Abridged version

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Recent Activities of Ironmaking Laboratory

Hiroshi Itaya

Synopsis :

R&D activities of ironmaking laboratory in these past ten years are described. In the area of cokemaking, the contributions to usage of large amount of low cost semi-soft coal and the decrease in the trouble of hard push were brought about through the coal blending technologies. In the field of sintering fundamental studies on the sinter reaction based on new experimental methods such as x-ray CT and also a newly developed charging apparatus of raw material contribute the cost reduction. On the other hand, in the blast furnace technologies a new charging system of the furnace top, burden distribution control technology, computer simulation system of blast furnace operation are developed. These developments have realized a stable operation and also the large amount use of low cost burden and fuel. In the area of smelting reduction, a commercial plant of STAR process for stainless steel dust recycling has started its operation and the application of this process to electric arc furnace dust recycling is under development.

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Hiroshi Itaya
Dr. Eng.,
General Manager,
Ironmaking Lab.,
Technical Res. Labs.

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1 Introduction

Restructuring has been underway in the steel industry in Japan in order to maintain its international competitiveness.[1] Further measures for restructuring will be taken in the days to come as a result of the economic depression in Japan created by the decline of currencies in Asia. In such an economic environment and under circumstances where no expansion can be expected in the volume of production, various measures including concentration of facilities to improve productivity, development of techniques to utilize inexpensive raw-burden and fuel for cost reduction and automatic operation of facilities for labor force reduction and improvement of working environment are being taken in the field of ironmaking.

With respect to the technological developments made by Kawasaki Steel in the field of ironmaking, there is already a report written by Suzuki *et al.*,[2] therefore, this report will outline the R&D work in this field centering on the company's research group.

2 Major R&D by the Ironmaking Laboratory

2.1 Coke-making

The most important subject in the area of coke-making is to use a large amount of low cost semi-soft coal. Increasing the bulk density of coal charged into a coke oven is effective at improving the coke strength, therefore, coal moisture control (CMC)[3] has become popular among many steel manufacturers including Kawasaki Steel. In addition to this technique, we have developed various techniques including a model for controlling charging density in an oven,[4] a two-stage charging method[5,6] and a coal moisture control technique[7] for the purpose of improving coke strength by increasing bulk density. Blending a large amount of semi-soft coal results in a large drop in coke strength, therefore, it is necessary to accurately estimate the coke strength and reflect it in the coal blending design. For this reason, we have developed a coke strength estimation model[8] which has made it possible to extensively improve the accuracy by newly introducing a pore structure factor as well as a model to accurately estimate the maximum fluidity (MF)[9] which has a large effect on coke strength and we have been using these models for coal blending.[10]

Furthermore, we recently developed another coke strength estimation model made by taking the interaction between different kinds of coal into consideration. This model is facilitating the increased usage of large

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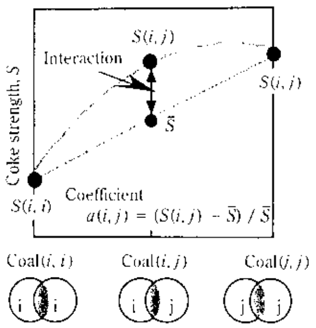

Fig. 1 Definition of interaction of coal on coke strength

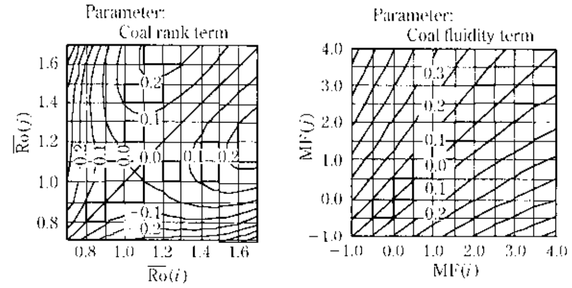

Fig. 2 Contour lines of $a(i, j)$ dependent on coal rank (Ro) and maximum fluidity (MF)

amounts of low grade coal.[11] In this model, a mixture with multiple coals is considered as an assembly of combinations of two coals and the strength of a multi-kind blended coke (S) is assumed to be a weighted average of the values of the combined strength of two coals which are not affected by any third coal. An important feature of this model is that an interaction coefficient: $a(i, j) = (S(i, j)\bar{S})/\bar{S}$, is introduced as an index to indicate the difference between the combined strength $S(i, j)$ of coal i and coal j and the average strength of these two kinds of coal as shown in **Fig. 1**. In addition to the above, we considered the reason why simple addition does not hold for the strength as a result of each blended coal being affected by the other to be that the differences in coal rank Ro and maximum fluidity MF of a single coal mutually affect "expansion and contraction" during coking and affect various coke strength determining factors such as melt-adhesion between grains, pore formation and crack formation. In other words, we considered that the interaction between expansion and contraction to be the same as that described in Fig. 1 and these interaction coefficients can be expressed using Ro and MF.

With the above concept, we measured the coke strengths of single coals as well as those of 54 different combinations of blended coals and also carried out expansion and contraction tests. These studies made it clear that these interaction coefficients can be expressed using Ro and MF. Furthermore, it has been made clear concerning $a(i, j)$ that a proper combination of regions exists in coal ranks and the interaction becomes stronger for combinations with larger differences in the maximum fluidity as shown in **Fig. 2**. In addition to the above, it has become clear that the interaction coefficient $a(i, j)$ for strength can also be expressed by the coefficients for expansion and contraction. This result supports the idea that the blending effect on strength is strongly affected by the differences in expansion and contraction between each coal. This method for estimating strength has been applied to coal blending and is facilitating the increased usage of large amounts of inexpensive coal.

Another important subject in the area of coke making is extending the expected life span of ovens and R&D of hardware has been carried-out covering various phases including carbon removal, glass coating, diagnosis of furnace walls by ITV and spray repair, etc.[2] Preventing troubles with hard push in coke ovens is also related to the extension of ovens' life and is an indispensable technique for large amount blending of semi-soft coal. Therefore, we have developed a numerical model for the clearance between the furnace wall and the coke cake that takes into consideration the expansion and contraction of all three phases of coal; liquid, solid and gas,[12] and have been using this model for coal blending. On the other hand, we are also developing techniques for preventing hard push troubles from the operation management aspect on the basis of basic experiments. We performed coking tests for various kinds of blended coal using a test oven fitted with a movable wall and made detailed investigations on the push-out behavior of coke cakes, mechanisms of crack generation and load transmission to side walls, etc.[13] The results have been reflected in the electric current control while pushing-out as well as in the blending design.

As explained above, the quantity of low cost semi-soft coal being used has increased through development of various techniques and improved operation management and such coal now accounts for more than 50% of the blended coal being used.

On the other hand, we have also tackled development of new coke-making technologies and have been engaged developing formed coke shapes which are strong against damage caused by internal cracks because such damage had been hindering the usage of large amounts of formed coke.[14] We have also developed binders for formed coke.[15] Furthermore, we recently participated in SCOPE 21, a national project to develop coke-making technology and investigate hot molding techniques.

2.2 Sintering

The most important subject in the area of sintering is how to use a large amount of inexpensive ore with high combined water content both from the resource and cost points of view. Ore with high combined water content, if

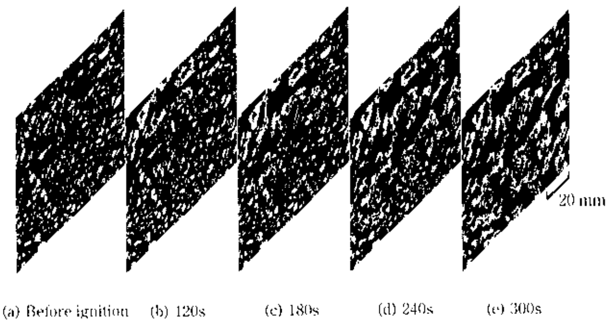

Fig. 3 Change in CT image of sinter cake during sintering

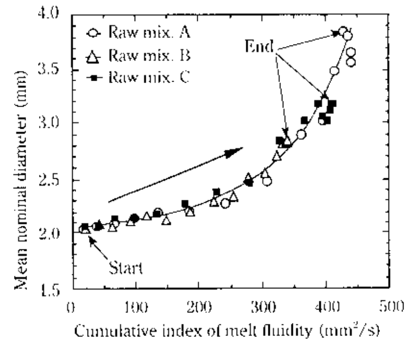

Fig. 4 Relationship between cumulative index of melt fluidity and mean nominal diameter of grain through sintering

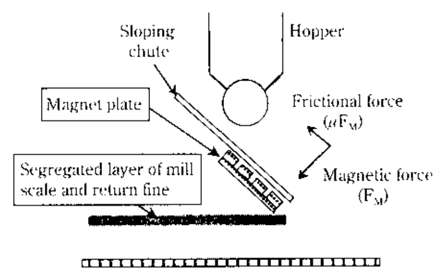

Fig. 5 Schematic diagram of magnetic braking feeder

simply blended in a large amount, lowers strength and permeability and as a result, the yield and productivity greatly deteriorate. The reasons are the low bulk density of the ore itself, increased condensation of water in the lower layer of the bed, low fluidity of the generated liquid, etc. Therefore, we have been conducting studies in order to basically clarify the causes of deterioration of the yield and permeability[16,17] and at the same time, have developed the magnetic braking feeder technology[18] as well as the venting slit technique[19] for improving permeability of the lower layer of the bed.

The molten liquid flow analysis by means of X-ray CT observation and the magnetic braking feeder technology are explained as follows.

Changes in the pore structure due to the flow of melt are important factors which determine the strength of sintering ore. Therefore, we developed a hot X-ray CT sintering test apparatus capable of observing the sintering process in a hot condition and clarified the flow behavior of melt of ore with a high combined water content and changes in the pore structure as well. **Figure 3** shows CT images during the sintering process and indicates the progress of growth and unification of pores (black parts) and agglomeration of sintered parts as sintering proceeds. By quantitatively evaluating agglomeration, morphorogy of pore branches, liquid flow, etc. by means of image analysis, it was made clear that decreased fluidity and pore unification suppression occur by blending high combined water containing ore (mix. B) and suppression of unification is reduced by adding mill scale (mix C). **Figure 4** shows the relationship between the solid's mean grain diameter and the liquid's cumulative value of the fluidity index from the beginning to the end of the sintering process. This relationship follows a curve irrespective of the condition of the raw materials and it can be understood that liquid flow and agglomeration simultaneously progress and the differences in raw material conditions appear as a difference in the progress of agglomeration due to cumulative differences of liquid flow until end of sintering. These results suggest that the improvement of the molten liquid's fluidity is effective and have led us to develop mill scale blending and provisional grain formation techniques.

We have also developed a segregated charging system utilizing magnetic force, that is a magnetic braking feeder (MBF), to improve permeability. The outline of this feeder is shown **Fig. 5**. The basic structure is simple with permanent magnets arranged under the back surface of the sloping chute in order to make energy supply unnecessary and maintenance easy. The purpose of adopting this design is to increase the voidage in the bed and to improve permeability by braking the flow of raw materials which slide down the chute through the application of a magnetic field, thus soft-landing the raw materials on the feeder which is possible because of the large amount of various magnetic materials such as mill scale and returned fine contained in the raw materials for sintering. Another effect is that it segregates easily dissolvable raw mixtures such as mill scale and returned fine raising them to the upper layer part by applying magnetic force, thus improving the yield rate at the upper part. After optimizing the conditions using a feeder installed in laboratory, we installed an MBF in Mizushima Works' No. 3 DL. Segregation of raw mixtures is shown in **Fig. 6**. Returned fine which was easy to melt was segregated to the upper layer side and permeability was improved. As a result, the consumption of quicklime used as binder was 1.5 kg/t-s and the yield

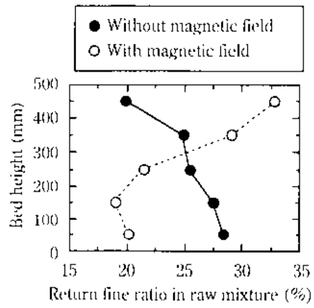

Fig. 6 Effect of magnetic field on segregation of return fine

rate also improved by 1.2%. Because of the superior features in installation cost, maintainability and economics, MBFs have been installed to all sintering machines in the Mizushima Works as regular facilities. Following this success, we have also developed and installed an MBF for the drum chute on the No. 4 sintering machine in the Chiba Works and have been getting similar results.

2.3 Blast Furnace and New Smelting

The most important subject for blast furnaces is cost-reduction while maintaining stable operation. On the presumption that burden distribution control technology was the most important technology which would make possible stable operation, use of a large amount of fine grain raw burden and high production rate operation, we have also been making an effort to develop new charging equipment and to establish distribution control technology using burden distribution models.

To use a large amount of fine burden, we considered it necessary to adopt a multi-batch charging system in which burdens of different grain size and quality are charged separately. Therefore, we developed a bell-less top charging system of a three parallel bunker type[20] and installed it on the No. 3 blast furnace of Mizushima Works in 1990. A problem of parallel type bell-less charging system had been less-uniformity in the circumferencial direction, however, the newly developed feeder overcomes this problem by adopting an adequately shaped vertical chute, optimized diameter and starting position control for burden discharge. We have established a method to use a large amount of fine grain sintering ore of 17% blending ratio by separately charging raw burden of each grain size[21].

The No. 6 blast furnace of Chiba Works achieved a long-term operation of 20 years and 9 months and was blown down in March, 1998. We have made every effort to develop a new charging system preparing for the revamping of the No. 6 furnace. For burden distribution, we performed an enormous number of model tests and theoretical evaluation from the viewpoints of stability of deposited layers and permeability through layers[22,23] and have clarified that the following three points are requir-

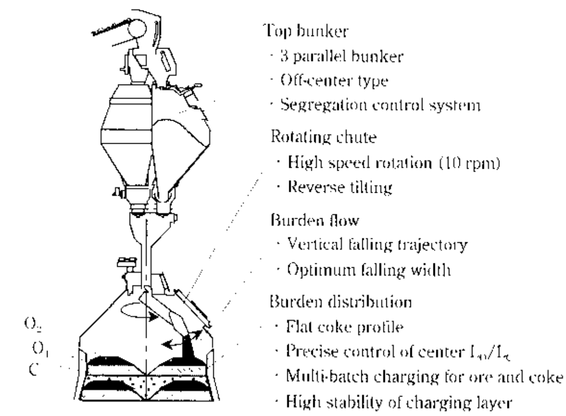

Fig. 7 New top charging system equipped to Chiba Works No. 6 BF

ed as functions of any new charging system.[24]

(1) Multi-batch charging in order to make it posssible to control grain diameters in the radius direction and ore layer thickness ratio Lo/(Lo + Lc)
(2) Nearly vertical burden falling locus and adequate burden falling width
(3) Flat charging which forms a flat burden surface

As an example which exhibits such new functions, we developed the new top charging system shown in **Fig. 7**. The system is composed of three parallel bunkers (3PB) which enable multi-batch charging, reverse tilt charging and a rotating chute fitted with a stabilizer to make the falling locus vertical and stable.

The special feature of this new bell-less feeder is that it has excellent controllability and a large degree of freedom for distribution. Therefore, we developed burden distribution models at the same time in order to determine charging patterns suitable for the intended burden distribution.[25] We verified the models through a pre-inaugural charging examination in May, 1998 and succeeded in early stable starting up by adopting burden distribution control based on the developed model. By fully utilizing those new functions, we anticipate that successful cost reduction and stable operation will be realized from now on.

In order to achieve stable operation of blast furnaces while using a large amount of low grade raw mixtures, we have also developed indices which enable quantitative evaluation of burden descend anomaly occurrence limits[26] and a blast furnace operation simulator[27] and are using them also for reducing silicon content.[28]

The conditions at the blast furnace hearth have not been well clarified due to difficulties in direct measurement. However, by analyzing temperature distribution in the blast furnace hearth and the behavior of the tapping detailed actual data from operating furnaces, we formed our opinion that there exists in the bottom of blast furnaces a low permeable region for molten pig ion and slag.[29] **Figure 8** shows an example which explains the generation of large temperature deviations at the switch-

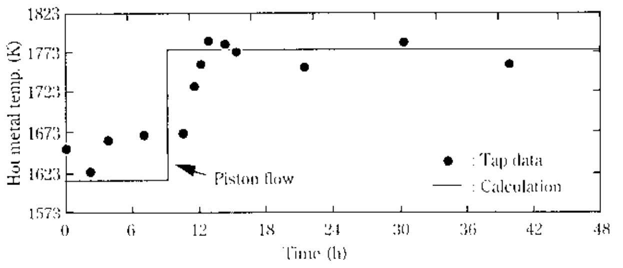

Fig. 8 Comparison of calculated hot metal temperature with measured one

ing of the tap hole due to liquid flow at the furnace hearth where the existence of low permeable region is assumed. Studies are underway to verify the hypothesis of the low permeable region through analysis of the furnace bottom refractories temperature, clarification of the furnace bed structure by injection of tracers from the tuyere and analysis of the deviation of hot metal temperatures between tap hotes using low permeable region models for the blast furnace hearth.[30,31] However, there remain many points which have not been clarified with respect to the control method and we are planning to continue our studies further.

Large amounts of pulverized coal injection will be an indispensable technique in the future. Therefore, we have been studying the combustibility of pulverized coal using test furnaces and numerical models and have made it clear that highly-volatile coal and low fluidity steam coal exhibit the highest combustibility.[32] Furthermore, we have developed a two-dimensional mathematical model which enables evaluation of the flow and combustion of pulverized coal.[33-35] Using this model, we have found that the combustibility of pulverized coal is governed by the turbulent flow generated in the downstream of lances and have used this knowledge to develop high turbulence burners.[36,37] We are now carrying-out studies related to the elucidation of the pulverizing mechanism of coke when blowing highly pulverized coal as well as those related to coke quality design.[38,39]

In the field of new smelting processes, on the other hand, we applied the coke packed bed smelting reduction process with two stage tuyeres (STAR process, **Fig. 9**) to a smelting furnace for stainless steel smelting dust recycling and started its commercial operation in 1994, the first of its kind in the world.[40] This process was originally developed for the purpose of producing ferro alloy by smelting fine ores without agglomeration but was commercially applied to the recycling of stainless steel smelting dust from converters. The furnace was designed to produce metal of 140 t/d, however, it is producing 150–160 t/d at present. We are also developing a process to recover zinc and iron from electric arc furnace dust aiming at commercialization within a few years by making full use of the special features of this recycling furnace.[41] The STAR process is one of the

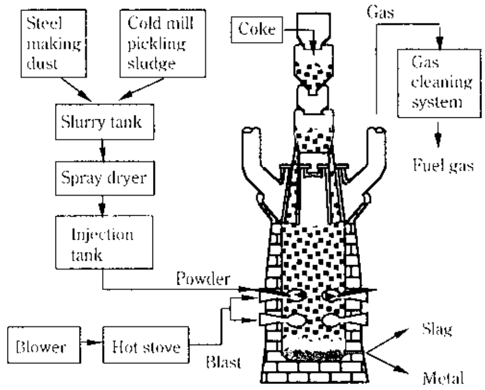

Fig. 9 Process flow of commercial plant of STAR process

results obtained by the Ironmaking Laboratory of Kawasaki Steel through many years of R&D and we intend to expand this process further. We also participated in the development of a smelting reduction process as an alternative to blast furnaces under a national project (the DIOS project) and engaged in the developed of a fluidized bed preliminary reduction technique.

3 Closing Remarks

The activities of the Ironmaking Laboratory of Kawasaki Steel over the last ten years were presented in this paper. The group has achieved various results in the respective areas of coke-making, sintering, blast furnaces and new smelting. We will continue technological development while fully considering various matters such as changes in natural resources, deterioration of coke ovens, CO_2 emissions, energy consumption, reduction of waste and environmental problems at the same time.

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