High Strength Steels for Jack-Up Platforms

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ABSTRACT
During the last years the demand of new steels for the use in extreme environments has constantly increased. On the one hand the operational temperatures for the development of arctic oil and gas fields are ranging from about -70 °C to +30 °C which has a big influence on the mechanical properties of the steels. On the other hand there is also a need of special steels with high yield strength up to f_y = 690 MPa and high ductility at -40 °C and below. With this the advantages of thinner sections, like less weight, less welding costs and a lower wall-thickness reduction factor can be taken into account. Under these aspects steel manufacturer are developing better production lines and steel qualities resulting in heavy plates and seamless hollow sections, also with varying thickness over the length, and in high strength materials with high toughness and good weldability. In the following a few aspects and some assistance are offered how and where to find the right material and which standards should be taken into account.

KEY WORDS: Material selection, steel grade, high strength steel, toughness, fatigue, arctic steel

INTRODUCTION
High strength steels with yield strengths up to 700 MPa are widely used in Jack-up Rigs since many years, whereby the main applications are legs, spud cans, racks and pinions. The offshore certification companies like DNVGL, ABS and others included these steels in their recommendations and defined their mechanical and chemical properties. For many years the design was done for temperatures down to -40 °C, which is fully sufficient for most applications. New challenges and developments are aiming for more severe applications in arctic regions with special toughness requirements at temperatures of -60 °C and below. At the same time the steel manufactures improved the properties of their products also for very thick steel plates and new hot rolled seamless hollow sections. In the following some information about these new steels and their properties are given.

Normally, steels are classified according to their yield strength. Depending on the fabrication process and the thickness plates with yield strength up to 1100 MPa and more are available. Seamless hot rolled circular hollow sections are produced with yield strengths up to 960 MPa. Actually, steel grades up to 700 MPa are used in offshore oil and gas.

In general, steel can be ordered in the following conditions:
A - age hardened (commonly known AR for as-rolled)
N - normalized or normalized rolled (N)
M - thermo-mechanical rolled (M, also known as TM)
Q - quenched and tempered (Q, commonly known as QT)

The denomination of the different grades follows the rules given in the particular standards. Table 1 explains the symbols and the system used in the European standards for example [8].

TABLE 1: Steel denomination according to European standards [8]

<table>
<tr><td colspan="2">Main symbols</td><td colspan="5">Additional symbols</td></tr>
<tr><td rowspan="2">character</td><td rowspan="2">Mechan. Prop.</td><td colspan="5">for steel</td></tr>
<tr><td colspan="3">Category 1a</td><td></td><td>Category 2</td></tr>
<tr><td rowspan="10">G=Cast steel (when required)

S= Structural steel</td><td rowspan="10">nnn = defined minimum yield strength in MPa</td><td colspan="3">Charpy V-energy</td><td>Test temp.</td><td rowspan="10">C = with specific cold formability
D = for hot-dip screedings
E = for enameling
F = for forging
H = hollow section
L = for low temperatures
M = thermo- mechanical rolled
N = normalized
P = for sheet piles
Q = quenched
S = for shipbuilding
T = for pipes
W = weather-proof
an = chemical symbols</td></tr>
<tr><td>27 J</td><td>40 J</td><td>60 J</td><td>°C</td></tr>
<tr><td>JR</td><td>KR</td><td>LR</td><td>+20</td></tr>
<tr><td>J0</td><td>K0</td><td>L0</td><td>0</td></tr>
<tr><td>J2</td><td>K2</td><td>L2</td><td>-20</td></tr>
<tr><td>J3</td><td>K3</td><td>L3</td><td>-30</td></tr>
<tr><td>J4</td><td>K4</td><td>L4</td><td>-40</td></tr>
<tr><td>J5</td><td>K5</td><td>L5</td><td>-50</td></tr>
<tr><td>J6</td><td>K6</td><td>L6</td><td>-60</td></tr>
<tr><td colspan="4">A = age hardened
M = thermo- mechanical rolled
N = normalized
Q = quenched and tempered
G = other characteristics, when required with 1 or 2 characters</td></tr>
</table>

INFLUENCE OF MANUFACTURING PROCESS

The correct selection of the appropriate steel grades and categories is strongly influenced by the steel properties of the base material and the influence of the welding process during fabrication.

Commonly used are thermo-mechanical rolled steels (M) because of their low carbon equivalent (CE) and their good weldability. Depending on the cooling process during the fabrication yield strengths up to 1100 MPa can be reached. Plate thicknesses are offered up to 130 mm and depend on the steel grade. The rolling processes for M steels lead to:

- Low content of alloying elements and therefore to
- Good weldability
- Yield strength up to 500 MPa also for thicker plates up to 100 mm thickness
- Less preheating
- High plasticity and high toughness even at -50 °C, on request also -80 °C
- Already used in linepipe and shipbuilding industry with very good experiences

Comparing the preheating temperature of normalized (N) and thermo-mechanical rolled steels (M) in dependency of the relevant plate thickness another advantage of M steels becomes clear. Besides the good weldability, also a lower pre-heating temperature for welding is sufficient compared to normalized steels.

Another interesting comparison between normalized and thermo-mechanical rolled steels gives Figure 1, where the correlation of the carbon equivalent value CEV with the rolling process is shown. It becomes clear that for same CEV by M rolling higher yield strengths compared to N rolled steels can be achieved, which is another advantage of these steel types.

Together with the increasing yield strength and wall thicknesses, the risk of lamellar fracture occurs for rolled steels due to the manufacturing process and greater concern is given to brittle fracture.

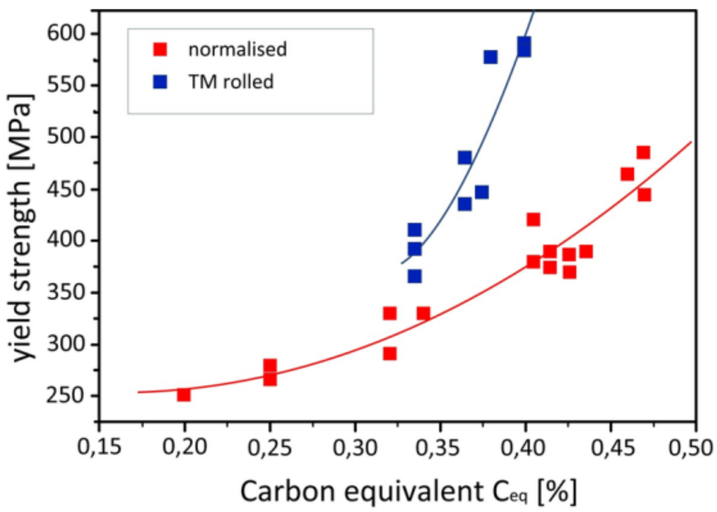


FIGURE 1: INFLUENCE OF THE ROLLING PROCESS ON THE YIELD STRENGTH IN DEPENDENCE OF THE CEV (SOURCE: DILLINGER HÜTTE)

Weldability qualifications, therefore, usually have to be performed on the thickest material used in the project. Here the toughness is characterized by impact and CTOD-test on welds. Due to the fact that the specimen sizes for the CTOD tests are changing with the plate thickness but the impact test specimens do not, it becomes more difficult for the producers to fulfill the necessary requirements, which also can be different in the relevant standards. Especially for stresses in direction of the thickness it is important to provide sufficient toughness to avoid brittle fracture.

So, going to greater thickness with more than 100 or 120 mm the process changes from thermo-mechanically rolled to quenched and tempered (Q) steels, formerly known as QT steels. Using this process for thicker plates a higher content of alloying elements is needed, which also leads to higher carbon equivalents (CE). This is the reason why for these steels it is necessary to take special care during welding. Another possibility is to modify the thermo-mechanical rolling process by using special cooling processes like an accelerated cooling or direct intensive cooling, e.g. Figure 2 shows schematically the relation between rolling process, carbon equivalent and yield strength.

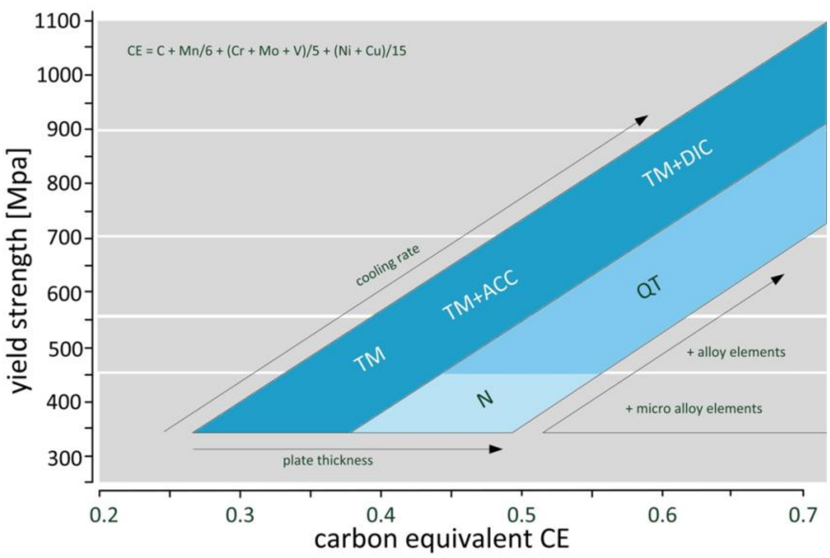
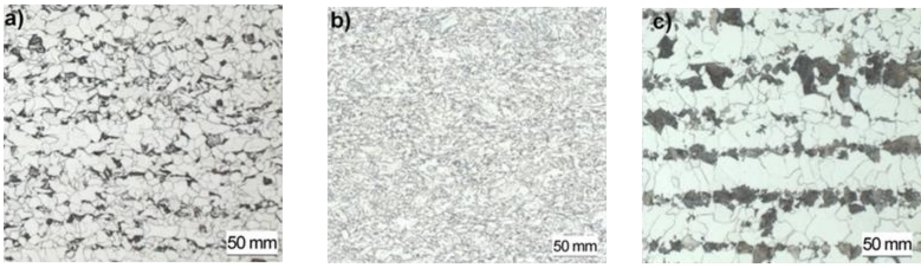


FIGURE 2: RELATION BETWEEN YIELD STRENGTH – CEV AND ROLLING PROCESS (SCHEMATIC OVERVIEW) (SOURCE: VOESTALPINE)

The rolling and cooling process directly influences micro structure of the steel, which is the basis for yield strength, toughness, hardness and weldability. The differences of the microstructures can clearly be seen in the direct comparison given in Figure 3.



a) Normalized   b) Thermo-Mechanical Rolled   c) Quenched and Tempered

FIGURE 3: COMPARISON OF THE RESULTING MICRO STRUCTURES FOR DIFFERENT ROLLING PROCESSES FOR HIGH-STRENGTH STEELS (R_{EH} > 355 MPA) (SOURCE: DILLINGER HÜTTE)

These processes are well-known and commonly used by all major steel producers. Nevertheless, the production of heavy plates or thick walled seamless hollow sections needs the proper equipment which can handle the needed very high forces during the rolling, the exact timing and measurements during the cooling and re-heating steps. Especially for a big wall thickness very high forces are needed in the rolling stands. Only then a good deformation in the mid thickness can be achieved to get the micro structure and properties needed over the whole thickness. Together with that a lot of experience is important to bring together the perfect chemical composition and purity of the raw material and the appropriate rolling processes.

NEW DEVELOPMENTS

Latest developments in the market for offshore applications are in need of increased cost efficiency and high reliability of products which are excellent in their mechanical properties. Harsh environmental conditions like swells, storm loads and the extremely low service temperatures determine the demanding requirements on steels for offshore constructions. At the same time new challenges are aiming for more severe applications in arctic regions. The most important factor is the combination of high strength and high toughness properties at temperatures down to -60 °C and below for these challenging environmental conditions.

Next to that, excellent weldability is required for optimized and efficient production of offshore constructions, acknowledging the challenge of matching properties of the arctic steels and the weld material. All features are crucial factors to guarantee safe construction and operation of offshore structures to meet the severe challenges in these exploration fields.

Actual developments, e.g. by Dillinger Hütte are aiming to plates with thickness over 200 mm performing yield strength of 690 MPa and sufficient toughness properties throughout the plate cross-section at test temperatures of down to -60 °C. Developments like this not only are made for very heavy platforms but also can be used in the field of arctic installations. As these heavy sections are outside of the standard ranges of the most rules and standards they need to have relevant certificates from the certification companies. These certificates are provided by the steel manufacturers.

Besides all strength and toughness requirements also the processing of the steels is to be kept in mind, which especially can be a challenge for quenched and tempered steels.

- Cold forming is possible, but always related to introduction of residual stresses which cause a hardening of the material and a reduction of the toughness. In this case an additional heat treatment may be necessary.
- Hot forming above the maximum allowable stress relief temperature will alter the initial properties of the steel and might require a subsequent heat treatment also.
- Flame cutting and preheating before welding will be necessary as well as a careful temperature control during the processes.

Usually all steel producers give hints and recommendations how to process the various materials and they help to develop the fabricators own fabrication procedures. Preliminary tests under actual shop conditions are also recommended to prove the suitability of the processing conditions for the particular conditions of welding chords to racks and rack to rack butt welds. In any case a close contact to the steel producers is suggested before ordering.

Especially fatigue as a consequence of swell and stormy weather requires the use of seamless pipes and seamless hollow sections, which are predestined for such challenging applications. In the following a closer look into the development of a new arctic steel grade for seamless hot rolled hollow sections will explain the influences of the chemical composition and the production process on the final material properties. These are similar to plates as well and will help to understand the background of the new high strength steel grades themselves and their weldability. Nevertheless, due to the rolling process no M rolled seamless hollow sections are available.

Alloying Concept

High strength combined with high toughness values at low temperature and good weldability depends on low carbon, fine grain steels in quenched and tempered condition. Micro-alloying and advanced processing supports the strength level, while the elements nickel and copper target for a smooth toughness transition at extremely low temperatures.

Table 2 shows the chemical element limits of the developed alloy and the limits for the carbon equivalent (CE_{IIW} and CE_{Pcm}) as defined according to API 5L [2]. The alloying concept is based on the requirements of different specifications, e.g. API 5L [2], prEN 10225-3 [13], DNVGL-OS-B101 [4], ABS MODU Rules [1] and NORSOK M-120 [14]. In addition, different customer specifications were included.

TABLE 2. CHEMICAL ELEMENT LIMITS OF THE INVESTIGATED ALLOY (WT. - %) FOR REFERENCE GRADES X80 TO X100 (SEE ALSO TABLE 4)

C	Si	Mn	P	S	Cr	Cu	Nb, W, Al, N	Ni	Mo	CE_{IIW}	CE_{Pcm}
≤ 0.08	0.10 - 0.45	≤ 1.60	≤ 0.015	≤ 0.005	≤ 0.50	≤ 1.00	alloyed	0.50 - 1.00	≤ 0.50	≤ 0.57	≤ 0.27

Due to the applied low carbon concept, the presented alloy shows an optimized and comparatively low carbon equivalent. The CE_{Pcm} limit of the new Super Oceanfit® 100 WeldFIT [17] [19], which is the relevant indicator according to API 5L for steel grades with a carbon content up to 0.12 wt. - %, has been kept on the same level as for the previously developed Oceanfit® 80 WeldFIT to Oceanfit® 100 WeldFIT [16][18].

Steel Making and Steel Pipe Production

The developed alloy is molten by the basic oxygen furnace (BOF), as well as the electrical arc furnace (EAF) process. Using well sorted iron ore and scrap in combination with an excellent secondary metallurgy, very low contents of residual elements like sulfur or phosphorous can be provided. By additional use of vacuum degassing, aluminum killing and calcium treatment in combination with controlled casting and solidification processes, high cleanliness requirements are fulfilled.

The investigated alloy can be produced by different seamless pipe rolling techniques, e.g. Continuous, Pilger and Plug rolling or Premium Forging processes. Using these different techniques and processes the new X100 pipes with a wall thickness up to 40 mm can be produced. The outer diameter ranges from 26.9 mm up to 711 mm. After rolling, the pipes were heat treated using an appropriate quenching and tempering process to ensure homogeneous mechanical properties through pipe length and wall thickness. Therein, the austenitization temperatures are higher than 900 °C and the tempering temperatures are above 600 °C.

Figure 4 shows a micrograph from light optical investigations in quenched and tempered condition in two magnifications. The sample location is situated in mid wall position. Both pictures show the typical homogeneous micro-constituent constellation of a very fine structures mixture of tempered bainite and martensite with lath sizes of only few microns. A similar constellation of the microstructure can be found over the complete wall thickness of the pipes.

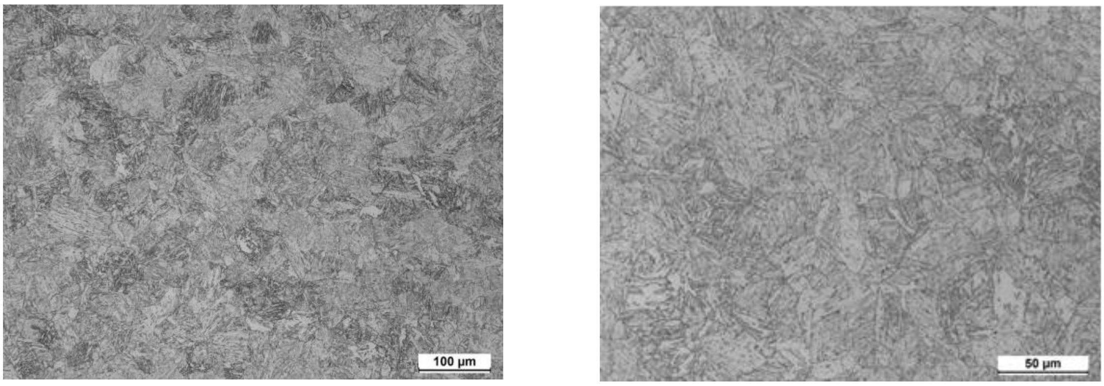


FIGURE 4: LIGHT OPTICAL MICROGRAPH, MID WALL, RECORDED WITH MAGNIFICATION 200X AND 500X

Mechanical Properties
Figure 5 shows the $R_{t0.5}$ yield strength and the ultimate tensile strength (UTS) of the new X100 for three different wall thicknesses, tested in accordance with ASTM A 370-16 [3]. For the investigation, tendentially thicker walls have been chosen which represent the most commonly requested thickness range from 27.8 mm to 40 mm. According to DNV GL and ABS [1] regulations bigger diameters and wall thicknesses qualify lower ones. Nevertheless, also thinner and thicker walls will be qualified in the future to complete the industrialization phase. The yield strength values of the new alloy decrease slightly with increasing pipe wall thickness.

For all three wall thicknesses the requirements of the API 5L (X100Q) [2], prEN 10225-3 (S690QLHHO) [13], DNVGL (VL FO690QT) [4] and ABS (FQ70) [1] for yield strength, min. 690 MPa, and tensile strength, min. 770 MPa, are met. For example the yield strength for wall thickness t = 40 mm ranges from 695 MPa to 736 MPa and the tensile strength is between 780 MPa and 818 MPa. With a f_u/f_y ratio > 1.10 the requirements of EN 1993-1-12 [6] which requests $f_u/f_y > 1.05$ for steel grades between S460 and S700 are fulfilled.

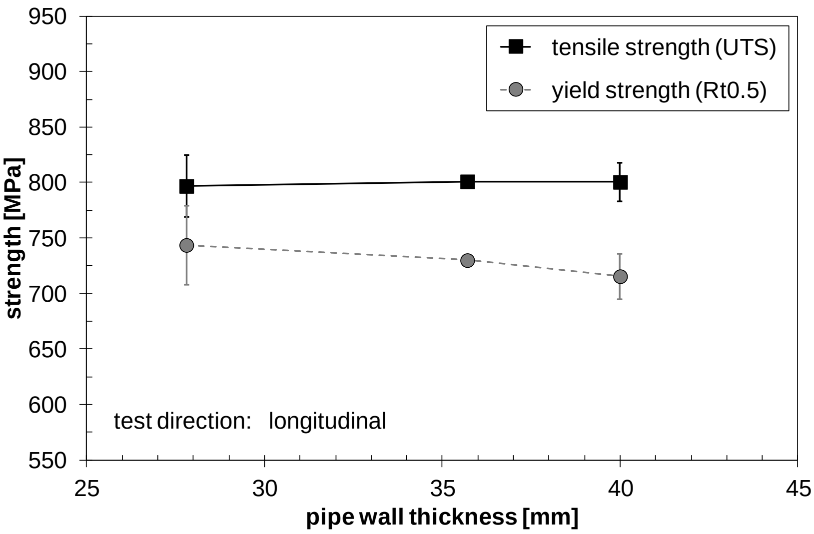


FIGURE 5: RT0.5 AND UTS AS A FUNCTION OF THE PIPE WALL THICKNESS, TESTED AT ROOM TEMPERATURE

The decrease of the strength with increasing wall thickness is in line with the common knowledge. Therein, the developed alloying concept guarantees a high strength grade level X100 for a wall thickness range up to 40 mm.

The impact energy decreases slightly with a marginal slope with higher wall thickness at test temperature -60 °C (see Figure 6). The minimum measured impact energy is 141 Joule at a wall thickness of 27.8 mm, while the lowest value is given at 40 mm wall thickness with 85 Joule.

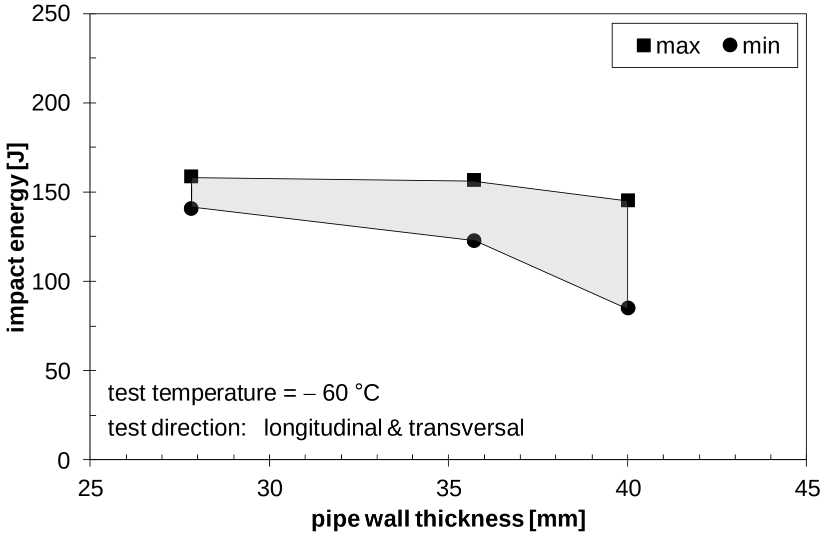


FIGURE 6: MINIMUM AND MAXIMUM MEASURED IMPACT ENERGY OF FULL SIZE CHARPY-V NOTCHED SPECIMENS AS A FUNCTION OF THE PIPE WALL THICKNESS

The minimum and maximum measured impact energies for a CHS with 40 mm wall thicknesses as a function of test temperature are shown in Figure 7. A similar behavior was found for all other tests on CHS with different wall thicknesses which show a sufficient toughness even at -60 °C (requirement according to DNVGL-OS-B101 and ABS MODU Rules: min. 69 Joule average longitudinal and min. 46 Joule average transversal). The impact energies drop constantly with decreasing test temperatures, which is commonly known, but within the tested temperature range no sharp transition to a lower shelf is observed. This behavior guarantees sufficient buffer for extreme conditions.

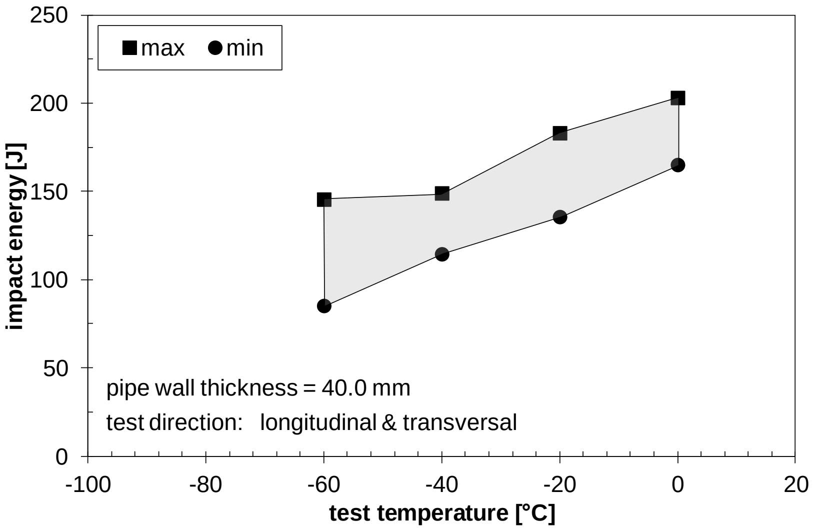


FIGURE 7. MINIMUM AND MAXIMUM MEASURED IMPACT ENERGY OF FULL SIZE CHARPY-V NOTCHED SPECIMENS AS A FUNCTION OF THE TEST TEMPERATURE AT 40 MM WALL THICKNESS

TABLE 3: MECHANICAL PROPERTIES OF SEAMLESS HOT ROLLED CHS (SOURCE: VALLOUREC)

Steel grade acc. API 5L	Yield strength R_{eH} in MPa at wall thickness t ≤ 40 mm	Tensile strength R_m in MPa	Elongation A_{min} in % after fratcure		Impact energy KV_{min} in J (average value) at -40 °C	
			long.	trans.	long.	trans.
X52	355	490 – 620	22	20	50	30
X60	420	530 – 680	22	20	60	30
X65	460	570 – 700	19	17	60	40
X70	485	580 – 760	19	17	60	32
X75	520	610 – 770	18	16	60	40
X80	555	670 – 825	18	16	60	40
X85	590	703 – 862	17	15	62	41
X90	620	720 – 890	17	15	62	41
X100	690	770 – 940	17	15	69	46

In general the new developed steels now allow the production of hot rolled seamless CHS with yield strengths between 355 and 770 MPa and impact toughness down to -60 °C. Depending on the harshness of conditions, these grades can be selected to precisely match application requirements in ship construction, superstructures, jack-up rigs, platform cranes, helicopter decks and housings specifically designed for long-term resistance in challenging project environments. Table 3 shows the mechanical properties for a CHS with good weldability and high impact toughness for wall thickness less or equal 40 mm. Tubes with thicker wall thicknesses can be delivered on request.

As the different standards use different denominations of these steel grades Table 4 helps to compare between API [2], ISO [11], DNVGL [4], ABS [1], EN [10] and NORSOK [14].

TABLE 4: COMPARISON OF STEEL GRADES FOR CHS ACCORDING THE DIFFERENT STANDARDS AND RULES [18]

Designation	**API 5L**	**ISO 3183**	**DNVGL-OS-B101**	**ABS**	**EN Steel Name**	**EN Steel No.**	**NORSOK M-120**
Oceanfit® 52	X52Q PSL 2	L360Q PSL 2	(VL E36)	(EH36)	(S355G14+QT) (S355G15+QT)		(Y27) (Y22)
Oceanfit® 60	X60Q PSL 2	L415Q PSL 2	(VL E420)	(EQ43)	S420G6+QT	1.8852+QT	Y32/Y37
Oceanfit® 65	X65Q PSL 2	L450Q PSL 2	(VL E460)	(EQ47)	S460G6+QT	1.8884+QT	Y42/Y47
Oceanfit® 70	X70Q PSL 2	L485Q PSL 2					
Oceanfit® 75	X75Q PSL 2	L520Q PSL 2	(VL E500)	(EQ51)			Y52/Y57
Oceanfit® 80	X80Q PSL 2	L555Q PSL 2	(VL E550)	(EQ56)			
Oceanfit® 85	X85Q PSL 2	L590Q PSL 2					
Oceanfit® 90	X90Q PSL 2	L620Q PSL 2	(VL E620)	(EQ63)			
Oceanfit® 100	X100Q PSL 2	L690Q PSL 2	(VL E690)	(EQ70)			

Similar to hot rolled plates, also circular hollow sections need to have the relevant certificates showing that they fulfill the requirements of the relevant standards and rules as they are mentioned in Table 4 for example. These certificates are provided by the steel manufacturers. For specific offshore class projects offshore grade approvals are required according to offshore societies as ABS and DNVGL.

Welding
An important factor for good weldability is a low carbon content as well as a low carbon equivalent. Residual elements like Sulphur and Phosphorus should be limited to a minimum. An additional requirement for extra high strength steels up to 690 MPa yield strength concerns the hardness HV10 which limited to 420 HV10 after welding through the wall thickness according [5].

Especially for high strength steels hydrogen induced cold cracking is a particular concern for welding. To avoid such cracks in the heat affected zone and the weld metal, welding conditions and filler materials which add very little hydrogen to the base metal, have been developed and need to be used. One possibility is to use shielded arc welding with a correct gas protection, which avoids exposing the weld area to current air. For manual arc welding, electrodes with basic coating (very low hydrogen type HD < 5 in accordance with ISO 3690), and dried according to the manufacturer's instructions, are to be used. The same applies for weld fluxes and their treatment.

An increased heat input leads to lower tensile properties in the weld metal. Experience has shown that the welding conditions should be chosen in a way that t8/5 the cooling time in the weld and HAZ does not exceed 15. Heat input and interpass temperatures have to be restricted correspondingly to about 2 kJ/mm and 200 °C to keep t8/5 below this limit. For the welding consumables the same conditions apply as for the base materials.

In case welds with undermatching strength properties are acceptable, which depends on the design, lower strength consumables can be used as they are less susceptible to hydrogen induced cracking and usually achieve better elongation and ductility. They are also recommended for tack and root welds.

For experienced fabricators it is no problem to fulfill the requirements of these processes.

STANDARDS AND RULES

There are different relevant standards and recommendations available which help to choose the appropriate steels for applications in jack-up rigs as there are EN 10225 [10], DNVGL-OS-B101 [4], ABS [1], API Spec 5L [2], NORSOK M-120 [14] and EN ISO 19902 [12] for fixed offshore structures to name the most common ones. The following overview will help to see the differences and to choose the right material. A closer look inside of these standards is given in [15].

EN 10225 - Weldable structural steels for fixed offshore structures
The technical delivery conditions of EN 10225 [10] - Weldable structural steel for fixed offshore structures are limited to steels up to grades with 460 MPa yield strength and are based mainly on the technical delivery conditions for onshore steels as EN 10025 [7] for flat and open sections and EN 10210 [9] for hot-rolled seamless hollow sections. Depending on the requirements, EN 10225 distinguishes between Group 1 for standard applications and group 2 for applications which need better resistance in thickness direction. All steel grades given there are to be delivered in normalized (N) or quenched and tempered (QT) condition.

Currently the standardization committee is working on a new release of this standard which will include steel grades up to 770 MPa yield strength and – that is new – also hot rolled seamless hollow sections made of high-strength steels [13].

EN ISO 19902 – Fixed steel offshore structures
More detailed help concerning the material selection for different parts of a structure is given in EN ISO 19902 [12] – Fixed steel offshore structures. There, the following types of fixed steel offshore structures for the petroleum and natural gas industries are fixed: caissons, free-standing and braced; jackets; monotowers; towers. In addition, it is applicable to compliant bottom founded structures, steel gravity structures, jack-ups, and other applications (such as underwater oil storage tanks, bridges and connecting structures), to the extent to which its requirements are relevant.

EN ISO 19902 distinguishes different material categories, which help to select the relevant steel. These categories differentiate between the various components and the location of the components in the structure and give the adequate yield strength group and toughness classes for each of the five groups. The specified minimum yield strengths range between 200 MPa and 495 MPa.

DNVGL–OS-B101 (2015)

In contradiction to the standards mentioned before DNVGL–OS-B101 [4] also gives some information about steel grades with f_y > 460 MPa. There, the delivery conditions of the rolled steel and the relevant CVN requirements for temperatures down to -60 °C are defined. The maximum plate thickness is limited to 150 mm.

The DNVGL rules define 3 categories of steel grades:

- normal strength steels (NS) with a minimum yield strength of 235 MPa
- high strength steels (HS) with minimum yield strength between 265 and 390 MPa and
- extra high strength steels (EHS) with minimum yield strength between 420 and 690 MPa

As an example the mechanical properties for extra high strength steels are given in Figure 8, which is an excerpt of DNVGL–OS-B101 [4].

Grade	*Yield stress ReH minimum (MPa)*	*Tensile strength Rm (MPa)*	*Elongation A5 minimum (%)*	*Impact energy, average minimum (J)1)*		
				Temperature (°C)	*t ≤ 150 (mm)*	
					L	*T*
VL A420 VL D420 VL E420 VL F420	420	530 to 680	18 2)	0 -20 -40 -60	42	28
VL A460 VL D460 VL E460 VL F460	460	570 to 720	17 2)	0 -20 -40 -60	46	31
VL A500 VL D500 VL E500 VL F500	500	610 to 770	16 2)	0 -20 -40 -60	50	33
VL A550 VL D550 VL E550 VL F550	550	670 to 830	16 2)	0 -20 -40 -60	55	37
VL A620 VL D620 VL E620 VL F620	620	720 to 890	15 2)	0 -20 -40 -60	62	41
VL A690 VL D690 VL E690 VL F690	690	770 to 940	14 2)	0 -20 -40 -60	69	46

1) Test direction shall follow [5.3] of this section

2) For full thickness flat test pieces with width 25 mm and gauge length 200 mm, the minimum elongation (%) is reduced to the following values

Thickness, mm	t ≤ 10	10 < t ≤ 15	15 < t ≤ 20	20 < t ≤ 25	25 < t ≤ 40	40 < t ≤ 50	t > 50
Strength level 420	11	13	14	15	16	17	18
Strength level 460	11	12	13	14	15	16	17
Strength levels 500 and 550	10	11	12	13	14	15	16
Strength level 620	9	11	12	12	13	14	15
Strength level 690	9	10	11	11	12	13	14

FIGURE 8: MECHANICAL PROPERTIES FOR EXTRA HIGH STRENGTH STEELS, EXCERPT FROM DNVGL-OS-B101 [4]

A new edition of DNVGL-OS-B101 will be launched 1st of July 2017, where new extra high strength steels and steel grades up to 960 MPa yield strength will be introduced.

ABS RULES (2017)
The American Bureau of Shipping released new rules for building and classing mobile offshore drilling units in 2017, which also are known as MODU 2017 rules [1]. Nevertheless, the part about the Material Selection for ABS Grades of High Strength Quenched and Tempered Steel is the same as in the issue of 2013.
In Chapter 5 of MODU 2017 detailed rules for all steel grades are given as well as the differentiation between Special, Primary and Secondary Application, which is based on what a failure will mean to the structure. This is also influencing the choice of material in a certain way. Here, we only want to give an insight into the details about the material selection for high strength steels as they are given in Part 3 of the ABS rules in Chapter 1, Appendix 3. These rules are applicable for steel plates only, for tubes special considerations have to be made.

Basically, for the application of the ABS rules [1] the steel plates are to be finished as quenched and tempered, but also thermo-mechanical rolled plates and direct quenching and tempering processes are included.

The steels are grouped in 6 categories according to their yield strength as can be seen in Figure 9. Each of these categories is linked to 4 different grades of Charpy V-notch toughness connected to 4 different test temperatures (Figure 10).

	Category					
	43	47	51	56	63	70
Yield strength in N/mm²	420	460	500	550	620	690
Tensile strength in N/mm²	530 – 680	570 – 720	610 – 770	670 – 835	720 – 890	770 - 940

FIGURE 9: STEEL CATEGORIES ACCORDING TO ABS RULES [1]

	Steel grades			
	AQ	DQ	EQ	FQ
Test temperature in °C	0	-20	-40	-60

FIGURE 10: STEEL GRADES ACCORDING TO ABS RULES [1]

For each of these grades the minimum average Charpy V-notch toughness is given, where it has to be distinguished whether the specimens are taken transversal (T) or longitudinal (L) to the rolling direction. Further, depending on the yield strength of the material different minimum values are tabulated. Detailed information about the minimum Charpy V-notch energy required is mentioned in the ABS Material Selection rules. For example, EQ43 requires a minimum of 41 J in longitudinal direction. Compared to this, for steel grade EQ70 a minimum of 69 J in the same direction is given.

The requirements of ABS [1] and DNVGL [4] are comparable.

SUMMARY AND RECOMMENDATIONS
This article gives a short overview where the development of modern steels for offshore applications stands today and gives some ideas what to keep in mind when choosing plates and sections for an offshore project.
Today thermo-mechanically rolled plates with thickness over 200 mm performing yield strength of 690 MPa and sufficient toughness properties throughout the plate cross-section at test temperatures of down to -60 °C are available. Hot rolled seamless circular hollow sections show similar properties up to wall thickness of 40 mm. Thicker sections are available on request. The very high toughness makes these steels particularly suitable for arctic applications.

For the application in Jacket structures the various certification companies confirm the accordance with the relevant rules and standards.

Different design aspects have to be kept in mind when choosing these semi-finished products as the wall thickness influences the yield strength, low temperature reduces the toughness, notches and structural stresses as well as the wall thickness and surrounding seawater reduce the fatigue resistible life.

For all aspects of processing the various steels the producers give hints and recommendations and help to develop the fabricators own fabrication procedures. In any case a close contact to the steel producers is suggested before ordering.

Finally, it has to be noted that the differentiation of normal strength steel, high strength steel and extra high strength steels is different in various recommendations and publications. So, a clear definition of the yield strength is the only way to avoid confusion when using terms like high strength or extra high strength steels. Onshore for example, the range of high strength steels comprises yield strength from 460 MPa up to 770 MPa.

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