DNV·GL

CLASS PROGRAMME

Type approval

DNVGL-CP-0291 Edition June 2019

Additive manufacturing feedstock

DNV GL AS

FOREWORD

DNV GL class programmes contain procedural and technical requirements including acceptance criteria for obtaining and retaining certificates for objects and organisations related to classification.

Any comments may be sent by e-mail to *rules@dnvgl.com*

CHANGES – CURRENT

This is a new document.

CONTENTS

SECTION 1 GENERAL

1 Objective

The objective of this class programme (CP) is to give a description of the type approval (TA) scheme for feedstock intended for additive manufacturing (AM).

The general requirements for obtaining DNV GL type approval certificate are given in DNVGL-CP-0338.

2 Scope

This class programme specifies the requirements the manufacturer shall comply with in order to obtain, maintain and renew the Society's TA certificate for manufacturing of feedstock, intended for products manufactured by additive manufacturing, see DNVGL-CP-0267.

3 Application

The document is applicable for feedstock for additive manufacturing and for manufacturers of feedstock.

It covers in particular feedstock for:

- normal, high and extra high strength steels
- boiler and pressure vessel steels
- steels for low temperature service
- austenitic stainless steels
- duplex steels
- aluminium alloys
- copper alloys
- nickel and nickel alloys
- titanium alloys

Feedstock types covered by this class programme are given as follows:

- metal powder feedstocks, produced by air atomization or inert gas atomization method. Qualification programme for qualification of feedstock manufactured by other processes like plasma atomization, centrifugal atomization, water atomization shall be agreed
- wire feedstock, typically manufactured by the same process as for welding wire.

Other types of feedstock may be approved upon agreement.

4 References

Applicable reference standards are given in Table 1.

Table 1 Reference standards

Document code	*Title*
ASTM/ISO 52921	*Standard Terminology for Additive Manufacturing*
ASTM B213	*Standard Test Methods for Flow Rate of Metal Powders Using the Hall Flowmeter Funnel*
ASTM B417	*Standard Test Method for Apparent Density of Non-Free-Flowing Metal Powders Using the Carney Funnel*
ASTM B527	*Standard Test Method for Tap Density of Metal Powders and Compounds*

Document code	Title
ASTM B822	*Standard Test Method for Particle Size Distribution of Metal Powders and Related Compounds by Light Scattering*
ASTM C1444	*Standard Test Method for Measuring the Angle of Repose of Free-Flowing Mold Powders*
ASTM E112	*Standard Test Methods for Determining Average Grain Size*
ASTM E1409	*Standard Test Method for Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by Inert Gas Fusion*
ASTM E1941	*Standard Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys by Combustion Analysis*
ASTM F3049	*Standard Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes*
ASTM G48	*Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution*
DNVGL-CG-0197	*Additive manufacturing - qualification and certification process for materials and components*
ISO 3651-2	*Determination of resistance to intergranular corrosion of stainless steels - Part 2: Ferritic,austenitic and ferritic-austenitic (duplex) stainless steels - Corrosion test in media containing sulfuric acid*

5 Definitions and abbreviations

5.1 Overview of additive manufacturing processes and related definitions

DNVGL-CG-0197 gives the overview of AM process and methods.

5.2 Abbreviations

Table 2 Abbreviations

Abbreviation	Description
A	minimum tensile elongation required by the material specification [%]
AM	additive manufacturing
BPT	blown powder technology additive manufacturing
CP	class programme
d	maximum former diameter [mm]
F-AM	feedstock for additive manufacturing
HPHT	high pressure heat treatment
HIP	hot isostatic pressing
ID	inner diameter [mm]

Abbreviation	*Description*
MPIF	Metal Powder Industries Federation
MT	magnetic particle testing
NDT	non-destructive testing
OD	outer diameter [mm]
TA	type approval
P	beam power [W]
PBF-LB	powder bed fusion for laser beam melting
PBF-EB	powder bed fusion for electron beam melting
PT	liquid penetrant testing
Q	heat input [kJ/mm]
RT	radiographic testing
t_s	thickness of the bend test specimen [mm]
UT	ultrasonic testing
v	travel speed [mm/min]
WAAM	wire arc additive manufacturing

6 Definitions and terminology related to additive manufacturing

6.1 Material grade designations

6.1.1 Grade designation related to delivery condition

The DNV GL material grade designations related to feedstock for AM products intended for different delivery conditions are defined as follows:

— F-AM-A: as printed
— F-AM-SR: stress relieve heat treated
— F-AM-SA: solution annealed (e.g. for homogenization)
— F-AM-HIP: HIP (hot isostatic pressed)
— F-AM-HPHT: HIP (high pressure heat treatment)
— F-AM-X: other delivery conditions.

6.1.2 Grade designation related to additive manufacturing technique

The grade designation related to AM technology are defined as follows:

— PBF-LB: powder bed fusion for laser beam melting
— PBF-EB: powder bed fusion for electron beam melting
— BPT: blown powder technology
— WAAM: wire arc additive manufacturing
— other methods: subject to agreement.

6.1.3 Grade designation corresponding to non-additive manufacturing grades

Grade designation shall correspond to those given in DNVGL-RU-SHIP Pt.2 Ch.2, e.g. grade VL C400U according to DNVGL-RU-SHIP Pt.2 Ch.2 Sec.8 Table 7.

Designations of grades qualified as low hydrogen feedstock will be appended with *-H5, -H10 or -H15* as applicable.

6.1.4 Grade designation examples

Table 3 illustrates examples of material grade designations.

Table 3 Grade designation examples

Example	*DNV GL grade*	*Feedstock for additive manufacturing*	*Delivery condition*	*AM technology*	*Corresponding grade in DNVGL-RU-SHIP Pt.2 Ch.2*	*Description*
VL F-AM-A-PBF-L-C400U	VL	F-AM	A	PBF-L	C400U	Feedstock for as-printed AM products of steel corresponding to grade VL C400U according to DNVGL-RU-SHIP Pt.2 Ch.2 Sec.8 Table 7, for manufacturing using the PBEL technique.
VL F-AM-SA-WAAM-C19Cr11Ni	VL	F-AM	SA	WAAM	C19Cr11Ni	Feedstock for solution annealed AM products of steel corresponding to grade VL C19Cr11Ni according to DNVGL-RU-SHIP Pt.2 Ch.2 Sec.8 Table 8, for manufacturing using the WAAM technique.

6.2 Standard terminology

Standard terminology on axis is given as per ASTM/ISO 52921 *Standard Terminology for Additive Manufacturing-Coordinate Systems and Test Methodologies*, see also Figure 1.

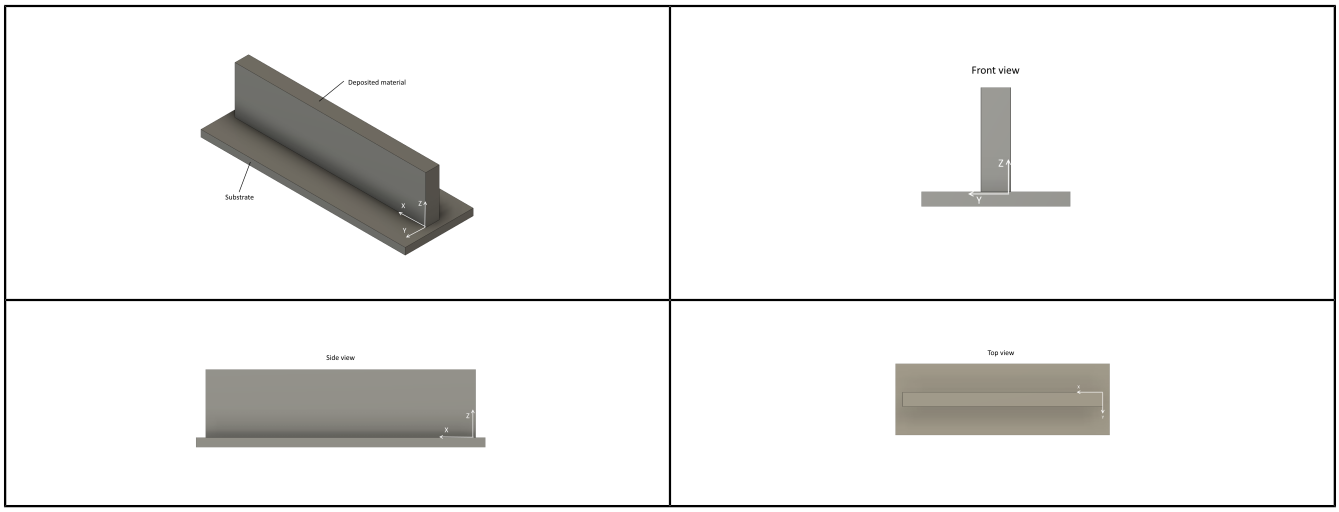

Figure 1 Visualization of adopted orientation naming system in AM products.

SECTION 2 TYPE APPROVAL

1 Type approval procedure

1.1 General

The general procedure and requirements for obtaining DNV GL type approval certificate is given in DNVGL-CP-0338.

1.2 Application for type approval

See DNVGL-CP-0338.

1.3 Documentation requirements

General requirements are given in DNVGL-CP-0338. Additional information required is listed below.

General manufacturer information:

- an outline of the organization's structure including quality control responsibilities
- manufacturing process description, visualized in flow chart(s) indicating all process steps
- a list of the manufacturer's written procedures for testing and inspection. The procedures need not to be submitted, but shall be available for review at the manufacturer's works upon request
- procedure for identification and traceability of feedstock products throughout the manufacturing process and until final packing, including also traceability of in-process test samples
- examples of manufacturer's test reports and product certificates
- documentation of surface roughness obtained for the AM product
- manufacturer's documentation and reports relevant for the type approval, signed by the manufacturer's staff in charge.

Information specific to in-process testing:

- quality control steps for the manufacturer's in-process testing
- typical records from the manufacturer's in-process testing.

Product/feedstock specifications with respect to:

- type of feedstock
- intended production process (e.g. PBF-LB, PBF-EB, BPT, WAAM, see Sec.1 [5.2])
- AM process parameters specified by the feedstock manufacturer
- procedures for storage (including humidity limits), handling, pre-conditioning and processing requirements (for proper use of feedstock and to control its properties)
- shelf life for unopened feedstock powder and also for the opened powder
- required tests to be carried out at the AM manufacturer, if relevant
- recommendations for use of recycled (reused) feedstock
- cleanliness of environment, quality of vacuum or protective gas
- recommended parameters for AM processing, such as layer height, laser power etc.
- health, safety and environmental issues
- for each specific feedstock/process combination, the typical range of properties for AM parts (such as gas permeability, tensile strength etc.). See also DNVGL-CG-0197 Sec.2
- documentation related to the feedstock specification and characteristics for PBF-LB, PBF-EB, BPT, including:
  - powder chemistry/composition/size distribution

- uniformity/homogeneity
- morphology characterization
- flow characteristics
- density
- particle agglomeration
- surface area
- interparticle friction
- flow and packing
- internal microstructure
- contamination
- recommended beam parameters: power, speed and dwell

- documentation related to the feedstock specification and characteristics for WAAM, including:
  - wire chemistry/composition
  - wire diameter(s).

1.4 Initial assessment

General requirements are given in DNVGL-CP-0338. Additional procedural requirements specific for this CP are given as follows:

- initial survey of product and production facilities including witnessing of feedstock manufacturing process
- survey of manufacturer's process control to ensure repeatability of the AM feedstock quality
- assessment of quality control related to sampling and testing.

1.5 Type testing

General requirements are given in DNVGL-CP-0338. Additional requirements are given in Sec.3 and in the following.

If AM feedstock is manufactured at several factories of the same company, the complete series of approval tests shall at least be carried out in one of the works. In the other factories, a reduced test programme, at least equivalent to annual tests and including hydrogen testing for low hydrogen type feedstock, may be permitted if the manufacturer can prove that materials and fabrication processes used are identical with those used at the works where complete series of approval tests are carried out. This requirement on reduced test programme is applicable to all manufacturers of filler products under licence (sister firms). However, the Society may require complete test-series when found necessary.

All testing shall be documented by test records. Qualifications of test personel including personnel for NDT shall be documented to the satisfaction of the surveyor.

1.6 Assessment of documentation

See DNVGL-CP-0338.

1.7 Validity of type approval certificate

See DNVGL-CP-0338. The certificate is valid for 5 years provided compliance with the requirements given in this document and DNVGL-CP-0338.

1.8 Documenting compliance with the type approval by marking of the product

See DNVGL-CP-0338.

2 Retention of type approval certificate

2.1 General

General requirements are given in DNVGL-CP-0338. Additional requirements are given in the following.

2.2 Periodical assessments and testing

General requirements for periodical assessment and testing are given in DNVGL-CP-0338. Following additional requirements are applicable for annual tests:

— samples for annual test of the approved feedstock shall be selected by the Society
— the samples shall be tested as detailed in relevant sections of this document
— the testing shall be witnessed by the surveyor.

One test assembly shall be printed for each type of feedstock. Testing shall comply with requirements of Sec.3.

2.3 Modifications of the product

Any modification of the product shall be handled according to requirements given in DNVGL-CP-0338. Additional requirements are given in the following.

Upgrading or up-rating of AM feedstock will be considered only at the manufacturer's request, preferably at the time of annual testing. For this purpose, type tests are required in addition to the annual approval tests.

3 Renewal of type approval certificate

See DNVGL-CP-0338.

4 Suspension and withdrawal of type approval certificate

See DNVGL-CP-0338.

SECTION 3 TYPE TESTING

1 General

General requirements are given in Sec.2 [1.5].

The AM feedstock specification for type testing shall comply with the specification listed by an end user which shall be the basis for the feedstock material grade. All additives intentionally added, e.g. colouring agents, are considered essential parameters. All essential variables listed by the feedstock manufacturer and AM printer manufacturer shall be taken into account, like amperage, voltage, travel speed, laser power etc. and shall be within the range recommended by the printer manufacturer for normal, good AM practice. For WAAM, welding parameters recommended by the wire manufacture shall be taken into account.

All AM tests may either be performed by the manufacturer or by other party appointed by the manufacturer and recognised by the Society.

The tests prescribed shall be carried out for each type and grade of feedstock for which approval is requested.

The Society may give additional requirements or request additional tests considered necessary.

All test assemblies shall be prepared under the supervision of the surveyor, and all testing shall be carried out in his/her presence

Guidance note:

The test samples for qualification of the feedstock may be printed on any suitable printer model, i.e. the printer model is not limiting the approval.

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The feedstock should preferably result in additive manufactured materials, as represented by the test block for type testing, with composition and properties similar to corresponding materials (e.g. castings, forgings, etc.) given by DNVGL-RU-SHIP Pt.2 Ch.2. Other materials need special consideration. Unless otherwise agreed, the corresponding requirements (e.g. mechanical properties) shall be met.

Where feedstock shall be qualified for printing in different positions, each position shall be qualified separately. For definition of welding positions, see DNVGL-RU-SHIP Pt.2 Ch.4 Sec.5 [6.2.7].

Test specimens extracted from test blocks shall be made under controlled conditions. Unless otherwise agreed, longitudinal axis of the test specimens shall be positioned at 1/4 thickness from the as-printed surface, except for radial specimens and for directly printed specimens.

After being printed, the test assemblies shall not be subjected to other heat treatments than those given by feedstock manufacturer's and AM manufacturer's specification.

It is recommended that test blocks are subjected to suitable non-destructive testing prior to type testing, to ascertain whether there are unacceptable defects in the material. See also [3.10].

2 Preparation of test blocks and sampling of test specimens

Test blocks and printed test specimens shall be manufactured using parameters representative for the typical process. Specimens shall be prepared according to one of the following options (, other test blocks may be agreed):

— test specimens printed directly as shown in Figure 1
— rectangular shape test blocks of sufficiently large dimensions for extraction of test specimens as indicated in Figure 1
— cylindrical shape test blocks with dimension ID 95 mm x OD 205 mm x height 400 mm, see Figure 2.

In case of multi-laser machines density specimens shall be prepared for each laser.

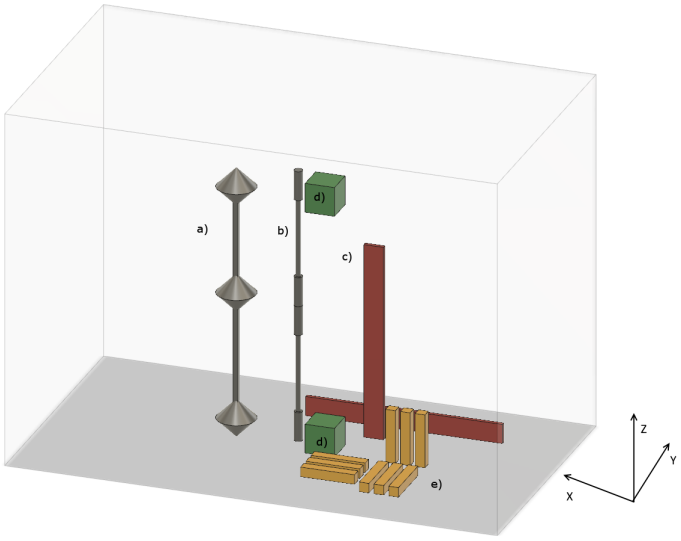

Figure 1 Printed test specimens, and rectangular test block configuration: a) feedstock recycling specimen; b) tensile test; c) bend specimen; d) density, micro, macro and hardness specimens; e) Charpy V-notch specimen

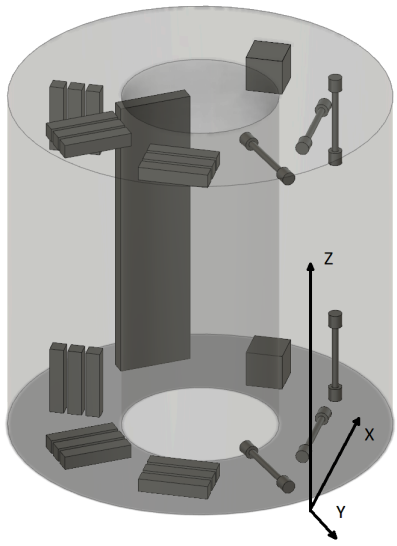

Figure 2 Cylindrical test block configuration

Selection of test block type is based on the applicable AM technique. Following requirements apply based on manufacturing technique:

— PBF-L and PBF-E: test specimens shall be printed as shown in Figure 1. Range of laser power shall be specified, and maximum heat input shall be used, see guidance note.

— BPT: cylindrical shape test block shall be prepared, unless otherwise agreed. Range of laser power shall be specified, and maximum heat input shall be used, see guidance note.

Guidance note:

Essential parameters directly influencing the heat input are typically:

— laser power
— laser spot size
— scanning speed
— hatch spacing
— powder layer thickness.

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— WAAM: two cylindrical shape test blocks shall be printed. Following additional requirements apply to this manufacturing technique:
  — range of printing parameters shall be specified, and one test block each for minimum and maximum heat input shall be prepared. Where qualification for several printing positions is requested, one test for each position suffices

Guidance note:

Formula for calculation of heat input:

$$Q = \frac{P \cdot 60}{\mathrm{v} \cdot 1000}$$

where

— Q: Heat input [kJ/mm]
— P: Beam power [W]
— v: Travel speed [mm/min].

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

  — height, width and overlap for each welding pass shall be measured and recorded, see Figure 3
  — layer pattern shall be recorded, e.g. see Figure 4.

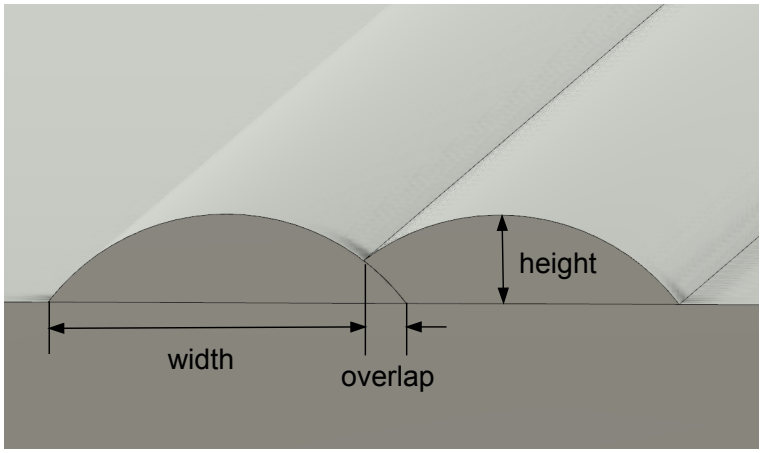

Figure 3 Measures for height, width and overlap for WAAM

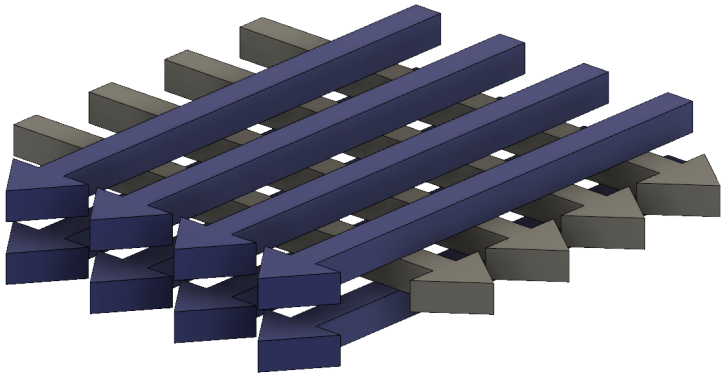

Figure 4 Layer pattern example.

3 Testing of powder and product

3.1 General

Test specimens and test methods referred to in this section are described in DNVGL-RU-SHIP Pt.2 Ch.1 Sec.3. The term"product" in the following refers to specimens prepared as per [2].

3.2 Visual examination of product

Visual examination shall be conducted and recorded according to relevant requirements set out in DNV GL rules for classification or as per agreed specification, with the following additional requirements:

— surfaces shall be adequately prepared for inspection
— surfaces shall not be hammered, peened or treated in any way which may obscure discontinuities
— examination shall be done for all applicable sides and areas.

3.3 Chemical composition of powder and product

Chemical composition shall be determined both for the feedstock and the AM test block, and shall comprise all the elements specified by DNV GL rules for classification for a similar non-AM material grade (e.g. C-Mn steel casting for steel castings for machinery, see DNVGL-RU-SHIP Pt.2 Ch.2 Sec.8 Table 6). The analyses shall also include all elements intentionally added, and those designated as residual elements.

For powder composition analysis, a recognised standard method shall be applied, e.g. ASTM E1409-13 (for O and N), ASTM E1941-10.

3.4 Density of powder and product

Density of the AM product shall be determined by microscopic analysis. Unless otherwise agreed, density specimen size shall be 40 mm x 40 mm x 40 mm or bigger. Specimens shall be tested for bottom and top position in the test block. In case of multi-laser machines the specimens shall be prepared and tested for each laser.

Density of the powder shall be measured, see ASTM B417 for apparent density and ASTM B527 for tap density.

3.5 Tensile testing of product

The following is required:

— tensile specimens shall be tested from each test block at x,y,z direction
— mechanical properties shall, unless otherwise agreed, comply with the relevant DNV GL rules for classification for similar non-AM materials.
— because of its influence on the test results, it shall be stated whether the surface condition of the tensile specimens is "as printed" (after final heat treatment, if applicable, and surface cleaning) or "machined".

3.6 Impact testing of product

The following is required for each AM test block:

— at least three sets of Charpy V-notch specimens shall be tested for x,y,x direction
— tests shall be carried out at three different temperatures, starting from 20°C below the specified temperature for that grade, at the specified temperature, and at 20°C above that temperature. However, testing is not required at temperatures higher than 20°C unless specially agreed
— for approval of grades for low temperature applications, test temperatures shall be agreed, see also e.g. DNVGL-CP-0243 and DNVGL-CP-0246
— the impact toughness requirements shall, unless otherwise agreed, fulfil the corresponding requirements given in DNV GL rules for classification at and above the test temperature specified by the rules
— in case no requirements for Charpy V-notch impact toughness are given and unless otherwise agreed, the requirements given in relevant specific approval programme (e.g. DNVGL-CP-0246) apply.

3.7 Bend testing of product

The following is required:

— at least two test specimens shall be tested
— the bend test specimens shall be bent on a mandrel with maximum diameter as given in the following formula:

$$d = \frac{\left(100 \cdot t_s\right)}{A} - t_s$$

— the bending angle shall be at least 180°
— after bending, the test specimens shall not reveal any open defects greater than 3 mm in any direction. Defects appearing at the corners of a test specimen during testing shall be investigated case by case.

3.8 Metallographic examination of product

The following is required:

— one specimen shall be sampled near the surface and one specimen at the mid-wall thickness of the test product and/or coupon
— high quality photomicrographs showing the microstructure at 100x and 400x/500x magnification shall be prepared with a brief description. The magnification shall be indicated on the micrographs by a line symbol, e.g. with length of 0.5 mm or 100 µm. Arrows or letters may be used to identify features referred to in the report
— the ferrite grain size shall be determined in accordance with ASTM E112 or equivalent standard, except for austenitic metals and steels supplied in quenched and tempered condition.

3.9 Corrosion testing of product

Where applicable, testing for resistance to corrosion shall be performed for all corrosion resistant materials. Surface finish of the test specimens shall be representative of the surface finish of the material/product in final supply condition.

For austenitic stainless steel:

— at least 2 specimens (preferably on material from tensile test specimens) shall be subjected to intercrystalline corrosion test in accordance with ISO 3651-2 or another recognized international standard. The bent specimens shall be free from cracks indicating the presence of intergranular attack.

For duplex stainless steel:

— corrosion test shall be carried out in accordance with ASTM G48 method A or an equivalent recognised international standard
— the test sample position shall be proposed and agreed. The test temperature shall be +20°C for type 22Cr duplex and +50°C for type 25Cr duplex. The exposure time shall be 24 hours
— no pitting on specimen surfaces is allowed when viewed at 20x magnification. The specimen mass loss shall be less than 4.0 g/m2 .

3.10 Non-destructive testing of product

Final NDT shall be carried out after final heat treatment and after machining if applicable. NDT timing shall follow relevant DNV GL rules and standards.

3.11 Hydrogen testing of product

Where relevant, low hydrogen feedstock shall be subjected to a hydrogen test. The test shall be carried out in accordance with DNVGL-CP-0069.

3.12 Powder recycling test

Powder intended for re-use shall be qualified according to adequate testing by the manufacturer. Re-use depends on the type of AM process. Qualification test and acceptance criteria shall be agreed with the Society.

3.13 Other mandatory tests

Following tests are mandatory:

— hardness testing (product)
— surface roughness testing (product)
— particle size distribution, ASTM B822 (powder, not relevant for WAAM)
— particle morphology, ASTM F3049 (powder, not relevant for WAAM)
— flow rate MPIF standard 03, ASTM B213 (powder, not relevant for WAAM)
— angle of repose, ASTM C1444 (powder, not relevant for WAAM).

Either the standards specified above, or equivalent standards shall be applied.

Documentation of any other tests carried out by the manufacturer, e.g. to customer purchase specification requirements, shall be provided.

3.14 Supplementary tests

The manufacturer may perform further tests which they assesses to be useful for qualification of the feedstock, such as:

— shear strength testing (product)
— compressive strength testing (product).

4 Re-testing

For re-testing, see DNVGL-RU-SHIP Pt.2 Ch.1 Sec.2 [3.8].

CHANGES – HISTORIC

There are currently no historical changes for this document.

About DNV GL

DNV GL is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. We provide classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas, power and renewables industries. We also provide certification, supply chain and data management services to customers across a wide range of industries. Operating in more than 100 countries, our experts are dedicated to helping customers make the world safer, smarter and greener.

SAFER, SMARTER, GREENER