



**BUREAU  
VERITAS**

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## 1. Introduction

This document lists the available international standards and Classification Societies' guidelines issued for additive manufacturing. It provides an overview of the available standards and practices of testing methods

which may be used for the characterization of simple small constructs and full-scale demonstrators manufactured by WAAM.

## 2. Additive manufacturing

### 2.1. Standard guide and terminology

*Table 1: Additive manufacturing – List of standard guide and terminology*

Standard reference	Standard title
ASTM F2971-13	Standard practice for reporting data for test specimens prepared by Additive manufacturing
ASTM F3122-14	Standard guide for evaluating mechanical properties of metal materials made via Additive manufacturing processes
ISO/ASTM 52900-15	Standard terminology for Additive manufacturing – general principles – terminology
ISO/ASTM 52901-16	Standard guide for Additive manufacturing – general principles – requirements for purchased am parts
ISO/ASTM 52902-19	Additive manufacturing — test artifacts — geometric capability assessment of Additive manufacturing systems
ISO/ASTM 52910-18	Additive manufacturing — design — requirements, guidelines and recommendations
ISO/ASTM 52915-16	Specification for Additive manufacturing file format (AMF) Version 1.2
ISO/ASTM 52921-13	Standard terminology for Additive manufacturing – coordinate systems and test methodologies
ISO 17296-2:2015	Additive manufacturing — general principles — part 2: overview of process categories and feedstock
ISO 17296-3:2014	Additive manufacturing — general principles — part 3: main characteristics and corresponding test methods



Standard reference	Standard title
ISO 17296-4:2014	Additive manufacturing — general principles — part 4: overview of data processing

## 2.2. Classification Societies guidelines

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*Table 2: Additive manufacturing – List of Classification Societies guidelines*

Standard reference	Standard title
ABS Guidance Note: 2018	ABS guidance note on Additive manufacturing - September 2018
Bureau Veritas – NI 662	Additive manufacturing - guidelines for certification of product made using wire arc Additive manufacturing (WAAM) process
DNVGL-CG-0197:2017	Additive manufacturing - qualification and certification process for materials and components
DNVGL-CG-0267:2018	Additive manufacturing
DNVGL-CG-0291:2019	Additive manufacturing feedstock
LR - TWI Guidance Note:2017	Additive manufacturing - guidelines for certification of product made using wire arc Additive manufacturing (WAAM) process

## 3. Welding consumables

### 3.1. Wires and Gases

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*Table 3: Welding consumables – List of standards for wires and gases*

Standard reference	Standard title
AWS A5.01:2019	Welding and Brazing Consumables - Procurement of Filler Materials and Fluxes - 6th Edition
AWS A5.14:2018	Specification for Nickel and Nickel- Alloy Bare Welding Electrodes and Rods - 11th Edition
AWS A5.18:2017	Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding - 7th Edition
AWS A5.28:2005	Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding - 3rd Edition
AWS A5.32:2011	Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes - 2nd Edition
AWS A5.7:2007	Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes - 7th Edition
AWS A5.9:2017	Welding Consumables-Wire Electrodes, Strip Electrodes, Wires, and Rods for Arc Welding of Stainless and Heat Resisting Steels- Classification - 9th Edition
ISO 14175:2008	Welding consumables — Gases and gas mixtures for fusion welding and allied processes
ISO 14341:2010	Welding consumables — Wire electrodes and weld deposits for gas shielded metal arc welding of non-alloy and fine grain steels — Classification
ISO 14343:2017	Welding consumables — Wire electrodes, strip electrodes, wires and rods for arc welding of stainless and heat resisting steels — Classification
ISO 16834:2012	Welding consumables — Wire electrodes, wires, rods and deposits for gas shielded arc welding of high strength steels — Classification
ISO 18274:2010	Welding consumables — Solid wire electrodes, solid strip electrodes, solid wires and solid rods for fusion welding of nickel and nickel alloys — Classification
ISO 24373:2018	Welding consumables — Solid wires and rods for fusion welding of copper and copper alloys — Classification
ISO 17632:2015	Welding consumables — Tubular cored electrodes for gas shielded and non-gas shielded metal arc welding of non-alloy and fine grain steels — Classification
ISO 17633:2017	Welding consumables — Tubular cored electrodes for gas shielded and non-gas shielded metal arc welding of stainless and heat resisting steels — Classification



Standard reference	Standard title
ISO 17634:2015	Welding consumables — Tubular cored electrodes for gas shielded and non-gas shielded metal arc welding of creep resisting steels — Classification
ISO 18276:2017	Welding consumables — Tubular cored electrodes for gas shielded and non-gas shielded metal arc welding of high strength steels — Classification
ISO 12153:2011	Welding consumables — Tubular cored electrodes for gas shielded and non-gas shielded metal arc welding of nickel and nickel alloys — Classification
ISO 1071:2015	Welding consumables — Covered electrodes, wires, rods and tubular cored electrodes for fusion welding of cast iron — Classification
ISO 544:2003	Welding consumables — Technical delivery conditions for welding filler materials — Type of product, dimensions, tolerances and markings

### 3.2. Testing methods

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Table 4: Welding consumables – List of standards for test methods

Standard reference	Standard title
AWS A4.3:1993 (R2006)	Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding
AWS B4.0:2016	Standard Methods for Mechanical Testing of Welds - 8th Edition
ISO 15792-1:2000	Welding consumables — Test methods — Part 1: Test methods for all-weld metal test specimens in steel, nickel and nickel alloys
ISO 5178:2019	Destructive tests on welds in Metallic materials — Longitudinal tensile test on weld metal in fusion welded joints
ISO 9016:2012	Destructive tests on welds in Metallic materials — Impact tests — Test specimen location, notch orientation and examination

## 4. Metallic materials – Testing methods

## 4.1. Microscopic examination

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Table 5: Metallic materials – List of standards for microscopic examination

Standard reference	Standard title
ASTM E112-13	Standard test methods for determining average grain size
ISO 643:2019	Steels — micrographic determination of the apparent grain size
ISO 17639:2013	Destructive tests on welds in Metallic materials — Macroscopic and microscopic examination of welds

## 4.2. Tensile testing

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Table 6: Metallic materials – List of standards for tensile testing

Standard reference	Standard title
ASTM E1450-16	Standard test method for tension testing of structural alloys in liquid helium
ASTM E21-17	Standard test methods for elevated temperature tension tests of Metallic materials
ASTM E8/E8M-16	Standard test methods for tension testing of Metallic materials
ISO 19819:2004	Metallic materials — tensile testing in liquid helium
ISO 6892-1:2019	Metallic materials — tensile testing — part 1: method of test at room temperature
ISO 6892-2:2018	Metallic materials — tensile testing — part 2: method of test at elevated temperature

### 4.3. Impact testing

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Table 7: Metallic materials – List of standards for impact testing

Standard reference	Standard title
ASTM E23-18	Standard test methods for notched bar impact testing of Metallic materials
ISO 148-1:2016	Metallic materials — charpy pendulum impact test — part 1: test method

### 4.4. Hardness testing

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Table 8: Metallic materials – List of standards for hardness testing

Standard reference	Standard title
ASTM E10-18	Standard test method for brinell hardness of Metallic materials
ASTM E18-19	Standard test methods for rockwell hardness of Metallic materials
ASTM E384-17	Standard test method for microindentation hardness of materials
ISO 4545-1:2017	Metallic materials — knoop hardness test — part 1: test method
ISO 6506-1:2014	Metallic materials — brinell hardness test — part 1: test method
ISO 6507-1:2018	Metallic materials — vickers hardness test — part 1: test method
ISO 6508-1:2016	Metallic materials — rockwell hardness test — part 1: test method
ISO 9015-1:2011	Destructive tests on welds in Metallic materials — Hardness testing — Part 1: Hardness test on arc welded joints



#### 4.5. Fracture toughness testing

Table 9: Metallic materials – List of standards for fracture toughness testing

Standard reference	Standard title
ASTM 1820-20	Standard test method for measurement of fracture toughness
ASTM E647-15	Standard test method for measurement of fatigue crack growth rates
ISO 12108:2018	Metallic materials — fatigue testing — fatigue crack growth method
ISO 12135:2016	Metallic materials — unified method of test for the determination of quasistatic fracture toughness

#### 4.6. Corrosion testing

Table 10: Metallic materials – List of standards for corrosion testing

Standard reference	Standard title
ASTM G31-12	Standard guide for laboratory immersion corrosion testing of metals
ASTM G3-14(2019)	Standard Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing
ASTM G48-11	Standard test methods for pitting and crevice corrosion resistance of stainless steels and related alloys by use of ferric chloride solution
ASTM G71-81:2019	Standard Guide for Conducting and Evaluating Galvanic Corrosion Tests in Electrolytes
ISO 10271:2011	Dentistry — corrosion test methods for Metallic materials
ISO 17474:2012	Corrosion of metals and alloys — Conventions applicable to electrochemical measurements in corrosion testing



Standard reference	Standard title
ISO 17475:2005	Corrosion of metals and alloys — Electrochemical test methods — Guidelines for conducting potentiostatic and potentiodynamic polarization measurements
ISO 3651-1:1998	Determination of resistance to intergranular corrosion of stainless steels — part 1: austenitic and ferritic-austenitic (duplex) stainless steels — corrosion test in nitric acid medium by measurement of loss in mass (Huey test)
ISO 3651-2:1998	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 3651-3:1998	Determination of resistance to intergranular corrosion of stainless steels — part 3: corrosion test for low-Cr ferritic stainless steels

#### 4.7. Fatigue testing

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*Table 11: Metallic materials – List of standards for fatigue testing*

Standard reference	Standard title
ASTM E2368-10 (2017)	Standard practice for strain controlled thermomechanical fatigue testing
ASTM E466-15	Standard practice for conducting force controlled constant amplitude axial fatigue tests of Metallic materials
ASTM E606/E606M-19	Standard test method for strain-controlled fatigue testing
ISO 1099:2017	Metallic materials — Fatigue testing — Axial force-controlled method
ISO 1143:2010	Metallic materials — Rotating bar bending fatigue testing
ISO 12111:2011	Metallic materials — fatigue testing — strain-controlled thermomechanical fatigue testing method

#### 4.8. Wear testing

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*Table 12: Metallic materials – List of standards for wear testing*

Standard reference	Standard title
ASTM B611-13	Standard Test Method for Determining the High Stress Abrasion Resistance of Hard Materials
ASTM G105-16	Standard Test Method for Conducting Wet Sand/Rubber Wheel Abrasion Tests
ASTM G65-16	Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus
ASTM G190-15	Standard Guide for Developing and Selecting Wear Tests
ISO 28080:2011	Hardmetals - Abrasion tests for hardmetals

## 5. Non-destructive testing

### 5.1. Penetrant testing

*Table 13: Non-destructive testing – List of standards for penetrant testing*

Standard reference	Standard title
ISO 3059:2012	Non-destructive testing — Penetrant testing and magnetic particle testing — Viewing conditions
ISO 3452-1:2013	Non-destructive testing — Penetrant testing — Part 1: General principles
ISO 3452-2:2013	Non-destructive testing — Penetrant testing — Part 2: Testing of penetrant materials
ISO 3452-3:2013	Non-destructive testing — Penetrant testing — Part 3: Reference test blocks



Standard reference	Standard title
ISO 3452-4:1998	Non-destructive testing — Penetrant testing — Part 4: Equipment
ISO 4987:2020	Steel castings — Liquid penetrant testing
ISO 23277:2015	Non-destructive testing of welds — Penetrant testing — Acceptance levels

## 5.2. Magnetic particle testing

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*Table 14: Non-destructive testing – List of standards for magnetic particle testing*

Standard reference	Standard title
ISO 4986:2020	Steel and iron castings — Magnetic particle testing
ISO 9934-1:2016	Non-destructive testing — Magnetic particle testing — Part 1: General principles
ISO 9934-2:2015	Non-destructive testing — Magnetic particle testing — Part 2: Detection media
ISO 9934-3:2015	Non-destructive testing — Magnetic particle testing — Part 3: Equipment
ISO 17638:2016	Non-destructive testing of welds — Magnetic particle testing
ISO 23278:2015	Non-destructive testing of welds — Magnetic particle testing — Acceptance levels

## 5.3. Eddy current testing

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*Table 15: Non-destructive testing – List of standards for eddy current testing*

Standard reference	Standard title
ASTM E2884-17	Standard guide for eddy current testing of electrically conducting materials using conformable sensor arrays
ISO 15548-1:2013	Non-destructive testing — Equipment for eddy current examination — Part 1: Instrument characteristics and verification
ISO 15548-2:2013	Non-destructive testing — Equipment for eddy current examination — Part 2: Probe characteristics and verification
ISO 15548-3:2008	Non-destructive testing — Equipment for eddy current examination — Part 3: System characteristics and verification
ISO 15549:2019	Non-destructive testing — Eddy current testing — General principles

#### **5.4. Ultrasonic testing**

*Table 16: Non-destructive testing – List of standards for ultrasonic testing of metallic materials*

Standard reference	Standard title
ISO 12710:2012	Non-destructive testing — Ultrasonic inspection — Evaluating electronic characteristics of ultrasonic test instruments
ISO 12715:2014	Non-destructive testing — Ultrasonic testing — Reference blocks and test procedures for the characterization of contact probe sound beams
ISO 16810:2012	Non-destructive testing — Ultrasonic thickness measurement
ISO 16811:2012	Non-destructive testing — Ultrasonic testing — Sensitivity and range setting
ISO 16823:2012	Non-destructive testing — Ultrasonic testing — Transmission technique
ISO 16826:2012	Non-destructive testing — Ultrasonic testing — Examination for discontinuities perpendicular to the surface



Standard reference	Standard title
ISO 16827:2012	Non-destructive testing — Ultrasonic testing — Characterization and sizing of discontinuities
ISO 17405:2014	Non-destructive testing — Ultrasonic testing — Technique of testing claddings produced by welding, rolling and explosion
ISO 2400:2012	Non-destructive testing — Ultrasonic testing — Specification for calibration block No. 1
ISO 4992-1:2006	Steel castings — Ultrasonic examination — Part 1: Steel castings for general purposes
ISO 4992-2:2006	Steel castings — Ultrasonic examination — Part 2: Steel castings for highly stressed components

*Table 17: Non-destructive testing – List of standards for ultrasonic testing of welds*

Standard reference	Standard title
ISO 11666:2018	Non-destructive testing of welds — Ultrasonic testing — Acceptance levels
ISO 17635:2016	Non-destructive testing of welds — General rules for Metallic materials
ISO 17640:2018	Non-destructive testing of welds — Ultrasonic testing — Techniques, testing levels, and assessment
ISO 22826:2005	Non-destructive testing of welds — Ultrasonic testing — Testing of welds in austenitic steels and nickel-based alloys
ISO 23279:2017	Non-destructive testing of welds — Ultrasonic testing — Characterization of discontinuities in welds
ISO 5817:2004	Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections

## **5.5. Ultrasonic testing - Time-of-flight diffraction technique (TOFD)**

*Table 18: Non-destructive testing – List of standards for TOFD*

Standard reference	Standard title
ISO 10863:2011	Non-destructive testing of welds — Ultrasonic testing — Use of time-of-flight diffraction technique (TOFD)
ISO 15626:2018	Non-destructive testing of welds — Time-of-flight diffraction technique (TOFD) — Acceptance levels
ISO 16828:2012	Non-destructive testing — Ultrasonic testing — Time-of-flight diffraction technique as a method for detection and sizing of discontinuities

## **5.6. Ultrasonic testing - Phased array ultrasonic testing (PAUT)**

*Table 19: Non-destructive testing – List of standards for PAUT*

Standard reference	Standard title
ISO 13588:2019	Non-destructive testing of welds — Ultrasonic testing — Use of automated phased array technology
ISO 18563-1:2015	Non-destructive testing — Characterization and verification of ultrasonic phased array equipment — Part 1: Instruments
ISO 185632:2017	Non-destructive testing — Characterization and verification of ultrasonic phased array equipment — Part 2: Probes
ISO 18563-3:2015	Non-destructive testing — Characterization and verification of ultrasonic phased array equipment — Part 3: Combined systems
ISO 19285:2017	Non-destructive testing of welds — Phased array ultrasonic testing (PAUT) — Acceptance levels
ISO 19675:2017	Non-destructive testing — Ultrasonic testing — Specification for a calibration block for phased array testing (PAUT)

## **5.7. Radiographic testing**

*Table 20: Non-destructive testing – List of standards for radiographic testing*

Standard reference	Standard title
ISO 17636-1:2013	Non-destructive testing of welds — Radiographic testing — Part 1: X- and gamma-ray techniques with film
ISO 17636-2:2013	Non-destructive testing of welds — Radiographic testing — Part 2: X- and gamma-ray techniques with digital detectors
ISO 19232-1:2013	Non-destructive testing — Image quality of radiographs — Part 1: Determination of the image quality value using wire-type image quality indicators
ISO 19232-2:2013	Non-destructive testing — Image quality of radiographs — Part 2: Determination of the image quality value using step/hole-type image quality indicators
ISO 19232-3:2013	Non-destructive testing — Image quality of radiographs — Part 3: Image quality classes
ISO 19232-4:2013	Non-destructive testing — Image quality of radiographs — Part 4: Experimental evaluation of image quality values and image quality tables
ISO 19232-5:2013	Non-destructive testing — Image quality of radiographs — Part 5: Determination of the image unsharpness and basic spatial resolution value using duplex wire-type image quality indicators
ISO 4993:2015	Steel and iron castings — Radiographic testing
ISO 5579:1998	Non-destructive testing — radiographic examination of Metallic materials by x- and gamma rays — basic rules
ISO 5579:2013	Non-destructive testing — Radiographic testing of Metallic materials using film and X- or gamma rays — Basic rules

## **5.8. Radiographic testing - Tomography**

*Table 21: Non-destructive testing – List of standards for tomography*





Standard reference	Standard title
ASTM E1441-19	Standard guide for computed tomography (ct)
ASTM E1570-19	Standard practice for fan beam computed tomographic (ct) examination
ISO 15708-1:2017	Non-destructive testing — Radiation methods for computed tomography — Part 1: Terminology
ISO 15708-2:2017	Non-destructive testing — Radiation methods for computed tomography — Part 2: Principles, equipment and samples
ISO 15708-3:2017	Non-destructive testing — Radiation methods for computed tomography — Part 3: Operation and interpretation
ISO 15708-4:2017	Non-destructive testing — Radiation methods for computed tomography — Part 4: Qualification

## 6. Demonstrators

### 6.1. Ship propeller

*Table 22: Non-destructive testing – List of standards for ship propeller*

Standard reference	Standard title
NR467 R12 January 2020	Bureau Veritas Rules for the Classification of Steel Ships - Part C Section 8 "Propellers"
NR216 R11 July 2019	Bureau Veritas Rules on materials and welding for the classification of marine units

*Table 22: Non-destructive testing – List of standards for ship propeller*

### 6.2. Mold for automotive industry

*Table 23: Non-destructive testing – List of standards for mold for automotive industry*



Standard reference	Standard title
EB01.10.110 /B - 11/2008	Renault standard - Worked steels for mold cavities for plastics Technical specifications

### **6.3. Mobile ring for hydroelectric plant**

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*Table 24: Non-destructive testing – List of standards for mobile ring for hydroelectric plant*

Standard reference	Standard title
CCH 70-3 – PT 70-3 Page 33	Contrôle par ressuage – critères d’acceptation
CCH 70-3 – RT 70-3 Page 77	Pièces en acier moulé pour machines hydrauliques - Contrôle par radiographie – critères d’acceptation

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