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YP690 MPa Class Heavy Gauge Steel Plates with Low Temperature Toughness for Offshore Structures†

1. Introduction

In response to increased demand for steel plates for offshore structures accompanying more active development of petroleum resources in recent years, JFE Steel is promoting higher performance in steel products in high strength, heavy thickness, low temperature specifications, etc. in order to meet strict requirements for steel materials, and has expanded its product line of steel plates for offshore structures[1,2]. Development of petroleum resources is continuing to expand into arctic seas and deepwater areas. This trend has heightened demand for YP (yield point) 690 MPa class heavy gauge steel plates with thicknesses exceeding 150 mm and low temperature toughness at −40°C or lower to meet the requirements of larger scale of structures and use in low temperature environments.

Conventionally, it was necessary to manufacture heavy gauge high strength steel plates for low temperature specifications by the ingot casting process in order to satisfy strict quality requirements. However, this had the disadvantages of a complex manufacturing process, which included ingot casting, breakdown rolling, etc., and the resulting prolonged production period.

JFE Steel applied a combined forging and plate rolling process using continuous casting slabs to commercial production of heavy gauge steel plates with product thicknesses exceeding 100 mm, and established a manufacturing process that improves the internal soundness and homogeneity in the thickness direction of steel plates after plate rolling by applying a forging process to annihilate the porosities by pressure that unavoidably exist in the slab interior during continuous casting. This process has already been applied to steel plates for boilers, pressure vessels, etc.[3,4]. This report introduces the features of YP690 MPa class heavy gauge steel plates with low temperature toughness, which are produced by the continuous casting (CC)-forging-rolling processes.

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Table 1 Specification of YP690 MPa class high strength steel plate

Grade	YS (MPa)	TS (MPa)	El (%)	vE (ave.) (J)	
AB EQ70/ DNV E690	≧690	770–940	≧14	−40°C	(L)≧69 (C)≧46

Specimen: 14ϕ×70GL
YS: Yield strength, TS: Tensile strength, El: Elongation, vE: Absorbed energy

2. Features and Concept of Developed Steel

2.1 Applicable Standards

Offshore structures for extraction of petroleum and natural gas from the sea bottom are generally manufactured in accordance with ship classification standards. Recently, the offshore use standards of ABS (American Bureau of Shipping) and DNV (Det Norske Veritas) have frequently been applied to plate thicknesses of 150 mm and larger. JFE Steel has developed, and obtained certification for, products which satisfy the corresponding requirements from these ship classification societies. **Table 1** shows the representative values required under these standards.

In some cases, mechanical properties in the center-of-thickness (1/2t, t: Plate thickness) position are required in heavy gauge plates. Thus, securing internal soundness becomes a key issue in plate manufacturing.

2.2 Improvement of Internal Quality by Application of CC-Forging-Plate Rolling Processes

Due to the heavier gauge and stricter low temperature toughness requirements for steel plates for offshore structures, it is necessary to satisfy both internal soundness to the center-of-thickness position and strength and toughness requirements. JFE Steel has adopted the continuous casting-forging-plate rolling processes in order to satisfy these requirements. In these processes, the internal soundness of steel plates is improved by adding a forging process for the continuous casting slab production route in order to annihilate porosities in cast slabs by pressure. As a result, mechanical properties at the

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plate center-of-thickness position can be improved. This process has been formally approved as a special practice mitigating the reduction ratio limitation of thickness from a cast slab to finished plate, and makes it possible to manufacture heavy gauge steel plates with excellent internal soundness in product thicknesses up to 180 mm from 310 mm thick continuous casting slabs (reduction ratio: 1.72).

2.3 Features of Developed Steel

In the developed steel, both high strength and low temperature toughness, namely, YP≧690 MPa and −40°C toughness, are demanded. The hardenability of the developed steel is optimized by adjusting alloying elements such as Cr, Mo, etc. and adding B and other microalloying elements. Toughness is improved by securing a mixed microstructure of martensite and lower bainite microatructure, together with addition of the optimum amount of Ni.

Low temperature toughness is improved by refining the prior γ grain size by controlling the temperature in each of the processes of heating, rolling, and heat treatment. This makes it possible to achieve mechanical properties which satisfy all the requirements of the applicable standards without excessive addition of Ni.

In addition to this chemical composition design, because the porosities in continuous casting slabs can be annihilated by applying the above-mentioned continuous casting-forging-plate rolling processes, it is possible to manufacture steel plates with excellent internal quality at the center-of-thickness in a short production time without adopting the ingot casting-breakdown rolling process.

3. Properties of Developed Steel

3.1 Performance of Base Metal

Tables 2 and **3** show the chemical compositions and mechanical properties of the developed steel AB EQ70/DNV E690 with plate thicknesses of 155 mm and 180 mm. Strength and excellent low temperature toughness which amply satisfy the respective standards can be obtained, including the center-of-thickness (1/2t) position.

3.2 Performance of Welded Joints of Developed Steel

Table 4 shows the performance of welded joints under two heat input conditions as examples of the welded joint performance of the developed steel AB EQ70/DNV E690. In all cases, joint strength and high weldment toughness which satisfy the standard values for the base metal under each standard has been obtained, and the welds of the developed steel possess excellent welded joint performance.

Table 2 Chemical compositions of developed steel AB EQ70/DNV E690

(mass%)

Grade	Thickness (mm)	C	Si	Mn	P	S	others	Ceq	P_{CM}
AB EQ70/ DNV E690	155	0.12	0.19	1.13	0.006	0.0005	Cu, Ni, Cr, Mo, V, Ti, B	0.74	0.31
	180	0.12	0.19	1.13	0.006	0.0005	Cu, Ni, Cr, Mo, V, Ti, B	0.75	0.31

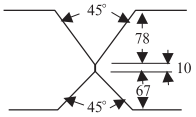
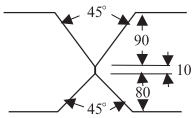
$Ceq = C + Mn/6 + Cu/15 + Ni/15 + Cr/5 + Mo/5 + V/5$,
$P_{CM} = C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + 5B$

Table 3 Mechanical properties of developed steel AB EQ70/DNV E690

Grade	Thickness (mm)	Tensile properties				Charpy impact properties		Drop weight properties
		Position, Direction	YS (MPa)	TS (MPa)	El (%)	Position, Direction	$vE_{-40°C}$ (J)	T_{NDT} (°C)
AB EQ70/ DNV E690	155	1/4t-C	745	815	19.8	1/4t-L	206	−65
						1/4t-C	187	
		1/2t-C	733	814	16.2	1/2t-L	118	
						1/2t-C	74	
	180	1/4t-C	749	821	19.3	1/4t-L	201	−60
						1/4t-C	153	
		1/2t-C	739	821	17	1/2t-L	183	
						1/2t-C	222	

AB EQ70/DNV E690 Specification: YS≧690, 770≦TS≦940 MPa, El≧14%, RA≧35%, $vE_{-40°C}$≧69 J (L), 46 (C)
YS: Yield strength, TS: Tensile strength, El: Elongation, vE: Absorbed energy

Table 4 Typical welded joint's mechanical properties of developed steel AB EQ70/DNV E690

Grade	Thickness (mm)	Welding procedure			Tensile properties	Charpy impact properties	
		Method	Edge preparation	Welding condition	TS (MPa)	Position	$vE_{-40°C}$ (J)
AB EQ70/ DNV E690	155	SAW		Welding consumable: US-80 LT (4.0 ϕ), PFH-80AK* Heat input: 50 kJ/cm	812 810	WM	108
						FL	131
						HAZ	292
		GMAW		Welding consumable: MGS-88A (1.2 ϕ)* Heat input: 15 kJ/cm	867 869	WM	114
						FL	149
						HAZ	224
	180	SAW		Welding consumable: US-80 LT (4.0 ϕ), PFH-80AK* Heat input: 50 kJ/cm	812 806	WM	86
						FL	133
						HAZ	260
		GMAW		Welding consumable: MGS-88A (1.2 ϕ)* Heat input: 15 kJ/cm	872 875	WM	109
						FL	115
						HAZ	177

SAW: Submerged-arc welding, GMAW: Gas-Metal arc welding
TS: Tensile strength, vE: Absorbed energy, WM: Weld metal, FL: Fusion line, HAZ: Heat affected zone
*Kobe Steel, Ltd.

4. Conclusion

As a heavy gauge steel plate for offshore structures, JFE Steel developed a YP690 MPa class steel plate which satisfies −40°C low temperature toughness requirements in thicknesses up to 180 mm. The developed steel plate is manufactured by the continuous casting-forging-plate rolling processes. Use of the forging process in combination of a chemical composition design that utilizes microalloys makes it possible to achieve improved internal quality at the center-of-thickness of continuous casting slabs while also substantially reducing manufacturing lead time. The developed steel has been certified by ABS and DNV, and already has an extensive manufacturing record of use, including equivalent products under JFE Steel brand standards.

Development of petroleum resources has shown a progressively increasing tendency, and that development is also expanding into arctic seas and deepwater areas. As increasing needs for higher performance steel plates for offshore structures are anticipated in the future, application of the developed steel is expected.

References

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4) Hayashi, K. et al. JFE Technical Report. 2005, no. 5, p. 66.

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