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Additive manufacturing for metals — General principles — Registration of data acquired from process monitoring and for quality control

Fabrication additive de métaux — Principes généraux — Enregistrement de données acquises à partir de la surveillance du procédé et pour le contrôle qualité

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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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, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 438, *Additive manufacturing,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

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Introduction

Additive manufacturing (AM) is the general term for those technologies that successively join material to create physical objects as specified by their 3D design model data. Current AM technologies can fabricate parts layer-by-layer using different material types as inputs. The resulting parts have complex geometries that are needed for applications in a variety of manufacturing industries, where AM parts offer significant advantages or where the parts cannot be made using the traditional manufacturing technologies, such as machining and welding.

AM machines are being instrumented with various types of sensors which collect data throughout a build. Often, each sensor is designed to collect only one type of measurement dataset in a unique coordinate system. The use of this monitoring data for applications such as qualifying AM components is enhanced when a diverse range of sensor datasets are used and compared to post-process inspection. This requires multi-modal dataset registration including data alignment.

Registration of these datasets consists of recording necessary metadata and data alignment. A registered dataset allows the extraction of features from data from different sensors to be appropriately registered to post-process inspection. These features can be used for a range of applications including to control variations in feedstock, melt-pool geometry, thermal stability, layer integrity, defect detection, and part quality.

It is the intention of this document to provide a procedure and methods to register AM data, including:

a) associating validated data with known time, locations, and origin, and

b) data alignment for process monitoring and control.

Laser-based powder bed fusion for metals (PBF-LB/M) is used to demonstrate the data registration procedure. The procedure can be applied to monitor other AM processes, such as direct energy deposition, polymer or ceramic powder bed fusion, binder jetting, and photopolymerization.

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Additive manufacturing for metals — General principles — Registration of data acquired from process monitoring and for quality control

1 Scope

This document sets and defines the minimum requirements for registration of data acquired from process monitoring and for quality control in additive manufacturing (AM), including the description of a procedure.

Furthermore, this document comprises actions that users shall execute to register multi-modal AM data and store them in an appropriate repository.

This document is not applicable for data cleansing, sensor calibration, and image processing.

This document is only applicable for data gathered and generated from non-destructive test methods and sensors, e.g. X-ray computer tomography (XCT), thermal sensor, cameras and coordinate measuring machines (CMM).

This document is only applicable to metallic parts produced by means of laser-based powder bed fusion (PBF-LB); nevertheless, the procedures described in this document can be applied to monitor other AM processes and materials (e.g. directed energy deposition, polymer or ceramic powder bed fusion, binder jetting, and photopolymerization), but this document does not provide any data or case studies for them.

2 Normative reference

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/ASTM 52900, *Additive manufacturing — General principles — Fundamentals and vocabulary*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the terms and definitions given in ISO/ASTM 52900 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Terms and definitions

3.1.1
data alignment, noun
process of transforming different sets of geometrically or temporally related data into a single, global coordinate system

3.1.2
data registration, noun
procedure of aligning data, recording metadata, and assigning a persistent identification to the aligned data set

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3.1.3
digital imaging sensor, noun
detection device, usually photoelectric, that captures photographic images of an object in a digital format

Note 1 to entry: It is also called a digital, visible-light-imaging sensor.

3.1.4
ex-situ inspection, noun
measurement or examination performed on the part after it is extracted from the build chamber

3.1.5
fiduciary mark, noun
physical mark on a build plane or a layer to locate the scan tracks relative to the image coordinate system

3.1.6
global coordinate system, noun
unique coordinate system to which all the data is referenced

3.1.7
in-situ measurement, noun
measurement performed on the part during the build cycle

3.1.8
staring camera, noun
camera that is installed in a staring configuration used for layer-wise imaging or melt-pool imaging

3.1.9
layer image, noun
image of the layer taken by an image sensor, e.g., staring camera

Note 1 to entry: Other sensors that can be used include multi-colour pyrometer for taking thermal images, 3D scan by triangulation, interferometry, and confocal microscopy.

3.1.10
melt pool image, noun
image of melt pool taken by either a coaxial camera or a staring camera.

3.1.11
X-ray computer tomography three-dimensional model
three-dimensional (3D) model constructed using sets of two-dimensional (2D) images of an X-ray Computed Tomography (XCT)-scanned part.

3.2 Abbreviated terms

2D	Two-dimensional
3D	Three-dimensional
CAD	Computer-aided design
CCD	Charge-coupled device
CMOS	Complementary metal oxide semiconductor
CS	Coordinate system
HSI	Hyperspectral imaging
ID	Identification
LIPS	Laser-induced plasma spectroscopy

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LUS	Laser-induced ultrasonic
LZW	Lempel–Ziv–Welch
MPE	Maximum permissible error
OCT	Optical coherence tomography
SD	Sphere distance
TIFF	Tag image file format
XCT	X-ray computed tomography

4 Significance and use

This document provides methods and procedures for users to register measurements and associated metadata that they need for accurately qualifying complex metal additive manufacturing (AM)-built parts. Registered data can satisfy additional user's goals: detect AM processing instabilities, predict their impact on the part quality, and implement process control if needed and possible. Registered data can be from the following methods: in-situ photogrammetry, thermography, pyrometry, ex-situ XCT, CAD models and the associated metadata. These data sets are generated from a variety of sources, e.g., melt-pool images, thermal measurements, scan paths, layer images, and 3D models based on XCT.

This document enables the development of data registration software. The software can help users register the data needed to validate the AM system states, optimize process parameters, and control part quality. Data analytics and control software can be modified to use registered data extensively from a wide range of measuring instruments.

5 Data registration procedure

As shown in Figure 1, the data registration procedure shall start with capturing metadata, which has the information about sensors and their settings (see Clause 6). Then, in-situ and ex-situ sensing, data cleansing, and assigning identification to data shall occur in that exact sequence. Data identifiers should be assigned according to ISO/IEC 9834-8 or a company-specific scheme. Data alignment includes both temporal and spatial alignment. Spatial alignment shall convert sensor data from its original, local coordinate system to a global coordinate system in which all the data can be compared and fused correctly. Aligned data sets are used as inputs to data analytics software that makes predictions needed for decision making and control.

Although data cleansing is out of scope, it can be a part of data registration.

Some examples of data cleansing in an image include, but are not limited to, correction of scaling because of perspectives, correction of distortion because of lens geometry, handling of insensitive/dead pixels, offset gain from laser speckles, denoising, and gamma correction. Image processing is out of scope.

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