Steelmaking Technologies Contributing to Steel Industries

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NKK developed steelmaking technology in the 20th century while considering its social responsibilities. NKK developed and applied highly efficient production technology and produced high quality steel products while reducing the generation of wastes. The 21st century will face a worldwide borderless society. Hence, the newly formed JFE Steel Corporation will develop new steelmaking processes and contribute to meeting diverse demands from around the world.

1. Introduction

NKK has continued to develop new steelmaking technologies in its never-ending pursuit of the ideal of meeting the needs of society. The unique, world-leading steelmaking technologies developed and put into practice by NKK are represented by the dramatic reduction in the amount of slag generation due to efficient dephosphorization in the hot metal pre-treatment process; high-speed and extremely effective quality control in the continuous casting process; and the development of useful products made from steelmaking slag. These technologies constitute an important foundation for the newly formed JFE Steel Corporation to continue responding to social needs into the 21st century.

This paper summarizes major steelmaking technologies that NKK has developed in recent years, noting their significance.

2. Refining technologies

2.1 Hot metal pre-treatment technology

The hot metal pre-treatment method, where hot metal is dephosphorized prior to refining in a converter, was actively put into practice in the 1980's by the major steelmakers of Japan in order to meet customers' requirements for lower phosphorous content in steel products, while reducing slag generation and increasing the iron yield. However, dephosphorization by this method is still insufficient, and a more effective process was desired.

A thorough investigation by NKK on the dephosphorization mechanism revealed that lowering the silicon content in the hot metal to an ultimate level leads to a dramatic improvement in the efficiency of lime for dephosphorization. Based on this finding, a first-in-the-world, open-ladle-type desiliconization station was installed at Fukuyama Works in March 1998. The silicon content of the hot metal was minimized before dephosphorization, improving the efficiency of lime for dephosphorization. Moreover, slag generation through the entire steelmaking process was successfully lowered to an ultimate level. The phosphorous content of the steel was lowered to the level of the final product specification while still in the hot metal stage, and slag generation during dephosphorization in the converter was nearly eliminated. Therefore, this technology was named the ZSP (Zero Slag Process) and deployed at Keihin Works as well in May of the same year, expanding the application of this process company-wide[1). **Fig.1** shows the process flow at the Fukuyama Works. Hot metal is transferred through the desiliconization station, a mechanical-stirring-type desulfurization process called KR, a ladle type dephosphorization station called the NRP (New Refining Process), or an LD-converter-type dephosphorization process called LD-NRP, before finally being charged into a converter. Each technology for the ZSP is described below.

2.1.1 Technology for mass-production ultra-low silicon hot metal

The silicon content of hot metal tapped from the blast furnace is already lowered to a level of 0.2% by the low silicon operation of the blast furnace. This is achieved by methods such as low temperature operation, wherein the temperature is measured continuously. The low silicon hot metal is then sent to the desiliconization station, where itbecomes ultra-low silicon hot metal with a silicon content of less than 0.10%.

At the desiliconization station, oxygen gas is used along with sintered iron ore (iron oxide) as the oxidizer for de

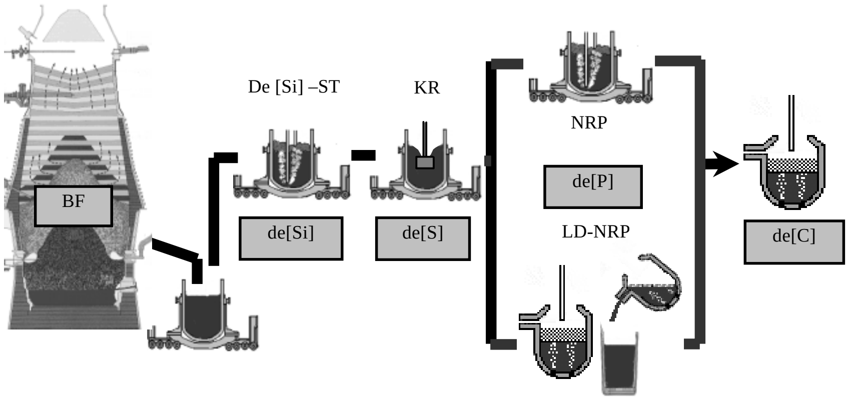

Fig.1 ZSP process flow at NKK's Fukuyama Works

siliconization. The reaction vessel is a ladle type, and the hot metal is vigorously stirred by injecting lime through a submerged lance. This method dramatically improved the oxygen efficiency for desiliconization over the conventional method of desiliconization, which is performed in hot metal runners on the cast-floor, and provides a highly efficient and stable supply of ultra-low silicon hot metal.

2.1.2 Hot metal dephosphorization technology

Experiments confirmed that reducing the silicon content of hot metal in turn lowers the amount of CaO that reacts with silica to form calcium silicate ($2CaO\text{-}SiO_2$) in the early stage of desiliconization. Instead, calcium phosphate ($3CaO\text{-}P_2O_5$) is formed directly. Also, a practical technology was established for performing the dephosphorization of the ultra-low silicon hot metal by controlling the oxygen flow rate and temperature. The reduced silicon content increased the efficiency of lime for dephosphorization, significantly lowering the lime consumption and stabilizing the phosphorous content in the hot metal after treatment.

At the Fukuyama No.2 steelmaking shop where the ladle-type dephosphorization process (NRP) is employed, the reduced slag generation retards the slag foaming phenomenon and other process-hindering factors. Hence, the extent of dephosphorization in the NRP was markedly increased by elimination of freeboard limitation in the hot metal transfer ladle.

On contrary, the LD-converter-type dephosphorization process (LD-NRP) has been in operation at the Fukuyama No.3 steelmaking shop since 1995. The LD converters in this shop are used as a decarburization furnace in the first half of their vessel life and then as a dephosphorization furnace in the latter half. Using ultra-low silicon hot metal, the dephosphorization furnace performs high-speed dephosphorization operation on all the hot metal that goes through this shop. This dephosphorization operation is synchronized with the tap-to-tap time of the decarburization furnace, to which the hot metal is then sent. The efficient high-speed dephosphorization achieved by these technological developments allowed an increase in the ratio of hot metal for which the dephosphorization operation can be applied. At Fukuyama Works, it is now possible to apply the ZSP to 100% of hot metal, even at the high production amount of 10 million tons per year. The average phosphorous content of hot metal after treatment is consistently less than 0.012%, allowing the decarburization furnace to be operated without the need of performing dephosphorization. Hence, flux consumption at the decarburization furnace was lowered to the minimum level required to protect the furnace refractories. **Fig.2** shows slag generation before and after the desiliconization station was installed. The slag, which was previously generated at a rate of more than 100 kg per ton of steel, was decreased by half. The slag generated in the converter dropped to less than 10 kg/t.

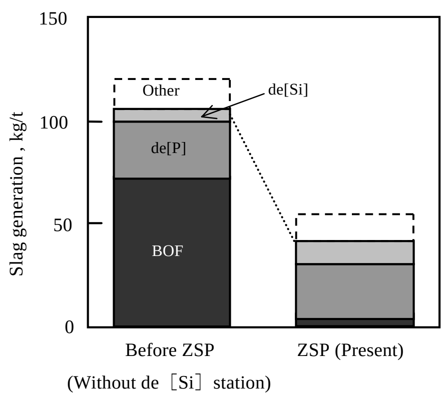

Fig.2 Effect of ZSP on slag generation

The lowered generation of slag brought about various additional benefits. The first is that the direct reduction of manganese ore in the converter became possible. Thus, ferromanganese consumption was markedly reduced. The second is that the life of the refractory lining of the converters was extended from 3000 charges to 8500 to 9000 charges. In addition, the ZSP had a large effect on improving the quality of the steel produced, such as a significant reduction in the generation of alumina, as described later.

Further, the compositions of the slags were simplified, which expanded their effective uses. As also described later, slag from desiliconization is now used effectively as potassium silicate fertilizer, while slag from dephosphorization is formed into large blocks by carbonation for constructing artificial fishing reefs. These slag products have been commercialized by NKK as environmentally friendly products that open the way to the next-generation steelmaking process.

2.2 New converter technologies

2.2.1 High-speed blowing technology

In the 1980's, a top-bottom-combined blowing technology (NK-CB) was developed by NKK for steelmaking converters[2]. Next, the development of the ZSP described above turned a converter into a decarburization furnace that can effectively perform direct reduction of manganese ore[3]. Major problems associated with this operation were iron spitting during oxygen blowing due to the minimized slag volume, decreased iron yield due to the increased dust generation rate, and unstable furnace operation. These problems hindered the realization of high-speed blowing for increasing productivity. NKK achieved high-yield, high-speed blowing by developing new technologies, as listed below, and shortened the blowing time by about 25%. As a result, the steel-producing capacity of one furnace (in the Fukuyama No.3 steelmaking shop) was increased to more than 480000 tons per month, contributing greatly to the increase in productivity.

(1) On-line dust measurement system

Dust generation from a converter has complicated relationships with various factors, such as the speed of oxygen gas blown through the oxygen lance and the lance nozzle shape. These make it difficult to quantitatively predict the dust generation behavior, and no effective method had been available for directly evaluating the dust generation volume or rate. Hence, an on-line dust measurement system was developed[4]. This system continuously measures the converter dust generation volume by continuously sampling the dust-collecting water discharged from a wet-type dust catcher and measuring the dust concentration optically. The on-line dust measurement system adopted at the Fukuyama No.3 steelmaking shop is schematically shown in **Fig.3**. With this system, the dust generation during converter blowing operation is measured on-line, allowing optimization of the oxygen blowing pattern and other operational parameters. Those data resulted in the rapid development of a new lance nozzle.

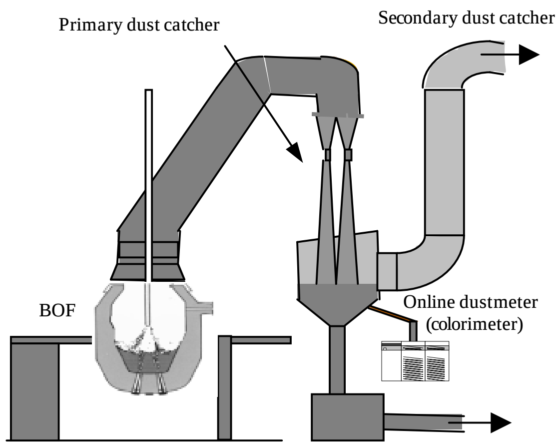

Fig.3 Schematic view of on-line dust measurement system

(2) Dynamic pressure control of top-blown oxygen

Iron spitting and dust generation rates in a converter are correlated with the dynamic pressure of the top-blown oxygen jet on the molten metal surface. This correlation was used to develop a new technology for controlling dust generation by using the dynamic pressure calculated from the nozzle shape and other blowing conditions[5]. When applying this technology to actual operation, the on-line dust measurement system was used to rapidly optimize the nozzle shape and other blowing conditions. These technologies reduced the amount of dust generation from the converter and stabilized the operation (**Fig.4**).

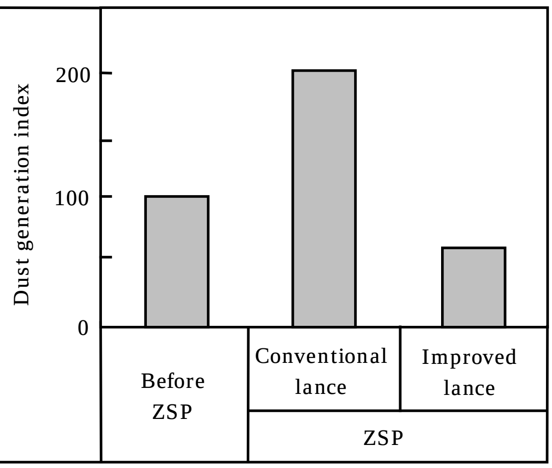

Fig.4 Amount of dust generation

2.2.2 New stainless steel refining process

A new stainless SRF (Steel Refining Furnace) was started up in Fukuyama Works in September 1990 to reduce the production cost of the stainless steel[6]. This process is characterized by epoch-making technology, wherein refining is performed by repeatedly using a single converter, and nickel ore and chromium ore are directly reduced in the furnace. The production flow of austenitic stainless steel is schematically shown in **Fig.5**. Using hot metal as the primary material, Ni-containing hot metal is produced by the reduction of nickel ore. Next, dephosphorization is performed by the aforementioned hot metal pre-treatment facility. The material is then charged again into the converter, where Cr- and Ni-containing hot metal is produced by the reduction of chromium ore. After the hot metal and slag are tapped from the converter, the hot metal is charged into the converter once again, and oxygen is blown for decarburization. Lastly, RH degassing or the other secondary ladle refining technique is carried out for adjusting the final steel composition.

A horizontal, hot cyclone dust separator incorporated in the off-gas dust catcher recycles dust by separately recovering nickel and chromium from the dust. Thus, high-yield, stable operation was achieved using crude ores, and the technology was established for producing high-quality stainless steel at low cost.

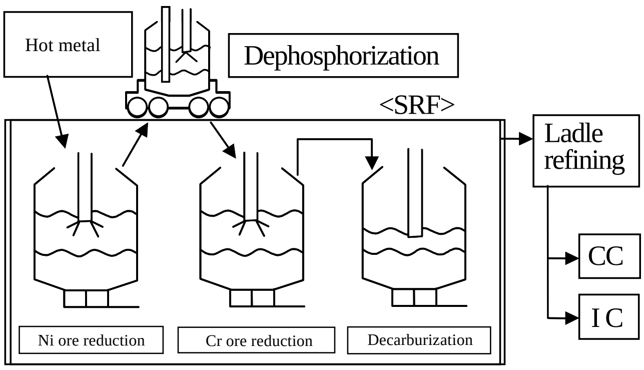

Fig.5 Process flow of new stainless steel refining process

2.3 Secondary refining technology

In recent years, the necessity for developing high-quality steel has increased, as steel products tend to be used in increasingly severe environments, and customers' requests for resource saving is getting stronger. Improvements in material properties and reductions in the various defects are necessary to produce high-quality steel products, which in turn require purer and cleaner molten steel.

NKK has been promoting the development of technologies for mass-producing ultra-low-carbon and ultra-low-nitrogen steel to improve formability, such as deep-drawing capability, and the anti-aging property, as typically required of automotive steel sheets. These purer steel grades are also required to permit the production of highly formable steel sheets by applying a continuous annealing process after cold rolling.

To make ultra-low-carbon steel, it is necessary to promote the decarburization reaction when treating molten steel in a RH vacuum degassing vessel. Analysis using a model[7] that simulates the decarburization reaction revealed the effectiveness of increasing the reaction interface area and molten steel circulation rate in the degasser. Hence, the diameter of the lower vessel for RH degassing was increased as well as that of the snorkel. It was also decided to inject a large amount of Ar gas from the snorkel pipe to promote molten steel circulation in the vessel. These techniques enabled the lower limit of the carbon content in the molten steel to be consistently reduced from 30 ppm to less than 20 ppm[8]. A major problem in trying to produce ultra-low-nitrogen steel by the RH process was that progress of the denitrization reaction slows down once the nitrogen content drops below 20 ppm. It was found that air that penetrates into molten steel though the snorkel refractories causes this behavior. Hence, the snorkel was purged by Ar gas, which enabled the stable production of ultra-low-nitrogen steel containing less than 20 ppm nitrogen[9].

These technological developments made it possible to consistently produce steel that has both carbon and nitrogen contents of less than 20 ppm, as shown in **Fig.6**. Currently, this type of steel is being produced at a level of over 150000 tons per month.

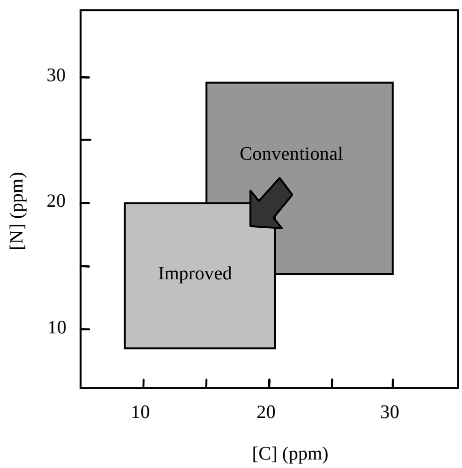

Fig.6 Effect of improved RH

A problem to be solved in producing cleaner steel is the presence of defects due to alumina inclusions in ultra-low-carbon steel sheets. Alumina inclusions are caused by oxides (mainly FeO) in the slag in the ladle which was carried over from a converter. This type of defect was largely eliminated by ZSP, which minimizes slag generation in the converter. Slag conditioning and composition control were also effective in this regard[10].

The reduction of HIC (Hydrogen-Induced Cracking) is required for steel plates, particularly those used for fabricating line pipes for sour gas service. Lowering the sulfur content to ultra-low levels is effective for controlling the shapes of inclusions that act as starting points of HIC. A new ladle refining technology named NK-AP (NKK Arc Process)[11] was developed for controlling the slag composition by lowering its oxidizing capability and increasing its desulfurizing capability. The process also incorporates strong stirring by a top-blowing lance. As a result, the mass production of ultra-low-sulfur steel became possible, as shown in **Fig.7**[12].

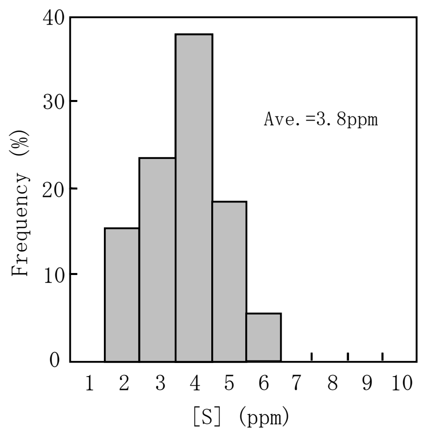

Fig.7 Final ladle analysis of [S]

3. New continuous casting technologies

NKK installed two new CC (Continuous Casters) to simultaneously achieve high productivity and high quality. The Fukuyama No.5 CC was started in September 1984 and is dedicated to steel sheet production. The Fukuyama No.6 CC was commissioned in December 1993 and is a single-strand CC that mainly produces steel for plates, but can also produce steel for sheets. Both of these machines perform high-speed casting. With machine lengths of 42 m and 49 m, respectively, their designs aim to reduce strain and thermal stress during casting by such methods as narrowed roll pitch, multi-point bending, and air-mist spray for secondary cooling. A large 80 ton tundish and vertical-bending-type casting method were employed to produce cleaner steel. The vertical sections have lengths of 2.5 m and 3 m, respectively, to facilitate the floating separation of inclusions. They also incorporate a fully air-sealed casting to prevent re-oxidization during casting. In addition to these design features, various other unique technologies developed by NKK were utilized. Thus, an advanced, continuous casting technology was established for simultaneously achieving high productivity and high quality. These features are outlined below.

3.1 High-productivity casting technology

The Fukuyama No.5 CC was installed upstream of the No.2 hot-strip mill[13] and started operation in an ideal layout, where the CC and hot strip mill are directly linked. The development of technology that allows stable and high-speed casting at a rate exceeding 2 m/min was essential to synchronize its operation with hot rolling. One of the major problems associated with high-speed casting is the increased fluctuation of the molten steel level in the mold that is caused by the increased velocity of the molten steel stream from the submerged entry nozzle. Another problem is breakout caused by the reduced mold powder consumption rate.

As a countermeasure against molten steel level fluctuations, highly accurate level control technology was adopted that uses an eddy-current-type sensor developed in-house. In addition, the molten steel surface flow velocity was optimized through controlling the molten steel flow in the mold, as described later. These measures enabled suppression of the level fluctuations during high-speed casting to less than those in conventional casting.

As a countermeasure against the decrease in the mold powder consumption rate, a new method was developed for generating mold oscillation that has a non-sinusoidal mode with a longer positive strip time[14]. Further, a new mold powder using Li_2O was developed for high-speed casting. Through these measures, a new casting technology was established that provides the powder consumption rate required for stable, high-speed casting (more than 0.3 kg/m^2). As a result, maximum casting speeds of 2.7 m/min and 2.4 m/min were realized for casting low-carbon steel and ultra-low-carbon steel, respectively. These set new records of annual production of 3.6 million tons in 2001 and monthly production of 355 thousand tons in May 2002, as shown in **Figs.8** and **9**.

The Fukuyama No.6 CC is a single-strand CC that mainly produces steel for plates, but is also used for producing steel for sheets[15]. The steel for plates this machine

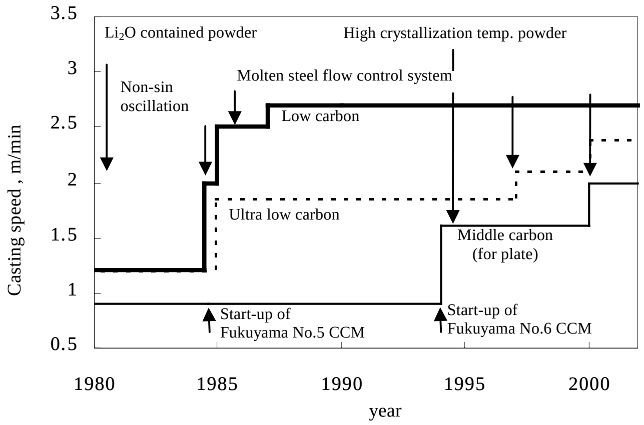

Fig.8 Change of casting speed at Fukuyama Works

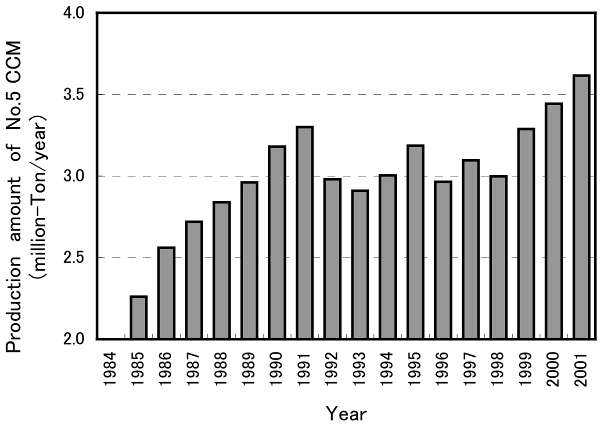

Fig.9 Annual production by No.5 CC at Fukuyama Works

produces is primarily medium-carbon steel, which poses a new problem for high-speed casting in addition to those discussed previously. Longitudinal surface cracks occur that are caused by the uneven growth of the solidifying shell. In order to overcome this problem, a new mold powder was developed that has a markedly elevated crystallization temperature and permits moderate cooling of the molten steel in a mold. In addition, a mist cooling method was developed for cooling the material uniformly in the secondary cooling zone. This technology completely eliminated crack generation in high-speed casting at 2 m/min[16]. In order to increase the production yield, this machine was provided with the ability to produce slabs with three different thicknesses: 220, 250, and 300 mm. To increase the operating ratio, the machine was equipped with a newly developed system that permits production to be quickly changed from one thickness to another in less than 20 min. As a result, this single-strand CC achieved a monthly production record of more than 160 thousand tons. It also achieved another record in that 98% of the slabs for producing steel plates needed no conditioning.

3.2 High-quality slab casting technology

Entrapment of mold powder into the molten steel must be prevented to achieve high-speed casting of high-quality slabs. This entrapment occurs by the surface flow and vortex in the molten steel and can be prevented by lowering the surface flow velocity[17]. However, too slow a surface flow lowers the heat supply to the mold powder and tends to cause surface defects such as slag spots. To perform casting under an optimized surface flow velocity, NKK developed unique technology to control the molten steel flow in a mold[18] and applied it to the Fukuyama No.5 and No.6 CCs. In this technology, an alternating current electromagnet is installed at the vertical center of the mold, which imposes a traveling magnetic field along the width direction, to control the molten steel stream spouting out of the submerged nozzle and thereby control the surface flow. As shown in **Fig.10**, the magnetic field thus applied not only slows the spouting stream, but also accelerates it. The former function is called the EMLS (Electro-Magnetic Level Stabilizer), while the latter is the EMLA (Electro-Magnetic Level Accelerator). This method is characterized by the ability to always control the surface flow in an optimum state under any casting condition; i.e., not just in the steady state where high-speed casting is possible, but also in the non-steady state, where slowing down the casting speed is inevitable. Currently, in furtherance of high-speed, high-quality casting, a dynamic control method based on direct measurement of the molten surface flow velocity is being developed to replace the conventional static control method where the intensity of imposed magnetic flux is pre-determined by casting speed, slab width, and other casting conditions.

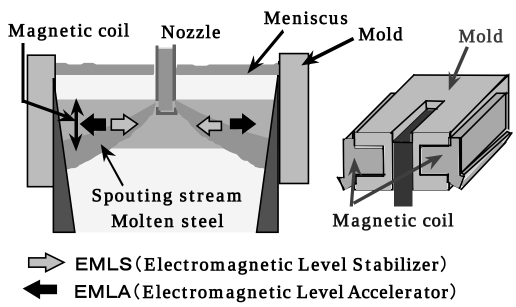

Fig.10 Molten steel flow control using traveling magnetic field

Owing to the combined effect of these new casting technologies and aforementioned technology for producing cleaner steel by reducing alumina generation, a non-conditioning ratio exceeding 90% was achieved for slabs for producing steel sheets, as shown in **Fig.11**.

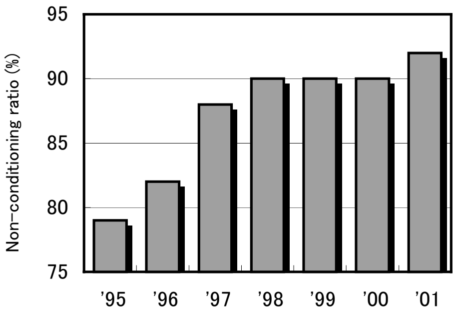

Fig.11 Slab non-conditioning ratio

Soft reduction casting technology was developed for casting slabs for producing steel plates and line pipe materials and commercially applied to reduce center segregation[19]. Center segregation is caused by the fluidity of solute-enriched molten steel due to shrinkage that takes place in the final stage of solidification. Narrowing the gap of the guide rolls at the final stage of solidification to compensate for the solidification shrinkage prevents center segregation by applying soft reduction to the slab, which suppresses the fluidity of the partially solidified steel. This technology effectively mitigates not only the continuous segregation at the center of a slab, but also non-continuous, semi-macro segregation that is less than several mm in diameter. Reducing the roll diameter, narrowing the roll pitch, and selecting a soft reduction rate optimized to casting conditions such as slab thickness and casting speed maximize the effect of this technology[20].

To further advance this technology, NKK developed the IBSR (Intentional Bulging Soft Reduction) method, where the slab is intentionally bulged before soft reduction is applied. Bulging corrects the uneven solidification along the width direction[21]. As a result, a system was established for stable production of steel plates for fabricating sour gas service line pipes at a rate of more than 20 thousand tons per month.

3.3 Technology for continuous casting of billets for seamless pipes without billeting

NKK started the Keihin No.5 CC in November 1982 and the horizontal CC in 1983 for producing billets for making seamless pipes. Using these machines, a new process technology and production system were established for continuous casting of round billets in diameters from 170 to 330 mm that are then directly pierced and rolled into seamless pipes without billeting process. At the Keihin No.5 CC, the surface and bulk quality were improved by applying newly developed technologies, such as a high-viscosity mold powder that allows uniform slow cooling of billets, and equiaxed crystallization using M-EMS. At first, the horizontal CC suffered from cold shut cracks on the billet surface in the early stage of solidification. The development of a break ring and a new shape of casting mold solved this problem[22]. As a result, the technology for continuous casting of billets was established, not only for carbon steel, but also for alloy steel.

4. Technologies for producing high quality cast slabs

High quality cast products are produced by combining the high quality improvement technologies described above, along with process optimization for various requirements. Technologies used to produce representative high quality steel products are outlined below.

4.1 High quality slabs for automotive and canning steel sheets

Steels used for automobile production and canning are representative types of high quality steel sheets. These are made of ultra-low-carbon IF steel and low-carbon aluminum-killed steel, respectively. The amount of inclusions originating from fine-grained alumina and mold powder must be low for these steels. The typical production flow of these steel grades at the Fukuyama Works starts with the ZSP applied to hot metal pre-treatment and converter operation, followed by RH, and then the No.5 CC. In the steelmaking process, various new technologies described above, such as the technology for preventing slag from flowing into the ladle in the ZSP, technology for modifying the slag composition[23], and that for producing highly clean steel in the RH process, play important roles in decreasing the amount of alumina inclusions.

In the continuous casting by the No.5 CC, the technology for optimizing the molten steel surface flow velocity, the large-sized tundish[15] and the floating separation of inclusions at the vertical section are used to lower the amount of inclusions. A problem encountered in casting IF steel is that the initial solidification shell tends to grow quickly and deepen the oscillation marks that act as trap sites for inclusions. The mold oscillation pattern was modified to have a higher cycle rate and a shorter stroke to make the oscillation mark shallower and produce defect-free slabs with a sound surface. Also, the mold oscillation has a non-sinusoidal curve with a longer positive strip time. The trend of the frequency of diversion during cold rolling is shown in **Fig.12**. The prevention of powder entrapment by optimizing molten steel flow in a mold and the reduction of alumina generation by the ZSP achieved a sharp drop in the frequency of diversion, as well as in the number of slabs that need conditioning, as mentioned before. Further newly developed technologies such as "Laser IPC"[24] that can quickly identify the causes of surface defects and correlate them to operating conditions, and "Delta Eye"[25] that can automatically detect and mark surface defects on steel sheets on-line were used in the production lines. A total quality assurance system that covers all the processes from steelmaking to final products was established. As a result, high quality IF steel is being consistently produced at a rate exceeding 150 thousand tons per month.

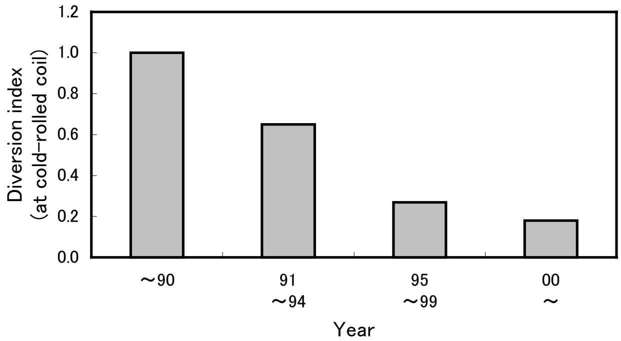

Fig.12 Trend of diversion index of cold rolled coils

4.2 High strength line pipe material

Low susceptibility to HIC (Hydrogen-Induced Cracking) is important for steel plates used for fabricating sour gas resistant line pipes.

Typical production flow to produce slabs for this application at the Fukuyama Works starts with the ZSP applied to hot metal pre-treatment and converter operation, followed by AP, RH, and then the No.6 CC. The steelmaking shop can produce this steel grade at a rate of more than 20 thousand tons per month. In the steelmaking process, impurities are thoroughly reduced through dephosphorization by the ZSP and desulfurization by AP[12]. HIC starts from MnS in the segregation area and propagates through the segregation band. Hence, shape control of the sulfide[26] is performed by controlling the Ca content within a narrow band in the AP. In the casting process, semi-macro segregation particles pose problems as well as center segregation. Therefore, the IBSRR method[21] was applied to the No.6 CC for realizing stable production.

Fig.13 shows the annual production record of sour gas resistant line pipes. Since 1983, NKK has been producing sour gas resistant line pipe materials that exceed the API-X65 specification and fully meet the NACE standard, which is more strict than other standards.

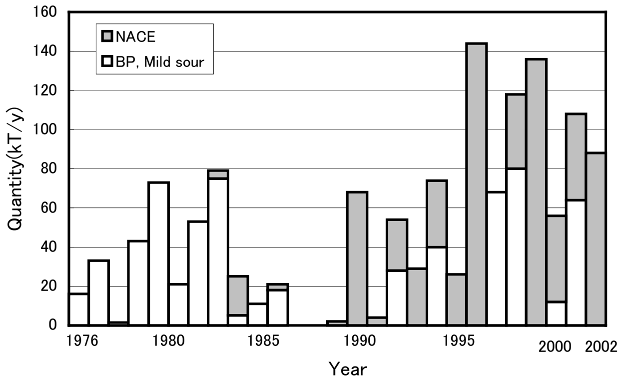

Fig.13 Annual production of sour gas line pipes

4.3 High performance invar alloy

Invar alloy is a high Ni steel that is characterized by low thermal expansion and is used for producing shadow masks for PC displays and large, high-grade TV screens. Non metallic inclusions in these products lead to image unevenness through aperture shape defects during etching. Micro segregation has a similar adverse effect through forming laminar patterns on the shadow mask. Applying the ZSP and controlling the composition of slag in a ladle reduced non metallic inclusions. Micro segregation was suppressed through homogenization by a soaking treatment. By combining these with highly accurate rolling technology, a high-quality, high-yield, integrated production system was established covering all processes from steel making to etching substrate production.

5. Technologies for effective use of steelmaking slag

ZSP reduced the generation of slag to an ultimate level. Each type of slag generated by hot metal pre-treatment has a unique and uniform composition according to the type of process. These characteristics widened the range of applications, effectively using the unique composition of each type of slag. Two new technologies for the effective use of slag generated by hot metal pre-treatment are introduced below: marine blocks and slow-release potassium silicate fertilizer.

5.1 Marine Blocks

Focusing on the CaO contained in steelmaking slag, carbonated solid blocks were produced by reacting the slag with CO_2 gas. This product was commercialized under the registered trade name of Marine Block.

In the Marine Block production process, CO_2-containing exhaust gas is injected into slag. The CO_2 reacts with CaO in the slag, forming calcium carbonate, which covers the slag particles and firmly bonds them together. Thus, a solid block is formed, which eliminates the expansion collapse and increased pH value of seawater; those were formerly problems that arose when steelmaking slag was used in seawater. Thus, a structural body that is very stable in seawater was achieved. A 5-ton block was experimentally produced that is the largest of those reported in the past. In April 1999, a number of carbonated solid blocks made of steelmaking slag, each having a bottom area of 1 m square and a height of 50 cm, were piled on the sea bottom for investigating their effect on cultivating seaweed and other marine organisms (**Fig.14**). The experiment confirmed that seaweed proliferated on these blocks, and a large shoal of fish gathered in the space between the blocks[27].

CO_2 is absorbed at a rate of 200 kg per ton of slag in the Marine Block production process. This means that as much as 800 thousand tons of CO_2 could be fixed if only 30%, or 4 million tons, of the steelmaking slag annually generated in Japan is used for producing Marine Blocks. This consumption would make a significant contribution to global warming prevention.

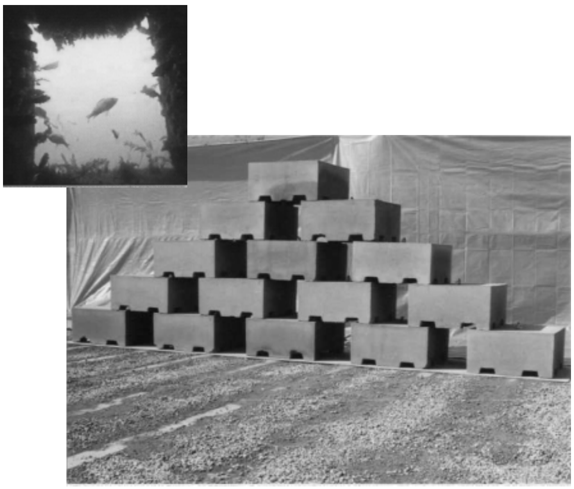

Fig.14 A pile of carbonated steelmaking slag blocks

5.2 Technology for producing slow-release potassium silicate fertilizer

Silica (SiO_2) is drawing attention because of its effect as a fertilizer for increasing the resistance of rice plants against diseases and vermin. A slow-release potassium silicate fertilizer was developed by focusing on the slag generated in the desiliconization process, which is mainly composed of silica. The fertilizer is produced by reacting the desiliconization slag with potassium material. The silica and potassium material do not easily dissolve in water, so it is slowly released into soil. The chemical composition is shown in **Table 1**[28].

Table 1 Chemical composition of NKK potassium silicate fertilizer (%)

K_2O	SiO_2	CaO	MnO	MgO	FeO	Al_2O_3
22.1	37.7	21.3	3.7	0.9	3.1	3.5

Tests of this product as a fertilizer confirmed that its effect exceeds that of other commercial potassium silicate fertilizers, potassium chloride fertilizers, and calcium silicate fertilizers[29]. The Ministry of Agriculture, Forestry and Fisheries issued the official Japanese standard on potassium silicate fertilizers made from steelmaking slag in January 2000 as Notice No.91, “Fused potassium silicate fertilizer”, under the Fertilizer Control Law. In April 2000, NKK registered its new fertilizer at the Ministry of Agriculture, Forestry and Fisheries as “Manganese-containing 20.0 fused potassium silicate fertilizer” and started marketing it in December 2001.

6. Future prospects

In the future, NKK will continue to further improve the productivity of the steelmaking process, centering on the technologies described above. In addition, the Company will promote technological development to achieve the ultimate steelmaking process that is also environmentally friendly. The targets will include the reduction of the flux consumption rate to a theoretical limit, the achievement of 100% slab non-conditioning ratios, perfection of the technology for producing defect-free cast products, expansion of the use of slag, and the achievement of zero emission of wastes.

7. Conclusion

This paper outlined the recent progress NKK has made in technological development for the steelmaking process. We believe these technologies will continue to meet the needs of the world after the start of the JFE Steel Corporation. Based on these achievements in the past, we will continue to promote the development of new technologies in response to the changing requirements of society.

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