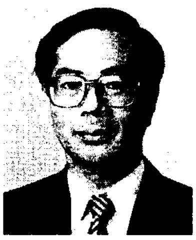
# Progress in Technological Developments During the Past 50 Years at Kawasaki Steel and Future Prospects*


Fumio Sudo
Member of the Board and Executive Vice President



Tetsuya Fujii
Dr. Eng.,
Director of Technical Res. Labs., Member of the Board and Senior Executive Officer



### *Synopsis:*

*Starting with brief historical description of construction and expansions of both major Chiba and Mizushima Works, this article introduces the transition of technological developments in Kawasaki Steel and a number of developed world's leading technologies, including diagnosing and controlling system for a blast furnace, mass production process of ultra-low carbon steel (IF steel), plane view pattern control system in plate rolling, endless hot strip rolling, multipurpose continuous annealing and various types of size-free rolling. A variety of new products which have been developed based on new metallurgical principles, are also introduced. The new products include heavy gauge plates, heavy wall H shapes, large diameter bars, all having high strength with high toughness, ultra-fine grain ERW pipes, extra deep drawing cold rolled high strength steel sheets, cold rolled steel sheets with ultra-high Lankford value (r-value), and high performance coated steel sheets. Here further touched upon are steel plant engineering, steel structure construction engineering and new businesses of waste treatment and ultra-fine nickel powder production.*


## 1 Introduction

Kawasaki Steel which was established in 1950, opened the road for Japan's remarkable growth into one of the world's leading iron and steel producing nations following the Second World War. In 2000, the company celebrated its 50th anniversary. In publishing this 50th Anniversary Commemorative Issue of Kawasaki Steel Technical Report, the authors have reviewed the progress achieved by Kawasaki Steel in iron and steel manufacturing during the last half century from the viewpoint of technological development.

From the establishment until the present day, the management of Kawasaki Steel has consistently assigned high priority to technology maintaining the company's traditional position as a pioneer in the Japanese steel industry. During this period, the company has also contributed greatly to the development of steel consuming industries by responding promptly to the needs of society and the marketplace. Outstanding technology is the most essential requirement for providing a stable supply of products which offer the highest levels of quality, performance, and service and thereby ensure customer satisfaction. From this starting point, Kawasaki Steel has boldly and actively undertaken the development of its own technologies, while continuing to improve technologies introduced from the United States and Europe, thus playing an important role as a leader in the steel industry.

Kawasaki Steel began to create an organization for technical development from the long-term perspective, with the establishment of the Technical Research Laboratories in 1957. The following year, the company inaugurated technical service teams consisting of engineers from the Technical Research Laboratories, steel works, and Technical Department for the purpose of developing new products and improving quality in close cooperation with customers. Tie-ups with customers were a major driving force for promoting technical development in the years that followed. In 1969, facilities of the Technical

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Research Laboratories were completed at a location adjoining the company's Chiba Works, making it possible to strengthen technical development further. Kawasaki Steel then proceeded to develop numerous processes which introduced new concepts in advance of the world's other steel makers, and new products which applied new metallurgical principles.

This paper will first describe the brief history of the establishment of Kawasaki Steel, and present an outline of the construction and expansion of the company's two main steel works, Chiba Works and Mizushima Works, and the processes which led to the establishment of mass production technologies, centering on the introduction of large scale blast furnaces and the LD converters. Progress in technological development will then be described, citing typical examples of process and product development during the divided two periods, from early 1970s to the early 1980s, and from the second half of the 1980s to the present. The following sections will also touch on the development of new businesses which apply the fundamental technologies of iron and steel production and discuss the prospects for future technical development.

The authors hope that this report will be useful to our readers. In addition to this historical overview, readers are also invited to see the other reports in this issue for recent trends in technical development in individual fields.

## 2 Establishment of Kawasaki Steel and Construction and Expansion of Two Main Steel Works

### 2.1 Establishment of Kawasaki Steel[1)]

The history of Kawasaki Steel begins in 1906, when the company which was then known as Kawasaki Dockyards Co. constructed Hyogo Works in Kobe as part of its Steelmaking Division in order to ensure self-sufficiency in steel castings for shipbuilding and railway cars. Construction of Fukiai Works began in 1917 with the aim of producing steel materials for shipbuilding, and in the following year, the plant began manufacturing plates. The company's high strength steel plates were the first to be used in bridges in Japan and were praised for their dimensional accuracy.

In 1924, Fukiai Works started up a pull-over mill, entering the steel sheet market, and at the same time, also began to produce galvanized steel sheets. It also drew international attention for successfully test-rolling ultra-thin sheet USG32 (thickness: 0.258 mm), which was difficult to roll at the time. In 1931, Fukiai Works began producing hot rolled silicon steel sheets, responding to increasing demand in the electrical machinery industry, and constructed a 3-high cold rolling mill to enter the market for high grade finished steel sheets for automobiles, railway rolling stock, and high grade furniture. The subsequent construction of a 4-high cold rolling mill, together with efforts to increase production of the well regarded high grade finished sheets and improve dimensional accuracy, were rewarded with excellent results.

In 1938, Kawasaki Dockyards Co. constructed Nishinomiya Works, which was a special steel bar plant located in Hyogo Pref., and Kuji Works, which produced iron pellets, in Iwate Pref. In the same year, Kawasaki Dockyards Co. changed its name to Kawasaki Heavy Industries, Ltd. In 1943, the company began construction of Chita Works, which manufactured special steels, in Aichi Pref.

The production facilities which made up Kawasaki Steel when the company was organized after the Second World War were Fukiai, Hyogo, Nishinomiya, Kuji, and Chita Works. The present-day company was established in August 1950 when the steel manufacturing division of Kawasaki Heavy Industries, Ltd. was separated from that company under a reorganization plan based on the Industrial Reconstruction Act, and Yataro Nishiyama assumed office as the first President. The new company then began to build the first modern coastal integrated steel works in Japan in Chiba, fronting on Tokyo Bay, based on President Nishiyama's long-held concept of "constructing the world's most advanced continuous steel strip rolling mill with priority placed on export products, thereby making an important contribution to Japan's economic independence."

### 2.2 Construction of Chiba Works

Chiba Works was Japan's first integrated steel works of the postwar era, and was opened in February 1951. The construction was carried out based on the four principles of simplification, concentration, continuation, and integration, together with the fundamental concepts of realizing large scale, high speed, and high degree of automation. In 1953, No. 1 blast furnace (BF) was blown in. No. 1 hot strip mill and No. 1 cold strip mill were completed in succession in 1958, establishing a complete integrated iron and steel works centered on the production of steel strip. Subsequently, a series of plant expansions were carried out, but the construction of main equipment slowed somewhat following the blowing-in of No. 5 BF in 1965.

Around 20 years after the start of construction, Chiba Works was beginning to fall behind other, more recently constructed plants in various aspects, including cost and productivity, and there were also limits to environmental preservation. For these reasons, No. 6 BF, No. 3 steelmaking shop, and No. 3 slabbing mill were constructed on a newly reclaimed site called the West Plant in 1977, aiming at modernization and rationalization, together with improvement of the environment.

### 2.3 Construction of Mizushima Works

In 1960, the Cabinet led by Prime Minister Ikeda announced a plan to double the national income of Japan. Because it would have been nearly impossible to respond to the increase in long term demand for steel which accompanied this high growth policy by expanding Chiba Works alone, Kawasaki Steel began construction of Mizushima Works in July 1961. The fundamental concept was to construct one of the world's largest steel works, bringing together the best of innovative technologies on a new site. In constructing the new works, the experience gained at Chiba Works was used wherever possible, and large scale, high efficiency equipment was introduced based on the principles of integration, large scale, automatization, continuation, and high speed. In particular, the computer system was planned from the first for the purposes of efficient operation of advanced equipment and production control.

In 1967, an integrated steel works with an annual crude steel production of 2 million ton was realized at Mizushima Works, beginning with the blowing-in of No. 1 BF and start-up of the converter shop and No. 1 plate mill. The equipment was steadily expanded thereafter, and an annual crude steel capacity of 12 million ton was achieved with the blowing-in of No. 4 BF and the startup of No. 6 converter in 1973.

### 2.4 Development of Mass Production Technologies

The upsizing newly built blast furnaces in Japan advanced rapidly from around 1965 onward, but declined somewhat after reaching a peak in the first half of the 1970s. Tracing the history of BFs at Kawasaki Steel, Chiba Works No. 1 BF, which was blown-in in 1953, had an inner volume of only 877 $m^3$. In contrast, No. 5 BF, which was blown-in in 1965, was a large scale BF with an inner volume of 2 142 $m^3$, and also included a variety of new technologies such as high pressure operation, oil injection, and high hot-blast temperature. Mizushima Works No. 4 BF (1973) had an inner volume of 4 323 $m^3$, ranking a close second behind the world's largest BF of the time (4 326 $m^3$). Ultra-high pressure operation and steam cooled staves were adopted, movable armor and other new technologies for stable BF operation were introduced, and the tapping operation was mechanized.

In the field of converters, Kawasaki Steel started up Japan's largest LD converter of the time, with a capacity of 150 t/charge, at Chiba Works in 1962. In 1970, all the company's open hearth furnaces were replaced by converters, and a large scale 250 t/charge converter was introduced at Mizushima Works. The company also began applying computer control systems to its converters around 1970. In the field of the continuous casting machine (CCM), a bloom CCM with an annual capacity of 600 000 t was started up at Mizushima Works in 1968, followed by slab CCMs at both Chiba and Mizushima Works in 1971. In 1973, Mizushima Works introduced a slab CCM with an annual capacity of 1.5 million ton and a combined bloom and beam blank CCM with an annual capacity of 960 000 t. The changeover from the ingot casting process to the continuous casting (CC) process was a major technical revolution on the same order of impact as the adoption of the large scale BF and the introduction of the LD converter.

## 3 Development of High Efficiency Technologies and Realization of High Quality in Products (First Half of 1970s to First Half of 1980s)

### 3.1 Impact of Oil Crises on the Japanese Steel Industry

The two Oil Crises of the 1970s marked the end of the period of rapid quantitative growth that Japan had enjoyed up to the time, and the Japanese economy enter a long period of stable low growth. This resulted in a large drop in steel demand, and the steel industry as a whole was forced to make numerous rationalization efforts to overcome the ensuing recession. These included strengthening of management fundamentals, structural improvements, and adjustments in hiring, among others.

The priorities for technical development also changed greatly, from technologies for large scale operation and mass production, which had characterized the high growth era, to technical development for realizing higher levels of quality and saving energy, resources, and labor. For example, with the BF, long campaign life was promoted and efforts were made to maintain stable operation at low operation level. In the steelmaking division, technologies for producing high purity steel were developed in response to higher quality requirements for products and the diversification of user needs. The main stream in converter technology shifted to the top and bottom blown converter, and the adoption of continuous casting expanded rapidly. Great progress was made in technical development in the rolling division, including the adoption of direct linkage, synchronized operation, continuous processing and high speed operation in various processes, improvement of yield, and other advances.

High quality requirements for products were characterized by ultra-low S and ultra-low P in steel materials for severer service environments, such as cryogenic steel and steels for sour service, and by an increasing need for high purity steels with reduced contents of C, N, O, P, S, and other impurity elements in steel sheets for automobiles and household appliances, where formability is an important requirement. In particular, ultra-low C, ultra-low N became essential requirements in many applications of sheet products. Applying higher purity steels, remarkable progress was also achieved in the thermo-mechanical control process, which is a technology for on-line control of material properties.

### 3.2 Development of High Efficiency Technologies

In the ironmaking division, Chiba Works No. 6 BF (inner volume: 4 500 $m^3$), which was blown-in in 1977, was the first large scale blast furnace in Japan to be equipped with the PW type parallel 2-hopper bell-less top. In the same year, Kawasaki Steel developed a computer-aided diagnosis and control system (GO-STOP system) for a BF, contributing greatly to stable operation of its BF. As a result of the sharp increase in the price of heavy oil following the 2nd Oil Crisis, Kawasaki Steel also made a major change in blast furnace operation, converting from heavy oil injection operation to all-coke operation, with importance given to the energy balance. The company led the industry in this changeover. In 1984, Kawasaki Steel developed a pulverized coal injection (PCI) technology and successively practiced it to all BFs.

In the steelmaking division, in 1977, when the top blown LD converter was at the peak of its popularity, Kawasaki Steel started operation of the pure oxygen bottom blown converter (Q-BOP) first introduced in Japan, based on a confident belief in the metallurgical principle that "bottom blowing is good" and a top management judgment that "the bottom blown converter is the way of the future." The Q-BOP proved that refining characteristics are remarkably improved by the strong stirring effect of bottom blowing. Following this finding, many steel companies began active development of the top-and-bottom blown converter, which rapidly gained popularity and represented a revolution in converter technology. Kawasaki Steel lost no time in developing and applying top-and-bottom blown converters (K-BOP, LD-KGC). In the second half of the 1970s, the company also adopted fully automatic blowing at all converters.

In response to requests for the development of cold rolled steel sheets with excellent deep drawability from various industries, and particularly in the automotive industry, Kawasaki Steel led the industry in developing extra-deep drawing cold rolled steel sheets and high strength cold rolled steel sheets using Nb-bearing extra-low carbon IF (interstitial atom free) steel. Considering the excellent product quality characteristics of IF steel, and with the switchover from box annealing to the continuous annealing process for cold rolled steel sheets, mass production of IF steel became necessary. Kawasaki Steel realized this by developing a mass production refining technology for Nb-bearing IF steel ($C \leqq 20$ ppm) in advance of the industry, using a combination of refining to the low carbon region by the Q-BOP and vacuum decarburization in the RH degasser, and began full-scale industrial production at Chiba Works No. 3 steelmaking shop in 1981.

In continuous casting, No. 2 CCM at Mizushima Works achieved a world's record for sequential casting at 129 heats in 1974. In the second half of the 1970s. Kawasaki Steel greatly improved the productivity of its continuous casting operations by developing sequential casting of different grades and automatic slab width changing during casting and applying these technologies in standard production, and by developing a system for predicting and preventing sticking type breakout in the CC earlier than other companies. The grades to which continuous casting could be applied also expanded rapidly, and the company's CC ratio increased dramatically from approximately 18% in 1973 to around 95% in 1985. Kawasaki Steel was among the world's first companies to make a complete switchover to continuous casting.

In the field of stainless steelmaking, Kawasaki Steel developed the strongly stirred vacuum oxygen decarburization process (SS-VOD) at Nishinomiya Works in 1976, and established a mass production process for ultra-low C + N ferritic stainless steels. As a feature of this technology, a large quantity of Ar is bottom-blown in the degassing vessel. This technology led to the development of new steel grades and made it possible to satisfy the higher quality requirements of customers. Together with the technology transfer to the LD-KGC, the SS-VOD bottom blowing technology was also incorporated in the state-of-the-art No. 4 steelmaking shop, which was constructed at Chiba Works in 1994.

As a technology for direct linkage and continuation of processes in the rolling division, the highly computer-controlled vehicle system for hot bloom transportation was developed in the first half of the 1980s and used to directly link Mizushima Works No. 1 CCM and the new billet mill and wide flange beam mill, achieving a direct hot charge rolling (DHCR) ratio of 92.1%, and synchronized operation between the CCM and succeeding rolling mills. In continuous cold rolling processes, in the first half of the 1980s, the skinpass mill, coil preparation line, and packaging line at Chiba Works No. 1 cold rolling plant were incorporated in a continuous process, followed by fully continuous rolling of Chiba Works No. 2 tandem cold mill (TCM), which is an exclusive facility for ultra-thin gauge strip. Chiba Works also succeeded in producing functional stainless steel sheets for the automotive exhaust system by tandem cold rolling, which is normally used as a mass production process for cold-rolling ordinary carbon steel. This technology realized high productivity in the manufacture of stainless steel sheets, which had conventionally been cold-rolled using the Sendzimir mill.

For continuation of the annealing process, Kawasaki Steel independently developed a multipurpose continuous annealing line (KM-CAL) which can easily provide the heat cycles required for products of various grades, and applied this technology in a practical operation at Chiba Works in 1980. The extremely active technological development, through mutual cooperation among researchers and engineers involved in process and product development related to Nb-bearing IF steel at that time, in combination with the development of the KM-

CAL, is still fresh in memory. Together with systematizing new continuous annealing technologies through the construction and operation of this line, the KM-CAL also provided the motive force for subsequent technical innovations. A large capacity, high temperature annealing KM-CAL which makes practical use of new metallurgical principles, based on IF steel, was started up at Mizushima Works in 1984. These lines were followed by more compact, large capacity, high efficiency KM-CALs at Chiba and Mizushima Works.

In the field of dimension and shape control technology, important results were achieved in yield improvement by plane view pattern control in plate rolling. Mizushima Works No. 2 plate mill, which was started up in 1976, combined the technologies which had been accumulated at Chiba and Mizushima Works No. 1 plate mill, and was the first plate mill in Japan to make practical use of a total system in which operation and information processing were fully computerized over the entire process from the slab yard to the warehouse. On the basis of the introduction of a high accuracy automatic control system as the center of the total system, a technology for manufacturing plates with a rectangular plane view pattern, called the new Mizushima automatic plane view pattern control system (MAS rolling method), was developed for the first time in the world, and provided the trigger for rapid progress in plane view control technology. After the MAS rolling method was adopted as a standard operating technology in 1978, Mizushima Works achieved a world's record for total product yield of plate at 93.8% (1978). Profile and flatness control technologies were also established for hot rolled strip.

As an on-line technology for controlling the material properties of plates, the multipurpose accelerated cooling system (MACS), in which controlled cooling equipment and direct quench equipment are incorporated in the mill line, was developed in the first half of the 1980s and applied in practical operation at Mizushima Works No. 2 plate mill, establishing the thermo-mechanical control process (TMCP), which combines controlled rolling and the MACS. TMCP rapidly became the main plate manufacturing process because it not only has the energy saving effect of eliminating reheating, but when used in combination with an appropriate alloy design, also makes it possible to control the microstructure of the steel after transformation, thus achieving high strength with no loss of toughness and weldability. In the field of hot strip rolling, a TMCP technology similar to that used with plate was established by introducing controlled cooling on the run-out table. For seamless pipe, a direct quenching device was developed and applied on-line in 1982.

As a size-free rolling technology for H-shapes, in the second half of the 1970s, a technology for producing multiple sizes H-shapes from a single size of beam blank was developed and commercialized at the Mizushima Works large section shape mill. In 1980, a technology for rolling large section H-shapes from continuously cast slabs in one heat was developed. These technologies made it possible to manufacture virtually all sizes of H-shapes from continuously cast material. In 1981, caliber-less rolling for square bars and round bars was developed and applied at the Mizushima Works billet mill.

In the field of seamless pipe, Kawasaki Steel developed the world's first numerical control rolling method, which automatically controls the entire process by computer. This technology was adopted in standard operation at medium diameter seamless pipe mill and small diameter seamless pipe mill at the company's Chita Works.

The transition in crude steel production and progress in the development of process technologies in Kawasaki Steel (typical examples) are shown in **Fig. 1**.

### 3.3 Trend Toward High Quality Products

The Oil Crises resulted in greatly increased development activity of oil wells in extremely cold arctic regions and the North Sea, highly corrosive gas wells and deeper wells, which had been left undeveloped up to the time. The increased activity heightened the need for steel materials which could withstand such severer environments. With line pipes for oil transportation, the direction was toward large diameter and high strength steels from the viewpoint of reducing transportation costs. Kawasaki Steel responded to these needs by developing corrosion resistant high strength pipes for oil country tubular goods, high strength and high toughness steel plates, and other new products. Steel plates with excellent low temperature properties were also developed for use in offshore structures in arctic seas. For shipbuilding, high strength plates which enable high efficiency welding were developed in response to the need to reduce construction costs and reduce ship weight for lower fuel costs. TMCP played an important role to the development of all these new plate products.

For automotive applications, the development of high strength steels was required as a measure for improving auto safety in the early 1970s, and as a weight reduction measure for improving fuel economy after the first Oil Crise. In the field of hot rolled steel sheets, precipitation hardened steel sheets were the first type to be developed. Thereafter, however, as-hot rolled dual phase (DP) high strength steel sheets, which have a dual phase structure of ferrite and martensite and possess good formability, were developed by applying controlled cooling on the hot run-out table. These DP steels offer improved economy in high strength hot rolled steel sheets. Similarly, in the field of cold rolled steel sheets, Kawasaki Steel first developed solid solution hardened and precipitation hardened high strength steel sheets for reinforcement parts using the box annealing method. In response to further progress in the adoption of high strength mater-

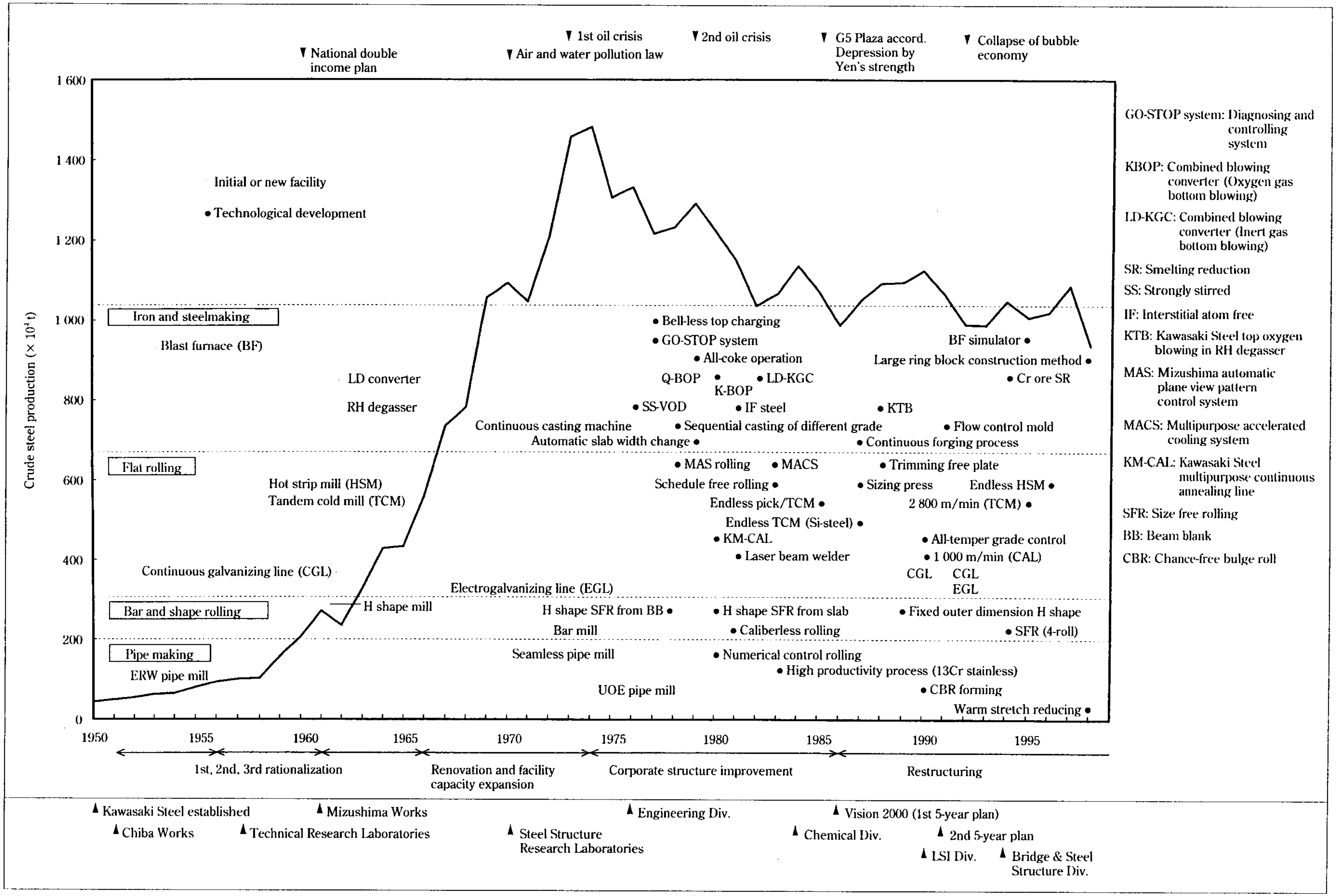


Fig. 1 Transition of crude steel production (fiscal year) and technological developments in Kawasaki Steel

ial in inner and outer panels for automobiles, the company developed extra-deep drawing high strength cold rolled steel sheets using a P-added IF steel, and extra-deep drawing cold rolled steel sheets with high bake hardenability (BH) using Nb-bearing IF steel, taking full advantage of the KM-CAL. These materials are widely used in automobile outer panels. DP high strength cold rolled steel sheets were also developed applying a heat cycle with rapid cooling, which is possible with the KM-CAL.

The adoption of anti-rust coated steel sheets in auto bodies began in the second half of the 1970s as a solution to the auto body corrosion caused by the rock salt used to prevent roads from freezing in winter. Subsequently, new anti-rust coated sheets were developed to meet increasingly strict corrosion-resistance codes, beginning with one-side galvanized steel sheets, which were originally required, followed by alloy electroplated, double layered alloy electroplated, and organic composite coated steel sheets in response to the needs of the times. Extra-deep drawing high strength hot-dip galvanized steel sheets were developed as a response to the trend, which has continued up to the present, to substitute high strength cold rolled steel sheets for high strength coated steel sheets in order to reduce auto body weight and improve corrosion resistance.

In the field of coated steel sheets for household appliances and office equipment, Kawasaki Steel has responded to customer needs for higher grade and higher performance products by developing self-lubricant steel sheets, fingerprint resistant steel sheets, which make it possible to omit oiling and degreasing, and fingerprint removal work in customers' press forming processes, blackened steel sheets, and other products. As steel sheets for can manufacturing, a lightly tin-coated steel (RIVERWELT) was developed for use in welded cans and has contributed greatly to the shift from solderd cans to welded cans. In the field of electrical machinery, various types of high performance grain oriented and non-oriented electrical steel sheets were developed in response to the need for low iron loss and low noise in transformers, motors, and other equipment.

### 3.4 Development of Environmental and Energy Saving Technologies

Kawasaki Steel is deeply committed to preservation of the environment and has made doubly sure of the effectiveness of its environmental protection measures. As a countermeasure for preventing air pollution by sulfur oxides, the company constructed the steel industry's first and the world's largest desulfurization facilities for coke oven gas and sinter plant exhaust gas. For nitrogen oxides, the company conducted a large amount of research and development, which included the installation of an experimental large scale denitrogenization facility, and in 1976, constructed the world's first practical plant of this type at Chiba Works No. 4 sinter plant. Other efforts include conversion from liquid fuels to gas fuels, the adoption of low $NO_X$ burners, and the development of low $NO_X$ operation technologies for the hot stove and the sintering furnace. Thoroughgoing countermeasures have also been implemented for waste water treatment, noise prevention, dust collection, and water pollution prevention.

The company has also been a leader in energy saving technologies, beginning with the introduction of the free world's first top gas pressure recovery turbine (TRT) at Mizushima Works No. 2 BF in 1974, and also including the installation of coke dry quenching units, facilities for recovering the sensible heat of exhaust air from the sinter cooler, air preheaters for the hot stove, and others. Significant reductions in fuel unit consumption at reheating furnaces have also been achieved by adopting DHCR for continuously cast slabs.

### 3.5 Development of Overseas Engineering Business by Applying Basic Iron and Steel Technologies

As part of a strategy of diversification, the Engineering Division was organized in 1976 in order to strengthen and expand the engineering sector, and an overseas engineering business was developed based on the company's accumulated steel manufacturing technologies, including steel works equipment, operation, and system technologies, and port and harbor civil engineering/steel structure construction technologies which the company had developed in the construction of its coastal steel works.

Development in the steel plant sector began with the construction of the Philippine Sinter Corp. (PSC), which started operation in 1977 followed by the construction of a full-scale integrated steel works at Companhia Siderurgica de Tubarao (CST) in Brazil, which was carried out on a full turn key basis, with construction beginning in 1978. The experience gained in these projects established a firm foundation for expanding the company's overseas engineering business. In the fields of rolling and coating, the company steadily gained a foothold in overseas engineering through the construction of a series of electrolytic tinning lines (ETL) and galvanizing lines in Thailand, Malaysia, and elsewhere, and supplied a KM-CAL to a client in the former West Germany.

The starting point in the civil engineering and construction sector was the construction of the PSC plant and a large 250 000 DWT ore sea berth at PSC using long, large section steel pipe piles. This sea berth has become a symbolic civil engineering structure in Southeast Asia. The results achieved at PSC were also linked to a number of subsequent projects, including a coal unloading facility in Taiwan, port and harbor facilities in the Philippines, in which the interlocked steel pipe pile wall and double sheet pile wall methods were adopted, and a port and harbor expansion project in Malaysia, in which a large quantity of KPP (Kawasaki plastic coated pipe) piles were used. The development of an overseas business involving steel structure construction technology began with the supply of steel frames. Starting with an electric furnace steelmaking shop and CC plant in Iran in 1976, deliveries of various types of steel frames had reached a cumulative total of 250 000 t by 1985.

## 4 Efforts to Maintain Competitiveness and Development of High Quality, High Performance Products (Second Half of 1980s to Present)

### 4.1 Appreciation of the Yen and Rationalization

Following the Plaza Agreement by the G5 nations in 1985, the Japanese economy was confronted with a rapid appreciation of the yen, and the steel industry was obliged to adopt drastic rationalization plans for the middle and long term. The main features of these plans included the consolidation of production facilities, manpower saving, and curtailment of labor costs. To rationalize its steel manufacturing operations, Kawasaki Steel shifted crude steel production to Mizushima Works, shut down the plate mill and No. 2 steelmaking shop at Chiba Works, carried out a major overall modernization at Chiba Works, and concentrated the production of stainless steel sheets and electrical steel at Chiba Works and Mizushima Works, respectively.

In the modernization project at Chiba Works, the main production processes were concentrated from the East Plant to the West Plant, and No. 4 steelmaking shop was put into operation in 1994, followed by No. 3 hot strip mill in 1995. The steelmaking shop was designed to produce especially stainless steel and high carbon steel, which consists of state-of-the-art No. 4 CCM, converters, and VOD. Chiba Works now specializes in the production of high quality flat products with state-of-the-art facilities for steelmaking and hot rolling, in addition to No. 6 BF, which was relined in 1998. The completion of this modernization transformed Chiba Works into a medium scale urban-type steel works and ensures that Chiba Works will have the world's best cost competitiveness well into the future.

The concentration of electrical steel production at Mizushima Works was completed in 1995. Mizushima Works is now the company's main steel works, producing a wide range of high value added products, including electrical steel, and also playing the role of a material supply base for Chita Works and Chiba Works. The site has become a totally integrated steel works with the world's highest levels of cost competitiveness, quality, service, and technology.

### 4.2 Pursuit of Higher Efficiency

The period from 1985 to the present has been characterized by progress in technical development aimed at achieving higher equipment efficiency in all processes in order to strengthen cost competitiveness. With the BF, technical development was carried out in order to realize flexible stable operation in response to economical fluctuation, and extend campaign life of BF while continuing to use lower-grade burden materials. In the steelmaking division, technologies were developed not only to meet the requirements of higher quality, but also to improve productivity. Technical development in the rolling division was oriented not only toward continuous and high speed operation, as it had been up to the time, but also saw great progress in size free rolling techniques, corresponding to a shift toward small-lot, multikind production. Furthermore, new material property control technologies which can be utilized in the development of new products, such as lubricated ferrite rolling in fully continuous hot strip rolling (endless hot strip rolling), and warm stretch reducing of ERW pipe.

In the ironmaking division, a new BF operation control system (advanced GO-STOP system) using artificial intelligence was developed in the second half of the 1980s, and a BF operation simulator which is capable of predicting the influence of burden distribution, raw material quality, and other factors on blast furnace operation was developed and put into practical use. In the relining of Mizushima Works No. 3 BF, Japan's first three parallel bunker bell-less top was introduced, realizing advanced burden distribution control.

In the relining of Chiba Works No. 6 BF, the large ring block construction method was adopted. This method, which was developed independently by Kawasaki Steel, made it possible to complete the relining in a short time of only 62 days. In this revamping, the inner volume of No. 6 BF was increased to 5 153 $m^3$, making it the second largest BF in Japan. Although No. 6 BF had set a world's record for long campaign life, at 20 years and 9 months after blow-in in June 1977, this record was today superceded by Mizushima Works No. 2 BF. It is fair to say that these records are proof of the excellence of this company's BF technologies.

In steelmaking, the Kawasaki Steel top oxygen blowing (KTB) method for use in the RH degasser was developed in the second half on the 1980s, improving the efficiency of IF steel production, and mass production of IF steel was made possible by adopting a large diameter snorkel and lower vessel. For the continuous casting machine, a second generation electromagnetic flow control mold (FC mold) was developed to prevent surface defects originating in the continuous casting of IF steel, and high quality, high productivity casting of IF steel at speeds of more than 2.5 m/min was achieved. An in-line continuous forging process was developed for use during the continuous casting of blooms, and a continuous forging machine was installed at No. 3 continuous bloom caster at Mizushima Works in 1990. This solved the problem of internal quality originating in center segregation and established a system for manufacturing

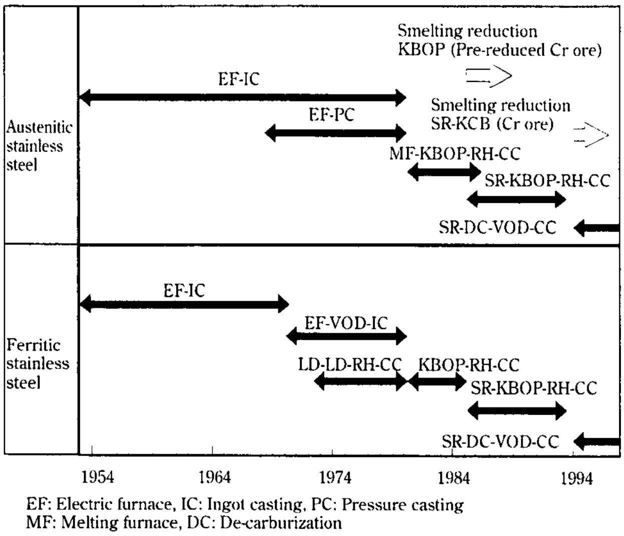


Fig. 2 Trend of stainless steel making process in Kawasaki Steel

intermediate materials for high grade bars and wire rods. In stainless steelmaking, Kawasaki Steel developed the world's first stainless steelmaking method using smelting reduction of Cr ore directly in the converter, realizing a mass production process for stainless steel with highly flexible raw material choice at Chiba Works No. 4 steelmaking shop. **Figure 2** shows the trend in stainless steel making processes at Kawasaki Steel.[2)]

In the rolling division, Kawasaki Steel developed the world's first sizing press which enables heavy reduction of the slab width and installed this equipment at the Mizushima Works hot strip mill. Combined with the previously developed schedule free hot strip rolling technology, this has made a large contribution to synchronized and continuous operation between steelmaking and hot strip rolling. However, the most significant achievement in process continuation and high speed operation was the revolutionary endless hot strip rolling method, which is carried out by fully continuous finishing rolling, and was realized for the first time in the world at Chiba Works No. 3 hot strip mill in 1996. **Figure 3** shows an outline of the endless hot strip rolling process. Endless hot strip rolling was completed by bringing together the hot strip rolling technologies which had been developed at Chiba and Mizushima Works and developing various innovative technologies such as sheet bar welder, high speed shear, etc. The new process enables lubricated ferrite rolling and heavy reduction rolling, and has made it possible to produce a series of new high performance products which had been impossible to roll by conventional mills. Examples include thin gauge wide hot rolled steel sheets, DP high strength steel sheets with excellent total elongation, ultra-high Lankford value ($r$-value: index of drawability) cold rolled steel sheets, which is manufactured using endless hot rolled material. Thus, the endless hot rolling process is continuing to open up new markets.

In the continuation of cold rolling processes, fully continuous operation of the picking line and No. 1 TCM was achieved at Mizushima Works in 1985. This, in combination with the KM-CAL, realized a two-process operation at the cold rolling plant. A fully continuous rolling of high silicon steel, which had conventionally been rolled using the Sendzimir mill, was realized for the first time in the world at Mizushima Works No. 2 TCM. In 1988, fully continuous operation was achieved at Chiba Works No. 3 TCM, which is used for high grade steel sheet production. In realizing its fully continuous operation, a large laser beam welder was developed and successfully applied to continuous rolling of stainless steel sheets and high carbon steel sheets. A high speed pickling method which performs pickling treatment in-line at a continuous annealing line (CAL) for plain carbon steel was also developed, making it possible to anneal stainless steel sheets with a CAL for carbon steel. Productivity was substantially improved by applying these continuous rolling and annealing processes to stainless steel. In the area of high speed cold rolling, an ultra high speed of 2 800 m/min, which is the world's highest level, was realized at Chiba Works No. 2 TCM by developing a new direct rolling oil, Ti-enhanced work rolls with high wear resistance.

In response to the increased use of high performance corrosion resistant steel sheets in recent years, Kawasaki Steel constructed new state-of-the-art facilities at the Mizushima Works continuous galvanizing line (CGL) in 1989 and No. 2 electrogalvanizing line (EGL) in 1991, and at Chiba Works No. 2 CGL in 1991. The technical development for high quality and high efficiency processes significantly advanced accompanying the full-scale operation of these lines.

Among on-line material property control technologies, Kawasaki Steel continued to develop TMCP and discovered the new metallurgical principle of TPCP

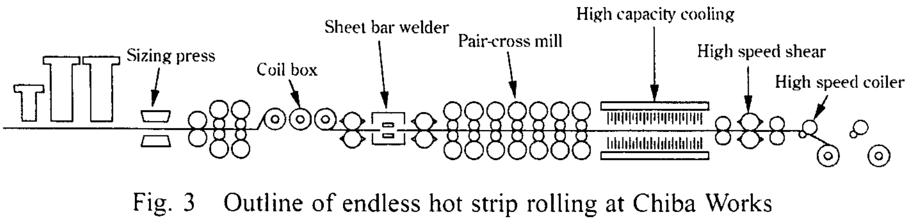


Fig. 3 Outline of endless hot strip rolling at Chiba Works

(thermo-mechanical precipitation control process), which uses bainitic transformation and precipitation hardening in ultra low C steel to control strength. Application of TPCP made it possible to achieve as-hot rolled high strength in heavy gauge plates, heavy section shapes, and large diameter bars. Chiba Works No. 4 CAL, which integrated the continuous annealing furnace, the multipurpose cold rolling mill and the coil preparation line, started its operation in 1990, and realized to manufacture all grades of tin mill black plate on one line by combining proper base materials including IF steel, and cold rolling reduction ratio after annealing. At the same No. 4 CAL, the world's highest speed continuous annealing process was attained by developing advanced tension control system and buckling prevention technique. The line has a maximum speed of 1 000 m/min with ultra-thin gauge sheets as thin as 0.15 mm.

As a technology for achieving high accuracy in the dimensions and shape of plate products, a manufacturing process for trimming free plate, was developed in the second half of the 1980s by optimizing the MAS rolling method and edging rolling method, responding to the need for highly accurate plate dimensions. For cold rolled steel sheets, the one-side tapered work roll shifting method, which was developed by Kawasaki Steel, was applied to Mizushima Works No. 2 TCM, and an edge drop control system was developed for hard-to-roll thin-and-hard steel strip products.

In the field of size free rolling of H-shapes, the world's first rolling process for manufacturing fixed outer dimension H-shapes (Super HISLEND-H) was developed and commercialized in 1989. The world's first size free rolling technology for high dimensional accuracy steel bars and wire rods was also established applying newly developed 4-roll mill. The 4-roll mill was first incorporated in the bar mill line in 1994, and thereafter, in the wire rod mill line at Mizushima Works. In 1978, a maximum outer diameter 26 inch $\phi$ ERW pipe mill (full-cage roll forming method) with the world's largest mill specification was introduced at Chita Works. Further development of this cage-roll forming method was carried out, and the chance-free bulge roll forming process (CBR forming) was developed. This method was introduced in the small diameter ERW pipe mill at Chita Works in 1990, enabling stable production of high quality ERW stainless steel pipe.

The warm stretch reducing method, which makes it possible to secure an ultra-fine grain structure in ERW pipe, was developed in 1998. Because ultra-fine grained ERW steel pipe (HISTORY steel pipe) with high strength and high elongation has already won a high evaluation from auto makers, a production line started up in the autumn of 2000. For stainless steel seamless pipe, a high productivity manufacturing technology using the Mannesmann method was established by developing a production technology for defect free billets and a technology for preventing rolling defects. In 1986, Kawasaki Steel succeeded for the first time in the world in realizing industrial production of austenitic stainless steel pipe, including Mo added SUS316, and dual phase stainless steel pipe. By establishing a mass production technology for these products, the company secured a world share of approximately 40% in the market for 13Cr stainless steel pipe, which is a major product.

In the field of transportation equipment and technology for materials and steel products, productivity in on-site material handling was improved by adopting large scale transportation vehicles and switching over to a trackless carrier and pallet system, and by adopting an operator guidance system in the warehouse and computer-integrated management and control system for products inside the works. For steel transportation outside the works, the company has constructed all-weather berth network, established a computer-integrated planning and administration system for coastwise transportation, and developed a unit transportation system for H-shapes and sheet piles from the finishing process to the delivery center. At Mizushima Works, new equipment for loading coils on ships was developed, and automatic coil transportation was realized from the packing line in the cold rolling plant to shipping.

### 4.3 Development of High Quality, High Performance Products

Although quantitative growth can no longer be expected in either domestic or foreign demand, there is a continuing trend toward greater diversification in customer needs, small-lot, multi-kind production of products, higher added value, and higher performance. In product development during this period, Kawasaki Steel has continued to develop high strength steels, even though this material has not shown quantitative growth, and has also expanded the applications of TPCP. New needs include rising demand for products which enable customers to eliminate processing process and achieve higher efficiency from the viewpoint of cost reduction, and products which place little load on the environment.

In the field of energy development, in order to improve the transportation efficiency of petroleum and natural gas pipe lines, heavy gauge, high strength steel plates were developed, responding to the requirements of larger diameter, greater wall thickness, and higher strength. Heavy wall large diameter ERW pipe with improved toughness of the welded seam was also developed. This pipe was the first ERW pipe in the world to be used in the North Sea as a sea bottom line pipe. Together with growing demand for LNG as a form of clean energy from the viewpoint of global environmental problems, there is also a trend toward larger capacities in transportation and storage tanks from the viewpoint of economy. Heavy section 9% Ni steel plate, which has excellent strength and toughness at low temperature and is therefore suitable for such applications, was developed as a commercial product.

In building construction, the trend is toward very tall buildings, larger structures, and longer spans. High strength, ultra-heavy gauge, large section steels are required for use in these structures. In response to these needs, Kawasaki Steel developed heavy wall H-shapes with improved weldability, and also developed large section, heavy wall H-shapes for use in the columns of ultra-high rise buildings by applying TPCP. Super HISLEND-H, which offers both improved executability and improved economy, became a hit product. The ultra-low yield strength steel, which damps vibration structures caused by earthquake, and fire resistant steel were also developed. For building applications, highly atmospheric corrosion resistant ferritic stainless steel sheets with a high purity of $(C+N) \leqq 100$ ppm were developed. This product was adopted in the roof of the terminal building (total area of 90 000 $m^2$) at the Kansai International Airport, which is located offshore.

For bridges, steel plates which help to reduce the life cycle cost, including the cost of construction and maintenance, are required. Low preheat type high strength steel plates with excellent weldability had been developed in response to this need, and were expanded for a large scale application in the Akashi Kaikyo Bridge, which is the world's longest suspension bridge. Extremely-low carbon bainitic type heavy gauge high strength plates developed by using TPCP, are weldable without preheating, which have also been applied to bridges. The same bainitic type anti-corrosion steel plates for coastal use, which Kawasaki Steel also developed, can be used without painting even in seaside areas. Longitudinally profiled steel plates for bridges and ships were developed to enable cost savings by reducing weights and welded joints.

Responding to the need for further weight reduction in automobiles, in the field of hot rolled steel sheets, Kawasaki Steel developed high strength steel sheets with high fatigue strength and an excellent balance of tensile strength and elongation by applying a new microstructure control technology. This product was applied to high strength and light weight wheels for the first time in the world and received an excellent evaluation. As new coated products, the company developed thin organic composite coated BH steel sheets and galvannealed high strength steel sheets. HISTORY steel tubes and high strength cold rolled steel sheets with excellent formability were developed in response to the requirement of high rigidity in automobile members in order to reduce body weight and improve crashworthiness. Alloyed steel powders, which meet the need for higher strength in sintered parts for automobiles have also been developed and commercialized.

Automobile manufacturers and other customers have a high need for products which make it possible to simplify or omit processes in them. High strength, high

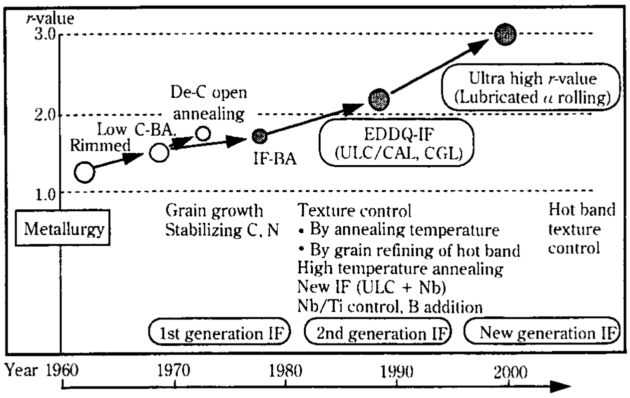


Fig. 4 History of development of deep drawing cold-rolled steel sheet

toughness as-hot rolled bars which make it possible to eliminate the heat treatment process in customers were developed by applying TPCP. A revolutionary new product, ultra-high $r$-value cold rolled steel sheets (world's highest $r$-value of 3) were developed, which are applied to integrated parts that can simplify the press forming process. These steel sheets could be realized for the first time by using the texture controlled hot rolled coils produced by the new endless hot rolling (lubricated ferrite rolling). At present, this product is being mass produced and shipped to auto and home appliance manufacturers. **Figure 4** shows the history of improvement in the $r$-value of cold rolled steel sheets for deep drawing at Kawasaki Steel.[3] From this, it can be understood how the company has improved the deep drawability of cold rolled steel sheets in the course of material development.

In coated steel sheets for automotive applications, thin organic composite coated steel sheets were developed in the second half of the 1980s and are now widely used. Double layered galvannealed sheets were also developed. Precoated galvannealed steel sheets which do not contain Pb were recently developed as a response to global environmental problems and have been adopted in automotive fuel tanks. Various types of high oxidation resistant, high corrosion resistant stainless steel sheets for use in automotive exhaust systems were developed in response to recent strengthening of regulations applied to automotive exhaust gas and the trend toward higher engine performance. The company's ferritic stainless steel foil for catalytic converters used to purify automobile exhaust gas have also been widely adopted in Japan and other countries.

Domain-controlled grain oriented electrical steel sheets with excellent magnetic properties and non-oriented electrical steel sheets suitable for high efficiency motor cores were developed to satisfy the need for reduced size, higher reliability, and other requirements of electrical equipment. Iron powders for use as noise suppresser materials in electrical and electronic equipment were developed and commercialized. From environmental point of view, Cr-free precoated steel sheets with good electrical conductivity were developed for household appliances and office equipment. This product has been adopted in pressed parts for copying machines as part of the customer's green procurement program.

### 4.4 Development of Environmental Technologies

From the viewpoint of achieving zero emissions from the steel works, Kawasaki Steel is promoting the recycling and effective use of slag and the recovery of resources from dust. The company developed a new smelting reduction process (STAR process) which consists of a coke packed-bed shaft furnace with two-stage tuyeres, for recycling stainless steelmaking dust containing useful metals oxides such as Cr, Ni. The recovered metal can be reused without treatment as a raw material for stainless steel. The gas generated in this process is used as fuel, and the slag is used as a road bed material. By combining the STAR process and Zn recovery technology, an energy-creating type advanced dust treating process (Z-STAR process) was also developed. Using this process, it is possible to produce energy efficiently, from combustible substances which had been difficult to treat up to the present and metallic dusts (electric furnace dust and shredder dust) which contain Zn and Pb, and to recover metals from dusts. The STAR process was put into operation at Chiba Works in 1994, and the Z-STAR was started up at Mizushima Works in March 2000. Both facilities are contributing to the recovery of valuable resources.

### 4.5 Development of New Businesses by Applying of Basic Iron and Steel Technologies

Engineering projects in the field of ironmaking include the construction of a sinter plant in India and, as an individual technology, the supply of PCI to steel works in China, Turkey, and Canada. In steelmaking, the company is steadily accumulating a record of sales of the LD-KGC and KTB technologies, which are highly effective when introduced in existing shops. In the early 1990s, the company constructed Taiwan's first H-shape plant including an electric arc furnace, three-strand beam/bloom caster, and H-shape rolling mill. More recently, the company was responsible for total engineering and plant construction at a steelmaking shop in China and constructed an electric arc furnace/steel bar plant in the Philippines. Pretreatment facilities for pig iron were supplied to steel works in Taiwan, China, and Korea. As a large scale project in the field of rolling and coating, Kawasaki Steel received an order for a complete cold rolling plant for tin mill black plate with an annual production capacity of 600 000 t in Taiwan and completed this job in only 2 and 1/2 years. The company has also accumulated a growing record of sales of KM-CAL and CGL plants overseas. Moreover, the company first constructed a tinplate line outside of Japan in 1973, and started up its 9th overseas tinplate line in 1996 for a client in China.

In the field of construction and steel structure technologies, Kawasaki Steel has commercialized various column materials, including the steel built-up box column, cold roll formed rectangular column, heavy gauge H-shapes, circular steel pipes with attached diaphragm for CFT, and others. Heavy gauge H-shape columns have been adopted in a large number of very tall buildings, including the Rinku Gate Tower Building, which is a development project related to the Kansai International Airport. For an anti-seismic steel frame structures, brace dampers and hysteretic damper panels using low yield stress steel were developed. Among other technologies, Kawasaki Steel possesses a unique long span structural system (Super Wing) and a roof construction technique employing three-dimensional roof trusses, and has systematized design and execution techniques for large scale roofs. The company also markets urban-type building systems as products which apply steel frame structures, and has developed a new architectural system called K-FLAT for medium and high rise prefabricated apartment buildings.

As bridge and road structures, Kawasaki Steel has commercialized composite slab bridges and roadway composite bridge columns using deformed H-shapes (CT shape steel), which have a high composite effect in combination with concrete. The walled steel pipe pile well method, which was originally developed and used as a construction technique for blast furnace foundations, has also been applied in a large number of bridge foundations. Semi-prefabricated zinc-coated steel wire strands for prestressed concrete (PAC-H type stay cable system), which were developed for use in cable-stayed bridges, were adopted in the Shin-Onomichi Bridge, which is one of the large suspension bridges in the Onomichi-Imabari route of the Honshu-Shikoku bridge spanning Seto Inland Sea. The company has also developed products and construction methods for various special applications and service environments, such as the negative friction countermeasure pile, which is a foundation pile technology for soft ground, heavy corrosion resistance KPP piles, and the low noise and low vibration piling method using steel pipes. As a technology for port and harbor structures, the underwater junction method, which is one of Kawasaki Steel's unique technologies, has been used in the construction of piers, mooring dolphins, and other structures. As revetment structures, the company undertook the development of the double sheet pile wall structure, sheet pile cell structure, and similar methods which are used in revetments, partition structures for underwater construction work, etc. In the field of pipe lines, the company had engaged in the design and execution of a large diameter sea bottom pipe line in the Singapore water pipe line project and the construction of a natural gas pipe line across the mountainous backbone of Japan between Niigata on the Sea of Japan and Sendai on the Pacific Ocean.

Kawasaki Steel entered the field of environmental engineering as part of an effort to utilize the environmental protection technologies which the company had cultivated in the course of developing and introducing new technologies aiming at zero emissions from the steel works, as mentioned previously. Beginning with public sewerage facilities and other water treatment facilities, with which it has a large record of sales in Japan and overseas, the company expanded its environmental business to include the stoker type and fluidized bed type incinerator, the plasma arc melting system for incinerator ash compaction, and facilities for producing refuse derived fuel (RDF). In particular, Kawasaki Steel, as a leader in RDF in Japan, is contributing not only to RDF technology but also to system building, and holds the top share of projects in Japan with a record of 13 plants of date. The company has also constructed an RDF carbonization plant on the site at Mizushima Works and is putting effort into the further development of RDF utilization techniques.

## 5 Future Trends in Technological Development

### 5.1 Further Innovation in Existing Technologies

Looking back on the course of technical development at Kawasaki Steel up to the present, it can be pointed out that, whether in process development or in product development, fundamental principles, such as metallurgical and physical principles, played more important roles as the higher the level of development becomes. There are also examples of equipment which had not been developed even though its merits were understood in principle, but which was realized through changing concepts and making a conceptual leap. In the future, this kind of principle-based viewpoint is likely to become increasingly important in promoting technical innovation in all fields.

It seems that there are a large number of technologies which were not commercialized in the past in spite of having excellent principles, and technologies which were left unrealized even though they were proved good in the laboratory-scale studies. As an old proverb goes, we could discover new ideas by studying the past. In this context, it would be important to examine our predecessor's excellent ideas (which often involve basic principles), on the basis of the level of technology at present and in future, and to extend them in the future technological innovation. Moreover, it is also considered that innovative processes can be realized by pursuing the potential of apparently matured technologies from the viewpoint of basic principles. Breakthroughs which go beyond the existing state of affairs, through "possibility thinking" based on principles, are important.

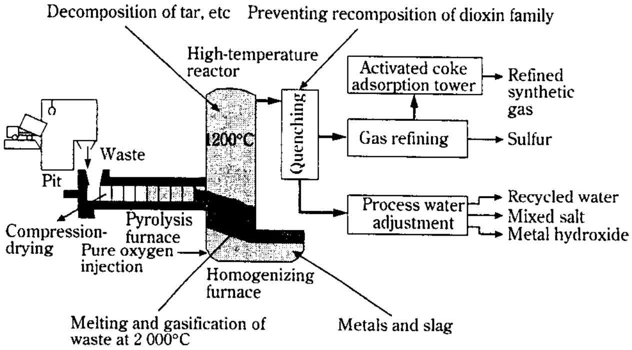


Fig. 5 Outline of Kawasaki Steel Thermoselect System

### 5.2 Application of Accumulated Technologies to New Businesses

#### 5.2.1 Waste treatment using Kawasaki Steel Thermoselect System

A next generation waste treatment plant called the Kawasaki Steel Thermoselect gasification melting furnace, with a daily capacity of 300 t, was constructed at Chiba Works and put into operation in September 1999. **Figure 5** shows an outline of the Kawasaki Steel Thermoselect System. In this process, compressed waste is dried and degassed in a pyrolysis furnace and is then charged into a high temperature reactor. Pure oxygen is blown from the bottom of the high temperature reactor, and the descending waste is melted and gasified at a high temperature of approximately 2 000°C. Ash is converted into slag, and metals are recovered.

The gas is kept in a high temperature condition at 1 200°C at the top of the high temperature reactor, and dioxins, tars, and other high molecular compounds are reformed into substances such as carbon monoxide and hydrogen. The gas at 1 200°C is then rapidly cooled by spraying a large quantity of water, preventing the recomposition of dioxins. After hazardous substances have been removed, the gas is led to the gas refining process. Basically, this refined gas is utilized as a fuel gas in the steel works, but in the future, use as a fuel gas for generating electric power by a gas engine or use in fuel cells is conceivable. The system is designed to recover all hydrogen chlorides and heavy metals in the form of metal hydroxides, mixed salts, and other recyclable substances, making it possible to achieve zero emissions. Thus, the system meets the requirements of the times by minimizing the environmental load and contributing to a recycling society. In the future, Kawasaki Steel intends to expand its industrial waste treatment business, as well as its Thermoselect plant manufacturing and sales business.

#### 5.2.2 Wholesale power generation

Following the liberalization of wholesale power generation under a recent revision of the Electric Utilities Industry Law, Kawasaki Steel will enter the wholesale power supply business. The Kawatetsu Clean Power Station, which is now under construction at Chiba Works, is scheduled to begin operation in June 2002 with an output of 410 000 kW. Gas turbine combined cycle generating equipment manufactured by Kawasaki Heavy Industries, Ltd.-ABB was adopted in this plan. The equipment has the world's highest level of power generating efficiency (58%), and will use clean city gas as fuel considering the surrounding environment. In this connection, it should be noted that Kawasaki Steel already has considerable experience in power generation. In particular, the company developed a technology for gas turbine power generation using BF off-gas, which it has used for many years in operating power plants at its steel works, and thus has ample accumulated human resources and technologies to support a stable power supply business, including operation control technology and equipment diagnosis technology.

#### 5.2.3 High purity silicon for solar cells

The company plans to begin production of high purity silicon for solar cells at a 100 t per year class plant to be constructed at Mizushima Works. Using metallurgical high purification technology, this plant will refine industrial grade metallic silicon (purity 99.5%) to a purity of more than 99.9999%, which is necessary for use in solar cells. This refining technology was developed jointly with the New Energy and Industrial Technology Development Organization (NEDO). It has been confirmed that solar cells using the high purity silicon obtained by this technology offer the same conversion efficiency as cells using semiconductor grade silicon. Up to the present, silicon for solar cells has been obtained by converting off-grade high purity silicon for semiconductors or scrap from the semiconductor industry, but these sources are limitted and unreliable. Because the new technology will ensure a stable, low cost supply of silicon for solar cells, it is expected to support wider popularization of solar cells.

#### 5.2.4 Ultra-fine nickel powder and other new materials

The commercialization of ultra-fine nickel powder deserves special mention as one result of research and development efforts, centering on magnetic materials, metal powders, and ceramics, which have been carried out since Kawasaki Steel set up the New Material Research Center in 1985. Ultra-fine nickel powder is produced by hydrogen reduction after heating and vaporizing $NiCl_2$ in a chemical reactor vessel. Because it is a powder with good crystallinity, having a spherical particle shape and narrow grain size distribution, its dispersibility, packing property, and sintering property are good, therefore it shows excellent properties as an internal electrode material for multi-layered ceramic capacitors in cellular telephones and personal computers. At present, this material is being produced by Kawatetsu Mining Co., Ltd., a member of the Kawasaki Steel Group, which holds the world's largest share. Other new materials which have been commercialized include Kawasaki mesophase fine carbon (KMFC), which is used as a negative electrode material for lithium ion secondary batteries, and hexagonal boron nitride powder, which is used in cosmetics and solid lubricants.

### 5.3 Future Prospects

Considering the urgent need to preserve the global environment and ensure sustainable development, one important mission of the steel industry in the future will be to provide a stable supply of steel materials which offer the highest possible performance, using high efficiency and environmentally friendly steel manufacturing processes.

For example, the conventional functions of the BF are to produce pig iron and generate fuel gas. However, from the viewpoint of zero emissions, it is conceivable that the blast furnace will be assigned the newly expanded function of utilizing general waste as a resource, as seen in the use of waste plastic as a blast furnace feedstock. Although the existing BF has many outstanding features, remodeling of the blast furnace as a high efficiency system may be necessary. Considering future environmental problems and raw material conditions, the development of a new high productivity ironmaking process which reduces the load on the environment and has no restrictions in the use of raw materials is desirable.

High efficiency has also been achieved in steelmaking technology, but breakthroughs to realizing innovative technologies such as higher speed blowing, higher speed refining, and higher speed casting are required. On the other hand, from the viewpoints of scrap recycling and harmony with the environment, the realization of a steelmaking process with greater flexibility in the selection of raw materials is desired. High purity, high cleanliness steelmaking technologies have made a large contribution to higher quality and higher performance in products up to this time. These will also become more important in relationship to the creation of higher performance materials, centering on ultra-fine microstructure control in the innovative rolling process, which is expected in the future. A cost minimum process must be developed by achieving high efficiency and optimization in these areas.

In the field of rolling, further linkage, continuation, and integration of processes will be promoted. It is desirable to develop a high quality, high productivity chance-free rolling process for small-lot, multi-kind production corresponding to more diverse and higher level customer needs. Resource saving and recycling require a flexible and compact manufacturing process which uses a steel material with the simplest possible composition system, and then builds the required properties into the product by controlling the process conditions in the rolling process.

Japan has begun two national projects aimed at the development of innovative steel materials. These are the "Ultra-Steel" and the "Ferritic Super-Metal." The goal of both projects is to obtain strength and toughness by ultra-refinement of the crystal structure, while absolutely minimizing the use of alloying elements. The results of these projects are expected to provide advance indicators regarding how the results can be realized in existing iron and steel processes and how these processes must be innovated.

The Japanese steel industry achieved the world's highest level of technology on the base of technologies introduced from the United States and Europe, which it improved and developed while also developing its own new technologies. In the future, however, the Japanese steel industry must lead other nations in developing innovative technologies linked to next generation processes and products, and contribute to the world of the 21st century in this way. In developing innovative technologies, there are many challenges which must be faced, including fundamental principles, theory, basic and applied research, and the hardware and software for realizing the targets. To a greater extent than in the past, this will require collective wisdom. Strategic, priority oriented research and development through the organic cooperation of industry, government, and universities are needed.

Research and development will become more and more important for increasing customer satisfaction. Kawasaki Steel is promoting research and development by applying the combined capabilities of its technical staff toward this end. For this reason, higher efficiency in research and development is essential. The company will therefore strongly promote research and development, for which Technical Research Laboratories will be the center.

## 6 Conclusion

Because steel is overwhelmingly superior to other materials in numerous respects, including quantity, price, strength, and recyclability, the possibilities and future potential of steel will continue to expand. The authors believe that realizing a high efficiency steel manufacturing process while making the fullest possible use of the world's vast resources of iron ore, pursuing the maximum possible performance in steel as a material with unlimited potentialities and producing and stably supplying high performance products will make an important contribution, both directly and indirectly, to resource saving, energy saving and reducing the load on the global environment. Moreover, many fundamental iron and steel technologies have potential applications in other areas. For example, the high temperature, high thermal technologies developed for steel manufacturing can be applied to waste treatment and recycling, and energy obtained from low temperature waste heat in the steel works can be supplied to neighboring cities. Expanding and developing these technologies in areas surrounding steel, aiming at coexistence with local society and the general public, is also an important social role for the steel industry.

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