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Heavy Section Cr-Mo Steel Plates for Energy Plants†

1. Introduction

Various types of steel plates are used in the energy plant field, which includes oil refineries and other chemical plants, as well as power generating equipment and the like. In recent years, there has been an orientation toward heavier weight in the steel products used in these plants due to the adoption of heavy gauge, wide, and long products in response to plant upscaling, more severe operating conditions and service environments, and the need for higher efficiency in welding with the aim of reducing construction costs. Together with these trends, thickness reduction by high strength, improved toughness and weldability, and other features are required. Moreover, increased global energy demand has resulted in a higher level of activity in energy plant construction, and this has heightened the need for high performance steels.

JFE Steel is developing heavy section Cr-Mo steel plates to meet these needs[1–4]. This report introduces various types of heavy section Cr-Mo steel plates developed for energy plants.

2. Production Technologies for Heavy Section Cr-Mo Steel Plates

2.1 Heavy Section Plate Production Technologies by Ingot Casting and Forging and/or Rolling Process

Among the production processes for large weight, heavy section steel plates, in addition to the continuous casting process, JFE Steel has an ingot casting process which makes it possible to produce large-scale steel ingots up to 120 tons in weight by melting high purity steel in an LD converter-RH vacuum degassing process. In addition to slabbing mills and plate rolling mills, JFE Steel also employs a 6 000 tons free forging process (**Photo 1**) which makes it possible to produce high quality, heavy section, large weight steels[1, 2].

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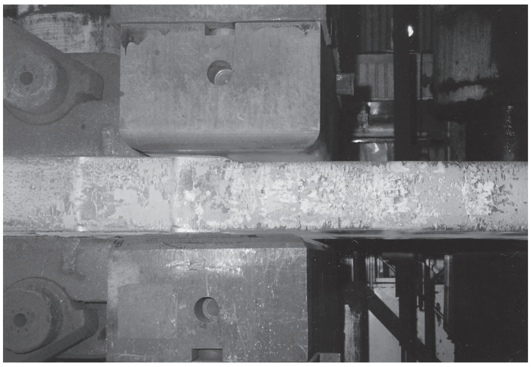

Photo 1 Forging reduction in thicknesswise of continuous casting (CC) slab

Table 1 Capacity of main equipment

Equipment	Capacity
Batch type heat treating furnace	Capacity: 150 t Max. temperature: 1 050˚C Effective height: 400 mm
Quenching pit	Dipping type
Surface grinder	Max. thickness: 450 mm Rough and fine whetstone
Flame cutter	Max. thickness: 400 mm

2.2 Heat Treatment Technology for Large Weight Plates

A new heat treatment plant (new special plate equipment, **Table 1**) for production of heavy thickness, wide, and long heat-treated plates with large weight was started up in 2011. As a result, JFE Steel now has the capability to perform high temperature heat treatment (up to 1 050°C) of heavy section steel plates up to 400 mm in thickness by a batch type heat treating furnace and quenching by a dip-type water quenching pit[2].

3. Features of Representative Heavy Section High Performance Cr-Mo Steels

By using the heavy section steel production process described in Chapter 2, JFE Steel can produce not only plate product standards, but also high quality heavy section heat-treated steels for forged product standards.

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Table 2 Specifications for typical Cr-Mo steel plates and forgings

	ASME		JIS	
	Plate	Forging	Plate	Forging
1Cr-0.5Mo	SA-387-12-2	SA-336-F12	SCMV2-2	SFVA F 12
1.25Cr-0.5Mo	SA-387-11-2	SA-336-F11-3	SCMV3-2	SFVA F 11 B
2.25Cr-1Mo	SA-387-22-2	SA-336-F22-3	SCMV4-2	SFVA F 11 B
2.25Cr-1Mo-V	SA-542-D-4a	SA-336-F22V	SCMQ4V	SFVCM F22V

ASME: The American Society of Mechanical Engineers
JIS: Japanese Industrial Standards

Table 2 shows examples of ASME and JIS for the main Cr-Mo steel plates and forgings for energy plant pressure vessels. JFE Steel has developed heavy section high performance Cr-Mo steels for these plate and forging standards, and already has an extensive production record. Examples of the features of these products are presented in the following. (ASME: The American Society of Mechanical Engineers, JIS: Japanese Industrial Standards)

3.1 Heavy Section High Performance 1.25Cr-0.5Mo Steel

1.25Cr-0.5Mo steel is used in a wide range of applications in the energy field. With heavy section materials, there is a tendency to apply high-temperature/long-time post weld heat treatment (PWHT) conditions and strict toughness conditions, including the plate center (1/2*t*) position. JFE Steel has developed various types of heavy section 1.25Cr-0.5Mo steel in response to these needs. Examples of their chemical composition are shown in **Table 3**. In addition to limiting impurity elements to low levels, microalloying elements are actively used for microstructural control.

3.1.1 Thick high toughness 1.25Cr-0.5Mo steel (SA-387 Gr. 11 Cl. 2)

Table 4 shows the mechanical properties of the base material of 1.25Cr-0.5Mo steel plate (ASME SA-387 Gr. 11 Cl2) with a thickness of 130 mm, which is produced by the ingot casting-slabbing-plate rolling-heat treatment (Q-T) process. This steel amply satisfies the ASME standard and has high Charpy absorbed energy at −20°C, including the 1/2*t* position.

3.1.2 Heavy section 1.25Cr-0.5Mo steel (SA-336 Gr. 11 Cl. 3)

Table 5 shows the mechanical properties of the base material of a 1.25Cr-0.5Mo forged steel product (SA-336 Gr.11 Cl.3) with a plate thickness of 279 mm, which is produced by the ingot casting-forging-plate rolling-heat treatment (Q-T) process. This steel amply satisfies the ASME standard and has high Charpy absorbed energy at −10°C, including the 1/2*t* position. As a high reduction in area (RA) is obtained in the tensile test of the plate thickness direction (*Z*-direction) at the 1/2*t* position, this steel has good internal properties at the plate center of thickness.

Table 3 Chemical compositions of 1.25Cr-0.5Mo steel (mass%)

Thickness (mm)	C	Si	Mn	P	S	Cr	Mo	Others
130	0.14	0.55	0.44	0.004	0.001	1.44	0.62	Cu, Ni
279	0.14	0.54	0.59	0.003	< 0.001	1.44	0.60	Cu, Ni, Ti, B
380	0.14	0.54	0.59	0.003	< 0.001	1.44	0.60	Cu, Ni, Ti, B

Table 4 Mechanical properties of 1.25Cr-0.5Mo steel (SA-387 Gr.11 Cl.2)

Thickness (mm)	PWHT	Tensile properties					Charpy impact properties		
		Position, Direction	YS (MPa)	TS (MPa)	El (%)	RA (%)	Position, Direction	$vE_{-10^\circ C}$ (J)	$vE_{-20^\circ C}$ (J)
130	691°C × 21.5 h	1/4*t*-C	417	571	31	78	1/4*t*-C	333	321
		1/2*t*-C	385	555	30	78	1/2*t*-C	277	229
	675°C × 6 h	1/4*t*-C	472	624	29	77	1/4*t*-C	337	308
		1/2*t*-C	446	606	28	78	1/2*t*-C	355	302

SA-387 Gr.11 Cl.2 Specification: YS≧310 MPa, 517≦TS≦690 MPa, El≧22%
$vE_{-18^\circ C}$≧54 J (API RP 934-C, *t*≦100 mm)
YS: Yield strength, TS: Tensile strength, El: Elongation, RA: Reduction in area
vE: Absorbed energy

Table 5 Mechanical properties of 1.25Cr-0.5Mo steel (SA-336 Gr.11 Cl.3)

Thickness (mm)	PWHT	Tensile properties					Charpy impact properties		
		Position, Direction	YS (MPa)	TS (MPa)	El (%)	RA (%)	Position, Direction	$vE_{0^\circ C}$ (J)	$vE_{-8^\circ C}$ (J)
279	691°C ×20 h	1/4*t*-C	374	543	29	76	1/4*t*-L	404	265
		1/2*t*-C	381	561	29	74	1/2*t*-L	329	168
		1/2*t*-Z	—	560	—	73	—	—	—
	691°C × 4 h	1/4*t*-C	400	563	29	76	1/4*t*-L	414	313
		1/2*t*-C	403	580	29	71	1/2*t*-L	118	243
		1/2*t*-Z	—	580	—	64	—	—	—

SA-336Gr.11 Cl.3 Specification: YS≧310 MPa, 517≦TS≦690 MPa, El≧18%, RA≧40%
YS: Yield strength, TS: Tensile strength, El: Elongation, RA: Reduction in area
vE: Absorbed energy

3.1.3 Heavy section 1.25Cr-0.5Mo steel (SCMV3-2 Mod.)

Table 6 shows the mechanical properties of the base material of a 1.25Cr-0.5Mo steel plate (JIS SCMV3-2 Mod.) with a plate thickness of 380 mm, which is produced by the ingot casting-forging-plate rolling-heat treatment (Q-T) process. Strength equivalent to JIS SCMV3-2 can be obtained at the 1/2*t* position of the 380 mm thickness even after long-time PWHT. Excellent internal properties (*Z*-direction properties) at the center of thickness position and sufficient Charpy impact properties are also obtained.

Table 6 Mechanical properties of 1.25Cr-0.5Mo steel (JIS SCMV3-2 Mod.)

Thick-ness (mm)	PWHT	Tensile properties					Charpy impact properties		
		Position, Direction	YS (MPa)	TS (MPa)	El (%)	RA (%)	Position, Direction	$vE_{0^\circ C}$ (J)	$vE_{-10^\circ C}$ (J)
380	710°C × 21.6 h	1/4*t*-C	351	527	32	78	1/4*t*-L	315	414
		1/2*t*-C	357	530	32	76	1/2*t*-L	191	243
	710°C × 9.2 h	1/4*t*-C	377	548	32	77	1/4*t*-L	411	423
		1/2*t*-C	382	550	31	79	1/2*t*-L	403	383
	—	1/2*t*-Z	—	657	—	59	—	—	—

SCMV3-2 Specification ($t \leqq 200$ mm) : YS≧315 MPa, 520≦TS≦690 MPa, El≧22%
YS: Yield strength, TS: Tensile strength, El: Elongation, RA: Reduction in area
vE: Absorbed energy

3.2 Heavy Section High Strength 2.25Cr-1Mo-V Steel (ASME SA-542 Gr. D Cl. 4a)

The chemical composition, tensile strength, and Charpy impact properties and temper embrittlement properties of a heavy section high strength 2.25Cr-1Mo-V Steel (ASME SA-542 Gr. D Cl. 4a) with a 210 mm plate thickness, which is produced by the ingot casting-slabbing-plate rolling-heat treatment (N-Q-T) process are shown in **Tables 7**, **8**, and **9**, respectively. As a result of an alloy design in which impurity elements are reduced and microalloying elements are used, combined with rolling and high temperature heat treatment technologies for heavy section steel, this steel has excellent strength/high-temperature strength and toughness after long-time PWHT, and satisfactory temper embrittlement properties can also be obtained.

4. Conclusion

JFE Steel produces heavy section Cr-Mo steel plates by using state-of-the-art heavy steel manufacturing technologies and microalloying technologies. These ultra-heavy gauge plates possess excellent internal quality, and also have excellent strength and toughness, including the plate center of thickness position. These products, which include not only plate product standards but also forged product standards, have an extensive record of application as materials for various types energy plants. They have also been applied as plate products for welded structure use in parts where steel castings had conventionally been used, thereby contributing to reduction of the cost of structures. Use in a wide range of applications is expected in the future.

Table 7 Chemical compositions of 2.25Cr-1Mo-V steel (SA-542 Gr. D Cl. 4a)

(mass%)

Thickness (mm)	C	Si	Mn	P	S	Cr	Mo	V	Others	*J*-Factor
210	0.14	0.04	0.55	0.009	0.001	2.41	1.07	0.32	Cu, Ni, Nb, Ti, B	55.5

J-Factor = (Si+Mn) (P+Sn)$\times 10^4$

Table 8 Tensile properties of 2.25Cr-1Mo-V steel (SA-542 Gr.D Cl.4a)

Thick-ness (mm)	PWHT	Tensile properties					High-temperature tensile properties	
		Position, Direction	YS (MPa)	TS (MPa)	El (%)	RA (%)	454°C YS (MPa)	454°C TS (MPa)
210	712°C × 34.3 h	1/4*t*-C	499	625	26	78	—	—
		1/2*t*-C	490	617	26	79	396	476
		1/2*t*-Z	—	627	—	76	—	—
	698°C × 7 h	1/4*t*-C	557	673	26	79	—	—
		1/2*t*-C	549	665	25	78	—	—
		1/2*t*-Z	—	679	—	76	—	—

SA-542Gr. D Cl. 4a Specification: YS≧414 MPa, 587≦TS≦758 MPa, El≧18%
YS (454°C) ≧338 MPa (Sy) , TS (454°C) ≧456 MPa (0.9 Su)
YS: Yield strength, TS: Tensile strength, El: Elongation, RA: Reduction in area

Table 9 Charpy impact properties and temper embrittlement properties of 2.25Cr-1Mo-V steel (SA-542 Gr.D Cl.4a)

Thick-ness (mm)	PWHT	Charpy impact properties					After Step cooling	
		Position, Direction	$vE_{-29^\circ C}$ (J)	$vE_{-50^\circ C}$ (J)	vTrs (°C)	vTr55 (°C)	vTrs (°C)	vTr55 (°C)
210	712°C × 34.3 h	1/4*t*-C	288	190	−57	—	—	—
		1/2*t*-C	189	159	−49	—	—	—
	698°C × 7 h	1/4*t*-C	240	196	−62	—	—	—
		1/2*t*-C	205	108	−46	−62	−47	−72

SA-542Gr.D Cl.4a Specification: $vE_{-18^\circ C} \geqq 55$ J, $vE_{-29^\circ C} \geqq 55$ J (API RP 934-A)
vE: Absorbed energy, vTrs: Fracture appearance transition temperature, vTr55: 55 J Transition temperature

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