Comparison between European Standard and Chinese Standard for Structural Steel used in the Offshore Wind Industry

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Offshore wind is one of the most mature renewable energy with large-scale potential and commercial prospects. The available wind energy is widely distributed and has huge reserves worldwide. With the continuous innovations of offshore wind related technologies and the upgrading of equipment, the global offshore wind industry has been developing rapidly in the last decade and will continue to grow at a fast pace in the next two to three decades. Europe and China will be the two largest offshore wind markets in the world. For offshore wind projects in different countries or regions, due to the differences in project owners' requirements and design specifications, steel materials used for offshore wind structure are not the same, and there may even be conflicts caused by different material standards, which is not conducive to the technological progress and industrial globalization of steel used for offshore wind.

At present, European offshore wind structural steel design generally chooses EN10025-2 standard "non-alloy steel", EN10025-3 standard "normalizing/normalizing rolling welded fine grain steel" or EN10025-4 standard "thermomechanical rolling welded fine-grained steel", such as S355J2, S355NL, S355ML etc.; for offshore wind structural steel in the North Sea region of Europe, EN10225 standard "weldable structural steel for fixed offshore structures" is also adopted, such as S355G8, S355G10, etc.. For the design of steel materials for offshore wind structures in China, GB/T 1591 standard "low alloy high-strength structural steel" is generally selected, such as Q355C, Q355ND, etc.; GB/T712 standard for structural steel used for offshore and marine engineering" is also adopted. ", such as DH36, EH36 and other grades.

The main supply standards and product brands of offshore wind structural steel used in China and Europe are shown in Table 1:

Table 1 Standard products and grades of steel for offshore wind

Standard number	Standard name	Typical grade
GB/T 1591 :2018	Low-alloy high-strength structural steel	Q355B/C/D, Q355NB/NC/ND/NE/NF, Q355MB/MC/MD/ME/MF
GB/T 28410	Structural steel plate for offshore wind tower	Q345FTC/D/E/F

GB/T 712	Structural steel for ships and marine engineering	DH36、EH36
EN10025-2	Non-alloy steel technical delivery conditions	S355JR/J0/J2/K2
EN10025-3	Delivery conditions of normalizing/normalizing rolling welding fine grain technology	S355N/NL, S420N/NL
EN10025-4	Delivery conditions of thermomechanical rolling and welding fine grain technology	S355M/ML, S420M/ML, S460M/ML, S500M/ML
EN10225:2009 EN10225-1:2019	Weldable structural steel for fixed offshore structures	S355G7/8/9/10, S420G1/2, S355MLO/NLO, S420MLO/QLO
JIS G3106	Rolled steel for welded structure	SM490, SM520, SM570
ASTM A572/A572M	Specification for high strength low alloy steel	A572Gr50/Gr60/Gr65
ASTM A709/A709M	Standard Specification for Structural Steel for Bridges	A709Gr50

To be in line with international standards and reduce international trade barriers, China actively promotes the revision of the GB/T1591:2008 standard, focusing on the ISO 630 standard and EN10025-2, EN10025-3, EN10025-4 and other international standards. The current GB/T1591:2018 standard was released on May 14, 2018 and implemented on February 1, 2019. European standards and Chinese standards are the most commonly used standards for selecting materials for offshore wind structural steel. This paper will focus on comparison of the European EN10025 standard S355 series grades with the Chinese GB/T 1591 standard Q355 series grades and the Chinese GB/T 712 standard DH36 series grades.

1. The way of designation

(1) GB/T 1591 standard, for example Q355ND, in which:

- "Q" represents the initial letter of the Chinese pinyin of "qu" which is the yield strength of steel;
- "355" represents the specified minimum upper yield strength value, in MPa (MPa);
- "N" stands for normalizing or normalizing rolling;
- "D" stands for quality grade D (-20℃). When the delivery status of the steel is hot-rolled AR, the delivery status can be omitted from the grade and directly expressed as Q355D.

(2) GB/T 712 standard, for example: DH36 is a high-strength ship plate, where:

- "D" represents the quality level of D (-20℃);
- "D" represents high strength;
- "36" represents the high strength level Strength (≥355Mpa).

(3) EN10025-2, for example: S355J2, where:

- "S" represents the initials of structural steel (Structure);
- "355" represents the minimum yield strength of steel with a thickness of ⩽16mm, in megapascals (MPa);
- "J2" The representative quality grade is J2 (-20℃).

(3) EN10025-3 or EN10025-4 standard, for example: S355NL or S355ML, where:

- "S" stands for the initials of structural steel (Structure);
- "355" stands for the minimum yield strength of steel with a thickness of ⩽16mm, in MPa (MPa);
- "N" or "M" delivery status N or TMCP;
- "L" specifies the minimum impact material at a temperature of not less than -50° C, indicated by capital letter L.

2. Delivery status

(1) Hot rolled (AR), the state of the steel without any special rolling and/or heat treatment.

(2) Normalizing (N), a heat treatment process in which steel is heated to a suitable temperature above the phase transition temperature, and then cooled in air to below a certain phase transition temperature.

(3) Normalizing rolling (+N), the final deformation is carried out in the rolling process within a certain temperature range, so that the steel reaches a normalized state, so that the specified mechanical properties can be achieved even after normalizing Numerical rolling process.

(4) Thermomechanical rolling (M), a rolling process in which the final deformation of the steel is carried out within a certain temperature range, so as to ensure that the steel obtains properties that cannot be obtained only through heat treatment.

3. Standard grade comparison

In the GB/T 1591:2018 Standard, Q355 has 13 grades, of which there are three grades for hot-rolled delivery, 5 grades for normalizing or normalizing rolling, and 5 grades for thermomechanical rolling. B, C, D, E, F correspond to the impact test temperature of 20℃, 0℃, -20℃, -40℃, -60℃;

In the GB/T 712 standard, there are four grades: AH36, DH36, EH36, FH36. The corresponding impact test temperature is 0℃, -20℃, -40℃, -60℃, but the delivery status is not reflected in the grade name.

See Table 2 for the comparison table of specific grades:

Table 2 Comparison table of China and Europe standard

Delivery Status	GB/T 1591-2018	GB/T 712	EN10025-2	EN10025-3	EN10025-4
AR	Q355B		S355JR		
	Q355C	AH36	S355J0		
	Q355D	DH36	S355J2		
			S355K2		
N/+N	Q355NB				
	Q355NC	AH36			
	Q355ND	DH36		S355N	
	Q355NE	EH36		S355NL	
	Q355NF	FH36			
TMCP	Q355MB				
	Q355MC	AH36			
	Q355MD	DH36			S355M
	Q355ME	EH36			S355ML
	Q355MF	FH36			

4. Technical requirements comparison

The chemical composition requirements of different standard grades are shown in Table A-1, the carbon equivalent requirements are shown in Table A-2, and the mechanical performance requirements are shown in Tables A-3 and A-4.

(1) Standard delivery status distinction:

a) For GB/T1591 and EN10025, chemical composition, CEV, mechanical properties are different because of different delivery states of AR, N/+N, and TMCP.
b) The GB/T 712 does not distinguish the chemical composition and mechanical properties according to the delivery status. It only requires the CEV requirements for TMCP.

(2) The GB/T1591:2018 standard is relatively close to the EN10025 standard. The GB/T1591 standard has 5 quality levels: B, C, D, E, and F, among which:

a) Q355B/C/D with AR delivery status corresponds to EN10025-2 standard S355JR/J0/J2; the minimum impact value Q355B/C requires 34J, higher than 27J required by S355JR/J0; the minimum impact value Q355D requires 34J , higher than S355J2 requirement of 27J, lower than S355K2 requirement if 40J; Q355D and S355K2 can agree on -30℃ temperature shock.
b) Q355ND/NE with N/+N delivery status corresponds to EN10025-3 standard S355N/NL. Q355NE requires -40℃ or -50℃ temperature shock.
c) Q355MD/ME with TMCP delivery status corresponds to EN10025-4 standard S355M/ML. Q355ME requires -40℃ or -50℃ temperature shock.

(3) GB/T712's DH36/EH36 are different with EN10025 S355:

a) DH36/EH36 require that the yield strength of all thicknesses is not less than 355Mpa; while the EN10025 standard requires that the minimum yield strength of thickness ⩽16mm is 355Mpa. The yield strength of thicker steel plates decreases with the increase in thickness.
b) The tensile strength requirements of DH36/EH36 are 490-630Mpa; while the minimum value of the conventional tensile strength of EN10025 standard is 470Mpa, and the minimum value of tensile strength will decrease to varying degrees after the thickness increases.
c) For DH36/EH36, the impact performance is based on different thicknesses, such as thickness⩽50mm, 50＜thickness⩽70mm, 70＜thickness⩽150mm, the minimum impact values are 34J, 41J, 50J, and the test value requirements for different quality grades/impact temperatures are the same; while the EN10025 standard conventional impact value is not distinguished by thickness, but the lower the impact temperature, the smaller the impact value requirement.

Therefore, for offshore wind steel materials designed to the EN10025 standard and grades, it can be replaced by the same grade according to the corresponding standard and grade of GB/T1591:2018. See Table 3 for details.

Table 3 Substitution of national and European standards

EN10025 Standard grade		GB/T 1591-2018 Standard grade	Remarks
EN10025-2	S355JR	Q355B	
EN10025-2	S355J0	Q355C	
EN10025-2	S355J2	Q355D	
EN10025-2	S355K2	Q355D	impact temperature -30℃
EN10025-3	S355N	Q355ND	
EN10025-3	S355NL	Q355NE	impact temperature -40℃or-50℃
EN10025-4	S355M	Q355MD	
EN10025-4	S355ML	Q355ME	impact temperature -40℃or-50℃

Appendix A

Table A-1 Chemical composition of different standard grades (%)

Standard	Steel Grade	Delivery Status	C	Si	Mn	P	S	Nb	V	Ti	Alt	Cr	Ni	Mo	Cu	N
			max	max		max	max				Min	max	max	max	max	max
GB/T 1591	Q355B		0.24	0.55	-1.60	0.035	0.035				0.020	0.30	0.50		0.40	0.012
GB/T 1591	Q355C		0.20	0.55	-1.60	0.030	0.030				0.020	0.30	0.50		0.40	0.012
GB/T 1591	Q355D		0.20	0.55	-1.60	0.025	0.025				0.020	0.30	0.50		0.40	
EN10025-2	S355JR	AR	0.24	0.55	-1.60	0.035	0.035								0.55	0.012
EN10025-2	S355J0		0.20	0.55	-1.60	0.030	0.030								0.55	0.012
EN10025-2	S355J2		0.20	0.55	-1.60	0.025	0.025				0.020				0.55	
EN10025-2	S355K2		0.20	0.55	-1.60	0.025	0.025				0.020				0.55	
GB/T 1591	Q355NB		0.20	0.50	0.90-1.65	0.035	0.035	0.005-0.05	0.01-0.12	0.006-0.05	0.020	0.30	0.50	0.10	0.40	0.015
GB/T 1591	Q355NC		0.20	0.50	0.90-1.65	0.030	0.030	0.005-0.05	0.01-0.12	0.006-0.05	0.020	0.30	0.50	0.10	0.40	0.015
GB/T 1591	Q355ND		0.20	0.50	0.90-1.65	0.030	0.025	0.005-0.05	0.01-0.12	0.006-0.05	0.020	0.30	0.50	0.10	0.40	0.015
GB/T 1591	Q355NE	N/+N	0.18	0.50	0.90-1.65	0.025	0.020	0.005-0.05	0.01-0.12	0.006-0.05	0.020	0.30	0.50	0.10	0.40	0.015
GB/T 1591	Q355NF		0.16	0.50	0.90-1.65	0.020	0.010	0.005-0.05	0.01-0.12	0.006-0.05	0.020	0.30	0.50	0.10	0.40	0.015
EN10025-3	S355N		0.20	0.50	0.90-1.65	0.025	0.020	-0.050	-0.120	-0.050	0.020	0.30	0.50	0.10	0.55	0.015
EN10025-3	S355NL		0.18	0.50	0.90-1.65	0.025	0.020	-0.050	-0.120	-0.050	0.020	0.30	0.50	0.10	0.55	0.015
GB/T 1591	Q355MB		0.14	0.50	-1.60	0.035	0.035	0.01-0.05	0.01-0.10	0.006-0.05	0.020	0.30	0.50	0.10	0.40	0.015
GB/T 1591	Q355MC		0.14	0.50	-1.60	0.030	0.030	0.01-0.05	0.01-0.10	0.006-0.05	0.020	0.30	0.50	0.10	0.40	0.015
GB/T 1591	Q355MD		0.14	0.50	-1.60	0.030	0.025	0.01-0.05	0.01-0.10	0.006-0.05	0.020	0.30	0.50	0.10	0.40	0.015
GB/T 1591	Q355ME	TMCP	0.14	0.50	-1.60	0.025	0.020	0.01-0.05	0.01-0.10	0.006-0.05	0.020	0.30	0.50	0.10	0.40	0.015
GB/T 1591	Q355MF		0.14	0.50	-1.60	0.020	0.010	0.01-0.05	0.01-0.10	0.006-0.05	0.020	0.30	0.50	0.10	0.40	0.015
EN10025-4	S355M		0.14	0.50	-1.60	0.030	0.025	-0.050	-0.100	-0.050	0.020	0.30	0.50	0.10	0.55	0.015
EN10025-4	S355ML		0.14	0.50	-1.60	0.025	0.020	-0.050	-0.100	-0.050	0.020	0.30	0.50	0.10	0.55	0.015

GB/T 712	AH36		0.18	0.50	0.90–1.60	0.030	0.030	0.02–0.05	0.05–0.10	–0.02	0.020	0.20	0.40	0.08	0.35	
GB/T 712	DH36/EH36		0.18	0.50	0.90–1.60	0.025	0.025	0.02–0.05	0.05–0.10	–0.02	0.020	0.20	0.40	0.08	0.35	
GB/T 712	FH36		0.16	0.50	0.90–1.60	0.020	0.020	0.02–0.05	0.05–0.10	–0.02	0.020	0.20	0.80	0.08	0.35	0.009

注：1) 0.015% fused aluminum (Als) can be used to replace 0.020% Alt.；

2) If the minimum Als content in the steel is 0.015%, or the minimum Alt content is 0.020%, or other nitrogen-fixing alloying elements are added, the N content is not limited.

3) Refined grain elements Al, Nb, V and Ti can be added to steel alone or in any combination. When they are added separately, their content should meet the requirements in the table. If two or more refined grain elements are added together, the lower limit of refined grain element content in the table is not applicable, and Nb+V+Ti should be no more than 0.12%。

Table A-2 CEV of different steel grades

Standard	**Grade**	**Delivery Status**	**Maximum CEV of various thicknesses**		
			≤30	>30, ≤150	>150, ≤250
GB/T 1591	Q355B/C/D	AR	0.45	0.47	0.49
EN10025-2	S355JR/J0/J2/K2		0.45	0.47	0.49
Standard	Grade	Delivery Status	Maximum CEV of various thicknesses		
			≤63	>63, ≤100	>100, ≤250
GB/T 1591	Q355NB/C/D/E/F	N/+N	0.43	0.45	0.45
EN10025-3	S355N/NL		0.43	0.45	0.45
Standard	Grade	Delivery Status	Maximum CEV of various thicknesses		
			≤40	>40, ≤63	>63, ≤120
GB/T 1591	Q355MB/C/D/E/F	TMCP	0.39	0.40	0.45
EN10025-4	S355M/ML		0.39	0.40	0.45
Standard	Grade	Delivery Status	Maximum CEV of various thicknesses		
			≤50	>50, ≤100	>100, ≤150
GB/T 712	DH36/EH36/FH36	TMCP	0.38	0.40	0.42

Table A-3 GB/T1591 and EN10025 mechanical properties

Standard	Grade	Yield strength ReH/MPa									Tensile strength Rm/MPa			Impact	
		≤16	>16, ≤40	>40, ≤63	>63, ≤80	>80, ≤100	>100, ≤150	>150, ≤200	>200, ≤250	>250, ≤400	≤100	>100, ≤250	>250, ≤400	Impact Temperature ℃	Impact Value/J
GB/T 1591	Q355B/C	≥355	≥345	≥335	≥325	≥315	≥295	≥285	≥275		470-630	450-600	-	20/0	≥34
GB/T 1591	Q355D	≥355	≥345	≥335	≥325	≥315	≥295	≥285	≥275	≥265	470-630	450-600	450-600	-20	≥34
EN10025-2	S355JR	≥355	≥345	≥335	≥325	≥315	≥295	≥285	≥275	-	470-630	450-600	-	20	≥27
EN10025-2	S355J0	≥355	≥345	≥335	≥325	≥315	≥295	≥285	≥275	-	470-630	450-600	-	0	≥27
EN10025-2	S355J2	≥355	≥345	≥335	≥325	≥315	≥295	≥285	≥275	≥265	470-630	450-600	450-600	-20	≥27
EN10025-2	S355K2	≥355	≥345	≥335	≥325	≥315	≥295	≥285	≥275	≥265	470-630	450-600	450-600	-20	≥40

Standard	Grade	Yield strength ReH/MPa									Tensile strength Rm/MPa		Impact Temperature ℃	Impact Value/J
		≤16	>16, ≤40	>40, ≤63	>63, ≤80	>80, ≤100	>100, ≤150	>150, ≤200	>200, ≤250	>200, ≤250	≤100	>100, ≤250		
GB/T 1591	Q355NB/C	≥355	≥345	≥335	≥325	≥315	≥295	≥285	≥275		470-630	450-600	20/0	≥34
GB/T 1591	Q355ND	≥355	≥345	≥335	≥325	≥315	≥295	≥285	≥275		470-630	450-600	-20	≥40
GB/T 1591	Q355NE	≥355	≥345	≥335	≥325	≥315	≥295	≥285	≥275		470-630	450-600	-40	≥31
GB/T 1591	Q355NF	≥355	≥345	≥335	≥325	≥315	≥295	≥285	≥275		470-630	450-600	-60	≥27
EN10025-3	S355N	≥355	≥345	≥335	≥325	≥315	≥295	≥285	≥275		470-630	450-600	-20	≥40
EN10025-3	S355NL	≥355	≥345	≥335	≥325	≥315	≥295	≥285	≥275		470-630	450-600	-50	≥27

Standard	Grade	Yield strength ReH/MPa						Tensile strength Rm/MPa				Impact Temperature ℃	Impact Value/J
		≤16	>16, ≤40	>40, ≤63	>63, ≤80	>80, ≤100	>100, ≤120	≤40	>40, ≤63	>63, ≤100	>100, ≤120		
GB/T 1591	Q355MB/C	≥355	≥345	≥335	≥325	≥325	≥320	470-630	450-610	440-600	430-590	20/0	≥34
GB/T 1591	Q355MD	≥355	≥345	≥335	≥325	≥325	≥320	470-630	450-610	440-600	430-590	-20	≥40
GB/T 1591	Q355ME	≥355	≥345	≥335	≥325	≥325	≥320	470-630	450-610	440-600	430-590	-40	≥31
GB/T 1591	Q355MF	≥355	≥345	≥335	≥325	≥325	≥320	470-630	450-610	440-600	430-590	-60	≥27
EN10025-4	S355M	≥355	≥345	≥335	≥325	≥325	≥320	470-630	450-610	440-600	430-590	-20	≥40
EN10025-4	S355ML	≥355	≥345	≥335	≥325	≥325	≥320	470-630	450-610	440-600	430-590	-50	≥27

Table A-4 GB/T 712 mechanical properties

Standard	Grade	Yield strength ReH/MPa	Tensile strength Rm/MPa	Impact value /J			
				Impact Temperature ℃	≤50	>50，≤70	>70，≤150
GB/T 712	AH36	≥355	490-630	0	≥34	≥41	≥50
	DH36			-20			
	EH36			-40			
	FH36			-60			