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Petroleum and natural gas industries — Arctic operations — Material requirements for arctic operations

Industries du pétrole et du gaz naturel — Opérations en Arctique — Exigences relatives au matériel requis pour les opérations en Arctique

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Contents

Page

Foreword

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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).

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This document was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 8, *Arctic operations*.

Introduction

Operations in an Arctic environment are characterized by low ambient temperatures, the presence of sea ice and ice bergs and icing of structures and components. In many cases they are also associated with remote locations relative to infrastructure and logistics. Maintenance operations are therefore expensive and accidents leading to emissions can have severe environmental consequences.

Structural failure is in most cases failure of materials and caused by well-known degradation mechanisms such as fatigue and corrosion. Under Arctic conditions, failure due to possible brittle materials behaviour needs to be given special consideration.

This document was developed to bridge the gap between the functional requirements to offshore structures in Arctic environments given in design standards and the material requirements given in material and fabrication specifications where Arctic operating conditions have not been considered in sufficient detail.

Petroleum and natural gas industries — Arctic operations — Material requirements for arctic operations

1 Scope

This document provides recommendations for material selection, manufacturing and fabrication requirements, testing and qualification of steel structures and components for offshore and onshore petroleum and natural gas facilities operating in Arctic and cold environments.

This document is intended to be used as a supplement to existing standards for steel structures where the particular operating conditions in Arctic regions are not sufficiently addressed.

This document gives particular requirements to ensure safe operation with respect to the risk of brittle fracture at low temperatures. These requirements will affect the selection of material grade and design class as well as the technical delivery conditions for steel. They will also affect the fabrication requirements as well as testing and qualification requirements.

This document also gives recommendations:

— to mitigate the operational and integrity aspects related to snow and ice accretion on topside structures;

— to take into account the particular Arctic operating conditions in corrosion assessments and requirements for corrosion protection systems;

— for particular operational requirements to ensure safe operation in Arctic regions.

The requirements in this document are applicable to any operating temperatures, but particular requirements related to de-rating (loss of strength) at high temperatures are not addressed. Limitations to the applicable minimum design temperature caused by the capability of the materials' low temperature performance can exist, but are not a limitation for the scope of this document.

As a practical guideline for the use of this document, low temperature is defined as lowest anticipated service temperature (LAST) below −10 °C.

NOTE For determination of LAST, see 6.3.2.

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 19900, *Petroleum and natural gas industries — General requirements for offshore structures*

ISO 19901-1, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 1: Metocean design and operating considerations*

ISO 19901-2, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 2: Seismic design procedures and criteria*

ISO 19901-4, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 4: Geotechnical and foundation design considerations*

ISO 19902:2007, *Petroleum and natural gas industries — Fixed steel offshore structures*

ISO 19906, *Petroleum and natural gas industries — Arctic offshore structures*

EN 10225:2009, *Weldable structural steels for fixed offshore structures — Technical delivery conditions*

API RP 2Z, *Preproduction Qualification for Steel Plates for Offshore Structures*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19900, ISO 19901-1, ISO 19901-2, ISO 19901-4, ISO 19902 and ISO 19906 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/

4 Abbreviated terms

BCC	body centred cubic
BM	base material
DC	design class
CJP	complete joint penetration
C-Mn	carbon manganese
CP	cathodic protection
CTOD	crack-tip opening displacement
ECA	engineering critical assessment
HAZ	heat affected zone
LAST	lowest anticipated service temperature
PWHT	post weld heat treatment
RT	room temperature
SAW	submerged arc welding
SENB	single edge notch bend
SMYS	specified minimum yield strength
SN	stress number approach for fatigue design
UEL	uniform elongation
ULS	ultimate limit state
WM	weld metal
Y/T	yield to tensile stress ratio

5 Symbols

The following is a summary of the main symbols that are used throughout this document. Other symbols are defined where they are used. This use includes main symbols with one or more subscripts when a more specific use and associated definition of the symbol is intended.

a	defect height
c	defect half length
h_{char}	characteristic height
K_{ca}	crack arrest toughness
T	temperature
t	thickness
X_{δ}	constraint correction factor for CTOD
γ_{CTOD}	safety factor on characteristic CTOD
γ_{m}	materials safety factor
σ_{b}	average bending stress acting over the characteristic height
σ_{eff}	effective stress
σ_{TS}	tensile strength
σ_{t}	average tensile stress acting over the characteristic height
σ_{Y}	yield strength
$\sigma_{0,2}$	0,2 % yield strength
τ_{t}	average shear stress acting over the characteristic height

6 Technical basis

6.1 Design considerations

6.1.1 Present applications and industrial achievements

Offshore field developments have been carried out in the northern part of the Atlantic Sea offshore New Foundland, United Kingdom and Norway with successful application of structural steels designed for LAST equal to −10 °C with technical delivery conditions specified by EN 10225 and corresponding API standards with weldability qualification in accordance with API RP 2Z. NORSOK N-004 has also extended the application range of the design requirements to −14 °C.

Developments have also taken place in colder areas, such as the Barents Sea, offshore Sakhalin and the Caspian Sea. In these cases, project-specific requirements to structural steel qualification have been provided to compensate for the lack of industry standards. After delivery of these projects, the steel industry has promoted “Arctic steel grades” as available for more industrial applications. However, unified requirements and documentation of performance are still missing.

6.1.2 Developments for future applications

As the offshore industry moves to Arctic and other cold areas, cost efficient solutions for low temperature applications are needed. Therefore, the low temperature performance, testing requirements and acceptance criteria as well as alternative steel grades have been investigated to reach this goal. In addition to the field experience, results from such investigations form the basis for this document. Investigations have been carried out at temperatures down to −60 °C. A short-term realistic temperature limit is −40 °C, unless very specialized alloying systems are implemented.

As a design consideration, it should be taken into account that it is not sufficient to demonstrate acceptable properties at low temperatures. It is also recommended to demonstrate that these properties can be combined with cost efficient fabrication procedures including e.g. heat input, pre-heating and post weld heat treatment.

6.1.3 Areas of concern in design for Arctic structures

At low temperatures, the risk of brittle fracture in structural steels will be more significant and it is required to establish a specific fracture limit state to verify a safe design. A particular feature of a brittle fracture mechanism is that it can affect the redundancy of the structure after a local overloading, as it is difficult to predict the extent and path of brittle crack extension.

The introduction of a fracture limit state includes an á priori assumption that a crack is present at the location considered. As the combination of high stress level and crack is associated with certain likelihood, this is inevitably a probabilistic issue, and it is highly dependent on the fabrication quality and inspection level of the structure.

The most critical failure locations associated with low temperature behaviour of welded steel structures are WM and HAZ. The BM is usually less critical, because the properties are normally better and the likelihood of defects is smaller. However, in forged and cast steel, also BM should be considered.

The brittle fracture resistance is controlled by the steel temperature, while the LAST is defined on the basis of environmental temperature data in combination with operational factors. The minimum steel temperature should be estimated as part of the design process, but can be conservatively estimated from the ambient temperature.

The main effects of low temperatures on mechanical properties of steels should be clarified in order to document the feasibility of the steel and welding procedure in terms of WM and HAZ toughness (see ISO 19902:2007, Annex F) or if other requirements should be given. With regard to “low temperatures”, the main focus will be temperatures in the range −60 °C to −10 °C. For testing, this can require temperatures down to −90 °C. The temperature will have an effect on both elastic, plastic, and fracture properties of steels. The former is apparently less significant than the two others in the temperature range considered, and is not discussed in detail. Regarding plastic and fracture properties the following main categories are considered:

— tensile properties;

— fracture toughness;

— arrest toughness;

— fatigue.

6.1.4 Fracture assessment

Resistance to deformation and separation in atomic lattices is intimately linked to energies representing barriers to these features. In general the thermal energy in the material will affect the available energy to overcome barriers for these mechanisms. For plastic deformation, it is observed that the resistance will increase with decreasing temperature due to less thermal energy available in the system to help overcome e.g. barriers to dislocation movements. This leads to an observed increase in yield stress with decreasing temperature. The resistance to initiation of cleavage fracture is closely linked to the stress level possible to achieve in the material. This stress level is again correlated with the tensile properties of the material. As the yield stress increases with decreasing temperature, the local stress level in the material increases, and the likelihood of initiation of fracture increases accordingly.

Fracture assessments in general address both considerations regarding initiation of crack growth and possibly arrest of propagating cracks. Further, a distinction between initiation of crack growth and arrest will depend on the magnification used to study the phenomenon. Fracture is a strongly multiscale phenomenon, ranging from the details around separation of atoms up to observations at the continuum level. In this document classification is related to the continuum level. Thus, the term “fracture toughness” is taken to represent the resistance to initiation of crack growth leading to crack extension typically of the order of 1 mm or more (i.e. significantly longer than the typical microstructural length scales). In the same fashion, the “arrest toughness” is taken as the resistance needed to arrest cracks having propagated 1 mm or more.

6.2 Effects of low temperatures on mechanical properties of steels

6.2.1 Tensile properties

With regard to the effects of tensile properties on low temperature behaviour of steels, they can be divided into explicit and implicit effects. The explicit effects consider the resistance to plastic deformation in the material and the level mismatch in inhomogeneous material systems (e.g. welds). Implicit effects are addressing fracture and fatigue through influence of the magnitude of stress levels and size of local plastic zones.

The key engineering tensile properties are:

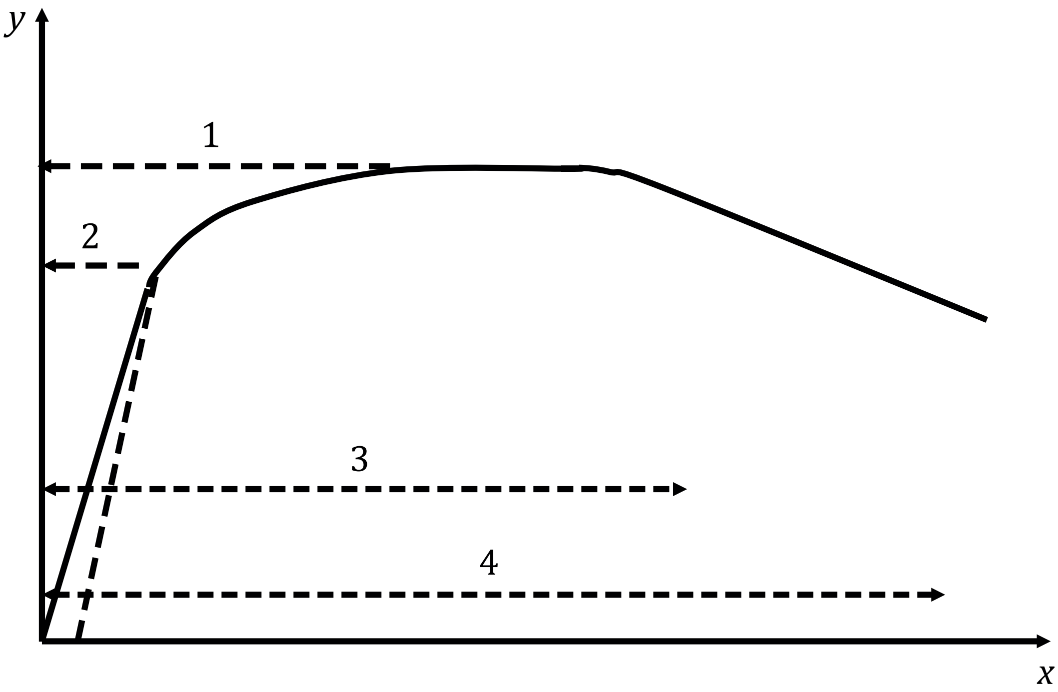
— the yield stress;

— the tensile strength;

— the uniform elongation (UEL);

— the fracture strain.

The parameters are illustrated in Figure 1. Regarding the yield stress different definitions are applied, however, the most frequently used is the stress level corresponding to 0,2 % permanent deformation of the material. In addition, some steels will display discontinuous yielding, or so-called Lüders band formation.



Key

1	tensile strength	*x*	engineering strain
2	yield stress	*y*	engineering stress
3	UEL		
4	fracture strain		

Figure 1 — Tensile property parameters

Leaving out very high strain rate scenarios, where inertia effects start to play significant roles, the effects of temperature and strain rate on plastic properties are claimed to be of a similar nature. The basis for this is that they are affecting the activation energy for dislocation movement in the same way. Zener and Hollomon proposed the following general relation to describe the phenomenon:

$$\sigma_y = f\left[T\log\left(\frac{A}{\dot{\varepsilon}}\right)\right] \tag{1}$$

where

σ_y is the yield stress;

T is the temperature;

A is some constant related to the activation energy;

ε is the strain rate.

The detailed nature of the function should be determined through experimental testing as there are no theoretical models available to deduce this directly. Figure 2 shows examples of evolution of yield stress and tensile strength with temperature for two different materials not normally used for structural applications.

