



DPC: 24/30478052 DC

BSI Group Headquarters

389 Chiswick High Road London W4 4AL

Tel: +44 (0)20 8996 9000

Fax: +44 (0)20 8996 7400

www.bsigroup.com

Date: 12 December 2024

Origin: European

Latest date for receipt of comments: 04 February 2025

Project No. 2023/01721

Responsible committee: PVE/1/16 Pressure Vessels - Fabrication and Joining Techniques

Interested committees:

Title: Draft BS EN WI 00054205 EN 13445-14 Unfired pressure vessels. Part 14: Additional requirements for pressure equipment and pressure components fabricated with additive manufacturing methods.

Please notify the secretary if you are aware of any keywords that might assist in classifying or identifying the standard or if the content of this standard

- i) has any issues related to 3rd party IPR, patent or copyright
- ii) affects other national standard(s)
- iii) requires additional national guidance or information

WARNING: THIS IS A DRAFT AND MUST NOT BE REGARDED OR USED AS A BRITISH STANDARD. THIS DRAFT IS NOT CURRENT BEYOND 04 February 2025

This draft is issued to allow comments from interested parties; all comments will be given consideration prior to publication. No acknowledgement will normally be sent. **See overleaf for information on the submission of comments.**

No copying is allowed, in any form, without prior written permission from BSI except as permitted under the Copyright, Designs and Patent Act 1988 or for circulation within a nominating organization for briefing purposes. Electronic circulation is limited to dissemination by e-mail within such an organization by committee members.

Further copies of this draft may be purchased from BSI Shop <http://shop.bsigroup.com> or from BSI Customer Services, Tel: +44(0) 20 8996 9001 or email cservices@bsigroup.com. British, International and foreign standards are also available from BSI Customer Services.

Information on the co-operating organizations represented on the committees referenced above may be obtained from <https://standardsdevelopment.bsigroup.com/>.

Responsible Committee Secretary: Miss Sarah Kelly (BSI)

Direct tel: 020 8996 7990

E-mail: sarah.kelly@bsigroup.com

Full document details: 24/30478052 DC

Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

- **Annotated drafts are not acceptable and will be rejected.**
- All comments should be submitted online at <https://standardsdevelopment.bsigroup.com/>. You will need to register in order to comment.

Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
------------------	------------------------

1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

English Version

Unfired pressure vessels - Part 14: Additional
requirements for pressure equipment and pressure
components fabricated with additive manufacturing
methods

Réceptacles sous pression non soumis à la flamme -
Partie 14 : exigences complémentaires pour
équipement et composants sous pression obtenus par
fabrication additive

Unbefeuerte Druckbehälter - Teil 14: Zusätzliche
Anforderungen an additiv gefertigte Druckgeräte und
deren Bauteile

This draft European Standard is submitted to CEN members for enquiry. It has been drawn up by the Technical Committee CEN/TC 54.

If this draft becomes a European Standard, CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

This draft European Standard was established by CEN in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and United Kingdom.

Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

Warning : This document is not a European Standard. It is distributed for review and comments. It is subject to change without notice and shall not be referred to as a European Standard.



EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

Contents

Page

European foreword	4
Introduction	5
1 Scope.....	6
2 Normative references.....	6
3 Terms and definitions	8
4 General requirements	12
5 Materials	13
5.1 General requirements	13
5.1.1 General requirements for establishing mechanical properties	13
5.1.2 Materials with specified mechanical data.....	13
5.1.3 Materials where mechanical properties of the processed parts are specified by the part manufacturer	13
5.1.4 Material data for establishing the design reference value R_f	13
5.2 Material documentation.....	14
5.3 Methodology for the certification of material	14
5.4 Contents of the particular material appraisal (PMA)	14
5.5 Avoidance of low brittle fracture	14
6 Design.....	14
6.1 General.....	14
6.2 Nominal design stress	15
6.3 Design by experimental method	15
7 Fabrication	16
7.1 General.....	16
7.2 Quality management system route for verification of the process.....	16
7.3 Direct inspection route for the verification process.....	16
7.4 Heat treatment.....	16
7.5 Identification system.....	17
7.6 Permanent joining of AM components.....	17
8 Inspection and testing.....	17
8.1 General.....	17
8.2 Non-destructive and destructive testing.....	17
8.3 Marking and documentation	18
8.3.1 General.....	18
8.3.2 Marking and documentation of components.....	18
Annex A (normative) Powder bed fusion (PBF).....	19
A.1 Requirements for PBF (all materials)	19
A.2 PBF for steels	32
A.3 PBF for aluminium alloys.....	35
A.4 PBF for nickel alloys	35
Annex B (normative) Directed energy deposition (DED).....	40
B.1 Requirements for DED wire (all materials)	40
B.2 DED for steel	56
B.3 DED for aluminium.....	77

B.4	DED for nickel alloy	93
B.5	DED for titanium alloy	93
B.6	DED copper alloy.....	93
B.7	DED for zirconium alloy	93
Annex ZA (informative) Relationship between this European Standard and the essential requirements of Directive 2014/68/EU aimed to be covered		94
Bibliography		95

European foreword

This document (prEN 13445-14:2024) has been prepared by Technical Committee CEN/TC 54 “Unfired pressure vessels”, the secretariat of which is held by BSI.

This document is currently submitted to the CEN Enquiry.

This document has been prepared under a standardization request addressed to CEN by the European Commission. The Standing Committee of the EFTA States subsequently approves these requests for its Member States.

For the relationship with EU Legislation, see informative Annex ZA, which is an integral part of this document.

Introduction

This document is applicable to unfired pressure vessels or parts of pressure vessels made with additive manufacturing (AM) processes.

This document is organized in a main part common to all additive manufacturing processes and normative Annexes A to D.

Those Annexes are dedicated to specific AM processes and contain requirements relevant to specific materials.

In this first edition of this document, only Annex A and Annex B are available. The other Annexes will be added to this document during amendment or revision as they are completed.

The structure of the specific Annexes is described in Table 1.

Table 1 — Structure of Annexes of this document

Annex		Annex A	Annex B	Annex C	Annex D
AM Process		Powder bed fusion	DED using wire feedstock	DED using powder feedstock	Binder jetting
General		A1	B1	C1	D1
Materials	Steel	A2	B2	C2	D2
	Aluminum alloys	A3	B3	C3	D3
	Nickel base alloys	A4	B4	C4	D4
	Titanium alloys	A5	B5	C5	D5
	Copper alloys	A6	B6	C6	D6
	Zirconium alloys	A7	B7	C7	D7

1 Scope

This document specifies general requirements for the application of additive manufacturing processes for pressure vessels and parts.

Separate Annexes of this document provide detailed requirements for specific additive manufacturing processes and materials.

This document is currently limited to metallic material applications. If a pressure part manufactured to this document is integrated into a pressure vessel, all parts of EN 13445 apply for this integration.

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.

EN 764-4:2014, *Pressure equipment — Part 4: Establishment of technical delivery conditions for metallic materials*

EN 764-5:2014, *Pressure equipment — Part 5: Inspection documentation of metallic materials and compliance with the material specification*

EN 10204:2004, *Metallic products — Types of inspection documents*

EN 13445-1:2021, *Unfired pressure vessels — Part 1: General*

EN 13445-2:2021+A1:2023, *Unfired pressure vessels — Part 2: Materials*

EN 13445-3:2021, *Unfired pressure vessels — Part 3: Design*

EN 13445-4:2021+A1:2023, *Unfired pressure vessels — Part 4: Fabrication*

EN 13445-5:2021+A1:2024, *Unfired pressure vessels — Part 5: Inspection and testing*

EN 13445-8:2021, *Unfired pressure vessels — Part 8: Additional requirements for pressure vessels of aluminium and aluminium alloys*

EN 13445-10:2021, *Unfired pressure vessels — Part 10: Additional requirements for pressure vessels of nickel and nickel alloys*

EN 14532-1:2004, *Welding consumables — Test methods and quality requirements — Part 1: Primary methods and conformity assessment of consumables for steel, nickel and nickel alloys*

EN 14532-2:2004, *Welding consumables — Test methods and quality requirements — Part 2: Supplementary methods and conformity assessment of consumables for steel, nickel and nickel alloys*

EN 14532-3:2004, *Welding consumables — Test methods and quality requirements — Part 3: Conformity assessment of wire electrodes, wires and rods for welding of aluminium alloys*

EN ISO 148-1:2016, *Metallic materials — Charpy pendulum impact test — Part 1: Test method (ISO 148-1:2016)*

EN ISO 636:2017, *Welding consumables — Rods, wires and deposits for tungsten inert gas welding of non-alloy and fine-grain steels — Classification (ISO 636:2017)*

EN ISO 3452-1:2021, *Non-destructive testing — Penetrant testing — Part 1: General principles (ISO 3452-1:2021)*

EN ISO 4136:2022, *Destructive tests on welds in metallic materials — Transverse tensile test (ISO 4136:2022)*

EN ISO 5173:2023, *Destructive tests on welds in metallic materials — Bend tests (ISO 5173:2023)*

EN ISO 5178:2019, *Destructive tests on welds in metallic materials — Longitudinal tensile test on weld metal in fusion welded joints (ISO 5178:2019)*

EN ISO 6892-1:2019, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature (ISO 6892-1:2019)*

EN ISO 6892-2:2018, *Metallic materials — Tensile testing — Part 2: Method of test at elevated temperature (ISO 6892-2:2018)*

EN ISO 9015-1:2011, *Destructive tests on welds in metallic materials — Hardness testing — Part 1: Hardness test on arc welded joints (ISO 9015-1:2001)*

EN ISO 10042:2018, *Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections (ISO 10042:2018)*

EN ISO 14175:2008, *Welding consumables — Gases and gas mixtures for fusion welding and allied processes (ISO 14175:2008)*

EN ISO 14341:2020, *Welding consumables — Wire electrodes and weld deposits for gas shielded metal arc welding of non alloy and fine grain steels — Classification (ISO 14341:2020)*

EN ISO 14343:2017, *Welding consumables — Wire electrodes, strip electrodes, wires and rods for arc welding of stainless and heat resisting steels — Classification (ISO 14343:2017)*

EN ISO 14732:2013, *Welding personnel — Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials (ISO 14732:2013)*

EN ISO 15708-2:2019, *Non-destructive testing — Radiation methods for Computed tomography — Part 2: Principles, equipment and samples (ISO 15708-2:2017)*

EN ISO 15614-1:2017,¹ *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1 : arc and gas welding of steels and arc welding of nickel and nickel alloys*

EN ISO 15614-2:2005, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 2: Arc welding of aluminium and its alloys (ISO 15614-2:2005)*

EN ISO 15614-11:2002, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 11: Electron and laser beam welding (ISO 15614-11:2002)*

EN ISO 17635:2016, *Non-destructive testing of welds — General rules for metallic materials (ISO 17635:2016)*

¹ As impacted by EN ISO 15614-1:2017/A1:2019.

EN ISO 17636-1:2022, *Non-destructive testing of welds — Radiographic testing — Part 1: X- and gamma-ray techniques with film (ISO 17636-1:2022)*

EN ISO 17637:2016, *Non-destructive testing of welds — Visual testing of fusion-welded joints (ISO 17637:2016)*

EN ISO 17639:2022, *Destructive tests on welds in metallic materials — Macroscopic and microscopic examination of welds (ISO 17639:2022)*

EN ISO 17640:2018, *Non-destructive testing of welds — Ultrasonic testing — Techniques, testing levels, and assessment (ISO 17640:2018)*

EN ISO 18273:2015, *Welding consumables — Wire electrodes, wires and rods for welding of aluminium and aluminium alloys — Classification (ISO 18273:2015)*

EN ISO 21952:2012, *Welding consumables — Wire electrodes, wires, rods and deposits for gas shielded arc welding of creep-resisting steels — Classification (ISO 21952:2012)*

EN ISO/ASTM 52900:2021, *Additive manufacturing — General principles — Fundamentals and vocabulary (ISO/ASTM 52900:2021)*

EN ISO/ASTM 52904:2024, *Additive manufacturing of metals — Process characteristics and performance — Metal powder bed fusion process to meet critical applications (ISO/ASTM 52904:2024)*

EN ISO/ASTM 52907:2019, *Additive manufacturing — Feedstock materials — Methods to characterize metal powders (ISO/ASTM 52907:2019)*

EN ISO/ASTM 52911-1:2019, *Additive manufacturing — Design — Part 1 : Laser-based powder bed fusion of metals (ISO/ASTM 52911-1:2019)*

EN ISO/ASTM 52926-1:2023, *Additive Manufacturing of metals — Qualification principles — Part 1: General qualification of operators (ISO/ASTM 52926-1:2023)*

EN ISO/ASTM 52926-5:2023, *Additive manufacturing of metals — Qualification principles — Part 5: Qualification of operators for DED-Arc (ISO/ASTM 52926-5:2023)*

EN ISO/ASTM 52928:2024, *Additive manufacturing of metals— Feedstock materials — Powder life cycle management (ISO/ASTM 52928:2024)*

CEN ISO/ASTM/TS 52930:2021, *Additive Manufacturing — Qualification principles — Installation, operation and performance (IQ/OQ/PQ) of PBF-LB equipment (ISO/ASTM/TS 52930:2021)*

EN ISO/ASTM 52941:2020, *System performance and reliability — Acceptance tests for laser metal powder-bed fusion machines for metallic materials for aerospace application (ISO/ASTM 52941:2020)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 13445-1:2021 and EN ISO/ASTM 52900:2021 and the following apply.

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**additive manufacturing****AM**

process of joining materials to make parts from 3D model data, usually layer 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.

[SOURCE: EN ISO/ASTM 52900:2021, 3.1.2]

3.2**annealed**

heat treatment to increase the ductility of the material and reduce its hardness, making it more workable

Note 1 to entry: Annealed involves heating a material above its recrystallization temperature, maintaining a specified temperature for a defined time, and then cooling according to the selected method.

3.3**batch**

<of feedstock> defined quantity of feedstock with uniform properties and composition

Note 1 to entry: One batch of any feedstock can be used in one or more production runs using different process parameters.

Note 2 to entry: For some types of feedstock, for example powders and resins, one batch can consist of virgin material, used material or a blend of virgin and used materials.

[SOURCE: EN ISO/ASTM 52900:2021, 3.6.1]

3.4**bead**

single deposition run made on the build surface

3.5**build cycle**

single process cycle in which one or more parts are built up in layers

[SOURCE: EN ISO/ASTM 52900:2021, 3.3.8, modified]

3.6**build platform**

<of a machine> base which provides a surface upon which the building of the part(s) is started and supported throughout the build process

[SOURCE: EN ISO/ASTM 52900:2021, 3.3.5]

3.7

build surface

area where material is added, normally on the last deposited layer 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 (A.2.3.5).

Note 2 to entry: In the case of directed energy deposition 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.

[SOURCE: EN ISO/ASTM 52900:2021, 3.3.6]

3.8

component

part of pressure equipment which can be considered as an individual item for the calculation

[SOURCE: EN 13445-3:2021, 3.7]

3.9

design class

DC

class for design which determines the design class factor to use for the design according to the level of non-destructive testing (NDT)

3.10

design class factor

F_{dc}

reducing factor taking into account the NDT range, applied to the design stress to account for any manufacturing imperfections

3.11

directed energy deposition

DED

additive manufacturing 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.

[SOURCE: EN ISO/ASTM 52900:2021, 3.2.2]

3.12

feedstock

bulk raw material supplied to the additive manufacturing 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.

[SOURCE: EN ISO/ASTM 52900:2021, 3.6.5]

3.13**feedstock supplier**

feedstock vendor
provider of feedstock

Note 1 to entry: In additive manufacturing, the feedstock supplier can often be a different entity than the feedstock manufacturer.

[SOURCE ISO/ASTM 52900:2021, 3.6.7]

3.14**layer**

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

Note 1 to entry: A layer may include single or multiple deposition runs.

[SOURCE: ISO/ASTM 52900:2021, 3.3.7 modified]

3.15**longitudinal bend test specimen**

test specimen for a test that is longitudinally bisected by the portion of the weld included in it; tests in welding direction or within the layers, respectively

[SOURCE: ISO/TR 25901-1:2016, 2.2.3.8 modified]

3.16**multi-bead performance**

wall thickness made from two or more beads

Note 1 to entry: Multi-bead performance can include weaving.

3.17**near net shape**

condition where the components require little post-processing to meet dimensional tolerance

[SOURCE: EN ISO/ASTM 52900:2021, 3.11.7]

3.18**part**

joined material forming a functional element that could constitute all or a section of a pressure equipment

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

[SOURCE: EN ISO/ASTM 52900:2021, 3.9.1, modified]

3.19**post-processing**

process step, or series of process steps, taken after the completion of an additive manufacturing build cycle in order to achieve the desired properties in the final product

[SOURCE: EN ISO/ASTM 52900:2021, 3.6.10]

3.20

powder bed fusion

PBF

additive manufacturing process in which thermal energy selectively fuses regions of a powder bed

[SOURCE: EN ISO/ASTM 52900:2021, 3.2.5]

3.21

process parameters

operating parameters and system settings used during a build cycle

[SOURCE: EN ISO/ASTM 52900:2021, 3.3.10]

3.22

reference value

R_r

value used for design calculations or burst test procedure for pressure vessels and parts with varying mechanical properties depending on the position and orientation within the part

Note 1 to entry: This is the value taking into consideration all stress directions or for a simplified approach the lowest value of mechanical properties considering all positions/orientations.

3.23

single-bead performance

wall thickness made from one bead

Note 1 to entry: Single-bead performance can include weaving.

3.24

solution annealing

heat treatment in order to place the constituents into solid solution

Note 1 to entry: The material is held at the temperatures for a period necessary to bring the alloying elements into a solid solution.

4 General requirements

The material manufacturer is the party responsible for providing certification of the consolidated material. This is typically the party that performs the additive manufacturing process, although in exceptional cases where the feedstock supplier confirms that consolidated material properties comply with a European Standard or other published specification (see 5.1.2) then the feedstock supplier can be the material manufacturer (see Figure 1). The material manufacturer can also be the part manufacturer.

The material manufacturer shall produce a material certificate 3.1 or 3.2 as defined in EN 10204:2004 in accordance with EN 764-5:2014, based on a material specification issued in compliance with EN 764-4:2014 and the applicable Annex of this document. The material manufacturer shall affirm the mechanical properties used for the design.

5 Materials

5.1 General requirements

5.1.1 General requirements for establishing mechanical properties

EN 13445-2:2021+A1:2023 is applicable only where it is referred to in this document.

Materials selected in accordance with this document shall be suitable for the additive manufacturing process.

The part manufacturer shall document the mechanical properties used for design and the source of these data.

5.1.2 Materials with specified mechanical data

Material mechanical data used for design shall be as specified in the specific Annex of this document or according to harmonized additive manufacturing material standards or according to standards within other pressure equipment codes and standards. For mechanical data coming from non-harmonized codes and standards, a PMA is required.

The procedure to verify these values shall comply with the requirements in the specific Annex of this document.

5.1.3 Materials where mechanical properties of the processed parts are specified by the part manufacturer

The mechanical data used for design shall be either those given in the specific Annex of this document or the way of obtaining the values shall be described fully. The procedure to verify the values used shall comply with the requirements in the specific Annex of this document.

5.1.4 Material data for establishing the design reference value R_r

R_r is the reference value used to determine the nominal design stress, f_{Rr} (see 6.2), used in the design calculations or burst test procedure.

NOTE See 3.22 for full definition.

Figure 1 describes how to obtain the appropriate data for material.

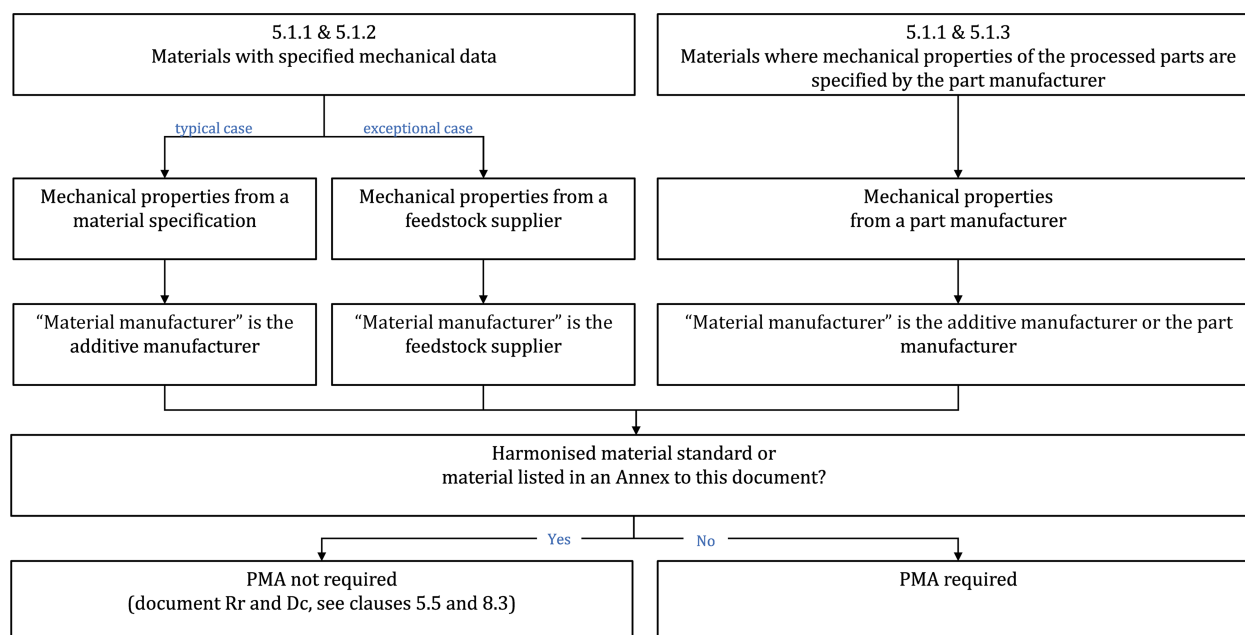


Figure 1 — Flowchart to obtain material data for design

5.2 Material documentation

The material manufacturer shall provide the inspection documents required by Clause 4. The documentation shall comply with the requirements in the specific Annex of this document.

The part manufacturer shall ensure that the material conforms with the material specification.

5.3 Methodology for the certification of material

Requirements of EN 764-5:2015 apply. Where applicable, further requirements are detailed in the relevant Annexes of this document.

5.4 Contents of the particular material appraisal (PMA)

The PMA, where required, shall consider the material specification as referred to in Clause 4. Where applicable, further requirements are detailed in the relevant Annexes of this document.

5.5 Avoidance of low brittle fracture

The method for avoidance of low temperature brittle fracture shall be either one of the methods described in EN 13445-2:2021+A1:2023, EN 13445-8:2021 or EN 13445-10:2021 or a method specified in the specific Annex of this document.

If a method is specified in a specific Annex dealing with carbon steels, low-alloy steels or austenitic steels, the toughness requirements of EN 13445-2:2021+A1:2023, 4.1.6, shall be fulfilled.

6 Design

6.1 General

EN 13445-3:2021 applies with the following:

Unless specifically addressed in one of the specific Annexes of this standard, fatigue design for more than 500 full equivalent pressure cycles is not covered by this document for pressure vessels and parts made by additive manufacturing. For the determination of 500 full equivalent pressure cycles, see EN 13445-3:2021, 5.4.2.

NOTE 1 This will be subject to a future revision of or an amendment to this document.

For establishing of nominal design stresses, refer to 6.2.

Where creep design is applied, the approach described in EN 13445-3:2021, Clause 19 shall be used.

NOTE 2 A pre-supposition of the requirements in EN 13445-3:2021, Clause 19 is usage of sufficiently creep ductile materials. Since the material grades listed in EN 13445-2:2021+A1:2023, Table E.2-1 do not include additively manufactured materials, other evidence that the AM material is sufficiently creep ductile is necessary for the application of 13445-3, Clause 19.

The safety factor S used in EN 13445-3:2021, EN 13445-8:2021, and EN 13445-10:2021 for establishing nominal design stresses applies, provided that the specified minimum elongation after fracture fulfils the criteria as laid down in EN 13445-2:2021+A1:2023, EN 13445-8:2021, and EN 13445-10:2021.

Material(s) with lower elongation values may also be applied, provided that the requirements of EN 13445-2:2021+A1:2023, Clause 4.1.5 are fulfilled. The corresponding measures shall comply with the specific Annexes of this document.

NOTE 3 Examples for compensation:

- application of higher safety factors in design;
- performance of burst tests to demonstrate ductile material behaviour.

If applicable, more detailed requirements are specified in the specific Annex of this document.

6.2 Nominal design stress

Nominal design stresses f_{Rr} shall be determined using Formula (1) as follows:

$$f_{Rr} = F_{dc} \cdot R_r / S \quad (1)$$

where

f_{Rr} shall be used instead of the nominal stresses in EN 13445-3:2021 for establishing the calculated wall thickness e or for establishing the design pressure for burst testing as described in EN 13445-3:2021, Annex T;

F_{dc} is the design class factor as defined in 3.10;

R_r is the appropriate mechanical property (see 5.1.4) and used in EN 13445-3:2021, EN 13445-8:2021, and EN 13445-10:2021 for establishing nominal design stresses;

S is the safety factor used in EN 13445-3:2021, EN 13445-8:2021, and EN 13445-10:2021 for establishing nominal design stresses;

Nominal design stress f_{Rr} shall be established at design temperature.

6.3 Design by experimental method

Where a product is designed by experimental methods, EN 13445-3:2021, Annex T may be used. This requires several values to be determined, in particular the actual wall thickness, e_{act} . In cases where direct measurement can be made of the wall thickness (where bursting is likely to start), this shall be used for e_{act} . However, it is recognized that the AM process is expected to produce a single, enclosed pressure component, in which case it is unlikely that the wall thickness would be directly measurable. Therefore, the following alternative methods may be used, in conjunction with the approach described within EN 13445-3:2021, Annex T, subject to satisfying the stated conditions:

- (i) Produce a representative test piece of the pressure boundary and interior of the non-measurable pressure equipment and perform a burst test on this test piece. To be representative, the nominal wall thickness and predicted stresses with increasing pressure in the area where bursting is likely to start shall be consistent with those in the actual part. The predicted stresses in the actual part and the test piece shall be determined using the same method and the same material properties (as stated in the material specification); where a finite element analysis approach is used, the requirements stated in EN 13445-3:2021, Annex B apply. Following the burst test, actual material property values (that conform to the requirements of the material specification) shall be used for determining the design pressure, as described within EN 13445-3:2021, Annex T.
- (ii) Test an actual pre-production part using measurements taken during the build process of the actual part to determine e_{act} (e.g. utilizing images of the fused layers), provided that the method used is validated beforehand using actual measurements on test pieces that have been subjected to the same build process and thermal post-processing.
- (iii) Test an actual pre-production part using measurements determined from a test piece that is representative of a section of the actual part containing the wall thickness to be measured, and directly measure that wall to determine e_{act} . The test piece shall be produced using the same build process and thermal post-processing as the actual part, prior to taking the measurement.

For each approach described above, where a representative test piece is specified, three test pieces shall be produced, before manufacturing of the final part, and used to demonstrate consistency and the minimum value for e_{act} shall be used in calculations.

7 Fabrication

7.1 General

EN 13445-4:2021+A1:2023 is applicable only where it is referred to in this document.

7.2 Quality management system route for verification of the process

The material manufacturer shall comply with the requirements of EN 764-5:2014, Clause 4, and requirements within the specific Annex of this document.

Parameter control is essential for the consistency of R_r throughout the build, and the reproducibility of R_r between builds. The requirements for parameter control for the selected AM method are defined within the specific Annex of this document.

7.3 Direct inspection route for the verification process

The material manufacturer shall comply with the requirements of EN 764-5:2014, Clause 5, and requirements within the specific Annex of this document.

Parameter control is essential for the consistency of R_r throughout the build. The requirements for parameter control for the selected AM method are defined within the specific Annex of this document.

7.4 Heat treatment

Heat treatment applied during or after additive manufacturing shall fulfill the requirements of the material specification and the establishment of the value R_r . It shall be part of the qualification of the manufacturing process. This qualification shall include as a minimum the type of heat treatment, heat treatment parameters and parameter tolerances. Any deviation from these parameters shall require a new qualification.

7.5 Identification system

The part manufacturer shall have and maintain an identification system for materials and feedstock used in fabrication. All material subject to stress due to pressure in the completed work shall be traceable to its origin by recording the batch number.

7.6 Permanent joining of AM components

This document is not applicable to the joining by welding or brazing of additively manufactured parts to other additively manufactured parts or to conventionally manufactured parts. For permanent joining, the requirements of EN 13445-4:2021+A1:2023, EN 13445-8:2021 and EN 13445-10:2021 shall apply, including consideration of dissimilar materials, or physical properties.

Where the build platform remains in the finished part, the requirements for proving the joint between the build platform and AM material is addressed in B.1.7.2.2.4 (ii) (Parts with integrated build platform) and B.1.7.2.4 (iii).

8 Inspection and testing

8.1 General

EN 13445-5:2021+A1:2024 applies with the following modifications:

- in 4.2 the reference to testing group shall be replaced by a reference to design class;
- 4.3 does not apply;
- in addition to the requirements listed in 5.2.2 c), the value R_r and the design class DC shall be given;
- Clause 6 does not apply;
- 7.1 and 7.2 do not apply.

8.2 Non-destructive and destructive testing

All pressure vessels and parts shall be subject to 100 % visual examination of all areas that can be exposed to view.

The required extent of non-destructive and destructive testing depends on the design class. Relation between design classes and testing is given in Table 2.

Non-destructive testing (NDT) typically includes volumetric testing and surface testing. The type of NDT as well as the acceptance criteria are specified in the specific Annex of this document.

If NDT is specified as “Full” in Table 2, all areas governing the design shall be fully tested.

If NDT is specified as “Spot” in Table 2, areas governing the design shall be spot-tested. The extent of NDT shall be specified for each individual pressure vessel or part in the applicable Annex of this document.

NOTE A full test of the areas governing the design means either to test the area in question by 100 % or to apply a suitable grid covering this area. Similarly, in the case of spot-testing the chosen areas are either to be fully tested or by application of a suitable grate.

If NDT is specified as “Random spot” in Table 2, areas governing the design shall be spot-tested for a randomly chosen lot of pressure vessels and parts. The designation of the lot and the extent of NDT are specified in the applicable Annex of this document.

If destructive testing is specified in Table 2, this destructive testing shall be carried out to verify R_r .

Table 2 — Design classes

Design class	DC 1	DC 2	DC 3	DC 4
F_{dc}	1	0,85	0,7	0,5
Burst test method ^{a, c}	A, B, C	A, B	A	A
Destructive testing	See specific Annexes	See specific Annexes	See specific Annexes	See specific Annexes
Non-destructive testing	Full	Full unless specified otherwise in the specific Annex	Spot unless specified otherwise in the specific Annex	Random spot ^b
^a For explanation of the different burst test methods, see EN 13445-3:2021, Annex T. ^b In the case of a pneumatic pressure test with a test pressure of 1,1 PS (see e.g. EN 13445-5:2021+A1:2024, 10.2.3.4.2 or EN 13445-8:2021, 8.7), NDT shall be carried out and the extent of this NDT shall be not less than for DC 2. ^c When selected as design base.				

8.3 Marking and documentation

8.3.1 General

The requirements in EN 13445-5:2021+A1:2024, 11.5 and Clause 12, shall be followed.

8.3.2 Marking and documentation of components

This subclause is applicable if a manufacturer supplies a component manufactured under the provisions of this document to other parties.

Components shall be marked in such a way that they can be attributed to the documents as described below.

Where a component is to be incorporated into a larger pressure assembly, the component shall be accompanied by a certificate that references this document and confirms the value R_r and the design class DC.

If further information/documentation (such as information about NDT, destructive testing, heat treatment) is required, the purchaser of the component shall specify this in the order.

Annex A (normative)

Powder bed fusion (PBF)

A.1 Requirements for PBF (all materials)

A.1.1 Application boundary of this Annex

This Annex contains specific requirements for laser and electron beam powder bed fusion processes.

A.1.2 Background information

For the purpose of this Annex, the normative references cited in Clause 2 are applicable.

A.1.3 Terminology

For the purpose of this Annex, the terms and definitions cited in Clause 3 are applicable.

A.1.4 General requirements

This Annex has the structure according to Table A.1.

Table A.1 — Structure of Annex A

		Process
		Powder Bed Fusion (PBF) - Annex A
General		A.1
Materials	Steels	A.2 (Later version)
	Aluminium alloys	A.3 (Later version)
	Nickel Base alloys	A.4
	Copper alloys	A.5 (Later version)
	Titanium alloys	A.6 (Later version)
	Zirconium alloys	A.7 (Later version)
	Etc...	

A.1.5 Materials

A.1.5.1 General requirements

The sections of this Annex shall be applied for the maximum values of the nominal design stress for normal load cases and for test load cases.

Subclause 5.1 applies as modified by the material specific clauses.

A.1.5.2 Material documentation

A.1.5.2.1 General

Material documentation, as outlined in the following subclauses, is required.

A.1.5.2.2 Requirements for the feedstock manufacturer

The feedstock shall be manufactured with reproducible quality and shall meet the requirements of the applicable standards, regulations and specifications as well as this technical delivery condition. The feedstock manufacturer shall ensure that the manufacturing process repeatedly produces the specified properties by suitable quality control with records for each batch traceable to the production lot; this applies to all production and delivery phases.

The feedstock manufacturer shall ensure the proper manufacture and testing of the feedstock through the use of appropriate methods, equipment and facilities. Personnel shall be suitably qualified for the production and testing methods used and the feedstock shall comply with the requirements specified in the material manufacturer's feedstock specification (see A.1.5.2.4) and EN ISO/ASTM 52907:2019.

The feedstock manufacturer shall provide a safety data sheet (SDS) and certificate with the feedstock batch in accordance with EN ISO/ASTM 52907:2019 to the material manufacturer. Where the feedstock manufacturer issues a Type 3.1 acceptance test certificate, they shall also have a suitable quality management system in place (e.g. certified to ISO 9001) and the test certificates shall meet the requirements of EN 10204:2004.

A.1.5.2.3 Requirements for the feedstock supplier

The feedstock supplier can be different from the feedstock manufacturer. The feedstock supplier shall work in accordance with EN ISO/ASTM 52907:2019.

The feedstock supplier has the role as intermediary, according to EN 10204:2004, and shall pass the original or a copy of the inspection documents provided by the feedstock manufacturer without any alteration.

A.1.5.2.4 Requirements for the material manufacturer

The part manufacturer and the material manufacturer shall agree a material specification that includes at least:

- required material properties, with defined acceptance criteria (with reference to the underlying material standard, where applicable, e.g. EN 10028 series);
- any specific chemistry requirements, where appropriate;
- provision of documentation in accordance with EN 10204:2004 Type 3.1 or 3.2, as appropriate, and test certificate in accordance with EN 764-5:2014.

The material manufacturer shall issue a feedstock specification to the feedstock supplier, based on the requirements within the material specification that as a minimum includes:

- Reference to EN ISO/ASTM 52907:2019 for powder property requirements, including test methods and acceptance criteria. The facility that performs the specified test shall be qualified for that test;
- Specific powder production method requirements, where appropriate;
- Provision of documentation in accordance with EN 10204:2004 Type 2.2 and EN ISO/ASTM 52907:2019 to enable subsequent compliance of the formed material with EN 10204:2004 Type 3.1 or 3.2.

Where powder is to be re-used, mixed or blended, the material manufacturer shall apply the requirements of EN/ISO ASTM 52928:2024, Clause 6.4.

A.1.5.3 Methodology for the certification of material

A.1.5.3.1 General

The mechanical properties of the material cannot be provided by the feedstock supplier. Therefore, the manufacturer of the pressure part shall document the mechanical properties used for design and the source of this data or the method(s) how they are obtained (see A.1.8).

There are two routes available for the certification of materials:

- quality management system (QMS) route, in accordance with EN 764-5:2014, Clause 4;
- direct inspection route, in accordance with EN 764-5:2014, Clause 5.

A.1.5.3.2 Quality management system (QMS) route

The material manufacturer shall comply with the requirements of EN 764-5:2014, Clause 4. Figure A.1 illustrates a typical flow path.

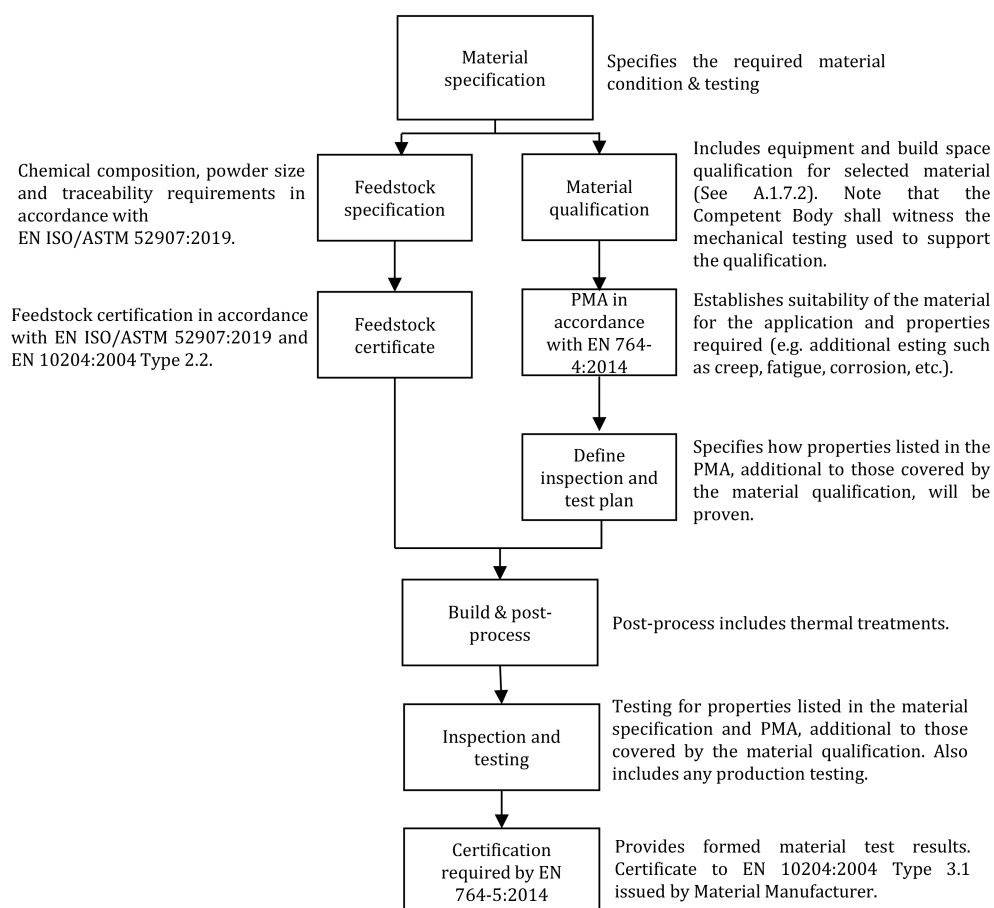


Figure A.1 — QMS route to material certification

A.1.5.3.3 Direct inspection route

The material manufacturer shall comply with the requirements EN 764-5:2014, Clause 5. Figure A.2 illustrates a typical flow path.

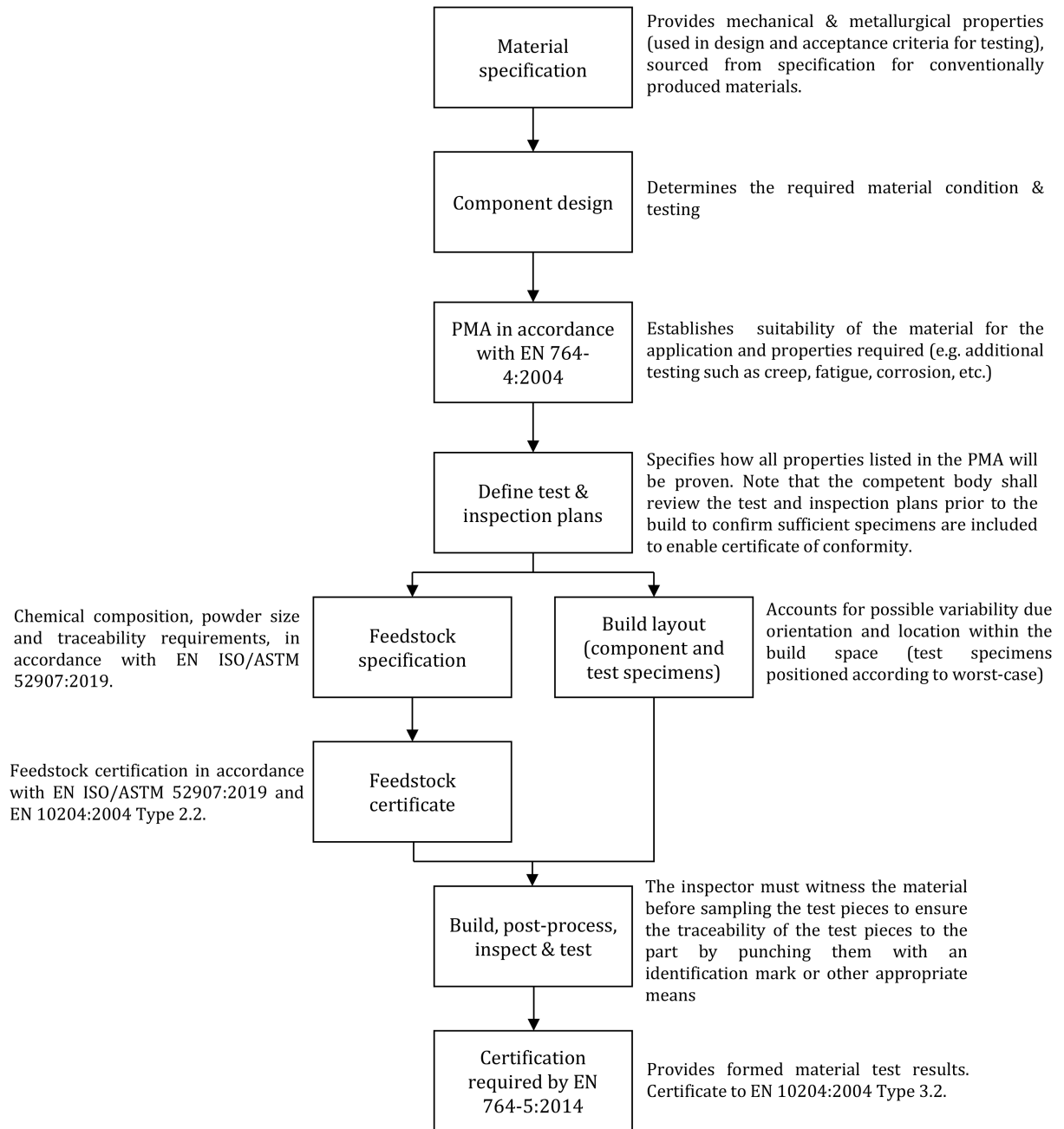


Figure A.2 — Direct inspection route to material certification

A.1.5.4 Contents of PMA

A.1.5.4.1 General

At present, there are no specific harmonized European standards, or EAM, for metallic materials developed by PBF and intended for pressure vessel applications. Therefore, this Annex is limited to the use of particular material appraisal (PMA).

The PMA shall be produced by the manufacturer of the pressure part. The manufacturer of the pressure part is responsible for collecting a data basis for determining the nominal design stress. According to the PED, the materials are qualified for the respective application by means of a particular material appraisal (PMA).

NOTE The implementation of Guideline G-01 (see 5.1.2) is the subject of future revisions (e.g. by round-robin tests according to EN ISO/ASTM 52917:2022).

The contents of the PMA shall be in accordance with EN 764-4:2014 and the following requirements.

A.1.5.4.2 Mechanical properties

See material specific Annex.

A.1.5.4.3 Chemical composition

See material specific Annex.

A.1.5.4.4 Anisotropy of the material

The PBF process used to produce the material, introduces anisotropy that shall be taken into account in the determination of the mechanical properties required for the design. This anisotropy can be removed by heat treatment to homogenize the mechanical properties of the material. In this case, the PMA shall define the heat treatment applied. In cases where heat treatment is performed, the minimum target values of the mechanical properties used to design the pressure component, will be considered identical in all directions (X, Y, Z).

If heat treatment of homogenization is not performed, the values used for design will be the minimum target values in the most disadvantageous direction. The determination of the mechanical properties in the different directions can be carried out according to A.1.8. In this case it is necessary to determine these properties in accordance with a method agreed by the material manufacturer, the part manufacturer, and where applicable, the competent body.

A.1.5.5 Avoidance of low brittle fracture

Subclause 5.5 applies as modified by the material specific clause.

A.1.6 Design

A.1.6.1 General

The requirements of Clauses 5 and 6 apply with the additional following requirements.

A.1.6.2 Nominal design stress

A.1.6.2.1 Maximum allowable values for nominal design stress

This subclause specifies the maximum allowable values for nominal design stresses on pressure-bearing parts.

EN 13445-3:2021, Clause 6 and material grade-specific requirements within the corresponding sections of this Annex shall be applied for the maximum values of the nominal design stress for normal load cases and for test load cases.

Mechanical values shall be taken from the appropriate data basis in A.1.7.2.3.

A.1.6.2.2 Design class factor

The design class factor F_{dc} shall be obtained in accordance with Table A.2.

Table A.2 — Determination of design class factor, F_{dc}

Design class factor, F_{dc}	1	0,85	0,7
Burst test method (According EN 13445-3 2021 annex T)	A, B, C	A, B	A
Destructive testing (model)	Required	Required	Required
Non-Destructive Testing (Main part or model)	Full	Spot	Not Required

A.1.7 Fabrication

A.1.7.1 General

A.1.7.1.1 Machine requirements

The requirements according to CEN ISO/ASTM/TS 52930:2021 regarding the installation and operational qualification of the PBF machine shall be fulfilled in a site acceptance test of the machine. Qualification of the individually defined test component is also described in the performance qualification section of CEN ISO/ASTM/TS 52930:2021. The site acceptance test would require requalification or at least partial requalification of the equipment.

Calibration and capability of the machine shall be maintained by the additive manufacturer using an established procedure (e.g. in accordance with the equipment manufacturer's instructions or according to CEN ISO/ASTM/TS 52930:2021).

Documented records of qualification and maintenance activities shall be retained by the additive manufacturer.

A.1.7.1.2 Requirements for digital design data

Digital design data shall be prepared according to EN ISO/ASTM 52911-1:2019.

A.1.7.1.3 Requirements for part manufacturing

The material manufacturer shall demonstrate a procedure verification for the manufacturing process, as per A.1.7.2 or A.1.7.3.

A.1.7.1.4 Determination of dimensional tolerances

The absolute value δ_e (taken from existing material standard) for the negative tolerance of the nominal thickness of the components, which is required for the design in EN 13445-3:2021, shall be determined for each machine and for each set of process parameters in the form of samples that are manufactured and measured in advance.

The standard test piece geometries of EN ISO/ASTM 52902:2023 can be used as sample bodies. The class of the test objects (coarse/medium/fine) as well as the shape of the test objects shall be adapted to the geometric requirements of the components to be produced.

Further tolerances that are not linked to the finished part dimensions shall be agreed between the purchaser and the manufacturer of the components.

A.1.7.2 Quality management system (QMS) route for verification of the process

A.1.7.2.1 General

Prior to part production, each additive manufacturing system used shall be qualified; this includes a build space qualification and a process qualification.

A.1.7.2.2 Build space qualification

The build space qualification assesses the mechanical and geometrical properties produced throughout the build space. This assessment shall be carried out on all additive manufacturing systems used for the planned production. The verification of the build space serves to determine the manufacturing quality as a function of the process parameters and the position of the samples in the build space.

The build space qualification is the responsibility of the user of the machine.

Build space qualification should consider the whole volume of the build chamber: the specimens required for each area (checkered, side length 150 mm max) should be produced close to the build platform (z min.) and at the highest quote of the build chamber (z max: for PDF, the lowest position of the build platform), provided with the adequate supports.

For the verification of the build space, CEN ISO/ASTM/TS 52930:2021 may be used as the basis.

As a first step, the orientation or build direction in which the lowest characteristic values are achieved has to be determined (e.g. z-axis orientation). For this purpose, at least 2 round tensile specimens shall be prepared and tested according to EN ISO 6892-1:2019 in x/y-orientation and z-direction as well as one set each of impact energy specimens according to EN ISO 148-1:2016 with the longitudinal axis of the notch in the x/y-, x/z- and z-direction.

For the actual qualification of the build space, the build space is – similar to a checkerboard – divided into areas (the side length of a field should not exceed 150 mm) in which the relevant data are checked on the basis of several series of measurements:

- tensile specimens according to EN ISO 6892-1:2019 in the direction of the weakest axis orientation,
- impact tests according to EN ISO 148-1:2016 in weakest orientation.

At least 2 tensile test specimens and 1 set of impact test specimens shall be produced and tested per area.

The results shall be recorded in a test report. The results can be used to qualify and determine the areas with the highest average values and those with the lowest average values in the build space.

A.1.7.2.3 Extent of testing

(i) Requirements

The values forming the manufacturer's data basis can be obtained across all machines and parameters. However, for each process parameter of a machine, the extent of testing listed in Table A.3 shall be applied for each respective material.

NOTE The approach here is to use the lowest mechanical values that have been achieved, taking into account all influencing variables.

Table A.3 — Extent of testing to determine the data basis

Type of testing	Extent of testing
Tensile test at room temperature	Minimum 25 specimens (minimum 3 per production run with minimum 5 production runs)
Impact testing	Minimum 25 specimen sets (minimum 3 per production run with minimum 5 production runs)
Tensile test at elevated temperatures ^(a)	Minimum 10 specimens per temperature step
NOTE For pressure equipment higher or equal to Category II this is done in collaboration with a notified body. ^a Temperature steps of approximately 50 K (see EN 764-4:2015).	

The contents of Table A.3 represent the minimum requirements for the initial database. This shall not be considered to be a completely validated database but should be continuously extended by ongoing production control tests (See A.1.7.2.6).

A verification of the reproducibility of the chemical composition with limit deviations between product analyses and powder analyses shall be performed.

(ii) Test methods

The sample geometries for generating the data basis during process qualification shall be consistent with the sample geometries used for production test control (see A.1.7.2.6).

For tensile testing at room temperature, specimens shall be prepared in accordance with EN ISO 6892-1:2019 and for tensile testing at elevated temperatures, EN ISO 6892-2:2018 shall be used.

For impact testing in accordance with EN ISO 148-1:2016, a standard specimen with V-notch in the transverse direction shall be prepared for each test unit.

(iii) Acceptance criteria

The minimum elongation after fracture under all influencing variables shall be $\geq 14\%$.

See material specific clause for acceptance criteria.

A.1.7.2.4 Process qualification

The process qualification shall be performed by all operators using additive manufacturing systems in their area of responsibility.

For additive manufacturing, it should be noted that the reliable verification of an additive manufacturing process cannot be traced back to the production of standard samples alone. In addition to the production of standard specimens, reference components (test pieces that are representative of the component) shall also be produced.

NOTE CEN ISO/ASTM/TS 52930:2021 gives guidance on qualification of processes.

A.1.7.2.5 Validity of the process

Time of validity is not required. With additive manufacturing process, a Type 3.1 or 3.2 certificate shall be produced for each component or equipment, so the verification procedure is applicable for each production.

A.1.7.2.6 Production control test

A production test shall be carried out to ensure that, under the local manufacturing conditions and the process parameters applied, the same quality of the additive manufacturing process can be reproduced as in the process verification. The number, location and orientation of control test pieces shall be specified by the manufacturer. The production tests shall be carried out by all operators involved and for the additive manufacturing system used in their area of responsibility.

Geometric control on non-inspectable pressure equipment can be achieved according to the material specific Annex of this document.

A.1.7.3 Direct Inspection route for verification of the process

A.1.7.3.1 General

To satisfy the material certification requirements of A.1.5.3, the material manufacturer shall demonstrate that the production performed complies with the material requirements (harmonized standards, EAM, PMA).

Specimens shall be produced to enable mechanical and metallurgical testing to be performed, to prove the conformity of the formed material against the requirements of the material specification. These specimens shall:

- be representative of the pressure part and therefore sized accordingly to represent different features throughout the part;
- be taken from various positions throughout the build space to confirm consistency of the material, regardless of build location (this includes consideration of multiple lasers for different areas of the build space, where applicable);
- include the range of specimen types to perform the required testing to demonstrate compliance with the tests required by the PMA, defined in A.1.5.4 (e.g. specimens for elevated temperature testing);
- be produced in sets of sufficient number to establish conformity in a statistically robust manner (i.e. a minimum of three test specimens per set).

This implementation plan shall be validated by the competent body for each production run to enable the issue of a Type 3.2 certificate.

A.1.7.3.2 Representativity of samples

The position of the test pieces shall correspond to the maximum height of the melted powder (part height) and shall incorporate, at least, the longest length of the platform used, as well as the presence of different laser zones in the case of multi-laser machines (see Figure A.3).

The position of these specimens will also be placed in the most unfavourable area of the manufacturing platform (e.g. downstream of part, relative to gas flow direction, where applicable). The determination of this area shall be carried out in accordance with EN ISO/ASTM 52941:2020 and EN ISO/ASTM 52904:2024.