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Petroleum, petrochemical and natural gas industries — Scheme for conformity assessment of manufacturers of special materials

Industries du pétrole, de la pétrochimie et du gaz naturel — Système d'évaluation de la conformité des fabricants de matériaux spéciaux

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is based on NORSOK M-650, 4th edition, which was developed by the Norwegian petroleum industry to ensure adequate safety, value added and cost effectiveness for petroleum industry developments and operations.

The conformity assessment requirements provide a Scheme for manufacturers to demonstrate their competence and experience to manufacture the relevant material grades and product forms. The intention is that a manufacturing procedure conformity record (MPCR) accepted by one customer should also be acceptable for other customers, within the essential variables of this document.

This document includes the following annexes that are either normative or informative:

— Annex A provides the Manufacturing Procedure Summary front page and examples (informative);

— Annex B contains the Temperature Uniformity Survey with additional requirements to Annex M of ISO 10423:2009 and ASTM A991-10 (normative);

— Annex C provides an example of verification of the heat treatment procedure (informative);

— Annex D contains requirements related to fasteners (normative);

— Annex E contains requirements related to induction bending in the case of testing for qualification of bends without post-bend heat treatment (normative);

— Annex F contains requirements for the assessment of testing laboratories (normative);

— Annex G provides the Manufacturing Procedure Conformity Record front page (normative).

Petroleum, petrochemical and natural gas industries — Scheme for conformity assessment of manufacturers of special materials

1 Scope

This document establishes a procedure for verifying that the manufacturer of special materials for the petroleum, petrochemical and natural gas industries has sufficient competence and experience of the relevant material grades of metal, and the necessary facilities and equipment, to manufacture these materials in the required shapes and sizes with acceptable properties according to the applicable standard, material specification and/or material data sheet specified by the purchaser.

This document is applicable to manufacturers of various materials, product forms and manufacturing processes when specified by the purchaser. This document has been established considering especially, but not exclusively:

a) duplex stainless steel;

b) high alloyed austenitic stainless steel;

c) nickel-based alloys;

d) titanium and its alloys.

This document is also applicable to the processes of induction bending and strain-hardened products.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3834-2, *Quality requirements for fusion welding of metallic materials — Part 2: Comprehensive quality requirements*

ISO 9000, *Quality management systems — Fundamentals and vocabulary*

ISO 10423:2009, *Petroleum and natural gas industries — Drilling and production equipment — Wellhead and christmas tree equipment*

ISO 10474, *Steel and steel products — Inspection documents*

ISO 14343, *Welding consumables — Wire electrodes, strip electrodes, wires and rods for arc welding of stainless and heat resisting steels — Classification*

ISO 15590-1, *Petroleum and natural gas industries — Induction bends, fittings and flanges for pipeline transportation systems — Part 1: Induction bends*

ISO 15614-1, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*

ISO/IEC 17000:2004, *Conformity assessment — Vocabulary and general principles*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ASME Boiler and Pressure Vessel Code, Section II, Materials, Part C, *Specifications for welding rods, electrodes, and filler metals* (also referred to ASME II Part C)

ASME Boiler and Pressure Vessel Code, Section IX: *Welding and Brazing Qualifications* (also referred to ASME IX)

ASTM A370-14, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

ASTM A991-10, *Standard Test Method for Conducting Temperature Uniformity Surveys of Furnaces Used to Heat Treat Steel Products*

ASTM E407, *Standard Practice for Microetching Metals and Alloys*

EN 10204, *Metallic products — Types of inspection documents*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the terms and definitions given in ISO 9000, ISO/IEC 17000 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1 Terms and definitions

3.1.1
conformity assessment
demonstration that specified requirements relating to a product, process, system, person or body are fulfilled

[SOURCE: ISO/IEC 17000:2004, 2.1]

3.1.2
continuous furnace
furnace in which the item/product to be heat treated is loaded and heat treated in a continuous cycle

3.1.3
company
owner or organization that is responsible for development of and/or operation of an installation/facility

Note 1 to entry: For the purposes of this document, the company is normally an oil company.

3.1.4
equalization time
time used to ensure a uniform pre-set temperature throughout a heat treatment load and/or throughout all section thicknesses of a component

3.1.5
heat sink
separate block used to monitor temperature during heat treatment and made from the same generic type of material as the parts being heat treated

3.1.6
high alloyed austenitic stainless steel (SS)
austenitic stainless steel typically having PREN ≥ 40 or [%Ni + 2(%Mo)] > 30 where %Mo > 2, all mass fractions expressed as percent

EXAMPLE UNS S31254, UNS N08367, UNS N08926, UNS S31266, UNS S32654, UNS S34565, J93254.

3.1.7
holding time
time from when the controlling thermocouple(s) [normally the furnace thermocouple(s)] has reached set temperature until the specified soaking time is completed

Note 1 to entry: See also Annex C.

Note 2 to entry: Holding time consists of equalization time + soaking time. Holding time is not applicable to continuous and semi-continuous furnaces.

3.1.8
main contractor
party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project, or operation or maintenance of a facility, on a contract awarded by the company

3.1.9
manufacturer
party, including subcontractors, which carries out operations that affect the material properties of the finished product

Note 1 to entry: A manufacturer should have minimum one operation, which affects material properties in-house.

Note 2 to entry: These operations can include forming, heat treatment, etc.

3.1.10
pitting resistance equivalent number
PREN
number indicating the resistance of stainless steel to pitting corrosion and related to chemical composition

Note 1 to entry: PREN is calculated from one of the following equations:

a) PREN = %Cr + 3,3 %Mo + 16 %N

b) PREN = %Cr + 3,3 %(Mo + 0,5 W) + 16 %N

where all mass fractions are expressed as a percentage.

Note 2 to entry: The requirement for the minimum PREN value applies to the applicable material specification, MDS and/or material standard as specified by purchaser.

3.1.11
purchaser
party which purchases a product from a manufacturer

Note 1 to entry: Company (end user), main contractor and buyer are purchasers in the context used in this document.

3.1.12
Qualifying Company
body or person that performs *conformity assessment activity* (3.1.13)

3.1.13
second-party conformity assessment activity
conformity assessment activity that is performed by a person or organization that has a user interest in the object

Note 1 to entry: Persons or organizations performing second-party conformity assessment activities include, for example, purchasers or users of products, or potential customers seeking to rely on a supplier's management system, or organizations representing those interests.

[SOURCE: ISO/IEC 17000:2004, 2.3]

3.1.14
semi–continuous furnace
furnace for which the load to be heat treated is prepared as a batch in front of the furnace and then passed in a continuous way through the furnace

3.1.15
soaking time
time that the entire part/section being heat treated (throughout its cross-sections) remains within the specified soaking (material) temperature range

Note 1 to entry: See also Annex C.

3.1.16
soaking zone
zone in a continuous/semi-continuous heat treatment furnace where the material is maintained within the specified soaking temperature range

3.1.17
SS type 22Cr duplex
ferritic/austenitic stainless steel alloys with 30,0 < PREN < 40,0 and Cr ≥ 19 % (mass fraction)

EXAMPLE UNS S31803 and UNS S32205.

3.1.18
SS type 25Cr duplex
ferritic/austenitic stainless steel alloys with 40,0 ≤ PREN < 48,0 (mass fraction)

Note 1 to entry: This alloy is often referred to as “super duplex”.

EXAMPLE UNS S S32505, UNS S32550, UNS S32750, UNS S32760 and UNS S39274.

3.1.19
test direction
direction in which testing is carried out as defined relative to the geometry of the component to be tested

Note 1 to entry: For the purposes of this document, the definitions given in ASTM A370-14, section 5, apply, with axial defined as the longitudinal axis of the test specimen located parallel to the main axis of the component.

3.1.20
third-party conformity assessment activity
conformity assessment activity that is performed by a person or organization that is independent of the person or organization that provides the object, and of user interest in that object

Note 1 to entry: Criteria for the independence of the conformity assessment bodies and accreditation bodies are provided in the International Standards and Guides applicable to their activities [see Bibliography (in ISO/IEC 17000)].

[SOURCE: ISO/IEC 17000:2004, 2.4]

3.2 Abbreviated terms

AOD argon oxygen decarburization

API American Petroleum Institute

ASTM American Society for Testing and Materials

EN European Standard

HIP hot isostatic pressed

HV	Vickers hardness
MDS	material data sheet
MOM	minutes of meeting
MPCR	manufacturing procedure conformity record
MPS	manufacturing procedure summary
NDE	non-destructive examination
NORSOK	Industry Standards for the Competitive Standing of the Norwegian Offshore Sector
PED	Pressure Equipment Directive
PREN	pitting resistance equivalent number
PWHT	post-weld heat treatment
SS	stainless steel
UNS	unified numbering system
VOD	vacuum oxygen decarburization
WPQR	welding procedure qualification record
WPS	welding procedure specification

4 Responsibilities

4.1 Purchaser's responsibilities

The purchaser is responsible for ensuring that the manufacturers engaged for a project are qualified within the essential variables of this document. Existing manufacturer's procedure conformity records (MPCRs) shall be reviewed for conformance with this document. Manufacturers unknown to the purchaser should in addition be visited.

Acceptance of an MPCR and the manufacturer chosen are at the discretion and determination of the purchaser.

The purchaser is not exempted from his responsibility for quality surveillance of his subcontractors, even if these fulfil the requirements of this document.

4.2 Manufacturer's responsibilities

The manufacturer is responsible for establishing and maintaining required documentation and carrying out verification and testing in accordance with this document.

A manufacturer conforming to this document assumes the obligation to carry out manufacturing and establish material/test certificates of products in accordance with the qualified Manufacturing Procedure Summary (MPS), including all referenced procedures. If an order requiring conformance with this document is outside the qualified range as defined in 10.2.15, the purchaser shall be informed.

4.3 Qualifying Company's responsibilities

The Qualifying Company shall monitor the conformity assessment activities, review and finally approve the resulting MPCR by signing and stamping the MPCR front page (see Annex G).

The Qualifying Company person signing the MPQR shall have the following,

a) a relevant education on bachelor level from a university college or equal;

b) good knowledge of metallurgical aspects of the applicable alloys, which shall be evaluated, including phase and transformation diagrams, effects of hot forming, welding, heat treatment, testing, etc.;

c) relevant knowledge of the manufacturing process(es) to be evaluated;

d) in-depth knowledge and understanding of this document;

e) previous experience with this document or received guidance/supervision from a person with previous qualification experience with this document.

The Qualifying Company shall be independent of the manufacturer.

NOTE Qualification (conformity assessment) experience with NORSOK M-650 Ed. 4 is considered equal to conformity assessment experience with this document.

5 Conformity assessment of manufacturers

5.1 Conformity assessment

The conformity assessment shall be carried out in cooperation with and verified by the Qualifying Company. The conformity assessment shall be carried out as either

a) a second-party conformity assessment activity (see definition in 3.1.13), or

b) a third party conformity assessment activity (see definition in 3.1.20), but only where the third party is accepted as a competent Qualifying Company by Company, Main Contractor or Purchaser.

A Qualifying Company can be engaged:

a) through projects for which the manufacturer has specific orders; that is, through contact between the manufacturer and the Companies, Main Contractors or Purchasers;

b) through a third party in cases where manufacturer wants to be evaluated without having any specific orders. In such cases the acceptance of the Qualifying Company and of the MPCR shall be by future customers prior to purchase order placement. Acceptance may be indicated by counter signature of the MPCR front page as specified in 5.5.

5.2 Basis for assessment of manufacturers

The manufacturer, including any nominated subcontractors, shall have:

a) knowledge and relevant manufacturing experience with the type of material to be qualified (see Clause 7);

b) acceptable manufacturing facilities and equipment (see Clauses 7 and 9);

c) an established MPS (procedure) covering all manufacturing steps from melting or start material, as defined in Table 1, column “Type of start material”, to finished product (see Clause 8);

d) an established heat treatment procedure (see Clause 9);

e) a management system that conforms with the requirements of ISO 9001 or equivalent;

f) satisfactory verification test results in conformance with this document (see Clause 10).

5.3 Evaluation for conformity

The Qualifying Company shall carry out a review and inspection of the manufacturing facilities, equipment, implementation of procedures and documentation, as required by this document, on the premises of the manufacturer and his subcontractors.

The results of the evaluation shall be documented in an evaluation report or minutes of meeting (MOM).

5.4 Review of manufacturing procedure conformity record (MPCR)

A complete MPCR with content in accordance with Clause 11 shall be established for review.

The only way to qualify a manufacturing procedure is to fulfil all the requirements of this document. It is not possible to deviate from this document with respect to being qualified. When all requirements in this document are fulfilled, the MPCR front page (see Annex G) shall be signed off and stamped by the Qualifying Company.

5.5 Statement of conformity

The original MPCR front page (see Annex G), completed with all data indicated in Annex G and signed by the Qualifying Company, is the only valid proof of conformity in accordance with this document.

Where a party authorized by the Company, Main Contractor or Purchaser is used as the Qualifying Company, the Company, Main Contractor or Purchaser who has given the authorization shall co-sign the MPCR front page to confirm their acceptance of the MPCR.

NOTE ISO does not keep any listing of qualified manufacturers who are accepted in accordance with this document.

6 Validity of the manufacturer procedure conformity record (MPCR)

6.1 Term of validity

The manufacturer's MPCR is valid for a maximum of five years starting from the date of signing and stamping of the MPCR front page. For new manufacturers, see 7.1.2.

For renewal of an existing MPCR according to 6.2, the renewal is valid for a maximum of five years starting from the expiry date of the original conformity assessment.

The conformity assessment is valid within the parameters specified in 10.2.

6.2 Renewal of the MPCR

The MPCR from a manufacturer with regular production of the originally conformity assessed products and alloys to a valid MPS is considered renewed without additional testing provided that production testing records are retained that demonstrate continued conformance to the specifications employed for the original conformity assessment. It is a prerequisite that applicable requirements of this document are complied with.

A renewal shall be initiated prior to the expiry date of the existing MPCR. If this is not the case, a complete new conformity assessment shall be carried out.

The following actions shall be executed for a renewal of the conformity assessment:

a) evaluating and reviewing the manufacturer's and subcontractors' premises according to 5.3 by the Qualifying Company;

b) reviewing and updating the MPS and referred procedures and making a decision whether retesting is required;

c) reviewing the heat treatment procedure and its corresponding verification (see 9.3) and making a decision whether a new verification is required;

d) the renewed MPCR shall contain a MOM, which describes the actual parts of the MPCR, which shall be updated, and the conditions for the renewal of the conformity assessment;

e) establishing and properly signing a new MPCR front page with new revision number.

6.3 Transitional requirements

A valid NORSOK M-650 Ed. 4 QTR, which complies with the essential variables of this document, is considered equivalent to this document provided the original material specification, e.g. NORSOK M-630 MDS, remains applicable.

Renewal of a NORSOK M-650 QTR to an ISO 17782 MPCR shall be in accordance with 6.2.

7 General requirements

7.1 Knowledge and relevant experience

7.1.1 Knowledge

The manufacturer shall have in-house knowledge of the relevant metallurgical aspects of the alloys to be qualified, including phase transformation diagrams, effects of hot forming, welding, and heat treatment parameters, etc. as applicable to the manufacturing processes employed.

7.1.2 Relevant experience

The manufacturer shall have relevant experience with manufacture of the type of material to be qualified.

Relevant experience shall be demonstrated by statistical data presented in the form of a histogram for key properties, e.g. tensile strength, impact toughness, corrosion resistance, etc. In addition, a relevant reference list from the last two years' production for the products, materials and the range of sizes to be qualified shall be included.

New manufacturers with less than two years of documented production for actual product and material may be qualified to this Scheme, but with a validity period limited to two years, after which a renewal according to 6.2 shall be carried out. The reason for the limited validity period shall be included on the MPCR front page.

7.2 Manufacturing facilities and equipment

Facilities and equipment shall be fit for purpose, regularly maintained and calibrated in conformance with pertinent International Standards and other requirements specific to the processes employed or the material grade being manufactured as specified in this document.

Requirements for heat treatment facilities and equipment are further described in 9.1.

7.3 Subcontractors and suppliers

The manufacturer is responsible for ensuring that subcontracted services shall meet the requirements of this document for all manufacturing steps performed by the subcontractor.

The manufacturer shall demonstrate adequate and consistent control of supply chain regarding purchase of start materials as defined in Table 1, column “Type of start material”.

7.4 Quality requirements for test laboratories and manufacturers of welded products

7.4.1 Test laboratories

Test laboratories shall operate in accordance with ISO/IEC 17025 for the applicable test methods.

Conformance to ISO/IEC 17025 shall be documented by,

a) a national accreditation certificate with definition of the scope of the certificate, issued by an ISO/IEC 17011 conforming national accreditation body or;

b) the test laboratory shall complete and sign the form in Annex F. The form shall be presented to the Qualifying Company for evaluation. In such cases,

   1) the Qualifying Company shall carry out an assessment of the laboratory to review listed procedures and how they are implemented.

   2) In addition, microstructure examination, as applicable, shall be demonstrated to the Qualifying Company's satisfaction.

   3) The results of the assessment shall be documented by a statement of conformity, which shall be signed by the laboratory and the Qualifying Company. The statement of conformity shall be attached to the filled in form in Annex F.

7.4.2 Manufacturers of welded products

Manufacturers of welded products shall conform to ISO 3834-2 or equivalent, as accepted by the Qualifying Company.

8 Manufacturing procedure summary (MPS)

8.1 General

The manufacturer shall have an MPS for each production route, type of product, grade of material and size range.

NOTE Sometimes it can be convenient to combine several production routes, types of product and/or grades of material into one MPS, e.g. as shown in the flow chart in Annex A.

The MPS 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. Each production route shall be illustrated with a flow chart.

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, e.g. forming, heat treatment, pickling, etc., are subcontracted, this shall be identified in the documentation. The documentation shall then include the name and address of each subcontractor and the relevant documentation from the subcontractor's equipment and procedures.

The MPS is the property of the manufacturer. Distribution is at the manufacturer's discretion.

8.2 Content of the manufacturing procedure summary (MPS)

8.2.1 Scope of the manufacturing procedure summary

The scope of the MPS shall be clearly defined, stating:

a) name and address of the manufacturer;

b) grade of material, UNS number, with reference to standard and material specifications;

c) type and size range of products for which the MPS is applicable (in conformance with 10.2.);

d) identification of the manufacturing process(es).

8.2.2 Manufacturing procedure summary requirements

The MPS shall as a minimum include applicable requirements for the following.

a) Start material:

   1) type of start material;

      NOTE For the definition of start material see Table 1, column "Type of start material".

   2) manufacturer's start material purchasing specification;

   3) name of start material manufacturer(s).

b) Manufacturer's inspection of start material on reception.

c) Melting shop practices, including:

   1) melting and refining processes;

   2) casting methods, e.g. ingot, continuous cast, etc..

d) Foundry practices, including:

   1) melting and refining processes;

   2) handling of and maximum percentage of internal returns (gates, sprues, risers, and rejected castings) in the melt;

      With respect to 1) and 2) remelting of AOD or VOD refined raw material in induction furnaces is acceptable. Raw material composed from virgin materials such as ferro-alloys is regarded to be equivalent to AOD or VOD refined materials. Internal revert after remelting of AOD or VOD treated steels should not be used.

   3) casting processes, e.g. investment, centrifugal, sand castings, etc.;

   4) moulding method, type of sand, binding agent and method of casting.

e) Hot forming, including:

   1) all hot-forming processes, such as forging, pressing, rolling and induction bending, with details regarding size and thickness range of each hot-forming process;

   2) maximum and minimum hot-forming temperatures and how these temperatures are monitored and controlled;

   3) possible reheating cycle;

   4) method of cooling after completion of the hot-forming process;

   5) minimum reduction ratio, including how the reduction ratio is calculated;

   6) a sketch illustrating each step in the forming process (see Annex A);

7) for induction bending, an MPS shall be established in accordance with ISO 15590-1 or equivalent, as accepted by the Qualifying Company.

f) Fasteners, including:

1) manufacturing method, e.g. forged or machined from bar;

2) method of threading, e.g. rolled or machined.

g) Heat treatment, including:

1) for batch furnaces, description of heat treatment cycle, e.g. loading temperature, heating rate, furnace set temperature, soaking (material) temperature with tolerances and holding and soaking times;

2) for continuous, semi-continuous and induction furnaces and for seamless pipes and tubes directly quenched from hot forming, the soaking (material) temperature range, and minimum soaking time as a function of size (e.g. thickness, diameter, cross-section) of products to be heat treated according to 9.2.4;

3) cooling details, e.g. cooling medium (water, air or combination thereof, etc.), type of cooling (quenching, spraying, etc.), relevant parameters (temperatures of cooling medium; for spraying medium-velocity, the type and size of nozzles, quantity, etc. as applicable.);

4) reference to the specific heat treatment procedure according to 9.2.

h) Blasting/cleaning equipment, including the type of grit.

i) Pickling.

j) Welding (including weld repair), where the WPS and WPQR applicable for the conformity assessment shall be listed.

k) PWHT (if applicable).

l) Type of NDE and inspection methods.

m) Strain hardening, including:

1) description of the strain hardening process with information about dimensional range of each process;

2) strain hardening parameters to be used for each dimension;

3) sketch illustrating each step in the forming process (see Annex A).

n) Production testing, including:

1) extent of production testing;

2) type of tests to be carried out, together with acceptance criteria for each test;

3) test sampling, which shall be identified as a separate activity and described in the correct sequence in the MPS;

4) sketches showing typical samples with dimensions for production tests, including location and orientation of test specimens;

5) procedure for microstructure examination, if applicable, that shall include as a minimum:

i) test sampling if not specified in the test sampling sketch(es) included in the MPS;

ii) preparation of specimens;

iii) type of etchant(s) to be used, with reference to the etchants listed in ASTM E407;

iv) areas on test specimen to be examined;

v) how examination for intermetallics, precipitates and other deleterious phases are carried out and documented;

vi) measuring of ferrite content, e.g. location and number of fields to be examined, method, grid size to be used, calculation of ferrite content and how it will be reported;

vii) magnification;

NOTE For duplex steels in particular, more than one etchant can be required for detecting intermetallic phases, carbides and nitrides.

6) whether testing is from actual product or transferred from start material.

o) Material/test certificate, including:

1) type of certificate to be issued;

2) content of certificate, including:

i) steel melting practice and refining method;

ii) results of all specified tests. If test results are transferred from start material certificate shall this be denoted;

iii) heat treatment condition, solution annealing temperature, holding time and quench medium;

iv) identification of manufacturing summary and/or MPCR used for the manufacture.

p) Description of the material traceability system.

q) List of applicable procedures with revision numbers; the list may include the following note.

NOTE This assessment is based on the stated revision of the procedures in the list. The listed procedures can be revised without the MPS or the MPCR being revised, provided there is no infringement of the essential variables given in 10.2, and other specified requirements.

An excerpt from a typical MPS is included in Annex A as an example.

9 Heat treatment

9.1 Facilities and equipment

9.1.1 General

Heat treatment facilities and equipment shall fulfil the requirements given in 9.1.2 to 9.1.8.

NOTE Further good practice is given in API RP 6HT.

9.1.2 Foundries

Foundries shall have heat treatment facilities within their own premises or located a maximum of 10 km from their plant.

9.1.3 Heat treatment furnaces

Heat treatment furnaces shall be adequately dimensioned for the loads to be heat treated. Electrical furnaces shall have mechanical means of circulating air during the heat treatment. The only exception

is cases where it can be documented through verifications (see 9.3) that uniform heating is achieved without forced circulation. Furnaces shall be equipped with automatic temperature controlling and recording devices which shall have an accuracy of ±1 % of their full-scale range.

A temperature uniformity survey of the quality heat treatment furnaces shall be carried out annually in accordance with Annex M of ISO 10423:2009, ASTM A991 or equivalent, and the additional requirements given in Annex B.

NOTE For the purposes of this provision, API 6A:2010 is equivalent to ISO 10423:2009.

9.1.4 Thermocouples and pyrometers

Thermocouples and pyrometers shall be calibrated at least once every three months and fulfil the requirements of Annex M of ISO 10423:2009. For continuous and semi-continuous furnaces, the calibration interval may be extended to every six months provided the manufacturer documents by historical records that no drift outside the calibration tolerances have occurred.

NOTE For the purposes of this provision, API 6A:2010 is equivalent to ISO 10423:2009.

9.1.5 Quenching baths

Quenching baths shall have dimensions and cooling facilities adequate to keep the water temperature below 50 °C at any time during the quenching operation, and shall not exceed 40 °C immediately prior to the quench. The quench tank shall be equipped with pumps or propellers to ensure satisfactory circulation and agitation during quenching. Quenching facilities should include provisions for internal cooling for the quenching of products with penetrating bores such as pipes.

Continuous temperature monitoring of the quenching bath shall be carried out during quenching, and the records maintained.

9.1.6 Loading of components

Pallets or other fixtures shall be used for placing of parts during heat treatment and quenching to ensure free circulation of air and water between each component. Parts shall not be placed directly onto the furnace floor.

Placement of components in baskets in a manner that restricts flow or access of quenching medium around each component of the load shall not be allowed.

9.1.7 Transfer time between furnace and quenching bath

For alloys requiring water quenching the equipment shall be capable of transferring materials from the heat treatment furnace into the quenching bath within a maximum of 60 seconds. For larger components, it is recognised that a transfer time of 60 seconds can be difficult to achieve and/or may not be beneficial to obtain optimal properties. In such cases, a longer transfer time may be specifically qualified. Qualification tests shall comprise both thin and heavy sections of such components, as agreed with the Qualifying Company. Details of the extended transfer time, including for which products it is applicable, shall be highlighted on the MPCR front page. The qualified extended transfer time shall not be exceeded.

The transfer time is measured from the time the furnace door is fully open, or the furnace roof is fully removed, until the component(s) is completely submerged in the quenching bath.

9.1.8 Continuous, semi-continuous and induction furnaces

Continuous, semi-continuous and induction furnaces shall generally fulfil the principles stated in 9.1.2 to 9.1.7. A specific evaluation shall be made in each case, and agreed with the Qualifying Company.

9.2 Heat treatment procedure

9.2.1 General

A specific heat treatment procedure shall be established. The procedure shall provide the information asked for in 9.2.2 to 9.2.6.

9.2.2 Heat treatment facilities and equipment

The following information about heat treatment facilities and equipment shall be included:

a) type and identification of furnace(s);

b) maximum allowable mass in batch furnaces, which shall not exceed the mass of the load used at the heat treatment verification;

c) sketch of furnace, showing overall dimensions and location of heating elements/burners as applicable. For batch furnaces, the working zone shall be shown. For continuous furnaces and semi-continuous furnaces, the heating zone and, as far as practical, the soaking zone shall be clearly defined;

d) location and identification of pyrometers and/or thermocouples in the furnace for control and recording respectively;

e) maximum operating temperature of furnace(s);

f) description of how temperature is controlled;

g) method and frequency of calibration of temperature-controlling and -recording devices, including thermocouples.

h) cooling facilities;

i) sketch of heat treatment facilities, showing furnace(s) and quenching bath locations relative to each other.

9.2.3 Loading and unloading of components and transfer between furnace and quenching bath

The following information about loading and unloading of components and transfer between furnace and quenching bath shall be included:

a) placement of components in furnace and during quenching (sketch to be prepared);

b) method(s) for unloading of components from furnace. If several pallets/components are heated in the furnace at the same time, the unloading sequence of these should be documented;

c) maximum transfer time of components, from open furnace door until components are completely submerged in quenching bath.

9.2.4 Description of heat treatment cycle

The following information shall be documented.

a) *For batch furnaces:* loading temperature, heating rate, soaking (material) temperature with tolerances, furnace set temperature, criteria for start of holding time, and holding and soaking times (for definitions of holding and soaking times, see 3.1.8 and 3.1.15, respectively). “Set” temperature in the sense used means the soaking (material) temperature.

b) *For continuous and semi-continuous furnaces:* soaking (material) temperature with tolerances in the soaking zone, furnace set temperature(s), travel speed and minimum soaking time as a function

of size (e.g. thickness, diameter, cross-section) of products to be heat treated and other relevant parameters.

c) *For induction furnaces:* the parameters listed in 9.2.4 b) and the diameter, with number of turns of induction coils, together with the current to be used as function of the size of the component(s) to be heat treated, normally presented in a table. How the temperature measurements are carried out to ensure that the specified soaking temperature and the minimum soaking time are achieved shall be described.

d) *For seamless pipes and tubes directly quenched from hot forming temperature:* this method is only acceptable when specifically stated in the relevant specified product standard. A description of the relevant heat treatment/annealing parameters applicable to the production process, the component sizes (outside diameter and wall thickness), the transfer time and minimum temperature at start of cooling, with how this is measured and documented and when relevant, the soaking temperature (including tolerances) and time.

e) *Cooling details:* e.g. cooling medium (water, air, gas or combination thereof, etc.), type of cooling (quenching, spraying, etc.), relevant parameters (temperatures of quenching bath; spraying medium velocity, type and size of nozzles, etc.).

9.2.5 Production testing and traceability

The following information about production testing and traceability shall be included:

a) principles for selection of components to be used for production testing within each heat treatment load (sketch to be prepared);

   For batch heat treatment; the selected component shall represent the coldest/slowest area of the furnace to heat up, typically from the centre and close to the bottom of a heat treatment load. For bars, pipes and tubes, the production test sample may be taken from the end provided this has proven to be representative during the qualification testing.

b) description of:

   1) how traceability of heat and heat treatment lot is ensured throughout the entire heat treatment process;

   2) how components within each heat treatment load are identified;

   3) how components used for production testing in each heat treatment load are identified.

9.2.6 Documentation of heat treatments

The following descriptions related to heat treatments shall be included:

a) how the temperature cycle is recorded and documented;

b) documentation of maximum temperature of quenching bath during quenching;

c) how documentation of the heat treatment loads is carried out [via photographs (preferred) or loading map];

d) actual location of components used for production testing in each heat treatment load.

9.3 Verification of heat treatment procedures

9.3.1 General

Verification is required for heat treatment procedures in accordance with this document.

9.3.2 Objective

The objective of the verification is to ensure that the specified parameters in the established heat treatment procedure are correct by comparing the readings of the furnace temperature-controlling devices and the temperature-controlling devices measuring the temperature of the load, components and/or heat sinks.

The verification shall especially verify that:

a) all components in a heat treatment load reach the specified soaking (material) temperature throughout their thickness;

b) the soaking time is not started before the load/components have actually reached the specified soaking (material) temperature with the minus tolerance subtracted. For guidance see section 6.3.8 of API RP 6HT:2013 and Annex C.

9.3.3 Extent of verification

Verification shall be carried out for each furnace used for quality heat treatment using the heaviest load and/or most densely packed load to be heat treated. Manufacturers or heat treatment contractors having several heat treatment procedures shall verify the most extreme conditions (e.g. a combination of shortest soaking time, shortest heating time, highest set temperature) in their procedures, in order to minimise the number of verifications required.

Furnaces used for stress reliving heat treatment do not require verification testing.

After a major refurbishment of a furnace, or after a furnace modification changing the heating or monitoring configuration or method, a new verification shall be carried out.

9.3.4 Procedure for verification

9.3.4.1 Batch furnaces

The verification of batch furnaces shall be carried out as follows:

a) For components with thickness $t < 15$ mm, contact thermocouples shall be fixed onto the surface of at least three components, which are respectively located in the middle of the heat treatment load and in two corners of the load diametrically opposite to each other. For plates, thermocouples shall be located in the centre and in each corner of the plate.

b) For components with $t \geq 15$ mm, holes shall be drilled into the components down to mid-thickness and the thermocouples placed into the holes. The holes should be at least 100 mm from the second surface of the component and shall be sealed with insulating material to avoid contact with the hot atmosphere. To avoid damaging the components, heat sinks may be used, which shall be made from the same general type of material as the parts being heat treated. The cross-section of the heat sink shall be equal to that of the heaviest cross-section of the parts being heat treated, with dimensions that permit location of the drilled hole as specified in the preceding text. The number and location of the heat sinks shall be as specified in a) above. For plates, thermocouples shall be located in the centre and in each corner of the plate.

c) Readings from the contact thermocouples and, if applicable, inserted thermocouples shall be compared with the readings from the controlling thermocouple of the furnace by superimposing the time-temperature curves from the contact thermocouples onto the curve from the controlling thermocouple.

   See the example in Annex C.

d) The manufacturer shall establish a procedure describing how the verification is proposed to be carried out, including how the mid-thickness temperature will be checked. The procedure shall be accepted by the Qualifying Company prior to start of the verification.

9.3.4.2 Special heat treatment furnaces and related operations

9.3.4.2.1 General

The requirements in 9.3.4.1 d) apply.

It is difficult to control temperature variations in semi-continuous and continuous furnaces. Often it is necessary to locate thermocouples/pyrometers at additional locations. A pre-test to establish the variations and decide the final number and location of thermocouples/pyrometers should be carried out in cooperation with Qualifying Company. For the same reason, it is often necessary to carry out the verification on more components of different sizes.

The number and location of the temperature-measuring and -recording devices to be used at the verification shall be agreed with Qualifying Company.

The verification shall be carried out on products. A minimum of two surveys shall be carried out with products representing respectively the smallest (thinnest) and largest (thickest) sizes to be heat treated. For pipe and tubes, different combinations of outside diameter and wall thickness shall be verified. The components to be used for the verification shall be agreed with Qualifying Company.

The temperature readings from the components shall be correlated to the readings of the temperature-controlling devices on the furnace or process, normally by superimposing the respective time-temperature curves onto each other.

9.3.4.2.2 Semi-continuous furnaces

Thermocouple(s) shall be located at the end of the load/component which enters the furnace first. The thermocouple readings shall be recorded as the load/component passes through the furnace. For tubes and pipes, the thermocouple(s) shall be located at both the inside and outside and in the mid-thickness for $t > 15$ mm. When a load consists of more components, typically tubes/pipes, thermocouples shall be located on three of the components in the load and located at each side and in the middle of the load respectively. For plates, thermocouples shall be located in the centre and in each corner of the plate.

9.3.4.2.3 Continuous furnaces

Recording of the material temperatures shall be carried out at the start and end of the soaking zone in the furnace for the most extreme combination of conditions which can be used in the procedures. For plates and strips, three pyrometers or travelling thermocouples shall be used along the width, located to measure the temperature at each edge and in the middle.

9.3.4.2.4 Induction furnaces, and forgings, pipes and tubes directly quenched from hot-forming temperature

Pyrometers shall be used for temperature measurement. The location and number of pyrometers to be used shall at least be those described in the heat treatment procedure in 9.2.4 c) and d), with addition of pyrometers as required to verify that the specified heat treatment parameters, such as soaking temperature and minimum soaking time, as relevant, are complied with.

9.3.5 Reporting

A report shall be established identifying the furnace verified, describing the heat treatment load used and the location of temperature-controlling and -recording devices within the load (photograph). The superimposed time-temperature curves from the contact thermocouples and the temperature-controlling device(s) of the furnace shall be included in the report with the achieved and minimum specified equalization (or soaking) times. The report shall include a separate section “Conclusions” containing clear statements whether the heat treatment procedure is considered satisfactory. If the requirements of the heat treatment procedure are not met during the verification exercise, the heat treatment procedure shall be revised.

9.3.6 Witnessing

The verification of the heat treatment procedure shall be witnessed by the Qualifying Company, who also shall sign the final report on completion of the verification exercise.

10 Verification of the manufacturing process

10.1 Objective of verification testing

The manufacturing process as described in the MPS shall be verified by testing of products in order to

a) document that the proposed manufacturing route and production parameters result in products meeting the specified requirements in the specified MDS or material specification, and

b) verify that the proposed production test sampling gives results which are representative of the properties of the components they represent.

10.2 Essential variables

10.2.1 General

A change in one or more of the manufacturing parameters stated in 10.2.2 to 10.2.17 requires re-qualification or supplementary qualification and/or verification tests.

10.2.2 Castings

Requalification is required for a change between the following methods:

a) sand moulding (sand castings);

b) ceramic moulding (investment castings, e.g. lost wax, unicast, Shaw method, etc.);

c) graphite moulding (titanium castings only);

d) change from melting in electric furnace + secondary refining to melting in induction furnace using AOD or equally refined scrap with limited use of return scrap;

e) change of casting technique between static casting, centrifugal casting or vacuum casting. This is not applicable to titanium castings that shall always be cast in vacuum;

f) addition or removal of HIP treatment.

Other changes between moulding methods may require requalification.

10.2.3 Fittings

Qualification on a welded fitting may also qualify for seamless fittings manufactured according to the same forming method and parameters, provided the manufacturer of the seamless pipe is qualified.

10.2.4 Forgings

Forgings for qualification shall be representative in geometry of the products to be manufactured. Typically, separate qualifications shall be carried out for flanges, bars, rings and discs. Also other component types may require separate qualification as agreed with Qualifying Company.

10.2.5 Heat treatment

Change or refurbishment of the heat treatment furnace within the same premises does not require requalification, provided the requirements in Clause 9 are fulfilled.

A requalification is required if any of the following changes in heat treatment procedure are introduced:

NOTE Requirements specific to titanium components are given at the end of this subclause.

a) change in heat treatment temperature outside the allowable range:

   1) *for batch heat treatment:* the allowable range of heat treatment temperature is –10 °C to +30 °C from the soaking temperature applied to the component in the qualification testing;

   2) *for continuous furnaces:* the start and end set temperatures in the soaking zone may be different. In such cases, the heat treatment start and end set temperatures in the soaking zone, with tolerances, shall be specified in the heat treatment procedure, together with the maximum travel speed of the components through the furnace dependent on thickness and component dimensions;

In cases where the heat treatment start and end set temperatures in the soaking zone are different, the basis for verification of the heat treatment procedure shall be the end set temperature. The qualified temperature range in such cases is –10 °C to + 30 °C along the soaking temperature curve.

b) change in heat treatment cycle, e.g. from a one-step to a two-step cycle, or vice versa;

c) reduction of holding and/or soak time to a time shorter than that established during verification of the heat treatment procedure;

d) change from furnace heat treatment to induction heat treatment, or vice versa;

e) change from batch furnace heat treatment to continuous furnace heat treatment, or vice versa;

f) for hot-finished seamless pipes only: change from furnace heat treatment to direct quench, from hot finish operation, or vice versa;

g) change in quench medium from water to polymer, oil, nitrogen, air and similar, or vice versa;

h) change in quenching method from quenching in bath to spray quenching, or vice versa.

For unalloyed titanium, i.e. Grades 1 to 4, the essential variables for heat treatment above are not applicable as stress-relieving only applies. For other titanium grades, the heat treatment essential variables [a) to h) above] shall apply unless otherwise agreed with the Qualifying Company.

A change in furnace atmosphere is an essential variable applicable to the heat treatment of all titanium alloys.

10.2.6 Hot forming

Requalification is required for a change from one forming method to another and a change in forging temperature outside the established and qualified tolerances.

Typical examples are:

a) from rolling to forging, or vice versa;

b) from closed die forging to open die forging, or vice versa;

c) from hammer forging to press forging, or vice versa;

d) from hot pressing to extruding, or vice versa;

e) from hot to cold forming/rolling, or vice versa;

f) change in cooling method after hot forming from water quenching to any other cooling method.

10.2.7 Hot isostatic pressed (HIP) products

Requalification is required for changes in the following:

a) the manufacturer of powder for HIP;

b) reduction in HIP parameters:

— temperature: $T \geq 20$ °C;

— pressure: $p \geq 5$ %;

— time: $t \geq 5$ %;

c) change in HIP equipment.

10.2.8 Induction bending

The intention of conformity assessment to this Scheme is to demonstrate the capability of the manufacturer only. Individual bend-procedure qualification testing, which normally is carried out for each new delivery, is required as agreed with the customer in each case.

Qualification testing shall be carried out on the combination of the smallest outside diameter (OD) with the largest wall thickness (WT) and on the largest OD with the smallest WT to be bent.

It should be noted that:

a) the essential variables to start material as given in 10.2.11, 10.2.12 and 10.2.13 apply;

b) bending with and without post-bend heat treatment require separate qualifications;

c) qualification of one radius qualifies all larger radii, but not vice versa;

d) qualification is required for each bending machine.

10.2.9 Manufacture at different plants and/or locations

If production is carried out at different plants/locations, a separate qualification is required for each plant. This applies also for a change in subcontractors for essential operations, such as heat treatment, HIP operations, welding, etc.

10.2.10 Manufacturing equipment

A change in manufacturing equipment as described in the MPS that can negatively influence the product properties requires requalification. This applies also if the manufacturer has several alternative manufacturing routes for a product.

10.2.11 Material grade

A change from one material grade to another, e.g. a change in UNS number requires requalification (except for change from UNS S31803 to UNS S32205 and vice versa).

Qualification of a higher strength grade unalloyed titanium will also qualify lower grade titanium.

10.2.12 Melting and refining process

A change from multiple refining (e.g. AOD + VOD or AOD/VOD + ES) to single refining (e.g. AOD or VOD) requires requalification.

10.2.13 Start materials

A change in one or more of the variables in Table 1 requires requalification. If any of the essential variables listed in Table 1 changes, then each grade of material affected shall be requalified.

10.2.14 Strain hardening

In addition to the essential variables in 10.2.2 to 10.2.13, requalification is required for a change of more than 2 % units on the qualified percentage reduction of area for each dimension as stated in the qualified procedure.

Table 1 — Essential variables for start materials

Type of product	Type of start material	Essential variables			
		Manufacturer of start material shall be ISO 17782 qualified[b]	Change of start material manufacturer	Other changes requiring requalification	Other requirements
All products without subsequent heat treatment, including strain-hardened products	All	Yes	—	—	—
Bars	Ingots and rolled and forged billets, blooms and slabs	—	Yes	— From forged to rolled — From wrought to cast	10.2.12
Castings — melting in induction furnace without secondary refining	Scrap and ingots	—	Yes	From scrap to ingots, or vice versa	10.2.12 Certificate to EN 10204 type 3.1 or ISO 10474 type 3.1 minimum
Induction-bent bends and spools	Seamless and welded pipes and tubes	Yes	—	Change from seamless to welded	—
Forgings all types including fittings, fasteners and ring rolled products	Ingots and rolled and forged bars, billets, blooms and slabs	Optional	Yes[a]	— From forged to rolled — From wrought to cast — From heat treated condition or semi heat treated condition to untreated condition	10.2.12
HIP	Powder	—	Yes	—	10.2.12

Table 1 *(continued)*

Type of product	Type of start material	Essential variables			
		Manufacturer of start material shall be ISO 17782 qualified[b]	Change of start material manufacturer	Other changes requiring re-qualification	Other requirements
Plates	Slabs, billets and blooms	—	Yes	A change from ingot casting to continuous casting or vice versa	10.2.12
Seamless fittings including dished heads	Plates and seamless tubes	Optional	Yes[a]	—	10.2.12
Seamless pipes and tubes	Billets	—	Yes	—	10.2.12
Welded fittings including dished heads	Welded pipes, plates and strip	Optional	Yes[a]	—	10.2.12
Welded pipes	Plates and strip	Optional	Yes[a]	—	10.2.12

[a] The requirement may be disregarded if:

1) the manufacturer of the start material holds a valid ISO 17782/NORSOK M-650 Edition 4 qualification for the specific start material used, or

2) the manufacturer can document that the specific start material from a manufacturer has already been used in other qualifications for the same grade of material.

[b] Manufacturers qualified to NORSOK M-650 Ed. 4 are also acceptable.

10.2.15 Thickness and mass limitations

The maximum qualified mass and thickness shall be according to limits given in Table 2, but shall in no case exceed the limits specified in the MPS.

Table 2 — Maximum qualified thickness and mass for applicable products

Type of product	Type of material	Maximum tested thickness t mm	Maximum qualified thickness mm	Mass of tested component m kg	Maximum qualified mass kg
Strip, plate, pipe, tube, wrought fittings, dished heads and cold-bent bends and spools	High alloyed austenitic SS, Ni-alloys & SS type 25Cr duplex	$t \leq 40$	t + 25 % max. 40 mm	N/A	N/A
		$t > 40$	t		
	SS type 22Cr duplex	$t \leq 60$	t + 25 % max. 60 mm	N/A	N/A
		$t > 60$	t		
	Titanium	t	t + 25 %	N/A	N/A

NOTE The qualified thickness of an applicable welding procedure depends on the weld qualification standard and can be different from this table.

Table 2 *(continued)*

Type of product	Type of material	Maximum tested thickness t mm	Maximum qualified thickness mm	Mass of tested component m kg	Maximum qualified mass kg
Castings, forgings, bars, and HIP	High alloyed austenitic SS, Ni-alloys + SS type 25Cr duplex	$t \leq 60$	t + 10 % max. 60 mm	$m \leq 250$	m + 100 %
				$m > 250$	All
		t > 60	t	$m \leq 250$	m + 100 %
				$m > 250$	All
	SS type 22Cr duplex	$t \leq 120$	t + 10 % max. 120 mm	$m \leq 250$	m + 100 %
				$m > 250$	All
		$t > 120$	t	$m \leq 250$	m + 100 %
				$m > 250$	All
	Titanium	t	t + 25 %	$m \leq 150$	m + 100 %
				$m > 150$	All
Induction bends	All	The capability of the manufacturer is considered to be the combination of the smallest outside diameter (OD) with the largest wall thickness (WT), and the largest OD with the smallest WT tested			
Investment castings	All	$t \leq 60$	t + 25 % max. 60 mm	N/A	N/A
		$t > 60$	as for the relevant material under castings		
Fasteners in solution-annealed condition	SS type 25Cr and Ni-alloys	$t \leq 60$	t + 10 % max. 60 mm	N/A	N/A
		$t > 60$	t		
Strain-hardened products including fasteners	All	t	t	N/A	N/A

NOTE The qualified thickness of an applicable welding procedure depends on the weld qualification standard and can be different from this table.

10.2.16 Welded products

Requalification is required in case any of the following changes in welding procedure specification is introduced:

a) change from double-sided to single-sided welds;

b) change in welding process or combination of welding processes;

c) change from addition of filler material to no addition;

d) change in filler classification in accordance with ISO 14343 or ASME II Part C.

10.3 Qualification testing

10.3.1 Selection of components for testing

The selection of components for testing and test sampling shall be as agreed with Qualifying Company.

Components for testing shall be selected with a section thickness so that the desired section thickness according to Table 2 is qualified. Except for castings and HIP components, the components shall be representative in geometry of what actually is to be manufactured. Castings and HIP components

selected for testing shall be actual products, i.e. not test blocks. For castings, qualification should be carried out on a cored component, e.g. a valve body.

For forged flanges, contour-forged valves and similar products where production testing is planned to be carried out on an integral prolongation, such a prolongation shall also be integral to the qualification test forging.

Components for testing shall be from regular production or from test production, and shall be manufactured according to the normal manufacturing route and with regular production equipment. Components shall be tested in their final manufactured condition except that machining, as applicable, does not need to be carried out. Strain-hardening, threading and similar operations affecting the properties of the components shall be carried out before testing.

10.3.2 Testing

10.3.2.1 Verification of test sampling and test record

All extraction of test samples and testing specifically related to the qualification tests shall be witnessed by the Qualifying Company or a party authorised to act on behalf of the Qualifying Company. For corrosion tests and metallographic examination the test reports need only to be reviewed and accepted. Inspection certificates according to ISO 10474 Type 3.2 or EN 10204 Type 3.2 shall be issued.

10.3.2.2 Extent of testing for qualification

Testing for qualification shall as a minimum comprise:

a) production testing with test sampling as specified in the applicable standard, material specification, MDS and/or the MPS;

b) additional testing for qualification according to Table 3;

c) for forged flanges, contour-forged valves and similar products with integral prolongations: testing on both the prolongation and the product itself;

d) non-destructive testing as specified in applicable material specifications.

The type of tests to be performed and minimum requirements shall be as specified in the applicable material specification.

10.3.2.3 Requirements for materials requiring impact testing

For materials requiring impact testing, the requirement for base material shall be 20 J higher than the production test requirements. This does not apply to the additional testing specified in 10.3.3 or to the testing in position 2 for flanges.

For qualification of dimensions outside the range specified in applicable standard, material specification and/or MDS, special acceptance requirements may be agreed, e.g. exception to the requirement for the impact test results to be 20 J higher during qualification than the production test requirements. In such cases this shall be clearly stated on the MPCR front page.

10.3.2.4 Acceptance of production testing from integral prolongations from forged products

To accept production testing to be taken from the prolongation, the test results from the prolongation shall be representative of the properties obtained from the same position of the sacrificial product. It is at the discretion of the Qualifying Company to decide what is “representative”, i.e. an acceptable difference between results from tests located in the prolongation and in the product itself.

10.3.3 Additional testing

Additional testing shall be carried out as required in Table 3.

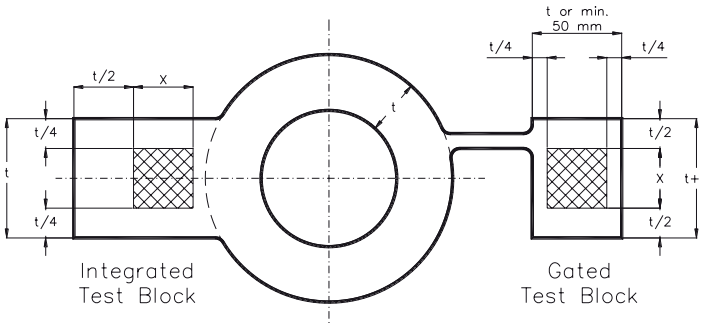
For all materials having section thickness $t > 50$ mm and requiring impact or corrosion testing specified in the applicable standard, material specification and/or MDS, additional testing shall be carried out as follows, using specimens located in the mid-thickness position ($t/2$) and at a distance from any second surface of t or at least 100 mm. Forged and rolled bars shall be tested in one end and in the mid-length position.

a) Impact testing in axial and tangential directions: the minimum absorbed energy shall be 27 J/20 J (average/single values) tested at maximum –46 °C;

b) Corrosion and micro-examination in accordance with the requirements specified in the applicable standard, material specification and/or MDS.

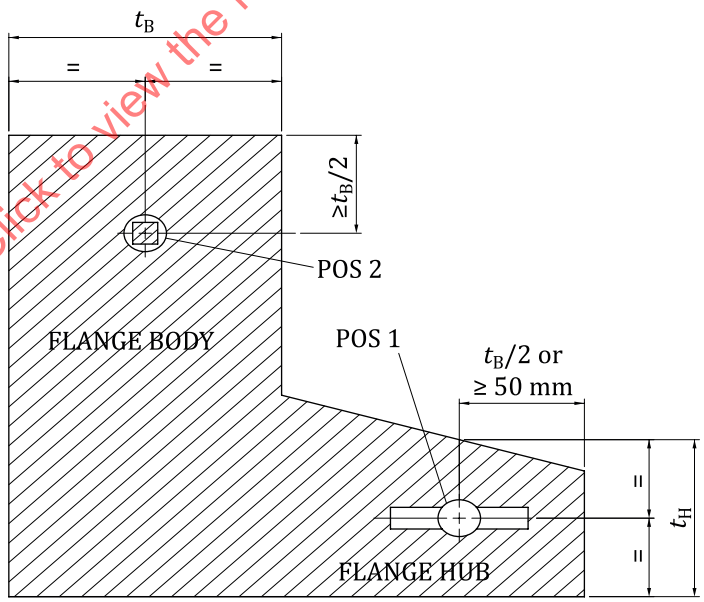
It is recognised that for certain applications, corrosion properties and microstructure in mid-thickness are not important for the functionality of the component as agreed with purchaser and Qualifying Company. In such cases it may be agreed that the tests shall be carried out for information only, and a note about this shall be included on the MPCR front page.

Table 3 — Testing required for qualification

Item No.	Type of product	Sample for production test	Additional tests for qualification
1	All products	Test sampling as specified in applicable standard, material specification, MDS and/or the MPS.	Type, number and location of tests as specified in applicable standard, material specification and/or MDS unless otherwise specified in this table. Additional testing as agreed by purchaser or Qualifying Company.
2		A sketch shall be prepared with dimensions of production test samples and components tested for qualification. The location and orientation of test specimens shall be shown. The components used for qualification should in addition be documented with photographs.	
3	Bars — Rolled and forged	Cut from over-length of bar.	Tests shall be carried out at one end and at the mid-length position of one bar. Additional testing according to 10.3.3 shall be carried out when section thickness $t > 50$ mm for all materials requiring impact or corrosion testing according to applicable standard, material specification and/or MDS.
4	Castings	Integral or gated test blocks. See figures next column. Production test blocks shall be tested as part of the qualification testing.	Tests from thin and thick sections of a sacrificial casting. 
5	Dished heads	From over-length of the component	Tests shall be carried out from the over-length and from the deformed area of the component. For dished heads made of plates and welded together prior to forming, the tests shall include a weld.

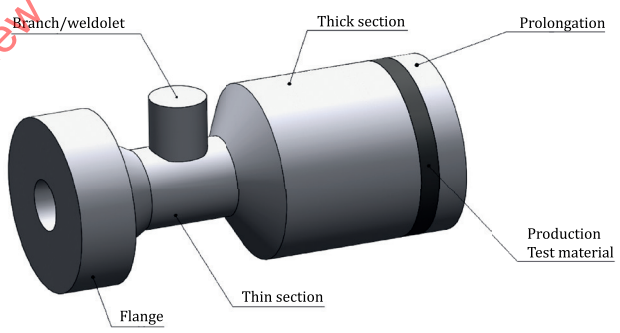
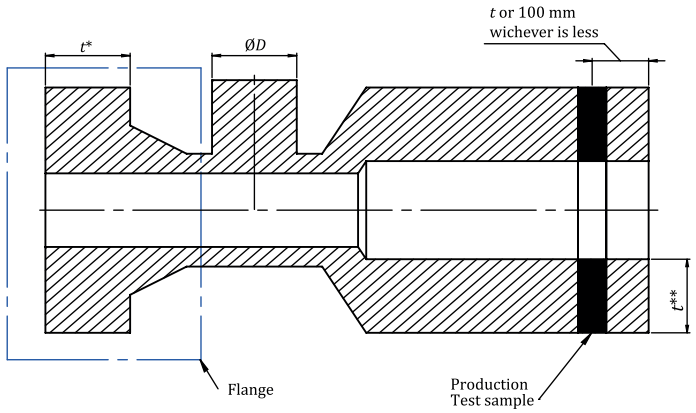
a Qualification of fasteners machined from bar may be omitted or limited as agreed with purchaser.

Table 3 *(continued)*

Item No.	Type of product	Sample for production test	Additional tests for qualification
6	Fasteners	As specified in the applicable standard, material specification and/or MDS	Distinction is made between a) Forged and heat treated fasteners. b) Fasteners machined from bar in heat treated or strain hardened condition.[a] Qualification testing shall be carried out according to Annex D. Verification shall be carried out of the bars used for manufacture of fasteners in strain hardened condition according to Table 3, item 15.
7	Flanges — all manufacturing methods	Sacrificial flange or an integral prolongation	Qualification testing shall encompass testing of a sacrificial flange in both the flange neck and flange ring, position 1 (t_H /2) and position 2 (t_B/2) respectively as shown in the figure. t_H = mid-thickness of hub in a distance t_B/2 or minimum 50 mm from the weld end. t_B = thickness of flange ring. In position 1 impact testing, as applicable, shall be taken in both axial and tangential directions. If not otherwise specified in the applicable standard, material specification and/or MDS the minimum absorbed energy for impact tests in Pos. 1, tangential direction, shall be minimum 27 J/20 J (average/single values) tested at –46 °C. 
8	Forgings — closed die	Sacrificial forgings	Additional testing according to 10.3.3 shall be carried out if section thickness t > 50 mm for all materials requiring impact or corrosion testing according to the applicable standard, material specification and/or MDS. Other additional testing may be required depending on shape and functionality of the forging as agreed with purchaser and Qualifying Company. Tees shall be tested both on one end and in the crotch area. For sleeves, nozzles and similar products the qualification tests shall be carried out on a component with the heaviest WT and smallest ID. The thickness limitations in Table 2 shall still be considered.

[a] Qualification of fasteners machined from bar may be omitted or limited as agreed with purchaser.

Table 3 *(continued)*

Item No.	Type of product	Sample for production test	Additional tests for qualification
9	Forgings — open die	Tests from prolongation on actual forging or from sacrificial forging	Additional testing according to 10.3.3 shall be carried out when section thickness t > 50 mm for all materials requiring impact- or corrosion-testing according to the applicable standard, material specification and/or MDS. Other additional testing may be required depending on shape and functionality of the forging as agreed with purchaser and Qualifying Company. Tees shall be tested both on one end and in the crotch area. For sleeves, nozzles and similar products the qualification tests shall be carried out on a component with the heaviest WT and smallest ID. The thickness limitations in Table 2 shall still be considered.
10	HIP components except flanges	Integral test blocks.	Testing shall be made from thin and thick sections of a sacrificial product. The figure shows proposed geometry of sacrificial component for qualification covering also flanges. Additional testing according to 10.3.3 shall be carried out when section thickness t > 50 mm for all materials requiring impact- or corrosion-testing according to the applicable standard, material specification and/or MDS. For sleeves, nozzles and similar products, the qualification tests shall be carried out on a component with the heaviest WT and smallest ID. The thickness limitations in Table 2 shall still be considered.  

a Qualification of fasteners machined from bar may be omitted or limited as agreed with purchaser.

Table 3 *(continued)*

Item No.	Type of product	Sample for production test	Additional tests for qualification
11	Induction bend pipe spools and bends	From the over-length of the bend or from a sacrificial bend. The over-length for testing shall have undergone the same heating cycles as the bend.	a) Bends subject to post-bend heat treatment: As specified for wrought fittings, Table 3, item 20 with addition of dimensional inspection and non-destructive examination according to Annex E; b) Bends delivered in the "as-bent" condition according to Annex E.
12	Plates	Cut from over-length of plate	Both ends on one plate shall be tested with three sets of tests at each end, located in the middle and at each edge. Table 3, item 1, specifies location of test specimens with reference to the applicable material specifications, MDSs etc.
13	Ring-rolled products	Tests from prolongation on actual forging or separate forged test ring	Additional testing according to 10.3.3 shall be carried out when section thickness exceeds 50 mm for all materials requiring impact- or corrosion testing according to applicable standard, material specification and/or MDS.
14	Seamless pipe and tube	Cut from over-length of pipe	One pipe/tube in the upper thickness range specified in the MS shall be tested at one end and at the mid-length position. Additional testing of a pipe/tube with the smallest diameters and heaviest wall thicknesses may be required at the discretion of the Qualifying Company.
15	Strain-hardened products	Testing of strain hardened products consists of a) testing of the strain hardened products themselves and b) verification of the strain hardening process.	
		a) Testing of strain hardened products	
		Cut from over-length of the strain-hardened mother bar or from a sacrificial part	Testing shall be as specified for rolled and forged bars in Table 3, item 3. In addition the following tests shall be carried out: 1) hardness tests of the cross-sections using HV10 with 2 mm spacing; 2) materials requiring impact testing with diameter ≥12 mm: One set of impact tests located as close to the surface as possible. Testing requirements as specified in 10.3.2.3.
		b) Verification of the strain hardening process The verification shall be carried out by strain hardening and testing of three bars within the dimensional range to be qualified. One bar each shall be from the lower and upper end of the dimensional range to be qualified and on bar shall be from the middle of the range. The strain hardening shall be carried out according to the parameters specified in the MPS or its referred procedures. The verification shall be witnessed by the Qualifying Company. Testing shall be carried out as specified in Table 3, item 15 a). A verification report shall be established with a description of the strain hardening equipment and parameters used and dimensions of the bars used for the verification. The test report from testing of the strain hardened bars shall be attached to the verification report, which shall be signed by the strain hardening manufacturer and Qualifying Company.	

[a] Qualification of fasteners machined from bar may be omitted or limited as agreed with purchaser.

Table 3 *(continued)*

Item No.	Type of product	Sample for production test	Additional tests for qualification
16	Strip	Cut from over-length of strip	Each section of strip used for qualification shall be tested with three sets of tests at both ends, located in the middle and at each edge.
17	Welded pipe and tube	Cut from over-length of pipe or from test plate welded as prolongation of the pipe/tube weld	Weld and base materials shall be tested at one end and in the mid-length position on one pipe in the upper thickness range specified in the MPS. Additional testing of a pipe/tube with the smallest diameters and heaviest wall thicknesses may be required at the discretion of the Qualifying Company.
18	Wrought fittings — seamless and welded	Cut from sacrificial fitting, over-length of fitting or, for welded fittings, test plates welded as a prolongation of the fitting weld	One fitting of each type shall be tested at one end as a minimum. In addition, different locations with different deformation ratios should be tested, e.g. inner and outer radii and neutral zone for elbows. Tees shall be tested both on one end and in the crotch area. For welded fittings, testing shall comprise base material and weld(s).
[a] Qualification of fasteners machined from bar may be omitted or limited as agreed with purchaser.			

10.4 Welding procedure qualifications

The qualification exercise shall include the supporting WPQR for the WPS for the following:

a) welded products in accordance with the applicable standard, material specification and/or MDS;

b) repair welding of welds in accordance with the applicable standard, material specification and/or MDS;

c) minor and major repair welding of castings as defined in the referred product standard.

11 Manufacturing procedure conformity record (MPCR)

11.1 General

The manufacturer shall establish a manufacturing procedure conformity record with content as listed in 11.2. One MPCR shall be established for each production route, type of product, grade of material and size range, if not otherwise agreed with Qualifying Company. The language to be used in documents included in an MPCR and essential procedures referred to in an MPCR shall be English. Documents may also be established as bilingual documents.

The MPCR shall be issued with document and revision numbers and shall have a front page with format and content as shown in Annex G.

It is essential that all documentation shall be accurate, specific and in accordance with this document. The documentation shall otherwise be rejected, and thereby also the qualification.

11.2 Content of manufacturing procedure conformity record (MPCR)

The MPCR shall contain the following:

a) MPCR front page. See format and content as shown in Annex G.

In the row "Other information" of the MPCR Front Page, possible comments, etc. which are essential for the assessment of the MPCR shall be stated.

A statement that heat treatment verification, see 9.3, has been carried out with reference to the corresponding heat treatment verification report shall be included:

b) Sect. 1 Table of contents;

c) Sect. 2 Applicable standard, material specification and/or MDS used as basis for the conformity assessment. Make reference to actual standards as ISO, EN, API, ASTM, NORSOK, etc. see Reference [2].

d) Sect. 3 Manufacturing Procedure Summary, see Clause 8, including:

1) process flow chart;

2) sketches showing typical samples, with dimensions of production test samples and location and orientation of test specimens;

3) procedure for microstructure examination, see 8.2.2 n) 5);

4) list of applicable procedures with revision numbers;

e) Sect. 4 Heat treatment procedure, see Clause 9, including:

1) report from the verification of heat treatment procedure, see 9.3;

2) report from the temperature uniformity test, see 9.1.3 and Annex B;

3) procedure for temperature uniformity survey, see 9.1.3 and Annex B;

f) Sect. 5 Results of qualification testing, including:

1) description of component(s) tested for qualification. Sketch(es) shall be prepared showing dimensions of test sample and location and orientation of test specimens;

2) heat treatment chart(s) from heat treatments of the components used for the qualification testing;

3) test reports with results from qualification testing;

4) start material certificate (when applicable);

g) Sect. 6 WPSs and WPQRs

1) welded products: a list of WPSs/WPQR with revision numbers shall be included;

2) castings: the actual WPS/WPQRs for repair welding of minor and major repairs shall be included;

h) Sect. 7 Specific reference list, including statistical data, see 7.1.2.

i) Sect. 8 Documentation of quality assurance system:

1) certificate(s) in accordance with ISO 9001 also from main subcontractors;

2) certificate of compliance to PED 2014/68/EU, Annex I, 4.3, if applicable.

3) for laboratories: ISO/IEC 17025 accreditation certificate with definition of the scope of the certificate, see 7.4.1 a). Alternatively, statement of conformity together with the filled-in Annex F form , see 7.4.1 b).

j) Sect. 9 MOM(s) from visit(s) to manufacturer by Conformity Assessment Body, as required in 5.3.

11.3 Required copies and distribution of manufacturing procedure conformity record

After acceptance, one electronic copy and one paper copy shall be issued to the purchaser having initiated or ordered the conformity assessment of the manufacturer, and to the Qualifying Company, if different from the purchaser, which monitored the conformity assessment and accepted the MPCR by signing the MPCR front page.

End users and purchasers intending to accept an MPCR initiated or ordered by others shall be given the possibility to review the subject MPCR. Whether this shall be carried out at the manufacturer's premises or by submitting the MPCR to the requesting body is at the manufacturer's discretion.

Annex A
(informative)

Manufacturing Procedure Summary front page and examples

A.1 Example of information to be included on the front page:

Actual plants, locations and equipment facilities where this procedure is relevant.

Product(s): *e.g. CLOSED-DIE FORGINGS*

Specification(s): *e.g. NORSOK M-630, MDS D44 Rev. 4*

Limitations in the procedure:

Mass:

Length:

Thickness:

Other:

Qualification documentation: *Ref. to the relevant document(s)/reports/test result(s) which confirm that manufacturing of materials in accordance with this procedure will ensure satisfactory results per the actual specification.*

Other relevant information:

Revision:	**Date:**	**Made by:**	**Checked by:**	**Approved by:**

Manufacturing Procedure Summary No.:

A.2 Example of Manufacturing Procedure Summary (4 pages)

Doc. No.: MS-03
Page 1 of 4

MANUFACTURING PROCEDURE SUMMARY
TEE MADE BY FORGING
Seamless pipe
Size 1" to 24"/Thickness 10 mm to 31,25 mm
ASTM A 815 UNS S31803 — MDS D43 REV. 24
(Prototype Tee 6" sch. 160)

No.	Phase	Description	Procedure
1	Identification of base material	Pipe to ASTM A790 S31803 MDS D41 *N* = 0,14 % to 0,20 % Manufacturer:	POQ-05
2	PMI	100 % raw material.	PMI-01
3	Cutting	Cutting to required length by saws	POQ-09
4	Identification marking	Hard-stamping of last two digits of heat number	POQ-05
5	Heating	Heating at *xxxx* °C to *xxxx* °C; holding time minimum 1 min for each mm thickness. Temperature controlled by optical pyrometer. Equipment = furnace bloss No. 3; furnace gibbon No. 2	POQ-09 I.O. 13
6	Ovalisation	Ovalisation of pipe by pressing Equipment = 60 t; 100 t; 150 t; 200 t; 250 t; 300 t; 400 t; 900 t; 1 200 t.	POQ-09 I.O. 13
7	Re-heating	Reheating at *xxxx* °C to *xxxx* °C, holding time minimum 1 min for each mm thickness. Temperature controlled by optical pyrometer.	POQ-09 I.O. 13
8	Forming	Forging by presses Start forming temperature *xxxx* °C to *xxxx* °C Equipment = 60 t; 100 t; 150 t; 200 t; 250 t; 300 t; 400 t; 900 t; 1 200 t. After forming, the temperature shall not be less than 950 °C.	POQ-09 I.O. 13
9	Cooling	Quenching in cold water.	
10	Cutting hole	Cutting of bulge.	
11	Re-heating	Re-heating at *xxxx* °C to *xxxx* °C holding time minimum 1 min for each mm thickness. Temperature controlled by optical pyrometer.	POQ-09 I.O. 13
12	Extrusion	Extrusion of branch by press After extrusion, the temperature shall not be less than *xxxx* °C. Re-heating at *xxxx* °C if more than one step is necessary.	POQ-09 I.O. 13
13	Cooling	Quenching in cold water.	
14	Cutting	Cutting to final dimensions by plasma, except section connecting test samples to body of tee	

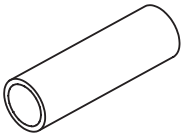
MANUFACTURING PROCEDURE SUMMARY
TEE MADE BY FORGING
Seamless pipe
Size 1" to 24"/Thickness 10 mm to 31,25 mm
ASTM A 815 UNS S31803 — MDS D43 REV. 4
(Prototype Tee 6" sch. 160)

No.	Phase	Description	Procedure
15	Heat treatment	*Heat treatment:* Solution-annealing in gas-heating furnace *Equipment:* Sottri truck-hearth with dimensions of: *Furnace loading temperature:* room temperature *Heating rate: xxxx* °C/h (above *xxxx* °C) *Holding temperature*: *xxxx* °C *Holding time:* 1h/1" wall thickness or minimum 15 min *Quenching:* In cold water maximum *xxxx* °C within 60 s.	HT-01
16	Shot blasting	Stainless steel grit.	
17	Sampling	Removal of material for test samples.	MDS D43 Test sample plan N° SP-01
18	Mechanical test	According to NORSOK MDS D43	MDS D43 Test sample plan N° SP-01
19	Pickling	Immersion in acid solution at temperature of xx °C Equipment: N° 2, pickling bath dimensions 900 mm x 1 600 mm x 1 000 mm	PK-01
20	Machining	Working of the ends as per purchase order	
21	Dye penetrant test	According to ASTM A815 Supplementary requirement S7 Acceptance criteria: ASME VIII Div.1 100 % of the fittings	ASME VIII Div.1 App.8
22	PMI	100 % of the fittings	PMI-01
23	Marking	Marking by low-stress stamping according P.O.	MDS D43
24	Visual and dimensional	By calibrated equipment	POQ-05 Drw. No. 972
25	Pickling	Re-immersion in acid solution for final cleaning and passivation	PK-01
26	Final dossier	Inspection certificate plus NDE certificates	EN 10204, 3.1
27	Packing	According to order requirements	ASTM E700

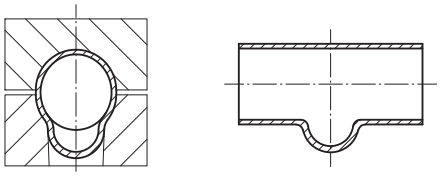
Revision No.:	**Date:**	**Made by:**	**Approved by:**	**NOTE** Flow chart is shown on page 4 coloured route.

MANUFACTURING SEQUENCE FOR SEAMLESS TEES	DWG N.972

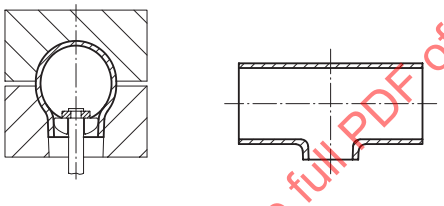
1) RAW MATERIAL



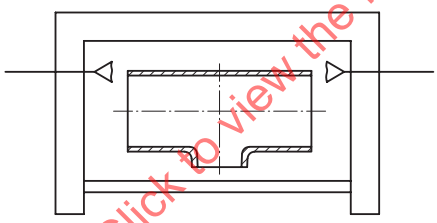
2) FORMING



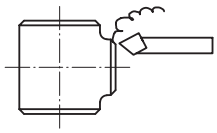
3) BRANCH SIZING (BY PULLING)



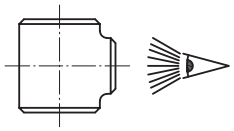
4) HEAT TREATMENT



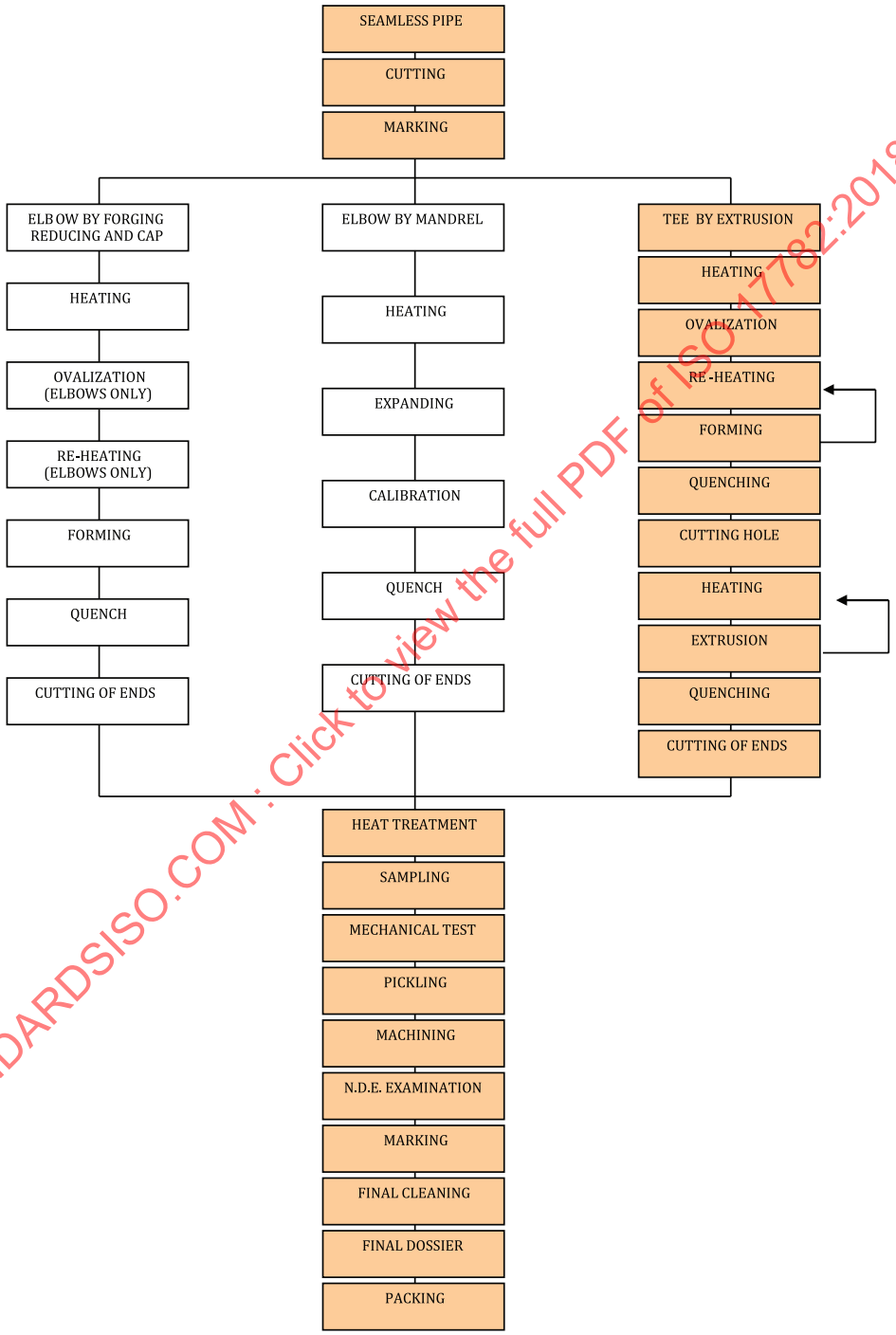
5) MACHINING (BEVEL)



6) VISUAL & DIMENSIONAL CHECK



Example of manufacturing flow chart
Manufacture flow chart for elbow and tee manufacture



Annex B
(normative)

Temperature Uniformity Survey — Additional requirements to Annex M of ISO 10423:2009 and ASTM A991-10

B.1 General requirements

A temperature uniformity survey (TUS) of quality heat treatment furnaces shall be performed in accordance with ISO 10423:2009 or ASTM A991-10, with the following additional requirements.

NOTE For the purposes of this requirement, API 6A:2010 is equivalent to ISO 10423:2009.

a) The alternatives of attaching thermocouples to the extremities of each load as described in ASTM A991-10, 1.4, or the alternative surveying techniques as described in ASTM A991-10, 7.7, are not acceptable as an alternative to the specified temperature uniformity survey.

b) The temperature uniformity survey shall be carried out at the maximum set-point temperature for the materials being qualified per this document, which will be processed in the furnace. The maximum limit of 1 100 °C stated in ASTM A991-10, 6.1.1.2, shall not apply.

c) The documentation of the temperature uniformity survey shall include a sketch of the furnace with the working zone of furnace and the number and location of thermocouples used for the survey, see ISO 10423:2009, M.3.3, or ASTM A991-10, 8.2.7 and 8.2.8.

NOTE For the purposes of this requirement, API 6A:2010 is equivalent to ISO 10423:2009.

d) A uniformity survey shall be performed annually on the actual furnaces cited in the MPS for solution heat treatment.

e) The manufacturer shall establish a procedure for carrying out the temperature uniformity survey.

B.2 Batch type furnaces

The following additional requirements to ASTM A991-10 apply:

a) for furnaces with set-point temperature in the working zone above 800 °C, the temperature at any point shall not vary by more than ±14 °C from the furnace set-point temperature after the furnace working zone has been brought up to temperature;

b) for furnaces with set-point temperature in the working zone below 800 °C, the temperature shall not vary by more than ±8 °C from the furnace set-point temperature after the furnace working zone has been brought up to temperature;

c) once the furnace temperature has reached the set-point temperature, the temperature of all test locations shall be recorded at maximum 2 min intervals for at least 10 min, then readings shall be taken at maximum 5 min intervals for sufficient time to determine the recurrent temperature pattern of the furnace working zone for at least 30 min.

B.3 Continuous and semi-continuous conveyance furnaces

The temperature uniformity check may be carried out as verification of the heat treatment procedure, see 9.3.

In any case, the following requirements apply:

a) the survey shall verify that:

   1) the specified heat treatment temperature for a material can be kept uniform within the specified tolerances through the soaking zone of the furnace, as defined in the heat treatment procedure;

   2) the component travel speeds defined in the heat treatment procedure result in the minimum specified soaking time being achieved, measured from when the set temperature is reached.

b) the temperature survey shall be carried out on actual products. A minimum of two surveys shall be carried out with products representing respectively the smallest (thinnest) and largest (thickest) sizes to be heat treated.

Annex C
(informative)

Verification of the heat treatment procedure — Example

A comparison of time-temperature curves of the contact thermocouples (three-off) fixed to the load itself with the furnace thermocouple is shown in Figure C.1. Note the time difference to reach set temperature between the furnace thermocouple and the contact thermocouples fixed onto the load.

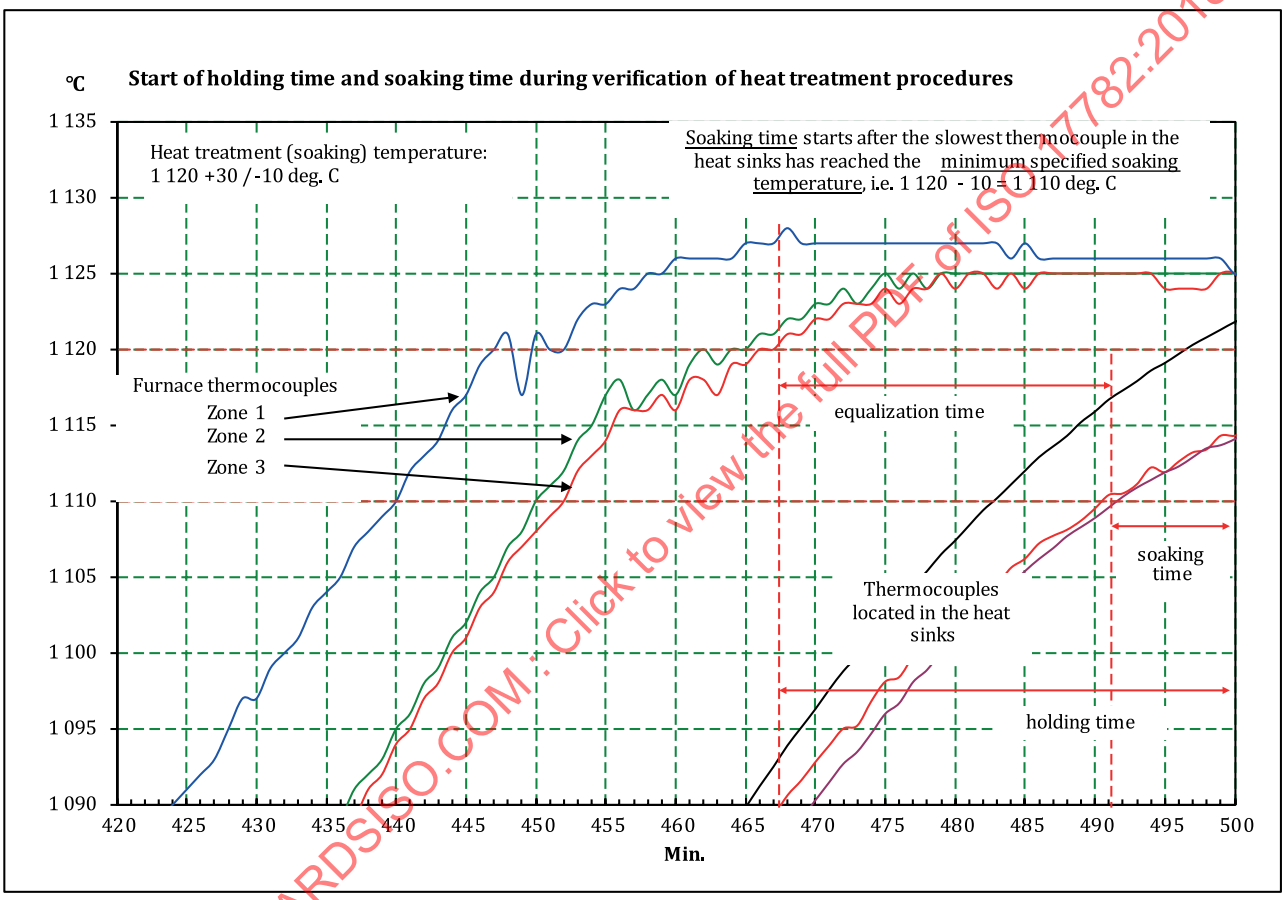


Figure C.1 — Comparison of time-temperature curves of contact thermocouples and furnace thermocouples during heat treatment

Annex D
(normative)

Fasteners

Annex D summarises production testing and additional testing for qualification.

Production testing: As specified in the applicable standard, material specification and/or MDS. Fasteners machined from bar material may be certified using test data which are transferred from the original and solution annealed bar material or the strain hardened bar material, whichever is applicable.

Qualification testing shall be carried out after threading as shown in:

— Table D.1 — Qualification testing of headed bolts hot forged and subsequently heat treated;

— Table D.2 — Qualification testing of headed bolts machined from bar in heat treated condition;

— Table D.3 — Qualification testing of studs made from bars in heat treated or strain hardened condition;

— Table D.4 — Qualification testing of nuts machined from bar or forged and heat treated;

Table D.1 — Qualification testing of headed bolts hot forged and subsequently heat treated

Type of tests[a,b]	Hex bolts $t \geq 37$ mm		Hex bolts $t < 37$ mm	
	Figure D.1			
	Shank	Head	Shank	Head
Impact close to surface	C			
¼ d tensile longitudinal	A + G			
½ d tensile longitudinal			B + H	
¼ d impact longitudinal	A + G			
½ d impact longitudinal	B		B + H	
½ d impact tangential[c]	E	D		D
¼ d micro transverse	A + G			
½ d micro transverse	B		B + H	
G48 from surface to mid thickness	F		F	
Wedge tensile testing Test method according to ASTM A370-14, Annex 3.	In addition to qualification testing of the largest size to be qualified, wedge tensile testing shall be carried out on a fastener with diameter equal or close to Ø 37 mm		Required	
Rockwell C hardness (HRC)	Figure D.4		Figure D.4	

a Specimens shall be located at a distance t or 100 mm, whichever is less, or at mid-distance, from any second surface.

b "*d*" = shaft diameter for bolts; "*d*" = "*t*" for heads, ref. Figure D.1.

c For "*d*" or "*t*" ≥ 60mm only.

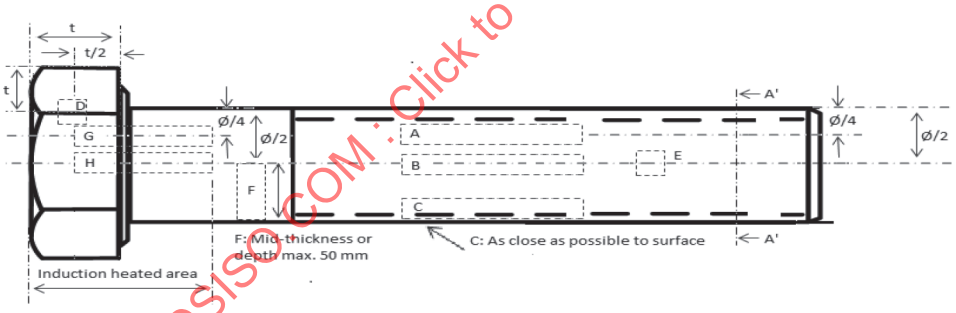


Figure D.1 — Location of test specimens for forged hex bolts