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Additive manufacturing — General principles — Terminology

Fabrication additive — Principes généraux — Terminologie

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Contents

Page

Foreword

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The committee responsible for this document is ISO/TC 261, *Additive manufacturing*, in cooperation with ASTM Committee F42, *Additive Manufacturing Technologies*, on the basis of a partnership agreement between ISO and ASTM International with the aim to create a common set of ISO/ASTM standards on Additive Manufacturing.

This first edition of ISO/ASTM 52900 cancels and replaces ASTM F2792.

Introduction

Additive manufacturing is the general term for those technologies that based on a geometrical representation creates physical objects by successive addition of material. These technologies are presently used for various applications in engineering industry as well as other areas of society, such as medicine, education, architecture, cartography, toys and entertainment.

During the development of additive manufacturing technology there have been numerous different terms and definitions in use, often with reference to specific application areas and trademarks. This is often ambiguous and confusing which hampers communication and wider application of this technology.

It is the intention of this International Standard to provide a basic understanding of the fundamental principles for additive manufacturing processes, and based on this, to give clear definitions for terms and nomenclature associated with additive manufacturing technology. The objective of this standardization of terminology for additive manufacturing is to facilitate communication between people involved in this field of technology on a world-wide basis.

This International Standard has been developed by ISO/TC 261 and ASTM F42 in close cooperation on the basis of a partnership agreement between ISO and ASTM International with the aim to create a common set of ISO/ASTM standards on Additive Manufacturing.

Additive manufacturing — General principles — Terminology

1 Scope

This International Standard establishes and defines terms used in additive manufacturing (AM) technology, which applies the additive shaping principle and thereby builds physical 3D geometries by successive addition of material.

The terms have been classified into specific fields of application.

New terms emerging from the future work within ISO/TC 261 and ASTM F42 will be included in upcoming amendments and overviews of this International Standard.

2 Terms and definitions

2.1 General terms

2.1.1
3D printer, noun
machine used for *3D printing* (2.3.1).

2.1.2
additive manufacturing, noun
AM
process of joining materials to make *parts* (2.6.1) from 3D model data, usually *layer* (2.3.10) upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies

Note 1 to entry: Historical terms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, solid freeform fabrication and freeform fabrication.

Note 2 to entry: The meaning of "additive-", "subtractive-" and "formative-" manufacturing methodologies are further discussed in Annex A.

2.1.3
additive system, noun
additive manufacturing system
additive manufacturing equipment
machine and auxiliary equipment used for *additive manufacturing* (2.1.2)

2.1.4
AM machine, noun
section of the *additive manufacturing system* (2.1.3) including hardware, machine control software, required set-up software and peripheral accessories necessary to complete a *build cycle* (2.3.3) for producing *parts* (2.6.1)

2.1.5
AM machine user, noun
operator of or entity using an *AM machine* (2.1.4)

2.1.6
AM system user, noun
additive system user
operator of or entity using an entire *additive manufacturing system* (2.1.3) or any component of an additive system

2.1.7
front, noun
<of a machine; unless otherwise designated by the machine builder> side of the machine that the operator faces to access the user interface or primary viewing window, or both

2.1.8
material supplier, noun
provider of material/ *feedstock* (2.5.2) to be processed in *additive manufacturing system* (2.1.3)

2.1.9
multi-step process, noun
type of *additive manufacturing* (2.1.2) process in which *parts* (2.6.1) are fabricated in two or more operations where the first typically provides the basic geometric shape and the following consolidates the part to the fundamental properties of the intended material (metallic, ceramic, polymer or composite)

Note 1 to entry: Removal of the support structure and cleaning may be necessary, however in this context not considered as a separate process step.

Note 2 to entry: The principle of *single-step* (2.1.10) and multi-step processes are further discussed in Annex A.

2.1.10
single-step process, noun
type of *additive manufacturing* (2.1.2) process in which *parts* (2.6.1) are fabricated in a single operation where the basic geometric shape and basic material properties of the intended product are achieved simultaneously

Note 1 to entry: Removal of the support structure and cleaning may be necessary, however in this context not considered as a separate process step.

Note 2 to entry: The principle of single-step and *multi-step processes* (2.1.9) are further discussed in Annex A.

2.2 Process categories

2.2.1
binder jetting, noun
additive manufacturing (2.1.2) process in which a liquid bonding agent is selectively deposited to join powder materials

2.2.2
directed energy deposition, noun
additive manufacturing (2.1.2) process in which focused thermal energy is used to fuse materials by melting as they are being deposited

Note 1 to entry: "Focused thermal energy" means that an energy source (e.g. laser, electron beam, or plasma arc) is focused to melt the materials being deposited.

2.2.3
material extrusion, noun
additive manufacturing (2.1.2) process in which material is selectively dispensed through a nozzle or orifice

2.2.4
material jetting, noun
additive manufacturing (2.1.2) process in which droplets of build material are selectively deposited

Note 1 to entry: Example materials include photopolymer and wax.

2.2.5
powder bed fusion, noun
additive manufacturing (2.1.2) process in which thermal energy selectively fuses regions of a *powder bed* (2.5.8)

2.2.6
sheet lamination, noun
additive manufacturing (2.1.2) process in which sheets of material are bonded to form a *part* (2.6.1)

2.2.7
vat photopolymerization, noun
additive manufacturing (2.1.2) process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization

2.3 Processing: General

2.3.1
3D printing, noun
fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology

Note 1 to entry: Term often used in a non-technical context synonymously with *additive manufacturing* (2.1.2); until present times this term has in particular been associated with machines that are low end in price and/or overall capability.

2.3.2
build chamber, noun
enclosed location within the *additive manufacturing system* (2.1.3) where the *parts* (2.6.1) are fabricated

2.3.3
build cycle, noun
single process cycle in which one or more components are built up in *layers* (2.3.10) in the process chamber of the *additive manufacturing system* (2.1.3)

2.3.4
build envelope, noun
largest external dimensions of the x-, y-, and z-axes within the *build space* (2.3.6) where *parts* (2.6.1) can be fabricated

Note 1 to entry: The dimensions of the build space will be larger than the build envelope.

2.3.5
build platform, noun
<of a machine> base which provides a surface upon which the building of the *part/s* (2.6.1), is started and supported throughout the build process

Note 1 to entry: In some systems, the *parts* (2.6.1) are built attached to the build platform, either directly or through a support structure. In other systems, such as *powder bed* (2.5.8) systems, no direct mechanical fixture between the build and the platform may be required.

2.3.6
build space, noun
location where it is possible for *parts* (2.6.1) to be fabricated, typically within the *build chamber* (2.3.2) or on a *build platform* (2.3.5)

2.3.7
build surface, noun
area where material is added, normally on the last deposited *layer* (2.3.10) which becomes the foundation upon which the next layer is formed

Note 1 to entry: For the first layer, the build surface is often the *build platform* (2.3.5).

Note 2 to entry: In the case of *directed energy deposition* (2.2.2) processes, the build surface can be an existing part onto which material is added.

Note 3 to entry: If the orientation of the material deposition or consolidation means, or both, is variable, it may be defined relative to the build surface.

2.3.8
build volume, noun
total usable volume available in the machine for building *parts* (2.6.1)

2.3.9
feed region, noun
<in *powder bed fusion* (2.2.5)> location/s in the machine where *feedstock* (2.5.2) is stored and from which a portion of the feedstock is repeatedly conveyed to the powder bed during the *build cycle* (2.3.3)

2.3.10
layer, noun
<matter> material laid out, or spread, to create a surface

2.3.11
machine coordinate system, noun
three-dimensional coordinate system as defined by a fixed point on the *build platform* (2.3.5) with the three principal axes labelled x-, y-, and z-, with rotary axis about each of these axis labelled A, B, and C, respectively, where the angles between x-, y- and z- can be Cartesian or defined by the machine manufacturer

Note 1 to entry: Machine coordinate system is fixed relative to the machine, as opposed to coordinate systems associated with the *build surface* (2.3.7) which can be translated or rotated. Machine coordinate system is illustrated in ISO/ASTM 52921.[6]

2.3.12
manufacturing lot, noun
set of manufactured *parts* (2.6.1) having commonality between *feedstock* (2.5.2), *production run* (2.3.19), *additive manufacturing system* (2.1.3) and *post-processing* (2.5.6) steps (if required) as recorded on a single manufacturing work order

Note 1 to entry: *Additive manufacturing system* (2.1.3) could include one or several *AM machines* (2.1.4) and/or *post-processing* (2.5.6) machine units as agreed by *AM* (2.1.2) provider and customer.

2.3.13
origin, noun
zero point
(0, 0, 0) <when using x-, y-, and z-coordinates>
designated universal reference point at which the three primary axes in a coordinate system intersect

Note 1 to entry: Coordinate system can be Cartesian or as defined by the machine manufacturer. The concept of origin is illustrated in ISO/ASTM 52921.[6]

2.3.14
build origin, noun
origin (2.3.13) most commonly located at the centre of the *build platform* (2.3.5) and fixed on the build facing surface, but could be defined otherwise by the build set-up

2.3.15
machine origin, noun
machine home
machine zero point
origin (2.3.13) as defined by the machine manufacturer

2.3.16
overflow region, noun
<in *powder bed fusion* (2.2.5) systems> location/s in the machine where excess powder is stored during a *build cycle* (2.3.3)

Note 1 to entry: For certain machine types the overflow region may consist of one or more dedicated chambers or a powder recycling system.

2.3.17
part location, noun
location of the *part* (2.6.1) within the *build volume* (2.3.8)

Note 1 to entry: The part location is normally specified by the x-, y- and z-coordinates for the position of the *geometric centre* (2.4.9) of the part's *bounding box* (2.4.3) with respect to the *build volume* (2.3.8) *origin* (2.3.13). Part location is illustrated in ISO/ASTM 52921.[6]

2.3.18
process parameters, noun
set of operating parameters and system settings used during a *build cycle* (2.3.3)

2.3.19
production run, noun
all *parts* (2.6.1) produced in one *build cycle* (2.3.3) or sequential series of build cycles using the same *feedstock* (2.5.2) batch and process conditions

2.3.20
system set-up, noun
configuration of the *additive manufacturing system* (2.1.3) for a build

2.3.21
***x*-axis**, noun
<of a machine; unless otherwise designated by the machine builder> axis in the *machine coordinate system* (2.3.11) that runs parallel to the *front* (2.1.7) of the machine and perpendicular to the *y-axis* (2.3.22) and *z-axis* (2.3.23)

Note 1 to entry: <unless otherwise designated by the machine builder> The positive *x*-direction runs from left to right as viewed from the front of the machine while facing toward the *build volume* (2.3.8) *origin* (2.3.13).

Note 2 to entry: It is common that the *x*-axis is horizontal and parallel with one of the edges of the *build platform* (2.3.5).

2.3.22
***y*-axis**, noun
<of a machine; unless otherwise designated by the machine builder> axis in the *machine coordinate system* (2.3.11) that runs perpendicular to the *z-axis* (2.3.23) and *x-axis* (2.3.21)

Note 1 to entry: <unless otherwise designated by the machine builder> The positive direction is defined in ISO 841[1] to make a right hand set of coordinates. In the most common case of an upwards *z*-positive direction, the positive *y*-direction will then run from the front to the back of the machine as viewed from the front of the machine.

Note 2 to entry: In the case of building in the downwards *z*-positive direction, the positive *y*-direction will then run from the back of the machine to the front as viewed from the front of the machine.

Note 3 to entry: It is common that the *y*-axis is horizontal and parallel with one of the edges of the *build platform* (2.3.5).

2.3.23
***z*-axis**, noun
<of a machine; unless otherwise designated by the machine builder>, axis in the *machine coordinate system* (2.3.11) that run perpendicular to the *x-axis* (2.3.21) and *y-axis* (2.3.22)

Note 1 to entry: <unless otherwise designated by the machine builder> The positive direction is defined in ISO 841[1] to make a right hand set of coordinates. For processes employing planar, layerwise addition of material, the positive *z*-direction will then run normal to the *layers* (2.3.10).

Note 2 to entry: For processes employing planar layerwise addition of material, the positive *z*-direction, is the direction from the first layer to the subsequent layers.

Note 3 to entry: Where addition of material is possible from multiple directions (such as with certain *directed energy deposition* (2.2.2) systems), the *z*- axis may be identified according to the principles in ISO 841, (4.3.3)[1] which addresses "swivelling or gimballing."

2.4 Processing: Data

2.4.1
3D scanning, noun
3D digitizing
method of acquiring the shape and size of an object as a 3-dimensional representation by recording x, y, z coordinates on the object's surface and through software the collection of points is converted into digital data

Note 1 to entry: Typical methods use some amount of automation, coupled with a touch probe, optical sensor, or other device.

2.4.2
Additive Manufacturing File Format, noun
AMF
file format for communicating *additive manufacturing* (2.1.2) model data including a description of the 3D surface geometry with native support for colour, materials, lattices, textures, constellations and metadata

Note 1 to entry: Additive Manufacturing File Format (AMF) can represent one of multiple objects arranged in a constellation. Similar to *STL* (2.4.16), the surface geometry is represented by a triangular mesh, but in AMF the triangles may also be curved. AMF can also specify the material and colour of each volume and the colour of each triangle in the mesh. ISO/ASTM 52915[5] gives the standard specification of AMF.

2.4.3
bounding box, noun
<of a part> orthogonally oriented minimum perimeter cuboid that can span the maximum extents of the points on the surface of a 3D *part* (2.6.1)

Note 1 to entry: Where the manufactured part includes the test geometry plus additional external features (for example, labels, tabs or raised lettering), the bounding box may be specified according to the test part geometry excluding the additional external features if noted. Different varieties of bounding boxes are illustrated in ISO/ASTM 52921.[6]

2.4.4
arbitrarily oriented bounding box, noun
<of a *part* (2.6.1)> *bounding box* (2.4.3) calculated without any constraints on the resulting orientation of the box

2.4.5
machine bounding box, noun
<of a *part* (2.6.1)> *bounding box* (2.4.3) for which the surfaces are parallel to the *machine coordinate system* (2.3.11)

2.4.6
master bounding box, noun
bounding box (2.4.6) which encloses all of the *parts* (2.6.1) in a single build

2.4.7
extensible markup language, noun
XML
standard from the WorldWideWeb Consortium (W3C) that provides for tagging of information content within documents offering a means for representation of content in a format that is both human and machine readable

Note 1 to entry: Through the use of customizable style sheets and schemas, information can be represented in a uniform way, allowing for interchange of both content (data) and format (metadata).

2.4.8
facet, noun
typically a three- or four-sided polygon that represents an element of a 3D polygonal mesh surface or model

Note 1 to entry: Triangular facets are used in the file formats most significant to *AM* (2.1.2): *AMF* (2.4.2) and *STL* (2.4.17); however AMF files permits a triangular facet to be curved.

2.4.9
geometric centre, noun
centroid
<of a bounding box>, location at the arithmetic middle of the *bounding box* (2.4.3) of the *part* (2.6.1)

Note 1 to entry: The centre of the bounding box could lie outside the part.

2.4.10
IGES, noun
initial graphics exchange specification
platform neutral CAD data exchange format intended for exchange of product geometry and geometry annotation information

Note 1 to entry: IGES is the common name for a United States National Bureau of Standards standard NBSIR 80–1978, Digital Representation for Communication of Product Definition Data, which was approved by ANSI first as ANS Y14.26M-1981 and later as ANS USPRO/IPO-100–1996. IGES version 5.3 was superseded by ISO 10303[3] *STEP* (2.4.15) in 2006.

2.4.11
initial build orientation, noun
<of a *part* (2.6.1)> orientation of the part as it is first placed in the *build volume* (2.3.8)

Note 1 to entry: Initial build orientation is illustrated in ISO/ASTM 52921.[6]

2.4.12
nesting, participle
situation when *parts* (2.6.1) are made in one *build cycle* (2.3.3) and are located such that their *bounding boxes* (2.4.3), *arbitrarily oriented* (2.4.4) or otherwise, will overlap

2.4.13
PDES, noun
Product Data Exchange Specification or Product Data Exchange using *STEP* (2.4.15)

Note 1 to entry: Originally, a product data exchange specification developed in the 1980s by the IGES/PDES Organization, a program of US Product Data Association (USPRO). It was adopted as the basis for and subsequently superseded by ISO 10303[3] *STEP* (2.4.15).

2.4.14
part reorientation, noun
rotation around the *geometric centre* (2.4.9) of the part's *bounding box* (2.4.3) from the specified *initial build orientation* (2.4.11) of that *part* (2.6.1)

Note 1 to entry: Part reorientation is illustrated in ISO/ASTM 52921.[6]

2.4.15
STEP, noun
standard for the exchange of product model data

Note 1 to entry: ISO standard that provides a representation of product information, along with the necessary mechanisms and definitions to enable product data to be exchanged. ISO 10303[3] applies to the representation of product information, including components and assemblies; the exchange of product data, including storing, transferring, accessing and archiving.

2.4.16
STL, noun
file format for model data describing the surface geometry of an object as a tessellation of triangles used to communicate 3D geometries to machines in order to build physical *parts* (2.6.1)

Note 1 to entry: The STL file format was originally developed as part of the CAD package for the early STereoLithography Apparatus, thus referring to that process. It is sometimes also described as "Standard Triangulation Language" or "Standard Tessalation Language", though it has never been recognized as an official standard by any standardization organization.

2.4.17
surface model, noun
mathematical or digital representation of an object as a set of planar or curved surfaces, or both, that can, but does not necessarily have to, represent a closed volume

2.5 Processing: Material

2.5.1
curing, verb
chemical process which results in the ultimate properties of a finish or other material

2.5.2
feedstock, noun
DEPRECATED: source material
DEPRECATED: starting material
DEPRECATED: base material
DEPRECATED: original material
bulk raw material supplied to the *additive manufacturing* (2.1.2) building process

Note 1 to entry: For additive manufacturing building processes, the bulk raw material is typically supplied in various forms such as liquid, powder, suspensions, filaments, sheets, etc.

2.5.3
fusion, noun
act of uniting two or more units of material into a single unit of material

2.5.4
laser sintering, noun
LS
powder bed fusion (2.2.5) process used to produce objects from powdered materials using one or more lasers to selectively fuse or melt the particles at the surface, *layer* (2.3.10) upon layer, in an enclosed chamber

Note 1 to entry: Most LS machines partially or fully melt the materials they process. The word "sintering" is a historical term and a misnomer, as the process typically involves full or partial melting, as opposed to traditional powdered metal sintering using a mould and heat and/or pressure.

2.5.5
part cake, noun
<in a *powder bed fusion* (2.2.5) process that uses a heated *build chamber* (2.3.2)> lightly bound powder surrounding the fabricated *parts* (2.6.1) at the end of a *build cycle* (2.3.3)

2.5.6
post-processing, noun
<one or more> process steps taken after the completion of an *additive manufacturing* (2.1.2) *build cycle* (2.3.3) in order to achieve the desired properties in the final product

2.5.7
powder batch, noun
powder used as *feedstock* (2.5.2) which could be *used powder* (2.5.11), *virgin powder* (2.5.12) or a blend of the two

Note 1 to entry: A powder batch could be used in one or more production runs using different process parameters.

2.5.8
powder bed, noun
part bed
build area in an *additive manufacturing system* (2.1.3) in which *feedstock* (2.5.2) is deposited and selectively fused by means of a heat source or bonded by means of an adhesive to build up *parts* (2.6.1)

2.5.9
powder blend, noun
quantity of powder made by thoroughly intermingling powders originating from one or several *powder lots* (2.5.10) of the same nominal composition

Note 1 to entry: A common type of powder blend consists of a combination of *virgin powder* (2.5.12) and *used powder* (2.5.11). The specific requirements for a powder blend are typically determined by the application, or by agreement between the supplier and end-user.

Note 2 to entry: In traditional powder metallurgy, a distinction is made between blended powders and mixed powders, in which case blended powders are combinations of powders with nominally identical composition, whereas mixed powders are combinations of powders with different compositions.

2.5.10
powder lot, noun
quantity of powder produced under traceable, controlled conditions, from a single powder manufacturing process cycle

Note 1 to entry: The size of a powder lot is defined by the powder supplier. It is common that the powder supplier distributes a portion of a powder lot to multiple *AM system users* (2.1.6).

Note 2 to entry: Source documentation of the powder lot is normally required for most *AM* (2.1.2) product applications. Source documentation is also referred to as a “certificate of conformance”, “factory certificate” or “certificate of analysis”.

2.5.11
used powder, noun
powder that has been supplied as *feedstock* (2.5.2) to an *AM machine* (2.1.4) during at least one previous *build cycle* (2.3.3)

2.5.12
virgin powder, noun
unused powder from a single *powder lot* (2.5.10)

2.6 Applications

2.6.1
part, noun
joined material forming a functional element that could constitute all or a section of an intended product

Note 1 to entry: The functional requirements for a part are typically determined by the intended application.

2.6.2
prototype, noun
physical representation of all or a component of a product that, although limited in some way, can be used for analysis, design and evaluation

Note 1 to entry: Requirements for *parts* (2.6.1) used as prototypes depend on the individual needs for analysis and evaluation and will therefore typically be determined in agreement between supplier and end-user.

2.6.3
prototype tooling, noun
moulds, dies, and other devices used for prototyping purposes; sometimes referred to as bridge tooling or soft tooling

Note 1 to entry: This type of tooling can sometimes be used to trial the tool design and/or to produce end-use *parts* (2.6.1) while production tooling is being manufactured. On these occasions, the tooling is typically referred to as bridge tooling.

2.6.4
rapid prototyping, noun
<in additive manufacturing> application of *additive manufacturing* (2.1.2) intended for reducing the time needed for producing *prototypes* (2.6.2)

Note 1 to entry: Historically, rapid prototyping (RP) was the first commercially significant application for additive manufacturing, and have therefore been commonly used as a general term for this type of technology.

2.6.5
rapid tooling, noun
<in additive manufacturing> application of *additive manufacturing* (2.1.2) intended for the production of tools or tooling components with reduced lead times as compared to conventional tooling manufacturing

Note 1 to entry: Rapid tooling may be produced directly by the additive manufacturing process or indirectly by producing patterns that are in turn used in a secondary process to produce the actual tools.

Note 2 to entry: Besides additive manufacturing, the term “rapid tooling” may also apply to the production of tools with reduced lead times by subtractive manufacturing methods, such as CNC milling, etc.

2.7 Properties

2.7.1
accuracy, noun
closeness of agreement between an individual result and an accepted reference value

2.7.2
as built, adjective
refers to the state of *parts* (2.6.1) made by an additive process before any post processing, besides, if necessary, the removal from a *build platform* (2.3.5) as well as the removal of support and/or unprocessed *feedstock* (2.5.2)

2.7.3
fully dense, adjective
state in which the material of the fabricated part is without significant content of voids

Note 1 to entry: In practice, material completely free of voids is difficult to produce by any manufacturing process and some micro-porosity will generally be present.

Note 2 to entry: The significance and the permissible content of voids are typically determined based on the requirements for the application of the final product.

2.7.4
near net shape, adjective
condition where the components require little *post-processing* (2.5.6) to meet dimensional tolerance

2.7.5
porosity, noun
<property> presence of small voids in a *part* (2.6.1) making it less than *fully dense* (2.7.3)

Note 1 to entry: Porosity may be quantified as a ratio, expressed as a percentage of the volume of voids to the total volume of the part.

2.7.6

repeatability, noun

degree of alignment of two or more measurements of the same property using the same equipment and in the same environment

Annex A
(informative)

Basic principles

A.1 Additive shaping of materials

The functionality of a manufactured object is derived from the combination of the object's geometry and properties. In order to achieve this combination, a manufacturing process is made up of a series of operations and sub-processes that brings the shape of the intended geometry to a material capable of possessing the desired properties. The shaping of materials into objects within a manufacturing process can be achieved by one, or combinations of three basic principles.

— Formative shaping: The desired shape is acquired by application of pressure to a body of raw material, examples: forging, bending, casting, injection moulding, the compaction of green bodies in conventional powder metallurgy or ceramic processing, etc.

— Subtractive shaping: The desired shape is acquired by selective removal of material, examples: milling, turning, drilling, EDM, etc.

— Additive shaping: The desired shape is acquired by successive addition of material.

The objects, or parts, with the acquired shapes can be combined into more complex shaped products by joining different parts in a physical, chemical or mechanical operation, such as welding, soldering, adhesive, fasteners, etc.

Additive manufacturing technology applies the additive shaping principle and thereby builds physical 3D geometries by successive addition of material.

"Addition of material" means that units of material feedstock are brought together and joined (e.g. fused or bonded), most commonly layer by layer to build a part. The determining factor for each process is in the technique used for adding the materials. This determines, for example, what types of materials are possible in the process, since different materials have different principles of fusion or adhesion. Basically, for additive manufacturing processing, the products' fundamental properties are determined by

a) type of material (polymer, metal, ceramic or composite),

b) principle applied for fusion or bonding (melting, curing, sintering etc.),

c) feedstock that is used for adding material (liquid, powder, suspension, filament, sheet etc.), and

d) how the material is brought together, i.e. machine architecture.

The process of successively adding material to build a part makes the properties of the material in this part highly dependent on the machine type and the process parameters in the additive operation. Therefore it is not possible to accurately predict these material properties without coupling them to a specific type of machine and process parameters.

A layered approach to the additive building of parts may also cause directional dependence in the material properties of that part. Therefore, material properties in an AM part may be dependent on that part's orientation and position in the build space during processing.

A.2 Single-step and multi-step additive manufacturing processes

It is rare that a finished product can be entirely manufactured within a single process principle. Normally, a series of operations and sub-processes are required to achieve the intended combination of geometrical shape and desired properties. However, in the context of AM there is a distinction between which operations are indispensable parts of the additive process and which are more product and application dependent pre-processing, and post-processing operations. When additive manufacturing is applied within an industrial manufacturing system, this distinction is needed to clarify what part of the entire manufacturing process constitutes the actual additive manufacturing process, as well as, what part of the entire manufacturing system constitutes the actual additive manufacturing system, so that standards can be appropriately applied.

The fundamental principle of AM processes is forming three dimensional parts by the successive addition of material. Depending on process, the parts may acquire the basic geometry and fundamental properties of the intended material in a single process step, i.e. a single-step process, or acquire the geometry in a primary process step and then acquire the fundamental properties of the intended material (for example: metallic properties for an intended metallic part and ceramic properties for an intended ceramic part) in a secondary process step, i.e. a multi-step process, see Figure A.1. For example, the object acquires the basic geometry by joining material with a binder in the primary process step which is followed by material consolidation by sintering, with or without infiltration, in subsequent process steps. Depending on the final application, both single-step, and multi-step may require one or more additional post-processing operations, [such as, heat treatments (including HIP), finishing machining, and others, see further ISO 17296-2[4]] to obtain all the intended properties in the final product.

AM technology can be used to produce tools moulds and casting patterns which may be applied to produce the intended products. In this scenario, however, it is the casting patterns, moulds, or tools that is produced by the AM process, not the intended product, and therefore such manufacturing processes should rather be considered as an application of AM technology than an AM production process.

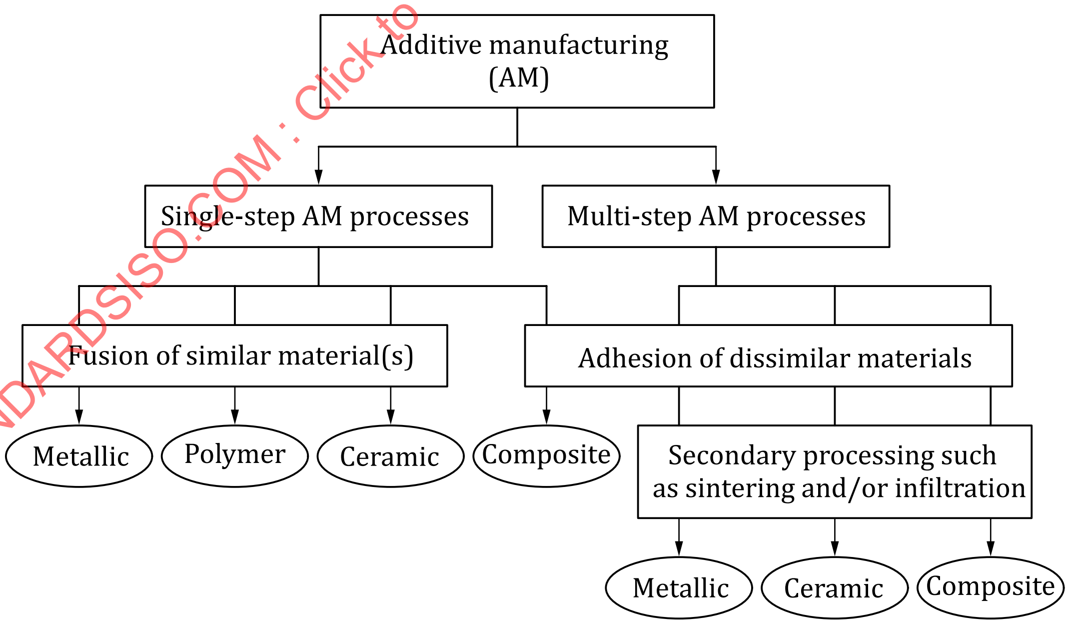

Figure A.1 — Single-step and multi-step AM process principles

A.3 Additive manufacturing processing principles

A.3.1 General

There are numerous ways in which units of material can be joined together to form a part. Different types of materials are being held together by different types of atomic bonds: metallic materials are typically held together by metallic bonds, polymer molecules typically by covalent bonds, ceramic materials typically by ionic-, and/or covalent bonds, and composite materials by any combination of the above mentioned. The type of bonding provides the most fundamental conditions for how that type of material can be joined in an additive process. Besides the type of material, the joining operation is also dependent on in which shape the material is delivered to the system, and how it is distributed. For additive manufacturing processes, the feedstock, the bulk raw material that is fed into the process, can typically come in the form of powder (dry, paste or slurry), filament, sheet, melted, and for polymers also in the shape of un-cured liquid material. Dependent on the shape, the feedstock may then be distributed layer by layer in a powder bed, deposited by a nozzle, applied as layers in a sheet stack, deposited through a print head, or applied as a liquid, paste or slurry in a vat. In respect to the great possibilities for variation in different types of materials, different types of feedstock and means of distribution of the feedstock, there is large number of possible principles that could be used for additive manufacturing processes. However, while there are significant research and development activities in this area world-wide, far from all potential solutions have been realized in a working process, and fewer still have reached the market. Figures A.2 to A.5 give an overview of process principles that are presently available on the market and have been proven viable in an industrial context.

A.3.2 Overview of AM single-step processing principles

The parts are fabricated in a single operation where the basic geometric shape and basic material properties of the intended product are achieved in a single operation simultaneously. Removal of the support structure and cleaning may be necessary. Figure A.2 to Figure A.4 represent overviews of single step AM processing principles for metallic materials, polymer materials and ceramic materials.

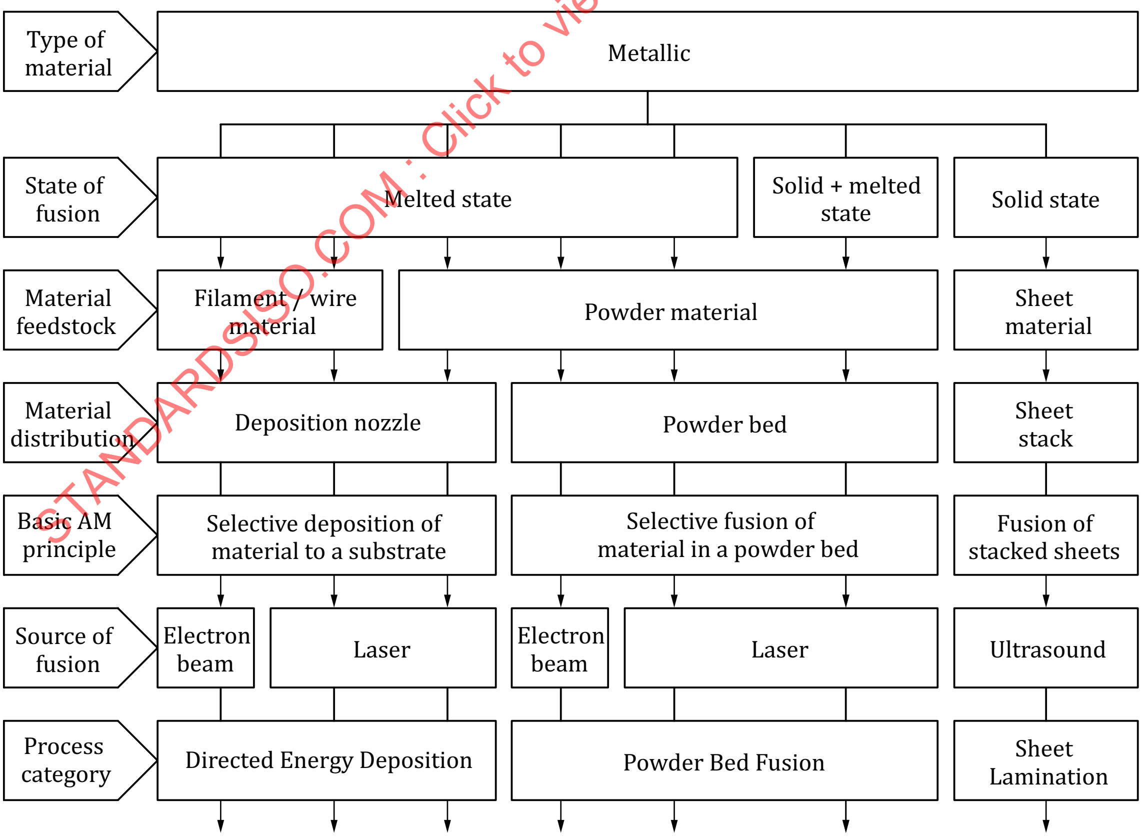

Figure A.2 — Overview of single-step AM processing principles for metallic materials