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YP690 N/mm^2 Class Heavy Gauge Steel Plates with Extreme Low Temperature Toughness for Offshore Structures

1. Introduction

In recent years, development of petroleum resources has been promoted in response to increased global energy demand. With the construction of larger scale offshore structures for increased production efficiency and expansion into arctic seas and deepwater areas of the construction area as a backdrop, higher strength, heavier gauges and more severe low temperature toughness have been required in steel products.

JFE Steel's available lineup of steel plates for offshore structures is shown in **Table 1**. In order to respond to the above-mentioned requirements, the company has developed high strength, heavy gauge steel plates for offshore structures and expanded its product lineup [1–4]. This report introduces a YP690 N/mm^2 class steel plate with a thickness of 210 mm and −60˚C low temperature toughness for offshore structures that was recently developed by JFE Steel.

Table 1 Available strength and thickness of steel plates for offshore structure

YS Class (N/mm^2)	Charpy temp. (˚C)	CTOD test temp. (˚C)	Thickness (mm)
355	−40	−10	≦101.6
	−60	−40	≦76.2
420	−40	−10	≦101.6
	−60	−40	≦76.2
500	−40	−10	≦75
	−40	—	≦150
	−60	—	≦150
550	−40	—	≦108
	−60	—	≦63.5
620	−40	—	≦180
690	−40	—	≦210
	−60	—	≦210

2. Concept and Features of Developed Steel

2.1 Development Targets

The target properties of the developed steel are shown in **Table 2**. Steel plates which are to be used in offshore structures constructed for extraction of petroleum and natural gas from the sea bottom are generally manufactured in accordance with ship classification standards. Because the offshore standards of the ABS and DNV GL are frequently applied to heavy gauge, high strength steel plates with extreme low temperature toughness specifications, the target properties of the developed steel were set referring to the required values of those ship classification standards.

2.2 Features of Developed Steel

The aim of the developed steel was to simultaneously satisfy YP690 N/mm^2 class and −60˚C low temperature toughness in product thickness up to 210 mm. In order to optimize hardenability corresponding to the increment of plate thickness, the contents of Cr, Mo and other alloying elements were adjusted, and B and other micro-alloying elements were added to control the microstructure to a mixed microstructure of martensite and bainite.

Low temperature toughness was improved by increasing dislocation mobility in the martensite during low temperature deformation by appropriate addition of Ni [5], and was further improved by refinement of the prior austenite grain size by strict control of the the conditions of hot rolling, quenching and tempering,

Table 2 Target properties of developed steel

Grade	YS (N/mm^2)	TS (N/mm^2)	El (%)	vE (ave.) (J)	
AB FQ70/ VL FO690	≧690	770-940	(L)≧16 (T)≧14	−60˚C	(L)≧69 (T)≧46

Tensile specimen: 14 ϕ×70GL
YS: Yield strength, TS: Tensile strength
El: Elongation, vE: Absorbed energy
L: Longitudinal
T: Transverse

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thereby satisfying the target properties.

3. Properties of Developed Steel

3.1 Base Material Performance

The chemical compositions and mechanical properties of the developed YP690 N/mm^2 class steel with a thickness of 210 mm are shown in **Table 3** and **Table 4**, respectively. Strength and low temperature toughness which amply satisfy the targets were obtained not only at the 1/4t thickness position, but also at the 1/2t (center-of-thickness) position.

3.2 Welded Joint Performance

As an example of the welded joint performance of the developed YP690 N/mm^2 class steel, **Table 5** shows the results of an evaluation of welded joints with two different heat input conditions. At both heat input conditions, welded joint strength and welded joint toughness satisfying the standard values for the base material under the above-mentioned standards were obtained, confirming that the developed steel has excellent welded joint performance.

4. Conclusion

JFE Steel developed a YP690 N/mm^2 class heavy gauge steel plate for offshore structures which satisfies the −60°C low temperature toughness specification with plate thicknesses up to 210 mm. High strength and low temperature toughness were achieved simultaneously by a chemical composition design, utilizing micro-alloying elements and microstructure control.

Table 3 Chemical compositions of developed steel (mass%)

Thickness (mm)	C	Si	Mn	P	S	Other elements	CET
210	0.13	0.21	1.12	0.006	0.0004	Cu, Ni, Cr, Mo, V, B	0.43

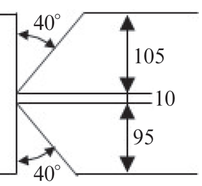
CET = C + (Mn + Mo)/10 + (Cr + Cu)/20 + Ni/40

Table 4 Mechanical properties of developed steel

Thickness (mm)	Position, Direction	Tensile properties			Charpy impact properties
		YS (N/mm^2)	TS (N/mm^2)	El (%)	$vE_{-60^\circ C}$ (J)
210	1/4t-L	769	849	21	225
	1/4t-T	762	847	21	165
	1/2t-L	750	843	20	210
	1/2t-T	736	843	21	166

YS: Yield strength, TS: Tensile strength, El: Elongation, vE: Absorbed energy

Table 5 Mechanical properties of welded joints of developed steel

Thickness (mm)	Welding procedure			Tensile properties	Charpy impact properties	
	Method	Groove shape	Welding condition	TS (N/mm^2)	Position	$vE_{-60^\circ C}$ (J)
210	SAW		Welding consumable: US-80LT (4.0 ϕ), PFH-80AK* Heat input: 50 kJ/cm	819	WM	86
					FL	93
					HAZ: 2 mm	180
					HAZ: 5 mm	177
					HAZ: 20 mm	179
	GMAW		Welding consumable: MGS-88A (1.2ϕ)* Heat input: 15 kJ/cm	930	WM	89
					FL	77
					HAZ: 2 mm	202
					HAZ: 5 mm	140
					HAZ: 20 mm	176

*Kobe Steel, Ltd.

TS: Tensile strength, vE: Absorbed energy
WM: Weld metal, FL: Fusion line, HAZ: Heat affected zone

The developed steel has received approval as AB FQ70 from the ABS and VL FO690 from the DNV GL.

As development of petroleum resources expands into arctic seas and deepwater areas to meet future increases in energy demand, ever-higher needs for high performance steel plates for offshore steel structures are forecast, and further increases in application of the developed steel are expected.

References

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4) Kitsuya, S.; Ichimiya, K.; Hase, K.; Hayashi, K.; Terazawa, Y.; Kinugawa, T. YP690 N/mm^2 Class Heavy Gauge Steel Plates with Low Temperature Toughness for Offshore Structures Manufactured by Continuous Casting, Forging and Rolling Process. 2016 ISOPE, p. 258.
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