RULES

PUBLICATION 129/P

ADDITIVELY MANUFACTURED METALLIC PARTS FOR MARINE AND OFFSHORE APPLICATIONS

July
2025

Publications P (Additional Rule Requirements) issued by Polski Rejestr Statków complete or extend the Rules and are mandatory where applicable.

GDAŃSK

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This Publication also applies to other PRS regulations if it is mentioned there.

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INTRODUCTION

The landscape of marine and offshore engineering is transforming with the advent of additive manufacturing (AM) technologies. This publication delves into the critical aspects of utilizing additively manufactured metallic parts within these demanding environments, building upon the foundational principles and guidelines established by leading industry bodies.

As industries strive for enhanced efficiency, reduced lead times, and the ability to produce complex geometries, AM presents a compelling solution, particularly for metallic components. This document is a comprehensive guide outlining the necessary considerations for the approval, certification, and in-service application of such parts—primarily for use in maritime and offshore industries. It addresses key areas, including design requirements, feedstock specifications, manufacturing process controls, post-processing, essential non-destructive testing (NDT) and repair procedures.

Drawing from the latest recommendations and best practices, this publication aims to provide stakeholders—including manufacturers, designers, shipyards, parts manufacturers, class societies, and operators—with a clear framework for ensuring the integrity, reliability, and safety of additively manufactured metallic components in marine and offshore settings. By detailing the rigorous qualification and approval processes, material specifications, and testing protocols, we aim to foster confidence and accelerate the adoption of this innovative technology, ultimately contributing to a new era of advanced engineering solutions at sea.

Since additive manufacturing is still a developing technology, special care must be taken when deciding its use in the industry. This document categorizes the metal AM processes into Powder Bed Fusion (PBF), Directed Energy Deposition (DED), and Binder Jetting (BJT). PBF and BJT manufacture relatively small parts with great precision in build chambers, rarely exceeding 30 cm. DED usually operates in unrestricted space, building parts well over 1 m dimension, further subjected to post-processing of rough surfaces. The AM processes are vastly different and further categorized into subtypes, most still emerging. They should never be treated as a family of closely related processes since they employ completely different physical phenomena and base material substrates to create the parts. The additive approach to manufacturing is the only thing in common, as opposed to the more traditional subtractive ways, which are equally diverse. Because of the differences, each method must be closely examined in terms of material densification, porosity, binding, homogeneity, ductility, thermal stresses, and fatigue strength. Parts designed to work under cyclic loads or significant temperature gradients are generally not advised for AM without additional analyses. AM processes are well-studied only regarding regular load-bearing or functional parts.

In all aspects related to certification of base materials, technology qualification, and AM technology services, PRS can provide relevant support, including interpretations or other assistance, to help solve problems or answer questions that may arise during stakeholders' familiarization with this publication's content. Specifically, because of the powerful dynamics of AM development, we assist with issues emerging from the new or related branches of AM processes not included at the moment of publication.

1 GENERAL

1.1 Scope

This recommendation provides a framework for consistent quality for metallic additive manufacturing (AM) processes to be applied as an alternative to the traditional materials manufacturing process, such as rolling, casting, forging, welding in construction.

This recommendation does not apply to hull structural members as defined in UR S6. The approval of any proposal to apply metallic additive manufacturing (AM) processes for hull structure members is subject to the individual Class Society.

For parts subject to classification, the manufacturer is to follow this recommendation. With the agreement of the Class Society, recognized international or national standards (refer to 1.7) may be accepted instead of sections of this recommendation for certified parts.

This recommendation covers guidance, within the scope of classification or certification activities by the Class Society, for qualification tests, production control and documentation associated with the design, materials, manufacturing, inspection & testing for:

i) Feedstock approval (Annex 1)
ii) Final material manufacturer approval (Annex 2)
iii) Part approval (Section 6)
iv) Repair procedure approval (Annex 3)

For metallic parts damaged in-service, an AM process could be selected for repair, which is similar to a welding repair for damaged metallic parts. The repair procedure or repair facility should be qualified and approved.

For the situations and projects involving reverse engineering, any such arrangements should be formally agreed to by the designer/original equipment manufacturers (OEMs), part manufacturer and end user.

Refer to 1.7 for international and national standards referenced in this document.

1.2 Metallic AM Process

This recommendation covers the following metallic AM processes in accordance with ISO/ASTM 52900:2021, for marine and offshore applications, which can be further subcategorized as:

i) Powder Bed Fusion (PBF) Process
   - PBF-LB: Powder Bed Fusion-Laser Beam
   - PBF-EB: Powder Bed Fusion-Electron Beam

ii) Directed Energy Deposition (DED) Process including Powder DED and Wire DED (also, named Wire Arc Additive Manufacturing, WAAM), which can be further subcategorized as:
   - DED-LB: Directed Energy Deposition-Laser Beam
   - DED-EB: Directed Energy Deposition-Electron Beam
   - DED-PA: Directed Energy Deposition-Plasma Arc
   - DED-GTA: Directed Energy Deposition-Gas Tungsten Arc
   - DED-GMA: Directed Energy Deposition-Gas Metal Arc

iii) Binder Jetting (BJT) or equivalent processes including post build sintering or an infiltration process to achieve the required material properties.

Notes:

1. Due to the process characteristics of BJT or equivalent processes, the final part, after de-binder and sintering/infiltration, may contain more and larger porosities than those parts built through the PBF and DED processes. Metallic parts through BJT or equivalent processes should be limited to non-cyclic loading applications until more successful service experiences are obtained.

1.3 Parts Categories

Part is technically defined as the combination of geometric requirements by CAD model or drawing (OEM/designer), material requirements by material specification (OEM/designer) and function requirements for the system (Purchaser). The part fabricated by the additive manufacturer should include the pre-build layout as specified in subsection 5.2 and a certificate of conformity which details the results of materials testing, inspection and non-destructive testing.

Parts are categorized into "class items" and "certified items".

For **class items,** AM metallic parts should meet the existing requirements in accordance with the applicable IACS Unified Requirements and the Rules of the Class Society.

For **certified items,** AM metallic parts should meet applicable specifications in accordance with industry standards, designer or OEM requirements.

1.4 Criticality Levels

The criticality level of the AM metallic part can be determined from the service environment, a risk analysis and the potential consequence of part failure. For certified items, criticality levels should be determined by the part designer/manufacturer and agreed with the purchaser. Class items should be in accordance with Class Rules, unless otherwise agreed by the part designer/manufacturer and the Class Society. Criticality levels are determined as follows:

i) Non-critical application, refer to services for habitability in Section 4 of UI SC 134 for machinery.

ii) Critical application, refer to primary essential services in Section 2 and secondary essential services in Section 3 of UI SC 134 for machinery or structural members other than hull structural members.

1.5 Test Levels

For qualification/approval and quality control during production, test levels can be referred to the additive manufacturing level (AM Level):

i) AM Level 1 for certified items for non-critical applications other than class items

ii) AM Level 2 for certified items for critical applications other than class items

iii) AM Level 3 for items subject to classification (hereinafter referred to as class items)

The agreed AM Level should be retained in the additive manufacturer's qualification/approval and production records.

1.6 Approval and Certification Process

The general process for approval and certification requirements is shown in Figure 1 as follows.

Figure 1 General Process for Approval and Certification

The details of requirements for AM feedstock, procedures, part and final material for approval are shown in Table 1 and listed as follows:

i) Approval should be requested by the client, along with the submitted information and a detailed inspection and test plan (ITP) (refer to, Annex 1 for AM Feedstock Approval, Annex 2 for Additively Manufactured - Final Materials Approval, Section 6 for AM Part Qualification and Approval, and Annex 3 for AM Repair Facility Approval).

ii) The ITP should be agreed and should include Part Design, AM Procedure Specification (AMPS), Post Process, Non-destructive Testing (NDT), Materials Testing, Functional Testing, Part Qualification and Certification Plan, Repair Methodology Plan.

iii) The part design should be reviewed for geometry modification or a different material grade from the original design.

iv) The CAD model or drawing for AM Level 3 should be reviewed and approved in accordance with classification Rules. The CAD model or drawing for AM Level 2 and Level 1 could be reviewed and type approval could be issued in accordance with industry standards.

v) The feedstock should be qualified according to international standards/specifications defined by the purchase specification for certified items, such as ISO 17296-2:2015, ISO/ASTM 52907:2019. The feedstock should be approved for class items by the Class Society. The approval of feedstock materials should be in accordance with Annex 1. The qualified/approved feedstock material should be linked to the feedstock supplier by a contractual agreement.

vi) For certified items, the purchaser should specify via a purchase order the requirements for manufacturer qualification. For this purpose, they can specify international standards/specifications, such as ISO/ASTM 52920:2023. For class items, the AM manufacturer should be approved by the Class Society in accordance with Annex 2. The range of approval should be determined by the Class Society and approved materials should be included in the manufacturer approval.

vii) If applicable, additive manufacturing repair procedures should be qualified according to international standards/specifications defined by purchase specification for certified items. Additive manufacturing repair procedures and facilities should be approved for class items by the Class Society in accordance with Annex 3.

viii) The Class Society should witness testing, review test results, complete the facility survey and issue an approval letter or certificate.

ix) During production, witness by the Class Society for final part acceptance is required prior to the issue of approval or certificates for class items in accordance with applicable Rules and in accordance with applicable industry standards for certified critical items. For non-critical items, witness by the Class Society is subject to agreement between the manufacturer and purchaser.

The initial survey should be conducted in accordance with the relevant steps in subsection 1.6 and Table 1. The approval tests should be witnessed by the attending surveyor. The annual survey should include a plan to demonstrate the essential parameters in Table 1 which should be followed during production.

Table 1
Approval and Certification Requirements

Qualification or Production Stages	Section or Subsection Number	Certified Items		Class Items
		AM Level 1	AM Level 2	AM Level 3
		Non-Critical	Critical	
		Requirements		
Part Design Review and Approval	3	MQ	MQ	CS
Powder Feedstock	4.1 and 4.2	MQ	MQ	CS
Wire Feedstock	4.1 and 4.3	MQ	MQ	CS
AM Procedure Specification	5	MQ	CS	CS
Post Processing	5.4	MQ	CS	CS
Inspection and Testing	7.3	MQ	CS	CS
Prototype Part Qualification	6 Table 2, 3, 4	MQ	MQ	CS
Functional Testing	6.2	MQ	MQ	CS
Range of Approval	6.4	MQ	CS	CS
Part Certification during Production	7.4	MQ	CS	CS
Approval for AM Feedstock	Annex 1	MQ	MQ	CS
Manufacturer Approval for AM Final Material	Annex 2	MQ	CS	CS
Approval for AM Repair Facility	Annex 3	MQ	CS	CS

Notes:

1. "MQ" in the table indicates manufacturer qualified requirements determined by the manufacturer, designer and purchaser, which may optionally include the Rules of the Class Society and recognized standard requirements.
2. "CS" in the table indicates approved requirements by the Class Society.

Approval and certificate for an AM part can be issued by the Class Society with documented qualification/production stages in accordance with Table 1. The AM process and documentation steps for an AM Part are shown in Table 2.

Table 2 Process and Documentation Steps

Step 1: Purchaser Specification

- Purchaser's Details
- Part Design Requirement
- Acceptance Criteria
- Decision on appropriate AM Level 1, 2, 3
- Additional Requirements by Specification or by Application

Step 2: Qualification Records

- Qualified and Documented Procedure with support of Qualified Specific Part and Final AM Material Grade

Step 3: Risk Assessment or Justification

- AM Level 3 may require qualification for each specific part
- AM Level 2 may accept a part family qualification
- AM Level 1 may recognize a qualification of a similar part with the same design feature family

Step 4: Production

- Apply Qualified Procedure and Specification
- Production
- Production Testing
- Inspection of Part
- Materials Tests for Required Properties by Design
- Verify Test Results against Acceptance Criteria

Step 5: Documentation

- Accepted with Compliance Record
- Engineering Justification for non-conformance, specifically agreed by Purchaser and the Class Society

Notes:

1. If a part is planned to be repaired, the evaluation plan and acceptance criteria should be agreed with the Class Society for Level 2 and 3 items.

1.7 References

UR M Series	Machinery Installations
UR S Series	Ship Structure
UR W Series	Materials and Welding
API 20S:2021	Additively Manufactured Metallic Components for Use in the Petroleum and Natural Gas Industries
ASME B46.1:2019	Surface Texture, Surface Roughness, Waviness and Lay
ASME BPVC II C:2023	Specifications for Welding Rods Electrodes and Filler Metals
ASME BPVC. II D Appendix I:2023	Materials Properties – Basis for Establishing Stress Values
ASME BPVC. II D Appendix II:2023	Materials Properties – Basis for Establishing Design Stress Intensity Values
ASME PTB-13:2021	Criteria for Pressure Retaining Metallic Components Using Additive Manufacturing
ASME Y14.100:2017	Engineering Drawing Practices

ASME Y14.36:2018	Surface Texture Symbols
ASME Y14.41:2019	Digital Product Definition Data Practices
ASME Y14.46:2022	Product Design for Additive Manufacturing
ASME Y14.5:2018	Dimension and Tolerancing
ASTM A20:2020	Standard Specification for General Requirements for Steel Plates for Pressure Vessels
ASTM A370:2023	Standard Test Methods and Definitions for Mechanical Testing of Steel Products
ASTM A751:2021	Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products
ASTM B213:2020	Standard Test Methods for Flow Rate of Metal Powders Using the Hall Flowmeter Funnel
ASTM B214:2022	Standard Test Method for Sieve Analysis of Metal Powders
ASTM B215:2020	Standard Practices for Sampling Metal Powders
ASTM B311:2022	Standard Test Method for Density of Powder Metallurgy (PM) Materials Containing Less Than Two Percent Porosity
ASTM B822:2020	Standard Test Method for Particle Size Distribution of Metal Powders and Related Compounds by Light Scattering
ASTM B962:2023	Standard Test Methods for Density of Compacted or Sintered Powder Metallurgy (PM) Products Using Archimedes' Principle
ASTM E10:2023	Standard Test Method for Brinell Hardness of Metallic Materials
ASTM E1417:2021	Standard Practice for Liquid Penetrant Testing
ASTM E1444:2022	Standard Practice for Magnetic Particle Testing
ASTM E1570:2019	Standard Practice for Fan Beam Computed Tomographic (CT) Examination
ASTM E1742:2018	Standard Practice for Radiographic Examination
ASTM E18:2022	Standard Test Methods for Rockwell Hardness of Metallic Materials
ASTM E23:2023	Standard Test Methods for Notched Bar Impact Testing of Metallic Materials
ASTM E2651:2019	Standard Guide for Powder Particle Size Analysis
ASTM E3:2017	Standard Guide for Preparation of Metallographic Specimens
ASTM E407:2023	Standard Practice for Microetching Metals and Alloys
ASTM E8:2022	Standard Test Methods for Tension Testing of Metallic Materials
ASTM E92:2023	Standard Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials
AWS A5.01:2019	Welding Consumables – Procurement of Filler Metals and Fluxes
AWS A5.32:2021	Welding Consumables – Gases and Gas Mixtures for Fusion Welding and Allied Processes
AWS D20.1:2019	Specification for Fabrication of Metal Components using Additive Manufacturing
ISO 10675-1:2021	Non-destructive Testing of Welds – Acceptance Levels for Radiographic Testing – Part 1: Steel, Nickel, Titanium and their Alloys

ISO 10675-2:2021	Non-destructive Testing of Welds – Acceptance Levels for Radiographic Testing – Part 2: Aluminum and its Alloys
ISO 11666:2018	Non-destructive Testing of Welds – Ultrasonic Testing – Acceptance Levels
ISO 14175:2008	Welding consumables – Gases and Gas Mixtures for Fusion Welding and Allied Processes
ISO 17295:2004	Additive manufacturing – General Principles Part Positioning, Coordinates and Orientation
ISO 17636-1:2022	Non-Destructive Testing of Welds – Radiographic Testing – Part 1: X- and Gamma-Ray Techniques with Film
ISO 17636-2:2022	Non-destructive testing of welds – Radiographic testing – Part 2: X- and Gamma-Ray Techniques with Digital Detectors
ISO 17637:2016	Non-destructive Testing of Welds – Visual Testing of Fusion-Welded Joints
ISO 17638:2016	Non-Destructive Testing of Welds – Magnetic Particle Testing
ISO 17640:2017	Non-destructive testing of welds – Ultrasonic testing – Techniques, Testing Levels, and Assessment
ISO 23277:2015	Non-destructive Testing of Welds – Penetrant Testing – Acceptance Levels
ISO 23278:2015	Non-destructive Testing of Welds – Magnetic Particle Testing – Acceptance Levels
ISO 31000:2018	Risk Management
ISO 3452-1:2021	Non-destructive Testing – Penetrant testing – Part 1: General Principles
ISO 3954:2007	Powders for Powder Metallurgical Purposes – Sampling
ISO 5817:2014	Welding – Fusion-Welded Joints in Steel, Nickel, Titanium and their Alloys (Beam Welding excluded) – Quality Levels for Imperfections
ISO/ASTM 52900:2021	Additive Manufacturing – General principles – Terminology
ISO/ASTM 52904:2019	Standard for Additive Manufacturing – Process Characteristics and Performance: Practice for Metal Powder Bed Fusion Process to Meet Critical Applications
ISO/ASTM 52905:2023	Additive manufacturing – General principles – Non-destructive Testing of Additive Manufactured Products
ISO/ASTM 52907:2019	Additive manufacturing – Feedstock materials – Methods to Characterize Metallic Powders
ISO/ASTM 52910:2018	Additive Manufacturing – Design – Requirements, Guidelines and Recommendations
ISO/ASTM 52911-1:2019	Additive Manufacturing – Technical Design Guideline for Powder Bed Fusion - Part 1: Laser-Based Powder Bed Fusion of Metals
ISO/ASTM 52911-3:2023	Additive Manufacturing – Technical Design Guideline for Powder Bed Fusion - Part 3: Electron-Based Powder Bed Fusion of Metals
ISO/ASTM 52922:2020	Guide for Additive Manufacturing– Design – Directed Energy Deposition
ISO/ASTM 52924-4:2023	Additive Manufacturing of Metals – Qualification Principles – Part 4: Qualification of Machine Operators for DED-LB

ISO/ASTM 52924-5:2023	Additive Manufacturing of Metals – Qualification Principles – Part 5: Qualification of machine operators for DED-Arc
ISO/ASTM 52926-1:2023	Additive Manufacturing of Metals – Qualification Principles – Part 1: General Qualification of Machine Operators
ISO/ASTM 52926-2:2023	Additive Manufacturing of Metals – Qualification Principles – Part 2: Qualification of Machine Operators for PBF-LB
ISO/ASTM 52926-3:2023	Additive Manufacturing of Metals – Qualification Principles – Part 3: Qualification of Machine Operators for PBF-EB
ISO/ASTM 52935:2023	Additive manufacturing – Qualification principles – Qualification of Coordinators for Metallic Parts Production
ISO/ASTM 52943-2:2023	Standard Guide for Directed Energy Deposition of Metals
ISO/ASTM 52950:2021	Additive Manufacturing – General principles – Overview of Data Processing

2 ABBREVIATIONS AND DEFINITIONS

ISO/ASTM 52900:2021 can be referred to for additive manufacturing terminology, abbreviations, and definitions.

2.1 Abbreviations

AM	Additive Manufacturing
AMF	Additive Manufacturing Format
AMPS	Additive Manufacturing Procedure Specification
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
API	American Petroleum Institute
AWS	American Welding Society
BJT	Binder Jetting
CAD	Computer Aided Design
CT	Computerized Tomography
DED	Directed Energy Deposition
EB	Electron Beam
GMA	Gas Metal Arc
GTA	Gas Tungsten Arc
HIP	Hot Isostatic Pressing
ISO	International Organization for Standardization
ITP	Inspection and Testing Plan
LB	Laser Beam
NDT	Non-destructive Testing
OEM	Original Equipment Manufacturer
PT	Liquid Penetrant Testing
PA	Plasma Arc
PBF	Powder Bed Fusion
PWHT	Post Weld Heat Treatment

SDS	Safety Data Sheet
QMS	Quality Management System
QR	Qualification Records
QP	Quality Procedure
STEP	Standard for the Exchange of Product Model Data
STL	Standard Tessellation Language
SWI	Standard Work Instruction
WAAM	Wire Arc Additive Manufacturing
3MF	3D Manufacturing Format
UR	IACS Unified Requirement
Rec.	IACS Recommendations

2.2 Definitions

Acceptance criteria	A set of values or criteria which a design, product, service or process is required to conform with, to be considered in compliance
AM facility	Equivalent to AM manufacturer, which is considered as an entity with the capability of making an AM final part/component/material following a qualified process to meet the requirements by the client or purchaser
Approval	The granting of permission for a design, product, service or process to be used for a stated purpose under specific conditions based upon a satisfactory appraisal by the Class Society
Audit	Planned systematic and independent examination to determine whether the activities are documented, that the documented activities are implemented, and that the results meet the stated objectives
Brown part	A brown part is a green part which has been heated and/or chemically treated to remove the binding material. It is a body ready to be sintered/infiltrated to become a final part.
Certificate	A formal document attesting to the compliance of a design, product, service or process with defined acceptance criteria
Certification	A procedure whereby a design, product, service or process is approved in accordance with defined acceptance criteria
Class	Short for Classification Society or Class Society
Class approval	An AM material/part which is to be manufactured at a works approved by a Classification Society
Classification	A specific type of certification, which relates to the Rules of the relevant Classification Society
Component	A part or member of some equipment or a system
Conformity	Where a design, product, process or service demonstrates compliance with defined specific requirements
Design	All relevant plans, documents, calculations described in the performance, installation and manufacturing of a product
Defect	One or more flaws whose aggregate size, shape, orientation, location or properties do not meet specified acceptance criteria and are rejectable.
Design analysis	Investigative methodology selectively used to assess the design

Design review and approval	Part of the appraisal process to evaluate specific aspects of the design including drawing or solid model review and approval supported by the final material specification
Green part	A green part is a body that is made of powdered material that has been compressed and is held together with a binding material
Equivalent	An acceptable, no less effective alternative to the specified criteria
Essential Parameters	Any parameter is considered to be essential when any aspect falling outside the qualified range affects the mechanical properties or final part quality. Essential parameters are to be defined in the specification and are required to be reviewed and surveyed. Any change of essential parameters outside the qualified range requires requalification
Infiltration	A process of filling the pores of an un-sintered or sintered object with a metal or alloy of lower melting point than that of the object
Installation	The assembling and final placement of components, equipment and subsystems to permit operation of the system
Manufacturer	The party responsible for the manufacturing and quality of the product
Manufacturing process	Systematic series of actions directed towards manufacturing a product
Manufacturing process approval	Approval of the process whereby a manufacturer produces a part using additive manufacturing
Modification	A limited change that does not affect the current approval
Part, specific	A specific part or component with the same geometric requirements, material requirements and function requirements.
Part, family	A family of parts (or similar parts) with the same function requirements, material requirements and same design features or shape but different size or section thickness.
Part, similar	A similar part with similar function requirements, the same material requirements and similar design features including different shape, size, thickness.
NDT indication	A response from a reflector during an NDT test that can further be classified as relevant or non-relevant, and usually requires further evaluation to determine its acceptability against the specified acceptance criteria.
Performance test	A technical operation where a specific performance characteristic is determined
Prototype test	Investigations on the first or one of the first new parts for optimization, fine tuning of equipment/system parameters and verification of the expected running behavior
Qualified or Qualification	The granting of permission for a design, product, service or process to be used for a stated purpose under specific conditions based upon a satisfactory appraisal by the manufacturer
Repair	Restore to original or near original condition from the results of wear and tear or damage for a product or system in service

Reverse Engineering	A process to disassemble and examine or analyze in detail (a product or device) to discover the concepts involved in manufacture, usually to produce something similar (a product or device). i.e. AM building a new product by scanning an existing product. Consideration of intellectual property (IP) issues should be addressed on a case-by-case basis
Sintering	A thermal treatment of a powder or compact, at a temperature below the melting point of the main constituent, for the purpose of increasing its strength by the metallurgical bonding of its particles
Specification	Technical data or particulars which are used to establish the suitability of materials, products, components or systems for their intended use. The specification could be provided by the manufacturer or purchaser and should be agreed by the purchaser
Witness	An individual physically present at a test and being able to record and give evidence about its outcome. Remotely present may be specially agreed by each Class Society.

3 DESIGN REQUIREMENTS

3.1 General

The quality and performance of the AM part should be considered for part design requirements and the material requirements, with appropriate control of essential parameters during the manufacturing process including pre-build, build and post-build.

The additive manufacturer should prepare a product design package, refer to Table 3, including additive manufacturing procedures, specifications in accordance with the purchase specification, the purchase order including all the requirements for the fabrication of all built parts, etc.

Table 3
Product Design Package

No.	Item
1	Design Code, Rules, Standards, or Manufacturer/OEM's Specifications
2	AM Level (1, 2 or 3)
3	Revision controlled drawing, CAD model or digital build file including test coupons (for reference)
4	The applicable material specification with acceptance criteria for each intended part/application
5	Design analysis report, if applicable
6	Powder/wire/binder specification
7	AM pre-build, build and post-build specification/procedure
8	Inspection and Testing Plan
9	Any other specifications, requirements or procedures identified as necessary by the additive manufacturer or purchaser.

Part solid model/drawing and materials specifications should be qualified in accordance with Section 6 and included in the qualification records in accordance with the applicable subsection 3.2 and 3.3

The qualified specifications and procedures for the AM part should be followed and retained in the additive manufacturer's production records.

3.2 Drawing or Solid Model

Part design includes the creation of the part drawing or solid model for end-use and should consider the achievable material properties defined in the final material specification.

The CAD model or drawing for the final AM part should include requirements for final geometry, dimensions, and tolerances in accordance with an internationally recognized industry standard, e.g.: ASME Y14.46:2018, Y14.41:2019, Y14.5:2018.

If the CAD model or drawing for the final AM part is redesigned, optimized by topology, or generated by design algorithms, the CAD model for the final AM part should be calculated or simulated using engineering software to verify design compliance and integrity for service. The design analysis report including the applicable procedure and results should be submitted for review by the Class Society for Level 3.

The optimized design requirements for the final AM part should demonstrate at least an equivalent level of functionality and integrity, such as the capability to withstand the applied loads or the applied environmental conditions to traditionally manufactured parts, which the Class Society should accept and approve for Level 3, and could accept and approve for Levels 1 and 2.

The revision number of the solid model, drawing or digital build file should be included in the AM part approval and included in manufacturer's production records.

3.3 Material Specification

Refer to Table 4, the material specification should include all material properties, including the specified AM process, for the final delivered condition and the acceptance criteria for the AM part or material. The selected material specification/grade with the heat treatment condition should be identified in the final AM material specification.

Depending on the intended application, the acceptable material properties should provide equivalency to traditional manufactured materials in accordance with applicable IACS UR W, Rec., or alternatively with internationally recognized industry standards or the designer's specifications.

Due to the inherent morphology of the AM process, consideration may be given to use an AM material with alternative chemistry and enhanced mechanical/corrosion properties, which are equivalent to or exceed the material properties typically required in the service condition, such as impact, fatigue, wear, or corrosion resistance. The selected final AM material should be appropriate for the loading condition, the functionality, the environment, and should be approved by the Class Society as an alternative new manufacturing method for the specified part/application.

The following items in Table 4 should be specified in the AM material specification for the final delivered condition. In the case of AM materials for AM Level 3, the material specification, including the following items in Table 4, should be submitted to the Class Society for approval.

Table 4
Final Material Specification

No.	Item
1	Material type and grade
2	Manufacturing process, including the AM process and any post-build heat treatment process
3	Chemical composition
4	Microstructure, such as grain size, and metallographic analysis
5	Fusion density, applicable to powder processes and not required for wire DED
6	Tensile properties
7	Charpy impact properties and test temperature, if required, according to the design temperature and material grade
8	Hardness tests, if required
9	Other special properties such as fatigue, fracture mechanics properties, corrosion, erosion, or wear resistance, if required for the intended application
10	Non-destructive testing methods, test level, quality level, and acceptance criteria

Notes:
1. Microstructure, fusion density and special properties are required during qualification/approval but are optional for production.

4 FEEDSTOCK SPECIFICATION

4.1 General

The feedstock supplier should maintain a quality management system, which should, at least, meet the minimum requirements in accordance with internationally recognized quality standards such as ISO 9001:2015.

Feedstock material should be qualified using feedstock materials approval tests in accordance with Annex 1, referred to in subsection 1.6 v).

If approval is already granted by other Classification Societies, evidence of the approval together with documentation of performed approval tests should be submitted. The indicated approval tests in Annex 1 could be reduced with the agreement of the Class Society.

4.2 Powder Feedstock

4.2.1 Powder Feedstock Specification

For powder feedstock material specification, documentation, handling, and storage, internationally recognized industry standards, such as ISO 17296-2:2015, ISO/ASTM 52907:2019, can be referred to by the manufacturer.

Refer to Table 5, the powder specification should be defined with the applicable powder manufacturing process and the range of essential parameters. Refer to Table 6, the nonessential parameters should be indicated for information.

Unless otherwise agreed the powder specification could be qualified for certified items by the manufacturer and should be approved for class items by the Class Society, to a range of parameters, refer to Annex 1. Any change of essential parameters outside the qualified range requires requalification. The essential parameters for powder feedstock include the following items in Table 5:

Table 5
Essential Parameters for Powder Feedstock

No.	Essential parameters for powder feedstock
1	Material grade
2	Powder manufacturing process, including the melting and atomization process, type of gas used, environmental conditions.
3	Post-atomization process, such as sieving.
4	Chemical composition
5	Powder size range
6	Particle size distribution
7	Powder morphology and internal microstructure
8	Flowability
9	The applicable additive manufacturing process (e.g., powder for PBF-LB, powder for PBF-EB, powder for DED, or powder for BJT)

Non-essential parameters for powder feedstock include the following items in Table 6:

Table 6
Non-essential Parameters for Powder Feedstock

No.	Non-essential parameters for powder feedstock
1	Density, such as apparent density, tap density, skeletal density, and fusion density
2	Thermal properties, such as solidus, liquidus temperature for reference
3	Oxygen content
4	Moisture content, etc.

The manufacturer should ensure that feedstock materials comply with all local and national regulations for environment, handling and safety.

4.2.2 Powder Feedstock Documentation

The powder supplier should issue a statement of conformity in accordance with the additive manufacturer's powder feedstock specification. For each powder lot and/or batch supplied, the powder supplier shall document, for raw material control and traceability, the information given in Table 7:

Table 7
Documentation for Powder Feedstock

No.	Item
1	Procurement information (Powder should be sourced from a feedstock supplier approved by the Class Society for class items.)
2	Powder supplier's contact information
3	Lot and Batch Number
4	Powder description
5	Powder manufacturing process, including the melting and atomization process, type of gas used, environmental conditions
6	Post-atomization process, such as sieving
7	Sampling methods such as chute splitting, blending or spin riffling
8	Testing method, standard, and results required by the powder material specification
9	Packing date, quantity, handling requirements, shelf life and storage instructions
10	SDS

Notes:

1. The control of powder feedstock is by Lot Number and Batch Number. Powder from the single Lot Number and single Batch Number indicates that quantity of feedstock produced under traceable and controlled conditions from a single manufacturing process cycle. The size of the feedstock lot is determined by the feedstock supplier. A single powder lot is used as feedstock in build cycles. Powder from the single Lot Number and multiple Batch Number indicates that quantity of feedstock produced under traceable and controlled conditions from a single manufacturing process cycle. The remaining feedstock of insufficient quantity to complete the build cycle that has been used in multiple AM machines is combined, blended and used to finish the powder lot. Powder from multiple Lot Numbers indicates that more than one powder lot is used as feedstock in build cycles. Multiple lots are usually blended before being loaded into the feed region.
2. Samples taken for testing should be representative of the powder lot, ensuring homogeneity when split. ASTM B215 can be referred to for sampling of metallic powders subject to a prior customer/supplier agreement. The sampling method(s) should be reported. For sampling metal powder, the preferred method is to use a dynamic sampling technique like chute splitting or spin riffling to ensure a representative sample is collected by dividing the powder stream while it is flowing, minimizing segregation issues that can occur with static sampling methods.

4.2.3 Powder Recycling

Powder should be protected against damage, contamination, and deterioration during handling, storage, and recycling. For the DED powder process, only powder which has not exited the DED nozzle may be recycled.

For the PBF or applicable BJT processes, powder recycling with mixed lots is not allowed. Powder recycling for the same lot may be allowed in accordance with procedures agreed by the Class Society. Procedures for powder recycling may consider the following factors in Table 8:

Table 8
Factors for Powder Recycling

No.	Factors
1	The documented methods for tracking the progression of powder recycling
2	Limitation for powder recycling times
3	Performance of the final delivered material property by the recycled powder
4	The documented control procedures, such as sieving, blending, testing oxygen, moisture, or other practices
5	Test results of the essential parameters should be within the specified range of virgin powder, if applied
6	Implementation of procedures for prevention of cross contamination on multi-materials use by one machine. Alternatively, linking one machine for one type of material

4.3 Wire Feedstock

4.3.1 Wire Feedstock Specification

For wire feedstock, internationally recognized industry standards such as AWS A5.01:2019, AWS A5.32:2021, ASME BPVC. II. C:2023 or other equivalent standards such as ISO 14175:2008 can be referred to by the manufacturer.

The wire specification should be defined including the manufacturing process and the acceptable range for the essential parameters in Table 9. Any non-essential parameters should be indicated for information in the procedure qualification record specified in subsection 5.5.

Unless otherwise agreed, the wire specification should be qualified for certified items by the manufacturer or approved for class items by the Class Society. Qualification should include the acceptable range for the parameters. Any change of the following essential parameters outside the qualified range requires requalification.

Table 9
Essential Parameters for Wire Feedstock

No.	Essential parameters
1	Material grade
2	Mechanical properties
3	Chemical composition
4	Wire size
5	Tolerance and surface condition (Ra) throughout the length
6	The applicable additive manufacturing process for which the wire feedstock can be used

4.3.2 Wire Feedstock Documentation

The wire material supplier should issue a statement of conformity and document the following information in Table 10 for raw material control and traceability per lot per batch.

Table 10
Documentation for Wire Feedstock

No.	Information
1	Wire should be sourced from a feedstock supplier approved by the Class Society for class items.
2	Wire supplier's contact information
3	Lot and Batch Number
4	Wire description such as wire size, material grade, AWS designation, F No., A No. if applicable
5	Wire manufacturing process
6	Associated shielding gas
7	Testing method and results as required by the wire specification
8	Packing date, quantity, and instructions for handling, storage, incoming control
9	As-built properties and Post Weld Heat Treatment (PWHT) properties, if applicable
10	SDS

4.4 Binder Feedstock

If required, the binder feedstock specification should be qualified by the AM facility. The following factors in Table 11 should be specified or considered by the manufacturer.

Table 11
Factors for Binder Feedstock

No.	Factors
1	Material grade
2	Chemical composition
3	Viscosity
4	Surface tension
5	Thermogravimetric analysis
6	Flash point
7	Evaporation temperature
8	Curing temperature
9	Storage, handling, and expiration date, if applicable

Notes:

1. Additional factors which should be considered during binder selection include: deposition method, compatibility with building process, interaction between binder and powder, effects on the strength of the as-built part, stability, and burnout characteristics.

The binder feedstock is a secondary material, which is a liquid bonding agent or glue that binds the metal/ceramic particles together. The binder feedstock can affect the binder jetting and sintering/infiltration process but should not affect the quality of the final part. The final material properties and part dimensions should be achieved by the post-build sintering/infiltration process. The qualification of binder materials should be documented by the AM facility and submitted to the Class Society, if deemed necessary.

5 ADDITIVE MANUFACTURING PROCEDURE SPECIFICATION (AMPS)

5.1 General

The AMPS should be documented by the additive manufacturer for controlling and monitoring both the essential parameters and non-essential parameters that may affect the final part quality.

The AMPS should be qualified using a range of parameters in association with the approval tests by the Class Society. Any change of essential parameters beyond the range should be requalified. Test witnessing is required for class items and certified critical items.

The applicable essential and non-essential parameters should be documented by the AM facilities/manufacturers. Any parameter that influences heat source/input and heat deposition/history should be considered as an essential parameter.

The additive manufacturing procedure should be included in the additive manufacturer's production records.

5.2 Pre-Build Procedure

The following pre-build process characteristics in Table 12 should be defined and identified, which may be supported by slicing software for the preparation of the manufacturing procedure:

Table 12
Pre-build Process Characteristics

No.	Pre-build process characteristics
1	Part location and orientation
2	Test coupon location and orientation
3	Machining allowance for part and test coupon, if applicable
4	Build location and nesting, if applicable
5	Build surface, direction, and gravity direction, if applicable
6	Support/infill structure, if applicable
7	Appropriate cleaning procedure for build platform

Notes:

1. Part orientation should be identified relative to a specified build surface, such as the build platform or incorporated substrate. If applicable or required, the build location should be identified using X, Y, Z directions in accordance with internationally recognized industry standards, such as ISO 17295:2023.
2. For PBF or applicable BJT processes, the part may be oriented and optimized using pre-build software, to reduce the build time or thermal residual stress. For PBF processes, the location of a single part may be specified within a build envelope. Multiple build locations may be necessary when multiple parts are built simultaneously within the same building envelope.

3. For DED processes, parts may be oriented vertically, horizontally or to other angles determined by machine flexibility to manipulate the substrate.
4. Test coupons should be identified in the build layout with a unique label. If the build layout and build surface are depicted, the build location, orientation, and related tolerance for test coupons are also to be indicated in accordance with internationally recognized industry standards such as ISO 17295:2023. Digital build models of parts and test coupons should be submitted for reference as part of the submission.
5. For PBF or applicable BJT processes, test coupons may be built as near-net-shape test samples or test samples could be retrieved from the sufficient test blocks.
6. For DED processes, test coupons may be taken from a prolongated part/artifact, or a separate test block that represents the part features or part section thickness, which can be specially considered and agreed to by the Class Society.
7. For PBF or applicable BJT processes, overhangs and sacrificial support structures may be applied for support during fabrication, if required. Alternatively, the part may be reorientated during the building process to avoid overhang if this is possible. If specified, a bounded surface or volume region may be used to define locations to limit or require support/infill structure. If not specified, a default support/infill structure may be applied depending upon the machine and software.

Internationally recognized industry standards, such as ISO/ASTM 52950:2021, may be referred to for an overview of data processing. Digital files may include derivatives from the original CAD model (e.g., STL, AMF, STEP or 3MF).

Digital build files should be accurately exported, especially for the critical features, documented and submitted for information, if deemed necessary by the Class Society. During exporting digital building files, the conversion of digital building file from solid model to machine recognized model/code should be verified and any errors should be fixed automatically by available software or manually by the operator.

5.3 Build Procedure

5.3.1 General

Building parameters related to heat source/input, refer to subsection 5.3.2 for PBF processes and 5.3.3 for DED processes, and heat deposition/history, refer to subsection 5.3.2 for PBF processes and 5.3.3 for DED processes, are considered as essential parameters and should be specified in the procedure specification, controlled, and qualified within the range.

Non-essential operating parameters identified by experience or fixed parameters imposed by the machine system should be documented and controlled as much as possible, including the build platform, build environment, and any other related parameters.

If process characteristics are required for in-process monitoring during building, those requirements should be monitored for conformance, such as machine building errors, failures, or defect inspection.

5.3.2 Powder Bed Fusion (PBF)

For powder processes, internationally recognized industry standards, such as ISO/ASTM 52904:2019, can be referred to by the manufacturer for inclusion in the procedure specification.

PBF-EB has similar capabilities as PBF-LB but demonstrates differences due to different beam sources. Compared with PBF-LB, the beam energy transferred by the electron beam is higher. The process may operate at higher temperatures, with faster build rates and relatively lower resolutions. Additionally, the powder bed is preheated to slightly below melting temperature, which results in less thermally induced stress.

The parameters in Table 13 should be defined in the PBF-LB or PBF-EB procedure specification.

Table 13
Additive Manufacturing Procedure Specification for PBF Process

No.	*Item*
1	**Heat Source:** a. Beam type, such as laser or electron beam b. Beam power c. Beam size d. Beam frequency or waveform control e. Beam splitting f. Beam focus setting
2	**Deposition:** a. Layer thickness b. Scan pattern/strategy c. Travel speed d. Hatch overlap, distance/spacing e. Specific settings control for edges or surfaces
3	**Build Environment for PBF-LB:** a. Build platform material specification/designation, thickness, surface finish, dimension, parallelism, and tolerance b. Build platform preheat temperature c. Shielding gas composition and flow rate d. Supplemental gas shielding e. Build chamber gas composition f. Environmental enclosure hardware and configuration
4	**Build Environment for PBF-EB:** a. Build platform material specification/designation and thickness b. Build platform preheat temperature c. Vacuum pressure d. Build Environment
5	**Other Parameters:** a. Re-coater blade type, material, or roller wear b. Powder dosing rate c. Ambient environmental conditions d. Feedstock condition, such as powder lot, batch number, virgin or recycled

5.3.3 Directed Energy Deposition (DED)

For DED processes, internationally recognized industry standards, such as ASTM F3187:2016, can be referred to by the manufacturer for inclusion in the procedure specification. The parameters in Table 14 should be defined in the DED procedure specification.

Table 14
Additive Manufacturing Procedure Specification for DED Process

No.	*Item*
1	**Heat Source:** a. Type of beam/arc b. Beam/arc power c. Beam/arc size d. Heat pulse frequency or waveform control e. Preheating by beam splitting (not applicable to PA-DED, GTA-DED, and GMA- DED) f. Use of energized (pre-heated) wire (not applicable to Powder DED) g. Beam/arc focus setting (not applicable to PA-DED, GTA-DED, and GMA-DED)
2	**Deposition:** a. Programmed layer thickness (applicable to laser powder DED, not applicable to other DED processes) b. Scan pattern/toolpath c. Travel speed d. Hatch overlap, distance/spacing (applicable to laser powder DED, not applicable to other DED processes) e. Feed rate f. Start working distance/nozzle standoff distance (not applicable to PA-DED, GTA-DED, and GMA-DED) g. Specific settings that may affect edge and surface build condition h. Wire delivery parameters such as incidence angle, offset distance or path orientation (not applicable to powder DED) i. The applied techniques such as weaving, multi-wires or pulse for wire DED, if applicable j. Start and stop point
3	**Build Environment:** a. Build platform material specification/designation, thickness, surface finish, dimension, and tolerance b. Build platform preheat temperature c. Inter-pass temperature and inter-pass cleaning, if applicable d. Shielding gas composition and flow rate (not applicable to EB-DED) e. Powder carrier gas flow rate (applicable to powder DED) f. Supplemental gas shielding (not applicable to EB-DED) g. Supply gas composition (not applicable to EB-DED) h. Build chamber gas composition, if applicable i. Vacuum pressure (applicable to EB-DED only) j. Environmental enclosure hardware and configuration
4	**Other parameters:** a. Orientation of heat source impingement b. Ambient environment conditions, such as temperature, moisture, etc. c. Feedstock type, such as powder or wire

Notes:
1. If the substrate is integrated within the final part, the mechanical and metallurgical properties at the bonding interface, together with any inspection requirements, should be included in the qualification tests. The substrate for qualification should be representative of the substrate for production.

5.3.4 Binder Jetting (BJT)

The main parameters in Table 15 should be defined in the BJT or equivalent procedure specification.

These factors are the AM build parameters, which should be controlled for the dimensions of the green part. The final dimensions and quality are determined by the sintering/infiltration process of the brown part.

Table 15
Main Parameters for BJT Process

No.	Main parameters for BJT
1	Layer thickness
2	Powder spread, if applicable
3	Build speed
4	Binder saturation, if applicable
5	Drying time and heater powder ratio, if applicable
6	Build orientation
7	Travel strategy

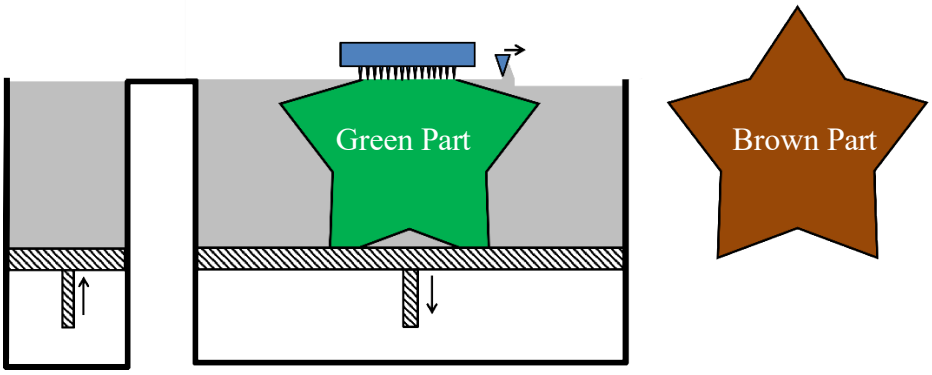

Figure 2 Schematic for Binder Jetting Process

5.3.5 In-Process Monitoring or Controlling

Some AM systems may have subsystems using one or more real-time sensors to monitor or control various performance and status indications during building, such as melt pool temperature, size, lack of fusion, spattering, and other parameters.

If subsystems can change or can control any qualified essential parameters, subsystems should be included in the AMPS and are required in qualification records, including details of the monitoring or controlling type and method, monitoring or controlling system settings and the qualified essential parameters. Subsystems are not required in AMPS and qualification records, if they do not change or do not control any qualified essential parameters.

5.4 Post-Build Procedure

5.4.1 General

The post-build process required to meet the quality and properties of the final delivered part should be provided in documented procedures or specifications.

The parameters such as temperature, soak time, and cooling media should be specified and controlled by the heat treatment facility. Reference should be made to industry standards depending upon materials.

If specified, allowances for machining could be referred to internationally recognized industry standards or manufacturer's practices.

The same post-build heat treatment processes should be applied to the test coupons and the sacrificial/actual parts if the post-build process affects the final delivered material properties or is defined as an essential parameter.

5.4.2 Powder Removal

The manufacturer's procedure should include a process for removal of loose powder from parts manufactured by PBF or BJT processes. The residual powder in the part may cause health and safety issues for personnel while working during the post processing steps, especially for reactive materials such as titanium-based or aluminum-based powder. Any health and safety risks should be identified and either designed out or minimized.

5.4.3 Heat Treatment

Heat treatment, where specified, should be in accordance with Class Rules, internationally recognized industry standards, or best practice suited to the materials, refer to the same traditionally manufactured material grade. To avoid distortion, the part should be adequately supported during heat treatment as appropriate for the component shape/complexity.

5.4.4 Part Removal

Procedures should be prepared by the manufacturer for part removal or support structure removal. The following information in Table 16 should be documented:

Table 16
Procedure for Part Removal

No.	Item
1	Suitable build platform temperature when the part is planned to be removed from build chamber
2	If applicable, powder removal needs to be verified before heat treatment
3	Applicable methods and tools, such as band saw, slow speed saw, manual tools, machining, grinding etc.
4	Step-by-step instructions

Generally, to reduce residual stress, stress relief heat treatment should be carried out before the part is removed. However, this might not be applicable for large parts due to the furnace capacity. Therefore, there are some cases where parts may be removed before stress relief heat-treatment. Depending upon materials, special attention to avoid cracking may be required and this should be specially considered and agreed to by the Class Society.

The removal of support structures should be done in a manner to avoid detrimental impact on the part. This can be proactively considered during design for the ease of removal of the interface between the support structure and the part.

5.4.5 Surface Finish or Machining

Surface finishing is important for fatigue, non-destructive testing, maintaining tolerance, surface texture and appearance. Surface finish should be in accordance with the manufacturer's procedure. Surface finishing or additional machining operations should be performed after the applicable heat treatment processing due to potential deformation and discoloring/oxidization during heat treatment.

5.5 Additive Manufacturing Procedure Specification Qualification

Refer to Table 17, the purpose of procedure qualification is to demonstrate the capabilities of an AM procedure to produce a specific AM build component, AM feedstock, AM final material, or repair part by an AM process to meet the requirements.

The AM procedure specification (AMPS) should document the required variables to ensure the repeatability of the AM process. Procedure qualification records should document the data recorded during qualification testing, including the applied parameters and corresponding test results.

Qualification records for AMPS should be established and documented for review and survey when approval is requested for an AM part, AM feedstock, AM manufacturers for final material, AM repair facilities, refer to Table 17.

The qualification procedure of an AM repair facility, as described in Annex 3, requires both a procedure specification and documented qualification records. See also subsection 10.4 for Repair of an AM Part.

Table 17
Additive Manufacturing Procedure Specification Qualification

Qualification records for AMPS	
Item	Detail
AM Part	The qualification procedure for an AM part, as described in Section 6, requires the procedure specification and the documented qualification records for the delivered part and should meet all the design requirements in Section 3.
AM Feedstock	The qualification procedure for AM feedstock, as described in Annex 1, requires the procedure specification and documented qualification records to meet the requirements for the final delivered feedstock material in subsection 3.3.
AM Manufacturer	The qualification procedure for an AM manufacturer for final material, as described in Annex 2, requires the procedure specification and documented qualification records for the final delivered material and should meet the acceptance criteria in subsection 3.3.
AM Repair	The qualification procedure for an AM repair facility, as described in Annex 3, is applicable when using an AM process for repair of in-service damaged parts. The part(s) will require a procedure specification and documented qualification records.

6 ADDITIVELY MANUFACTURED PROTOTYPE PART QUALIFICATION

6.1 General

A generic procedure qualification for prototype parts is required in accordance with subsection 5.5.

Refer to Table 18, AMPS and qualification records for part approval should be documented with revision control. Evidence should be provided that the technical/design requirements are achievable for the required application.

Table 18
Additively Manufactured Prototype Part Qualification

AMPS and qualification records for part approval	
No.	Detail
1	Test coupons and a prototype AM part should be built in the same build batch using the established digital build volume model including part location and orientation, support structure, machining stock, and the test sample's location and direction to meet the same specifications as for production.
2	Test coupons should represent the actual part or the worst-case scenario, such as edge of build platform in the Z direction for laser-based process.
3	As applicable, the height/length of each separately built tensile specimen in the Z direction should be at least the maximum height of the intended part for the PBF or applicable BJT process. If not applicable for a large part/component, the standardized tensile sample with 50 mm (2 in.) gauge length should be tested or multiple tensile samples should be tested in the Z direction to cover the height/length of the large part/component.
4	As applicable, for DED processes the samples should be retrieved from the prolongation of the intended part to replace the sacrificial part tests, considering that prolongation has similar dimensions (e.g., section thickness of the part). For separate coupons, the test samples should represent the intended part and features. For PBF process, the samples can be built separately from the intended part and at least one sample should be built for each laser zone, if applicable.
5	The relationship between controlled/specified process parameters as inputs and test results as output, in accordance with the part model and the materials specification, should be established by qualification records for the specific combination of parameters.
6	The relationships of dimensions and material properties between test coupons and the intended AM part should be established. The test coupons are used to assist quality control continuity during fabrication or production.
7	The test coupons and the specific part are to achieve the required properties by approval tests in accordance with applicable IACS UR's, Class Rules, industry standards, or designer/OEM specification.

6.2 Approval Tests for Prototype Part

The prototype part qualification for approval includes materials tests such as mechanical tests, metallurgical tests, non-destructive tests and functional tests. If the prototype part is built by an approved additive manufacturer in accordance with Annex 2, a reduced scope for mechanical and metallurgical testing could be agreed by the Class Society.

Unless otherwise agreed, the test samples, methods, and test quantity denoted in Table 19 for PBF processes, Table 20 for DED processes and Table 21 for BJT or equivalent processes should be followed.

Charpy impact testing may be specially considered and agreed to by the Class Society, depending upon materials, design temperature, and build process.

Depending upon the intended parts and applications, supplementary tests may be required, such as for fatigue, fracture mechanics, corrosion, wear, erosion, weldability, and residual stress measurements.

Depending on the application, function tests could be proof load tested for a load bearing part, pressure/leak tested for a pressure bearing part or balance tested for a rotary machinery part etc.

Alternative approval test samples, methods, and quantities may be accepted by the Class Society provided that the AM manufacturer submits explanations showing that they are technically similar.

Table 19
Approval Tests for Powder Bed Fusion Process

Sampling	*Types of Tests*	*AM Level 1*	*AM Level 2*	*AM Level 3 for Class*
		Certified and Non-Critical	*Certified and Critical*	
Test Specimen	Visual Inspection	Yes	Yes	Yes
	Surface Flaw Inspection	Yes	Yes	Yes
	Embedded Flaw Inspection	By Agreement	By Agreement	By Agreement
	Chemistry	Feedstock certificate	AM built coupon	AM built coupon
	Tensile	1	3	5
		1 in Z at one corner	3 in Z (diagonal 2 corners and 1 center)	5 in Z (4 corners and 1 center)
	Impact, if applicable	By Agreement	1 set	3 sets
			1 set in Z, at corner	1 set in Z, 1 set in X and 1 Set in Y, at corner
	Hardness	By Agreement	3	6
			1 at 1/8 below surface, 1 at 1/4 thickness, 1 at center	2 at 1/8 below surface, 2 at 1/4 thickness, 2 at center
	Microstructure	By Agreement	2	4
			1 in Z and 1 in X/Y	2 in Z and 2 in X/Y
	Density	Optional – to be agreed	3	3
Component Tests	Visual Inspection	Yes	Yes	Yes
	Surface Flaw Inspection	Yes	Yes	Yes
	Embedded Flaw Inspection	By Agreement	Yes	Yes
	Hardness Tests	If Applicable	If Applicable	If Applicable
	Function Tests	Yes	Yes	Yes

Notes:

1. For PBF-EB processes, tensile and Charpy test directions and quantities could be specially considered and agreed to by the Class Society.
2. X, Y, Z is the direction of the build, refer to internationally recognized industry standards.
3. Number count refers to the number of test specimens to be taken in each location, e.g. tensile '1 in Z at one corner' equates to "1 tensile test in the Z direction taken from one corner".

Table 20
Approval Tests for Directed Energy Deposition Process

Sampling	*Types of Tests*	*AM Level 1*	*AM Level 2*	*AM Level 3 for Class*
		Certified and Non-Critical	*Certified and Critical*	
Test Specimen	Visual Inspection	Yes	Yes	Yes
	Surface Flaw Inspection	Yes	Yes	Yes
	Embedded Flaw Inspection	By Agreement	By Agreement	By Agreement
	Chemistry	Feedstock certificate	AM built coupon	AM built coupon
	Tensile	1	3	6
		1 in Z	3 in Z	3 in Z, 3 in X or Y
	Impact, if applicable	By Agreement	1 set	3 sets
			1 set in Z	1 set in X and 1 set in Y
	Hardness	By Agreement	3	6
			1 at 1/8 below Surface, 1 at ¼ Thickness, 1 at Center	2 at 1/8 below Surface, 2 at ¼ Thickness, 2 at Center
	Microstructure	By Agreement	2	4
			1 in Z and 1 in X/Y	2 in Z and 2 in X/Y
	Density, if powder DED	By Agreement	3	3
	Bend, if wire DED	By Agreement	4	4
			2 in Z and 2 in X/Y	2 in Z and 2 in X/Y
Component Tests	Visual Inspection	Yes	Yes	Yes
	Surface Flaw Inspection	Yes	Yes	Yes
	Embedded Flaw Inspection	By Agreement	Yes	Yes
	Hardness Tests	If Applicable	If Applicable	If Applicable
	Function Tests	Yes	Yes	Yes

Notes:

1. For part approval by DED processes, reference or sacrificial parts are applicable for approval tests in lieu of test coupons.
2. If the DED procedure is qualified for an integrated build platform, the AM part or material should not be removed from the build platform for the final delivered condition. As a minimum, six tensile samples should be retrieved and tested for each integrated build platform material. Three tensile samples should represent the interface and heat affected zone (HAZ). The other three samples should represent the AM build materials in the gauge length. Charpy tests for integrated build qualification could be specially considered and agreed to by the Class Society. The interface and HAZ should be characterized and documented, with reference to traditional welding procedure qualification. Two bend tests in the Z and two bend tests in the X or Y direction for wire arc DED processes should be included for the integrated build component for AM Level 2 and AM Level 3 during the qualification stage.
3. Number count refers to the number of test specimens to be taken in each location, e.g. tensile '1 in Z' equates to "1 tensile test in the Z direction".

Table 21
Approval Tests for Binder Jetting or Equivalent Process

Sampling	*Types of Tests*	*AM Level 1*	*AM Level 2*	*AM Level 3 for Class*
		Certified and Non-Critical	*Certified and Critical*	
Test | Specimen	Visual Inspection	Yes	Yes	Yes
	Surface Flaw Inspection	Yes	Yes	Yes
	Embedded Flaw Inspection	By Agreement	By Agreement	By Agreement
	Chemistry	Feedstock certificate	AM built coupon	AM built coupon
	Tensile	1	2	3
		1 in any direction	1 in Z and 1 in X/Y	Agreed direction
		By Agreement	1 set	2 sets
	Impact, if applicable		1 set in Z, any location	1 set in Z, 1 set in X/Y, any location
	Hardness	By Agreement	3	3
	Microstructure	By Agreement	1	1
	Density	By Agreement	3	3
Component Tests	Visual Inspection	Yes	Yes	Yes
	Surface Flaw Inspection	Yes	Yes	Yes
	Embedded Flaw Inspection	By Agreement	Yes	Yes
	Hardness Tests	If Applicable	If Applicable	If Applicable
	Function Tests	Yes	Yes	Yes

Notes:
1. Number count refers to the number of test specimens to be taken in each location, e.g. tensile '1 in any direction' equates to "1 tensile test taken in the X, Y, or Z direction".

6.3 Information to be Submitted for Final Approval and Certification by the Class Society

The following documents in Table 22 should be submitted for AM part approval, for review and survey by the Class Society:

Table 22
Information to be Submitted
for Additively Manufactured Part Final Approval and Certification

No.	Item
1	Documentation identifying the part as either a class part or certified part
2	AM Level 1, 2, or 3
3	If applicable, CAD model or drawing for the final AM part and supporting engineering calculations or simulations for the model
4	If applicable, a digital build model of the part and test coupons for building, including orientation, support structures, etc., for reference
5	Evidence of approval for the AM manufacturer for class items or evidence of certification of the AM manufacturer by an appropriate inspection body for certified items
6	Final material specification including material grade, composition, properties requirements, and the NDT test standard and acceptance criteria
7	Evidence of approval of the feedstock material for class items or evidence of certification of the feedstock material by an appropriate inspection body for certified items
8	The AM procedure specification
9	The post-build procedure specification
10	Qualification records for the part approval, including inspection and testing results with traceability of applied parameters
11	Functionality testing procedures and results
12	Agreed plan for installation, operation, and survey
13	Inspection and test plan for the part certification during production, refer to Section 7.

6.4 Range of Approval

Refer to Table 23, the range of approval should consider the combination of the qualified model and procedures/specifications:

Table 23
Range of Approval for AM Part

No.	Item
1	Documentation identifying the part as either a class or a certified part
2	AM Level (1, 2, or 3)
3	CAD model or drawing with revision number
4	Materials specification of final delivered condition
5	AM machine model
6	Feedstock material linked to feedstock supplier
7	AM procedure specification including pre-build, build and post-build
8	The intended application of the finished part (e.g., the equipment/system in which the part is to be installed)

Approval of AM Level 3 parts, such parts may be qualified and approved with the support of the qualification record of a specific part.

Approval of AM Level 2 parts, a family of parts may be qualified and approved with the support of a risk analysis for the part family and/or with simulation model results, both of which should be specially considered and agreed to by the Class Society.

Approval of AM Level 1 parts, a similar part may be qualified and approved with the support of a risk analysis for the design feature family and/or with simulation model results, both of which could be specially considered and agreed by the Class Society.

Notes:

1. Requalification should be carried out if there are any quality concerns for the delivered part or if there are any changes as defined in Section 7.
2. Supplementary tests can be carried out and recorded to expand the range of approval. To extend the range of approval from AM Level 1 to AM Level 2, the manufacturer should complete the additional tests specified for AM Level 2.
3. To extend the range of approval from AM Level 1 to AM Level 3 or AM Level 2 to AM Level 3, the manufacturer should complete the additional tests specified for AM Level 3.
4. Additional testing for expanding the range of approval may also include the supplementary tests specified in Section 6.2.

7 PRODUCTION

7.1 General

During production, the approved, certified, classed parts should follow the qualified AMPS requirements for feedstock, pre-build, build and post-build. The inspection and testing reports should be documented by batch control and included in the additive manufacturer's production records to provide evidence that part design requirements have been achieved during the manufacturing process.

Notes:

5. The production batch is to be randomly selected and tested to represent all parts/components with the same batch feedstock, the same equipment, the same operator, the same process parameters, and the same post-processing.

7.2 Qualified Additive Manufacturing Process Specifications

Production for approved or certified parts with batch control should be completed following the steps in Table 24.

Table 24
Qualified Additive Manufacturing Process Specifications for Production

Step No.	Item	
1	Items/functions to be Qualified:	CAD model or drawing or digital build model with revision number
2	Qualified:	Feedstock material specification linked to feedstock supplier by contractual agreement
3	Qualified:	AM procedure specification
4	Qualified:	Post-buildheattreatmentprocedure/specification,if applicable
5	Items/functions to be verified by manufacturer and customer as agreed:	Machine maintenance, qualification, and calibration, operator knowledge - practices and qualification, the applicable essential and non-essential parameters, pre-build check of the digital file, test coupons, machine hardware and software, sufficient raw materials for the build cycle, planned or un-planned interruption etc.

Step No.	Item	
6	Inspectionand testingplan (ITP)tobe agreed:	The test scope for production control should be included in the ITP agreed by the purchaser and manufacturer. As a minimum, the test scope for AM Level 1 should be included in the ITP. Other applicable tests in subsection 6.2 could be added based on design requirements and the intended service environment. The test scope for AM Level 2 and Level 3 should be appropriately adjusted to a higher test frequency, quantity or extent above the test scope defined for Level 1. This should be defined in the purchase specification, and specifically considered and agreed to by the Class Society.

7.3 Inspection and Testing

The inspection and testing should verify that the technical design requirements and function requirements are met repeatedly, accurately, and consistently using representative parts and/or testing coupons through non-destructive or destructive testing methods.

The inspection and testing of representative parts and/or test coupons should be performed after all post-build processes. Material testing should be carried out after heat treatment and may exclude machining and surface finishing. NDT should be carried out with appropriate machining and surface finishing.

Testing should be in accordance with UR W2, applicable Class Rules, industry standards, or designer/OEM specifications for quality control during production.

The frequency of production testing should follow the agreed ITP, referred to Table 24 Step 6.

7.3.1 Chemical Composition

The chemical composition should be analyzed in accordance with internationally recognized industry standards such as ASTM A751, and the results should be documented including all elements. The chemical composition should meet the requirements of the materials specification of the final delivered condition, see subsection 3.3.

7.3.2 Microstructure

Samples should be prepared in accordance with internationally recognized industry standards. The microstructure after the final heat treatment should be examined using optical microscopy or scanning electron microscopy (SEM). The following information in Table 25 should be documented for qualification and production if required.

Table 25
Documentation for Material Microstructure

No.	Information
1	Sample ID
2	Part thickness at sectioning plane
3	Sectioning plane angle relative to build platform
4	Pictures at a quarter and half thickness with different magnifications, such as 5X, 100X, 500X or in line with the facility's procedures
5	Reported description of microstructure with grain size or other observation
6	Characterization of flaws or defects, such as morphology, type, size, location, frequency, if applicable

7.3.3 Tensile Properties

Tensile properties should be tested in accordance with internationally recognized industry standards such as UR W2, ASTM E8:2022. Subsize samples are acceptable for PBF or applicable BJT processes with a minimum gauge diameter of 6.25 mm (0.25 in.) according to ASTM E8:2022. Other alternative sample sizes may be specially considered and agreed to by the Class Society.

At least one tensile test, preferably in the Z orientation, should be carried out and the test results should be reported in accordance with ASTM F2971-13:2021 and documented for qualification and production including, as a minimum, the items in Table 26.

Table 26
Documentation for Tensile Properties

No.	Item
1	Tensile sample information such as identification, gauge length, diameter for round samples or width and thickness for flat samples, and the sample orientation
2	Test temperature should be stated if it is not room temperature
3	Test results such as yield strength, ultimate tensile strength, elongation, reduction of area, and tensile failure type and location

Notes:

1. At elevated temperatures different tensile properties to those at room temperature may be specified as additional requirements by the materials specification. If specified, tensile properties should be carried out in accordance with internationally recognized industry standards, such as UR W2 or ASTM E8:2022.
2. If required by the design, tensile properties may be tested at a defined temperature above the design temperature for the intended part application.
3. If required, the acceptance criteria for elevated temperature tensile properties should be defined in material specification for the final delivered condition.

7.3.4 Impact Properties

If required by material specification, at least one set of Charpy V-Notch impact tests should be carried out in accordance with UR W2. Test results should be documented and include the following items in Table 27.

Table 27
Documentation for Impact Properties

No.	Item
1	Charpy sample information such as identification, sample size, and notch orientation
2	Test temperature
3	Test results for qualification and production such as absorbed energy, crystallinity percentage, and lateral expansion
4	Ductile to brittle transition temperatures if required during qualification

7.3.5 Hardness

Three hardness tests can be applied for quality control in accordance with the manufacturer's procedure. These could be the Brinell Hardness test, the Rockwell Hardness test, the Vickers hardness test or other applicable hardness testing methods in accordance with internationally recognized industry standards. Hardness can also be a finished product design requirement.

7.3.6 Bend Test

If required, two bend tests should be carried out. Bend test sample size and bending mandrel can refer to the bend tests required for welding procedure qualification, or other internationally recognized industry standards.

7.3.7 Special Properties

Other special properties may need testing during qualification depending upon the material specification and intended application, which may include fusion density, fatigue properties, corrosion properties, wear, erosion, fracture toughness, high or low temperature properties, etc.

The inspection and testing plan and testing procedures should be submitted to the Class Society for review. Test results should be documented for qualification. The sampling of special properties for production control, including frequency and quantity, should be in accordance with the approved or agreed test plan.

Weldability testing may need to be performed depending on the fabrication, installation, and build process, etc. If welding is planned, specific testing will be considered and agreed to by the Class Society.

7.3.8 Non-destructive Testing

7.3.8.1 General

The final delivered part should be non-destructively tested by NDT personnel certified to the appropriate level of a nationally recognized scheme for the applied techniques, such as those schemes specified in UR W35. A surveyor witness is required for NDT processes for classification and certification. The NDT timing (delayed time between NDT starting and completion of fabrication) should be considered, refer to UR W33 and W34, which may be material dependent.

The extent of NDT should be in accordance with the agreed NDT plan.

For class items, NDT should be carried out in accordance with IACS UR W33 (conventional NDT techniques) and W34 (advanced NDT techniques) and meet the corresponding product standards, e.g., Rec. 68, Rec. 69 or other standards acceptable to the Class Society. The requirements for NDT suppliers, including certified operator and supervisor levels, should follow UR W35.

For certified items, NDT should be carried out in accordance with recognized national/international standards and meet the design specification.

7.3.8.2 Visual Examination

100% visual examination is required. The acceptance criteria should follow internationally recognized industry standards and the purchaser's specification, and should include surface finish, tolerance, and dimensions.

7.3.8.3 Surface Flaw Examination

Surface examination should follow the applicable NDT techniques in UR W33 or W34. The asbuilt surface of AM part may give false indications, so, where surface NDT is required, the surface should be made suitable for the NDT method applied.

7.3.8.4 Embedded Flaw Examination

Conventional ultrasonic or radiographic inspection should refer to UR W33. Further guidance on NDT is given in Rec. 68 and 69, for products corresponding to equivalent forged or cast components. Advanced NDT should refer to UR W34. Computerized Tomography (CT) scan may be applied where defined in the project specifications.

7.3.8.5 In-Situ Process Monitoring

In-situ process monitoring can be a viable method for qualification/production control, which can partially/fully replace surface or embedded flaw inspection, depending on the criticality level and the agreed ITP.

Before adoption in production, the in-situ process monitoring technology should be verified and validated, by suitable NDT techniques, with supporting data, in conjunction with agreed inspection quality levels, test levels and acceptance criteria. The acceptance of in-situ process monitoring for inspection could be qualified and agreed by the Class Society.

Guidance Notes for where in-situ process monitoring is applied:

1. The in-situ process monitoring model-based approach should apply the in-situ sensor data to monitor the AM build process. Methods and algorithms such as machine learning models may be utilized to calibrate and map layer-wise images to laser scan vectors. Images/Spectral/Data are stacked and exported to standardized 3D data formats to enable easy inspection and comparison to post-build a 3D CT or UT/RT surface or embedded flaw. Procedures are to be in place to address discrepancies between in-situ indications as identified during process monitoring and subsequent NDT results, including additional diagnostic scanning or other verification measures
2. The in-situ process monitoring model can be validated using the data captured by highresolution CT scans as verified data (actual flaw location and size).
3. NDT indications or defects, e.g. gas porosity, keyhole pores, lack of fusion, is classified or categorized by outputs/resultant data of the machine learning model, if applicable.
4. Unless otherwise agreed, the probability of detection for in-situ process monitoring should meet the 90%/95% reliability of flaw detection. e.g. 100 layers were selected for analysis and detection of flaws in 90 layers can meet the lower bound of 95% confidence interval for the defined flaw size in accordance with the acceptance criteria of the applicable sections of UR W33, W34, ISO 5817:2023, ISO 10675-1:2021, ISO 10675-2:2021 or equivalent standards, which may depend on the section thickness of the part. In-situ flaw detection procedures should be documented, and capability should be supported by procedure verification and validation results.
5. When in-situ process monitoring is adopted during initial qualification and production, repeatability and data detection should be verified, and results should be analyzed, with at least 10% of the cross-validated data verified by the traditional or advanced NDT techniques. (e.g. 10 parts use an in-situ process for flaw detection, at least 1 part should be inspected using traditional or advanced NDT techniques). To accept in-situ process monitoring for small-batch or one-off critical parts, the Class Society may require a higher percentage of cross-checking, commensurate with the criticality of the component and the agreed ITP.

7.4 Part Certificate

A part certificate should be issued by the Class Society for class. Certificates for certified items should be issued by the manufacturer and should be supported by the manufacturer's documents in accordance with 7.2 and 7.3 as applicable. Unless otherwise agreed, certification should be furnished for the final delivered part by the additive manufacturer indicating:

i) Material grade
ii) Chemical composition
iii) Reference to the Additive Manufacturing Procedure Qualification Record
iv) Tensile test results
v) Charpy test results, if applicable
vi) Hardness, if applicable
vii) Nondestructive test results
viii) Any additional specialized test results

ix) Function test results, if applicable
x) Other intermediate processes such as heat treatment, surface finish, machining conditions

8 NON-CONFORMANCE

If parts do not conform to the specified requirements, non-conformance reports should be generated, documented, and maintained by the additive manufacturer. Parts may be accepted or rejected with or without reworking based on engineering justification, which should be agreed to by the Class Society and purchaser.

The manufacturer should keep a record of all non-conformities, where warranted, and should carry out root-cause investigations, if systematic errors are identified within any part of the process or components.

9 DOCUMENTATION

The following items in Table 28 should be documented by the manufacturer in accordance with the quality management system/program and provided as production records with full traceability.

Table 28
Documentation for Production Records

No.	Item
1	AMPS with revision control including the feedstock specification, the final material specification, and the procedure (pre-build, build and post-build) specification
2	Drawing, solid model, software or digital build file with revision control
3	Type Approval Number or Feedstock test report
4	Additive manufacturing procedure qualification report
5	Part certificate
6	Any other part/application specific tests including test results and acceptance criteria
7	Any non-conformance reports

10 IDENTIFICATION, RETESTING AND SURVEYS

10.1 Identification

The manufacturer should adopt a system for the identification of AM parts e.g. build batch number control, which will enable the parts to be traceable to the applied AM process and test report, and the Surveyor should be given full facility access for tracing the material when required.

10.2 Retesting

Material retesting for parts subject to classification requirements should follow individual Class Rules. For certified parts, material retesting may be specifically agreed. Test results for the original test and retest should be reported for class and certified parts.

10.3 Surveys

Surveyor witness for functional testing, such as pressure or proof load tests, is required for class and certified critical parts during the prototype part qualification stage and may be required for class parts during production. Functional testing could be carried out at a workshop or on-board, subject to a factory acceptance test and/or a site acceptance test as specified in the approved ITP or contract agreement. Surveyor witness after installation should be agreed in accordance with the applicable Class Society requirements.

A surveyor witness for material testing is required for class and certified parts during the prototype qualification stage. During the production stage, surveyor witness for material testing is required for a class part but is optional for a certified part.

Notes:

1. AM parts may need additional survey when in service, when compared to traditionally manufactured parts. This may be required because AM parts do not yet have sufficient marine service history. This should be identified early on as part of the design and build philosophy.

10.4 Repair for AM Part

Unless otherwise agreed, repair of an AM class part is prohibited without approval by the purchaser and the Class Society.

If repair of the AM part during production is needed, repair procedures and the method for repair should be suitably established and agreed to by the Class Society prior to repair.

11 REPAIR OF AM PART DAMAGED IN-SERVICE

If repair of an AM class part in service is needed, repair procedures and the method for repair should be suitably established and agreed to by the original additive manufacturer or AM repair facility and the Class Society prior to repair, refer to Annex 3.

For the repair of non-class AM parts damaged in service, the repair procedure and the method of repair should be according to the applicable specifications per industry standards, designer/OEM requirements, refer to Annex 3.

ANNEX 1

APPROVAL FOR ADDITIVE MANUFACTURING FEEDSTOCK

1 General

Annex 1 provides recommendations for the approval of additive manufacturing feedstock materials by the Class Society for a feedstock supplier approval. The recommendations can also be used for feedstock qualified by the AM manufacturer for an AM manufacturer approval and applied under a commercial agreement between the two parties, the AM manufacturer and the feedstock supplier.

If the traditionally manufactured parts are class items, feedstock materials should be approved by the Class Society. For certified items, the approval for feedstock materials could be agreed by purchase specification.

Approval for feedstock materials involves a documentation review, an audit of the facility and the witness of approval tests. Unless otherwise agreed, the Class approval is valid subject to annual verification and/or endorsement by the attending Surveyor. An additional audit may be requested at annual verification.

2 Approval Application

Approval should be requested by the client, along with the information and a detailed inspection and test plan (ITP) as listed in Table 29.

Table 29
Approval Application for Additive Manufacturing Feedstock

No.	Item
1	An outline of the organization including the quality management system, a facility description, details of organization and quality control responsibilities
2	Manufacturing process description or flow charts indicating all process steps
3	A list of documented manufacturer's procedures, specifications, documentation, reports and product certificates
4	Documented procedures for feedstock identification and traceability using lot control and batch control
5	Documented historical data for parts built using the feedstock, if available
6	Inspection and testing plan (ITP)

3 FEEDSTOCK SPECIFICATION AND QUALIFICATION

3.1 General

An additive manufacturing feedstock specification should be prepared for each material grade for which approval is requested. Prior to conducting approval tests, the feedstock specification and ITP should be submitted and approved by the Class Society/AM manufacturer.

3.2 Feedstock Specification Approval

The feedstock specification should be submitted to the Class Society/AM manufacturer for review and approval. A description and specification of the feedstock should be prepared in accordance with 4.2.1 for a powder feedstock specification together with the following notes and with 4.3.1 for a wire feedstock specification.

Notes:

1. ISO 3954:2007 or ASTM B215:2020 can be referred to for powder sampling. The material grade may be a trade name, common name, or typical material designation.
2. The chemical composition is to be tested and determined by a suitable testing procedure such as wet chemical process, atomic absorption spectrometry, flame emission spectroscopy, X-ray fluorescence analysis, or other recognized methods. Industry standards may be referenced to determine the content of interstitial elements such as carbon, nitrogen, hydrogen, sulphur, and oxygen.
3. Powder size and distribution are to be tested in accordance with ASTM E2651:2019 or other equivalent standards, such as sieving in accordance with ASTM B214:2022 for DED powder, static or dynamic image analysis, light scattering, laser diffraction in accordance with ASTM B822:2020 or other recognized methods. The powder size distribution (PSD) may be described by D10, D50 and D90. D10 is the first decile (e.g.,1/10 of the statistical population is below this value). D50 is the median value (e.g., 50% of the statistical population is below this value). D90 is the last decile (e.g., 90% of the statistical population is below this value). Other powder size distribution methods may also be specified by the powder manufacturer. For a powder DED process, the maximum powder size may be specified depending upon the powder feeding system.
4. Morphology can be affected by the powder manufacturing process. The preferred inspection method is by scanning electronic microscopy (SEM), secondary electron imaging, or other recognized methods.
5. Flowability can be affected by multiple factors such as powder size and distribution, cohesive strength by moisture, inter-particles friction, powder sphericality, etc. Industry standards, such as ASTM B213:2020, may be referenced to test flowability through piping, nozzle, funnel, etc.

3.3. Approval Tests

Unless otherwise agreed, the following approval tests should be carried out and test results should be reported using AM built test coupons in accordance with subsection 7.3 for inspection and testing. The results should be included in qualification records. Refer to Table 30. Test coupons should represent the performance of the feedstock.

Table 30
Approval Tests and Test Results for Additive Manufacturing Feedstock

No.	Test Items
1	Visual inspection: Sample ID and results
2	Dimension inspection: Sample ID and results
3	Surface flaw inspection: Sample ID and results
4	If specified, embedded flaw inspection: Sample ID and results
5	3 tension tests: Sample ID, sample orientation, sample size and test results including yield strength, tension strength, failure type and location
6	If required, 1 set of Charpy impact tests, applicable to materials with ductile-to- brittle transition: Sample ID, sample orientation, sample size and test results
7	If applicable, bend tests: 2 bend tests in the Z and 2 bend tests in X or Y direction for wire arc DED processes and test results
8	Hardness test for the interface cross-section and heat affected zone (HAZ) in the substrate for an integrated build: Sample ID, harness values or hardness profile from AM build material to HAZ
9	Microstructure examination: Sample ID, part thickness at the section plane, section plane angle relative to build platform, magnification, and results
10	Chemical analysis: Sample ID and results
11	Density test: Sample ID and results
12	Other tests: other tests may be performed if the manufacturer assesses them to be useful for qualification of the feedstock or if they are specified by the powder purchaser.

4 Survey

4.1 Initial Survey

The manufacturer should be audited by the attending Surveyor. The initial survey of feedstock production facilities should include witness of the feedstock manufacturing process, survey of manufacturing control for repeatability of the AM feedstock quality, evaluation of the quality management system, document control for the manufacturing procedure and specification, and quality control for sampling, testing, reporting etc.

4.2 Witness of Approval Tests

The approval tests should be witnessed by the attending Surveyor.

4.3 Annual Survey

The annual survey should be carried out by the attending Surveyor. The annual survey should include a plan to demonstrate the essential parameters are followed during production. During the annual survey, full or partial approval tests could be requested based on the performance of the annual production record.

5 Information to be Submitted for Approval by the Class Society

For class parts, the following items in Table 31 should be submitted to the Class Society:

Table 31
Information to be Submitted for Additive Manufacturing Feedstock Approval

No.	Item
1	Operator qualifications record
2	Feedstock material specification and documentation
3	Recommend AM build parameters for the feedstock material
4	Types of approval tests, test standards and test results in accordance with Annex 1/3.3
5	Witness of the qualification approval tests
6	Qualification records with a certifying statement acknowledging the validity of the data and certifying the qualification tests and test results
7	Agreed plan for quality control during feedstock production

6 Range of Approval

Upon satisfactory completion of the feedstock specification review and survey, approval will be granted by the Class Society. The following information is to be stated in the approval certificate issued by the Class Society:

i) Feedstock supplier
ii) Qualified feedstock material specification in accordance with subsection 4.2.1 for powder feedstock and subsection 4.3.1 for wire feedstock.

ANNEX 2

APPROVAL FOR MANUFACTURER – ADDITIVELY MANUFACTURED METALLIC MATERIALS

1 General

For class items, the manufacturer should be approved in accordance with this Annex 2. For certified items, the approval of the manufacturer should be agreed by a purchase specification.

Manufacturers should comply with the applicable requirements in their quality management system. The machine, procedure and personnel should be qualified and documented. The procedure should be followed during production by the manufacturer.

The manufacturer should prepare the manufacturing specifications/procedures, qualified using approved tests of qualification build block or coupons. The manufacturing specifications/procedures should be approved with repeatedly and consistently achievable AM final materials properties.

Manufacturers should be evaluated with reference to both quality management system and AM capability. In addition, the sub suppliers or outsourcing of any services or production should be reviewed by using a specification/procedure. The sub suppliers or outsourcing may include a feedstock supplier, a post-build heat treatment shop, a machine shop, a laboratory for testing, NDT facilities, or service supplier.

Class approval involves a documentation review, an audit of the facility/manufacturer and witness of the approval tests. Unless otherwise agreed, the approval is valid for a maximum of 5 years subject to annual verification and/or endorsement by the attending Surveyor. Renewal approval should be requested and issued with the effective date being the 5 years anniversary date from the previous approval. An additional audit may be requested if there is any quality concern.

2 Approval Application

Approval should be requested by the AM manufacturer, and submitted with the information listed in Table 32 and a detailed inspection and test plan (ITP).

Table 32
Approval Application for Manufacturer - Additively Manufactured Metallic Materials

No.	Submitted documents
1	An outline description of the manufacturer including their quality management system (see subsection 2.1.1), a facility description (see subsection 2.1.2), and details of the manufacturer's organization and quality control (see subsection 2.1.3)
2	Additive manufacturing capability (see subsection 2.2)
3	Documentation for manufacturing equipment (see subsection 2.3)
4	Documentation for operators (see subsection 2.4)
5	A list of documented manufacturing procedure specifications, supporting documentation and test reports and the/any AM product/part/material certificates
6	Inspection and testing plan for qualification and production
7	Documented procedures for incoming feedstock materials identification and traceability using batch control
8	Documented historical data for previously built AM final parts or materials

2.1 Description of Manufacturer

2.1.1 Quality Management System (QMS)

The review and survey of the AM manufacturer by the Class Society should cover the facility description, organization, quality, and AM capability and should include any historical data for the AM manufacturer approval, to the satisfaction of the Class Society. A formal QMS in accordance with an internationally recognized standard is not mandatory, however, the AM manufacturer is to have a QMS in place which is documented, controlled, auditable, and embedded in the organizational structures.

2.1.2 Facility Description

General information for the facility should include the following items in Table 33.

Table 33
Description for the Facility

No.	General information for the facility
1	Name and address of AM facility
2	General relevant information and background
3	Estimated annual production of finished parts for AM products, and a brief description of intended applications

2.1.3 Organization and Quality

High level organization should provide the following items in Table 34.

Table 34 Organization and Quality

No.	Item
1	Organizational chart
2	Organization of the quality control department and the staff employed
3	Qualification of the operators involved in activities related to the quality of the part/material
4	Certification of compliance with the quality system with internationally recognized industry standards, where applicable
5	A management system of engineering specifications, procedures with revision control, and documentation for part/sample labelling and traceability

Notes:

1. If recognized certification is not available, then adequate controls should be demonstrated through a review of the manufacturer's QMS.

2.2 Additive Manufacturing Capability

The following items in Table 35 should be provided for AM capability.

Table 35
Additive Manufacturing Capability

No.	Item
1	Approval certificates/documentation already granted by the Class Society, if any
2	List of machines and materials/parts for approval
3	Manufacturing flow chart for the AM Process
4	Feedstock handling and storage procedure
5	Final delivered part/material handling and storage procedure
6	Details of the various equipment used or outsourcing facilities, including pre-build, AM build, and post-build activities (e.g., furnace, condition and recording method of heat treatment)
7	Non-destructive and destructive testing facilities or service suppliers intended to be used, if outsourced
8	Information about the different types of material grades the facility intends to manufacture, with frequency of manufacturing, and any previous examples
9	Information about the different types of AM processes the facility intends to use to fabricate parts with the manufacturing frequency and any previous examples
10	Previous examples of the different types of test coupons/manufactured parts at the facility
11	Information about maximum weights, dimensions, section thickness the facility is capable of handling

Notes:
1. The manufacturers should take responsibility for feedstock quality, storage, handling and re-use, if applicable.

2.3 Documentation for Manufacturing Equipment

The manufacturer should establish and document evidence to demonstrate the following items in Table 36 (refer to internationally recognized industry standards depending upon the AM process).

Table 36
Documentation for Manufacturing Equipment

No.	Item
1	Documentation to confirm that process equipment and ancillary systems can operate within the established/specified limits and tolerances.
2	Documentation that test coupons throughout the build envelope can achieve the required properties by approval tests for a standard qualification build.

The written quality procedures and machine qualification records should be documented for equipment calibration, maintenance, monitoring, and control by the manufacturer in their quality management system and submitted to the Class Society if deemed necessary.

Documentation of a machine should include the following information in Table 37.

Table 37
Documentation for AM Machine Qualification

No.	Documentation items
1	Machine manufacturer
2	Machine model
3	Serial number
4	Any additional components which impact build parameters
5	Software version

Notes:
1. Any changes to the above items should be documented as a change of machine. Any change should be linked to a machine model number. A serial number for the same machine model number is not considered as a change of machine. If multiple machines with different serial numbers are used, they should be separately documented.

2.4 Documentation for Operators

Operators should be competent with documented practical experience and knowledge tests (such as written exams, internal training, external training, certification by the third party, or a combination of these factors).

The operator should have the appropriate competence of understanding of the qualified additive manufacturing procedure specification (AMPS) and operating practices in accordance with the approved procedures for the part or material qualification builds.

For practical skills, the operator should demonstrate the necessary process steps on the machine and demonstrate the necessary capabilities to follow a preliminary/qualified AM procedure specification.

For the procedure, part and material qualification or production, the operator should be assessed based on the practical qualification/approval tests in accordance with the requirements of the procedure for material approval and/or part approval tests and as specified in the manufacturer's operating procedures.

The range of documentation for the operator should include the combination of process, feedstock material and machine, refer to Table 38.

Table 38
Documentation for AM Machine Operators Qualification

Item	Detail
Metal AM process	Change of process should be requalified.
Feedstock material group	Change of material group should be requalified.
Machine	Change of machine should be requalified.

The written quality procedures and operator performance/qualification records should be documented and managed by the manufacturer in their quality management system and available to the Class Society, as requested.

3 Approval Tests for Additive Manufacturer

A procedure should be qualified to produce AM final material/part. General requirements in subsection 5.5 are applicable to the AM facility/manufacturer/materials qualification. Additional procedure qualification requirements for the approval of additive manufacturers are included in this Annex with AM final materials properties in accordance with subsection 3.3 for final material specification.

AMPS and qualification records should be established by specification and documentation control to demonstrate that the material requirements meet the technical/design requirements in accordance with Class Rules, industry standards, or the designer/OEM specification.

Sufficient test coupons for the final delivered condition should be prepared for all qualification tests. Repeatability should be demonstrated and agreed to by the Class Society, refer to Table 39.

Table 39
Approval Tests for Additive Manufacturer

No.	Test coupons
1	Test coupons with or without a sacrificial/actual part should be built using standard qualification builds and should achieve the required material properties confirmed by approval tests.
2	For PBF or applicable BJT processes, test samples for approval tests should be evenly distributed on the overall build platform and represent a worst-case scenario for samples during production.
3	For DED processes, test samples should represent the intended section thickness such as thin and thick test blocks.
4	Test samples should represent the intended AM part and applications or worst- case scenario, such as edge of the build platform with fast cooling rate.
5	The relationship between input variables and output results should be established for the specific combination of parameters by qualification records for manufacturer approval.
6	Test quantities could be specially considered and agreed by the Class Society, if the AM facility/manufacturer can provide historical test results for the technically same combination of machine, feedstock, procedure, and final material of the final delivered condition.

If part approval and facility approval are carried out concurrently, the procedure qualification for part approval and facility approval should be combined in one build batch. The test methods, quantities, and acceptance criteria for approval tests should meet the requirements, whichever is more stringent.

Approval tests, test methods, and acceptance criteria should be related to the material specification of the final delivered condition and agreed to before testing samples are prepared. Test coupons should represent the performance of the overall build envelope. Alternative tests may be specially considered and agreed to by the Class Society.

Unless otherwise agreed, the following approval tests should be carried out and test results should be reported using the AM built test coupons in accordance with 7.3 for inspection and testing and included in the qualification records, refer to Table 40.

Table 40
Documentation for Approval Tests and Test Results

Types of tests	Recorded items in test results
Visual inspection:	Sample ID and results
Dimension inspection:	Sample ID and results
Surface flaw inspection:	Sample ID and results
Embedded flaw inspection:	Sample ID and results
Tensile tests:	3 in Z (refer to ASME PTB-13:2021) and 3 in X/Y including sample ID, sample orientation, sample size and test results including yield strength, tension strength, failure type and location
Charpy tests for materials with ductile- to-brittle transition (if applicable):	3 sets of Charpy impact test including sample ID, sample orientation, sample size and test results
Bend tests for wire arc DED processes (if applicable):	2 in the Z and 2 in X/Y direction
Microstructure examination:	Sample ID, part thickness at the section plane, section plane angle relative to build platform, magnification, and results
Chemical analysis:	Sample ID and results
3 fusion density tests for powder feedstock:	Sample ID and results
Residualstressmeasurement(if applicable and required):	Sample ID and results
Other tests:	Other tests may be performed depending on material grade or intended application, such as fatigue test, corrosion test or weldability test.

Notes:
1. Additional Charpy tests may be requested by the purchase specification at a different test temperature, such as 20 °C below the specified temperature, at the specified temperature, or 20 °C above the specified temperature.
2. Test direction for tensile, Charpy and bend tests could refer to Annex C of AWS D20.1

4 Survey

4.1 Initial Survey

The manufacturer should be audited by the attending Surveyor. The initial survey of additive manufacturing facilities for production should include:

- Witness of the additive manufacturing process
- Survey of manufacturing control for repeatability
- Evaluation of the quality management system
- Document control for the manufacturing procedure, specification and quality control for sampling, testing, reporting
- Incoming control for feedstock materials
- Outgoing control for the AM build final parts or materials etc.

4.2 Witness of Approval Tests

The approval tests should be witnessed by the attending Surveyor.

4.3 Annual Verification

The annual verification should be carried out by the attending Surveyor. The annual verification should include a plan to demonstrate the essential parameters are followed. During the annual verification, full or partial approval tests could be requested based on the performance of the annual production record.

5 Information to be Submitted for Approval by the Class Society

The following documents in Table 41 should be submitted for AM facility approval, for review and survey by the Class Society:

Table 41
Information to be Submitted for Additive Manufacturer Approval

No.	Documentation items
1	Quality management system
2	Additive manufacturing capability
3	Machine and operator qualification record, if requested by the Class Society
4	Build volume model or test plan for standard qualification build
5	Feedstock procurement specification and data sheet with testing results
6	AM procedure specification including pre-build, build, and post-build
7	Procedure specification qualification records linked to the material grade
8	Destructive and non-destructive testing standard and testing report
9	Material specification for final delivered condition

6 Range of Approval

The range of approval for the AM facility/manufacturer should be the combination of the following qualified specifications including any revisions.

i) Machine
ii) Feedstock material approved or qualified in accordance with Annex 1
iii) AM procedure specification including pre-build, build, and post-build
iv) Materials specification of final delivered condition
v) Supplementary tests can be carried out and recorded to expand the range of approval. Requalification should be carried out if there is any quality concern for the delivered AM part or material.

Notes:

1. For AM Level 1, 2 and 3, all test results should meet the minimum design requirements.
2. Unless otherwise agreed, powder and wire feedstock should be type approved in accordance with Annex 1. The manufacturer can procure approved feedstock from different approved suppliers/brands. The approved feedstock type and grade should be documented for each specific supplier.
3. Unless otherwise agreed, the approval tests in Annex 2 should be carried out for Approval for Manufacturer.
4. For AM Level 2 and 3, each material grade should be qualified and approved. For AM Level 1, a family of materials may be qualified and approved with the support of a risk analysis and/or physics simulation, which could be specially considered and agreed to by the Class Society. The material group could be categorized to:
   - A: Unalloyed, low-alloyed steels and high alloyed ferritic steels
   - B: Austenitic, martensitic and precipitation hardening steels
   - C: Titanium and Titanium alloys, Niobium, Zirconium and other reactive materials
   - D: Aluminum alloys

- E: Magnesium alloys
- F: Nickel alloys, Cobalt alloys
- G: Other than above, such as Copper alloys, Ceramic

5. The post-build heat treatment condition should be recorded during the qualification and the same heat treatment condition should be followed during production. Typical heat treatment conditions for AM final parts/materials include:
   - A: As build
   - SR: Stress Relief
   - SA: Solution Annealed
   - HIP: Hot Isostatic Pressed
   - Other: Other Delivery Conditions

ANNEX 3

APPROVAL FOR ADDITIVE MANUFACTURING REPAIR FACILITY

1 General

Annex 3 is to apply the additive manufacturing process to repair damaged parts back to the approved design.

If the parts are class items, the repair facility or repair process should be approved by the Class Society. If the parts are not class items, the repair process should be qualified by the repair facility and the repair facility may be recognized by the purchaser or approved by the Class Society.

Approval for a repair facility involves a documentation review, an audit of the facility and the witness of approval tests. Unless otherwise agreed, the approval is valid for a maximum of 5 years subject to annual verification and/or endorsement by the attending Surveyor. An additional audit may be requested.

2 Approval Application

Approval should be requested by the client, along with supporting information and a detailed inspection and test plan (ITP), refer to Table 42.

Table 42
Approval Application for Additive Manufacturing Repair Facility

No.	Item
1	An outline description of the repair facility including the quality management system, a facility description, details of the organization and quality control responsibilities
2	Additive manufacturing repair capability
3	Programme of inspection and evaluation of damaged parts prior to repair
4	Alistofdocumentedrepairfacility'srepairprocedures,specifications, documentation and reports and any historical repair certificates or data
5	Documented inspection and testing plan for parts after repair for both qualification and production

3 Repair Procedure Specification and Qualification

3.1 General

The additive manufacturing procedure specification for repair should be prepared for each material and each part. Prior to conducting the repair procedure qualification tests, the repair procedure should be submitted and approved by the Class Society.

3.2 Repair Procedure Specification Approval

The repair procedure specification should be submitted to the Class Society for review and approval. A general description of the procedure should be prepared in accordance with subsection 5.3 and 5.5.

3.3 Approval Tests

Test coupons should represent the shape of the intended parts such as flat or cylinder test coupons, and the specific form of repair as allowed by the application standard for the intended use. Refer to Table 43, test coupons should be sufficient to complete the required approval tests. Based on the design requirements, the repair facility should select the applicable tests in Table 44. Test methods and test results should be in accordance with Table 45.

Unless otherwise agreed, the following approval tests in Table 43 should be carried out and test results should be reported in accordance with subsection 7.3 for inspection and testing and included in the qualification records.

Table 43
Documentation for Approval Tests and Test Results

Types of tests	Recorded items in test results
Visual inspection:	Sample ID and results
Dimension inspection:	Sample ID and results
Surface flaw inspection:	Sample ID and results
Embeddedflawinspection(if required):	Sample ID and results
3 tensile tests for interface cross-section (if required and applicable to the damage):	Sample ID, sample orientation, sample size and testresultsincludingyieldstrength,tension strength, failure type and location
1 set of Charpy impact test for interface cross-section, applicable to materials with ductile-to-brittle transition (if required and applicable to the damage):	Sample ID, sample orientation, sample size and test results
Bend tests for wire arc DED processes (if applicable):	2 in the Z and 2 in X/Y direction
Hardness test for interface cross- section and heat affected zone (HAZ) in substrate:	Sample ID, hardness values or hardness profile from AM build material to HAZ
Microstructureandmacrostructure examination (if required):	Sample ID, part thickness at the section plane, section plane angle relative to build platform, magnification, and results
Chemical analysis:	Sample ID, and results

Table 44
Approval Tests for Additive Manufacturing Repair Process

Material	Test items (as listed in Table 45)
Structural Steels	(1) (2) (3) (4) (5)
Nonferrous Metals for Structural Use	(1) (2) (3) (4) (5)
Corrosion Resistant Layer	(2) (4) (6) (7)
Wear-resisting Layer	(1) (3) (4) (5) (7)
Other material or other application	Accordingtothetechnicaldesign requirements, such as (6) or (9)

Table 45 Test Methods

Test Type		Sampling and Test Process	Acceptance Criteria for Test Results
(1)	Tensile Test (Room and High Temperature)	Refer to URs, Rules or relevant internationally or nationally recognized standards and this Annex 3/3.3	The minimum tensile strength should meet the design technical requirements and not to be lower than the base metal value
(2)	Bending Test		The bent surface of the specimen is not to reveal any crack exceeding 3 mm
(3)	Impact Test		Meet the base metal requirements, or design technical requirements
(4)	Hardness Test		The repair layer is to meet the design technical requirements, andthe heat affected zone and base metal are to meet the recognized standards
(5)	Macro Section Test		Well fused, no defect
(6)	CorrosionTest,if required		Meet the design technical requirements
(7)	Chemical Composition		Meet the design technical requirements
(8)	Microstructure		Meet the design technical requirements
(9)	Fatigue Test, if required		Meet the design technical requirements

4 Survey

4.1 Initial Survey

The manufacturer should be audited by the attending Surveyor. The initial survey of additive manufacturing repair facilities should include:

- Witness of the additive manufacturing repair process
- Survey of repair control for agreed repeatability
- Evaluation of the quality management system, document control for repair procedure, specification and quality control for sampling, testing, reporting
- Incoming control for feedstock
- Inspection and testing procedure of damaged traditionally manufactured parts
- Outgoing inspection and testing procedure for the final repair parts through AM process etc.

4.2 Witness of Approval Tests

The approval tests should be witnessed by the attending Surveyor.

4.3 Annual Survey

The annual survey should be carried out by the attending Surveyor. The annual survey should include a plan to demonstrate the essential parameters are followed by production of a test coupon. During the annual survey, full or partial approval tests could be requested based on the performance of the annual production/repair record.

5 Information to be Submitted for Approval by the Class Society

The following items in Table 46 should be submitted to the Class Society:

Table 46
Information to be Submitted for Additive Manufacturing Repair Facility Approval

No.	Documentation items
1	Documentation of the damaged part including the original dimensions and material grade for substrate, allowed wastage, method of defect excavation and verification of defect removal.
2	Audit report for the repair facility by the Class Society
3	Operator qualifications record
4	AM build material specification and documentation
5	AM repair procedure specification
6	Types of approval tests, test standards and test results in Annex 3/3.3
7	Surveyor's report of the witness of the repair procedure qualification approval tests
8	Qualification records with a certifying statement acknowledging the validity of the data and certifying the qualification tests and test results
9	Agreed plan for nondestructive testing during production
10	Agreed plan for in-service survey

6 Range of Approval

For repair of a damaged metallic part, a repair procedure specific approval letter should be issued to the repair facility by the Class Society, refer to Table 47.

Table 47
Range of Approval for Additive Manufacturing Repair Facility

No.	Items to be included in approval letter
1	Qualified feedstock linked to feedstock supplier
2	Qualified procedure(s) for repair
3	Compatible substrate material grade(s)
4	Applicable range of part size or section thickness

In addition, the approved AM repair procedure may be applied to other application scopes provided supplementary tests are carried out to expand the range of approval.