DNV·GL

CLASS PROGRAMME

Approval of manufacturers

DNVGL-CP-0267 Edition July 2018

Additive manufacturing

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 provide a description on which the Society bases its approval of manufacturers intending to produce materials manufactured through additive manufacturing (AM) route in accordance with DNVGL-CG-0197 and DNVGL-RU-SHIP Pt.2 or other applicable standards provided by the Society.

2 Scope

The scope of this programme covers the approval process for manufacturers of additive manufacturing as referred in the Society's rules and standards. It includes the requirements for request for approval, documentation requirements, approval scope and limitations, approval testing, quality control and process verification. Description of general requirements, conditions and procedures related to the approval process for manufacturers are stated in DNVGL-CP-0346.

3 Application

This programme is applicable for the approval of manufacturers of AM materials/ products and sub-suppliers of materials and components adopting AM technologies.

4 Request for approval

As prerequisite for applying for approval of manufacturer according to this class program the manufacturer shall undertake a proof of concept that he has feasible technology and products as illustrated in the certification pathway in DNVGL-CG-0197 Sec.3 Figure 2.

When applying for approval of manufacturer (AoM), the manufacturer shall indicate the material types and grades that shall be covered by the approval, including manufacturing method, dimensions, weight and delivery conditions as per Sec.2 [3].

A list or table shall be provided, which shall include:

— type of products
— manufacturing method (as described in the manufacturing summary)
— range of applicable product sizes (dimensions and weight)
— applicable material types and grades
— delivery conditions
— reference to DNV GL rules for the applicable chemical composition, mechanical properties and heat treatment (if applicable), or to recognized standards (subject to agreement with the Society).

Further, the manufacturer shall consider for his request for approval the characteristics as listed in [5] approval scope and conditions.

5 Approval scope and conditions

The approval scope will be granted according to the product(s) and material grades subjected to approval testing (see Sec.3), as well as the correspondent process parameters and further determining conditions. I.e. limitations and conditions will be implicated according to the following:

— each material type, group or material grade:
    — carbon and carbon-manganese (C and C-Mn) steels
    — alloy steels
    — stainless steels

    - non-ferrous alloys
    - multi materials, etc.
    - non-metallic materials.
- each application area but not limited to:
    - for hull structures and equipment
    - for machinery components
    - for propellers, blades, hubs and bosses
    - for boilers, pressure vessels and piping systems
    - for liquefied gas cargo and process piping
    - for general applications, etc.
- AM equipment type and equipment manufacturer
- type of feedstock and feedstock manufacturer
- maximum dimensions
- maximum section/wall thickness
- heat treatment/post-processing.

Approval may be given for other materials and application areas not mentioned here. However such requests shall include a justification (e.g. classification requirement such as rule basis or approved drawing, etc.) for seeking approval.

Where AM products are produced by combining two or more items to form a composite/hybrid item, the requirements for manufacture approval of both/all shall be considered. Materials produced through other manufacturing methods shall be certified in accordance with relevant DNV GL class program for that manufacturing method.

For repair, reconditioning or re-manufacturing of products using AM, the manufacturer approval will be limited to that specific purpose.

Where applicable, the manufacturer's own product design facilities, pre-processing facilities/heat treatment/post processing facilities shall be evaluated and approved by the Society, either under this approval programme, or as an approved facility based on the relevant DNV GL class programme.

Where part of manufacturing activity(s) is/are performed by a sub supplier, the sub supplier shall be approved by the Society as "approved sub-supplier" in accordance with the relevant DNV GL class programme.

6 References

Table 1 List of references

Reference	*Title*
ASTM E112	Standard test methods for determining average grain size
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
DNVGL-CP-0351	Manufacture of heat treated products - heat treatment workshop
DNVGL-RU-SHIP Pt.2	Materials and welding
ISO 3369	Impermeable sintered metal materials and hardmetals - determination of density

Reference	*Title*
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
ISO 17296-3	Additive manufacturing - general principles
ISO/ASTM CD 52902 (ASTM F42)	Additive manufacturing -- test artefacts -- standard guideline for geometric capability assessment of additive manufacturing systems

See also App.A and App.B.

7 Abbreviations

Table 2 List of abbreviations

Abbreviation	*Description*
AM	additive manufacturing
AMF	additive manufacturing file format (AMF): an open standard for describing objects for additive manufacturing processes
AoM	approval of manufacturer
CP	class programme
HISC	hydrogen induced stress cracking
IR	infra-red
ISO	International Organization for Standardization
MT	magnetic particle test
NDT	non-destructive testing
PT	liquid penetrant test
QM	quality management
QT	quenched and tempered
STL	standard transformation language/stereo lithography: a file format used in 3D printing and modelling
UT	ultrasonic testing
XRCT	x-ray computed tomography

SECTION 2 DOCUMENTATION REQUIREMENTS

1 Manufacturing summary

Manufacturer shall submit documentation of the specific manufacturing process and related production records for products for which approval is requested. Documentation shall include manufacturer's material specifications related to the manufacturing process as described in this section.

2 Definition of the product to be manufactured

The product definition shall include the following elements:

— product geometry
— material specification
— final heat treatment condition
— tolerances
— surface texture
— repair methods (taking into account the testing categories defined in ISO 17296-3)
— weldability requirements
— acceptable imperfections or deviations
— process control information.

3 Requirements specification for additive manufacturing

The following documentation shall be submitted:

— existing product design specifications
— information regarding redevelopment or modification of existing product designs
— build orientation
— feature size (min. & max.)
— surface finish
— overhanging features.

4 Technology selection

Technology selection has a large impact on the part properties and quality. Therefore, conflicting aspects shall be thoroughly reviewed before selecting the right technology. Documentation shall be submitted for justification of chosen AM technology based on the following parameters:

— material selection
— size of the product
— complexity of the component
— quantity/production rate
— material deposition rate
— material properties
— resolution, post processing and finish.

5 Adaptation/design for additive manufacturing

The following documentation related to methodologies followed for design for AM shall be submitted:

— design requirements
— topology optimization

— concept generation
— preliminary design
— analysis
— design optimization
— validation
— final design

6 Feedstock

Feedstock shall be type approved.

If the feedstock is not type approved, at least the following documentation shall be submitted:

— type of feedstock (e.g. wire or powder)
— feedstock designation
— feedstock specification (e.g. particle size distribution, shape, size, flowability, aspect ratio, humidity, oxygen content, etc.)
— feedstock manufacturer
— feedstock manufacturing process
— requirements on pre-conditioning of feedstock
— required testing methods
— feedstock test certificates/reports
— test results for the additive manufactured material
— incoming control, storage and handling requirements and procedures
— process for re-usage of powder and procedure for verification/control parameters that the intended properties of the AM product are met
— health, safety and environmental issues
— for each specific feedstock/process combination the intended properties of product (such as gas permeability, tensile strength, etc.), including requirements of minimal values and information on feasible ranges of values. See also DNVGL-CG-0197 Sec.2.

For the consumable gases, at least the following documentation shall be submitted:

— gas type, composition and purity - gas manufacturer name (gas manufacturers facilities shall be ISO 9001 certified, or equivalent)
— gas handling facilities and its control and monitoring procedures.

7 Pre-processing and software control

The following documentation shall be submitted:

— details of 3D model received/prepared
— procedures for checking the quality of the 3D model and suitability for AM (e.g. inner surfaces, overhanging features)
— details of STL/AMF file and pre-processing software used
— procedures for quality check of STL/AMF file (e.g. magic software)
— details of rescaling, slicing, sub-division, hatch strategy, simulation model, boundary conditions
— identifying and repairing any problems and documentation of this procedure
— methods followed for positioning the part in the optimum orientation, adding fixtures, supports or other required geometry. The build orientation may follow the rules given in ISO/ASTM 52921
— approaches for integration of topology optimization with design for additive tools, lattice structures, geometric compensation approaches, optimization of input file, slicing and build orientation for achieving part tolerances as well as minimizing and optimal removal of support structures
— details of input file format per manufacturers' file format

— method for exporting the complete data in a suitable file format
— detail of software version and IP rights for the design to be printed
— methods for data encryption, compression and other cyber security issues.

8 Additive manufacturing machine/3D printing

— facility description, ambient conditions, climate control and any other relevant information
— specifications, capabilities and limitations of the AM machine (e.g. model number, software and firmware version)
— set parameters for AM machine and variable parameters which operator can control
— details of accreditation of AM machine
— operator qualification
— details of data sensing and logging-procedures to input file version verification, trace file revisions and machine logging
— automated part serialization and identification ensuring full traceability
— report generation of control data
— AM machine preparation and raw materials verification
— loading and retrieval of build data
— optimized process variables (laser power, scan speed, height and gap of layer, respectively height and width, overlap rate building direction, printing strategy including number and spacing of parts, etc.) and their control range
— scan and deposition strategies and methods to monitor these
— sieving type and mesh size
— details of gases used during the process, flow rate
— preheating of feedstock.

9 Process monitoring

Process monitoring routines as per Sec.4 [2] shall be submitted.

10 Post-processing

The following documentation shall be submitted:

— waiting time for the object on the machine's platform after completion of printing operation
— machining or other surface finishing operations
— methods for taking out the object from the machine's platform
— removal of powder particles in internal hollow sections
— cleaning of the object
— methods for removal of support from the product
— details of any post processing heat treatment.
— machining or other surface finishing operations, such as treatment with abrasive media or shot peening, and related requirements
— density achieved, as well as methods how this is verified
— process for cleaning the AM machine after printing.

11 Post-build hot isostatic pressing treatment (if applicable)

The following documentation shall be submitted:

— type of equipment and dimensions
— details of container material, geometry and dimensions

— container filling and outgassing
— HIP process parameters
  — the gas used
  — gas pressure
  — temperature ramp-up
  — pre-set soak time
  — depressurization
  — cooling down
— container removal
— records of hot isostatic pressing.

12 Heat treatment (if applicable)

When heat treatment is required, heat treatment facility shall be approved according to DNVGL-CP-0351. The following documentation shall be submitted for approval:

— type of furnace and dimensions
— heating source
— sketch indicating the positions of thermocouples
— working zone dimension and sketch of working zone
— accuracy and calibration status of temperature control devices
— furnace uniformity test report
— furnace loading plan and procedure
— heat treatment procedures, specifying temperatures and holding times, and where applicable, information about heating and cooling rates, quenching medium and cooling medium after tempering
— records of heat treatment
— any re-heat treatment procedure to be given, if applicable
— method of cleaning after heat treatment.

13 Test facilities and procedures

The following shall be submitted:

— details and description of relevant in-house testing facilities and calibration details, test procedures and qualification of testing personnel
— visual inspection: relevant templates for recording, and a few records of previously performed visual inspections of same or similar products
— NDT procedures, equipment for NDT including calibration details, and qualification of personnel for NDT, acceptance criteria
— information about procedures for i testing routines, such as specimen preparations, micro/macrographic inspection of products, mechanical testing.

14 Test results and records

The final report shall contain the test details and results of all performed tests as per Sec.3 [1.1].

Following are the additional requirements for reporting:

— Sampling:
  — type of artefacts and test blocks and their dimensions
  — drawings and photos of the artefacts and test blocks showing the positions of the specimens.
— Chemical composition:

  - sampling practices and methods for chemical analysis
  - the chemical composition shall be reported in percentage by mass
  - specified limits and the measured content of all the required elements.
- Tensile test:
  - yield (or proof) stress, tensile strength, elongation and reduction of area.
- Charpy V-notch impact toughness test:
  - test piece location and orientation, test temperature and absorbed energy (average and single values).
- Bend test:
  - a summary of the testing parameters and test results.
- Metallographic examination:
  - the applied etching methods for the metallographic examination.
- Corrosion test:
  - reporting in the format required by the referenced test standard.
- Visual examination:
  - report for visual inspection, dimensional measurements and surface condition.
- Non-destructive testing:
  - detailed records of non-destructive testing with clear conclusions written by qualified personnel, giving the extent of testing, methods of testing, acceptance criteria, and qualification of the NDT operator.

15 Production control method

The following shall be submitted:

- proposal for testing during production as per Sec.4 [2.4]
- template for own certificate form.

SECTION 3 APPROVAL TESTING

1 Test products, testing scope and test plan

1.1 General

The test products shall be selected so that the intended approval scope as outlined in Sec.1 [3] is covered. The sampling, testing procedures and acceptance criteria shall comply with the relevant requirements of the DNV GL rules or an agreed international standard or an approved manufacturer's specification.

The requirements specifications depend on the specific application of the product, functional requirements and its criticality, previous experience of the manufacturer, availability of statistical data, etc. Specifications may also vary within one part (e.g. critical mass). Some intrinsic properties depend on the choice of material and the technology used. Relevant requirements and test procedures shall be agreed on during the AoM process, stipulated and adhered to.

Following main quality characteristics determine the types of testing:

— Feedstock:

  — bulk raw material requirements: such as powder particle size, morphology, surface and distribution, density (tap and apparent), flowability/pourability, ash content, and carbon content.

— AM product:

  — surface requirements: appearance, surface texture, and colour
  — geometric requirements: size, length and angle dimensions, dimensional tolerances, and geometrical tolerancing (deviations in shape and position)
  — mechanical requirements: hardness, tensile properties, impact toughness, fracture toughness, compressive strength, flexural strength, fatigue strength, creep, ageing, frictional coefficient, shear resistance, and crack extension
  — build material requirements: density and physical and physico-chemical properties, microstructure analyses, non-destructive testing, etc.

1.2 Extent of approval testing

For each selected material and delivery condition, testing shall be carried out on at least two separately printed products where the first product shall represent maximum size/dimension and second part should represent an average size/dimension of the product for which approval is requested.

Where the product's geometry and/or dimensions are not suitable for extraction of all required test specimens and required directions (x, y, z) additional test blocks have to be integrally printed with the product.

Test blocks, test samples and test specimens shall be taken out in final delivery condition and shall not be subjected to any separate heat treatment.

Unless specified in the rules, specimen positions may be proposed by the manufacturer.

1.3 Test artifact

Measurements and observations made on the test artifact shall used to assess the performance of an AM system. The primary characterization of the AM system obtained by building and measuring a test artifact is via geometric accuracy and surface roughness of the test artifact. The test artifact described in ISO/ ASTM CD 52902 (ASTM F42) or similar standard may be used. The test artifact shall be built using the AM system used for the approval. All pertinent process parameters and machine settings used in building the test artifact should be documented. The test artifact is removed from the AM system and is measured by suitable methods for various (geometric) characteristics. The measured values (and deviations from nominal or specified values) and non-measured observed features provide an indication of the AM system's performance.

1.4 Test plan

The manufacturer shall prepare a detailed inspection and test plan (a formal document, dated and with version number) in accordance with [2] and submit to the Society in accordance with the DNV GL approval of manufacturer scheme (see DNVGL-CP-0346).

The test plan shall be specific to the tests that shall be performed. It shall describe all activities and tasks, even if these are entirely based on or taken from existing documents.

Depending on the test method, testing can be considered for the artifact, the test blocks and/or the product itself.

The test plan has to be accepted by the Society before manufacturing of the products.

2 Typical testing requirements

Test methods and their acceptance criteria shall be stated in the specification and to be agreed prior to testing preperation. Number of specimens, specimen orientation (e.g. x, y, z direction) shall be proposed and agreed in advance. The following tests are typically performed for metallic materials, for non-metallic [2.14] is applicable.

2.1 Chemical composition

Chemical composition shall be determined both by heat and by product analysis and shall comprise all the elements required by relevant DNV GL rules. The analyses shall include any other elements intentionally added or designated as residual elements.

2.2 Density

Density measurements shall be determined and reported according to the Archimedes principle (ISO 3369) or another similar standard.

2.3 Tensile testing

As minimum the following is required:

— Two tensile specimens shall be tested from each test block and each direction (x, y, z).
— The mechanical properties shall comply with the relevant DNV GL rules.

2.4 Impact testing

As minimum the following is required:

— At least three sets of Charpy V-notch specimens shall be tested for each direction (x, y, z).
— Tests shall be carried out at three different temperatures, starting from 20°C below the specified temperature for that material, at the specified temperature, and at 20°C above that temperature.
— For approval of grades for low temperature applications, tests shall also be carried out at the lowermost temperature for which approval is requested (if different from above. Will be specified on approval certificate).
— The impact toughness requirements shall fulfil the corresponding DNV GL rule requirements at and above the specified test temperature.
— In case no requirements for Charpy V-notch impact toughness are given and unless otherwise agreed, the requirements given in relevant specific approval program (e.g. DNVGL-CP-0246, DNVGL-CP-0247, etc.) applies.

2.5 Fatique testing

Where applicable, fatigue tests appropriate for the intended application shall be performed.

2.6 Bend testing

The following is required:

— At least two test specimens for each direction (x, y, z). The diameter of the mandrel shall be 3 x t (three times thickness of specimen).
— After bending, the test specimens shall not reveal any open defects in any direction greater than 3 mm.
— Defects appearing at the corners of a test specimen during testing shall be investigated case-by-case.

2.7 Metallographic examination

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.
— For ferritic steels, except for steels delivered in QT condition, the ferrite grain size shall be determined. See ASTM E112.

2.8 Corrosion testing

Where corrosion resistance is a relevant design parameter, corrosion testing is required - the surface of the test specimens shall be representative of the surface finish of the material/product in final supply condition - suitable test method for the applicable material and service conditions shall be selected and, unless otherwise agreed, testing shall be carried out in accordance with a recognised test standard.

— For testing of duplex stainless steel the following is required:
    — 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 22 Cr duplex and +50°C for type 25 Cr duplex. The exposure time shall be 24 hours.
    — No pitting on specimen (plate) surfaces is allowed when viewed at 20 x magnification. The specimen mass loss shall be less than 4.0 g/m^2 - austenitic stainless:
        — At least two 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.

2.9 Weldability testing

Where applicable, suitable weldability testing shall be performed.

2.10 Visual examination

The following is required:

- Visual examination shall be conducted and recorded according to the relevant rule requirement or as per agreed specification.
- The surfaces shall be adequately prepared for inspection.
- The 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, and the manufacturer shall ensure that lifting devices for handling and turning of the component are available.
- When relevant, visual examination shall include internal surfaces.
- Measurements shall be made for all applicable dimensions.
- Manufacturer shall present representative products used for approval purpose including reports for visual inspection, dimensional measurements and surface condition.

2.11 Non-destructive testing

The following is required:

- Each product shall be tested in accordance with the requirements of the relevant DNV GL rules.
- Detailed records of non-destructive testing with clear conclusions written by qualified personnel shall be submitted, giving the extent of testing, methods of testing, acceptance criteria, and qualification of the NDT operator shall be prepared.
- Inspection shall be done for all applicable sides and areas, and manufacturer shall ensure that lifting devices for handling and turning of the component are available.

Magnetic particle test (MT) shall be carried out for ferritic steels. Liquid penetrant test (PT) shall be applied for austenitic and duplex steels.

Ultrasonic testing (UT):

- where required by the rules UT shall be carried out.

Where required by the rules UT shall be carried out.

Any other applicable NDT shall be considered on case-by-case basis.

2.12 Residual stresses

Where applicable, the following is required:

- Residual stress shall be measured in each test product using a suitable method and standard.
- Acceptance criteria shall be proposed and agreed.
- Detailed records of residual stress measurement method with clear conclusions written by qualified personnel shall be submitted, giving the extent of testing, methods of testing, acceptance criteria, and qualification of the operator.

2.13 Other tests (if applicable)

Other applicable tests like HISC,surface treatment (carburizing, nitriding, etc.) which are carried out by the manufacturer, (e.g. customer purchase specification) should be provided.

2.14 Non-metallic materials

For non-metallic materials testing scope shall be agreed.

SECTION 4 QUALITY CONTROL AND PROCESS VERIFICATION

1 Quality control

1.1 General

Quality management (QM) system should be certified as complying with ISO 9001. If it is not certified, the required QM measures will be assessed by the Society. QM system shall meet the minimum requirements for a standard QM system. The QM system shall comprise the organizational structure, responsibilities, procedures, processes and resources for implementing the required quality, including process control and verification as per [2.1] to [2.4]. It mainly includes QM manuals, QM procedures and QM work instructions and shall at least cover all items stated in Sec.2.

1.2 Work instructions

All work instructions shall be under control by QM system and available to the relevant staff. The release of the work instructions shall fully follow the requirements according to the QM system, and a nominated person for maintenance is recommended.

1.3 Quality control

The quality control system shall among other include work instructions for control of incoming and outgoing goods and to in-process inspections.

The work instructions for in-process control shall ensure that all products will be checked for any damage and for compliance with all details to be listed in a material or product certificate, with clear scope of testing and acceptance criteria.

It shall ensure that test machine operators have adequate training and qualifications, and that interpretation of standards will be done by adequately trained personnel.

Procedures ensuring all measuring devices are calibrated before due date by accredited third parties shall be in place.

An internal calibration plan shall be available for all measuring devices. If calibration is conducted internally, it shall give the requirements for calibrated standard materials provided by a qualified third party. Additionally, the calibration instruction shall be available.

It is manufacture's responsibility to ensure that effective manufacture and process controls are implemented in production. Relevant procedures shall be in place for handling of non-conforming process or products, and include requirements for investigations to determine the cause and to establish countermeasures to prevent recurrence. Investigation reports to this effect shall be made available to Society on request.

1.4 Production and storage facilities

Capacity of production facilities needs to be considered in a way that the products intended for approval are manufactured in series of products. Production at research and development stage will usually not be accepted for AoM.

Maintenance records of all facilities shall be available and registered. Relocation or rebuilt of the facilities shall be recorded and the Society shall be informed. Society will assess if a re-approval is required.

Warehouse management system and work instructions shall be fully implemented. Stock rotation by first in first out system shall be practiced in the warehouse.

Storage shall be arranged in such a way that the identification of the materials, storage conditions and expiry dates are clearly visible. Materials whose duration of storage exceeds the expiry date shall be removed from the storage and blocked immediately for further application. The products shall be stored in accordance with the requirements from the material manufacturer or shall follow the Society's requirement.

2 Process control and verification

2.1 Process control information

Requirements for manufacturing process repeatability shall be identified, including reference to relevant standards or measurement methods for assessing repeatability, particularly for orders of multiple products or expected multiple orders of the same product.

Requirements for documenting process control information during manufacturing shall be identified. Required information as agreed upon between the manufacturer and the customer shall be documented during the manufacturing. A quality record for the AM product shall be retained by the manufacturer. The retention period for the quality record and the process control information shall be agreed upon between the customer and the manufacturer.

2.2 Guidance for process verification

Process monitoring can be used to identify the formation of defects and measure the thermal history of the material. Infra-red thermography, standard cameras, high speed video and pyrometry have all been used for in situ monitoring. Ultrasonic imaging, the Archimedes principle, X-ray computed tomography (XRCT) and neutron tomography have all been used as non-destructive means of quality control. The most common goal of defect detection is to determine the presence of porosity, inclusions, lack of fusion and incomplete penetration, although swelling and other defects can also be detected in this manner. To better understand solidification and thermal history, IR imaging, pyrometry and thermocouple measurement have been applied. Thermocouples can be used to effectively measure substrate temperature, but cannot be used to measure variation in product temperature or surface temperature, due to the nature of AM processes.

The location and orientation from which mechanical testing samples are taken from builds is important and should always be reported with results. Defects, such as porosity, that affect mechanical properties may influence the test results of as-fabricated material but can typically be eliminated or reduced by postprocessing.

When as-fabricated samples are tested, the geometry of test specimens, surface finish and type of measurement (global vs. extensometer) can all have a significant impact on resulting data. Comparisons of such data must therefore consider testing methodology.

Different machines may have very different thermal histories of material, which may manifest in as-fabricated mechanical properties as variance in hardening through coarsening or aging. Similarly, the details of any postprocessing heat treatments are equally important in determining mechanical properties.

Post-processing can improve mechanical properties, but must be applied correctly for a given starting microstructure. The starting microstructure can vary based on process parameters (which may impact solidification kinetics), which may cause need for non-standard postprocessing. Work must be done to characterize the range of microstructures that may form for a given material in a given machine. If a treatment can be applied across this variance in microstructure with acceptable results, then it can be applied uniformly. If not, then processing windows must be set to insure quality control on the material coming out of the machine.

2.3 Process monitoring

All additive manufacturing processes are computer-assisted. Therefore, it is fundamentally possible to record and statistically analyze important process-related data such as process temperature, process environmental conditions, time lapse and process speeds, beam parameter and emitted radiation, and other process-related parameters. The need for a scope of process monitoring depends on the required or anticipated reproducibility of the process and product quality for each application.

The process stability can also be monitored repeatedly at different intervals at a constant geometry.

Test specimens for process monitoring should be as representative as possible compared to the product. Complementary test specimens could be used to improve the testing of dimensional accuracy, reproduction accuracy and process stability.

2.4 Production control

The manufacturer shall prepare a proposal for production control which shall cover the following:

- it shall be suitable to ensure the required properties and features of the AM product
- critical areas shall be monitored
- artifacts and test blocks (including dimensions and specimen positions) which shall be subjected to destructive testing and NDT
- the applicable testing procedures.

2.5 Intermediate assessment

The intermediate assessment is aimed at ensuring in-progress quality and preventing occurrence of major deviations from the approved process, due to wrong or insufficient process control/ manufacturing process.

The Society may perform intermediate assessment in order to verify the correct application of the approved working procedures and the manufacturing process, appropriate process parameters and process control.

APPENDIX A GUIDANCE TABLE FOR RELEVANT TESTS

1 Guidance table for relevant tests

Relevant tests from the following guidance table shall be agreed and conducted.

Table 1 Guidance table

Requirement group	*Type of testing*	*Reference example standard*
Surface requirements	Appearance	ISO 16348
	Surface texture	ISO 1302 (specification)
		ISO 4288 (measurement)
Geometric requirements	Size, length and angle dimensions, dimensional tolerances	ISO 129-1
		ISO 286-1
		ISO 14405-1 (specification)
		ISO 1938-1 (measurement)
		ISO 2768-1
	Geometrical tolerancing (deviations in shape and position)	ISO 1101 (specification) + Isostatism
		ISO 2768-2
Mechanical requirements	Hardness	ISO 6507
	Tensile properties	ISO 6892-1
	Impact toughness	ISO 148-1
		ISO 148-2
	Compressive strength	ISO 4506
	Flexural strength	ISO 3327
	Fatigue strength	ISO 1099
		ISO 1143
	Creep	ISO 204
	Shear resistance	ISO 148-1
	Crack extension	ISO 22889
	Fracture toughness	ISO 12135
Physical properties	Density	ISO 3369
Non- destructive testing	Radiographic examination	ISO 5579
	Penetrant testing	ISO 3452-1
		ISO 3452-2
	Tomography	IEC 61675-1
		IEC 61675-2

Requirement group	*Type of testing*	*Reference example standard*
	Magnetic particle testing	ISO 9934-1
	Ultrasonic testing	BS EN 583-1
	Non-destructive testing of additive manufactured products	ISO/ASTM NP 52905

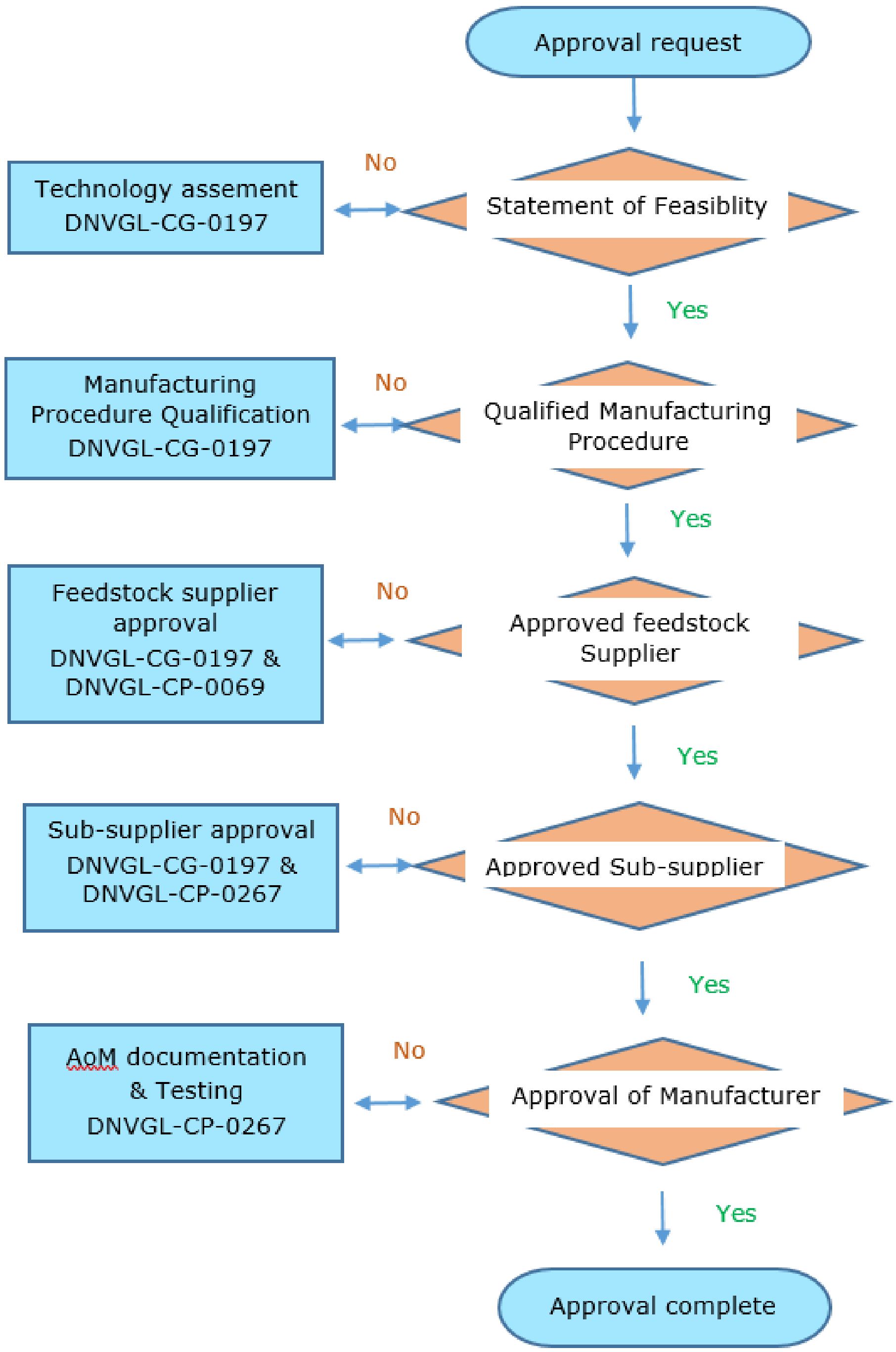
Guidance note:

Porosity, residual stress, test specimen orientation and thermal history are particularly important factors to consider when discussing mechanical test results of AM materials. Orientation of the build direction relative to the test direction, quality and production method of feedstock, void fraction of porosity, thermal history during processing and post-processing thermal history should all be included with any test results.

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

APPENDIX B ADDITIVE MANUFACTURING APPROVAL FLOWCHART

1 Outline of AoM process



CHANGES – HISTORIC

There are currently no historical changes for this document.

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