded surface region shall be indicated by "SURF*X*" where *X* is a unique label. The bounded surface region indicator may also be coupled with a feature control frame to specify a geometric tolerance as shown in Figure 4-7.

4.1.2.3 Defining a Transition Region. When used, a transition region shall be indicated as a separate bounded region according to paras. 4.1.2.1 and 4.1.2.2.

Refer to para. 4.2.2 for the method to describe transitions or gradients.

4.2 Design Characteristics

This subsection addresses practices for communicating design-specific characteristics using the geometry characteristics in para. 4.1. The concepts discussed in this subsection include lattice structures, gradient control, complex geometries, and design for assembly.

4.2.1 Lattice Structures. A *lattice structure* can be composed of repeated patterns of *unit cells* that are defined as volumetric geometric elements in a defined space. The unit cell pattern can then be repeated to create complex heterogeneous or homogeneous geometric volumes. Examples of unit cells are shown in Figure 4-8.

If the lattice unit cell requires a geometric tolerance control, then an appropriate geometric control may be applied per ASME Y14.5 and paras. 4.1.1 and 4.1.2.

4.2.2 Gradient Control. Variation of a controllable characteristic (e.g., composition, density, porosity, layer thickness) within a volume and between volumes shall be controlled with a gradient control. Figure 4-9 identifies a gradient control within a part that consists of three bounded volume regions. VOL2 is the transition region between material MAT1 in VOL1 and material MAT2 in VOL3. When used, a gradient control shall be annotated on the model with the following:

(a) bounded volume region notation (see para. 4.1.2.1), e.g., VOL2 (see Figure 4-9).

(b) equation notation for the mathematical function, e.g., EQ1 (see Figure 4-9). See Nonmandatory Appendix B for an example.

(c) percentage label indicating the allowed variation from the target value, e.g., ±0.5% MAT2. See Figure 4-9 for an example that combines gradient controls and transition regions.

Table 4-1 provides material gradient values for the example part shown in Figure 4-9. This example implements functions to specify a gradient. The tolerances on MAT1 and MAT2 are bilaterally identified in Table 4-1 as ±25% and ±12.5%, respectively. At the material boundaries, the tolerance values are unilaterally disposed within the bounded volume regions (e.g., z = 10, z = 25, or when nominals are either 0% or 100%). See Nonmandatory Appendix B for a detailed explanation and example.

NOTE: Unintended voids in a particular volume, due to processing, may cause measured material composition to not equal 100%.

4.3 Process-Related Characteristics

Specifications related to an AM process may not be separable from the product definition. The following are the most common process-related characteristics needed for AM: part location and orientation, build specification, support structures, and test coupons.

If there are requirements to monitor process-related characteristics during the build process, such as reporting on machine build errors and failures, then those requirements shall be assessed for conformance. See Nonmandatory Appendix C. Postprocessing allowances should be specified as per the ASME Y14 standard relevant to the process. Machining allowances shall be specified in accordance with ASME Y14.36M.

4.3.1 Part Location and Orientation. When specified, a build direction shall be identified using the model's coordinate system and unit vector (see Figure 3-3) and shall be consistent with *X*, *Y*, *Z* as defined in ISO/ASTM 52921. The unit vector shall be labeled "B DIR" for build direction (see Figure 4-10).

A build direction may be specified as preferred (e.g., manufacturing enhancement) or required (e.g., part tolerances or performance).

Multiple build directions may be specified as shown in Figure 4-11. In such cases, each build direction shall be labeled in a sequence, such as B DIR1, B DIR2, with the sequence of whole numbers starting at 1, and shall have a subscript to identify the coordinate system in which it is defined.

4.3.1.1 Defining the Build Surface. When used, a build surface shall be defined using a coordinate system that shall be located using basic dimensions and identified relative to the model's coordinate system. The build surface feature shall be indicated as "B SURF," as shown in Figure 4-12. When additional build surfaces are used, they shall be defined using additional coordinate systems and build surface features.

4.3.1.2 Defining the Part Orientation Relative to the Build Surface. If a part orientation is required, it shall be identified using a coordinate system that shall be located and identified relative to a specified build surface, such as the build platform. The coordinate system shall be identified per para. 3.1 (see Figure 4-13).

4.3.1.3 Build Location and Nesting. The location of a part may be specified within a build volume by identifying a build location. Multiple build locations may be necessary when a simultaneous build of multiple parts, identical or dissimilar, occurs within the same build volume. See Figure 4-14. Refer to ISO/ASTM 52900 for additional specifications for nesting.

When the specification of a build location is necessary, the build location shall be specified with Cartesian coordinates within a coordinate system (see Figure 4-13).

4.3.1.4 Free Zone. When used, a free zone shall be indicated with "FREE ZONE" followed by the offset dimension. The offset dimension is a uniform boundary, offset normal from the basic part geometry (see Figure 4-15).

A free zone may be applied to the bounding box of an object by appending "BOUNDING BOX" to the free zone specification (see Figure 4-16). The bounding box shall be associated to the model coordinate system.

If different bounded regions of a part, assembly, or nest require different free zones, then each bounded region shall be specified separately.

4.3.2 Build Specification. The following paragraphs describe how to communicate additional process parameter information.

4.3.2.1 Layer Thickness Specification. If a layer thickness specification is required for a part build, it shall be indicated. This may be accomplished directly via annotation or indirectly by a general note or by referencing an associated document. For the direct annotation method, layer thickness shall be indicated with "LAYER THICKNESS," followed by the limits of acceptable layer thickness values (e.g., 0.03–0.05), as shown in Figure 4-17. If the part has different bounded regions or if the part build uses different layer thicknesses, the bounded region and transition methods shall be used as applicable and as described in para. 4.1.2.

4.3.2.2 Track Path Specification. When used, a track path shall be identified with "TRACK" and unit vector coordinates, followed by a subscript of the related coordinate system, e.g., CS1 (see Figure 4-18). To indicate a track path that follows a boundary, a note shall indicate "FB" (follow boundary); see Figure 4-19. A number following "FB" shall indicate the number of passes. The absence of a number shall indicate that the track path continues throughout each layer profile. A "TRACK TABLE" annotation (or associated document) may also be included to specify layer numbers whose tracks are specified as unit vector notations. The "TRACK TABLE" concept introduced in Figure 4-20 provides flexibility to specify the contours using a table.

4.3.2.3 Build Environment. The characteristics of the build environment may differ depending on the process used and may include temperature, humidity, and other process conditions that may affect the quality of the build. Specific environmental requirements may be communicated as a note.

4.3.2.4 Fill Patterns. Fill patterns can be used to save material and decrease weight, cost, and time to build the part. Specific patterns can be used for modifying the item properties (e.g., increased stiffness or strength) by specifying one or more unit cell and fill volumes.

When used, fill patterns shall be defined as described in (a) through (e).

(a) The volume to be filled with the fill pattern shall be defined using one of the following methods:

(1) by specifying the shell thickness

(2) by defining explicitly the bounded volume region for the fill pattern

(b) The percentage of volume to be filled shall be specified.

(c) The specific unit cell for the pattern shall be specified as follows:

(1) The unit cell direction and orientation shall be specified.

(2) The unit cell shall be defined as a feature of the model, defined in a separate model, or specified by associated documents.

(d) A model view shall be created displaying an annotation with leader associated to the fill volume. The annotation shall start with "INFILL" followed by the percentage of volume to fill, followed by a dimension for the shell thickness [see Figure 4-21, illustration (a)], and unit cell identifier, if applicable.

(e) The unit cell can be explicitly positioned within the part in one of the following three ways:

(1) The part coordinate system and a unit cell coordinate system are defined using subscripts to the word "INFILL" and the unit cell identifier.

(2) The unit cell coordinate system will be aligned and positioned relative to the part coordinate system.

(3) The unit cell can float without restriction within the defined part boundary.

An example of a two-dimensional honeycomb infill unit cell is shown in Figure 4-21, illustration (c).

4.3.3 Support Structures. A bounded surface or volume region may be used to specify where to limit or require support structures. Figure 4-22 illustrates a default support structure without any specification, thus creating no new specification requirements. In some scenarios, support structure location may be a desired specification.

If necessary, specify locations where support structures attach to or are prohibited from nominal geometry. The following are examples of requirements that may be needed:

(a) exclusion zones for support structures. In this scenario, one or more regions are identified as being off limits to support structure considerations during the planning of the AM build. A structure exclusion area (SEA) shall be specified by the notation "SEA" (see Figure 4-23).

(b) limited surface area interface of support structures. In this scenario, one or more regions are identified as requiring support structures. The limiting note will set additional requirements on the amount of support structure coverage required on a specified region. A structure limiting area (SLA) shall be specified by the notation "SLA," followed by the maximum amount of area that may have support structures attached (see Figure 4-24).

(c) required location of support structures. In this scenario, one or more regions are identified as requiring support structure considerations during the planning of the AM build. A structure required area (SRA) shall be specified by the notation "SRA" (see Figure 4-25).

NOTE: Figures are for demonstrative purposes only. Support structure geometry in Figures 4-23 through 4-25 is exaggerated to demonstrate concepts.

If a note is associated to a feature of size, supports shall connect the identified surface to the feature of size. If the note is not associated to a feature of size, the support shall connect the indicated surface to adjacent surfaces (see Figure 4-25). When support structure geometry is used, it shall be included in the model as bounded surface or bounded volume regions. If a profile tolerance is required for support structure geometry, the profile tolerance shall be indicated with "SUPPORT" and a bounded volume region indicator (see Figure 4-26). This may be repeated, as necessary, to indicate support structures outside or inside the part.

4.3.4 Test Coupons. Test coupons, if specified, shall be identified with "Test Coupon *X*," where *X* is a unique label. If build layout and build surface are depicted (see Figure 4-27), the build location, orientation, and related tolerance specifications for test coupons shall be indicated as specified in para. 4.3.1.3.

Figure 4-1
Example of a Theoretical Supplemental Surface Used on a Rectangular Lattice Cuboid

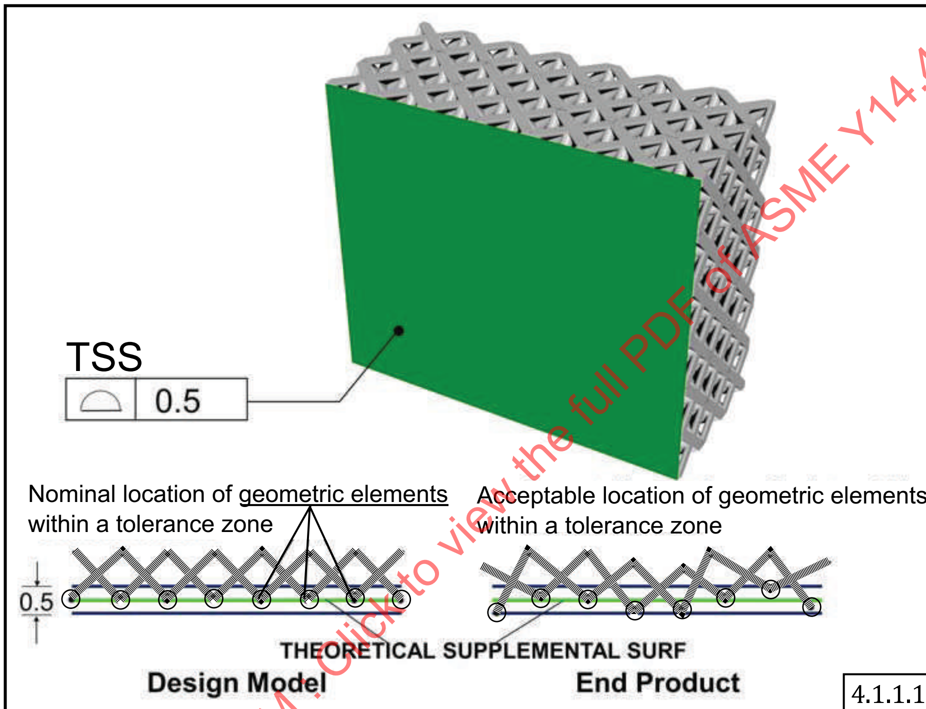


Figure 4-2
Example of a Nonplanar Theoretical Supplemental Surface

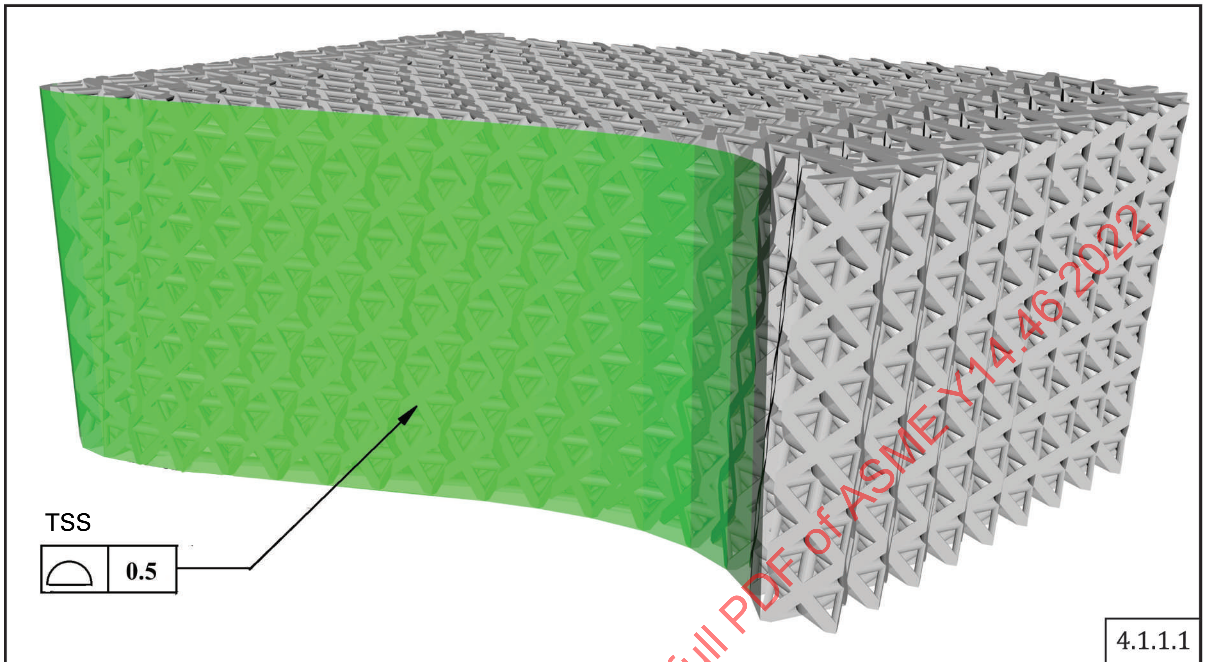


Figure 4-3
Example of a Tolerance Zone

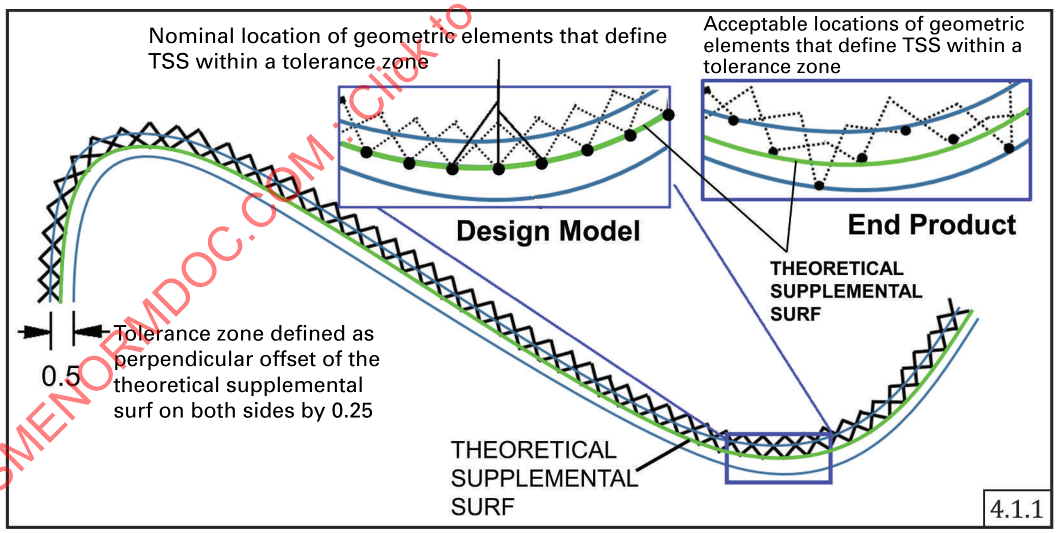
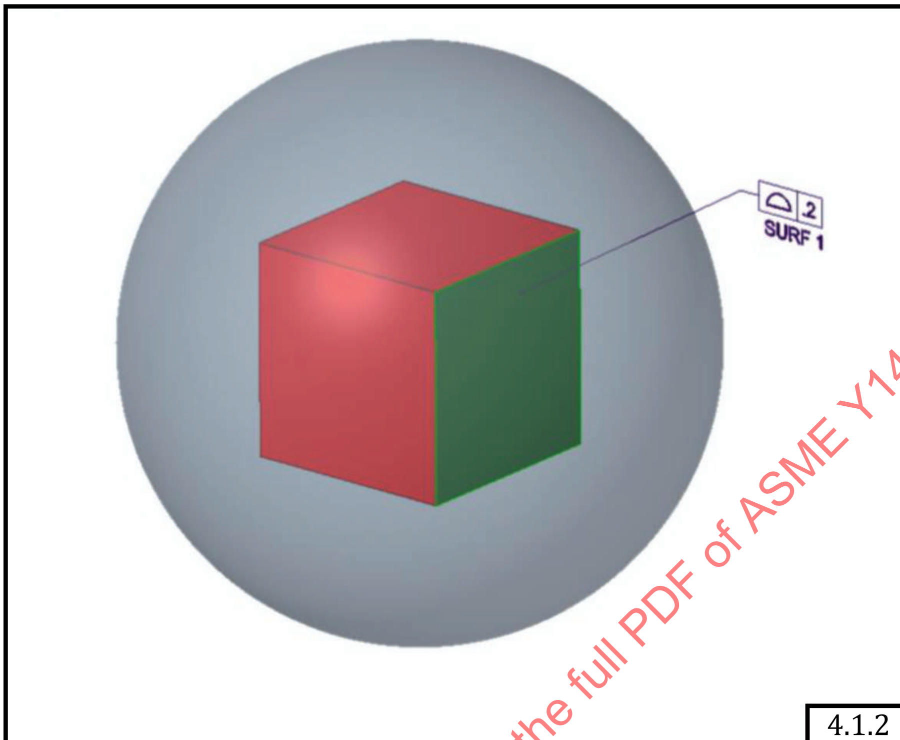


Figure 4-4
Bounded Surface Region to Indicate Internal and External Surfaces



GENERAL NOTE: Here, a surface on a cubic volume within a spherical object describes a bounded surface region.

Figure 4-5
Bounded Volume Region Indicator (VOL1) With a Profile of a Surface Tolerance

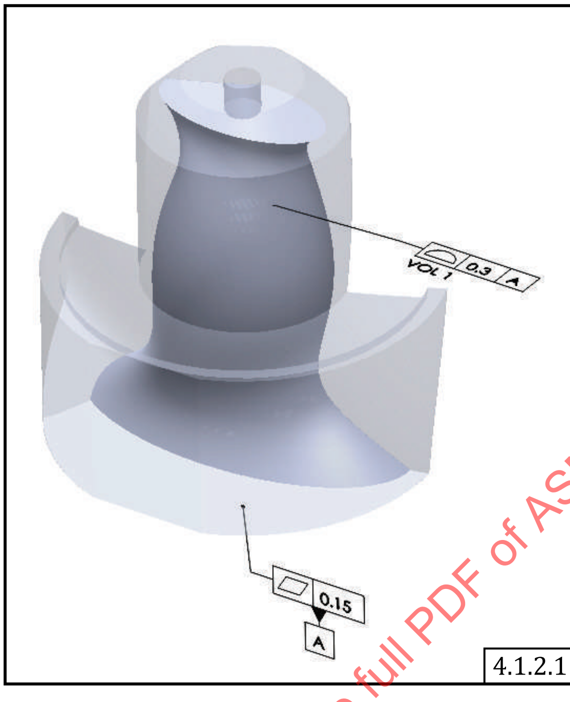


Figure 4-6
Bounded Volume Regions Represented by Several Bounded Volume Region Indicators in a Part

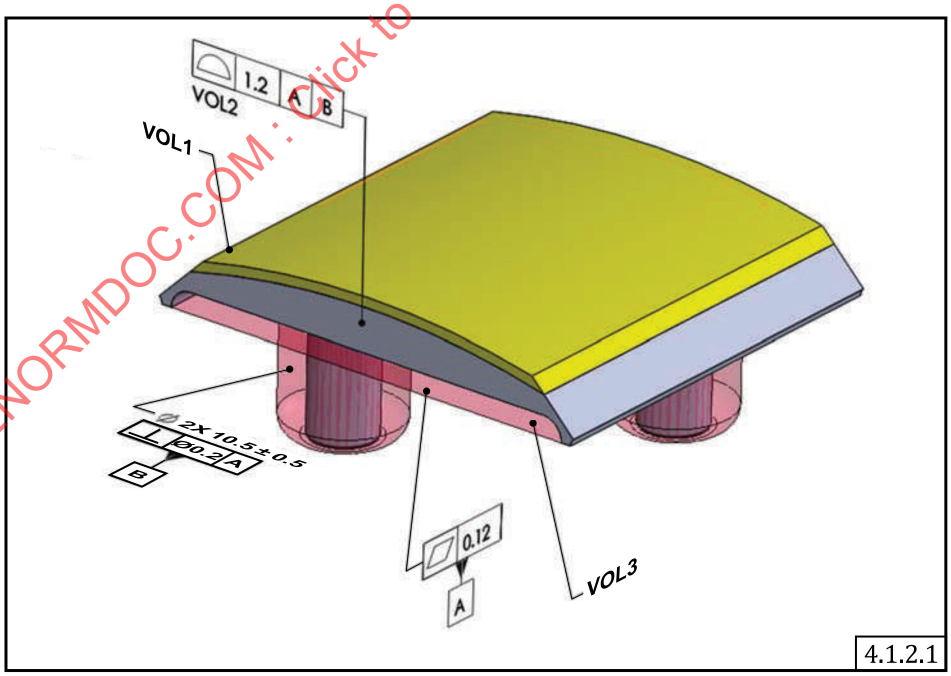


Figure 4-7
Bounded Surface Region Indicator Coupled With a Feature Control Frame

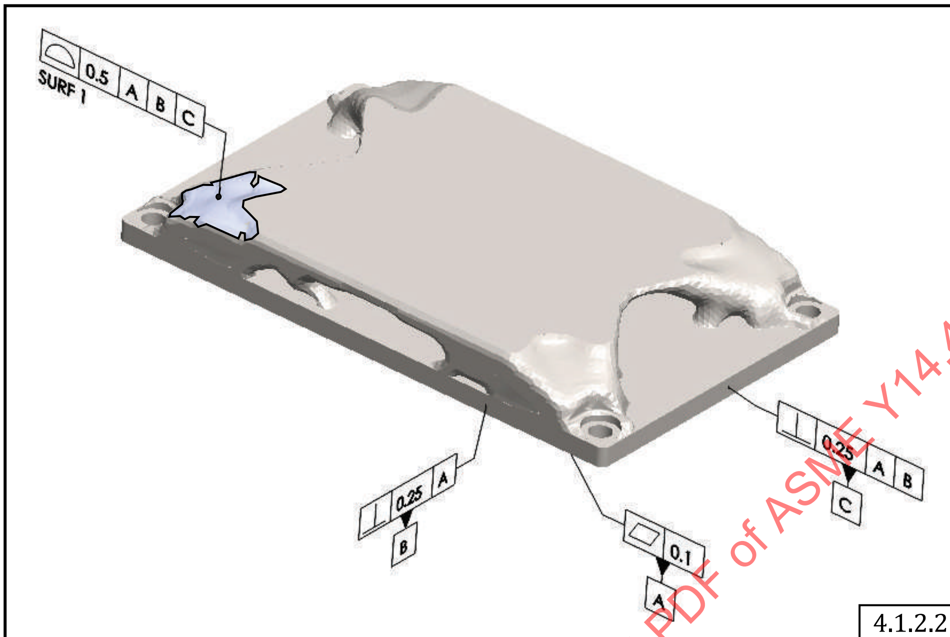
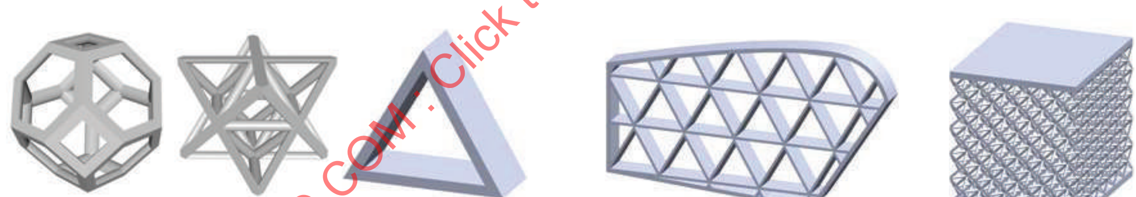


Figure 4-8
Examples of Unit Cell Geometries and Lattice Structures



(a) Individual Unit Cell Geometries Used in Lattice Structures

(b) Lattice Structures Formed by Repeating Unit Cells in a Pattern

4.2.1

Figure 4-9
VOL Local Notes That Describe Material Gradient Allocations Shown in Table 4-1

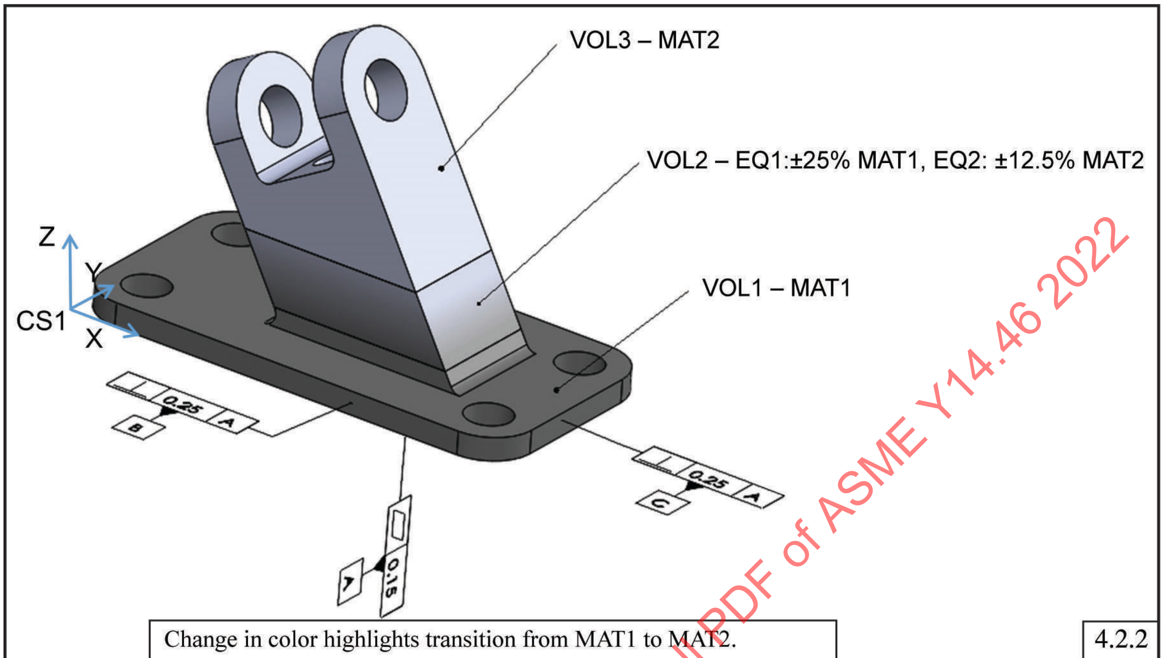


Table 4-1
Material Gradient Values Used in Figure 4-9

Annotation Label	*z*, mm	Nominal MAT1, %	Nominal MAT2, %	Tolerance on MAT1, %	Tolerance on MAT2, %
VOL1	10	100	0	−25	+12.5
VOL2	15	66	33	±25	±12.5
...	20	33	66	±25	±12.5
VOL3	25	0	100	+25	−12.5

Figure 4-10
Build Direction Indicated Using the Direction Unit Vector

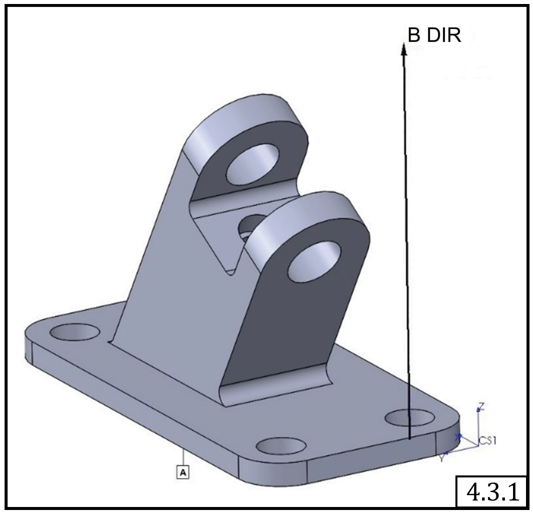


Figure 4-11
Multiple Build Directions

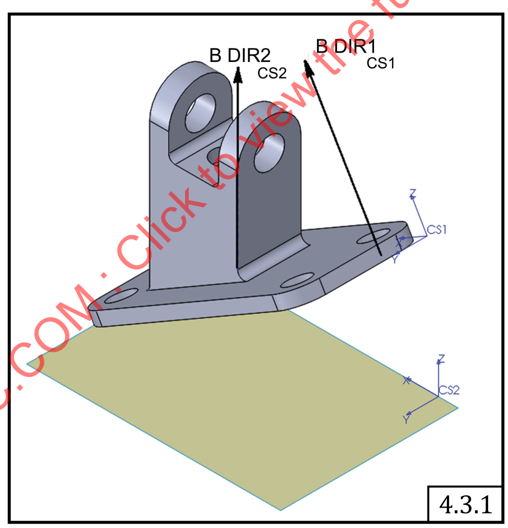


Figure 4-12
Planar Build Surface and a Nonplanar Build Surface

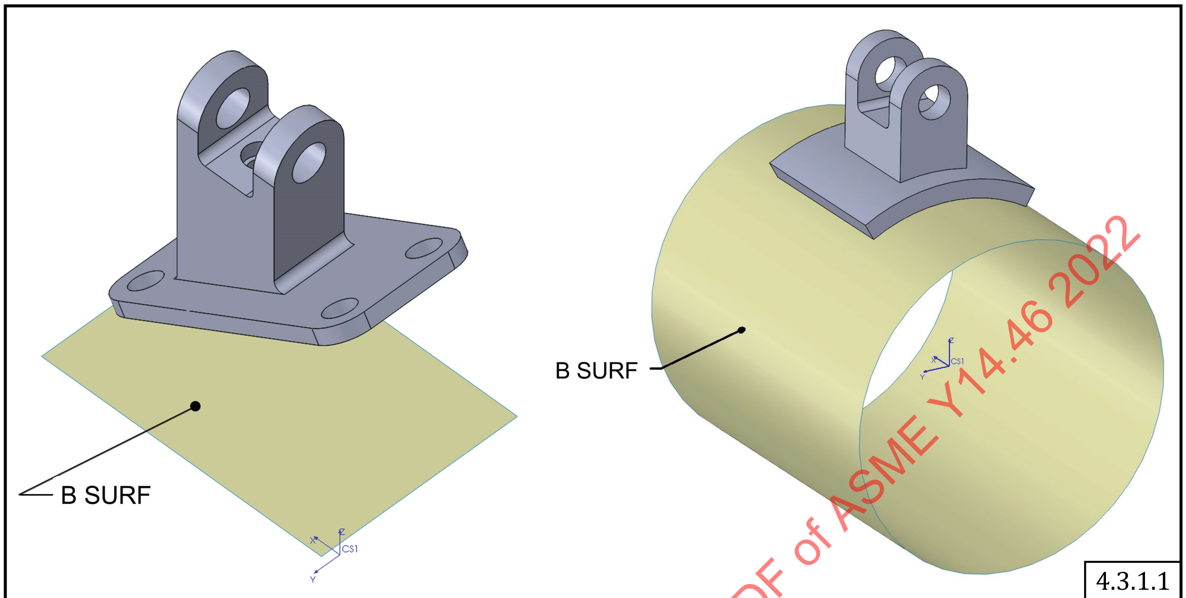


Figure 4-13
Coordinate Systems Are Used to Locate Parts Within a Build Volume

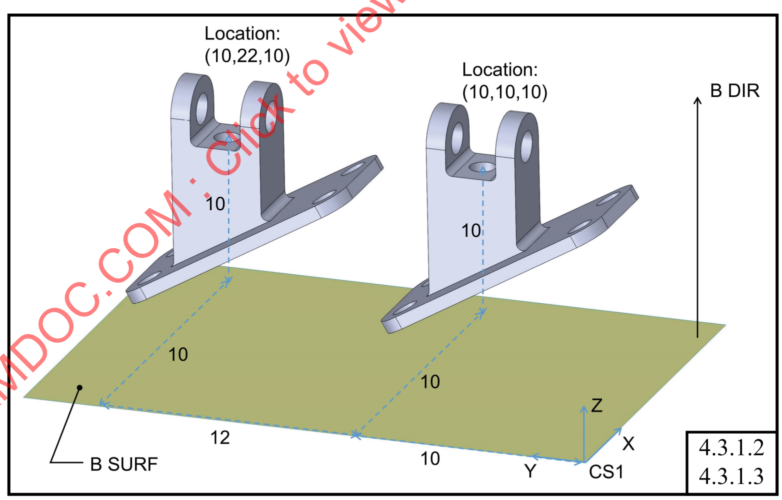


Figure 4-14
Four Separate Parts Nested Inside One Another on a Build Surface

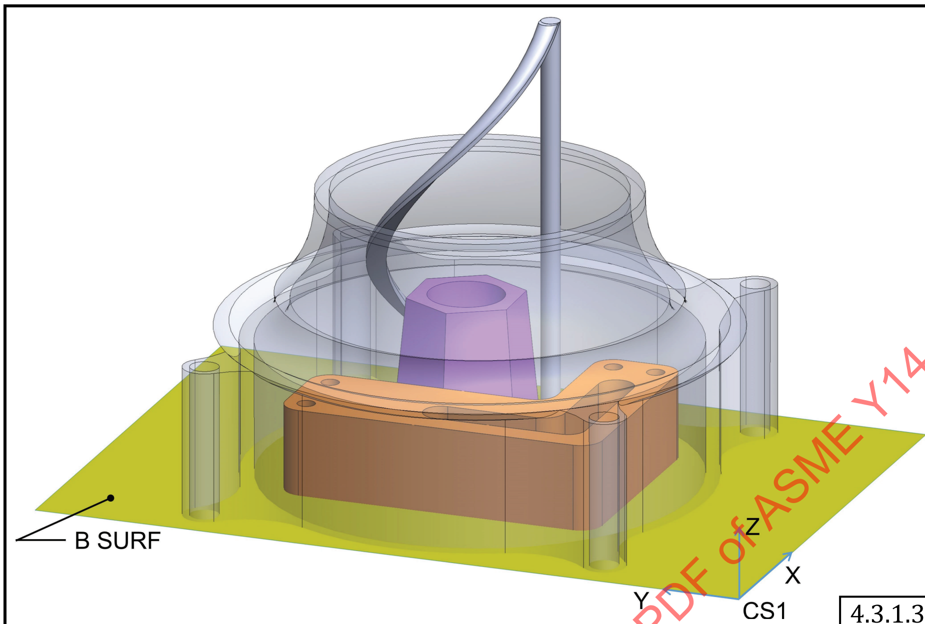
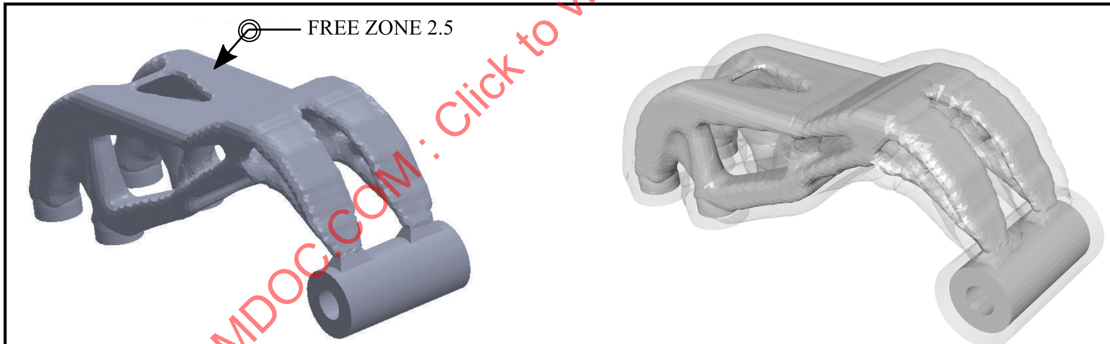


Figure 4-15
Free Zone Description With an Offset Dimension

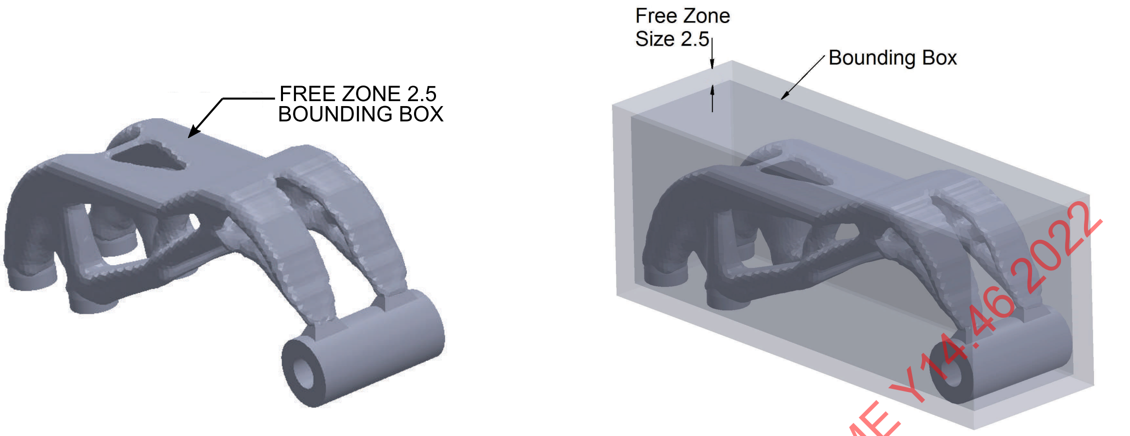


(a) Identification of a Free Zone of 2.5 mm Around the Part

(b) Visualization of the Invisible Boundary Around the Part at a Distance of 2.5 mm

4.3.1.4

Figure 4-16
Free Zone Bounding Box Description



(a) Identification of a Free Zone Around the Bounding Box of the Part

(b) Visualization of the Invisible Boundary Around the Part Established by the Free Zone Bounding Box.

Figure 4-17
Layer Thickness Specification

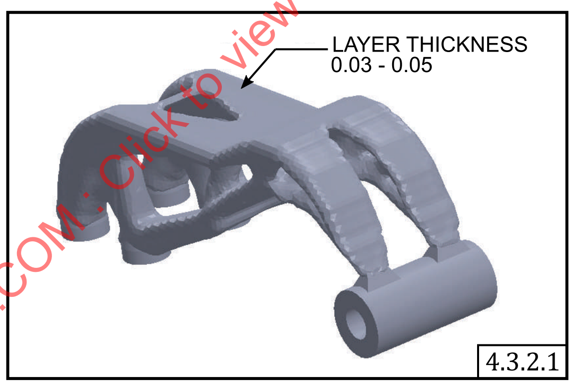


Figure 4-18
Specification of a Track Path With Three Contours

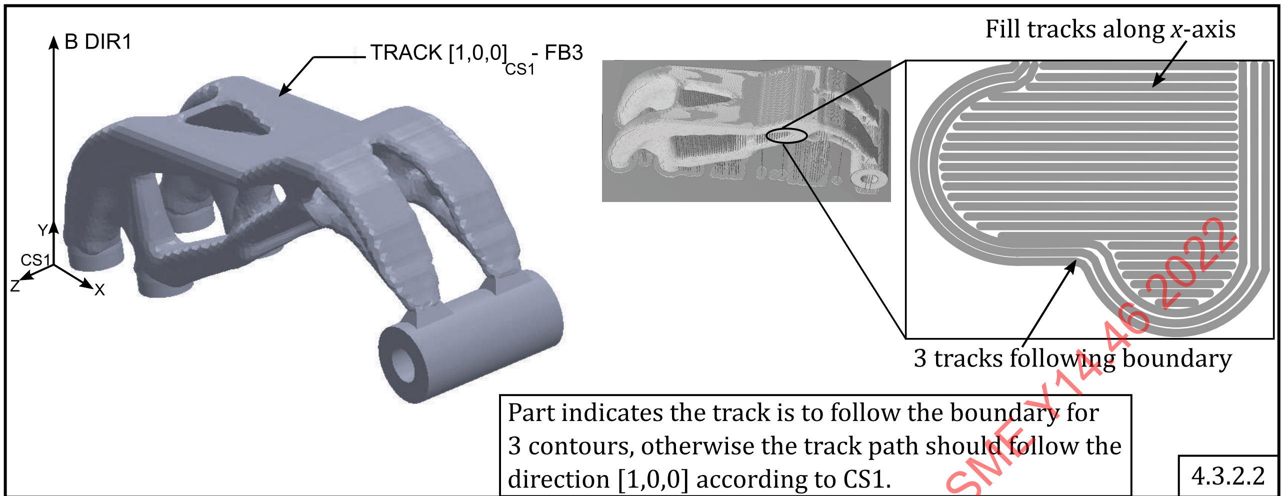


Figure 4-19
Specification of a Track Path Using a Follow Boundary (FB) Modifier

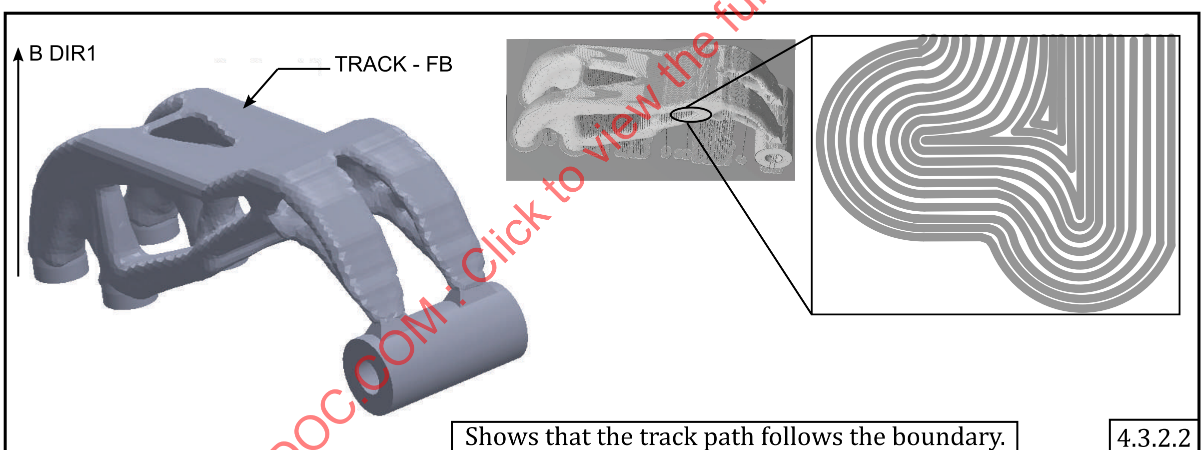
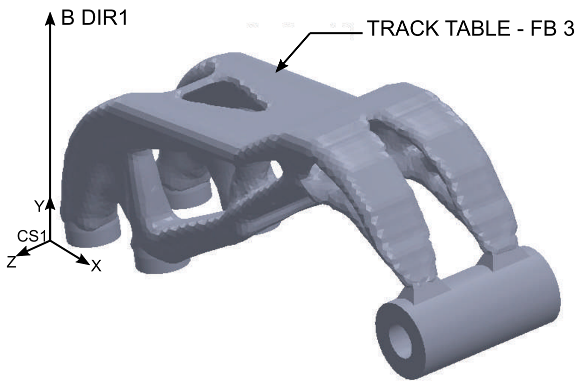


Figure 4-20
Specification of Track Paths on Different Layers



LAYER	Track Direction - CS1
Odd	[1,0,0]
Even	[0,1,0]
134	[1,1,0]
135	[-1,1,0]

4.3.2.2

GENERAL NOTE: "TRACK TABLE" indicates different track paths on different layers.

Figure 4-21
Examples of Infill and Unit Volumes

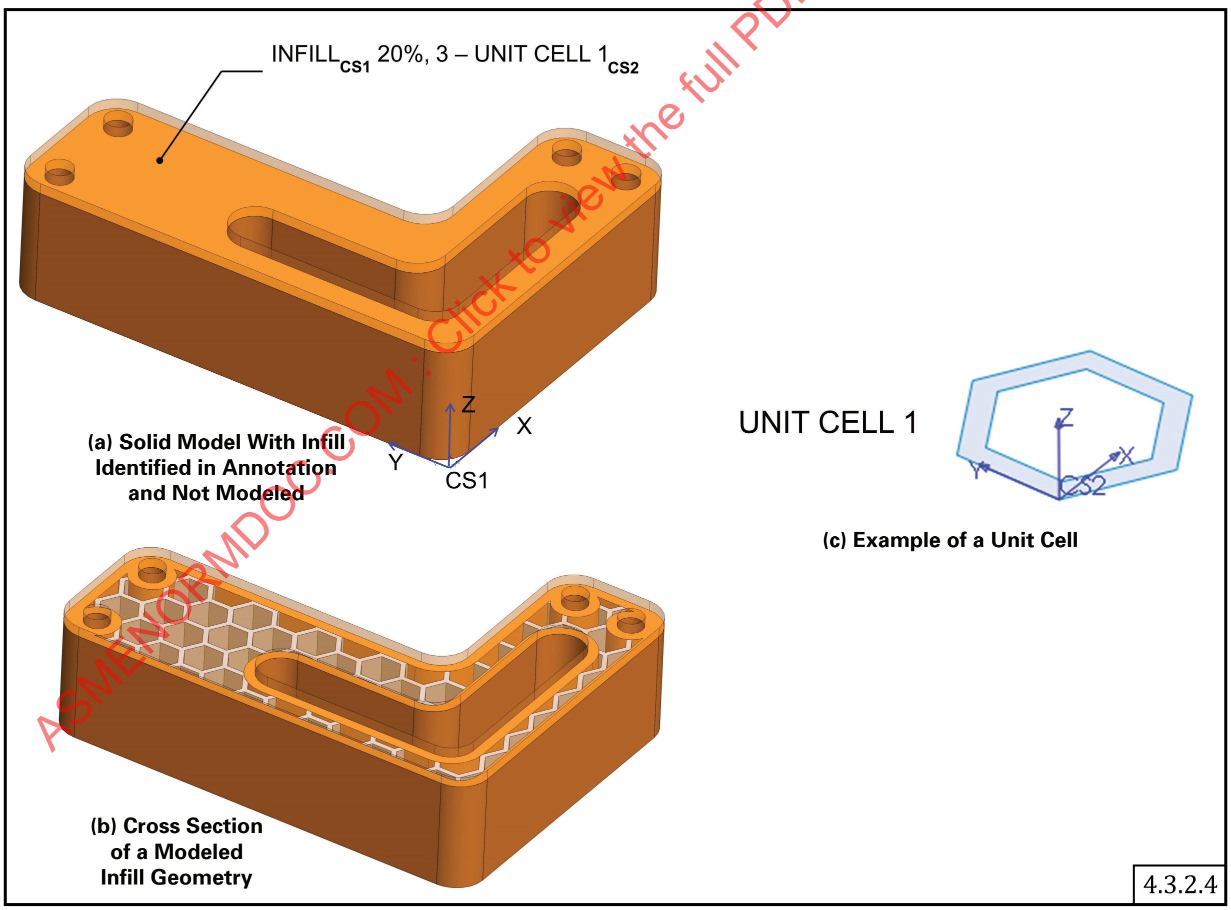


Figure 4-22
Example Where Support Structure Location Is Not Specified

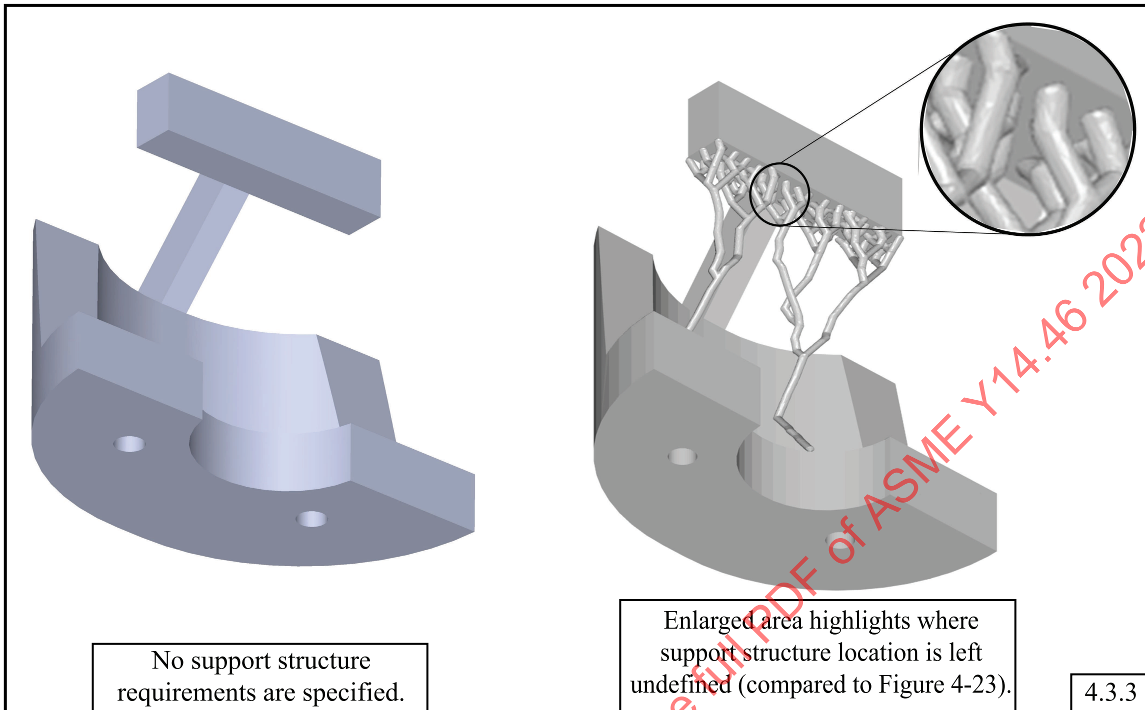


Figure 4-23
Example Where Bounded Surface Region 1 (SURF1) Is Annotated to Indicate a Structure Exclusion Area (SEA)

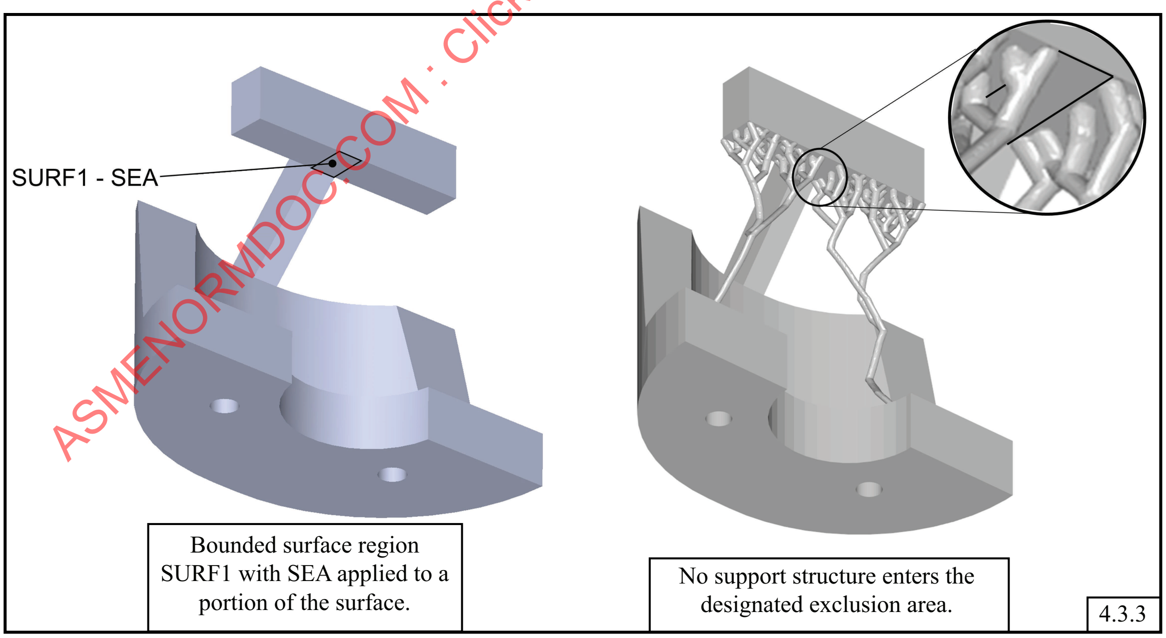


Figure 4-24
Example Where SURF1 Is Annotated to Indicate a Structure Limiting Area (SLA) of 20%

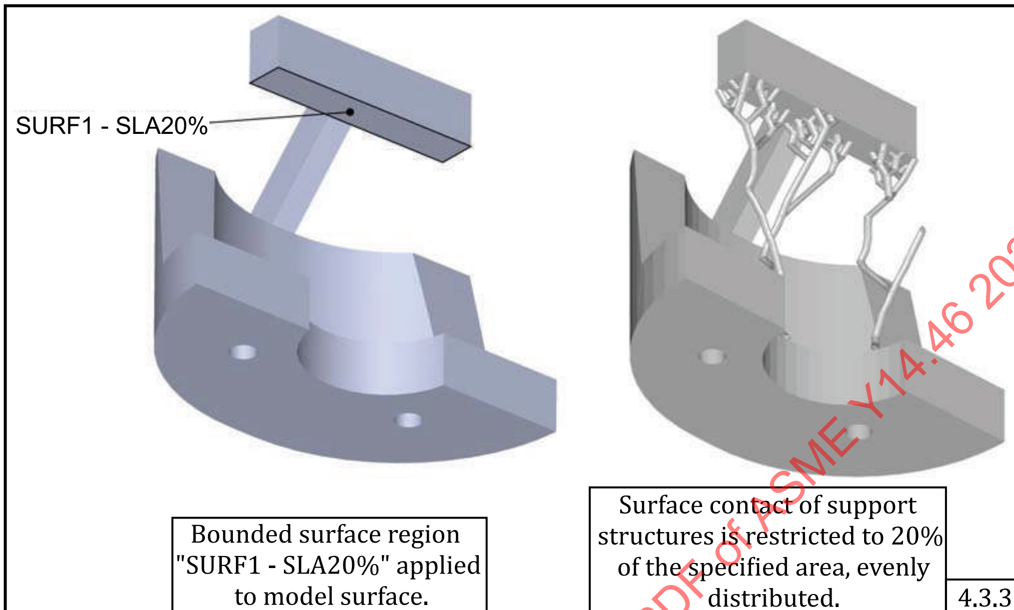


Figure 4-25
Example Where SURF1 Is Annotated to Indicate a Structure Required Area (SRA)

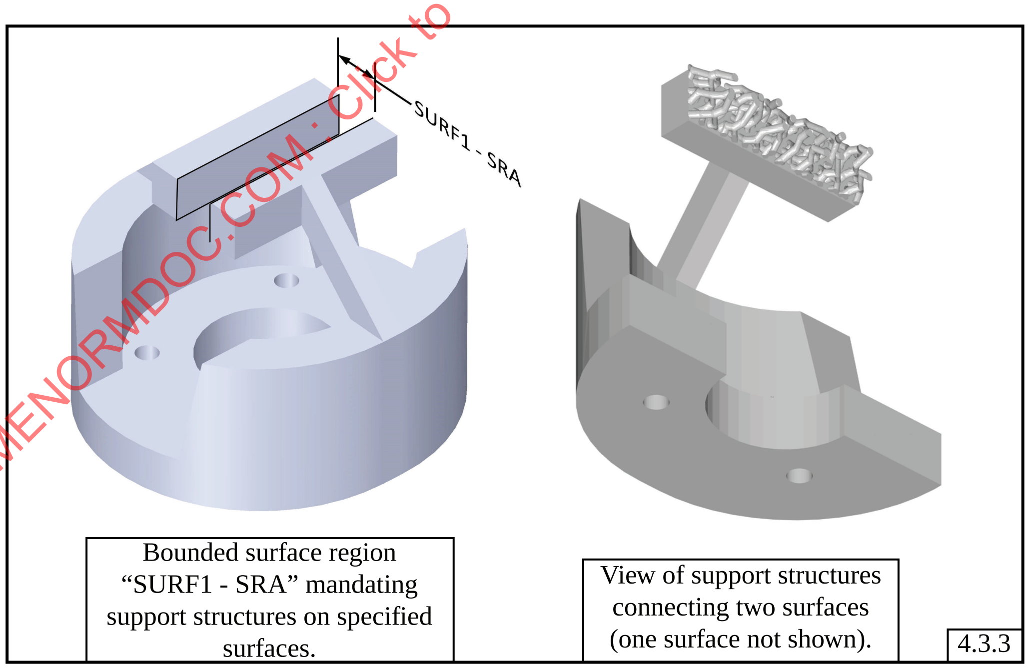


Figure 4-26
Indication of Geometry Created Inside the Part to Specify Support Structure

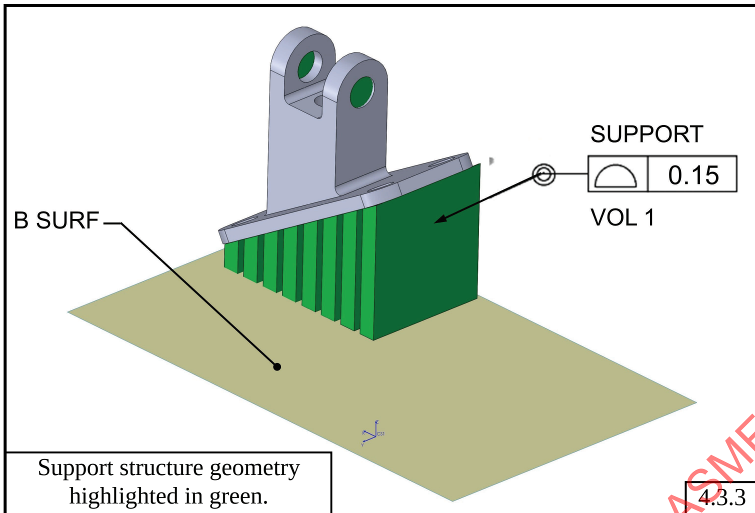
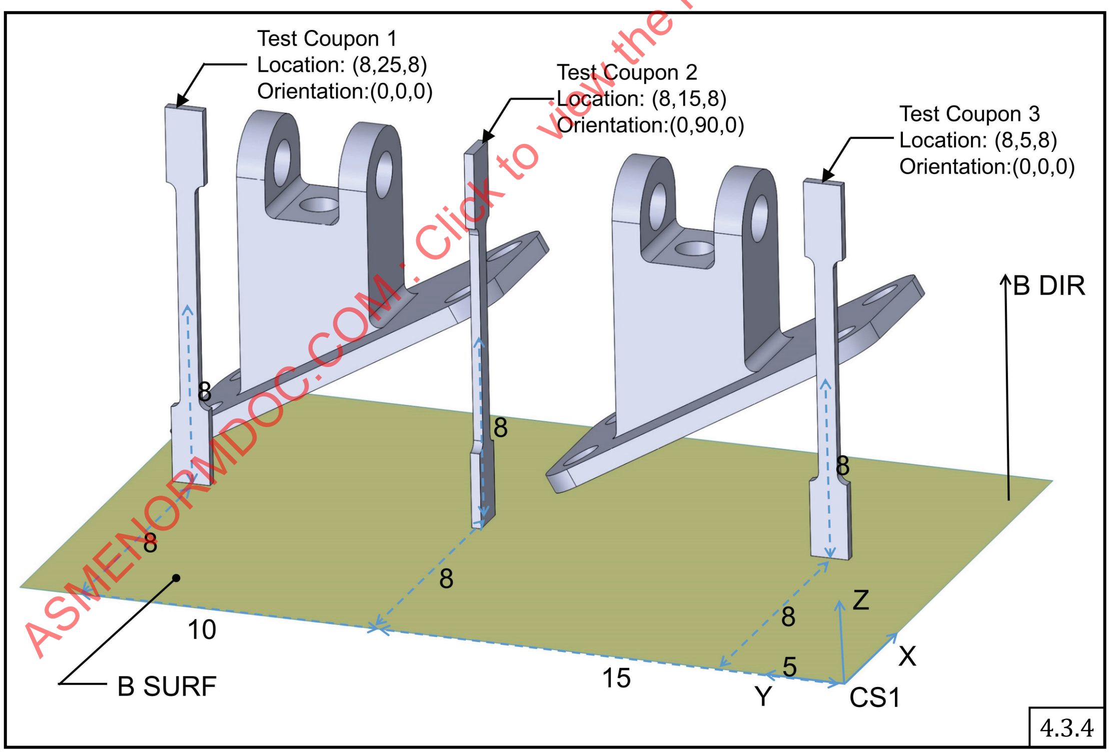


Figure 4-27
Local Notes Identifying Test Coupons



5 PRODUCT DEFINITION DATA SETS

5.1 General

Due to the inherently digital nature of AM processes, this section focuses on model-based requirements (see ASME Y14.41, Classification Codes 3, 4, and 5), as opposed to drawing-centric requirements.

5.2 Product Definition Data Set Types

This subsection establishes data requirements for managing different stages of an AM part. The process intricacies required to define the transition from a product definition data set to a part is like that of forgings and castings in both complexity and postprocessing requirements. As such, managing the AM transition shall be similar to managing transitions established in the applicable standards for castings and forgings. Each transition may be represented as a unique file set with unique formats. These files shall be collected into a product definition data set (PDDS) of the designated type. Table 5-1 presents examples of constituent PDDS types used in AM. At a minimum, one PDDS type is required.

The provided PDDS types define product characteristics at intermediate manufacturing process states. A PDDS type is selected based on the communication requirements for a given scenario. Each PDDS type is differentiated by the required and optional data elements.

5.3 PDDS Type Contents

5.3.1 AM Design PDDS. The AM Design Data Set content may include the required and optional elements identified in Table 5-2.

5.3.2 AM Build PDDS. The AM Build Data Set expands on the AM Design PDDS by introducing process information. This content may include the required and optional elements identified in Table 5-3.

5.3.3 AM Processed PDDS. The AM Processed PDDS content attributes are optional, and additional optional data elements associated with postprocessing are introduced. The process information requirement introduced by the AM Build PDDS is maintained. This content may include the required and optional elements identified in Table 5-4.

5.3.4 End Product PDDS. The End Product PDDS content reduces required data elements to geometry. This content may include the required and optional elements identified in Table 5-5.

5.4 Model Schema and Organization

AM product definition data shall comply with ASME Y14.47 requirements. An example of AM model schema and organization combinations beyond ASME Y14.47 examples is described in Table 5-6.

Reference ASME Y14.47, para. 6.5 for metadata that may be included in the product definition data set. Metadata elements indicated in Table 5-7 shall also be included.

Table 5-1
Required and Optional Data Sets for AM Products

PDDS Type	Required/ Optional	Description
AM design	Required	Identifies all requirements for the end product and may also include supplemental geometry as defined in section 3 and geometry characteristics as defined in paras. 4.1 and 4.2.
AM build	Optional	Identifies all requirements for the printed file geometry and build environment. May also include support structures, supplemental geometry from section 3, geometry characteristics as defined in paras. 4.1 and 4.2, and process-related characteristics as defined in para. 4.3.
AM processed	Optional	Identifies all requirements for completing the part. May include all elements of AM build data set complemented by additional instructions (e.g., notes) on postprocessing (e.g., machining, coatings, heat treatment, inserts) operations.
AM end product	Optional	Includes evidence of conformance to specification. Refer to Nonmandatory Appendix C for suggestions on collecting data representing the end product.
AM postproduction	Optional	Archive of all data used in the production of the part. May be a combination of some or all of the data sets produced.

Table 5-2
Required and Optional Elements Within the AM Design PDDS

Data Element	Required/ Optional	Description
Geometry	Required	Represents the final geometric definition, per ASME Y14.47, Code G3. May include requirements identified in section 3 and paras. 4.1 and 4.2.
Annotations	Required	Represents the final dimensions and tolerances required, per ASME Y14.47, Code A1, Code A2, or Code A3. May include requirements identified in section 3 and paras. 4.1 and 4.2.
Attributes	Required	Represents information that can be queried in the model per ASME Y14.41. May include requirements identified in section 3 and paras. 4.1 and 4.2.
Metadata	Required	Represents metadata per ASME Y14.47 and Table 5-7.
Support documentation	Optional	Additional documentation may be required and may be included in the PDDS. This may include, but is not limited to, analysis requirements and results, material specifications, and build environment requirements.
Additional digital formats	Optional	Additional digital file formats may be needed and are derivatives from the original native file. Examples of additional digital file formats are STL, AMF, STEP, and 3MF.

Table 5-3
Required and Optional Elements Within the AM Build PDDS

Data Element	Required/ Optional	Description
Geometry	Required	Represents the geometric definition as the model is to be printed, per ASME Y14.47, Code G3. May include requirements identified in section 3 and paras. 4.1, 4.2, and 4.3.
Annotations	Required	Represents the final dimensions and tolerance required, per ASME Y14.47, Code A1, Code A2, or Code A3. May include requirements identified in section 3 and paras. 4.1, 4.2, and 4.3.
Attributes	Required	Represents information that can be queried from the model per ASME Y14.41. May include requirements identified in section 3 and paras. 4.1, 4.2, and 4.3.
Metadata	Required	Represents metadata per ASME Y14.47 and Table 5-7.
Additional geometry	Optional	Additional PDDS requirements may be required to represent additional AM build information. May include requirements identified in section 3 and paras. 4.1, 4.2, and 4.3.
Additional requirements	Optional	Additional requirements may be specified to define the build environment. May include requirements identified in section 3 and paras. 4.1, 4.2, and, particularly, 4.3.
Additional manufacturing information	Optional	Additional digital file formats may be needed and are derivatives from the original native file. Examples of additional digital file formats include STL, AMF, STEP, 3MF, and manufacturer-specific slice and build files.

Table 5-4
Required and Optional Elements Within the AM Processed PDDS

Data Element	Required/ Optional	Description
Geometry	Required	Represents the geometric definition as the model is to be printed and postprocessed, per ASME Y14.47, Code G3. May include requirements identified in section 3 and paras. 4.1 and 4.2.
Annotations	Required	Represents the final dimensions and tolerance required, per ASME Y14.47, Code A1, Code A2, or Code A3. May include requirements identified in section 3 and paras. 4.1 and 4.2.
Metadata	Required	Represents metadata per ASME Y14.47 and Table 5-7.
Attributes	Optional	Represents information that can be queried from the model per ASME Y14.41. May include requirements identified in section 3 and paras. 4.1, 4.2, and 4.3.
Additional geometry	Optional	A variety of geometry representations may be required to represent multiple stages of postprocessing. For example, the AM build part may be processed using traditional machining operations. This geometry may be represented as a model in a variety of file formats.
Additional components and assembly	Optional	Additional components may be added to the part to complete the AM design requirements. An example is adding helical inserts into a part.
Additional procedural instructions	Optional	When processing steps are needed, these shall be included in the data sets. These may include, but are not limited to, support structure removal and removal from the build platform, heat treatments, and finishing processes. May include requirements identified in para. 4.3.
Additional manufacturing information	Optional	A variety of digital files may be produced to manufacture the part. An example is the G Code for milling to a final specification.

Table 5-5
Required and Optional Elements Within the End Product PDDS

Data Element	Required/Optional	Description
Geometry	Required	Actual 3D geometry, as evaluated to capture the end product. This model may be used to compare to the AM design model for quality validation.
Evidence of conformance	Optional	Actual measurement results representing the geometry to specifications.

Table 5-6
Examples of AM Use Cases Using the Codes in ASME Y14.47 to Show the Level of Content in an AM Data Set Type

	Categories									
	Maturity State, Level (Code)				Geometry State, Level (Code)			Annotation and Attribute State, Level (Code)		
Use-Case Examples	Conceptual (M1)	Developmental (M2)	Production (M3)	Postproduction (M4)	None (G1)	Partial (G2)	Full (G3)	None (A1)	Partial (A2)	Full (A3)
Fixturing	...	X	...	...	...	...	X	...	X	...
Production	...	...	X	...	...	...	X	...	...	X
Prototype	...	X	...	...	...	...	X	X	...	...
Visual novelties	X	...	...	...	...	X	...	X	...	...

Table 5-7
Examples of Metadata for Model-Based Definition (MBD) Data

Element Name	Required/ Optional	Data Type	Description	Data Category
PDDS_Type	Required	String	AM design/AM build/AM processed/End product/Postproduction	2
AM_Process	Optional	String	Specify AM process per ASTM Committee F42 on Additive Manufacturing Technologies: material extrusion, material jetting, binder jetting, vat photopolymerization, sheet lamination, powder bed fusion, directed energy deposition	3
AM_Joining_Mechanism	Optional	String	Specify joining mechanism textual input (e.g., binder, laser, electron beam, sinter, melt)	2

NONMANDATORY APPENDIX A
EXAMPLE AM NOTES

A-1 INTRODUCTION

This Appendix contains example notes for an AM part.

A-2 PRODUCT NOTES

INTERPRET PRODUCT DEFINITION IN ACCORDANCE WITH ASME Y14.5-2018, ASME Y14.41-2019, ASME Y14.47-2019, AND ASME Y14.46-2022 STANDARDS.

DESIGN MODEL MBD051861 IS REQUIRED TO COMPLETE THE PRODUCT DEFINITION.

UNLESS OTHERWISE SPECIFIED, ALL UNTOLERANCED FEATURES SHALL HAVE A PROFILE TOLERANCE OF

⌓	0.2	A	B	C

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OBTAIN DIMENSIONS FOR ALL UNDIMENSIONED FEATURES FROM THE MODEL. ALL VALUES QUERIED OR DERIVED FROM THE MODEL SHALL BE BASIC.

DATUMS Z, Y, X ARE DEFINED FROM CORRESPONDING AM-PROCESS PRODUCT DEFINITION.

MATERIAL ENVELOPE SHALL NOT EXCEED THE BOUNDARY DEFINED BY MECHANICAL ENVELOPE A051861.

A-3 PROCESS NOTES

A PLATFORM OF MINIMUM 3.75mm HEIGHT SHALL BE PRINTED BETWEEN THE BUILD PLATFORM AND THE PART AND CUT OFF AFTER THE ADDITIVE MANUFACTURING PROCESS.

THE PART SHALL BE SANDBLASTED AFTER THE ADDITIVE MANUFACTURING PROCESS AND BEFORE BEING POST-MACHINED.

THREE CYLINDRICAL WITNESS COUPONS SHALL BE PRINTED IN THE SAME BUILD AS EACH PART TO VERIFY MECHANICAL PROPERTIES PER NSC 1234567.

NONMANDATORY APPENDIX B DEFINING TRANSITION REGIONS

B-1 INTRODUCTION

This Appendix demonstrates the application of transition regions. Figure B-1 provides a representative example of the use of transition regions.

The transition property is indicated with the symbol m_i. The transition function is indicated as f_i. At any given location x, y, z within a unit-defined volume of the transition region, the required factor m_i is computed using eq. (1). The unit-defined volume is the volume within which the property is computed. Any given location can be normalized by using all factors m_i and summing to 1 [see eq. (2)]. Alternatively, tolerance on the value of the factor may be specified as t_{mi} and may be computed using eq. (3). All computed values may be taken as absolute positive values as deemed necessary. Mathematical functions defined in ISO/ASTM 52915 are also applicable.

The application of this method is illustrated in section B-2.

$$\frac{f_i(x, y, z)}{\sum f_i(x, y, z)} \tag{1}$$

where

$$\sum_1^n m_i = 1 \tag{2}$$

$$\sum_1^n m_i t_i = 1 \tag{3}$$

B-2 MATERIAL GRADIENT DEFINITION

Table 4-1 provides an example of material gradient values for the part shown in Figure 4-9. This example implements functions to specify a gradient, which are $f_2 = (z - 10)/15$ and $f_1 = 1 - (z - 10)/15$. These equations may be represented in the part or any derivative model. The tolerances on MAT1 and MAT2 are identified in Table 4-1 as ±25% and ±12.5%, respectively. The actual value of the material composition in a minimal measurable volume in the part space will equal 100% (including voids). Nominal material compositions are modified by changing the equations computed in the table. The tolerance values are unilaterally disposed within the VOL bounded region at the material boundaries (e.g., $z = 10$, $z = 25$ or when nominals are either 0% or 100%).

Figure B-2 describes the nominal values of materials along the z-axis with their tolerance zones and a set of allowable values for MAT1 and MAT2. The two lines with small dashes indicate the tolerance zone for each material. For a chosen allowable value of MAT2 (blue circle at a given z-coordinate), a corresponding maximum allowable value of MAT1 is shown in the graph. Although MAT2 values are at their upper/lower allowable limits, MAT1 values do not lie at the upper or lower allowable limits. This is due to different tolerance zones for each material fraction.

Figure B-2 indicates that nominal limits and acceptable material fractions along the z-axis for VOL2 are based on the equations embedded in the model of the part.

This example also allows for a void fraction. As depicted in Figure B-3, any value of MAT1 in the black area is acceptable, based on the given values of MAT2. When MAT1 fractions are below the top line connecting the black triangles, the material fractions of MAT1 and MAT2 do not add up to 1. In this case, the remainder of the material fraction is allowable void fractions. Similarly, if MAT1 fractions were given as depicted in Figure B-4 with black triangles, the respective maximum allowable fractions for MAT2 are shown with blue circles. All acceptable MAT2 fractions are shown as blue area. When MAT2 fractions are below the top line connecting the blue circles, the material fractions of MAT1 and MAT2 do not add up to 1. In this case, the remainder of the material fraction is allowable void fractions.

Given material fractions of MAT2, the acceptable material fractions of MAT1 are marked as gray area. Any value of MAT1 below the upper line marked with black triangles leads to acceptable void fractions.