POSITION PAPER

MATERIAL PROPERTY REQUIREMENTS FOR HIGH STRENGTH STEELS USED IN MOBILE OFFSHORE UNITS

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1 SUMMARY

This paper presents a status report on recent collaboration work between the regulators Petroleum Safety Authority Norway (PSA) and the Health and Safety Executive UK (HSE) and the Class Societies Det Norske Veritas Germanische Lloyds (DNV GL), Lloyds Register (LR) and American Bureau of Shipping (ABS) related to the class rules on high strength steels (HSS), material property requirements for mobile offshore units (MOUs). HSS is here regarded as structural steels with yield strength exceeding 420 MPa.

The aim of the work was to identify possible limitations of current rules and guidance for MOUs and identify areas for further development. The work entailed the review of the material properties, comparison of classification society and standards requirements for mobile and fixed structures, a review of structural performance, failures and discussions on the implementation of changes to rules with particular emphasis on International Association of Class Societies (IACS) UR W16. The work, which extended from 2014 to 2016, highlighted the need of the requirement for CTOD testing of weldment heat-affected zones during steel mill qualification phase in the revision to UR W16 published in March 2016. UR W16 has incorporated the CTOD test requirement in a manufacturing approval scheme of high strength steels for welded structures. This does not necessarily include CTOD testing of parent material unless required by the classification society.

The collaboration has not only provided the Classification Societies with technical inputs relevant to the revision of IACS UR W16 which includes requirements for the qualification of HSS used in MOUs but has also had a wider influence with the development of documents related to the application of HSS in MOUs.

2 INTRODUCTION

The work on the material property requirements for HSS used in mobile offshore units emanated from a safety concern about the fracture toughness property requirements for HSS, considered typically to be steels with yield strength exceeding 420 MPa, and particularly about the lack of a requirement for crack tip opening displacement (CTOD) testing which is performed routinely for fixed structures. HSS are also used in MOUs where better material toughness properties are needed to allow for the same standard defect acceptance criteria as for low strength steels.

A mitigating factor in the integrity management of MOUs is the opportunity to dry-dock in the event of an urgent need for inspection, maintenance and repair (IMR) and for routine IMR during periodic renewal of the class certificate which, to some degree, can be regarded as a presumption for mobile vessels rules and regulations. However, MOUs operated for oil and gas production at the same location beyond the usual five-year renewal period of the class certificate are being operated, in effect, as fixed structures and this could have safety implications or the need for further technical considerations.

Other important considerations in the collaborative work are;

- the wide range of HSS used in jack-ups (principally in legs and jacking systems);
- access to in-service experience is limited. Further information and associated guidance on high strength steel material properties for MOU structures is required;
- the matching of parent and weld metal properties is more challenging with increasing yield strength;
- fracture toughness data for high strength steels show that high values can be achieved in the parent material but tests also show that it may be difficult to achieve the same level of toughness in welded sections;
- the materials demonstration of suitability in many safety cases is inadequate – significant additional information is often required;
- some leg drawings identify the need to meet UKCS requirements but do not specify requirements;
- many operators and duty holders consider compliance with the class rules as meeting the regulatory requirements which may not always be the case;
- MOUs from other parts of the world with major modifications present particular challenges when moved to NW European waters due to:
  - not meeting current class rules
  - insufficient original materials information
  - insufficient assessment of materials suitability;
- limited in-house materials expertise:
  - reliance of operators / duty holders on class societies.

The regulators and the class societies agreed in 2014 to address the difference in the requirements for fixed and mobile structures, to assess whether there was a need to revise the material property requirements for MOUs for consistency and to ensure that an equivalent level of structural robustness and safety is achieved, particularly since HSS components may have a lower defect tolerance due to the higher design loads and potentially lower fracture toughness.

The collaboration work with the class societies is linked with ongoing International Association of Class Societies (IACS[i]) work on the document UR W 16, 'High Strength Steels for Welded Structures' [1], which covers steels with yield strengths in the range 420 MPa to 960 MPa, to improve the materials property requirements for MOUs and other offshore structures. UR W16 has been in use since 1984 and, prior to the revision of March 2016, used to define the minimal requirements which were complemented by additional proprietary standards specified by each class society. Unified requirements for all the class societies are now provided in the current version of UR W16. This has had an impact on related documents and IACS is revising these for consistency with UR W16.

3 Aims and Objectives

The aim of the collaboration was to identify the areas in which the requirements for high strength steels used in MOUs differed from the standards specified for fixed structures.

The specific objectives were as follows;

- to create a group comprising regulators and classification societies to provide a forum for the discussion of HSS issues and with a view to establishing a common position on materials property requirements for HSS for MOU applications;

- to review current rules and guidance for MOUs for comparison with those for fixed structures and identify areas for further development;
- to review the challenges in the practical application of HSS in the offshore environment and the availability of information on the performance of HSS;
- to review advances in HSS technology over the decades;
- to review performance and any incident data from MOUs to identify issues with HSS;
- to influence the development of existing guidance on HSS, as appropriate.

4 REGULATORY REQUIREMENTS

4.1 PSA requirements for Norwegian Continental Shelf

PSA has functional requirements in the regulations. The guidelines refer to a great extent to the NORSOK and ISO standards for fixed structures.

For MOUs, the maritime rules, as given by the frame regulation §3, with reference to Norwegian Maritime Authority (NMA) and class rules, may be followed. In addition, an Acknowledge of Compliance (AOC) certificate is required for MOUs to operate in the Norwegian sector, ref (Guidelines for application of AOC) issued by PSA.

The frame regulation § 3

Application of maritime regulations in the offshore petroleum activities

As regards mobile facilities registered in a national ships' register, and which follow a maritime operational concept, relevant technical requirements in the Norwegian Maritime Directorate's regulations for mobile facilities (the Red Book), such as they read after the amendments in 2007 and subsequent amendments, and with supplementary classification rules provided by Det Norske Veritas, or international flag state rules with supplementary classification rules providing the same level of safety, with the specifications and limitations that follow from Section 1 of the Facilities Regulations, can be used as an alternative to technical requirements laid down in and in pursuance of the Petroleum Act. The chosen maritime regulations shall be used in their entirety.

The Petroleum Safety Authority Norway can stipulate additional requirements, based on safety-related considerations.

4.2 HSE requirements for UK sector

The requirements for installations designed and operated in UK waters are specified in the Offshore Installations (Offshore Safety Directive) (Safety Case etc.) Regulations 2015 and the Safety Case Regulations (2005) and the Offshore Installations and Wells (design and construction, etc.) Regulations 1996. The goal-setting regulations are underpinned by codes and standards which are covered in this paper.

Specific regulatory requirements relevant to structural integrity are as follows:

(a) Offshore Installations (Safety Case) Regulations 2015:

A safety case for the installation shall be prepared which includes identification of all hazards with the potential to cause a major accident and that all major risks arising from these are or will be adequately controlled.

(b) Offshore Installations and Wells (Design and Construction etc.) Regulations 1996:

(i) Regulation 7 (Operation of an installation): The duty holder shall ensure that the installation is not operated in such a way as to prejudice its integrity. This includes setting and recording appropriate limits within which it shall be operated and the environmental conditions in which it shall safely operate. These limits include maximum loads which may be imposed on parts of the structure.

(ii)Regulation 8 (Maintenance of integrity): Suitable arrangements shall be in place to maintain the integrity of the installation, including periodic assessments of its integrity, including planned maintenance and inspection of structures, periodic assessment of an installation taking account of its condition in relation to the original design expectations; assessment of damage or suspected damage.

The demonstration of compliance with the regulations requires that the material properties are sufficient to ensure that structural integrity is maintained.

4.3 Class Societies requirements

For HSS, the class rules differ on the requirements of fracture mechanics testing during steel mill qualifications for base materials and for weld joints. Class rules have generally required fracture mechanics testing only in the steel mill qualification scheme for the base material, though in some cases CTOD testing is required for MOUs intended to be on location for a period of greater than five years. The corresponding requirements for fixed structures also include fracture mechanics testing in the welding and qualification scheme for fabrication.

4.4 Historical development and the use of HSS

There have been significant developments in the last decades, enabling the production of weldable structural steels with yield strengths exceeding 355 MPa, as shown in Figure 1.

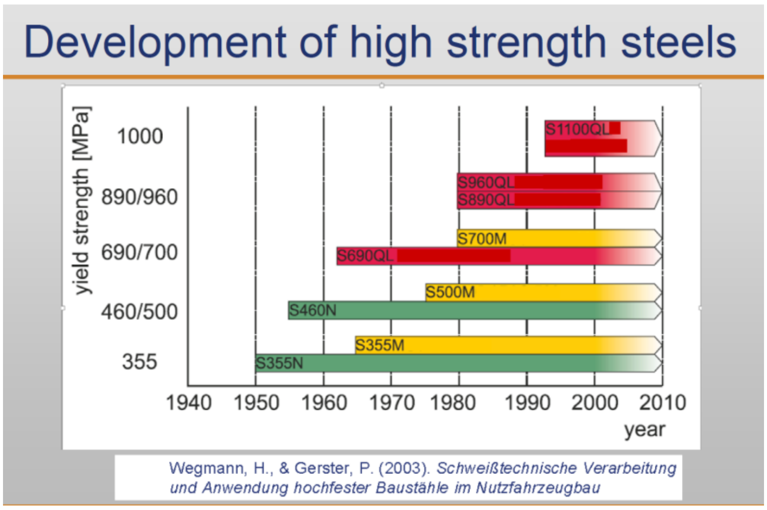

Figure 1: Development of high strength steels

High strength steels enable more economic design, slimmer structural elements and decreased structural weight. However, compared with lower yield strength steels, the use of HSS introduces a number of uncertainties concerning:

- the variability of the through-thickness properties of thick sections of rolled products, with sometimes reduced properties in the mid-section;
- standard test specimens being taken at a ¼ distance from surface;
- the adequacy of the testing requirements, in particular fracture toughness testing;
- the suitability of the acceptance criteria, in particular fracture toughness testing;
- the potential reduction of safety margins for HSS is due to:
  - an increase in the yield to tensile strength ratio, typically to greater than 0.9;
  - a reduction in the elongation requirement before tensile test rupture;
- crack arrest properties of modern steels not having improved despite the improvement of crack initiation toughness;
- the tensile strength of weldments and HAZ being lower than that of the base material, i.e. under-matching;
- the potential susceptibility of HSS to the risk of hydrogen-induced stress cracking (HISC);
- the applicability of the S-N fatigue curves for offshore structural steels to HSS with a yield strength greater than 690 MPa;
- the appropriateness of non-destructive inspection test acceptance criteria for HSS.

5 SCOPE OF COLLABORATION ACTIVITIES WITH THE CLASS SOCIETIES

The following activities were undertaken;

(1) review of the differences in fracture test requirements for HSS used in mobile vessels and fixed structures.

(2) an overview of developments in HSS by the Steel Construction Institute (SCI).

(3) review of HSS fracture properties.

(4) review of the structural performance of jack-up structures.

(5) review of recommendations on HSS in relevant standards.

(6) recommendations for the further development of the class rules and relevant guidance.

(7) preparation by the regulators of a position paper on the material property requirements for MOU HSS.

5.1 Review of Standards and Guidance

It is noted that the scope of the fracture toughness property requirements in current standards is varied and does not cover necessarily the latest weldable high strength steels: A number of documents specify material property requirements for offshore structures, see references.

The applicability of various standards and guidance documents to HSS is shown in Table 1:

Document	Applicability
DNVGL-OS-B101 (2012), Metallic Materials ABS Rules 'Rules for Materials and Welding 2008' (ABS, 2008) LR Rules for the Manufacture Testing and Certification of Materials (2015)	265 to 390 MPa yield strength (high strength steel), 420 to 690 MPa yield strength (extra high strength steel)
BS 7608 (2014), Guide to fatigue design and assessment of steel products	Design guidance for steels up to 1200 MPa yield strength
IIW-1823-07 (2008), Recommendations for Fatigue Design of Welded Joints and Components	Design recommendations for steels up to 960 MPa yield strength
NORSOK M-120 (2008), Material data sheets for structural steel	Can be applied but HSS are not defined
ISO BS EN ISO 19902 and 19904-1:2006: Petroleum and natural gas industries - Floating offshore structures, Part 1: Monohulls, semi-submersibles and spars	ISO 19902 for steels up to 500 MPa yield strength ISO 19904 does not specify yield strengths

Table 1: Standards fracture property requirements

5.2 Fracture Property Requirements for MOU Primary Structure

The requirements between the various class rules and ISO standards are variable in terms of the Charpy energy requirement, the test temperature and the Charpy transition curve temperature corresponding to 27J, (T_{27J}). The variability is reflected in the fracture toughness, K_{mat}, evaluated using the Master Curve from BS7910, and the corresponding critical flaw sizes for a load of 0.85 times the specified minimum yield strength, SMYS [OMAE2011-49654].

From the example calculations carried out, the relative flaw tolerance of structures generally decreases as the tensile properties increase and also as the section thickness increases. The relative flaw tolerance decreases as the yield strength (and applied stress) is increased. This suggests that it is advisable to increase the energy requirement, or decrease the Charpy test temperature for higher strength materials. Applying ISO 19904 yields greater flaw tolerance predictions for high SMYS steel than for the lower and midrange SMYS cases due to the specification of high energy (60J) at potentially very low temperatures (30°C below the lowest anticipated service temperature, (LAST)). However, it may be hard to satisfy these requirements at extreme low temperatures such as in Arctic environments where the LAST may be as low as -30/-40°C.

For the ABS, BV, DNVGL and LR codes, the tolerable defect size decreased as the SMYS increased. However, the ISO standard did not follow this trend for the highest strength steel. In this case, for both thicknesses, the Charpy energy requirement was high enough and the specified test temperature low enough (30°C below LAST) that a larger tolerable flaw length was predicted than for the cases where the SMYS was 400MPa.

Case	Details	Code	Required Charpy energy (J) and temp. (°C)	RT SMYS (MPa)	RT UTS (MPa)	T_{27J} (°C)	K_{mat} (MPa $\sqrt{m}$)	CTOD† (mm)	Flaw height (mm)	Critical flaw length (mm)
I	50mm thickness LAST=-10°C SMYS 250MPa	LR, ABS, BV and DNV	27J at -20°C	250	400	-20	90.99	0.231	10	41
		ISO	20J at -40°C	250	400	-33.5	109.27	0.334	10	85
II	50mm thickness LAST=-10°C SMYS~400MPa	LR, ABS and BV	40J at -20°C	400	510	-43	125.26	0.198	10	31
		DNV	41J at -20°C	400	510	-45	129.01	0.210	10	34
		ISO	35J at -10°C	395	510	-28.5	101.95	0.135	10	13
		ISO	45J at -10°C	400	510	-38.5	117.33	0.174	10	27
III	50mm thickness LAST=-10°C SMYS 690MPa	ABS	69J at -30°C	690	770	-67.5	182.66	0.204	10	18
		BV and DNV	46J at -20°C	690	770	-49.5	137.99	0.117	10	Not acceptable
		ISO	60J at -40°C	690	770	-79	220.32	0.297	10	35
		LR	For grades higher H40 (SMYS 390 MPa), approval is subject to special consideration							
IV	25mm thickness LAST=-10°C SMYS 250MPa	ABS, BV and DNV	27J at -20°C	250	400	-20	104.42	0.305	5	2520
		ISO	20J at -10°C	250	400	-3.5	84.34	0.199	5	77
		LR	27J at 0°C	250	400	0	80.90	0.183	5	43
V	25mm thickness LAST=-10°C SMYS~400MPa	ABS and BV	40J at -20°C	400	510	-43	145.18	0.266	5	231
		DNV	41J at -20°C	400	510	-45	149.64	0.283	5	362
		ISO	35J at -10°C	395	510	-28.5	117.45	0.179	5	43
		ISO	45J at -10°C	400	510	-38.5	135.74	0.232	5	112
		LR	39J at 0°C	390	510	-23	108.78	0.159	5	30
VI	25mm thickness LAST=-10°C SMYS 690MPa	ABS	69J at -30°C	690	770	-67.5	213.44	0.279	5	64
		BV and DNV	46J at -20°C	690	770	-49.5	160.32	0.157	5	19
		ISO	60J at -40°C	690	770	-79	258.23	0.408	5	480
		LR	For grades higher H40 (SMYS 390 MPa), the approval is subject to special consideration							

† Calculated value using BS7910:2013

Table 2: Fracture property requirements for MOU primary structure
(Ref. OMAE2011-49654, H. G. Pisarski and A. Stacey with updates)

The materials properties requirements of the main codes were reviewed and compared. It was found that in most cases the Charpy energy requirement values for longitudinal specimens specified were equal to approximately 10% of the SMYS. DNVGL-OS-B101, ABS, Bureau Veritas and Lloyd's Register requirements and the old HSE recommendations all follow this pattern. Requirements of test temperature have more variation; in most cases the test temperature is fixed and it is up to the designer to specify a suitable material grade. However, for the ISO requirements the test temperature is explicitly related to LAST. The ISO code also specifies fracture mechanics testing in certain cases and mentions the use of engineering critical assessment, ECA.

The different fracture property requirements in rules and standards for plate with thicknesses of 25mm and 50mm are shown below in table 2 which includes calculated critical flaw dimensions and CTOD values derived from K_{mat} using BS7910:2013. It should be noted that Charpy requirements are specified in the various rules for thicknesses up to 150mm.

5.3 Review of HSS Material Properties

A review of high strength steels material properties showed that considerable improvements in the material properties of HSS had been achieved but that it may not always be possible to meet the specified requirements for HSS suggesting that further data are required to improve understanding of the performance of HSS.

Furthermore,

- correlations between different types of toughness tests implies a Charpy value tested below the LAST will have sufficient fracture toughness, ref. table 2.
- modern steels have significantly improved Charpy properties; the resistance to fracture initiation is better but the improvement in crack arrest toughness has been relatively marginal.
- existing codes are based on work carried out on older steels – the validity of Charpy requirements based on these correlations is uncertain for improved steels.
- it was recommended to review the reliability of current underlying correlations between impact energy, fracture toughness and crack arrest toughness and their applicability to modern steels.
- micro-alloyed steels with superior toughness should result in safer and more economic structures.

5.4 Class Society Review of HSS

A review of findings on rack and chord materials was performed by the class societies which concluded that:

(1) There is a correlation between CTOD and Charpy values with BS 7910 providing an appropriate criterion for the calculation.

(2) A range of tests is performed during steel mill approval:

  (a) Pellini test to determine the Nil ductility transition temperature (NDTP);

  (b) Charpy tests to produce ductile to brittle transition curves;

  (c) Weldability tests carried out at high and low heat input.

It was agreed that UR W16 should incorporate the provision that steel mills should provide further information on the welding parameters, including the maximum heat input, relevant to the weldability qualification tests.

CTOD qualification at the steel mill can be considered as a step in the right direction. However, there is a need to identify a mechanism by which information such as the maximum heat input applied in welding can be conveyed to the fabricators and operators / duty holders in order to ensure that the appropriate weldment quality is achieved during fabrication

Furthermore, there is still no direct means of verifying whether qualified welding procedures are being applied correctly during the actual fabrication and adequate fracture toughness properties being achieved as a result of the absence of production testing during fabrication, with resultant complications at the yard pre- or post-delivery.

5.5 Requirements for fracture mechanics testing of fixed facilities during fabrication

CTOD requirements are given in NORSOK M-101 and in the latest version of IACS UR W16.

5.5.1 NORSOK M-101

As an example fracture mechanics test requirements in the NORSOK standard M-101, Structural Steel Fabrication, is stated below;

Clause 5.3.1:

CTOD testing shall be included in the qualification of welding procedures for weldments with a plate thickness above 50 mm for all strength levels for steel quality level I and II and for SMYS > 400 MPa for steel quality level III. CTOD testing shall be included in the qualification of welding procedures for weldments with a plate thickness below and equal 50 mm if requested by the designer for the specified steel quality level.

CTOD testing shall be executed from as welded and PWHT weld assemblies as applicable, covering the following combined conditions:

1) *full penetration butt weld with K- or half V –groove as deemed most representative for the actual fabrication. V and X groove are acceptable for weld metal test;*
2) *a welding procedure representing the maximum heat input to be used in fabrication;*
3) *maximum joint thickness (within 10 %).*

Assemblies shall be made and tested for the actual combination of steel manufacturer, welding process and welding consumable (brand) used, except welding consumables used for root passes only, provided these are removed completely by gouging and grinding.

NOTE: The changes specified in d) and e) above need not require re-qualification if HAZ properties for the material to be welded have been documented from the steel manufacturer for relevant thicknesses and heat input ranges. If sufficient documentation from the steel manufacturer is not available, a change of material shall require re-qualification of a reduced number of procedures. The number of procedures to be re-qualified shall be sufficient to verify that the HAZ properties of the new material is comparable with that used for the previous qualifications.

Clause 5.3.2 for welding of steels with SMYS > 500 MPa:

In addition to the requirements given in 5.3.1 the following additional requirements apply for welding of steels with SMYS > 500 MPa:

a) *a change in steel manufacturer;*
b) *CTOD testing as described in 5.3.1 i) shall be executed for thicknesses above 30 mm;*
c) *stress relieving if required/specified by designer.*

5.5.2 IACS UR W16, 'High Strength Steels for Welded Structures'

The collaboration between the regulators and the classification societies has contributed to the development of the revised version of IACS UR W16 with respect to fracture toughness requirements. The revised version of IACS UR W16, which was published in March 2016, has introduced CTOD testing as a requirement for the qualification of HSS for MOUs. Whilst this is a significant step forward, the guidance is limited to the CTOD testing of coarse-grained heat affected zones (considered to be the material with the lowest fracture toughness) in butt welds at -10°C which should be carried out by the mill and documented. MOUs operating in artic climate where LAST is less than -10ºC is not covered by the revised document.

Additionally, the revision to UR W16 includes a manufacturing approval scheme of high strength steels for welded structures, though this does not include CTOD testing of parent material unless deemed necessary by the classification society. The following additional guidance is provided in section 3.6.3 of Appendix A:

Additional tests such as CTOD test on parent plate, large scale brittle fracture tests (Double Tension test, ESSO test, Deep Notch test, etc.) or other tests may be required in the case of newly developed type of steel, outside the scope of W16, or when deemed necessary by the Society.

It is noted that the execution of the tests referred to in Appendix A, section 3.6.3 is at the discretion of the classification society. Furthermore, any test results obtained at the mill may not necessarily reflect the material properties of the actual steel being used.

5.6 MOU Data History

Results from a database on jack-ups, containing data for the last thirteen years, was queried for fractures in braces, legs and welds. It was found that there is little evidence to indicate that there is an existing or recurring problem relating to rack and chord on MOUs which would be resolved by means of CTOD testing:

(a) 145 results were found from 2002 to 2015;

(b) 4 cases involved rack failure – 3 related to broken teeth and 1 related to a spud can connection

(c) out of 600 survey reports, there were 80 reports with cracks of spudcan to leg connection

However, other incidents are known to the regulators to have occurred, e.g. chord brittle fracture at a defective weld HAZ in a jack-up and brittle fracture in MOU moorings.

5.7 Non-destructive Examination

As can be seen from table 2, the acceptable defect size decreases with increasing yield strength and that the acceptable defect sizes can differ between the class societies. This leads to a need for high quality welds with good HAZ properties and more stringent defect size acceptance criteria for HSS, but also a demand for skilled operators, adequate execution, proper reporting of non-destructive examination (NDE) and perhaps improvement in the NDE certification scheme.

With respect to NDE and qualification of NDE operators there are schemes that do require a third party approved independent body for certification such as CSWIP according to BS EN 473 and ISO 9712, Nordtest also according to EN 473 with requirements of EN 45013 for bodies certifying the operators and PCN (Personnel Certification in Non-Destructive Testing) scheme according to ISO/IEC 17024 and EN 473.

NDT operators, level 1 and 2, may also be certified according to the American Society for Non-destructive Testing (ASNT) in accordance with the SNT-TC-1A scheme by a qualified, company-employed, in-house, level 3 person. ASNT offers such qualification scheme according to SNT-TC-1A. All schemes seem to be acknowledged by the class societies for inspection of HSS special and primary structural components. Many yards and fabricators apply the SNT certification scheme where the operator’s certificate belongs to the company.

6 CONCLUSIONS

It was concluded that more stringent requirements may be necessary for MOUs intended to remain on site for a minimum of five years or where they are operated beyond the design life, or where dry docking and repair would not be carried out. In such circumstances, CTOD testing would constitute good practice for HSS structure.

It has been noted that:

- whilst UR W16 has been revised and includes additional testing requirements for high strength steels,
  - the new requirements are limited to qualification testing of weldments at the mill.
  - testing of parent plate and the conduct of large-scale tests is at the discretion of the classification society.
- steel mill qualification data, including CTOD testing of the parent plate, is not generally made available and is usually only shared with the classification society.
- Charpy test data is routinely obtained during WPS qualification. However, there continues to be uncertainty about the fracture toughness properties achieved during fabrication due to the absence of CTOD testing at that stage of the process. Thus, CTOD test results from the steel mill weldability testing may not necessarily be representative of welds made during fabrication if a fabrication yard does not know or apply the welding parameters established by the steel mill..

7 REFERENCES

(1) ABS Rules for Materials and Welding, 2008.

(2) BS EN ISO 19904-1:2006: Petroleum and Natural Gas Industries - Floating Offshore Structures, Part 1: Monohulls, Semi-submersibles and Spars.

(3) BS EN ISO 19905-1:2016: Petroleum and Natural Gas Industries - Site-specific Assessment of Mobile Offshore Units - Part 1: Jack-ups.

(4) BS EN ISO 19902:2007: Petroleum and Natural Gas Industries - Fixed Offshore Structures.

(5) BS 7608:2014, Guide to Fatigue Design and Assessment of Steel Products.

(6) Bureau Veritas Rules for the Classification of Offshore Units, 2006.

(7) Rules on Materials and Welding for the Classification of Marine Units, Materials and Welding, NR 216, Bureau Veritas, 2005.

(8) DNV Rules for Classification of Offshore Drilling and Support Units.

(9) DNV-OSS-101, Rules for Classification of Offshore Drilling and Support Units, DNV, 2015.

(10) DNV-OS-B101, Metallic Materials, DNV, 2012.

(11) DNV-OS-C401, 'Fabrication and Testing of Offshore Structures', DNV, 2004.

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(14) Guidelines for Application for Acknowledgment of Compliance (AoC) for Mobile Facilities Intended for Use in the Petroleum Activities on the Norwegian Continental Shelf, PSA, 2011.

(15) H. G. Pisarski and A. Stacey, Materials Property Requirements for Mobile Offshore Installations, OMAE2011-49654, American Society of Mechanical Engineers, 2011.

(16) IACS UR W16, High Strength Quenched and Tempered Steels for Welded Structures, May 2015, Rev. 3.

(17) IIW-1823-07, Recommendations for Fatigue Design of Welded Joints and Components, 2008.

(18) Lloyd's Register Rules and Regulations for the Classification of Offshore Units, Part 4, 2013.

(19) Lloyd's Register Rules for the Manufacture Testing and Certification of Materials, 2015.

(20) Offshore Technology Report 2001/048 'Floating Installations', HSE, 2001.

(21) Offshore Technology Report 2001/015 'Steel', HSE, 2001.

(22) NORSOK Standard M-101 Structural Steel Fabrication, Edition 5, October 2011.

(23) NORSOK Standard M-120 Material Data Sheets for Structural Steel, Edition 5, November 2008.

(24) International Association of IACS Recommendation No. 011, 'Materials Selection Guideline for Mobile Offshore Drilling Units', 1996.

(25) EN 10225-2001 Weldable Structural Steels for Fixed Offshore Structures – Technical Delivery Conditions.

[i] IACS is a membership organisation for class societies and will promote continual enhancement of class rules, procedures and guidelines and strive for consistency among its members in setting and verifying compliance against these technical standards.