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Progress and Outlook of Steel Plate Production Technology at Nippon Steel Corporation

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Abstract:

Recent demand for steel plates has been recovering from the slump brought about by the collapse of the bubble economy. The plate quality requirements of customers have increased in sophistication, strictness, and diversification. To meet these requirements, Nippon Steel has developed a variety of plate production and plate product technologies. The plate production technologies are mainly concerned with flatness and rolling control to improve the labor productivity, rolling efficiency, and direct shipping ratio of plate mills. The plate product technologies are represented by the development of HIAREST steel for the collision safety of ships, new weathering steel for use uncoated against airborne salt particles, and ultralow-yield point steels for building structures. In addition to the intensification of cost competitiveness and creation of new demand, it will become important to carry out technology development adapted to global environmental protection and integrated plate product technology development, including fabrication and utilization by customers.

1. Introduction

Steel plates are products that play a central role among steel structural materials. Structural design technology has advanced in sophistication amid a variety of calls for safety, environmental awareness, and cost reduction in recent years. Quality and functional requirements for steels have increased in severity and diversity. For example, crude oil tanker spills triggered demand for collision safety, which led to the double-hull construction of crude oil tankers and improvement in the fracture and crack propagation performance of steels used to build them. In the bridge sector, use in coastal areas and the need for maintenance-free operation combined and resulted in demand for new weathering steels that can be used uncoated against airborne salt particles. In the building field, the Great Hanshin Earthquake of January 17, 1995 prompted calls for building structures and steels with increased earthquake resistance. In their pursuit of lower production cost and higher production efficiency, customers have come to impose more exacting

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dimensional and flatness tolerances and to demand plates of irregular cross section with high accuracy. Nippon Steel Corporation has carried out technology development to meet these challenges and has won high evaluations from customers in Japan and abroad. This article describes the recent progress of plate production technology at Nippon Steel and presents our technical response to the requirements of customers in various fields.

2. Recent Progress of Steel Plate Production Technology

2.1 Recent changes in steel plate production and steel plate product mix

Fig. 1 shows the change in Nippon Steel's steel plate production from 1985 to 1996. The plate production volume temporarily declined as Japan's bubble economy collapsed in the wake of a higher-yen-induced recession in the late 1980s, but has been steadily recovering in the past few years. **Fig. 2** shows the change in the percentage distribution of plates by application. Among major plate applications are ships, buildings, industrial machinery, frames, and bridges. Of particular interest is the increase in the percentage of shipbuilding plates since 1990. This trend is attributable to the replacement of VLCC built in the 1970s and the double hulling of VLCCs compelled by repeated oil spills.

2.2 Improvement in productivity[1-3)]

The overall productivity improvement of plate mills is one of the major issues that must continue to be addressed for into the future. Labor productivity and rolling efficiency, principal indexes of plate mill operations, are described below by citing results achieved in recent years.

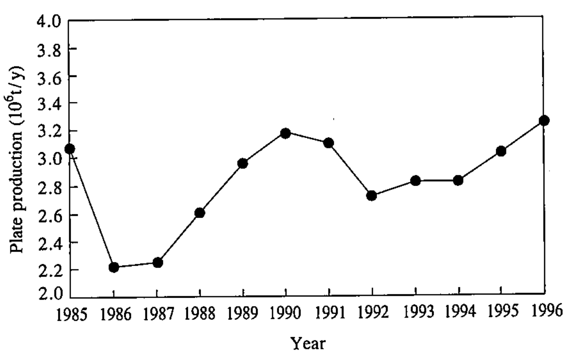


Fig. 1 Change in plate production

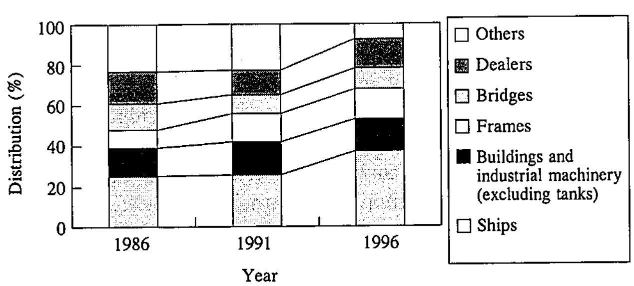


Fig. 2 Change in percentage distribution of plate products by application

2.2.1 Improvement in labor productivity

With the advent of high-performance sensors and controllers as a result of progress in electronics in recent years, the plate production technologies accumulated over many years have been combined into automated systems to achieve a marked improvement in labor productivity.

For example, the plate mill at the Oita Works drastically reduced operator intervention and work load in every aspect of operation by raising the level of automation on the basis of advanced production technology and by developing equipment monitoring systems and quality diagnostic systems to support operators. As a result of these efforts, the Oita plate mill accomplished the world's first one-man operation of heating, rolling, and shearing processes in June 1995. **Fig. 3** shows the change in the labor productivity of the Oita plate mill. The plate mill at the Kimitsu Works automated the gas cutting process and increased the gas cutting capacity by introducing plasma cutting (see **Fig. 4**.), and achieved large labor savings in the finishing process.

For the warehousing and shipping processes, the Kimitsu and Oita plate mills accomplished the steel industry's first unattended operation of their large-scale plate product warehouses by developing lifting magnet crane automation technology. The Oita plate mill developed a planning expert system for the purpose of enhancing the efficiency of shipping tasks and alleviated the shipping

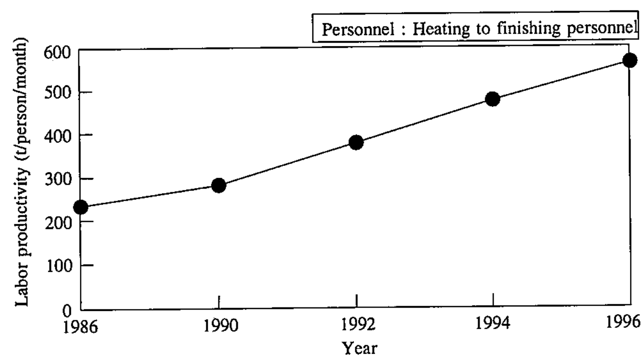


Fig. 3 Change in labor productivity at Oita plate mill

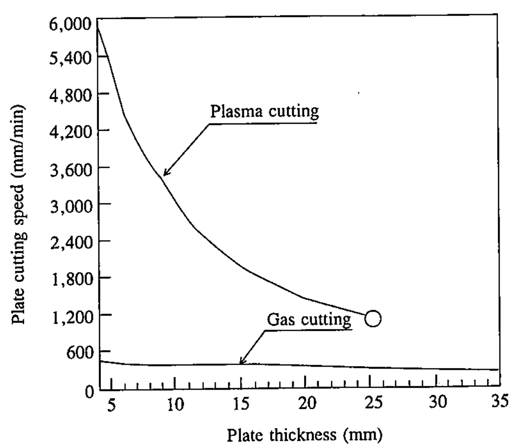


Fig. 4 Relationship between plate thickness and plate cutting speed

work load. The development of technology for automatically operating lifting magnet cranes is reported in detail in another article in this issue of the Nippon Steel Technical Report (NSTR).

2.2.2 Improvement in rolling efficiency[4)]

Nippon Steel's plate mills greatly improved their rolling efficiency from the 1980s to the 1990s. This was based on improvements in the speed control technology of main and auxiliary drives and the reduction in operator intervention by increases in the accuracy of rolling control models. The improvement in rolling efficiency also owed much to the development and commercialization of shape control mills (the pair cross mill for the Kimitsu plate mill and the work roll shift mill for the Oita plate mill). The pair cross mill at the Kimitsu Works is discussed in another article of the present NSTR issue. It represented the world's first application of the pair cross concept to a plate mill. The pair cross mill helped to eliminate light-reduction rolling, formerly performed in the finish rolling stage to ensure desired flatness and crown. The resultant sharp decrease in the number of rolling passes markedly increased the rolling efficiency of the Kimitsu plate mill.

2.3 Direct shipping ratio[5,6)]

The direct shipping ratio refers to the percentage of as-rolled plates that can be shipped without secondary operations, such as surface conditioning and releveling. Along with the yield, it is an important operational index of the level of rolling technology. The change in the direct shipping ratio is shown in **Fig. 5**. The changes in the releveling ratio and surface conditioning ratio that detract from the direct shipping ratio are shown in **Figs. 6**(a) and **6**(b), respectively. As the releveling ratio and surface conditioning ratio improved, the direct shipping ratio smoothly rose.

Positive flatness control by the shape control mills commercialized at the Kimitsu and Oita plate mills, as described above, and advancement of uniform controlled cooling technology energetically promoted for TMCP steels at each plate mill greatly contributed to the releveling ratio reduction. As far as the surface conditioning ratio is concerned, the plate mill at the Nagoya Works introduced a slab grinder to prevent slab corner defects. As a means for avoiding overlaps during broadsiding, the Kimitsu plate mill installed the slab corner forming unit illustrated in **Fig. 7**. The Oita plate mill established the method of effectively using edgers and installed a slab corner scarfing machine to reduce defects originating in the previous process.

Improving dimensional accuracy and increasing order yield have increased the need for reducing corner defects more than ever. There still remain many defects, including scale defects and handling defects. Further technology development will be required to solve these problems.

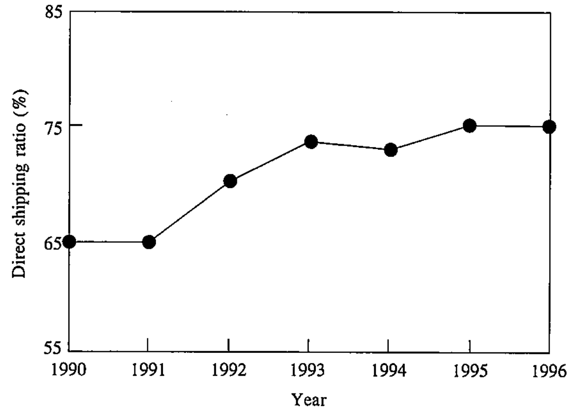


Fig. 5 Change in direct shipping ratio

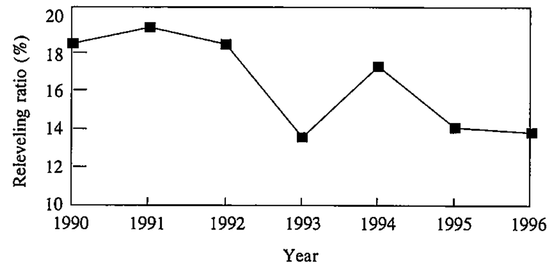


Fig. 6(a) Improvement in releveling ratio

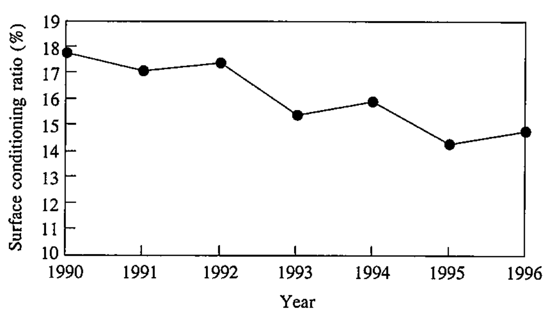
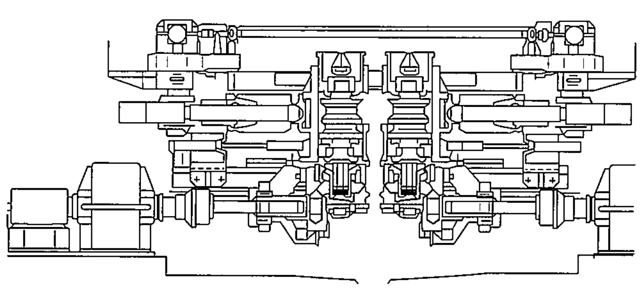


Fig. 6(b) Improvement in surface conditioning ratio



Applicable slab size	Thickness : 300 mm maximum Width : 1,000 to 2,300 mm Length : 2,200 to 10,800 mm
Forming pitch	Maximum : 90 sec (1 pass) Minimum : 120 sec (3 passes)
Forming force	Maximum : 280 tonf
Forming torque	Maximum : 42 ton-m
Grooved roll diameter	730 to 780 mm for 300 mm thick slabs 706 to 756 mm for 242 mm thick slabs
Gap setting speed	0 to 7 m/sec

Fig. 7 Slab corner forming unit

2.4 Improvement in hot charged rolling (HCR) ratio

The hot charged rolling (HCR) ratio has significantly improved since the 1980s. In particular, the Oita plate mill recorded an average HCR ratio of 84.7%, or the industry's top level, in the second half of 1996. To further improve the HCR ratio, it is indispensable to reduce the quantity of slabs conditioned cold to remove defects, to improve the slab surface quality, and to advance the material flow system by considering the balance between the steelmaking and rolling capacities.

2.5 Plate thickness control technology

In the past decade, Nippon Steel has greatly advanced the basic technology of plate rolling for dimensional control and flatness control, among other purposes. These advancements are outlined below.

As for plate thickness accuracy, Nippon Steel introduced absolute automatic gauge control (AGC) early in the industry and has constantly led the industry by developing dual-AGC to allow for asymmetry between the right and left sides of the plate mill and S-AGC to reduce the within-plate thickness deviation. Against the background of these leading technologies and improvements in computer performance, high-accuracy mathematical models (such as load and temperature prediction models), based on rolling theory, were developed and commercialized. As a result of these efforts, gaugemeter accuracy was markedly improved. These achievements not only improved plate thickness accuracy, but also increased the certainty of setup and an interpass adaptive control system characteristic of plate rolling, thereby providing a great driving force for the one-man operation of the Oita plate mill as already described.

Application of monitor AGC with proximate gamma-ray gauges as implemented at the Kimitsu and Oita plate mills has helped Nippon Steel to accomplish the industry's highest plate thickness accuracy. The thickness accuracy of steady-state plate portions is approaching the ultimate limit. The thickness accuracy of head and tail ends of plates (unsteady-state plate portions) has been improved by such measures as increases in AGC controller speed. This thickness accuracy is not high enough yet in pursuit of ultimate dimensional accuracy and calls for more technology development.

2.6 Crown and flatness control technology[4)]

Formerly, desired levels of crown and flatness were achieved in plate rolling by adjusting the draft distribution between the final rolling passes. This practice, however, severely limited the capacity of the plate mill itself and at the same time, did not permit plate crown and flatness to be controlled in positive response to changing rolling conditions. For this reason, conventional plate mills were modified to full-fledged shape control mills (pair cross mills and work roll shift mills).

Shape control mills were introduced early for the tandem rolling of strip. Single-stand, large-width, heavy-load plate rolling mills had many quality and equipment problems to be solved, including plate thickness accuracy and plate bending. These problems were aggressively solved to accomplish shape control mills for plate rolling. In parallel with these equipment modifications, a flatness adaptive control system utilizing a flatness meter was built to make the most of the effectiveness of shape control mills. In addition, a high-accuracy crown predictive model that allows for the roll deformation behavior characteristic of plate rolling mills and a two-dimensional thermal crown model that dramatically improves roll profile prediction accuracy were developed, thereby reducing plate crown.

2.7 Plate width and camber control technology[7)]

Plate rolling is characterized by broadsiding (transverse rolling) prior to finish rolling (longitudinal rolling). This broadsiding causes an excessive width deviation convex in the longitudinal direction as is not seen in strip rolling. The width deviation was improved by forming plate head and tail ends with hydraulic screwdowns to overcompensate for this condition. An advanced plan-view shape control technology that combines the overcompensating forming method with transverse and longitudinal edging was developed and applied at the Nagoya and Oita plate mills. In more recent years, the Oita plate mill installed a hydraulic screwdown unit in the edger and applied within-plate automatic width control (AWC), sharply reducing the longitudinal width deviation as shown in **Fig. 8**.

Between-plate width accuracy was improved by improving broadsiding control accuracy with width and length gauges in the final broadsiding pass and by improving edging accuracy in finish rolling passes. The Oita plate mill eliminated the rolling time loss spent in measuring the plate width and length by developing an original technique for measuring the plate width and length on the fly.

Camber control is as important as width control in achieving a plan-view rectangle. Nippon Steel early started work on the development of camber control technology, and applied walk control to detect the load difference between the right and left sides of the mill stand and to correct the plate path and dual-AGC to perform wedge control by considering the mill stiffness of the right and left sides of the mill stand. In more recent years, attempts have been made to apply next-generation camber control by making the most of sensors based on these techniques. The Oita plate mill has accomplished low-camber rolling for a plate length of 63 m, the longest in the industry.

2.8 Special shape rolling control technology

Major plate consuming industries are saving labor and processing steps in a series of manufacturing processes, including fab-

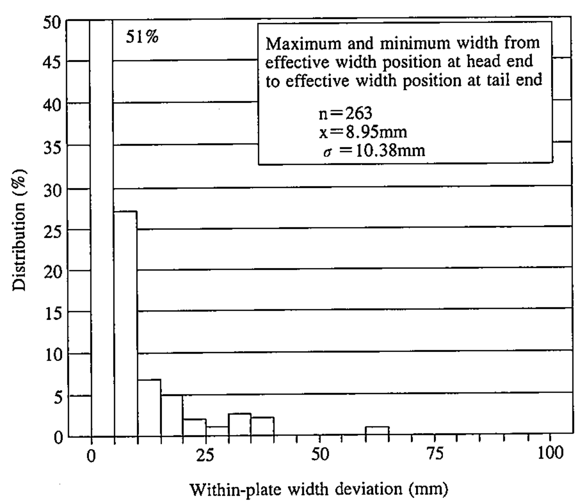


Fig. 8 Effect of AWC in reducing width deviation in longitudinal direction

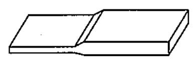
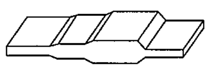
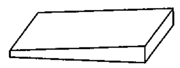
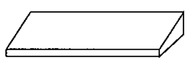
Shape	Name
	Differential-thickness plate
	Multiple-step differential-thickness plate
	LP plate (longitudinal taper plate)
	Transverse taper plate
	Differential-thickness corrugated plate

Fig. 9 Irregular-section plates

rication, assembly, and welding. The irregular-section plates shown in **Fig. 9** have attracted new attention as plates to meet these market needs. The manufacture of these irregular-section plates calls for sophisticated computer control technology in addition to plate thickness and flatness control technology required for flat plate rolling. Nippon Steel has developed three-dimensional (thickness, width, and length) setup computation and adaptive control systems, and has built a fully automatic system for producing irregular-section plates with high stability and efficiency.

3. Recent Progress of Plate Product Technology

3.1 Ships[8-10)]

The quality of shipbuilding steels has an extremely large impact on the quality, efficiency, and cost of ships built from those steels. Nippon Steel established a system to supply wide and long plates to the shipbuilding industry and support shipbuilders in international ship price competitiveness through the realization of "a highly efficient large-block construction method".

Various shipbuilding requirements, such as reduction in welding man-hours, shortening of welding lines, elimination of cutting steps, stabilization of fabricated part quality, and reduction in control costs, have been met by developing TMCP high-strength steels that require no preheating for welding, irregular-section plates and plates with close dimensional tolerances, and by increasing the stringency of preshipment plate quality control.

Nippon Steel also supported the construction of high-value added ships by development and commercialization of new shipbuilding steels, including high-heat input low-temperature steel for liquefied petroleum gas (LPG) carriers and heavy-gauge high-strength steel for container ships.

Recent years have seen increasing calls for response to environmental and safety issues and for reduction in ship maintenance cost in view of the social effects of VLCC stranding accidents, bulk carrier breaking and sinking accidents, and ship collision accidents. To meet the demand for response to these emergency safety problems, Nippon Steel developed HIAREST steel (High crack-arrestability endowed steel) and started its application to actual ships. The characteristics of HIAREST steel are discussed in detail in this issue of the Nippon Steel Technical Report.

3.2 Offshore structures[11-13)]

In recent years, the development bases of offshore energy resources have been going deeper and colder such as in the northern part of the North Sea and in the Arctic Ocean. Offshore structures installed in such deep and cold seas are larger in size and exposed to more severe environmental conditions, so that their need for fracture safety is emphasized more strongly than ever. The construction cost of offshore structures is being reduced by application of economical design in pursuit of higher economies and by simplification of construction steps.

In these respects, heavy-gauge and high-strength steels are demanded that have sufficient fracture toughness at low temperatures and are easy to weld. Nippon Steel has carried out research and development work to clarify metallurgical factors that govern the crack tip opening displacement (CTOD) that is applied as a fracture evaluation method to offshore structures, has established a system for manufacturing CTOD-guaranteed steels for offshore structures, and has supplied such steels for use in many offshore structure construction projects.

3.3 Buildings[14-16)]

Japan's buildings have appreciably changed, as represented by increases in height and span to make good use of aboveground space in large cities, adoption of large atriums, and pursuit of pleasing appearance. Building planning increasingly calls for steels that are heavy in gauge, high in strength and excellent in earthquake resistance and weldability, and that support architectural design. Economics call for reduction in the construction cost of buildings.

To meet these needs, Nippon Steel applied TMCP steels for the first time in the building field and supplied heavy-gauge and highly weldable steels, contributing to the increasing height and span of buildings. The Great Hanshin Earthquake intensified the requirements for earthquake resistance and spurred the installation of seismic dampers in buildings. Nippon Steel developed ultralow-yield point steels for such dampers.

To meet the demand for lower construction cost, Nippon Steel developed fire-resistant steels whose strength at a high temperature of 600°C is guaranteed to be not less than two-thirds of the room-temperature design strength. The fire-resistant steels with excellent high-temperature fire resistance have been used in many buildings, lessening or eliminating their need for fire-resistant coating or covering.

Buildings are expected to increase further in height in the near future with the possibility of super high-rise buildings. The development and commercialization of 780-N/mm^2 steels for buildings are already completed. When JIS G 3136 was established to specify rolled steels (designated SN) for building structures to ensure the safety of building structures, Nippon Steel conducted structural analysis and fracture experiment by using its own research facilities. The company is now engaged in the development of new building structural steels in pursuit of higher safety.

3.4 Bridges[17-19)]

In recent years, Japan's bridge builders have aggressively tackled technology improvement for the purpose of cutting bridge construction costs and have intensified their moves to adopt new structural types. Rational design is a key point for steel bridges, and "a smaller number of main girders" and "member section" are key words. High-performance steels, such as steel with lower preheat temperature and high-strength steel, are required to accomplish these targets. The Specifications for Highway Bridges, revised in December 1996, has doubled the applicable plate thickness from 50 to 100 mm against the above background. SM570Q steel plates, exceeding 50 mm in thickness, are used in bridges constructed with a smaller number of main girders in recent years. Welding procedure requirements are also increasingly severe, as noted with respect to lower preheat temperature performance suited for site welding and welding with a higher heat input. Steel bridges in coastal regions increasingly demand steels with a minimum of maintenance work.

An overview of Nippon Steel's response to these requirements is given below. With TMCP applied to I-beam flanges, 490-N/mm^2 and 570-N/mm^2 steels found increasing usage, and their weldability was notably improved by lowering the preheat temperature. Adoption of steel with excellent high-heat input weldability in webs permitted the application of the electrogas welding process and greatly rationalized bridge construction. Since the use of high-strength steels like the 780-N/mm^2 class was essential for long bridges. Cu-precipitation hardening 780-N/mm^2 high strength steel with low weld crack sensitivity were developed. These new steels were adopted in the construction of the Akashi Kaikyo Bridge.

The minimum-maintenance requirement was met with weathering steels with and without coatings. Recently, a new weathering steel (3% Ni steel) for coast use uncoated against airborne salt particles has been under development for commercial application.

3.5 Other main applications[20-22]

1) Penstocks

High-strength steels with a strength level of up to 780 N/mm^2 can be used to fabricate penstocks in the current design condition. In this case, however, the plate thickness becomes very large. In terms of cost, high-strength steels of the 950-N/mm^2 class are being studied for introduction. Nippon Steel has already developed a high-strength steel of the 950-N/mm^2 class, featuring weldability and workability practically equivalent to those of the 780-N/mm^2 high-strength steel. The new steel is expected to find increasing use in penstocks.

2) Chemical industry

In recent years, against the background of global environmental problems and fuel diversification measures, many LNG-fired and LPG-fired thermal power plants are being constructed, mainly in large cities, in addition to conventional thermal power plants burning oil and coal. The stacks of thermal power plants are generally lined to protect their shell. Many of these linings must be maintained to take care of their deterioration prolong service. This maintenance calls for a considerable amount of money and time, and sometimes necessitates a plant shutdown incurring great loss.

Natural gas-fueled thermal power plants present a relatively mild environment for stack steel because natural gas is free from sulfur. In cooperation with Mitsubishi Heavy Industries, Nippon Steel developed and commercialized a corrosion-resistant plate steel (trademarked WELACC5) with superior economy for use in the stacks of natural gas-fired power plants. The alloy design of the new steel is discussed in detail in another article in this issue of the NSTR.

3) Tanks

The number of tanks constructed in Japan decreased after the end of Japan's national oil stockpile program, but demand for tanks is expected to remain brisk in preparation against a future energy crisis and in consideration of global environmental protection and increasing changeover to clean sources of energy like LNG. A recent increase in the size of LNG tanks has created demand for steels of heavier gauge and higher toughness. To meet the demand, Nippon Steel developed a heavy-gauge 9% Ni steel, tested the new steel jointly with LNG tank owners and fabricators, and succeeded in increasing its thickness from 30 to 50 mm. The company has started activity to win a contract for the supply of the heavy-gauge 9% Ni steel for the Senpoku No. 18 LNG tank (volume of 180,000 kL) of Osaka Gas Co., Ltd..

In the LPG tank area, a 1.5Ni TMCP steel with high weld brittle crack safety was developed and is already being supplied to an Australian WOP project and other LPG tank projects.

In the oil tank field, hot-dip galvanized steel for roof plates and zinc-sprayed steel for bottom plates were developed for the purpose of maintenance cost reduction and are now under evaluation by customers.

4. Future Outlook

The steel plate property requirements imposed by customers have increased in severity and diversity, particularly in the past few years. Nippon Steel has whole-heartedly met these requirements and has won the high evaluation of customers in Japan and abroad. In recent years, however, South Korean and other foreign plate mills have expanded production capacities and intensified international competition. It is self-evident that Nippon Steel will be unable to maintain its technical advantages for many years to come. In addition to stronger cost competitiveness, technology development adapted to new values like global environmental protection and integrated product technology development embracing plate production to plate fabrication and utilization by customers are expected to assume increasing importance.

Current brisk demand for plates is mainly due to the construction of new VLCCs to take the place of older ones and will not last long. Product technology development, aimed at creating new demand areas like floating structures and steel bridges, is one of the future challenges.

Given the above situation, Nippon Steel will develop equipment and operating technology to produce steel plates of high quality with high efficiency, will develop plate production technology to accomplish energy conservation and elimination of process steps in response to global environmental protection, and will promote integrated plate product development in cooperation with customers, thereby expanding demand for plates and meeting plate quality requirements from customers.

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