Ironmaking and Steelmaking Technologies as Fundamentals for the Steel Production*


Toshio Uetani
Staff Manager, Technology Administration & Planning Dept.


Nagayasu Bessho
Dr. Eng., Staff General Manager, Technology Administration & Planning Dept.

Synopsis:

Recent R&D activities of ironmaking and steelmaking technologies at Kawasaki Steel are reviewed and the prospect for the 21st century is discussed. In the ironmaking field, efforts to utilize more inexpensive raw materials, such as the application of the high blending ratio of low cost semi-soft coal up to 53% at the coke-making process and ore blend containing high levels of pisolite ore ratio of 40% at the sintering process have contributed to the cost reduction of hot metal. In the blast furnace technology, stable furnace operations at various levels of productivity and fuel rates have been achieved by the advanced burden distribution control. Owing to stable furnace operations and technological development of furnace equipment and maintenance, the service life of a blast furnace has drastically extended and reached more than twenty years. In the steelmaking process for plain steel grades, economical mass production of clean steel, e.g., ultra low carbon steel for automobile use, has been established by the combination of refining steps including hot metal pretreatment, bottom blowing or top-and-bottom blowing converter refining and RH degassing. In the stainless steelmaking process, effective and stable production system of high purity stainless steel has been achieved by the development of a new process flow including the smelting reduction process that directly uses fine chromium ore, the top-and-bottom blowing converter process with high decarburization rate and VOD process. This process is linked with a smelting reduction process for recycling chromium containing dust (STAR process). In the continuous casting process, the introduction of a vertical-bending type continuous caster and the advanced method for molten steel flow control in a casting mold have been making a great contribution not only to high surface and internal quality and improved mechanical properties, but also to the synchronization with hot rolling process.

1 Introduction

Japanese annual crude steel production had been in decline since hitting its peak of 120 million tons in 1973, due to oil crises, a strong yen and other factor. In the past ten years, however the amount of production has stayed at around 100 million tons. Given this situation, the Japanese steel industry at the moment must enhance its technical development ability and production cost competitiveness so that it can meet the higher quality and shorter delivery time required by customer. In addition to the existing environmental protection measures, new important issues have come up, like shortages and recycling of resources.

This report presents examples of the technical development in the iron- and steelmaking that are key elements for the competitiveness of the Japanese steel industry and describes its future prospects.

2 Technical Subjects in Iron- and Steelmaking

Figure 1 shows the transition of annual pig iron and crude steel production of Kawasaki Steel. At Chiba and Mizushima Works, total amount of iron and steel production has been approximately 12 and 10 million tons per annum respectively since 1990.

During such stagnant steel production period, we must (1) improve our cost competitiveness against other domestic and foreign makers and (2) take measures to meet customers strict requirements for demands for higher quality. The steel industry has changed going

* Originally published in *Kawasaki Steel Giho*, **32**(2000)3, 183–190

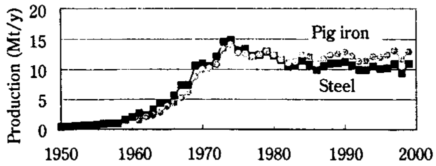

Fig. 1 Trend of pig iron and steel production

from quantitative expansion in the years before 1973 to technology-based, low cost mass production of high quality steel today. In such an environment, production costs and product quality depend highly on iron- and steelmaking fields, which must supply large amounts of products with consistently high quality and high performance to the down stream processes.

The target of the technical development of the ironmaking department of Kawasaki Steel is improvement of facility efficiency and shift to low cost materials under the limiting condition that quantitative expansion is not expected. The major issue of facility efficiency is to increase the service lives of BFs and coke ovens. Regarding low cost materials, technical development of inexpensive raw materials and fuels has been carried out,[1,2] by taking raw material market conditions into consideration.

In the steelmaking field we have carried out technical developments for improving steel product quality, mechanical characteristics and productivity. In the refining technology field, we have been promoting technical developments such as (1) purification of molten steel (reduction of C, P, S, N and O), (2) reduction of consumption of auxiliary material and alloying material, and (3) improvement of metallic yield. In the continuous casting field, we have (1) improved surface and inner quality of slabs cast and (2) increased sequential continuous casting number.

3 Technological Trends in Ironmaking

3.1 Cokemaking

The most important issue of cokemaking is increasing the mix ratio of inexpensive semi-soft coal, which directly reduces production costs. **Figure 2** shows the trend of soft coal ratio within purchased coal. It has been increasing gradually year by year and its estimated value in 1999 was 53% of the total coal mix, and reaching as much as 63% of the total coal when injected pulverized coal is taken into account. We have developed moisture control technology of charging coal[3] by introducing coal moisture control (CMC) equipment for increasing bulk density increment to keep coke strength because the large amount of soft coal in the charge reduces coke strength. Furthermore, to improve coke strength prediction accuracy, we have developed a mathematical model to calculate coke pore structure factor as an intermediate

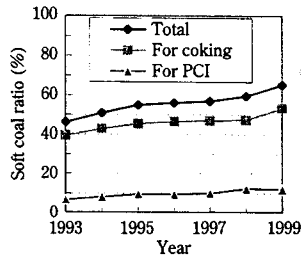

Fig. 2 Soft coal ratio in purchased coal

index from coal mix condition and coke oven operation condition and have utilized it for our actual coal blending design.[4] Recently, we have also developed a new coke strength prediction model that considers interactions among different kinds of coal. This model has helped us to use larger amount of low cost, low quality coal. This model calculates weighted average coke strength assuming many types of charged coal as a synergistic combination of two types of coal of the strength between two coals.[5]

Another important issue of the cokemaking is increasing the life span of coke ovens. The coke ovens in our company have deteriorated, the oldest of which is the 34 years-old No. 5 coke oven at Chiba Works. It is considered that the biggest operational factor to shorten the coke oven life is hard pushing. We have adopted glass coating scarfer of deposited carbon and so on to counteract this phenomenon. As operational software, we have developed mathematical models to estimate clearance between the oven wall and cokes cake and to evaluate the stability of cokes cake during push,[6] and have applied these models to actual coal blend design. As a result of these improvements we have succeeded in eliminating hard pushing at Mizushima Works. As for oven maintenance, we have tried to increase oven lives by developing end mouth gunning equipment, improving gunning material and promoting oven repair by short time relining of end mouth bricks and so on. As for automation, we fully automated the Nos. 6 and 7 coke ovens in 1997[7] and have completely automated operation at the moment. At the No. 5 coke oven of Mizushima Works, we automated the charging car in December 1996.[8]

3.2 Iron Ore Handling and Sintering

We have promoted technical development to reduce material handling costs, increase the amount of inexpensive iron ore in sintering, and recycle unutilized resources, which are the principal tasks of the material handling and sintering departments.

With regard to material handling, introduction of large scale continuous unloader No. 1 (unloading capacity: ore; 3 300 t/h, coal; 2 000 t/h) in 1995 and unloader No. 2 in 1998 at Mizushima Works and have helped to improve unloading capacity and reduce demurrage.[9]

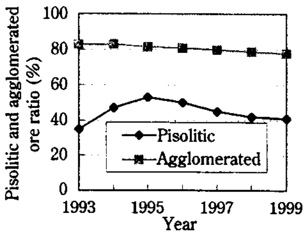

Fig. 3 Pisolitic and agglomerated ore ratio

In the sintering department, we have tackled with increment of mix of inexpensive iron ore, pisolite ore, and have achieved success. **Figure 3** shows the trend in the ratio of pisolite ore ratio (pisolite ore to purchased fine ore). In 1993, Pisolite ore ratio began to increase, exceeding 50% in 1995. However since 1996, it has decreased because priority has been given to reducing the agglomerated ore ratio to reduce production costs, as will be described later.

It is important to improve the physical properties of the fused phase during sintering and to take measures against moisture condensation on the lower layer of the sintering bed when using large amounts of pisolite ore because it is porous and contains a large amount of combined water. According to an analysis of fused phase characteristic by X-ray CT scan experimental sintering equipment, the strength of sintered ore lowered due to stagnation of agglomeration causeds by a reduction of fluidity of fused phase in cases where large amounts of pisolite ore were mixed. The effectiveness of the mill scale in improving characteristics of the fused phase fluidity has been confirmed with the industrial sintering equipment.[10] With regard to the moisture condensation on the lower layer of the sintering bed, increases in the amount of moisture of the material layer increased ventilation resistance, resulting in worse gas permeability. To counteract this phenomenon, we have developed and applied ventilation slits at the lower material layer[11] to improve gas permeability.

In addition, to improve productivity we have developed a magnetic braking feeder[12] and have applied to all of our sintering equipment including one at the PSC (Philippine Sinter Corp.), one of our affiliates. This equipment reduces feeding velocity of magnetic materials (such as mill scale and returned ore) in the sintering material by applying a magnetic field to them during charging. The equipment lowers bulk density by reducing charging velocity and improves gas permeability. Since the mill scale and returned ore are easily fusible, they should improve production yield at the upper layer by their segregation there.

In addition to this, the introduction of a burnt lime production on the sintering machine using so called two step charging method[13] and heat insulation sidewalls has helped to improve production.

As for recycling of resources, improvement of

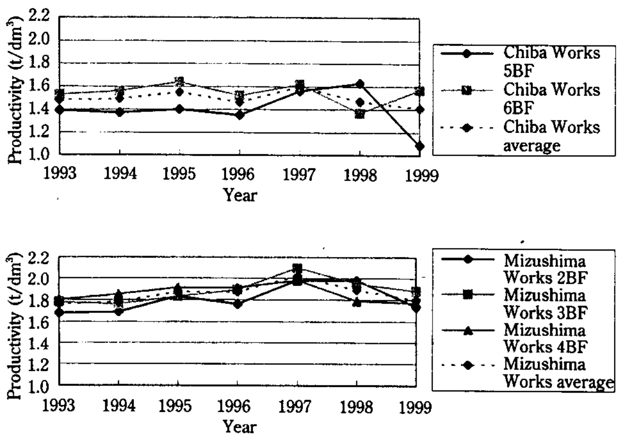

Fig. 4 Trend of productivity

dephosphorization capacity at the hot metal pretreatment equipment has allowed recycling of 100% of basic oxygen furnace slag. Wet dusts and sludge such as BOF wet dust, rolling mill sludge and acid cleaning sludge, which had been difficult to use, are now transported to the sintering plant as slurry to use as sintering material.

3.3 Blast Furnace

The most important issue in the BF department is to pursue production cost reduction based upon stable operation. **Figure 4** shows trends in BF productivity. Due to the shift of production from Chiba to Mizushima Works in October 1996 and increase in steel demand, the highest production was achieved in 1997, but there has been a slight reduction of production since then. Stable operation was secured at the highest production (productivity: 2.1 t/dm^3) in 1997 with lower agglomerated ore ratio compared to the former period of production increment and with conventional coke quality.[14] On the other hand at the No. 5 BF at Chiba Works, production has been reduced since 1998 and in 1999 operation with ultra low productivity lower than 1.0 was carried out. The increase of hot metal Si content, which had been a problem during ultra low production, has been suppressed by lowering theoretical flame temperature in front of the tuyeres. This has enabled stable operation with low agglomerated ore ratio.[15]

Figure 5 shows trends in fuel ratio. When the pulverized coal injection equipment at the No. 2 BF of Mizushima Works started operation in February 1998, all the BFs in our company were equipped with it. To reduce both production costs and operational load of coke ovens, the pulverized coal injection equipment operates at almost full capacity. The reason why the fuel ratio at Chiba Works is 10 to 20 kg/t higher than at Mizushima Works is that it operates the BFs to produce more gas than at Mizushima Works for power generation.[16]

The company has worked to develop new BF charging equipment and to establish burden distribution control

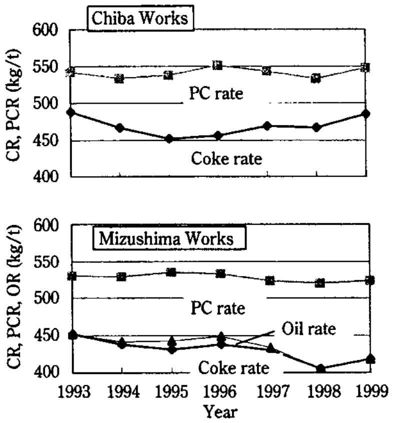

Fig. 5 Trend of coke, PC and oil rates

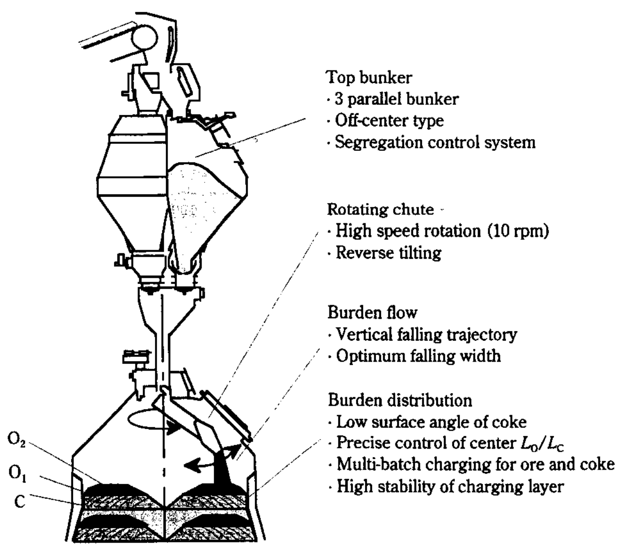

Fig. 6 New top charging system equipped to No. 6 BF at Chiba Works

technology (a key technology for stabilizing BF operation), use large amounts of inexpensive raw material (fine grain material) and achieve higher productivity. To use large amounts of fine grain raw material, it is necessary to carry out multi batch charging by which the BF can charge material of different grain sizes and different quality separately. For this purpose, three parallel bankers (3PB) were installed at the No. 3 BF of Mizushima Works (the third campaign) in June 1990.[17] This equipment has enabled multi batch charge technology to charge up to 17% of small size sinter.[18]

Based upon the experience at this BF, a new charging system was introduced at the No. 6 BF of Chiba Works (the second campaign) in 1998. As shown in **Fig. 6**, this new charging system entails new functions such as a reverse tilt charging, vertical falling trajectory and so on, in addition to the conventional 3PB.[19] Using this system, this BF has helped to reduce production costs by significantly reducing the agglomerated ore ratio (67%, February, 2000). With regard to the life of BF, remarkable progress has been made recently. At the moment, more than 20 years of furnace life can be expected, much longer than the five years, before 1980, as is shown in **Fig. 7**. Chiba Works No. 6 BF (first campaign) achieved a life of 20 years and nine months, the longest in the world at that time, when it was blown down in March 1998. After that, Mizushima Works No. 2 BF (the third campaign) broke the record of Chiba Works No. 6 (the first campaign) in December 1999 and is still in operation. It is said that the factors to decide BF life are damage to stack cooling devices and erosion of hearth bricks.[20] Chiba Works No. 6 BF and Mizushima Works No. 2 BF have attained their long lives through improvements in equipment and technology, especially furnace inside gas flow control, that enable more stable operation.

In earlier times, at least 100 days were required even in the case of short term relining. At the second repairing campaign Chiba Works No. 6 BF, an ultra short term repair in 62 days was achieved, using a large block repairing method. This is a method to demolish the old furnace body in a unit of large block and assemble large, pre-fabricated ring-shaped furnace body blocks using jacks.

3.4 New Refining

In the field of new refining processes, a coke packed bed smelting reduction process with two stage tuyeres (STAR furnace) was brought into production.[21] STAR

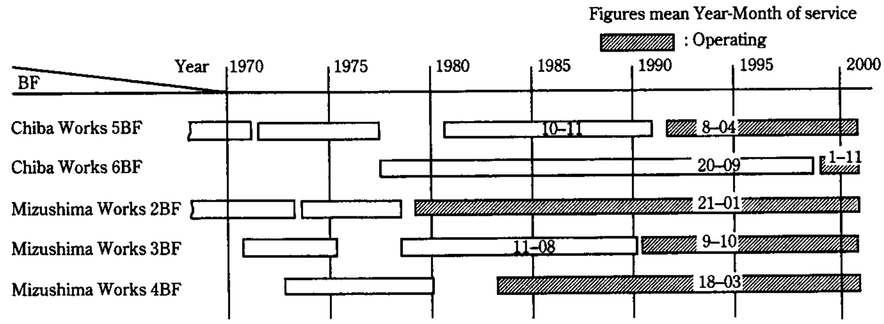

Fig. 7 Transition of the lives of the blast furnaces in operation in Kawasaki Steel (as of April, 2000)

furnace is a plant that directly smelts the stainless refining dust as powder without briquetting and allows the high-yield recovery of metals in the dust such as Cr and Ni. This plant has helped to reduce stainless refining costs because it has enabled the recycling of all of the refining dust.

And an energy generating advanced dust refining furnace (Z-STAR furnace) that recovers zinc and iron from electric arc furnace dust using a similar principle of coke packed bed smelting reduction with two stage tuyeres was developed at Mizushima Works and is being used commercially.[22]

3.5 Future Outlook of Ironmaking Technology

The requirements in the ironmaking field for the future are (1) establishment of stable operation technology for varying conditions such as amount of production and fuel ratio, (2) further production cost reduction using inexpensive raw materials, etc., (3) increase of equipment life, and (4) recycling of resources and technical development to comply with environmental regulations.

The task for the cokemaking is to pursue production cost reduction while taking measures to increase oven lives and for environmental improvement. The base of this cost reduction is clarification of quality criteria, which the user of cokes and BF requires, and construction of coal blending theory to achieve these quality criteria. In addition, with measures taken to lengthen the life of existing coke ovens, it is also necessary to establish a new process to replace the existing coke oven such as SCOPE21.

With regard to raw materials for sintering, it is anticipated that the high-quality Brockman iron ore of Australia will be exhausted and the ratios of high combined water content pisolite ore and powdery Morra Mamba ore will increase. Therefore, tasks for the sintering department are to increase productivity in the face of deteriorating raw material conditions and provide the product quality (such high strength and high reducibility) improvement that the BF need.

In the BF department, there will be greater need for lower coke ratio if the coke oven life span is taken into consideration. In addition, for greater flexibility in production, high BF productivity will be required. To achieve these goals, it will be necessary to improve the level of technology of BF burden distribution and tapping control based upon technology for producing raw materials and fuels with required quality. With regard to lengthening of the BF life, the current lifespan is now more than 20 years, but is should be increased further because the cost for relining and repair is enormous.

4 Trends in Steelmaking Technology

4.1 Hot Metal Pretreatment

Hot metal pretreatment that carries out preliminary dephosphorization and desulfurization, separating dephosphorization function form the BOF refining, was introduced in 1984 at Chiba Works and in 1988 at Mizushima Works for the purpose of reducing steel refining costs and producing steel of consistently high cleanliness (low oxygen steel and high purity steel).[23,24] Hot metal pretreatment ratio, which has increased year by year, has reached 90% at the both Chiba and Mizushima Works. **Figure 8**[24] shows an outline of the hot metal pretreatment process at Mizushima Works. At the runner of the BF cast house, desiliconization equipment to blast iron oxide such as dust has been installed. At the hot metal pretreatment center, which is installed between the BF and BOF plants, dephosphorization and desulfurization of hot metal have been done by applying torpedo cars as reaction vessels. For dephosphorization, burnt lime and iron ore are blown into hot metal and for desulfurization, done after the dephosphorization, a lime-based desulfurizing agent or soda ash is blown into the hot metal. Since various types of bottom-blowing and top and bottom-blowing converters for each steel grade are installed at Kawasaki Steel, we can enjoy the benefits of hot metal pretreatment. These benefits include (1) reduction of consumption of auxiliary materials and alloying elements used in BOF (2) metallic yield improvement in BOF refining (3) reduction of BOF slag volume and (4) improvement of molten metal cleanliness by modifying of ladle slag.

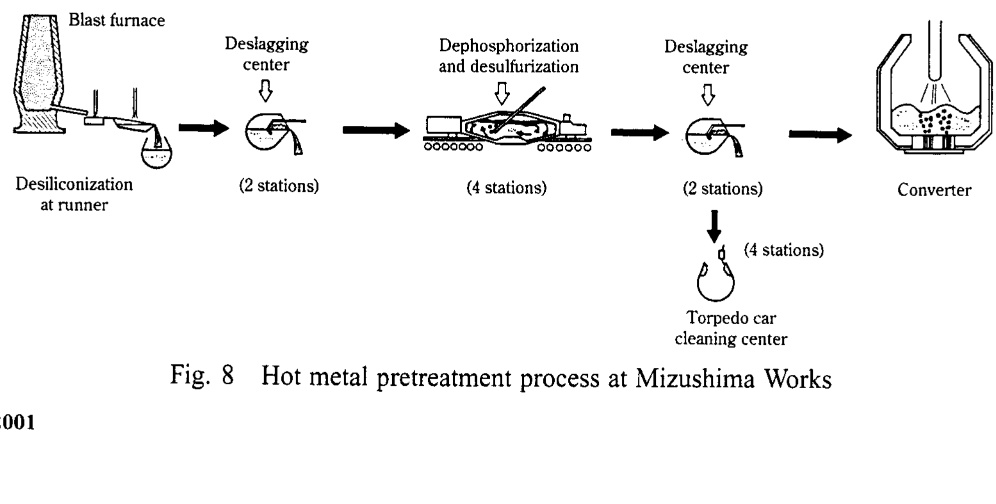

Fig. 8 Hot metal pretreatment process at Mizushima Works

4.2 BOF Refining

Kawasaki Steel introduced a bottom-blowing converter at Chiba Works in 1977 based on its belief that the key technology of refining is "molten metal stirring".[25,26] Around the world, BOF refining technology has since developed remarkably, driven by the technological development in our company. It was anticipated that the bottom-blowing converter would surpass top-blowing converter in the aspect of reactivity. However, at that time, its furnace life was a mere 500 heats. Kawasaki Steel has turned the bottom-blowing converter into a highly productive one by making the furnace life longer with the following technologies.

(1) Development of Automatic Refining Control Method[25–27]

Having installed a sensor lance at the bottom-blowing converter, we have developed dynamic end point control system, SMART (system for measuring and attaining the refining target) to simultaneously hit the carbon content and temperature targets of the molten steel bath at blow end. Simultaneous hitting rate reached 98.8% in February 1979 and the re-blowing rate decreased to a very low level of 1.2%.

(2) Development of a Quick and Direct Tapping Method[25–27]

Developing the SMART further, we established a method of controlling Mn and P contents in molten steel bath at blow end. A method QDT (quick and direct tapping) to tap molten steel directly without measuring temperature and chemical contents after blow end was applied.

(3) Development of Bottom Refractory[25–27]

As for the bottom refractory of the bottom-blowing converter, that with characteristics such as (a) excellent spalling resistance (b) high thermal conductivity and high modulus of elasticity and (c) resistant to slag attack, were required. Through AE (acoustic emission) experiments to measure crack occur in refractory during heating and application tests in a 5 t pilot-scale bottom-blowing converter, MgO-20%C refractory was developed, and it has helped to lengthen furnace bottom life.

Due to the technological development of items (1)–(3) mentioned above, the bottom of the bottom-blowing converter was improved to more than 2 000 heats and we could establish a process with high productivity suitable for mass production. The benefits obtained from conversion to bottom-blowing process are as follows.

(1) Fraction of oxygen reacting with carbon is high and the refining slag will not become over-oxidized. (2) Operation stability is secured because no slopping occurs. (3) Improvement of Fe and Mn yield and reduction of de-oxidizer consumption are feasible. (4) Reactions between slag and metal become more intensive and better dephosphorization and desulfurization are promoted than the top-blowing converter at the same slag conditions. (5) Chemical content and temperature of the molten steel bath are homogeneous and reproducible of chemical reactions in the bath is excellent. (6) Furnace exhaust gas recovery efficiency is remarkably improved by setting a clearance between the furnace mouth and the skirt of exhaust gas hood narrow because of no slopping and spitting.

Such success of bottom-blowing BOF stimulated the propagation of top and bottom-blowing BOFs that added bottom-blowing facility to the conventional top-blowing BOFs. At Chiba and Mizushima Works, besides the bottom-blowing converter, the LD-KGC method that blows small amounts of inert gas from the bottom tuyeres that consist of collective small diameter tubes and K-BOP that blows large amounts of oxygen through coaxial double tuyeres equipped at the bottom have been adopted.[27,28] The latter one (K-BOP) is also used for stainless steel refining.

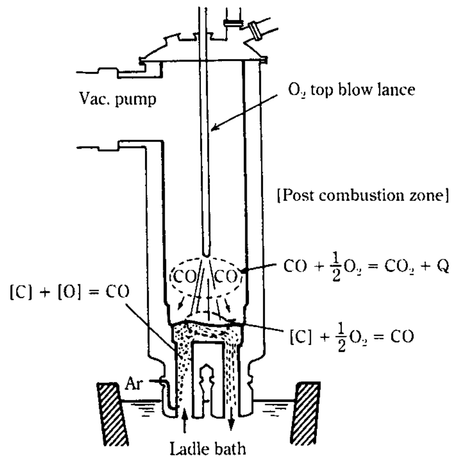

Fig. 9 Schematic illustration of KTB

4.3 Secondary Refining (Ladle Refining)

Requirement to melt large amount of ultra-low carbon ($C < 20$–30 ppm) steel was increased, to produce cold rolled steel sheets with excellent workability for automobile and other uses with continuous annealing process. To meet such needs, development of high-speed decarburization technology in RH (vacuum degassing equipment) was promoted. A process (KTB method[29], **Fig. 9**) to blow oxygen onto the molten steel surface by means of water cooled lance inserted from the top into the vacuum vessel has been implemented at the No. 3 RH at Chiba Works. This process promotes the decarburization reaction and thermal compensation of molten steel in the vacuum chamber with secondary gas combustion, resulting in remarkable lower temperature and higher carbon content at BOF tapping. These effects have brought benefits such as increased iron yield and BOF refractory life. We have analyzed and clarified the effects[30] of the shape of vaccum vessels such as snorkel diameter, molten metal surface area in the vacuum

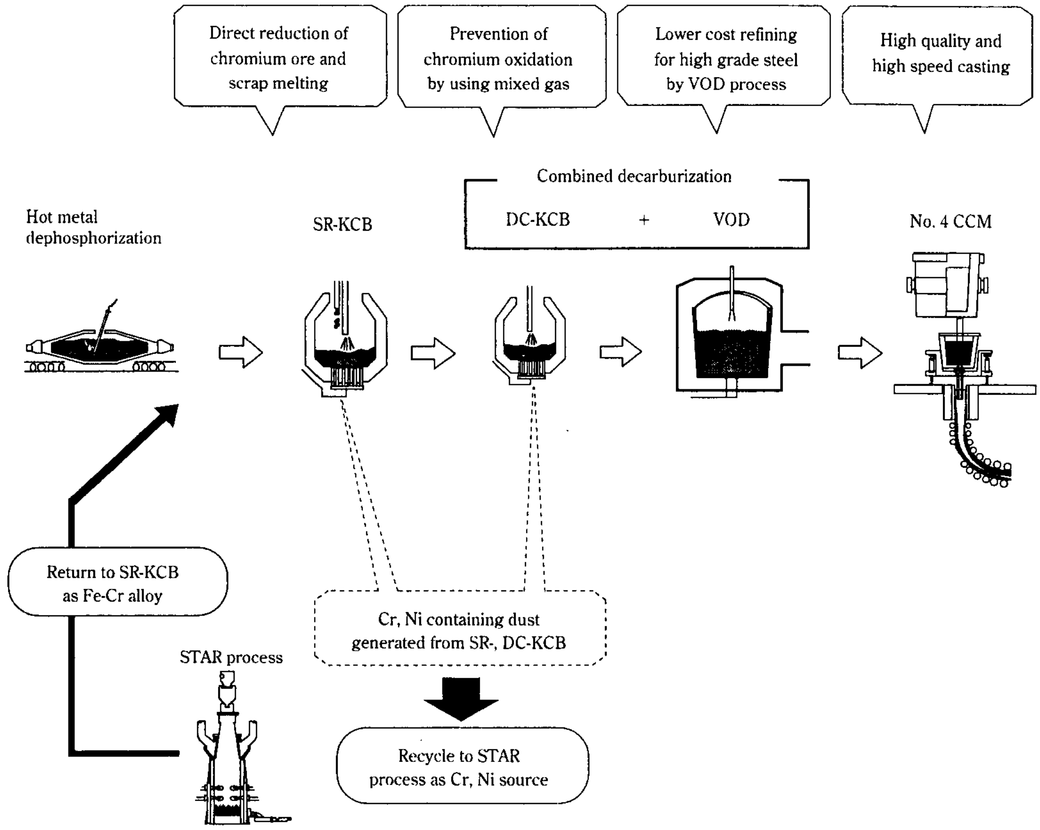

Fig. 10 Outline of stainless steelmaking process

chamber and ladle capacity on the decarburization rate. Based on the results of this analysis, RH degassers at Chiba and Mizushima Works were modified in 1991 to increase snorkel and lower vacuum vessel diameters, 1.25 and 1.4 times larger respectively than those of conventional degassers. The equipment has enabled us to produce large amount of ultra-low carbon steel.

4.4 Stainless Steel Refining

Modernization of Chiba Works (installation of No. 4 steelmaking shop and No. 3 hot strip mill) was carried out over five years starting in May 1991.[31)] In the steelmaking department the new No. 4 steelmaking shop for the production of stainless steel as the main grade was installed to replace No. 1 steelmaking shop to increase production capacity and produce higher quality slab. **Figure 10**[32)] shows an outline of the No. 4 steelmaking shop. The features of this process include (1) attainment of material cost reduction by using inexpensive raw materials that became feasible by adopting a chromium ore smelting reduction process that utilizes coal energy (2) establishment of high purity (ultra low carbon, ultra low nitrogen and ultra low sulphur) ferrite stainless steel production process by separating, smelting and refining functions with a combined process that consists of smelting reduction, high speed decarburization BOF and VOD (3) establishment of a steelmaking plant in harmony with the urban environment that stresses environmental protection, by installing a STAR furnace specializing in stainless refining dust treatment which has enabled its recycling as raw material for stainless production by melting and reducing Cr and Ni in the dust.

4.5 Continuous Casting

(1) Continuous Slab Caster for Plain Carbon Steel

In the production of ultra low carbon steel sheets for automobile and other uses, strict internal and surface quality control are required for continuous casting process. From such a background, Mizushima Works No. 4 continuous casting machine was installed in 1993. For the purpose of separation of non-metallic inclusions that float up, the machine was designed to be a vertical-bending caster (vertical length of 3 m) with large tundish capacity (70 t).[33)] The principal features of this caster are as follows: (a) Hot-Cycle Operation of Tundish: A technology to reuse the hot tundish in a short time after discharging residual steel in the tundish was introduced. Nitrogen gas jet burners are used for reheating the tundish to suppress reoxidation of the steel sticking to the tundish inner wall and improve the quality of the bottom of the first slab. (b) Transport of Slabs between the Steelmaking Shop and Hot Rolling Mill: An automatically controlled hot slab transport vehicle (D-liner) with heat

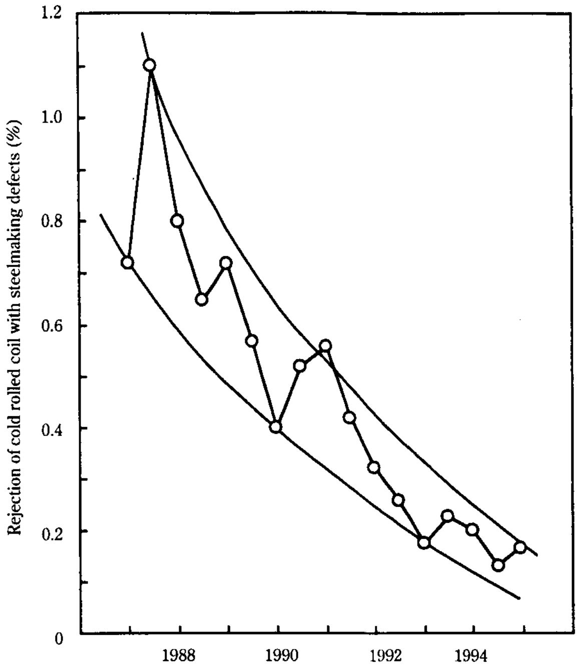

Fig. 11 Improvement of surface quality of cold rolled coil with steelmaking defects

insulation connects the steelmaking shop and the hot rolling mill, enabling high temperature cast slab charge into the reheating furnace at above 850°C. (c) Molten Steel Flow Control Technology in the Mold: Molten metal flow in the mold is closely related to the cast strand quality. FC mold (flow control mold)[34], which applies two level static magnetic fields (upper and lower) to the molten steel in the mold over its entire width to control molten metal flow, was installed at Chiba Works No. 3 continuous casting machine in 1991 and at Mizushima Works No. 4 continuous casting machine in 1993. Surface and internal qualities of plain carbon steel have been remarkably improved with not only the above method, but also by preventing the reoxidation of molten steel in a ladle and tundish, improving submerged entry nozzle shape and material, preventing inner cracks by shortening of guide roll pitches, optimizing secondary cooling and so on. **Figure 11**[35] shows the transition of surface defect ratio of cold rolled sheets attributable to steelmaking conditions as one of the examples. It is clear that the defect ratio has been reduced to 1/10 during the past 7 to 8 years.

(2) High Speed Casting of Stainless and High Carbon Steel

In 1994, Chiba Works No. 4 continuous casting machine was installed to provide high quality of slab cast and high productivity for stainless and high carbon steel.[36] To secure consistent cast strand quality, the world's first vertical-bending type continuous casting machine for stainless steel was adopted (Fig. 10). This machine allows high speed casting without surface and inner cracking and with low non-metallic inclusion content by applying multiple bending points, shortening of roll pitches, mist secondary cooling which can adjust spraying width, and improvement of submerged entry nozzle shape. Also the centrifugal flow tundish with high deoxidation capability was introduced to produce extremely clean aluminum killed stainless steel. These improvements have achieved 1.6 and 1.3 m/min of maximum casting speed for mass production grades SUS 304 and SUS 430, respectively, which are the highest in the world. In addition, stable high speed casting of 13%Cr seamless pipe material and 20Cr-5Al steel for metal honeycomb has been realized.

(3) Continuous Forging Process for Blooms

Since 1990, the Mizushima Works No. 3 bloom casting machine[37] has been equipped with a continuous forging system which forges cast strands continuously by a pair of anvils at its solidification end point. This process works to diminish center segregation and center porosities and has helped us to apply bar and wire products to higher functions.

4.6 Future Outlook of Steelmaking Technology

Future requirements for refining are considered to be (1) improvement of reaction efficiency of refining agents such as burnt lime (2) attainment of higher productivity and integration of equipments by doubling the refining reaction rate (3) development of environmental technology to reduce or recycle the slag and dust, save energy and so on. In the last 20 to 25 years, the refining process utilized strong stirring force and injection metallurgy such as gas bubbling and powder injection. For the future, it is highly desirable to create fundamental technologies that can replace the existing ones, such as wide space strong magnetic field application, and to develop technology to make it simpler and less expensive.

The future tasks in the continuous casting field would be to pursue greater productivity, improve cast strand quality, and develop a production system for short delivery. These will require breakthroughs in the following areas. (1) Production of cast strand with no defects by improving surface and internal quality further, (2) Strand integration by doubling casting speed and providing production flexibility, (3) Establishment of technology to prevent the mixing of different steel grades to minimize defects, and (4) Development of mold powder with multiple functions that enables mold lubrication, moderates cooling at the initial solidification point, and prevents mold powder entrainment into molten steel in the mold.

5 Conclusions

Recent trends in technological development and the future outlook of the ironmaking and steelmaking processes which support the foundation of the steel industry by supplying raw materials to the downstream processes are summarized. The future technological development in ironmaking and steelmaking will be aimed at stably producing large amount of products of consistently high quality and high function in a short delivery time at low cost and in harmonization with the local environment.

In the ironmaking field,

(1) We have developed ways of using large amounts of inexpensive raw materials that has attained a 53% semi-soft coal ratio in the present coal blend and 40% pisolite ore ratio within the powdery ore for sintering.

(2) Based upon burden distribution control technology, we have kept productivity and the fuel ratio stable and flexible.

(3) The life of BFs has been extended up to 20 years due to improvements in equipment and operation stability.

(4) We have developed a coke packed bed smelting reduction process with two stage tuyeres for the purpose of recycling of stainless refining dust from converters and electric arc furnace dust and have brought the process into operation at Chiba and Mizushima Works.

In the steelmaking,

(1) For plain carbon steel refining, we have developed an economical mass melt production method for highly clean steel such as ultra low carbon steel by constructing a process flow consisting of (a) hot metal pretreatment for dephosphorization and desulfurization (b) bottom-blowing or top and bottom-blowing BOF and (c) an RH vacuum degassing process capable of high speed decarburization and heat compensation.

(2) For stainless refining, we have developed an effective production system for highly pure steel with much freedom of material selection through technical developments such as (a) Cr ore smelting reduction furnace (b) Top and bottom blowing BOF for high speed decarburization (c) VOD and (d) the adoption of STAR furnace for stainless dust recycling.

(3) For continuous casting, we have improved the quality of cast slab and bloom, mechanical characteristics of products and synchronization with hot rolling process by such measures as (a) adopting vertical bending type continuous casting machines and (b) upgrading molten metal flow control in the mold.

References

1) T. Suzuki and H. Fujimori: *Kawasaki Steel Giho*, **29**(1997)1, 1
2) H. Itaya: *Kawasaki Steel Giho*, **31**(1999)1, 1
3) S. Sakamoto, K. Igawa, and K. Sorimachi: *CAMP-ISIJ*, **9**(1996), 40
4) S. Sakamoto, K. Igawa and K. Sorimachi: *CAMP-ISIJ*, **9**(1996), 652
5) S. Sakamoto, and K. Igawa: *CAMP-ISIJ*, **11**(1998), 97
6) S. Watakabe, Y. Hara, K. Takeda, H. Itaya, and H. Suginobe: *CAMP-ISIJ*, **10**(1997), 154
7) S. Watanabe, H. Kamano, and T. Matsumoto: *CAMP-ISIJ*, **10**(1997), 158
8) M. Honma, M. Hamaki, and S. Ito: *CAMP-ISIJ*, **11**(1998), 845
9) M. Ohgami, K. Hosomi, and T. Hayashioka: *Kawasaki Steel Giho*, **29**(1997)1, 19
10) K. Nushiro, N. Ohyama, and K. Igawa: *Kawasaki Steel Giho*, **29**(1997)1, 24
11) K. Nushiro, Y. Konishi, and K. Igawa: *Tetsu-to-Hagané*, **83**(1997)1, 413
12) N. Ooyama, K. Nushiro, and K. Igawa: *CAMP-ISIJ*, **11**(1998), 225
13) A. Satoh, M. Yasuda, and N. Ishihara: *CAMP-ISIJ*, **10**(1997), 192
14) O. Kawate, T. Yamamoto, M. Kiguchi, and Y. Yamauchi: *CAMP-ISIJ*, **10**(1997), 871
15) T. Shiozawa, N. Takashima, H. Kamano, H. Nishimura, and T. Matsumoto: *CAMP-ISIJ*, **12**(1999), 712
16) M. Yasuno, H. Nishimura, K. Kobayashi, S. Onishi, and Y. Sakuma: *CAMP-ISIJ*, **6**(1993)1, 44
17) S. Miyagawa, K. Takeda, S. Taguchi, T. Morimoto, M. Fujita, and H. Fujimori: *Kawasaki Steel Giho*, **23**(1991)2, 130
18) T. Sawada, T. Uetani, S. Taniyoshi, S. Miyagawa, H. Sugawara, and M. Yamazaki: *Tetsu-to-Hagané*, **78**(1992)8, 1337
19) T. Nouchi, T. Sato, K. Takeda, and T. Kawai: *CAMP-ISIJ*, **11**(1998), 895
20) E. Akimoto: 146–147th Nishiyama Memorial Lecture, (1993), 129
21) S. Hasegawa, H. Kokubu, and Y. Hara: *Kawasaki Steel Giho*, **29**(1997)1, 51
22) Ishiwata, T. Sato, S. Miyagawa, Y. Hara, and H. Itaya: *CAMP-ISIJ*, **10**(1997), 980
23) H. Nabeshima, K. Taoka, S. Yamada, N. Tamura, and M. Shimizu: *Kawasaki Steel Giho*, **22**(1990)3, 157
24) M. Suito, K. Aizawa, M. Ariyoshi, R. Nagai, H. Nishikawa, and S. Oomiya: *Kawasaki Steel Giho*, **22**(1990)3, 143
25) M. Kawana: 100th–101st Nishiyama Memorial Lecture, (1984), 1
26) T. Imai: 100th–101st Nishiyama Memorial Lecture, (1984), 161
27) T. Oota, M. Saegusa, J. Nagai, F. Sudo, K. Nakanishi, T. Nozaki, and R. Uchimura: *Kawasaki Steel Giho*, **12**(1980)2, 209
28) J. Nagai, T. Yamamoto, H. Yamada, H. Take, R. Tachibana, H. Oomori, K. Nakanishi, and Y. Iida: *Kawasaki Steel Giho*, **14**(1982)3, 240
29) K. Kameyama, H. Nishikawa, M. Aratani, R. Asaho, N. Tamura, and K. Yamaguchi: *Kawasaki Steel Giho*, **23**(1991)2, 136
30) Y. Kato, T. Fujii, S. Suetugu, S. Oomiya, and K. Aizawa: *Tetsu-to-Hagané*, **79**(1993), 1248
31) H. Yamada: *Kawasaki Steel Giho*, **28**(1996)4, 199
32) H. Nabeshima, S. Ogura, and S. Yamada: *Kawasaki Steel Giho*, **28**(1996)4, 206
33) J. Hasunuma, H. Bada, and T. Matukawa: *Kawasaki Steel Giho*, **28**(1996)1, 7
34) A. Idogawa, Y. Kitano, and H. Tozawa: *Kawasaki Steel Giho*, **28**(1996)1, 46
35) K. Sorimachi and J. Hasunuma: *Kawasaki Steel Giho*, **28**(1996)1, 1
36) M. Sugisawa, S. Ogura, and M. Aratani: *Kawasaki Steel Giho*, **28**(1996)1, 14
37) S. Kojima, H. Mizota, and K. Kushida: *Kawasaki Steel Giho*, **26**(1994)1, 1