Technology and Products of JFE Steel's Three Plate Mills[†]

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Abstract:

JFE Steel has 3 plate mills, which are located at Keihin District of its East Japan Works and Kurashiki and Fukuyama Districts of West Japan Works. JFE Steel's 3 plate mill system enables efficient operation taking full advantage of the respective features of each mill, including equipment, technologies, and location. JFE Steel has developed numerous advanced technologies for steel plate products in order to satisfy advanced customer requirements for mass production, quicker delivery, dimensional accuracy, heavier gauges, higher strength, and improved weldability.

1. Introduction

As a result of the merger of the former Kawasaki Steel and former NKK in 2003, JFE Steel now manufactures plates under a 3 plate mill system and is the largest plate supplier in Japan, with an annual production capacity of 5.6 million tons.

These 3 plate mills are located in Keihin District of JFE Steel's East Japan Works and Kurashiki and Fukuyama Districts of its West Japan Works, and form a system which supplies high performance, high quality products, taking advantage of the features of the respective mills by district and by field/application.

The requirements placed on steel plates in recent years cover a diverse range, including high strength, high weldability, and high performance. JFE Steel has responded to these requirements by developing advanced manufacturing technologies for plate production.

This paper describes the technological features and products of JFE Steel's 3 plate mills.

[†] Originally published in JFE GIHO No. 5 (Aug. 2004), p. 1–7

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2. Features of JFE Steel's Plate Mills

JFE Steel's first plate mill was a 4-high mill, which was introduced in the Tsurumi District in 1954 and was followed by plate mills started up in the Chiba District in 1961, Kurashiki District in 1967, and Fukuyama District in 1968, and in the Kurashiki District (No. 2 plate mill) and Keihin District in 1976. At present, JFE Steel has a 3 plate mill system, comprising mills at the Fukuyama, Kurashiki, and Keihin Districts, and has introduced or developed advanced equipment and leading-edge technologies at these respective mills and produces outstanding products.

The main equipment specifications of these 3 plate mills are shown in **Table 1**, and the history of advanced technologies and new product development is shown in **Table 2**. The features of the respective mills are described in the following.

- (1) The plate mill at the Keihin District is a rational mill which was designed on the preconditions of consideration for the environment and automated operation. The heat treatment furnace, where the highest level of control is applied, is the only facility in Japan which is capable of hardening plates with a maximum width of 5 300 mm and enables mass production of high value-added products. Keihin District is JFE Steel's plate production base in its East Japan Works. Its strengths include mass production of temperedtype high-tensile steels.
- (2) The Kurashiki District plate mill has a wide-width mill with a maximum 5 350 mm product width. As auxiliary equipment, the mill has introduced



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		Keihin District	Kurashiki District	Fukuyama District	
Year of start up		1976	1976	1968	
Production capasity (1 000 t/y)		1 670	2 050	1 900	
Plate size availability	Thickness (mm) Maximum width (mm) Maximum length (m)	360 5 300 25	360 5 350 27	200 4 500 25	
Continuous reheating furnace	Number Type	2 Walking beam	2 Walking beam	2 Walking beam	
Mill	Туре	4-High reversing mill	4-High reversing mill with attached edger and bender	4-High reversing 2 stand mill with work roll long-shift and bender	
	Work roll of finishing stand (mm)	D1 230 × L5 500	D1 220 × L5 490	D1 230 × L4 700	
	Back up roll of finishing stand (mm)	$D2\ 400 \times L5\ 400$	<i>D</i> 2 400 × <i>L</i> 5 390	$D2\ 200 \times L4\ 500$	
	Main motor	Finisher : 6 400 kW \times 2	Finisher : 8 800 kW \times 2	Rougher : 5 000 kW \times 2, Finisher : 8 800 kW \times 2	
ACC		Super-OLAC	Super-OLAC	Super-OLAC	
Hot leveler	Maximum leveling force (t)	1 600	4 100	3 500	
Shear line	Double-side, Slit, End shears	Rolling cut type	Double-side, End : Guillotine cut type, Slit : Rolling cut type	Rolling cut type	
	Feature	_	Edge milling	—	
Cold leveler	Maximum leveling force (t) Feature of function	3 500	3 500 Stretch, reflection, and intermesh control	1 400	
Heat-treatment furnace N : Normalizing, Q : Quenching, T : Tempering HOP : Heat-treatment online process (Available plate width : mm)		Non-oxidizing type for N and Q (5 400 W),	Non-oxidizing type for N, Q, and T (4 700 W),	Non-oxidizing type for N and Q (4 400 W),	
		Direct heating type for T (5 400 W)	Direct heating type for T (4 150 W),	Direct heating type for T (4 400 W),	
			Car direct heating type for N and T (5 300 W)	Direct heating type for stainless steel plate (4 000 W), HOP (4 500 W)	
Other equipment			Slab forging press for heavy gauge plate	2 Electron beam welders for clad plate, Pickling line for stainless steel plate	

Table 1 Specifications of JFE Steel's plate mills

an attached edger and edge milling equipment, a proximate γ -ray thickness gauge, and a work roll bender, and has devoted great effort to technologies for building high accuracy into products. The high level of Kurashiki District's integrated manufacturing capability is also one of the mill's features. The mill possesses a slab forging process which is advantageous for manufacturing single-thickness extra-heavy plates. In 2003, Kurashiki District installed a *Super*-OLAC (on-line accelerated cooling) device and added new functions to the cold leveler, strengthening its production system for as-rolled high-grade plates.

(3) Fukuyama District has two plate rolling mills, in contrast to one mill each at the Kurashiki and Keihin Districts, and is capable of manufacturing TMCP (thermo-mechanical control process) materials. Because Fukuyama District possesses equipment, beginning with the *Super*-OLAC, which makes it possible to build advanced material properties into products, the mill is capable of on-line manufactur-

ing responding to the performance requirements of advanced high-grade steels. The finishing mill is a full-scale shape control mill where the world's first work roll shift system for plate was introduced, and is capable of producing not only general steels, but also stainless steel plates, clad plates, and titanium plates for cryogenic service.

JFE Steel has clarified the division of roles among these 3 plate mills based on their geographical conditions and technical and equipment features and has allocated functions to take maximum advantage of their respective strengths, responding to globalization among customers and high quality requirements while also shortening delivery times.

3. Plate Manufacturing Technologies

JFE Steel has actively developed new equipment and new technologies, as shown in Table 2, for conservation of resources, including energy and iron sources,

	New technology and new equipment	New products	
1977	Keihin: Absolute AGC Kurashiki: Automatic operation technology***	Kurashiki: TS590 MPa grade steel plate for nuclear containment vessel	
1979	Keihin: Accurate gauge meter model Kurashiki: Mizushima automatic plan view pattern control system*	Fukuyama: TS780 MPa grade heavy gauge plate for rack and rig	
1980	Fukuyama: Accelerated cooling technology (OLAC)***	Fukuyama: Accelerated cooling type YP355 MPa grade steel plate for shipbuilding	
1982	Keihin: Automatic operation technology for heat-treatment furnace	Kurashiki: TS590 MPa grade steel plate for nuclear pressure vessel	
1983		Keihin: Rust-stabilizing coating "CUPTEN COAT"	
1984	Keihin: Attached edger with finishing mill	Keihin: Abrasion resistant steel plate "EVERHARD series"	
1985	Fukuyama: Work roll sift for plate mill		
1986	Fukuyama: High performace clad plate production technology**	Fukuyama: X80 and sour gas X65 line pipes, Ti clad plate Keihin: YS440 MPa grade steel plate with low yield ratio for building** Kurashiki: TS590 MPa grade steel plate for offshore structure	
1987	Kurashiki: Proximate γ ray thickness gauge, Edge milling technology	Kurashiki: Milling plate with accurate dimension	
1991	Kurashiki: Trimming free production technology ^{††}		
1993	Kurashiki: Longitudinal profile plate production technology	Kurashiki: Longitudinal profile plate Keihin: Low preheat temperature type TS590 and 780 MPa grade steel plate for bridge	
1996		Fukuyama: X100 line pipe	
1997		Keihin: New 610 MPa grade steel for casing (Three Gorges Dam PJ)	
1998	Fukuyama: New accelerated cooling technology (Super-OLAC)**. †	Fukuyama: New 610 MPa grade steel for penstock (Tree Gorges Dam PJ) Kurashiki: TS590 MPa grade ultra low C bainite steel plate	
1999		Fukuyama: New rust-stabilizing coating "CUPTEN COAT M" Kurashiki: TMCP type SGV480 grade steel plate Kurashiki and Fukuyama: Ni added weathering steel plate	
2000		Kurashiki: Rust-stabilizing coating "e-RUS"	
2001		Fukuyama: YP390 MPa grade steel plate with high-heat-input-weldability for container carrier, New construction and industrial machinery steel plate "JFE HT780LE," New anti-corrosion steel "NAC5" for oil cargo tanker	
2002		Keihin: YP385 MPa grade steel plate for building	
2003	Kurashiki: <i>Super</i> -OLAC Kurashiki: Multi function cold leveler	Keihin: New abrasion resistant steel plate "EVERHARD-LE series" Fukuyama: Steel plate with high-heat-input-weldability "JFE HITEN 610E" for oil storage tank Kurashiki: YP420 MPa steel plate with good CTOD value at -40°C for offshore structure	
2004	Fukuyama: Continuous heat-treatment process Keihin: Super-OLAC	Fukuyama: Continuous heat-treatment process type TS570–780 MPa grade steel plate Kurashiki: YP315–355 MPa grade steel plate with easy fabrications "Easyfab"	

Table 2 Chronological table of new technology and product developed in JFE Steel

* Okochi Memorial Prize, ** Okochi Memorial Prize for Technology, *** Okochi Memorial Prize for production,

[†] Iwatani Naoji Memorial Prize, ^{††} Aida Technology Prize

by achieving high accuracy and high efficiency and for developing high performance, high function plate products. The company's main plate manufacturing technologies are described in the following.

3.1 Rolling Technologies

3.1.1 Thickness control technology

Thickness control is the most basic technology in plate rolling. At its 3 plate mills, JFE Steel has constructed a plate thickness control system comprising high-response AGC (hydraulic automatic gauge control), sensors such as the γ -ray thickness gauge, and high-accuracy computer models, thereby establishing an advanced plate thickness control technology.

The basis of thickness control in plates is highaccuracy set-up using a gauge meter model and other high-accuracy computer models, thickness control over the full length of the plate by AG-AGC (absolute gauge-AGC), and model learning by comparison of the values measured by sensors between passes or between slabs and the values calculated by the model.



AGC : Automatic gauge control, AG-AGC : Absolute gauge-AGC

Fig.1 Configuration of AGC system

In addition to these, in 1987, JFE Steel installed a γ -ray thickness gauge located 2 m from the finishing mill, at the Kurashiki District plate mill and developed the world's first monitoring AGC in the field of plate using this device.

By implementing a variety of environmental countermeasures, the company succeeded in installing a precision device, namely, the thickness gauge, in the extremely poor environment 2 m from the finishing mill, which is characterized by high temperature, high humidity, and large vibration.

Figure 1 shows an outline of the plate thickness control system, including monitoring AGC using this proximate γ -ray thickness meter. The loads generated by rolling and the changes in the roll gap caused by those loads (roll flexure, mill housing deformation, etc.) are predicted by rolling load prediction and a gauge meter model, and the roll gap prior to rolling is set with high accuracy. Changes in the roll gap due to load fluctuations during rolling are corrected by AG-AGC, reducing deviations in plate thickness, and the difference between the target thickness and the measured thickness immediately after rolling is fed back to the roll gap, making it possible to control the full length of the plate to the target thickness. Using this technology, JFE Steel manufactures flat products with minimal deviation in plate thickness.

Based on conventional plate thickness control, JFE Steel has also developed a plate thickness control technology for longitudinally profiled (LP) steel plates, in which the thickness is changed continuously in the longitudinal direction. **Figure 2** shows an outline of the thickness control system for LP plates. An arbitrary thickness profile can be imparted to the plate with good accuracy by controlling the roll gap while tracking the plate longitudinal position. JFE Steel has also carried out various developments in manufacturing processes other than rolling, and has established a technology for manufacturing LP steel plates with a variety of material properties and shapes which can meet numerous requirements, including not only unidirectional profiling in the



Fig.2 Automatic gauge control system configuration for LP plate

longitudinal direction, but also convex profiling, asymmetrical profiling in the longitudinal direction, etc. LP plates are used in shipbuilding, bridges, and other applications to obtain various advantages, such as weight reduction in structures and labor-saving in plate joining work.

3.1.2 Flatness control technology/ plate crown control technology

Technology for realizing high accuracy in the flatness and dimensions of plates is an important task for meeting customers' requirements for process elimination. Strict control of the plate crown in each rolling pass is necessary in controlling the flatness of steel plates. In mills which do not have a shape control system, the larger part of plate crown control is performed using the work roll profile and control of the distribution of reduction in each pass. As a result, there are restrictions rolling chances and it is necessary to reduce the rolling load approaching the final pass, but these practices are obstacles to achieving shorter delivery times and improving productivity.

As described in Chapter 2, JFE Steel introduced the world's first shape control mill equipped with a work roll shift (WRS) system at its Fukuyama District in 1985. This mill has a maximum WRS distance of 1 000 mm and a powerful work roll bender (WRB) with a maximum load of 600 t/chock.

The plate crown control capacity of this system is shown in **Fig. 3**. The crown control capacity of the WRB at maximum WRS is approximately 400 μ m with widths of 3 000–3 500 mm, which is equivalent to approximately 3 500 t when converted to rolling load¹). Introduction of a shape control mill equipped with this WRS reduced plate crown, as shown in **Fig. 4**.

Furthermore, by realizing complete roll chance free production, the hot charge rolling (HCR) ratio was



Fig.3 Control range of plate crown





increased from 60% to 85%, contributing to a reduction in production time and energy savings.

In addition to the hardware development described above, the following software/ sensors were also developed:

- High-accuracy crown model which considers
 3-dimensional deformation of the rolling material
- (2) Proximate flatness sensor²⁾
- (3) FF/FB control based on measured flatness

As a result, it has become possible to manufacture flat plates with an average plate crown of 0.05 mm or less.

As described above, JFE Steel has achieved the mutually contradictory goals of improving flatness and shortening delivery times, responding to increasingly strict and diverse customer requirements.

3.1.3 Plan-view shape control technology

Plan-view shape control technologies which reduce the occurrence of top/bottom crops and side crops during rolling and improve the rectangularity of plates after rolling were introduced by all steel makers around 1980.

At each of its 3 plate mills, JFE Steel developed and applied methods for controlling the plan-view shape which impart the specified thickness profile by quantitatively predicting the plan-view shape of the plate after rolling and changing the roll gap during rolling in the final pass of forming rolling or broadside rolling. This technology has been licensed to a number of plate mills



Fig.5 Cutting accuracy of edge milling

outside of Japan and received the Okochi Memorial Award in fiscal year 1979.

Following the development of the plan-view pattern control system described above, JFE Steel installed the world's first attached edger adjacent to the finishing mill at the Kurashiki District plate mill in 1984 with the aim of improving absolute width accuracy and achieving rectangularity in the side surface shape (bulging prevention), as well as realizing rectangularity of the plan-view shape. This device enables edging at any desired timing during reverse rolling. A hydraulic AWC (automatic width control) function was also introduced, making it possible to minimize width fluctuations while also securing an adequate transverse reduction over the full length of the plate by considering entry-side width fluctuations and reduction of width spread ratio in the unsteady region at the top and bottom ends of the plate.

After realizing high width accuracy in rolling, JFE Steel installed an edge milling device at the shear line of the Kurashiki District plate mill in 1987, replacing plate width edge trimming with the conventional side edger and thereby creating an on-line manufacturing system for milling plates. As shown in Fig. 5, milling plates realize high accuracy within ± 0.5 mm in both width fluctuations and straightness, which had been impossible with shear cutting³). This level of accuracy allows customers to apply butt welding in the mill edge condition without recutting. As a result, these materials have been adopted in applications such as deck plates of car carriers and rectangular section column materials, among others. This technology, which is termed TFP (trimming free plate) manufacturing technology, was awarded the Aida Technology Prize by the Japan Society for Technology of Plasticity in 1991.

3.2 Accelerated Cooling Technology

Accelerated cooling technology makes it possible to increase the strength of steel or to achieve the same level of strength with a low carbon equivalent (C_{eq}) design by water cooling after hot rolling. Generally, the strength and weldability of steels are inversely related, in that welding becomes more difficult when strength is increased, but accelerated cooling technology solved this problem at a high level.

Practical application of accelerated cooling technology began with an accelerated cooling device called OLAC which was installed for the first time in the world at Fukuyama District plate mill in 1980. JFE Steel's plate mills the successively installed the MACS (multipurpose accelerated cooling system) at Kurashiki District and OLAC-II at Keihin District plate mills.

As a pioneer in accelerated cooling, JFE Steel continued its research on accelerated cooling technologies even after these systems were installed, and in 1998, when renovating the superannuated OLAC, the company installed the *Super*-OLAC at Fukuyama District plate mill. The *Super*-OLAC is based on the new concept that uniform cooling can be achieved simultaneously with a high cooling capacity if cooling is performed in an nucleate boiling condition in the all range of temperature⁴). During modernization of the plate mills in at JFE Steel's other districts, the same equipment was installed at Kurashiki District plate mill in May 2003 and at Keihin District in June 2004. As a result, all three of JFE Steel's plate mills now possess this advanced accelerated cooling equipment.

The features of the *Super*-OLAC include the following three points:

- (1) Achieves a high cooling rate at the theoretical limit with water cooling⁴).
- (2) Realizes symmetrical cooling of the upper and lower surfaces of the plate and uniform cooling in the plate plane, with temperature deviations in the plate on the same level as with non-water cooled materials.
- (3) Dramatically improves cooling end temperature accuracy under high cooling rates by subdivision of the cooling zones.

The high cooling rates achieved by the *Super*-OLAC make it possible to obtain high strength even with lower carbon equivalents than with the conventional technology and demonstrate effectiveness in the manufacture of heavy-gauge high-tensile products, in which weldability and welded joint toughness had been problems. For example, it is now possible to manufacture 70 mm EH40⁵ for container ship use, which is suitable for large heat input welding, and marine structural materials with a thickness of 75 mm, which are capable of guaranteeing a joint CTOD value of 0.38 mm⁶.

In accelerated cooling technologies, the temperature deviations in the plate at cooling end is important. Large temperature deviations in the plate at this time cause strain, and leveling work with a cold leveler or press is necessary to secure flatness. Because plates display an



Fig.6 Example of temperature profile after cooling

extremely uniform temperature distribution with the *Super*-OLAC, as shown in **Fig. 6**, leveling work has been reduced by half in comparison with the conventional technology. Furthermore, strain after cutting by the customer is also reduced, contributing to improved productivity and cost reductions on the customer side.

3.3 Heat Treatment Technologies

At both Keihin and Kurashiki Districts, heat treatment technologies comprise shot blast devices, heat treatment furnaces, hardening equipment, and heattreatment levelers. Normalizing/hardening furnaces have a non-oxidizing atmosphere with excellent sealability, ensuring good surface quality.

In particular, the heat treatment furnace at Keihin District, which is JFE Steel's main plant for heat-treated materials, is the only one in Japan which is capable of heat-treating plates with a maximum product width of 5 300 mm, maximum product length of 25 m, and maximum weight of 30 t.

Operation of the heat treatment equipment for plates had conventionally been limited to partial automatic control of the equipment, but complete automation of all lines has been realized with the heat treatment facilities at Keihin District. In-furnace control is controlled on the highest level, for example, enabling operation with a tempering parameter as a heat treatment index, using temperature tracking based on a heat transfer model. In 2003, higher functions were achieved by renovating the computer, and the cover ratio was increased by introduction of a charging support system, realizing even more efficient furnace operation.

The layout of Keihin District heat treatment equipment is shown in **Fig. 7**. Among this equipment, the No. 1 heat treatment furnace roller quench line and No. 2 heat treatment furnace are installed in parallel, with the shot blast device installed at the entry side and the heat treatment leveler at the delivery side, in a rational layout corresponding to the material flow.

Number 1 heat treatment furnace is a hightemperature furnace for normalizing/hardening, and the furnace interior is enclosed in N_2 atmosphere. Consideration is given to surface quality, as the sealability of the



Fig.7 Layout of heat-treatment facilities

furnace is extremely high and very few pickup defects occur during heat treatment. Number 2 heat treatment furnace is a tempering furnace and maintains a high soaking property in the furnace by utilizing side burners and a stirring fan in the furnace. The combination of these hardware considerations and computer control has realized an advanced quality control system which is unprecedented in the world.

JFE Steel developed/introduced on-line type advanced technologies including practical application of the OLAC, which is the core technology in TMCP manufacturing technologies, in advance of other steel makers worldwide. In addition to these, in 2004, JFE Steel developed a new technology called HOP (heattreatment on-line process) which enables on-line tempering heat treatment in advance of other steel makers, and introduced this technology at its Plate Rolling Plant (Fukuyama).

In the HOP system, a large capacity induction heating device is installed in direct linkage with the *Super*-OLAC to realize total manufacturing of high grade steels. As a result, high-grade steel production capacity, which had been governed by the capacity of the conventional heat treatment furnace, was dramatically expanded, and at the same time, production time was greatly shortened.

JFE Steel is now developing new products capable of meeting more advanced customer requirements by

applying this HOP system.

3.4 Special Steel Plate Manufacturing Technologies

3.4.1 Clad steel plate manufacturing technology

Fukuyama District plate mill began commercial production of clad steel plates in 1983. Clad steel plates are composite materials which are manufactured by covering one or both sides of a carbon steel or low-alloy steel, which is called the base material or backing material, with stainless steel or some other material, which is called the cladding material.

Although manufacturing methods for clad steel plates include the deposit welding method, explosive cladding method, casting method, and others, JFE Steel manufactures clad products with a rolling method suitable for manufacturing large plates.

The manufacturing process for rolled-type clad steel plates is shown in **Fig. 8**.

First, slabs for use in assembling the clad plate, the base material and cladding material slabs are manufactured by hot rolling.

Next, these rolled materials are surface-treated and made up into a built-up slab by stacking the respective materials and welding the four sides. The built-up slab is then hot-rolled again, bonding the based material and cladding material to produce a clad steel plate.



Fig.8 Manufacturing process for stainless clad steel plate

From the manufacturing perspective, the key points for improving bonding in clad plates are as follows:

- (1) Surface properties of the materials
- (2) Vacuum in the built-up slab
- (3) Method of rolling the built-up slab

Scale or other foreign matter remaining on the material surfaces is an obstacle to bonding. At JFE Steel, surface scale removal and other surface treatments are performed using continuous pickling equipment for stainless steel plate production.

For slab assembly, JFE Steel developed a highvacuum, high-speed assembly welding technology for slabs using a large-scale electron beam welding (EBW) device introduced in 1987. This clad-plate assembly technology was the first of its type in the world, and achieves improved bonding in clad plates. If air remains between the stacked base material and the cladding material, scale will form on the material surfaces in the reheating process, deteriorating bonding. Therefore, with the EBW equipment, the stacked slabs are charged into a large-scale vacuum chamber, a vacuum is drawn in each chamber, and finally electron beam welding is performed on the four sides of the material. The vacuum pump not only extracts the air in the stacked slabs from a certain limited location, but also creates a vacuum in the atmosphere as a whole. As a result, in comparison with the pump method, the vacuum is more than 100 times stronger and uniformity is greatly improved. Thus, the improved assembly efficiency possible with EBW has realized mass production.

Bonding has also been improved by applying a lowspeed, heavy-reduction rolling technology which was originally developed to improve the internal quality of ingots to plate rolling.

By applying the manufacturing technologies outlined above, JFE Steel has realized stable manufacturing and a shorter production period. It is now possible to manufacture clad steel plates with an excellent bonding property in a maximum thickness of 150 mm and maximum width of 4 200 mm. Monthly production is approximately 1 800 t.

JFE Steel also developed a manufacturing technology for titanium clad plates, which had been considered difficult to bond with the conventional rolling method. This technology received the Okochi Memorial Technology Award in 1993.

3.4.2 Extra-heavy continuous cast steel plates

From the viewpoint of internal quality, extra-heavy steel plates with thicknesses exceeding 240 mm had been manufactured using slabs produced by the ingotcasting route. Because production of slabs from ingotcast materials involves casting in a mold followed by slabbing, etc., the manufacturing load is high in comparison with continuous cast (CC) materials and production time is inferior.

JFE Steel therefore established a manufacturing technology for extra-heavy steel plates exceeding 240 mm using CC slabs by applying the clad plate manufacturing technology described in section 3.4.1. In this technology, one extra-heavy plate is manufactured from two CC slabs by performing surface treatment on one side of two CC slabs of the same steel grade, stacking the slabs so that the two bonding surfaces face each other, producing an built-up slab by EBW, and bonding the slabs by lowspeed, heavy-reduction rolling.

At present, plates with thicknesses of 270 mm and 360 mm are being rolled on a test basis using CC slabs with thicknesses of 251 mm and 310 mm with favorable bonding property results. Because clad plates are manufactured from heterogeneous metals, it is necessary to increase the reduction ratio (= (thickness of assembled slab)/(thickness of plate)). However, in the present case, because both plates are of the same steel grade, it is possible to reduce the reduction ratio in comparison with clad plates. Using this technique, satisfactory bonding up to a product thickness of 360 mm has been confirmed.

JFE Steel intends to realize a mass production process in the future. However, because CC materials are in steady production, it is comparatively easy to obtain extra-heavy plates using this technique. Therefore, the application will not be limited to ingot-substitute materials, but is expected to be extended to forged products and cast products as well.

4. Conclusion

JFE Steel's 3 plate mills have constantly developed/ introduced advanced manufacturing technologies and are responding to a diverse range of customer requirements, including high strength, high weldability, and high functionality. These manufacturing technologies are among the world's top class and supply products with high quality levels.

In the future, JFE Steel will continue to positively develop and introduce advanced technologies to meet higher customer requirements.

References

- Yako, K.; Ishihara, Y.; Murakami, S.; Yamawaki, M.; Sugimoto, T.; Suemura, Y. Special features and operation of the Fukuyama Plate Mill. NKK Technical Report. no. 117, 1987, p. 32–36.
- Yoshii, M.; Yoshizato, T.; Okamura, I. Shape control technology in plate rolling. Kawasaki Steel Giho. vol. 28, no. 2, 1996, p. 76–81.
- 3) Nishida, S.; Okumura, T.; Uemura, T. Development of steel

plate manufacturing technologies at Kawasaki Steel. Kawasaki Steel Giho. vol. 30, no. 3, 1998, p. 125-130.

- Omata, K.; Yoshimura, H.; Yamamoto, S. The leading high performance steel plates with advanced manufacturing technologies. NKK Technical Report. no. 179, 2002, p. 57–62.
- 5) Suzuki, S.; Muraoka, R.; Obinata, T.; Endo, S.; Horita, T.;

Omata, K. Steel products for shipbuilding. JFE Technical Report. no. 2, 2003, p. 41-48.

6) Deshimaru, S.; Takahashi, K.; Endo, S.; Hasunuma, J.; Sakai, K.; Nagahama, Y. Steels for production, transportation, and storage of energy. JFE Technical Report. no. 2, 2003, p. 55– 67.