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Additive manufacturing for automotive — Qualification principles — Generic machine evaluation and specification of key performance indicators for PBF-LB/M processes

Fabrication additive pour l'automobile — Principes de qualification — Évaluation générique de la machine et spécifications des indicateurs clefs de performance pour les procédés PBF-LB/M

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Foreword

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This document was prepared by Technical Committee ISO/TC 261, *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

This document provides a methodology to evaluate PBF-LB/M AM-machines in the context of automotive on an objective basis. The need to provide a document standardizing this topic exists because in high-volume industrial production, the reproducibility of the produced component is crucial to meet production goals. Therefore, reproducibility and capability of the machines used for manufacturing need to be evaluated upfront. A methodology and performance characteristics are introduced to enable the evaluation on an objective and quantitative basis. The documentation resulting from the AM-machine evaluation is used to obtain a reliable orientation selection and evaluation of PBF-LB/M AM-machines.

Moreover, the document provides guidelines for machine production key performance indicators (KPIs) which can be used in procurement, production planning and production to improve the understanding between the machine manufacturer and user. The KPIs to be determined within the scope of this document help to systematically evaluate the performance of PBF-LB/M machines. However, this does not necessarily guarantee that the KPIs can always be used to select the most suitable machine for a specific application scenario. Since a large number of very specific influencing factors affect the selection of an optimal machine, situational, individual parameters must be included in the decision. However, the KPIs can form the basis for this decision.

The requirements regarding quality and planning of build jobs are specific for the automotive industry. The introduced generic approach can be expanded to other industries.

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Additive manufacturing for automotive — Qualification principles — Generic machine evaluation and specification of key performance indicators for PBF-LB/M processes

1 Scope

This document specifies the methodology for generic AM-machine evaluation in automotive environment using objective test criteria and provides the framework for an objective AM-machine evaluation and comparison. This document finds application in benchmarks, in the preparation of purchase decisions, but also in AM-machine evaluation within the machine procurement, acceptance, and qualification processes. This document is specific to automotive, as it is related to existing series part requirements of various original equipment manufacturers, but the content can be transferred to other industries if necessary.

Furthermore, this document specifies machine KPIs in the context of machine procurement, production planning and production of PBF-LB/M components. It aims to reach a detailed understanding between machine supplier and machine user with respect to the acceptance criteria during the procurement process and evaluation of machine performance during running production. For using this document, all process parameters, such as scanning speed, laser power, etc., are fixed, since changing these parameters can affect the entire process performance and its stability. Therefore, variables are not changed any more during or after qualification. This document and the determination of the KPIs help in the evaluation of machine properties, but do not replace an application-specific approval process.

This document is applicable to the additive manufacturing technology PBF-LB/M.

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2 Normative references

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 3369, *Impermeable sintered metal materials and hardmetals — Determination of density*

ISO 4499-4, *Hardmetals — Metallographic determination of microstructure — Part 4: Characterisation of porosity, carbon defects and eta-phase content*

ISO 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

ISO 25178 (all parts), *Geometrical product specifications (GPS) — Surface texture: Areal*

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

ISO/ASTM 52902, *Additive manufacturing — Test artifacts — Geometric capability assessment of additive manufacturing systems*

ISO/ASTM 52928, *Additive manufacturing — Feedstock materials — Powder life cycle management*

ASTM E8M, *Standard test methods for tension testing of metallic materials*

3 Terms and definitions

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

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ISO and IEC maintain terminology 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
performance characteristics
defined characteristics which are measured in a defined framework (in this document based on generic build jobs and produced specimens) and can be used to evaluate machines on an objective basis

3.2
machine KPIs
machine key performance indicators (KPIs) measure the relevant output of a production machine in a defined framework, e.g. timeframe, defined production lots, etc

Note 1 to entry: Throughout this document, various such KPIs are introduced and their meaning, as well as how to measure them, is explained in detail.

EXAMPLE Overall equipment effectiveness.

3.3
quality level
defined ranges of values for a specified set of quality parameters such as relative density, surface roughness, mechanical properties, etc.

3.4
specimen package
set of different specimens

Note 1 to entry: See Table 1.

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4 Methodology for generic machine evaluation

4.1 Specification of use-cases

4.1.1 General

This clause introduces the methodology of generic machine evaluation. The generic machine evaluation shall be used to carry out an assessment to evaluate the performance of a PBF-LB/M machine on a defined objective basis.

The methodology of generic machine evaluation introduced here is not intended to define and verify compliance of target metrics but should instead be used to generate information and efficiency metrics to enable machine assessment and comparison. Further details of the machine acceptance process are shown in ISO/ASTM TS 52930. For this document it is mandatory that consistent handling sequences can be achieved through a good operator's expertise, since it is important on AM systems for a stable component quality (see ISO/ASTM 52926 series).

The generic machine evaluation shall be used to generate a sufficient, neutral, and documented evaluation basis for two different use-cases, which are described in 4.1.2 and 4.1.3.

4.1.2 Use-case 1 – Benchmarking of machines

The framework and methodology introduced in 4.3.1 shall be used in the context of benchmarking of machines. Therefore, a minimum of 1 run of the described build jobs according to 4.2.2 shall be produced and tested in the described way. To strengthen the statistical significance of the benchmark, production and evaluation of additional build jobs shall be necessary. This is an option at the discretion of the machine manufacturer or the user.

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4.1.3 Use-case 2 – Generic evaluation in factory/site acceptance test

The framework and methodology introduced in 4.3.1 shall furthermore be used in the machinery procurement process, more specific in the factory and site acceptance test. Before using the methodology, the specific target values for the performance indicators shall be agreed on between user and machine manufacturer. During factory and site acceptance test, at least one build job run is mandatory.

This methodology can also be used to evaluate build job-to-build job performance. For a better evaluation of the machine, further evaluations of build jobs with specific relevant part designs can be taken into consideration. The frame conditions for such specific build jobs can be derived from the framework of the expected (future) build jobs or be pre-arranged by agreement between machine manufacturer and user.

4.2 Specification of specimen and build job design

4.2.1 Specification of generic specimen and testing standards

In the following, the test specimens used in the generic construction jobs and for the evaluation of these construction jobs as well as the associated tests are defined. This clause gives an overview of the relevant use cases for the generic machine evaluation and introduces the framework for the data generation (specimens used, test methods, build job design and quality requirements).

Specimen geometries to be used throughout the generic build job are described in Table 1.

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Part, as well as build job powder removal methods cannot be changed, in order to maintain consistent mechanical and surface quality of the specimen. The surface measurement shall be performed prior to the porosity measurement.

The introduced methodology is applied to quasi-static mechanical properties, relative density, and surface. Further properties (e.g. dynamic, and cyclic properties) are excluded on purpose and can be included in individually designed build jobs following this methodology or individual agreements between user and machine manufacturer.

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Table 1 — Specification of specimen for measurement of surface roughness, relative density, and tensile strength

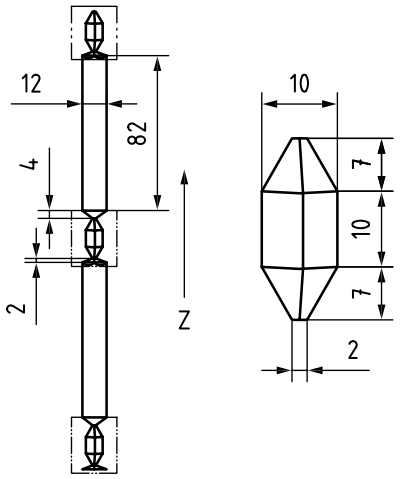
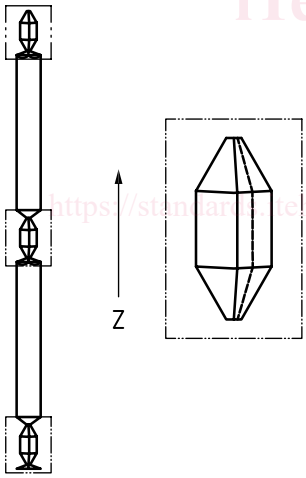
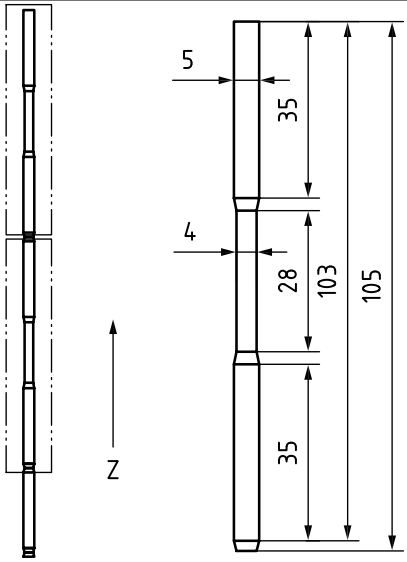
Test specimen	Test standard, purpose and description	Test procedure and criteria
	Surface measurement: — Test standard: ISO 25178 (all parts) — Test specimen:10 mm × 10 mm × 10 mm diamond surface/density specimen — Test purpose: Measurement of surface roughness on: — 45° — 90° and — 135° surfaces — Test specimen surface: powder removed with pressured gas (no surface modification)	— Measurement (in accordance with ISO/ASTM 52902) of S_z, S_a, S_{sk} and S_{ku}, on each of the 4 surfaces for 45°, 90°, 135° angle against the build plate — Determination of mean value and quantiles for each cube — Area of measurement shall be the complete area that is available in each direction — Typically used measurement filters in accordance with ISO/ASTM 52902
	Porosity measurement: — Test standard: — Preparation: ISO 4499-4 — Porosity measurement: ISO 4499-4 — Test specimen: 10 mm × 10 mm × 10 mm diamond surface/density specimen — Test purpose: measurement relative density in cross section — A testing with the Archimedes method in accordance with ISO 3369 can be added	— Cross section cut through the diamond specimen — Preparation of the cross section cut according to the test standard — Measurement of the relative density according to the test standard in 25 x magnification
	Tensile test (as-built surface): — Test standard: ISO 6892-1 — Test specimen: Near net shape tensile specimen (in accordance with ASTM E8M, the requirement regarding surface roughness may be waived) — Tensile testing near net shape with as-built surface (no post processing) — Enabling tensile strength trend analysis over height	— Testing according to test standard and measurement of R_m, $R_{p0,2}$ and A

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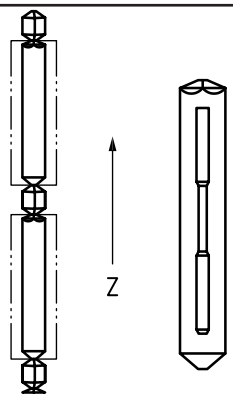
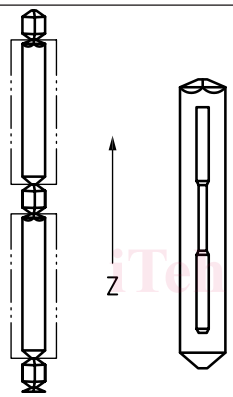
Table 1 *(continued)*

Test specimen	Test standard, purpose and description	Test procedure and criteria
	Tensile test (machined surface): — Test standard: ISO 6892-1 — Test specimen: Machined tensile/packing density specimen (in accordance with ASTM E8M) (optional) — Enabling density & surface trend analysis over height in multiple layers — Creation of packing density	— Machining of the cylinder in accordance with ASTM E8M — Testing according to test standard and measurement of R_m, $R_{p0,2}$ and A
	Specimen package: — Test specimen: combined diamond surface/density, near net shape tensile and machined tensile/packing density specimen — This combination of specimen is named specimen package and should be used in the following for build job design considerations — The specimen package has a height of 112 mm	— Test procedure according to the description for the individual components of the specimen package (see above)

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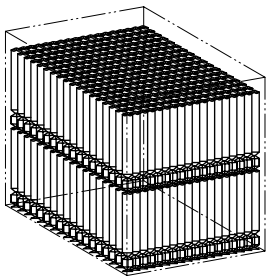
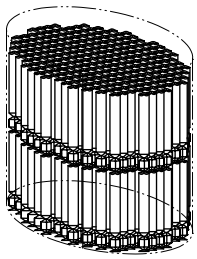
4.2.2 Build job design

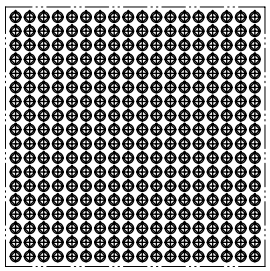
In Figure 1, the representation of the generic build job for two different kinds of machines (in this example 400 mm cubic/cylindrical build envelope) is shown.



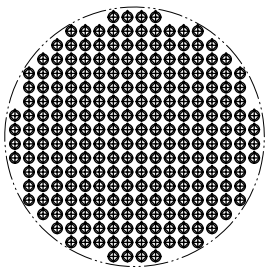
a) Isometric view: cubic build envelope



b) Isometric view: cylindrical build envelope



c) Top view cubic build envelope



d) Top view cylindrical build envelope

Figure 1 — Examples of build job design

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The requirements for the generic build job are:

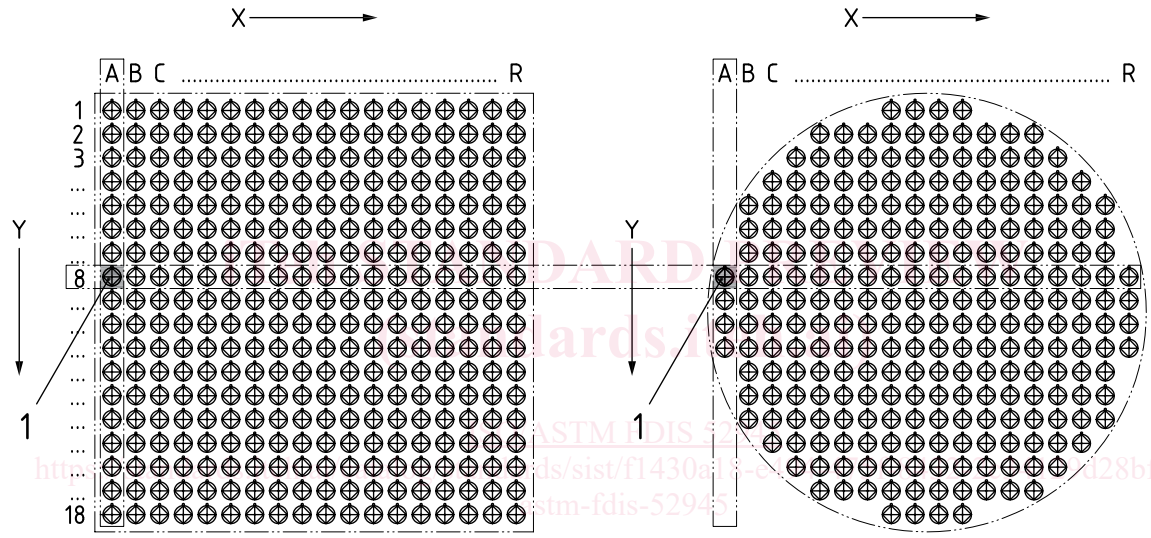
— The specimen packages shall be stacked in Z for the maximum Z-height possible within the present machine design (e.g. for a 400 mm Z-height shall be 3 layers of specimen packages, 112 mm each);

— The specimen packages shall be distributed homogeneously and with equal distances;

— The build job shall contain a packing density of approximately 30 % containing specimen packages and measured from the volume in the bounding box of the full build envelope in X-Y and the height of the build job (Z);

— The machine manufacturer shall provide the exact packing density and spacing used for the assessment as part of the documentation.

For further testing and evaluation of the specimen packages and single specimen from the specimen packages, distinctive naming shall be assigned. The distinctive naming is described in Figure 2 and Figure 3.



Key

X X-axis

Y Y-axis

1 example specimen label A8

Figure 2 — Build job labelling X-Y-directions

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