PART
2

CHAPTER 1 Materials for Hull Construction

SECTION 8 Extra High Strength Steel *(2018)*

1 General

The requirements in this Section are intended for product forms, which include plates, wide flats, sections, bars and tubulars.

Specific requirements described in this Section, together with the general requirements in Sections 2-1-1, 2-1-2 and 2-1-3, are applicable to ABS extra high strength steels. Manufacturers are to be approved. Refer to 2-1-1/1.2 and 2-A4-3.

Steels are grouped in eight categories of 43, 47, 51, 56, 63, 70, 91 and 98 based on the level of yield strength (see 2-1-8/1 TABLE 1). Each category is combined with four different alphabetic indicators of AQ, DQ, EQ and FQ according to the Charpy V-notch impact test temperature (see 2-1-8/1 TABLE 2) to designate the steel grades, except for 91 and 98 grade for which FQ grades are specially considered by ABS. For example, Grade AQ43 indicates the steel of yield strength of 420 N/mm^2 (43 kgf/mm^2, 61 ksi) given the test temperature of 0°C (32°F).

TABLE 1
Steel Category Based on Minimum Yield Strength *(2018)*

Yield Strength\ Category	***43***	***47***	***51***	***56***	***63***	***70***	***91***	***98***
N/mm^2	420	460	500	550	620	690	890	960
(kgf/mm^2, ksi)	(43, 61)	(47, 67)	(51, 73)	(56, 80)	(63, 90)	(70, 100)	(91, 129)	(98, 139)

TABLE 2
Steel Grade Suffix Based on Test Temperature *(2018)*

Test Temperature\ Grade Suffix	***AQ***	***DQ***	***EQ***	***FQ***
°C (°F)	0 (32)	-20 (-4)	-40(-40)	-60(-76)

2 Method of Manufacture

The steel is to be fully killed and manufactured by basic oxygen, basic electric arc furnace or by processes specially approved by ABS.

The steel mill is to have a documented process for control of raw materials.

The steel is to be fine grain treated, and is to have a fine grain structure. The fine grain practice is to be as detailed in the manufacturing specification. The manufacturer is to have the capability to produce a fine grain structure of ≥ 6 determined by micrographic examination in accordance with ISO 643 or ASTM E112 or alternative test method. Refer to 2-1-2/5.7 and 2-1-3/5 for fine grain practice.

The steels shall contain Nitrogen binding elements as detailed in the manufacturing specification. Also refer to note 4 in 2-1-8/4 TABLE 4A.

Processes used to control Hydrogen are to be applied. This includes Hydrogen out-gassing methods, such as holding plate at suitable temperatures in controlled conditions. Details of holding environments are to be submitted.

Vacuum degassing is mandatory for steel grades 70, 91 and 98 and for all grades with thickness greater than 50 mm.

3 Delivery Condition – Rolling Process and Heat Treatment

Steel is to be delivered in accordance with the processes approved by the ABS. These processes include:

- Normalized (N)/Normalized rolled (NR)
- Thermo-mechanical controlled rolled (TM)/with Accelerated cooling (TM+AcC)/with direct quenching followed by tempering (TM+DQ), or
- Quenched and Tempered condition (QT)

The definition of these delivery conditions are defined in 2-1-2/7.

Note:

Direct quenching after hot-rolling followed by tempering is considered equivalent to conventional quenching and tempering.

3.1 Rolling Reduction Ratio

The rolling reduction ratio of slab, billet or bloom to the finished product (plate, section or bar) is to be at least 3:1 unless agreed at the time of approval. In such cases, additional information and qualification testing may be required.

The plastic deformation during rolling is to be such as to obtain a uniform wrought structure and satisfactory mechanical properties through the cross section.

When manufacturing rolled products from ingots, slabs, billets or blooms and it cannot be certain that a wrought microstructure can be achieved with a 3:1 reduction ratio, a higher reduction ratio than 3 to 1 will be required. The heat, pressure and rolling technique is to be sufficient to produce a uniform microstructure and close voids, particularly when rolling from ingots. The plastic deformation during rolling is to be such as to obtain a uniform wrought structure and satisfactory mechanical properties through the cross section.

3.3 Thickness Limits

Maximum thickness of plates, sections, bars and tubulars for which a specific delivery condition is applicable are shown in 2-1-8/3.3 TABLE 3.

TABLE 3
Maximum Thickness Limits *(2018)*

Delivery condition	*Maximum thickness (mm)* [1]			
	Plates	*Sections*	*Bars*	*Tubulars*
N	250	50	250	70
NR	150	See Note 2		
TM	150	50	Not Applicable	Not Applicable
QT	250	50	Not Applicable	70

Notes:

1 Approval for steels with thickness greater than indicated in the above table are subject to the special consideration of ABS.

2 The maximum thickness limits of sections, bars and tubulars produced by NR process are to be agreed with ABS. (NR maximum thicknesses are generally less than N maximum thickness.)

4 Chemical Composition

Elements used for alloying, deoxidizing, fine grain treatment, nitrogen binding, inclusion shape control and modification, and any residual elements are to be included in the material specification.

Ladle Analysis – The chemical composition is to be determined by the steel manufacturer on samples taken from each heat and is to conform to the applicable requirements of the grade of steel listed in 2-1-8/4 TABLE 4A. The method of sampling is to be in accordance with that carried out for the initial qualification tests. The aim analysis is to be in accordance with the material specification. All elements listed in 2-1-8/4 TABLE 4A are to be reported.

i) For all steel grades, the carbon equivalent (C_{eq}) value is to be calculated from the ladle analysis. Maximum values are specified in 2-1-8/4 TABLE 4B in accordance with the following equation:

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}\ \%$$

ii) For steel grades 47 and higher, carbon equivalent (CET) may be used instead of C_{eq} at the discretionof the manufacturer, and is to be calculated in accordance to the following equation:

$$CET = C + \frac{(Mn + Mo)}{10} + \frac{(Cr\ \ + Cu)}{20} + \frac{Ni}{40}\ \%$$

Note:

The CET is included in the standard EN 1011-2:2001 used as one of the parameters for preheatingtemperature determination which is necessary for avoiding cold cracking.

iii) For TM and QT steels with carbon content no more than 0.12%, the cold cracking susceptibilityPcm for evaluating weldability may be used instead of carbon equivalent C_{eq} or CET atmanufacturer's discretion and is to be calculated using the following equation:

$$P_{cm} = C + \frac{Si}{30} + \frac{Mn}{20} + \frac{Cu}{20} + \frac{Ni}{60} + \frac{Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + 5B\ \%$$

TABLE 4A
Chemical Composition *(2018)*

Delivery condition[1]	*N/NR*[6]		*TM*[6]		*QT*	
Steel grade \ *Chemical Composition*[2,10]	AQ/DQ 43 AQ/DQ 47	EQ 43 EQ 47	AQ/DQ 43 AQ/DQ 47 AQ/DQ 51 AQ/DQ 56 AQ/DQ 63 AQ/DQ 70 AQ 91	EQ/FQ 43 EQ/FQ 47 EQ/FQ 51 EQ/FQ 56 EQ/FQ 63 EQ/FQ 70 DQ/EQ 91	AQ/DQ 43 AQ/DQ 47 AQ/DQ 51 AQ/DQ 56 AQ/DQ 63 AQ/DQ 70 AQ 91 AQ 98	EQ/FQ 43 EQ/FQ 47 EQ/FQ 51 EQ/FQ 56 EQ/FQ 63 EQ/FQ 70 DQ/EQ 91 DQ/EQ 98
Carbon % max	0.20	0.18	0.16	0.14	0.18[5]	
Manganese %	1.0~1.70		1.0~1.70		1.70 (max)	
Silicon % max	0.60		0.60		0.80	
Phosphorus %max[3]	0.030	0.025	0.025	0.020	0.025	0.020

Delivery condition[1]	*N/NR*[6]		*TM*[6]		*QT*	
Sulphur % max[3]	0.025	0.020	0.015	0.010	0.015	0.010
Aluminum total% min[4]	0.02		0.02		0.018	
Niobium % max	0.05		0.05		0.06	
Vanadium % max	0.20		0.12		0.12	
Titanium % max	0.05		0.05		0.05	
Nickel % max	0.80		3.50[7]		3.50[7]	
Copper % max[11]	0.55		0.55		0.50	
Chromium %max[11]	0.30		0.50		2.00	
Molybdenum %max[11]	0.10		0.50		0.70	
Nitrogen % max	0.025		0.025		0.015[8]	
Calcium % max	0.005		0.005		0.005	
Oxygen ppmmax[9]	Not applicable		Not applicable	50	Not applicable	30
Boron (maz)	0.005		0.005		0.005	

Notes:

1 Refer to 2-1-8/3 for delivery conditions.

2 The chemical composition is to be determined by ladle analysis and shall meet the approved material specification at the time of approval.

3 For sections the P and S content can be 0.005% higher than the value specified in the table.

4 The total aluminum to nitrogen ratio shall be a minimum of 2:1. When other nitrogen binding elements are used, the minimum Al value and Al/N ratio do not apply.

5 Higher carbon content may be agreed by ABS.

6 Total Nb+V+Ti $\leq$ 0.26% and Mo+Cr $\leq$ 0.65%, not applicable for QT steels.

7 Nickel content to be agreed at time of qualification by ABS.

8 Higher nitrogen content may be agreed by ABS.

9 The requirement on maximum oxygen content is only applicable to DQ/EQ 91/98.

10 The contents of any other elements intentionally added is to be determined and reported.

11 Elements may be reported as $\leq$ 0.02% where the amount present does not exceed 0.02%.

TABLE 4B
Maximum C_{eq}, CET and P_{cm} Values[1,2] *(2018)*

Steel Grade	*Delivery Condition*	*Carbon Equivalent (%)*							
		Ceq						*CET*	*Pcm*
		Plates			*Sections*	*Bars*	*Tubulars*	*A ll*	*All*
		t≤50 (mm)	*50<t≤100 (mm)*	*100<t≤250 (mm)*	*t≤50 (mm)*	*t ≤ 250 or d ≤ 250 (mm)*	*t ≤65 (mm)*	*All*	*All*
43	N/NR	0.46	0.48	0.52	0.47	0.53	0.47	N.A	
	TM	0.43	0.45	0.47	0.44	N.A			
	QT	0.45	0.47	0.49	N.A		0.46	N.A	
47	N/NR	0.50	0.52	0.54	0.51	0.55	0.51	0.25	N.A
	TM	0.45	0.47	0.48	0.46	N.A		0.30	0.23
	QT	0.47	0.48	0.50	N.A	N.A	0.48	0.32	0.24
51	TM	0.46	0.48	0.50	N.A	N.A	N.A	0.32	0.24
	QT	0.48	0.50	0.54	N.A	N.A	0.50	0.34	0.25
56	TM	0.48	0.50	0.54	N.A	N.A	N.A	0.34	0.25
	QT	0.56	0.60	0.64	N.A	N.A	0.56	0.36	0.28
63	TM	0.50	0.52	N.A	N.A	N.A	N.A	0.34	0.26
	QT	0.56	0.60	0.64	N.A	N.A	0.58	0.38	0.30
70	TM	0.56	N.A		N.A	N.A	N.A	0.36	0.30
	QT	0.64	0.66	0.70	N.A	N.A	0.68	0.40	0.33
91	TM	0.60	N.A	N.A	N.A	N.A	N.A	0.38	0.28
	QT	0.68	0.75		N.A	N.A		0.40	N.A
98	QT	0.75	N.A		N.A	N.A		0.40	

N.A Not Applicable

Notes:

1 Alternative limits can be specially agreed with ABS

2 Application of which formula is to be applied (Ceq, CET, Pcm) is subject to agreement between the manufacturer and purchaser.

5 Mechanical Properties

Test specimens and test procedures for mechanical properties are in accordance with Sections 2-1-1 and 2-1-2.

5.1 Tensile Test

Test specimens are to be cut with their longitudinal axes transverse to the final direction of rolling, except in the case of sections, bars, tubulars and rolled flats with a finished width or diameter of 600 mm or less, where the tensile specimens may be taken in the longitudinal direction. Plates for leg, rack and chord material may be tested in the longitudinal direction.

Full thickness flat tensile specimens are to be prepared. When the capacity of the test machine is exceeded by the use of a full thickness specimen, sub-sized flat tensile specimens representing either the full thickness or half of the product thickness obtained by machining and retaining one of the original surfaces may be used. Alternatively, machined round test specimens as per 2-1-1/11.5.2 may be used. The round specimens are to be located at a position lying at a distance of *t/4* from the surface and additionally at *t/2* for thickness above 100 mm or as near as possible to these positions.

The results of the tests are to comply with the appropriate requirements of 2-1-8/5.11 TABLE 5A. In the case of product forms other than plates and wide flats where longitudinal tests are agreed, the elongation values are to be 2 percentage units above those transverse requirements as listed in 2-1-8/5.11 TABLE 5B.

5.3 Impact Test

The Charpy V-notch impact test specimens are to be taken with their axes longitudinal or transverse to the final rolling direction and the results are to comply with the appropriate requirements of 2-1-8/5.11 TABLE 5A.

Sub-surface test specimens are to be located with their edges not more than 2 mm (0.08 in.) from the rolled surface. For thickness greater than 40 mm (1.57 in.) the impact test specimens are to be taken at quarter thickness (*t/4*) and for products with thickness in excess of 100 mm (4.0 in.), impact tests shall be taken at the quarter thickness (*t/4*) location and mid-thickness (*t/2*). Tests carried out at mid t and are to achieve at least 2/3 of the required Joule value indicated in table 2-1-8/5.11 TABLE 5A. Alternatively, the mid *t* test can be carried out at 10°C above the specified CVN test temperature to achieve the same Charpy value specified for the sub-surface specimen.

Impact test for a nominal thickness less than 6 mm are normally not required.

5.5 Through Thickness Tensile Test

For steels designated with improved through thickness properties, through thickness tensile tests are to be performed in accordance with 2-1-1/17.

5.7 Test Frequency

5.7.1 Tensile Test

For plates, tension test specimens are to be taken from each heat treatment batch of the same cast, delivery condition and thickness.

For sections, bars and tubulars, tension test specimens are to be randomly selected from every 25 tonnes or part thereof, from each heat treatment batch of the same cast, delivery condition and thickness.

5.7.2 Impact Test

For plates, impact test specimens are to be taken from each heat treatment batch of the same cast, delivery condition and thickness.

For sections, bars and tubulars, impact test specimens are to be randomly selected from every 25 tonnes or part thereof, from each heat treatment batch of the same cast, delivery condition and thickness.

Notes:

1 If the mass of the finished material is greater than 25 tonnes, one set of tests from each 25 tonnes and/or fraction thereof is required. (e.g., for consignment of 60 tonnes would require 3 pieces to be tested).

2 For continuous heat treated product special consideration may be given to the number and location of test specimens required by the manufacturer to be agreed by ABS.

5.9 Traceability

Traceability of test material, specimen sampling and test procedures including test equipment with respect to mechanical properties testing, is to be in accordance with 2-1-1/5 and 2-1-1/9.

5.11 Re-test

Re-test procedures for tensile tests and impact tests are to be in accordance with 2-1-1/9.5, 2-1-2/9.11 and 2-1-2/11.7.

TABLE 5A
Mechanical Properties Requirements *(2018)*

	Tensile Properties [1,3,8,10]			*Impact Test*	
Grade of Steel	*Yield Strength, ReH* [4] *N/mm² (kgf/mm², ksi)*	*Tensile Strength, RmN/mm² (kgf/mm², ksi)*	*Elongation % [5,6] in $5.65\sqrt{A}$ [7] minimum*	*Test Temperature °C (°F)*	*Energy Average J [1,2] (kgf-m, ft-lb)*
AQ43	420	530/680	18	0 (32)	41 (4.2, 30) [2] L
DQ43	(43, 61)	(54/69, 77/98)		-20 (-4)	or
EQ43				-40 (-40)	27 (2.8, 20) [1] T
FQ43				-60 (-76)	
AQ47	460	570/720	17	0 (32)	46 (4.7, 34) L
DQ47	(47, 67)	(58/73, 83/104)		-20 (-4)	or
EQ47				-40 (-40)	31 (3.2, 23) T
FQ47				-60 (-76)	
AQ51	500	610/770	16	0 (32)	50 (5.1, 37) L
DQ51	(51, 73)	(62/78, 88/112)		-20 (-4)	or
EQ51				-40 (-40)	33 (3.4, 24) T
FQ51				-60 (-76)	
AQ56	550	670/835	16	0 (32)	55 (5.6, 41) L
DQ56	(56, 80)	(68/85, 97/120)		-20 (-4)	or
EQ56				-40 (-40)	37 (3.8, 27) T
FQ56				-60 (-76)	
AQ63	620	720/890	15	0 (32)	62 (6.3, 46) L
DQ63	(63, 90)	(73/91, 104/129)		-20 (-4)	or
EQ63				-40 (-40)	41 (4.2, 30) T
FQ63				-60 (-76)	
AQ70	690	770/940	14	0 (32)	69 (7.0, 51) L
DQ70	(70, 100)	(78/96, 112/136)		-20 (-4)	or
EQ70				-40 (-40)	46 (4.7, 34) T
FQ70				-60 (-76)	
AQ91	890	940/1100	11	0 (32)	69 (7.0, 51) L
DQ91	(91, 129)	(96/112, 136/160)		-20 (-4)	or
EQ91				-40 (-40)	46 (4.7, 34) T
AQ98[9]	960	980/1150	10	0 (32)	69 (7.0, 51) L

	Tensile Properties [1,3,8,10]			*Impact Test*	
Grade of Steel	*Yield Strength, ReH* [4] *N/mm²* *(kgf/mm², ksi)*	*Tensile Strength, RmN/mm²* *(kgf/mm², ksi)*	*Elongation %* [5,6] *in* $5.65\sqrt{A}$ [7] *minimum*	*Test Temperature °C (°F)*	*Energy Average J* [1,2] *(kgf-m, ft-lb)*
DQ98[9]	(98, 139)	(100/117, 142/167)		-20 (-4)	or
EQ98[9]				-40 (-40)	46 (4.7, 34) T

Notes:

1 T = Transverse

2 L = Longitudinal

3 For plates and sections for applications, such as leg, rack and chord in Mobile Offshore Units (MOU), where the design requires that tensile properties are maintained through the thickness, a decrease in the minimum specified tensile properties is not permitted with an increase in the thickness. Materials intended for leg, racks and chords are to have a designation "R" after the Grade (i.e., EQ70-R).

4 For tensile test, either the upper yield stress (ReH) or where ReH cannot be determined, the 0,2 percent proof stress (Rp0.2) is to be determined and the material is considered to comply with the requirement if either value meets or exceeds the specified minimum value of yield strength.

5 TThe elongation for alternative B specimen in 2-1-1/16 FIGURE 2 is to be in accordance with 2-1-8/5.11 TABLE 5B.

6 The indicated elongations are for specimens taken transverse to the direction of roll. Where longitudinal specimens are specially approved, the minimum elongation values are to be 2% above those shown in 2-1-8/5.11 TABLE 5A and 2-1-8/5.11 TABLE 5B.

7 *A* equals cross-sectional area of test specimen.

8 For thickness greater than 100 mm, except as indicated in Note 3, ABS will consider a reduction in tensile properties provided they are accounted for in the design phase. Refer to Note in 3-1-4/1.1 and 3-1-4/3.7 of the *MOU Rules.*

9 Maximum thickness is 50 mm for 98 grades.

10 Tensile values that fall between the categories listed in the table will be considered.

TABLE 5B
Requirements for Alternative Specimen[1] *(2018)*

	Thickness, mm						
		>10	*>15*	*>20*	*>25*	*>40*	*>50*
Grade of Steel	*≤10*	*≤15*	*≤20*	*≤25*	*≤40*	*≤50*	*≤70*
AQ43 to FQ43	11	13	14	15	16	17	18
AQ47 to FQ47	11	12	13	14	15	16	17
AQ51 to FQ51	10	11	12	13	14	15	16
AQ56 to FQ56	10	11	12	13	14	15	16
AQ63 to FQ63	9	11	12	12	13	14	15
AQ70 to FQ70	9	10	11	11	12	13	14

Note:

1 91 and 98 specimens which are not included in this table shall be proportional specimens with a gauge length of $L_0 = 5.65\sqrt{S_0}$.

7 Tolerances

Unless otherwise agreed or specially required, the thickness tolerances are to be in accordance with 2-1-1/15.

9 Surface Quality

All materials are to be free from cracks, injurious surface flaws, injurious laminations and similar defects. The surface quality inspection method shall be in accordance with EN 10163 Parts 1, 2 and 3 or equivalent standards agreed between purchaser and manufacturer and accepted by ABS.

Surface finish requirement shall be in accordance with the relevant requirements in 2-1-2/15.

Surface inspection is the responsibility of the manufacturer. The acceptance by ABS Surveyor of material later found to be defective shall not absolve the manufacturer of this responsibility.

9.1 Plate Edge Inspection

Edge of the plate is to be inspected. Any discontinuity greater than 25 mm in length is to be further investigated for depth and extent. Treatment of discontinuity is to be agreed with ABS.

11 Internal Soundness

Verification of internal soundness is the responsibility of the manufacturer. The acceptance by the ABS Surveyor shall not absolve the manufacturer of this responsibility.

11.1 Ultrasonic Examination

All steel grades above 6 mm (1/4 in.) are to be inspected for internal quality at the mill in accordance with EN10160. Acceptance criteria is to be agreed between the purchaser and manufacturer, and accepted by ABS.

Acceptable standards are as follows:

For leg, rack and chord plates in Mobile Offshore Units (MOU), the acceptance criteria shall be a minimum of EN10160 Level S2/E3.

If chords are ordered with ultrasonic inspection in the final formed and heat treated condition, the specification and acceptance criteria is to be agreed between the purchaser and manufacturer, and accepted by ABS

Note:

For Z quality steels, ultrasonic examination is to be carried out on products of thickness 15 mm and above (refer to 2-1-1/17).

13 Stress Relieving Heat Treatment and Other Heat Treatments

Steels approved by the procedures given in 2-A4-3 are suitable for stress relieving heat treatment such as post-weld heat treatment and stress relieving heat treatment after cold forming (refer to 2-A4-3/5.11.3(e))

Note:

Products can be susceptible to deterioration in mechanical strength and toughness if they are subjected to incorrect post-weld heat treatment procedures or other processes involving heating such as flame straightening, rerolling, etc., where the heating temperature and the holding time exceed the limits provided by the manufacturer.

15 Fabrication & Welding

Upon request from the fabricator, the steel mill may supply the parameters applied during the weldability tests (carried out in accordance with 2-A4-2/5.13) in order to develop fabrication procedures. Also ABS can populate this information on ABS website with written consent from the steel mill.

17 Facilities for Inspection

Testing is to be carried out under the witness of the Surveyor in order to verify that the test results meet the specified requirements.

The manufacturer is to provide access to the steel works to enable the Surveyor to,

i) Verify that the approved manufacturing process is followed

ii) Select test materials

iii) Witness mechanical tests and to verify testing is in accordance with standards

iv) Witness/verify NDE inspection, calibration of inspection equipment.

19 Identification of Materials

The manufacturer is to adopt a system for the identification of ingots, slabs, billet or bloom and finished products, which will enable the material to be traced to its original cast.

The steel mill is to facilitate the Surveyor to verify traceability of the material.

21 Marking

Refer to requirements in 2-1-2/13.

Permanent marking of the grade and delivery condition is to be done on the product in the final delivery condition. Marking of the final designated grade is not permitted on semi-finished products.

Materials intended for leg, racks and chords are to have a designation “R” after the Grade (i.e., EQ70-R).

23 Documentation of Inspection Tests

The Surveyor is to be supplied with a copy, of the test certificates or shipping statements for all accepted materials. In addition to the description, dimensions, etc., of the material, the following particulars are to be included:

i) Purchaser’s order number

ii) Identification of the cast/heat, batch and plate number

iii) Manufacturer’s identification

iv) Identification of the grade of steel

v) Chemical analysis and Ceq, CET or Pcm value

vi) Delivery condition with heat treatment temperatures

vii) Mechanical properties test results, including traceable test identification

viii) Surface quality and inspection results

ix) UT report

x) Manufacturer’s Certificate refer to 2-1-1/7