1 FOREWORD

This standard has been developed by the NORSOK standardisation work group and agreed by the Norwegian industry for the widest possible national and international application.

2 SCOPE

The scope of this standard is to provide general principles, engineering guidance and requirements for material selection and corrosion protection for all parts of offshore installations.

This document gives guidance and requirements for:

- Corrosion and material selection evaluations.
- Life cycle cost evaluations.
- Specific material selection where appropriate.
- Corrosion protection.
- Design limitations for candidate materials.
- Qualification requirements for new materials or new applications.
3 NORMATIVE REFERENCES

API 5L Specification for Line Pipe. To be replaced by ISO 3183-3 when available.
API 6A Drilling and Production Equipment - Specification for Valves, Wellhead and Christmas tree equipment. To be replaced by ISO 10423 when available.
API RP 17B Recommended Practice for Flexible Pipe. To be replaced by ISO 13 628-2, when available.
API RP 2FP1 Recommended Practice for Design, Analysis and Maintenance of Moorings for Floating Production Systems.
ASME B31.3 Chemical Plant and Petroleum Refinery Piping.
ASTM A 193 Specification for Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service.
ASTM A 194 Specification for Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service.
ASTM D 2992 Practice for Obtaining Hydrostatic or Pressure Design Basis for Fibreglass Pipe and Fittings.
Det norske Veritas DnV Rules for Classification of Ships and Mobile Offshore Units.
EFC 086 WP1-93 Draft Document Guidelines on Material Requirements for Carbon and Low Alloy Steels for H2S containing Oil and Gasfield Service. (Adoption to CEN/ISO standard planned.)
NACE MR0175 Sulphide Stress Cracking Resistant Metallic Materials for Oilfield Equipment (National Association of Corrosion Engineers).
NS 3420 "Beskrivelsestekster for bygg og anlegg" (Specification texts for building and construction).
NS 3473 Concrete Structures. Design Rules.
NORSOK Standards:

L-CR-001 Piping and Valves
M-CR-101 Structural Steel Fabrication
M-CR-120 Material Data Sheets for Structural Steel
M-CR-501 Surface Preparation and Protective Coating
M-CR-503 Cathodic Protection Design
M-CR-505 Corrosion Monitoring Design
M-CR-601 Welding and Inspection of Piping
M-CR-621 GRP Piping Materials
M-CR-630 Material Data Sheets for Piping
M-CR-650 Qualification of Manufacturers of Special Materials
M-CR-701 Materials for Well Completion Equipment
M-CR-710 Qualification of Non-metallic Sealing Materials and Manufacturers

4 DEFINITIONS AND ABBREVIATIONS

4.1 Definitions

C- glass  A special fibre type that is used for its chemical stability in corrosive environments.

E-glass  The general purpose fibre that is most used in reinforced plastics.

ECR-glass  A modified E-glass fibre type with improved corrosion resistance against acids.

Free machining steel  Steel to which elements such as sulphur, selenium, or lead have been added intentionally to improve machinability.

Operating temperature  The temperature in the equipment when the plant operates at steady state condition, subject to normal variation in operating parameters.

Maximum operating temperature  The temperature in the equipment when the plant operate at unstable conditions, like control requirements, process flexibility and process upsets.

Oxygen  ppb oxygen + 0.3 x ppb free chlorine.

Equivalent PRE  Pitting Resistance Equivalent, PRE = % Chromium + 3.3 x % Molybdenum + 16 x % Nitrogen.
### Metallic Materials

<table>
<thead>
<tr>
<th>Generic type</th>
<th>UNS</th>
<th>Nominal alloy composition</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Cr</td>
<td>% Ni</td>
<td>% Mo</td>
</tr>
<tr>
<td><strong>Carbon and low alloy steels</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>235</td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>235LT</td>
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</tr>
<tr>
<td>360LT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5% Ni</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Martensitic stainless steels</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13Cr</td>
<td></td>
<td>13</td>
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</tr>
<tr>
<td>13Cr 4Ni</td>
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<td>4</td>
</tr>
<tr>
<td>17 - 4 PH</td>
<td>S17400</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td><strong>Austenitic stainless steels</strong></td>
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<td></td>
</tr>
<tr>
<td>310 S31000</td>
<td>25</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>316 S31600</td>
<td>17</td>
<td>12</td>
<td>2.5</td>
</tr>
<tr>
<td>6Mo</td>
<td></td>
<td></td>
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<tr>
<td>S31254 N08925</td>
<td>20</td>
<td>18</td>
<td>6</td>
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<tr>
<td>N08926</td>
<td>20</td>
<td>25</td>
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<td>N08367</td>
<td>21</td>
<td>24</td>
<td>6</td>
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<tr>
<td>904 N08904</td>
<td>21</td>
<td>25</td>
<td>4.5</td>
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<tr>
<td><strong>Duplex stainless steels</strong></td>
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<td></td>
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<tr>
<td>22Cr S31803</td>
<td>22</td>
<td>5.5</td>
<td>3</td>
</tr>
<tr>
<td>25Cr S32550 S32750 S32760</td>
<td>25</td>
<td>5.5</td>
<td>3.5</td>
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### Nickel base alloys

<table>
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<tr>
<th>Alloy</th>
<th>UNS</th>
<th>% Mn</th>
<th>% Cu</th>
<th>% Cr</th>
<th>% Ni</th>
<th>% Mo</th>
<th>% W</th>
<th>% Nb</th>
<th>Base materials:</th>
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<tbody>
<tr>
<td>C22</td>
<td>N26022</td>
<td>21</td>
<td>rem.</td>
<td>14</td>
<td>16</td>
<td>rem.</td>
<td>W=3</td>
<td>Nb=4</td>
<td>UNS N06625.</td>
</tr>
<tr>
<td>C-276</td>
<td>N10276</td>
<td>16</td>
<td>rem.</td>
<td>16</td>
<td></td>
<td></td>
<td>W=4</td>
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<tr>
<td>625</td>
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<td>22</td>
<td>rem.</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td>Nb=4</td>
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</tr>
<tr>
<td>718</td>
<td>N07718</td>
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<tr>
<td>800</td>
<td>N08810</td>
<td>21</td>
<td>33</td>
<td>-</td>
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<td></td>
<td></td>
<td>Al + Ti</td>
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<tr>
<td>825</td>
<td>N08825</td>
<td>21</td>
<td>42</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>Ti</td>
<td></td>
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<tr>
<td>Co-alloy</td>
<td>R30003</td>
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<td></td>
<td>Co=40</td>
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<td></td>
<td></td>
<td>Ti, Co</td>
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</table>

### 4.2 Abbreviations

- **AFFF**: Aqueous Film Forming Foams
- **AWS**: American Welding Society.
- **CRA**: Corrosion Resistant Alloy.
- **CTOD**: Crack Tip Opening Displacement.
- **EFC**: European Federation of Corrosion.
- **GRP**: Glass fibre Reinforced Plastic.
- **LCC**: Life Cycle Cost.
- **MDS**: Material Data Sheets.
- **NACE**: National Association of Corrosion Engineers.
- **SMYS**: Specified Minimum Yield Strength.
- **UNS**: Unified Numbering System.
5 GENERAL PRINCIPLES FOR MATERIAL SELECTION AND CORROSION PROTECTION

5.1 Material selection

Material selection shall be optimized, considering investment and operational costs, such that Life Cycle Costs (LCC) are minimized while providing acceptable safety and reliability.

The following key factors apply to materials selection:

- Primary consideration shall be given to materials with good market availability and documented fabrication and service performance.
- The number of different material types shall be minimized considering costs, interchangeability and availability of relevant spare parts.
- Design life.
- Operating conditions.
- Experience with materials and corrosion protection methods from conditions with similar corrosivity.
- System availability requirements.
- Philosophy applied for maintenance and degree of system redundancy.
- Weight reduction.
- Inspection and corrosion monitoring possibilities.
- Effect of external and internal environment, including compatibility of different materials.
- Evaluation of failure probabilities, failure modes, criticalities and consequences. Attention shall be paid to any adverse effects material selection may have on human health, environment, safety and material assets.
- Environmental issues related to corrosion inhibition and other chemical treatments.
- For main systems where materials/fabrication represent significant investments and/or operational costs, an LCC analysis shall be basis for material selection (Ref. Annex A).

5.2 Deviation from specified material selections

Where an overall evaluation of LCC, safety and reliability shows that it is more cost effective to deviate from the specific materials selections and corrosion protection principles given in this document and the NORSOK standards referenced herein the alternative solution should be implemented. Such deviations may include replacement of CRAs with carbon steel where CRAs are specified in this standard.

Suppliers standard materials shall be used for equipment, provided that:

- This is cost efficient.
- The supplier can document previous successful experience.
- The materials satisfy the general requirements given in this document with respect to corrosion resistance and/or maintenance and replacement.
5.3 Corrosivity and corrosion protection

5.3.1 Corrosion allowance

For carbon steel piping, a corrosion allowance of 3 mm shall be used, unless higher corrosion allowances are required.

Recommendation:

For submarine pipeline systems a total corrosion allowance of 10 mm is recommended as a general upper limit for use of carbon steel. Carbon steel can be used in pipelines where calculated inhibited annual corrosion rate is less than 10 mm divided by design life. Otherwise corrosion resistant alloys, solid or clad or alternatively flexible pipe, should be used. For pipelines with dry gas or dry oil, no corrosion allowance is required. Corrosion during installation and testing prior to start-up shall be considered.

5.3.2 Corrosivity evaluations in hydrocarbon systems

Evaluation of corrosivity shall as a minimum include:

- CO₂-content.
- H₂S-content.
- Oxygen content and content of other oxidizing agents.
- Operating temperature and pressure.
- Acidity, pH.
- Halogenide concentration.
- Velocity flow regime.

A gas system is defined wet when the relative humidity exceeds 50 %.

The evaluation of CO₂ corrosion should be based on the corrosion prediction model published by C. de Waard, U. Lotz/Shell, NACE Corrosion/93, Paper No. 69.

Note: This model shall be used on a preliminary basis unless previous experience from the same field justifies different predictions. Improved models are expected in the near future.

Corrosion inhibitors shall not be used to reduce corrosion of carbon or low alloy steels in production wells, subsea trees and subsea piping systems.

Recommendation:

Use of corrosion inhibitors in topside process systems is not recommended, but can be used provided inhibitor in each process stream satisfies the inhibitor suppliers minimum recommended concentration.

For pipelines, an inhibitor efficiency of 85 % shall be used for design, including effect of glycol and/or methanol injection. The inhibitor efficiency shall be qualified and documented by corrosion tests unless relevant field or test data are available.
In pipeline systems carrying hydrocarbons with condensed water, the corrosivity may be reduced by application of inhibitors in combination with pH stabilizers as an alternative to inhibitors alone. The combined effect of inhibitors and pH stabilizers shall be qualified and documented by corrosion tests unless relevant documentation exists.

Vessel materials for topside oil separation and gas treating systems shall be selected based on the same corrosivity criteria as for topside hydrocarbon piping systems. Vessels manufactured in solid CRAs, internally CRA clad or weld overlayed, will not need additional internal corrosion protection systems.

Risk for "sour" conditions during the lifetime shall be evaluated. Requirements to metallic materials in "sour" service shall comply with NACE MR0175 standard with amendments given in this standard.

Recommendation:

When new EFC standards are issued, such as EFC document EFC 086 WPI-93, it is recommended to replace NACE MR0175 by these. (The EFC standards are planned issued later as CEN and/or ISO standards).

Drying or use of corrosion inhibitors shall not relax the requirement to use "sour" service resistant materials if the conditions otherwise are categorized as "sour" by the above documents.

5.3.3 External corrosion protection

The external atmospheric environment shall be considered wet with the condensed liquid saturated with chloride salts. Material selection and surface protection shall be such that general corrosion is cost effectively prevented and chloride stress corrosion cracking, pitting and crevice corrosion are prevented.

Carbon steel shall always have surface protection to the external environment. Additional corrosion allowance or other means of protection are required for installations in the splash zone.

Recommendations:

Corrosion resistant alloys should not be coated, except under insulation or pipe clamps or when submerged in seawater. Submerged small bore stainless steel piping should not be coated.

Corrosion allowance sizing for carbon steel in the splash zone should follow the below guidelines:

- Structures with thin film coating: Min. 5 mm.
  - For design lives > 17.5 years.
  - Corrosion allowance = (Design life - 5 years) x 0.4 mm/year.
- Risers: Min. 2 mm in combination with min. 12 mm vulcanized chloroprene rubber. At elevated temperature the corrosion allowance should be increased by 1 mm pr. 10 degrees C increase in temperature above 20 °C.
Coating system selections for pipelines, structures and topside equipment shall take due consideration to structural design, operating conditions and conditions during storage and installation. The coating systems selection and requirements to application are covered by NORSOK Standard M-CR-501 for structures and topside equipment.

The following areas/conditions shall be subject to special evaluation:

- Coatings for areas in the splash zone.
- Use of thermally sprayed aluminium coating for elimination of maintenance coating.
- Coatings for passive fire protection.
- Coatings for bolts and nuts, flanges, machined surfaces of valves, etc. For such applications wax coatings should be considered.

Cathodic protection shall be used for all submerged, metallic materials, except for materials which are immune to seawater corrosion. Surface coating shall in addition be used for components with complex geometry and where found to give cost effective design.

Recommendation:

The extent and type of coating shall be determined by the following factors:

- Cost savings due to reduced anode weight.
- Required coating to obtain rapid polarization, including use of shop primers only.
- Required coating quality to obtain low coating breakdown.
- Accessibility for coating application.
- Cost saving by not coating weld areas.

The design shall be based on NORSOK Standard M-CR-503. Welded connections are recommended for subsea applications. Flanged and screwed connections shall be avoided where possible. The electrical continuity to the cathodic protection system shall be verified by actual measurements for all components and parts not having a welded connection to an anode.

Any components permanently exposed to ambient seawater and for which efficient cathodic protection can not be ensured, shall be fabricated in seawater resistant materials. Exceptions are components where corrosion can be tolerated. Material selection should take into account probability for, and consequence of, component failure.

Recommendation:

The following materials are regarded as corrosion resistant when submerged in seawater at ambient temperature:

- Alloy 625 and other nickel alloys with equal or higher PRE value.
- Titanium alloys (For limitation wrt. cathodic protection, ref. table 5).
- GRP.
- Other materials, provided adequately documented.

NOTE: Stainless steels Type 6Mo and Type 25Cr duplex are borderline cases and not considered as fully seawater resistant in this respect. These materials should not be used for threaded connections without cathodic protection.
5.3.4 Corrosion protection of closed compartments

For completely closed seawater filled compartments in carbon steel, e.g. in jacket legs, J-tubes and caissons, etc. no internal corrosion protection is needed. For compartments with volume to area ratios exceeding 1 m³/m², treatment with oxygen scavenger can be used as an alternative to cathodic protection.

5.3.5 Insulation, topside applications

Thermal insulation for topside applications shall be avoided to the extent possible, and only be used if required for safety or processing reasons. Piping and equipment which have to be insulated shall be coated in accordance with NORSOK Standard M-CR-501.

The requirement for coating under insulation also includes CRAs. Titanium alloys need not be coated even if insulated.

The design of insulation for structures and piping systems shall ensure drainage, and access in areas where maintenance and inspection are required. Heat tracing shall to the extent possible be avoided in conjunction with stainless steel materials.

5.3.6 Galvanic corrosion prevention

Wherever dissimilar metals are coupled together in piping systems, a corrosivity evaluation shall be made. If galvanic corrosion is likely to occur, the dissimilar materials shall either be electrically isolated with an isolating spool or the more noble material shall be internally coated close to the coupling. Length of coated/isolated section shall be minimum 10 pipe diameters. Necessary corrosion allowance shall be provided in transition areas. Alternatively, galvanic corrosion can be catered for by corrosion allowance, only.

Recommendation:

At galvanic connections between dissimilar materials without isolation, it can be assumed that the local corrosion rate near the interface is approximately 3 times higher than the average corrosion rate, decreasing exponentially away from the interface within a length of 5 pipe diameters. This should be used to establish magnitude of corrosion allowances. Particular systems may have higher corrosion rates depending on area ratio and material combinations.

For connections between copper alloys and stainless steel/nickel alloys/titanium, the use of easily replaceable spools with added wall thickness shall be evaluated.

In hydrocarbon systems, isolating spools shall be avoided and transitions shall normally be made in dry, inhibited or other areas with low corrosivity.

5.3.7 Carbon steel welds

For pipe systems with corrosive service the welds shall be compatible with the base material in order to avoid local corrosion of weldment and heat affected zone.
Welds in submarine flowline and pipeline systems for corrosive hydrocarbons shall be qualified by corrosion testing under simulated operating conditions with and without corrosion inhibitors at the latest as a part of weld procedure qualifications, unless relevant documentation exist.

Note: This implies that corrosion inhibitor selection has to be carried out at latest during the engineering phase. Corrosion problems have arisen in the past with nickel containing electrodes.

For systems with “sour service” requirements the Ni content shall be less than 2.2%.

Welding consumables for water injection systems shall have a chemical composition according to NORSOK standard M-CR-601 or have a composition which is documented not to give preferential corrosion in weld/heat affected zone.

5.4 Weld overlay

Weld overlay on carbon steel shall be performed in accordance with Table 6.2. In corrosive hydrocarbon systems weld overlay with Alloy 625, defined as AWS ERNiCrMo3, giving minimum 3 mm thickness as-finished, may replace homogeneous corrosion resistant materials. The maximum iron content at the finished surface shall be 10 weight per cent. When carbon steel or low alloy steel is chosen for oil and gas piping, overlay welding with Alloy 625 shall be evaluated for critical sealing surfaces.

Where weld overlay is used to prevent crevice corrosion in seawater systems, alloys with documented crevice corrosion resistance in the as weld overlayed condition shall be used. The maximum temperature shall be documented.

Recommendation:

The use of MTI test procedure, MTI Manual No. 3, is recommended for documentation of crevice corrosion resistance, using a tightening torque of 2 Nm. The selected tightening torque has been established based upon recent results and correlation to operational conditions should be verified.

Weld overlay for hardfacing shall be as specified in relevant data sheets. In corrosive service the hardfacing material as applied on the substrate shall have documented corrosion resistance.

5.5 Chemical treatment

Corrosion inhibitors, scale inhibitors, oxygen scavenger or other chemicals can be used to reduce corrosion in process, fresh water and seawater systems etc. The efficiency in the specified service shall be proven and documented as well as the compatibility with other chemicals to be used.

Biocides can be used in process, injection water systems etc. to prevent bacterial growth and possible microbiologically induced corrosion problems.
5.6 Corrosion monitoring

Design of corrosion monitoring systems shall be based upon criticality evaluations taking appropriate note of probability of failure/damage and the consequences. Such systems shall at least be evaluated for carbon steel pipelines and flowlines, carbon steel hydrocarbon piping and cathodic protection systems.

6 MATERIAL SELECTION FOR SPECIFIC APPLICATIONS/SYSTEMS

6.1 Introduction

This clause gives requirements to material selection for specific areas and systems. The selections are based upon contemporary North Sea practice and available technology.

All bulk materials for piping systems and structural components shall comply with relevant NORSOK Material Data Sheets. Material selections are given below and limitations for material alternatives are given in clause 7.

6.2 Drilling equipment

The materials used in drilling equipment shall be in compliance with the relevant API and ISO specifications. The material selection for drilling equipment shall be in accordance with general requirements in this document.

6.3 Well completion

All well completion materials, including elastomers, shall be compatible with produced/injected fluid. In addition, the materials shall as a minimum be compatible with the following well intervention fluids with additives for relevant exposure durations:

a) Completion and packer brine fluids
b) Mud acids (HCl - hydrochlorid acid, HF - hydrofluoric acid)
c) Stimulation fluids
d) Scale inhibitors
e) Methanol

Material selection for well completion is given in table 6.1.

Polymers shall satisfy the requirements given in 7.4.

Titanium alloys shall not be used in permanently installed well completion equipment, when hydrofluoric acid or pure methanol (less than 5 % water) are planned to be used.
Flow couplings shall be used at transitions between CRA and low alloy tubing materials to allow for galvanic corrosion in injection wells. The sealing surface of couplings to be used should not be located in areas expected to be affected by corrosion. Alternatively, internal baked phenolic coating can be considered. For production wells, flow couplings may be evaluated for use upstream and downstream of components causing obstructions to fluid flow, such as for downhole safety valves.

For hydraulic control lines for downhole safety valves stainless steel type 316 and UNS N08825 shall be used up to 60°C and 120°C respectively, with external thermoplastic sheathing. Clamps for cables and hydraulic control lines can be made in carbon or low alloy steel if the design allows for expected degree of corrosion.

Table 6.1 - Material selection for wells

<table>
<thead>
<tr>
<th>Well type</th>
<th>Tubing and liner</th>
<th>Completion equipment (Where different from tubing/liner)</th>
<th>Note</th>
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</thead>
<tbody>
<tr>
<td>Production</td>
<td>13Cr is Base Case. See table 5 for design limitations.</td>
<td>13Cr</td>
<td>1</td>
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<tr>
<td></td>
<td>Low alloy steel. (Option for systems with low corrosivity/short lifetime)</td>
<td>13Cr</td>
<td>1, 2</td>
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<tr>
<td></td>
<td>13 % Cr and 15 % Cr alloys modified with Mo/Ni, , duplex and austenitic stainless steels and nickel alloys are options for high corrosivity</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Deaerated seawater injection</td>
<td>Low alloy steel</td>
<td>UNS N09925, Alloy 718 22Cr or 25Cr duplex</td>
<td>2, 4, 7</td>
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<tr>
<td>Raw seawater injection</td>
<td>Low alloy steel with GRP or other lining</td>
<td>Titanium, Alloy C276</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Low alloy steel for short design life</td>
<td>Titanium, Alloy C276</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Titanium, Alloy C276</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Produced water and aquifer injection</td>
<td>Low alloy steel</td>
<td>13Cr (Limitations as for tubing for this service)</td>
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<td></td>
<td>Low alloy steel with GRP or other lining</td>
<td>13Cr (Limitations as for tubing for this service))</td>
<td>1, 5</td>
</tr>
<tr>
<td></td>
<td>13Cr. Provided oxygen &lt; 10 ppb, see also table 5.</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>22Cr duplex, Alloy 718, N09925. Provided oxygen &lt; 20 ppb.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas injection</td>
<td>Material selection shall be as for production wells and shall follow the guidelines in 5.3.2.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternating injection</td>
<td>Material selection shall take into account that the corrosion resistance of different material alternatives will differ for various media.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.4 Structural materials

6.4.1 Steel

Bolting materials shall comply with 6.5.5.

Recommendation:

It shall be considered to use only one steel grade in each project, e.g. steel grade with SMYS 355 or 420, in order to get benefits from standardization. Benefits of saving weight by using high strength steels (i.e. SMYS of 420 MPa or higher) shall be considered.

6.4.2 Concrete

Concrete materials properties shall comply with NS 3420, Exposure Class Ma - Highly Aggressive Environment and NS 3473. Maximum water to binder ratio shall be 0.45.

6.4.3 Aluminium

Aluminium alloys shall be of a seawater resistant grade, i.e. in the alloying system AlMg and AlMgSi. Acceptable material grades are AlMg3Mn (AA 5454), AlMg4.5Mn (AA 5083), AlMgSi0.7 (AA 6005) and AlSi1MgMn (AA 6082). The AA 6005 and AA 6082 alloys shall be used for extrusions and thick plates and the AlMg-alloys for thin plates. AlMg-alloys should be used as far as possible.
6.4.4 Passive fireproofing materials

Passive fireproofing materials for protection of structural steel or for area segregation should be of spray applied types. A corrosion protection coating system shall be applied to the steel. The passive fireprotection materials shall be sprayed to required minimum thickness.

For outdoor applications, or where the passive fireproofing is subjected to wear, impact or other mechanical damages, an epoxy based coating system shall be used. For other applications, cement type materials with a diffusion open top-coat can be used. Panel based passive fire protection products shall be considered as an alternative for protection of structures or for area segregation.

6.5 Topside facilities

6.5.1 General

Carbon steel can be used in topside systems where the calculated annual corrosion rate is less than corrosion allowance divided by design life. For inhibitors in topside systems reference is made to 5.3.2.

The piping materials shall be standardized on the following material types as far as practical:

- Carbon steel Type 235, Type 235LT, Type 360LT
- Stainless steel Type 316
- Stainless steel Type 22Cr duplex.
- Stainless steel Type 6Mo.
- Titanium.
- GRP.

Other materials shall only be introduced after their performance and availability have been considered.

Cast stainless steel Type 6Mo shall not be used for components to be welded.

Material selections for topside facilities are given in table 6.2 with amendments as given below. A premise for the selections in the table has been limitation of number of grades and types for each application.

6.5.2 Oil and gas processing

When assessing corrosivity throughout a processing system, the partial pressure of CO₂ and H₂S in the gas phase in separators and scrubbers can be used as basis for evaluating corrosivity. To compensate for the fact that these gases are not at equilibrium in each separator, the following assumptions shall be made unless otherwise justified by experience:

- When the corrosivity in a separator and the liquid carrying piping downstream this separator is evaluated, the mean partial pressure of the foregoing separator and the actual separator shall be used.
- For gas scrubbers and piping downstream separators carrying gas, the actual partial pressure can be used directly.
Pressure rating, maximum/minimum design temperature and size shall be taken into account when selecting materials.

All components which may contact oil well streams shall be resistant against well treating, well stimulating chemicals and other additives.

6.5.3 Seawater systems

Hot dip galvanized carbon steel can be used in seawater systems provided it is documented to be cost efficient by LCC analysis and replacement is planned for in design. If this material is evaluated for usage in firewater systems, special attention shall be made to the risk for plugging of sprinkler/deluge nozzles.

Graphite gaskets shall not be used in stainless steel seawater piping systems.

Downstream heat exchangers it shall be taken into account that relatively high operating temperatures may occur when marine fouling is not present inside the heat exchanger, i.e. initially and after cleaning operations.

Table 6.2 - Materials for topside facilities, Sheet 1 of 3

<table>
<thead>
<tr>
<th>Oil and gas production and processing</th>
<th>Materials</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosivity evaluations shall be based on 5.3.2. and 6.5.2.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wellhead equipment/ X-mas trees</td>
<td>13Cr4Ni, Low alloy steel with alloy 625 weld overlay. API 6A</td>
<td>1</td>
</tr>
<tr>
<td>Piping and vessels</td>
<td>22Cr duplex, 6Mo, 316.</td>
<td></td>
</tr>
<tr>
<td>Thick wall vessels</td>
<td>Carbon steel with 316, Alloy 625, N08825 or N08904 clad or weld overlay.</td>
<td></td>
</tr>
<tr>
<td>Piping and vessels in low corrosivity systems</td>
<td>Carbon steel.</td>
<td></td>
</tr>
<tr>
<td>Inlet side of compressors</td>
<td>Carbon steel. Carbon steel with CRA weld overlay or solid CRA if required, based upon corrosivity evaluations.</td>
<td></td>
</tr>
<tr>
<td>Piping, vessels for produced water</td>
<td>316, 22Cr duplex, 6Mo, Titanium or GRP.</td>
<td></td>
</tr>
</tbody>
</table>
Seawater systems and raw seawater injection | See also 6.5.3.
---|---
Wellhead equipment/ X-mas trees | Carbon steel with weld overlay according to 5.4
Vessels | Titanium, GRP, carbon steel with internal rubber lining or organic coating in combination with cathodic protection.
Piping materials | 6Mo, Titanium, GRP.
Valves in GRP systems | GRP, Carbon steel with polymeric lining, NiAl bronze.
Normally drained systems | Copper base alloys, 6Mo, Titanium. Carbon steel for short lifetimes, e.g. 5-10 years.
Pumps | 25Cr duplex, 6Mo, Titanium, 4, 5, 6

Deaerated seawater injection | See also 6.5.4.
---|---
Wellhead equipment/ X-mas trees | Low alloy steel with Alloy 625 weld overlay in sealing surfaces. Design must allow for corrosion on non overlayed parts. API 6A
Piping | Carbon steel, GRP.
Deaerated tower | Carbon steel with internal organic coating, plus cathodic protection in bottom section.
Pump and valve internals | Provided carbon steel housing: 13Cr4Ni, 316, 22Cr duplex, 25Cr duplex.
Produced water and aquifer injection | Carbon steel, 316, 22Cr duplex, 6Mo, Titanium, GRP. Wellhead and X-mas trees as for deaerated seawater injection.
Fresh and potable water | Hot dip galvanized carbon steel, GRP, Polypropylene, 316, Copper base alloys.

---
## Table 6.2 - Materials for topside facilities, Sheet 2 of 3

<table>
<thead>
<tr>
<th>Drains and sewage</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open drain</td>
<td>GRP, carbon steel.</td>
</tr>
<tr>
<td>Closed drain without oxygen</td>
<td>316, carbon steel.</td>
</tr>
<tr>
<td>Closed drain with oxygen</td>
<td>22Cr duplex, 6Mo, Titanium, GRP.</td>
</tr>
<tr>
<td>Sewage</td>
<td>GRP, polyethylene.</td>
</tr>
</tbody>
</table>

### Flare systems

<table>
<thead>
<tr>
<th></th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relief system</td>
<td>316, 6Mo, low temperature carbon steel.</td>
</tr>
<tr>
<td>Burner components</td>
<td>UNS N08810, Alloy 625; For temperatures below 650 °C: 310.</td>
</tr>
<tr>
<td>Flare boom</td>
<td>Structural steel with thermally sprayed aluminium.</td>
</tr>
</tbody>
</table>

### Dry fuel gas and diesel

<table>
<thead>
<tr>
<th></th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piping</td>
<td>Carbon steel.</td>
</tr>
<tr>
<td>Tanks</td>
<td>Carbon steel, GRP.</td>
</tr>
<tr>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

### Lubrication and seal oil

<table>
<thead>
<tr>
<th></th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry fuel gas and diesel</td>
<td>Carbon steel.</td>
</tr>
<tr>
<td></td>
<td>316, 22Cr duplex, 6Mo.</td>
</tr>
<tr>
<td></td>
<td>9</td>
</tr>
</tbody>
</table>

### Hydraulic fluid

<table>
<thead>
<tr>
<th></th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>316, carbon steel upstream filters.</td>
</tr>
</tbody>
</table>

### Instrument air

<table>
<thead>
<tr>
<th></th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>316, carbon steel upstream filters.</td>
</tr>
</tbody>
</table>

### Instrumentation

<table>
<thead>
<tr>
<th></th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tubing</td>
<td>316, Titanium.</td>
</tr>
<tr>
<td></td>
<td>5,10</td>
</tr>
<tr>
<td>Junction boxes/cabinets</td>
<td>GRP, 316.</td>
</tr>
<tr>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Cable trays</td>
<td>316; Hot dip galvanized carbon steel in fully HVAC controlled areas.</td>
</tr>
<tr>
<td></td>
<td>11</td>
</tr>
</tbody>
</table>

### HVAC ducts and units

<table>
<thead>
<tr>
<th></th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>316, Hot dip galvanized steel.</td>
</tr>
<tr>
<td>Air handling units</td>
<td>316.</td>
</tr>
<tr>
<td></td>
<td>11</td>
</tr>
<tr>
<td>Seawater coils</td>
<td>Titanium.</td>
</tr>
</tbody>
</table>

### Active fire fighting systems

<table>
<thead>
<tr>
<th></th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry CO₂ systems</td>
<td>Carbon steel.</td>
</tr>
<tr>
<td>Freshwater/plant air/nitrogen</td>
<td>316.</td>
</tr>
<tr>
<td>Glycol</td>
<td>Carbon steel, 316.</td>
</tr>
<tr>
<td>Methanol</td>
<td>Carbon steel, 316.</td>
</tr>
<tr>
<td>AFFF</td>
<td>316, GRP.</td>
</tr>
<tr>
<td>Heating/cooling media</td>
<td>Carbon steel. CRA in heat exchanger tubes.</td>
</tr>
<tr>
<td>Miscellaneous chemical systems</td>
<td>GRP, 316, 6Mo, Titanium.</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Bolting materials</td>
<td>See 6.5.5</td>
</tr>
</tbody>
</table>

Table 6.2 - Materials for topside facilities, Sheet 3 of 3.

NOTES

1. Sealing surfaces of components in Type 13Cr4Ni shall be overlay welded with Alloy 625. For wells with low corrosivity and/or short lifetime, low alloy steel with alloy 625 weld overlay in sealing surfaces only can be used. For weld overlay, ref. 5.4.
2. Shall also be used for process wetted parts of instrument systems.
3. See 7.3 for design limitations. Weld overlay can be applied to prevent crevice corrosion, ref. 5.4.
4. Copper alloys shall not be used in combination with CRAs. Exception can be components in fire water systems, provided galvanic corrosion can be avoided by proper isolation. If electrical isolation (15,000 ohm in dry system) is ensured and verified after installation, mechanical connections between bronze/brass and noble alloys such as Type 6Mo and titanium alloys are acceptable.
5. See clause 7 for design limitations.
6. Ceramic filled epoxy coatings can be used for shorter lifetimes, e.g. 5-10 years.
7. Large diameter piping and tanks can be made in internally coated carbon steel. Tanks not intended for potable water, shall in addition be cathodically protected. GRP, polypropylene and coating used for potable water shall be accepted by the national health authorities.
8. Tanks in carbon steel shall have 3 mm corrosion allowance at the bottom section. In addition the bottom and roof shall be coated. Cathodic protection shall only be used if corrosion products from the sacrificial anodes do not cause damage to the turbines.
9. Type 316 is acceptable up to operating temperature 70 °C provided located indoor or in sheltered areas and not insulated.
10. For uninsulated stainless Type 316 instrument piping downstream a shut-off valve, normally no extra precautions are required, provided process medium temperature is below 85 °C and there is no flow in the instrument piping.
11. Hot dip galvanized steel can be used in living quarter and domestic areas.
12. The combination of chemical and material has to be considered in each case. Titanium or GRP shall be used for hypochlorite systems.

Recommendation:

It is recommended to limit pressure rating of seawater systems to 10 bar in order to be able to use qualified valves in GRP and carbon steel with polymeric lining. If carbon steel valves with polymeric lining is considered for CRA based piping systems, the valve design shall be critically assessed with respect to possible accelerated galvanic corrosion.
6.5.4 Water injection

Water injection covers systems for injection of deaerated seawater, raw untreated seawater and produced water.

Corrosivity evaluations for deaerated injection seawater shall, for conventional deaeration process be based on a maximum operating temperature of 30 °C and the following Oxygen Equivalent levels:

- 50 ppb for 90 % of operation time.
- 200 ppb for 10 % of operation time, non continuous.

Even if the specification for the deaeration equipment gives more strict requirements, the above shall be basis for the material selection. If the specified Oxygen Equivalent or temperature is above 50 ppb or 30 °C, respectively for normal operation, the basis for material selection shall be subject to special evaluation.

Recommendation:

For carbon steel submarine injection flowlines the corrosion allowance should be minimum 3 mm.

In injection water systems where alternating deaerated seawater and produced water and/or gas could flow through the systems, the material selection shall take this into account. All components which may contact injection water, shall be resistant against well treating chemicals or well stimulating chemicals in case of back-flow situations. Titanium should not be used in these systems. For carbon steel piping maximum flow velocity shall be 6 m/s.

6.5.5 Bolting materials for piping, equipment, structural and subsea applications

The general bolting material for bolt diameters above 10 mm in piping systems and equipment shall be carbon or low alloy steel selected in accordance with the ASTM Standards listed in table 6.3 below. Bolts with a diameter <= 10 mm shall be stainless steel Type 316 for metal temperatures below 60°C for topside applications based upon maximum operating temperature.
Table 6.3 - Temperature range for bolting materials

<table>
<thead>
<tr>
<th>Temperature range, (°C)</th>
<th>BOLT</th>
<th>NUT</th>
<th>Size range, (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-100/+400</td>
<td>A 320 Grade L7</td>
<td>A 194 Grade 4/S4</td>
<td>&lt;=50</td>
</tr>
<tr>
<td></td>
<td>A 320 Grade L43</td>
<td>A 194 Grade 7</td>
<td>&lt;100</td>
</tr>
<tr>
<td>-46/+400 ¹)</td>
<td>A 193 Grade B7</td>
<td>A 194 Grade 2H</td>
<td>All</td>
</tr>
<tr>
<td>-29/+540 ¹)</td>
<td>A 193 Grade B16</td>
<td>A 194 Grade 7</td>
<td>All</td>
</tr>
<tr>
<td>-196/+540 ²)</td>
<td>A 193 Grade B8M</td>
<td>A 194 Grade 8M/8MA ³)</td>
<td>All</td>
</tr>
</tbody>
</table>

NOTES

1. These grades should not be used for permanent subsea equipment. For X-mas trees and retrievable equipment, Grade B7 can be used. Grade B16 is intended for high temperature service, outside the temperature range for Grade B7.
2. Type 316 bolts and nuts shall not be used at maximum operating temperature above 60 °C if exposed to wet marine atmosphere.
3. Use 8MA with class 1 bolts.

Bolting materials for **structural applications** shall generally be carbon or low alloy steels.

The following limitations shall apply:

- For topside applications, the strength class shall not exceed ISO 898 class 10.9.
- For submerged bolts, the strength class shall not exceed ISO 898 class 8.8, ASTM A 320 Grade L7 or A 193 Grade B7.
- Bolts with a diameter above 25 mm shall be impact tested to the same requirements as for the steels to be bolted.

If other bolting materials are required due to corrosion resistance or other reasons, the material shall be selected in accordance with the general requirements of this document. For subsea applications, Alloy 625 shall be used when corrosion resistant bolts are required at ambient temperature, i.e. for conditions where the bolts are exposed to aerated seawater and cathodic protection cannot be ensured. It shall be verified that the materials have acceptable mechanical properties at the actual design temperatures.

Bolts screwed into component bodies shall be of a material that is compatible with the body with respect to galling and ability to disassemble the component for maintenance, if relevant. Risk for galvanic corrosion, thermal coefficient if relevant, and for subsea applications the effect of cathodic protection, shall be considered.
Carbon steel or low alloy bolting material shall be hot dip galvanized or have similar corrosion protection. For submerged applications, where there is a risk that dissolution of a thick zinc layer may cause loss of bolt pretension, electrolytic galvanizing or phosphating shall be used. Electrolytic galvanizing shall be followed by post baking. For subsea installations the use of poly tetra fluoroethylene (PTFE) based coatings can be used provided electrical continuity is verified by measurements. Cadmium plating shall not be used.

6.6 Subsea production and flowline systems

6.6.1 General

Material selections for subsea production and flowline systems are given in table 6.4. For carbon steel flowlines the requirements given in 6.7 apply.

Recommendation:

Metal to metal seals that may be exposed to seawater without cathodic protection should be made in corrosion resistant alloys such as UNS R30035, R30003, N06625 and N10276. Generally, metal to metal sealing materials shall be more noble than surrounding surfaces.

All polymeric/elastomeric materials shall be qualified and the performance documented in all relevant exposure conditions in accordance with 7.4.

For levelling systems and other systems mainly used for installation, carbon steel shall be considered.

All bolting materials shall comply with 6.5.5.

Restrictions for maximum SMYS and actual yield strength shall apply for all components exposed to ambient seawater with cathodic protection, according to 7.1.

Table 6.4 - Material selection for subsea production and flowline systems, Sheet 1 of 2

<table>
<thead>
<tr>
<th>Application</th>
<th>Materials</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wellheads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wellhead equipment/X-mas trees for production</td>
<td>13Cr4Ni, Low alloy steel with Alloy 625 overlay. Relevant API/ISO standards</td>
<td>1</td>
</tr>
<tr>
<td>Wellhead equipment/X-mas trees for deaerated seawater</td>
<td>Low alloy steel with Alloy 625 weld overlay in sealing surfaces. Design must allow for corrosion on not-overlayed parts. Relevant API/ISO standards</td>
<td>1</td>
</tr>
<tr>
<td>Wellhead equipment/X-mas trees for aerated seawater</td>
<td>Carbon steel with weld overlay according to 5.4.</td>
<td></td>
</tr>
<tr>
<td>Retrievable equipment internals</td>
<td>13Cr or CRA's with higher PRE</td>
<td></td>
</tr>
<tr>
<td>Non-retrievable equipment internals, incl. X-mas trees</td>
<td>Alloy 718 or CRA's with higher PRE</td>
<td></td>
</tr>
</tbody>
</table>
### Subsea Manifold Piping

<table>
<thead>
<tr>
<th>Piping for...</th>
<th>Material Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piping systems for well fluids</td>
<td>6Mo, 22Cr duplex, 25Cr duplex.</td>
</tr>
<tr>
<td>Piping for deaerated seawater</td>
<td>6Mo, 25Cr duplex. Carbon steel can be used for shorter design life, i.e. less than 15 years.</td>
</tr>
<tr>
<td>Piping for gas</td>
<td>Carbon steel, 22Cr duplex, 6Mo. Material selection shall follow guidelines in 5.3.2.</td>
</tr>
<tr>
<td>Piping for produced water</td>
<td>22Cr duplex, 25Cr duplex, 6Mo. Carbon steel can be used for shorter design life (i.e. less than 6-8 years) and if low corrosivity.</td>
</tr>
<tr>
<td>Piping for raw seawater</td>
<td>Titanium.</td>
</tr>
<tr>
<td>Hydraulic fluids/glycol/methanol</td>
<td>316.</td>
</tr>
<tr>
<td>Chemical injection and annulus bleed systems</td>
<td>316.</td>
</tr>
<tr>
<td>Retrievable valve internals</td>
<td>13Cr, 17-4 PH, Alloy 718.</td>
</tr>
<tr>
<td>Non-retrievable valve internals</td>
<td>Alloy 718.</td>
</tr>
</tbody>
</table>

### Subsea Rigid Flowlines

<table>
<thead>
<tr>
<th>Application</th>
<th>Material Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil and gas</td>
<td>Carbon steel, 13Cr, 22Cr duplex or CRA cladded carbon steel. Material selection shall follow guidelines in 5.3.2.</td>
</tr>
<tr>
<td>Deaerated seawater injection</td>
<td>Carbon steel.</td>
</tr>
<tr>
<td>Produced water injection</td>
<td>Carbon steel, 22Cr and 25Cr duplex, 6Mo.</td>
</tr>
<tr>
<td>Raw seawater injection</td>
<td>Titanium, internally polyethylene lined carbon steel.</td>
</tr>
<tr>
<td>Hydrate Inhibitor Lines</td>
<td>Carbon steel, 316, 22Cr duplex.</td>
</tr>
</tbody>
</table>

### Subsea Production Control Systems

<table>
<thead>
<tr>
<th>Application</th>
<th>Material Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Umbilicals, metallic</td>
<td>25Cr duplex, encapsulated. Titanium.</td>
</tr>
<tr>
<td>Umbilicals, polymer hoses</td>
<td>Polyamide 11, Thermoplastic elastomer (TPE), High strength carbon or high strength polymer fibres.</td>
</tr>
</tbody>
</table>
### Table 6.4 - Material selection for subsea production and flowline systems, Sheet 2 of 2

#### NOTES

1. Sealing surfaces of components Type 13Cr4Ni shall be overlay welded with Alloy 625. For weld overlay, ref. 5.4.
2. Carbon steel and stainless steel with lower PRE than Type 316 can be used provided documented by field experience and/or tests.
3. Flexible pipe should be considered as alternative to rigid pipe. Carbon steel clad with CRA can be used as alternative to solid CRA. Guidance on selection of CRAs for injection is given in table 6.1.
4. Carbon steel and weld metal can be alloyed with approx. 0.5% chromium for oil production and deaerated seawater injection flowlines to improve corrosion resistance.
5. Type 25Cr and Type 13Cr to be documented with respect to feasibility/weldability.
6. Cost effectiveness of using duplex stainless steels with a lower alloying content than for Type 22Cr should be considered.
7. Carbon steel can be used if acceptable from cleanliness point of view.
8. See Table 5 for limitation for titanium in methanol service.
9. Type 22Cr duplex can be used if cathodic protection can be ensured. For 25Cr duplex without cathodic protection, external polymeric sheathing is required.
10. Carbon steel with external protection (cathodic protection in combination with coatings - organic or thermally sprayed aluminium) can be used if acceptable from cleanliness requirements point of view.
11. Documented functionability in relevant fluids with extrapolation of service life is required. Ref. 6.6.3. Not to be used for methanol service.

#### 6.6.2 Flexible flowlines and risers

Generally the requirements of API RP 17B and Det norske Veritas "Guidelines for Flexible Pipes" shall be satisfied. Due consideration shall be made to evaluate the possibility of failure due to corrosion and/or corrosion-fatigue of the steel reinforcement caused by the internal and/or the external environment. If "sour" conditions apply, the effect of H₂S on steel reinforcement shall be considered. The gas diffusing through the polymeric sheets shall be considered wet. If welding is performed on reinforcement wires, the resulting reduction in strength shall be taken into consideration in the design.

Measures to avoid internal galvanic corrosion by proper material selection and/or electrical isolation shall be ensured at all interfaces to neighbouring systems such as at subsea production manifold piping and flowlines.

The material for the inner metallic layer of non bonded pipe can be stainless steel Type 316 provided pitting corrosion and local erosion penetrating the liner do not deteriorate the functional performance and reliability of the flexible pipes. The choice of inner material shall take into account the possibility of being exposed to seawater during installation and commissioning.
The following shall be documented.

- Material properties verifying consistency between the design requirements and the fabricated quality.
- Documentation demonstrating that polymeric materials will be resistant to the internal and external environment and maintain adequate, mechanical and physical properties throughout the design life of the system shall be in accordance with 7.4.

### 6.6.3 Subsea production control systems

For polymeric based hoses, material selection shall be based upon a detailed evaluation of all fluids to be handled. The annulus bleed system will be exposed to a mixture of fluids, such as production fluid, methanol, completion fluid and pressure compensating fluid. A hose qualification programme shall be carried out including testing of candidate materials in stressed condition, representative for actual working pressure, unless relevant documentation exists. The results from qualification testing shall provide basis for service life extrapolation according to methods such as Arrhenius plots.

For umbilicals, the electric cable insulation material shall also be qualified for all relevant fluids. The materials selected for the electrical termination should be of similar type in order to ensure good bonding between different layers. The material selection for metals and polymers in electrical cables in the outer protection (distribution harness) and in connectors in distribution systems shall have qualified compatibility with respect to dielectric fluid/pressure compensation fluid and sea water. The functionality in sea water of the individual barriers relative to the service life, shall be documented.

The different parts of the components in hydraulic and chemical distribution systems shall have documented compatibility with relevant process fluids, dielectric fluid and sea water.

### 6.6.4 Drilling and workover risers

The required accumulated exposed design life shall be defined at an early stage.

Material selection shall take into account if the part will be welded or not. The strength shall be limited to enhance ductility and toughness. The specified minimum yield strength shall be limited to max. 640 MPa for unwelded parts (max. API 5 CT Grade C90) and 560 MPa for welded parts (max. API 5 CT Grade L80). All welded parts shall be post weld heat treated.

Resistance to "sour" conditions shall be taken into account for parts of the drilling and workover risers which may be exposed to reservoir fluids during drilling and testing. Compliance with "sour" service requirements as given in 5.3.2. shall be met, unless less stringent requirements are justified.

For drilling risers a total erosion/corrosion allowance of minimum 6 mm shall be included for accumulated design lives exceeding 10 years. For floating drilling and production units, the use of titanium for drilling risers shall be evaluated.

For workover risers manufactured from C-steel, reduction in wall thickness due to corrosion shall be evaluated. Effects of corrosion shall be accounted for by a minimum of 1,0 mm unless it can be demonstrated through routine maintenance that a corrosion allowance can be eliminated.
6.7 Pipeline systems

For pipeline systems for processed oil and gas and for injection water, carbon steel according to API 5L, grade X65 or lower shall be used.

The line pipe material shall be specified and tested to verify acceptable weldability under field welding conditions accounting for welding during barge installation and contingency hyperbaric repair welding situations during construction and operation. The latter shall also address replacement of anodes, unless doubler plates are used.

Where "sour" service requirements apply, this requirement shall also be fulfilled under hyperbaric welding conditions down to the maximum water depth along the pipeline route.

Pipeline systems containing gas shall be designed for a minimum design temperature that takes into account possible blow down situations.

For the reel laying method, it shall be documented that the base material and weld zones have acceptable properties after the total accumulated plastic strain that can be experienced during reeling and installation.

Pipelines for unprocessed or partially processed oil and gas shall follow the material selection requirements in 5.3.2.

6.8 Floating units - hull and marine systems

6.8.1 General

For floating units, including floating production ships, “DnV Rules for Classification of Ships and Mobile Offshore Units” shall apply.

6.8.2 Chains and mooring lines

In mooring line systems a corrosion rate of 0.4 mm/year for splash zone, and 0.1 mm/year for fully submerged conditions respectively, shall be used as basis for corrosion allowance and lifetime estimates. An evaluation of possible corrosion due to bacterial activity on the seabed shall be carried out.

Wire rope segments shall have a protection system in accordance with recommendations in API RP 2FP1.

7 DESIGN LIMITATIONS FOR CANDIDATE MATERIALS

7.1 General

Design limitations for the application of different material types, e.g. maximum/minimum temperature, maximum SMYS and actual yield strength, weldability, etc. are defined in the following.
The following general requirements apply for all steel types (including bolts):

- For carbon and low alloy steels, the yield to tensile strength ratio (actual values) shall not exceed 0.9.
- For materials intended for welding, SMYS shall not exceed 560 MPa.
- For submerged parts that may be exposed to cathodic protection, the following shall apply:
  
  For carbon and low alloy steels, SMYS shall not exceed 700 MPa (725 MPa for bolts). The actual yield strength shall not exceed 950 MPa. Alternatively, it may be verified that the actual hardness in base materials does not exceed 295 HB. For carbon steel welds a max. limit of 350 HV10 applies. For stainless steels and non-ferrous materials, resistance against hydrogen embrittlement shall be controlled by specifying that the actual hardness of the material shall be in accordance with NACE MR0175, unless otherwise documented.

- Metallic materials for pressure retaining components which are not covered by NORSOK Standards and Material Data Sheets or applicable codes, shall as a minimum be according to DnV RP B 201.

In cases where the minimum design temperature is a limiting factor for a material, also temperature exposures during intermediate stages (such as manufacturing, storage, testing, commissioning, transport, installation) shall be considered when specifying the minimum design temperature and handling procedures.

7.2 Materials for structural purposes

7.2.1 Steel

Material requirements to the applicable grades are defined in NORSOK Material Data Sheets, M-CR-120 and Standard M-CR-101.

The impact toughness test requirements given to, and the application of, the specified structural materials are based on a minimum design temperature of -10 °C. If lower design temperatures are applicable, sufficient fracture toughness properties have to be verified. For the most critical design class, this shall include CTOD testing of base material, weld metal and HAZ at the minimum design temperature.

7.2.2 Concrete

Design limitations for application of structural concrete shall be according to NS 3473 including Exhibit B and NS 3420.

7.2.3 Aluminium

Aluminium may be used for all relevant ambient temperatures. Aluminium alloys shall not be used for elevated temperatures. In particular, AlMg-alloys with Mg-content above 3.0 % shall not be used when design temperature is above 60 °C, as these alloys are sensitive to stress corrosion cracking. Special consideration shall be given to loss of strength above approximately +200 °C.
Hardened aluminium alloys suffer from a reduction in strength in the heat affected zone after welding. The actual reduction factors to be used shall comply with applicable design code but shall be evaluated and verified by welding and appropriate mechanical testing. The weld metal strength shall be included in this evaluation and minimum yield and tensile strength requirements shall also be defined. Necessary precautions shall be taken to ensure homogeneous material properties in extruded sections and in particular across extrusion welds.

Aluminium is not acceptable for components that are permanently submerged, unless suitable performance in this service is documented for the alloy in question in relevant temperature range.

7.2.4 GRP

For GRP used in applications such as panels, gratings and other secondary applications, special emphasis must be put on risk assessment and evaluation of fire performance.

7.3 Materials for pressure retaining purposes

7.3.1 General

Materials shall be used within the limits given in table 7.1. Materials for piping systems shall comply with NORSOK Standards L-CR-001 (M-CR-630), M-CR-601 and M-CR-621.

Recommended limitations for CRA's in “sour” service beyond NACE MR0175 are given in Table 7.2. It is emphasized that H2S limits for CRA material categories are difficult to state on a general basis. Specific limits for the material type and grades to be used should be established accordingly by testing at the actual conditions, i.e. yield strength, chloride content, temperature, pH, etc. For requirements to manufacturing, heat treatment and material properties, reference is made to NACE MR0175.

The lower temperature limits for carbon steel imposed by the design code and NORSOK Standards requirements shall be adhered to. In special circumstances impact tested steel may be used below these limits. Such cases require individual attention. The maximum design temperature shall be according to the applicable design codes for all types of materials. Free machining grades are not acceptable for pressure retaining purposes.

<table>
<thead>
<tr>
<th>Material</th>
<th>Min. design temp. (°C)</th>
<th>Impact tested</th>
<th>Other requirements</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon and low alloy steel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>235</td>
<td>- 15</td>
<td>X</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>235 LT</td>
<td>- 46</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>360 LT</td>
<td>- 46</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5 % Nickel steel</td>
<td>-101</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.1 - Metallic materials for pressure retaining purposes, Sheet 1 of 2
<table>
<thead>
<tr>
<th>Martensitic stainless steels</th>
<th></th>
<th>2,3</th>
</tr>
</thead>
<tbody>
<tr>
<td>13Cr</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>13Cr valve trim parts</td>
<td>10</td>
<td>X</td>
</tr>
<tr>
<td>13Cr4Ni</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>13Cr4Ni double tempered</td>
<td>29</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Austenitic stainless steels</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>316</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>6Mo</td>
<td>105</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>196</td>
<td></td>
</tr>
<tr>
<td></td>
<td>105</td>
<td></td>
</tr>
<tr>
<td></td>
<td>196</td>
<td></td>
</tr>
<tr>
<td>Max. operating temp. 60 °C. Higher temperatures acceptable if full HVAC control.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Mo seawater systems with crevices: Max. operating temp. 15 °C, max. residual chlorine 1.5 ppm. Without crevices: Max. operating temp. 30 °C and same chlorine level.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duplex stainless steels</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>22Cr</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>25Cr</td>
<td>46</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Risk for cracking should be assessed in systems affected by acidizing if sulphide containing scales can be formed. Temperature limits for 25Cr in seawater as for 6Mo austenitic stainless steels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nickel base alloys</td>
<td>-</td>
<td>196</td>
</tr>
<tr>
<td>Titanium base alloys</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Grade 2</td>
<td>-</td>
<td>196</td>
</tr>
<tr>
<td>Seawater operating temperature limits if crevices are present: Unchlorinated 95 °C, Chlorinated 85 °C, Brine 80 °C.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other grades</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Copper base alloys</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>90-10, 70-30, Al brass, NiAl bronze</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Fresh seawater and normally drained systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Admiralty brass, gun metal, tin bronze</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Seawater with sulphide and normally drained systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminium base alloys</td>
<td>-</td>
<td>196</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>
Table 7.1 - Metallic materials for pressure retaining purposes, Sheet 2 of 2

NOTES

1. Carbon steel Type 235 can be used in piping systems with minimum design temperature down to -15°C. If ambient temperature is lower than -15°C this type of carbon steel may be used down to -29°C without impact testing for thicknesses less than 30 mm. Lower design temperatures can be applied in accordance with ASME B.31.3 table 323.2.2 note 2.
2. A corrosivity evaluation shall be carried out if temperature > 90°C, or chloride concentration >5%.
3. Impact testing for well completion shall be carried out at -10°C or the min. design temperature if this is lower.
   Use of 13Cr at temperatures below -10°C requires special evaluation.
4. Impact testing of austenitic stainless steel Type 316 and 6Mo weldments has not been considered necessary above -105°C.
   Type 6Mo stainless steel can be used in seawater systems with crevices above 15°C if crevices are weld overlayed, ref. 5.4.
5. Impact testing shall be performed at the minimum design temperature or lower. For 25Cr min. design temperature of -30°C regards fabrication welds, while -46°C applies to piping components.
   Type 25 Cr stainless steel can be used in seawater systems with crevices above 15°C if crevices are weld overlayed, ref. 5.4.
6. Shall not be used for hydrofluoric acid or pure methanol (> 95%) or exposure to mercury or mercury based chemicals. Titanium shall not be used for submerged applications involving exposure to seawater with cathodic protection unless suitable performance on this service is documented for the relevant operating temperature range.
7. Service restrictions shall be documented for other Titanium grades.
8. Shall not be exposed to mercury or mercury based chemicals, ammonia and amine compounds. Velocity limits for smaller dimensions are lower. Not for stagnant conditions.
9. Shall not be exposed to mercury or mercury containing chemicals.

7.3.2 Glassfibre reinforced plastic (GRP)

Design of piping systems in GRP materials shall in general be according to UKOAA's "Specification and Recommended Practices for the Use of Glass Fibre Reinforced Plastic Piping Offshore" and according to ASME B 31.3. The need for fire and impact protection shall be evaluated whenever GRP is used.

The use of GRP for piping systems on platforms is limited as follows:

- No use in hydrocarbon and methanol systems.
- Max. internal design pressure 40 bar g.
- Design temperature range from -40 up to 95°C for epoxy and up to 80°C for vinylester.
- The possible hazard for static electricity built-up shall be accounted for.
For GRP tanks and vessels the following limitations apply:

- Design pressure in bar times internal volume in litres shall not exceed 75000 and a design temperature of maximum 75 °C.
- The potential hazard for static electricity build-up shall be accounted for.
- The possible use for containing hydrocarbons shall be based on risk assessment.

For systems where GRP can be applied, epoxy and vinylester resins shall be evaluated as alternatives for piping components and tanks. Polyester resin can be used in tanks for seawater and open drain services.

For systems handling hypochlorite, GRP with vinylester resin and PVC lining or titanium shall be used. For sulphuric acid, only GRP with vinylester resin and PVC lining shall be used. For other strong acids, GRP with C glass or ECR glass combined with resin rich internal barrier, or CRA of applicable grade, shall be used.

If GRP is considered used as rigid pipe for downhole produced water and seawater injection tubing, material properties shall be documented in accordance with relevant API standards and ASTM D 2992.

For other than seawater and freshwater, the fluid compatibility shall be documented in accordance with 7.4.

### 7.4 Polymeric materials

The selection of polymeric materials, herein included elastomeric materials, shall be based on a thorough evaluation of the functional requirements for the specific application. Dependent upon application, properties to be documented and included in the evaluation are:

- Thermal stability and ageing resistance at specified service temperature and environment.
- Physical and mechanical properties.
- Thermal expansion.
- Swelling and shrinking by gas and by liquid absorption.
- Gas and liquid diffusion.
- Decompression resistance in high pressure oil/gas systems.
- Chemical resistance.
- Control of manufacturing process.

Necessary documentation for all important properties relevant for the design, area/type of application and design life shall be provided. The documentation shall include results from relevant and independently verified tests, and/or confirmed successful experience in similar design, operational and environmental situations.

Polymeric sealing materials used in well completion components, X-mas trees, valves in manifolds and permanent subsea parts of the production control system shall be thoroughly documented. For these components documentation for relevant materials from all suppliers used shall be provided. Reference is made to NORSOK standard M-CR-710.
Table 7.2 - Proposed H₂S limits for generic CRA classes

<table>
<thead>
<tr>
<th>Material</th>
<th>Chloride concentration, max. (%)</th>
<th>In-situ pH</th>
<th>Temperature, max. (°C)</th>
<th>Partial pressure H₂S, max. (bar)</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Martensitic stainless steels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,2</td>
</tr>
<tr>
<td>13 Cr</td>
<td>5</td>
<td>3 - 3.5</td>
<td>90</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;5</td>
<td>&gt; 3.5</td>
<td>90</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Austenitic stainless steels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>316</td>
<td>1</td>
<td>&gt;= 3.5</td>
<td>40</td>
<td>0.1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>3.5</td>
<td>60</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>&gt;= 3.5</td>
<td>60</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>3.5</td>
<td>60</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;= 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6Mo</td>
<td>5</td>
<td>&gt;= 3.5</td>
<td>150</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>3.5</td>
<td>150</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Duplex stainless steels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>22Cr</td>
<td>3</td>
<td>3.5</td>
<td>150</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>&gt;= 3.5</td>
<td>150</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>&gt; 3.5</td>
<td>150</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>25Cr</td>
<td>5</td>
<td>&gt;= 4.5</td>
<td>150</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>&gt; 3.5</td>
<td>150</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Nickel alloys</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>625</td>
<td></td>
<td>&gt;= 3.5</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>C276</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Titanium</td>
<td></td>
<td>&gt;= 3.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTES

1. Maximum utilization 80% of SMYS.
2. The temperature limit may be increased based upon evaluation of specific field data and previous experience. Testing may be required.
3. The temperature can be increased to 120 °C provided completely oxygen free conditions can be guaranteed.
4. No practical limits to temperature and chloride concentration for oilfield service.
8 QUALIFICATION OF MATERIALS AND MANUFACTURERS

8.1 Material qualification

8.1.1 General

The selection of materials for applications which may affect the operational safety and reliability level shall be made among the listed qualified materials.

The materials listed in clause 5 and 6 shall be regarded as qualified when used within the design limitations given in clause 7. Other materials can be added to those listed if adequate documentation is available and the objective of limiting number of material types and grades is maintained.

Qualified materials shall fulfil the following requirements:

1. The material is listed by the relevant design code for use within the stated design requirements.
2. The material is standardized by recognized national and international standardization bodies.
3. The material is readily available in the market and stocked by relevant dealers.
4. The material is readily weldable, if welding is relevant, and known by potential fabricators.
5. The material has a past experience record for the applicable use, e.g. same type of component and dimensional range.

8.1.2 Qualification by past experience

Where the same type of material is regularly supplied for the same application, the qualification shall be based on experience. This applies to most materials supplied and used within the limitation of the design codes. The exception to this can be manufacturing of special components outside the normal dimensional range.

8.1.3 Qualification by general test data

Where well known materials are used in "new" applications or "new" materials are to be used, the qualification may be by reference to results from relevant laboratory or production tests.

8.1.4 Qualification by specific test programme

When a material is proposed for a new application and the selection cannot be based on the criteria in 8.1.1 to 8.1.3, a qualification programme shall be initiated. The objective of the programme shall be clearly defined before starting any testing. Such objectives may be qualitative or quantitative and aim at defining if the product is acceptable or not for the design life of the system.

The qualification programme shall consider both the effect of the manufacturing route as well as fabrication on the properties obtained. Where possible, reference materials with known performance (good, borderline or unacceptable) shall be included for comparison.
8.2 Manufacturer qualification

Under certain conditions it may be necessary to apply additional requirements to the potential or selected manufacturers to ensure their capabilities to supply the required material. Such qualification shall be evaluated when one of the following conditions are present:

1. The materials to be supplied include stainless steel Type 6Mo, Type 22Cr, Type 25Cr and titanium.
2. The requested material dimensions and/or quality require special demands by being outside the range of standardized products or outside the normal production range of the potential manufacturer.
3. For non-metallic sealing materials for topside gas systems subjected to rapid depressurization, well completion and critical permanent subsea equipment.

Reference is made to NORSOK standard M-CR-650 and M-CR-710.

8.3 Familiarization programmes for fabrication contractors

Fabrication contractors having limited experience with the specified material or with the intended fabrication procedures and equipment, shall perform familiarization programmes prior to initiating critical or major work during procurement, manufacturing, fabrication and construction. The purpose shall be to prequalify and verify the achievement of specified requirements on a consistent basis.

Areas identified which may require familiarization programmes are listed below:

- Joining and installation of GRP components
- Welding and fabrication of aluminium structures
- Aluminium thermal spraying.
- Internal vessel coating.
- Wax coating of valves and other components.
- Welding of steels with SMYS ≥ 460 MPa
- Welding of stainless steel Type 6Mo and Type 25Cr duplex.
- Welding of titanium
ANNEX A Requirements for LCC evaluations (NORMATIVE)

For optimum material selections for main systems, LCC analyses shall be performed. Factors to be included are:

- Corrosivity evaluation.
- Erosivity evaluation taking into account solid particles, high velocity liquid and droplets.
- Consequences of material selection for required wall thickness and thereby equipment weight.
- Possibility for satisfactory corrosion inhibition.
- Fabrication/welding and installation costs related to pipe wall thickness.
- For pipelines, the effect of wall thickness/pipe weight upon installation method and costs.
- Extra costs related to carbon steel i.e. inhibitor, corrosion monitoring, internal inspection, surface protection, etc.
- Access and cost for replacement of system or component.

Cost elements which shall be included in the LCC analysis are:

I Material/fabrication/installation costs

As a minimum, initial material investment costs and fabrication costs for the primary system shall be included.

II Commissioning costs

As a minimum, all commissioning costs including start-up, installation and testing shall be included.

III Operational costs

As a minimum, all costs for operation and maintenance of the primary system shall be included. Operational costs are defined to include costs for operating systems and for planned/unplanned shut-downs. Maintenance costs include costs of the primary system due to all types of maintenance activities such as (but not limited to) inspection, planned/unplanned repairs, equipment/system change outs and number of replacements during design life.

Other factors

Design life of the system has to be defined.

Interest rate, inflation rate and tax regulations have to be defined.

Possible residual or sales value of the replaced system or value at the end of the design life can be included in the LCC calculations.