NORSOK STANDARD M-123

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Forged structural steel

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Foreword

The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for existing and future petroleum industry developments.

The NORSOK standards are prepared to complement available international standards and fill the broad needs of the Norwegian petroleum industry. Where relevant NORSOK standards will be used to provide the Norwegian industry input to the international standardisation process. Subject to development and publication of international standards, the relevant NORSOK standard will be withdrawn.

These standards are developed according to the consensus principle generally applicable for most standards work and according to established procedures defined in NORSOK A-001

The preparation and publication of the NORSOK standards is supported by OLF (The Norwegian Oil Industry Association) and TBL (Federation of Norwegian Manufacturing Industries). NORSOK standards are administered and issued by NTS (Norwegian Technology Centre).

Introduction

This standard is based on former company specifications and experience from deliveries and operation.

1 Scope

This Standard defines the requirements for qualification of forges and the technical delivery requirements for forged structural steel components for use in offshore structures where Steel Quality Level I or II is required.

2 Normative references

The following standards include provisions which, through reference in this text, constitute provisions of this NORSOK standard. Latest issue of the references shall be used unless otherwise agreed. Other recognised standards may be used provided it can be shown that they meet or exceed the requirements of the standards referenced below.

ASME V, Article 2.	Radiographic Examination
ASME V, Article 7	Magnetic Particle Examination
ASME VIII, div.1, appendix 6	Methods For Magnetic Particle Examination
ASME VIII, div.1, appendix 7	Methods For Radiographic Examination
ASME VIII, div.1, appendix 8	Methods For Liquid Penetrant Examination
ASTM A 388	Standard Practice For Ultrasonic Examination Of Heavy Steel Forgings
ASTM E 112	Standard Test Method for Determining Average Grain Size
ASTM E 165	Standard Test Method For Liquid Penetrant Examination.
ASTM E 709	Standard Practice For Magnetic Particle Examination
BS 7448	Fracture mechanics toughness tests
EN - 473 / Nordtest	Qualification of NDE operators
ISO 148	Steel – Charpy impact test (V-notch)
ISO 2632	Roughness Comparison Specimens, Cast Surfaces
ISO 6892	Metallic material – Tensile testing at ambient temperature
ISO 9001	Quality management systems - Requirements (ISO 9001:2000)
EN 10204	Metallic materials – Types of inspection documents
EN 10225 (Aug. 2001)	Weldable structural steels for fixed offshore structures – Technical delivery conditions

3 Abbreviations

NDT	Non Destructive Testing
PWHT	Post Weld Heat Treatment
FATT	Fracture Appearance Transition Temperatures
CTOD	Crack Tip Opening Displacement

4 Qualification

The purchaser may accept the forge's qualification based on general information described in 4.1 combined with a verification or audit at the forgemasters premises.

However, depending on the criticality and complexity of the forging and the experience of the forge, the purchaser may require the forge to perform a qualification as described in 4.2.

4.1 General

4.1.1 Basis for qualification of steel forges

The basis for qualification:

- Documented knowledge and previous experience with the material and the manufacturing.
- Manufacturing facilities and equipment.
- Established manufacturing procedures covering all important manufacturing steps from melting to finished products.
- Manufacturers quality system, which shall fulfil the requirements of ISO 9001 or equivalent.
- Results of representative testing in compliance with this standard.

Prior to qualification, a complete report, with information and results of representative testing as required by this standard shall be available for review.

4.1.2 General requirements

The manufacturer shall have knowledge of relevant metallurgical aspects of the applicable steel grades including welding, heat treatment parameters, etc. as applicable for his manufacturing process.

The manufacturer shall have knowledge and relevant experience with manufacture of the steel grades to be qualified. Experience should be supported by statistical data or relevant test records for the size range to be qualified. The steel shall have been produced to manufacturing procedures and with equipment intended used for the actual manufacturing.

Facilities and equipment shall be fit for purpose, regularly maintained and calibrated as required. The assessment shall concentrate on facilities and equipment for melting, forging, heat treatment, etc.

If parts of the production is carried out at a sub-supplier, the manufacturer is responsible for ensuring that the sub-supplier meets the requirements of this standard for the manufacturing steps that he is performing.

4.1.3 Manufacturing

The manufacturer shall have a Manufacturing Summary for each production route. The Manufacturing Summary shall describe, step by step in a logical and correct sequence all important manufacturing activities with reference to detailed procedures. A short description and the main parameters for each activity shall be included. The production route shall be illustrated with a flow chart. The scope of the manufacturing summary shall be clearly defined:

- Name and address of manufacturer.
- Grade of material with reference to standard.
- Type and size range of products for which the manufacturing summary applies.
- Identification of the manufacturing process.

The manufacturing summary shall include procedures for:

- Melting and refining processes, if applicable.
- Forging method.
- Heat treatment, including:
  - Loading temperature, heating rate, holding temperature (range) and time.
  - Loading of components in furnace.
  - Type of furnace(s).
  - Max. operating temperature for furnace(s).
  - Temperature control and calibration of furnace(s).
  - Cooling facilities and max. time from furnace to quenching bath (if relevant).
  - Sketch of heat treatment facilities/furnace which also shall show location of pyrometers and/or thermocouples in the furnace.
- Blasting/cleaning equipment, incl. type of grit.
- NDT and inspection.
- Material testing. Type of tests and time of test sampling.

If the manufacturer has different plants or different production routes for a product, separate documentation is required for each of these. If essential parts of the work is subcontracted, this shall be identified in the documentation.

Whenever a change is made in the equipment or procedures, the documentation shall be updated accordingly.

4.2 Qualification based upon a test program

For critical structural forgings or forgings intended for welding, base material and weldability data shall be required documented according to 4.2.1 – 4.2.7

4.2.1 Qualification of the manufacturing process

The manufacturing process as described in the Manufacturing Summary shall be qualified by testing of actual products, to:

a) Demonstrate that the proposed manufacturing route and production parameters results in products meeting specified requirements.
b) Verify that the proposed production test sampling gives results which are representative of the properties in the actual components which they represent.

4.2.2 Validity of qualification

The qualification shall be repeated if there are changes in the production route, the manufacturing procedures or the specified composition or properties of the products which exceeds the limits given below.

If production is carried out at different plants/locations, a separate qualification is required for each plant. This applies also for change of subcontractors for essential operations.

4.2.2.1 Thickness limitations

The maximum thickness qualified is the thickness of the tested product plus 25 %.

The qualified maximum and minimum thickness shall in any case not exceed the limits specified in the Manufacturing Summary.

4.2.2.2 Material grade

A change from one steel grade to a higher grade (ref. table 1) shall require requalification.

4.2.2.3 Type of melting and refining equipment

A change of the melting/refining process requires a requalification.

4.2.2.4 Manufacturing equipment

A major change of manufacturing equipment requires requalification, unless the new equipment can be regarded as comparable to the old one with respect to its influence on the product properties. This applies also if the manufacturer has several alternative manufacturing routes for a product.

4.2.2.5 Heat treatment

A change of heat treatment method, e.g. a change from normalising and tempering to quenching and tempering will require requalification.

4.2.3 Selection of material for testing

Selection of components for testing and positioning of test samples shall be as agreed between purchaser and the manufacturer.
Generally shall both longitudinal and transversal direction compared with the main grain flow, be tested for mechanical properties.

4.2.4 Extent of testing

Testing for qualification shall comprise:

a) Production testing with test sampling as specified in this standard.
b) Additional testing for qualification as required in this standard.
c) Non-destructive testing as specified in this standard

4.2.5 Base material

The material used for the examinations to document properties shall be representative, implying that:

- The chemical composition and mechanical properties shall be within the guaranteed limits
- The steel making process, forging methods and heat treatment condition shall be equal to that proposed for the actual delivery
- The reduction ratio shall match the minimum specified ratio, see clause 5.2.

The tested section thickness shall be representative for the thinnest and thickest portion in the forging for the actual delivery.

4.2.5.1 Chemical composition and mechanical properties

The chemical composition and mechanical properties shall be as per clause 5 and 6.

4.2.5.2 Charpy V-notch impact test transition curves

Charpy V-notch impact test transition curves (-80, -60, -40 and –20°C) shall be made for the thickest material section both in longitudinal and transversal/tangential directions. The specimen shall be taken from 2 mm below surface and mid-thickness position. Three specimens shall be tested at each test condition.

Both the energy absorption (J) and the FATT (Fracture Appearance Transition Temperatures), defined as 50% crystallinity, shall be reported.

4.2.5.3 Micrographic examinations

The base material microstructure shall be documented by micrographs of magnification 500X from subsurface, 1/4 thickness and ½ thickness positions. The type of microstructure, grain size and inclusion level shall be reported for information. Testing to be carried out according to ASTM E 112.

4.2.6 Weldability

Weldability data are required for forgings with a weld bevel thickness above 25 mm. The thickness to be used for the weldability test shall be agreed, but is not to be more than 10% below the weld bevel thicknes to be delivered The documentation of the weldability shall be in accordance with EN 10225 (Aug 2001), Annex E. The heat input shall be 3.5 +/- 0.2 kJ/mm (EN 10225, Table E.3).

For weld bevel thicknesses above 50 mm the testing shall be carried out both in the as welded and PWHT condition.

CTOD testing is required for weld bevel thickness above 50 mm and shall meet a requirement of minimum 0.25 mm (as-welded) and 0.20 mm (PWHT), at – 10°C unless a lower value has been accepted by the purchaser. CTOD testing is limited to only grain-coarsened HAZ.

4.2.7 Qalification test record

The manufacturer shall present a qualification test record containing results of all required tests as well as details about test sampling and test procedures.

5 Requirement to forged structural steel

5.1 Steel making process

The steel for structural forged components shall be made by the basic oxygen or electric arc furnace process. The steel shall be made with low impurity level and low content of N, O and H, and be free from dangerous cracks, gross laminations, inclusions, segregations, shrinkage and porosity. The steel shall be fully killed and supplied to fine grain practice. The steel shall normally be ingot cast and the filling is to be by bottom feeding. Significantly segregated core and any piped ingot part shall be discarded prior to forging.

5.2 Forging process

The forging shall be mechanically hot worked throughout the section and length and to a shape as close as possible to the final. The working may be pressing, hammering, ring rolling or combination thereof, and where the method shall be selected to give a favourable grain flow and texture for the intended component

and application. Care shall be taken to assure that segregated parts of the steel will not be exposed after final machining.

The reduction ratio shall be min. 4:1 for Area 1 and min. 3:1 for Area 2 in order to obtain a minimum grain size of 7 at any section for Area 1 and to a minimum grain size of 5 for Area 2 according to ASTM E112. For area definition, see clause 7.

5.3 Heat treatment

All forgings shall be supplied in the normalised, normalised and stress-relieved or quenched and tempered condition. For stress relieving the temperature shall be in the range of 550 – 600 °C.

Heat treatment shall be carried out in properly constructed furnaces, which are efficiently maintained, and have adequate calibrated means for control and recording of temperature. The furnace dimensions shall be such as to allow for the whole forging to be uniformly heated to the specified temperature. Heat treatment records shall be submitted upon request from the purchaser.

If, after final heat treatment, a forging is locally re-heated, or any straightening operation giving more than 5% cold deformation, a repeated final heat treatment has to be conducted.

5.4 Chemical composition

Proposed chemical compositions are given in table 1. The values apply to both ladle and product analysis. Deviations from this proposal shall be agreed in each case.
- Ladle analysis shall be determined for each ladle
- Product analysis shall be determined for each ingot

Table 1 – Chemical composition

Element\Grade		355	420	460	500
		ladle/product	ladle/product	ladle/product	ladle/product
C	max	0,12	0,14	0,12	0,12
Mn	max	1.65	1,65	1,60	1,60
Si	max	0,35	0,35	0,35	0,35
S	max	0,005	0,007	0,007	0,007
P	max	0,015	0,015	0,015	0,015
Cu	max	0,30	0,30	0,30	0,30
Ni	min	0,35	0,35	0,8	0,8
	max	0,70	0,70	2,8	2,8
Cr	max	0,20	0,20	0,95	0,95
Mo	max	0,08	0,25	0,50	0,50
V [a)]	max	0,050	0,050	0,050	0,050
Nb [a)]	max	0,030	0,030	0,030	0,030
Ti	max	0,020	0,020	0,020	0,020
Al tot.	max	0,040	0,040	0,040	0,040
N	max	0,010	0,010	0,010	0,010
Sb	max	0,010	0,010	0,010	0,010
Pb	max	0,005	0,005	0,005	0,005
Sn	max	0,020	0,020	0,020	0,020
As	max	0,020	0,020	0,020	0,020
Bi	max	0,005	0,005	0,005	0,005
B	max	0,0005	0,0005	0,0005	0,0005
CEV	max	0,45	0,47	0,55	0,55
Pcm	max	0,22	0,22	0,27	0,27

All values are maximum values unless a range is given, all in weight percent.

$$CEV = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$$

$$Pcm = C + \frac{Si}{30} + \frac{Mn + Cu + Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B$$

[a] $Nb + V \leq 0{,}06\%$

6 Mechanical testing

6.1 General

Testing for mechanical properties as yield strength, ultimate tensile strength, elongation, reduction of area and charpy impact energy shall be performed for each forging above 1 ton weight. For smaller forgings, another test frequency may be agreed upon. The results obtained shall comply with the requirement given in table 2.

6.2 Test coupons

Each forging to be tested shall have full section prolongations for test coupons to represent the thinnest and thickest sections. The test coupons shall not be removed from the forgings until all quality heat treatments have been carried out. If batch testing is accepted, one or more sacrificial forgings shall normally act as test coupons.

6.3 Test sampling

Unless otherwise agreed, the longitudinal axis and mid-length of test pieces shall be positioned as follows, see table 3:
- for thickness, t, up to and including 50 mm, the axis shall be at the t/2 and with the mid-length of the test piece at least 50 mm from the end
- for thickness greater than 50 mm, the axis shall be at t/3 or 80 mm, whichever is less, and at sub surface, and with mid-length of the test piece at least 50 mm from the end.

Transverse and longitudinal tests are normally to be made except that rings, hollow forgings which are expanded, and disks are to be tested in tangential and longitudinal direction if length enough for longitudinal testing.

For each position and orientation described, a set of tests comprise 1 tensile test and 3 charpy V-notch test specimens.

The supplier shall prepare sketches for purchaser's acceptance showing location and sizes of the prolongations or sacrificial forgings and the location of all test specimens within them.

6.4 Test methods

The tensile testing shall be carried out according to ISO 6892 or equivalent.

The charpy V-notch impact testing shall be carried out according to ISO 148 or equivalent. The notch shall always be perpendicular to the surface.

6.5 Retesting and criteria for rejection

If one or more of the results fails to meet the requirements, the manufacturer may carry out double set of additional tests, preferably from the same test coupon and position. All results from retest shall meet the requirements.

If retesting fails, the forging will be rejected. However the manufacturer may choose to carry out a full reheat treatment (e.g. normalizing + tempering or quenching + tempering) once followed by full set of mechanical testing. If any results still are not acceptable, the forging or lot will be rejected.

6.6 Mechanical properties

Requirements to mechanical properties are given in table 2.

Table 2 – Mechanical properties

Steel grade	Yield strength R_e min MPa	Tensile strength R_m min MPa	Elongation A_5 min %	Reduction of area Z min %	Impact test KV min J aver./single	KV test temp. ^oC	Ratio R_e/ R_m max
355	355	470-630	22	50	50/42	-40	0,87
420	420	500-660	19	40	50/42	-40	0,90
460	460	540-700	17	40	50/42	-40	0,90
500	500	600-750	17	40	50/42	-40	0,90

For section thicknesses above 250 mm, lower values for R_e and R_m may be agreed
$R_e = R_{eH}$ or $R_{p0,2}$

6.7 Summary of mechanical testing

A summary of mechanical testing is given in Table 3

Table 3 – Summery of mechanical testing

Test	Forging Weight	Material thickness	Test frequency	Orientation	Test position	Clause
Tensile and impact test	< 1 tonne < 1 tonne	≤ 50 mm > 50 mm	To be agreed To be agreed	Transv. and longit. Transv. and longit.	t/2 t/3	6.1 and 6.3 6.1 and 6.3
	> 1 tonne > 1 tonne	≤ 50 mm > 50 mm	Per forging Per forging	Transv. and longit. Transv. and longit.	t/2 t/3 + Sub surface	6.1 and 6.3 6.1 and 6.3

7 Non destructive testing

7.1 Personnel

Personnel performing NDT in accordance with this standard shall be qualified level II in accordance with NS-EN 473 / Nordtest or equivalent in the relevant industrial sector.
Personnel shall have prior knowledge to the method by which the forgings are produced, and shall have access to all drawings defining the location of the critical zones.
An EN-473 / Nordtest or equivalent level III person shall be responsible for all NDT-activity.

7.2 Critical areas and extent of testing

7.2.1 Critical area

The item for inspection shall be divided into two areas with regard to the criticality of the construction. The most critical Area 1 shall be specified on drawings supplied by the purchaser. All other areas are defined as Area 2.

7.2.2 Extent of testing

Table 3 – Extent of non destructive testing

Test method	Extent of testing
Visual examination	100% of accessible surfaces
Magnetic particle testing	100% of accessible surfaces
Ultrasonic testing	100 % volumetric testing from all accessible surfaces at a production stage with simple configuration and best detectability of imperfections. The volume shall be divided into Core-zone & Rim-zone. The core zone is the mid 1/3 cross-section and the remaining volume is rim-zone. For cross-sections less than 60mm,all will be considered as rim-zone.
Radiographic testing	100 % of bevel ends with thicknesses < 50 mm, within 100 mm from ends and/or critical areas as agreed between the manufacturer and purchaser.

7.3 Methods

7.3.1 General

All Non Destructive Testing shall be carried out in final heat treated condition and in accordance with established procedures. Surface to be inspected shall be clean and free from oil, grease, sand and loose rust or scale that may interfere a satisfactory inspection.

7.3.2 Visual/dimensional examination

Methods for visual and/or dimensional examination shall be agreed and specified on approved drawing.

7.3.3 Magnetic particle testing

The performance shall be as per ASME V, art.7/ASTM E 709. The surface to be examined shall be machined to a roughness better than N 10 (Ra 12 μm), ref. ISO 2632 / III.
The tangential field strength shall be min. 25 Oersted and lifting power (AC- Yoke) min. 45N at the maximum pole spacing that will be used.

7.3.4 Ultrasonic testing

The performance shall be as per ASTM A388 with the following specified details:

Surfaces:
- Machined, better than N10 (Ra 12 μm) ref. ISO 2632 / III for straight beam and better than N9 (Ra 6 μm) for angle beam testing.

Probes:
- 2-4MHz,straight beam and/or angle beam.
- Straight beam: Ø10-24
- Angle beam: Preferred probes:20x22mm or 8x9mm.

Probe selection:
- Straight beam, scanning in two perpendicular directions.
- If not possible due to difficult configurations: Additional testing with angle probes.

Sound attenuation (permeability):
- To be checked at different typical locations (cross-sections) of the forging. Any attenuation differences shall be considered during the testing.

Reference block:
- Similar to the item inspected related to surface and acoustic response
- One-block technique: A reference block representing the thickest part of the item tested, containing a flat bottom hole (FBH) Ø3x15mm and a side drilled hole (SD) Ø3x40mm at a distance of 1/4 x cross-section.

DGS-method:

- Alternatively, the DGS-method may be used if agreed between the purchaser and manufacturer. Gain reference level: Ø3mm equivalent reflector.

7.3.5 Radiographic testing

- The radiographic testing and calibration shall be carried out in accordance with ASME V, Article 2.
- In addition to procedure, a shooting sketch shall be prepared prior to the testing.

7.4 Acceptance criteria

7.4.1 Visual examination

Requirements to surface conditions shall be agreed and specified on approved drawings.

7.4.2 Magnetic particle testing

- As a per ASME VIII, div.1,appendix 6
  - No linear indications
  - Acceptance criteria are given in table 4

Table 4 – Size and number of defects

Areas	Max. acceptable Indication size	Max. number of Defects	Note
Area 1	100 mm²	15/m²	1)
Area 2	500 mm²	5/m²	2)

1) Min. distance between indications shall exceed 10mm in any direction
2) Min. distance between indications shall exceed 25mm in any direction

7.4.3 Ultrasonic testing

Acceptance criteria for ultrasonic testing are given in tables 5

Table 5 – Reference level

	Definition		Reference level
Area 1	High stressed area	Core-zone	Ø3mm equiv. disk reflector
		Rim-zone	Ø3mm equiv. disk reflector
Area 2	Med./low stressed area	Core-zone	Ø6mm equiv. disk reflector
		Rim-zone	Ø3mm equiv. disk reflector

The evaluation of imperfections shall be at the scanning reference-level related to actual depth.

7.4.4 Radiographic testing

- Acceptance criteria shall conform to ASME VIII div.1, appendix 7.
- Cracks and any other type of defects are not acceptable.

8 Repair

Surface grinding is acceptable according to the following:

		Definition	Welding	Max grinding
	Area 1	High stressed	No	0,6mm
	Area 2	Moderate/low stressed	No	1,0mm

Other kind of repair is not accepted. All repaired areas shall be magnetic particle inspected in accordance with Clause 7.

9 Dimensions/tolerances

Dimensions and required tolerances shall be as given on the relevant drawing of the forgings or other information supplied.

10 Surface protection

All machined surfaces shall be protected by a rust protection coating (tectyl or equivalent).

11 Marking

Forgings shall be marked for identification against a certificate. The marking shall include Contractor's identification and heat number.

All markings shall be carried out by die stamping and be framed by white painting. The letters used for the stamping should be 15 mm in height.

12 Documentation

Certificate according to EN 10204 3.1B is required.

The certificate shall contain all relevant information including, but not restricted to the following:

- purchaser's name and order number;
- delivery condition;
- heat number/forging number;
- description of product, dimension and weight;
- yield strength, tensile strength, elongation and reduction of area;
- Charpy V-notch values and test temperature;
- chemical composition, carbon equivalent/Pcm;
- visual inspection and NDT, or reference to separate reports;