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Recent Activities in Research of Refractories and Slag

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Synopsis :

Technical trends during the last ten years in the fields of refractories and slag and an outline of the activities of the Refractories & Slag Laboratory of Kawasaki Steel are presented. In the field of refractories, successful results were achieved in the development of flame gunning repair and application to the coke oven, expanded use of monolithic refractories, and extension of oven life by structural design of refractory installation and slag design. In the field of slag, recycling of slag in the steel works, stainless slag treatment technology, and the development of applications for blast furnace slag are contributing to efforts to create an environment-friendly steel works through recycling of resources and reduction of industrial wastes.

The body can be viewed from the next page.

Recent Activities in Research of Refractories and Slag*

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1 Introduction

Refractories have played an essential role in the growth of the steel industry. With iron and steel production processes now tending to become even more diverse and advanced than in the past, the development of refractory technologies which are capable of meeting these needs has also become increasingly important.

On the other hand, slag accounts for approximately 80% of all the by-products which are generated in the iron- and steelmaking processes. With rising consciousness of environmental protection worldwide, the need to reduce the amount of slag generated and develop applications for slag has become urgent.

This reports presents an outline of technical developments during the last ten years at the Refractories & Slag Laboratory of Kawasaki Steel.

2 Technical Trends in Refractory Field and Slag Treatment/Use Field

2.1 Refractory Field

Reviewing the technical trends in the field of refractories during the last ten years, solutions to the problems posed by the more advanced processes adopted in iron- and steelmaking were achieved by applying higher purity raw materials, carbon-containing refractories, monolithic refractories, and other measures.

Among material technologies, in addition to expanded application of graphite-containing products in shaped refractories, steady progress was also made in production and use technologies for continuous casting refractories,[1,2] contributing to both higher product quality and improved productivity in steel materials. In the area of monolithic refractories, the application of monolithic refractories to the ladle and tundish using alumina materials was realized by the development of material technologies and installation/use technologies, and contributed to higher cleanliness and reduced costs in steel materials. In recent years, the development of basic, graphite-containing monolithic refractories has been promoted.

In installation and repair technologies, improvements were made in the pouring method for monolithic refractories[3] and the range of applications was expanded. The wet gunning method was also developed as a new repair technique.[4] The flame gunning technique was mechanized and a high capacity process was realized, which was linked to expanded application of monolithic reractories.[5,6]

In the area of refractory installation design and operating technologies, a higher level of accuracy was achieved in installation design and slag design technologies by adopting a computer based method of structural analysis and more advanced software for thermody-

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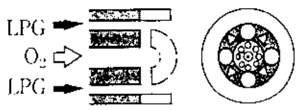
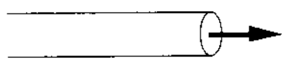
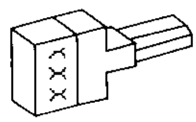
Table 1 Comparison of various flame gunning techniques for coke oven

	K-FG type	Fosbel type	Lava flame type
Burner construction			
Heating	LPG + Si + O_2	Si(+ Al) + O_2	LPG + O_2
Materials	SiO_2, Si	SiO_2, Si(+ Al)	SiO_2
Max. capacity (kg/h)	150	50	50

namic calculations.[7,8] A splash coating technique was developed, contributing to a large extension in furnace life.[9,10]

2.2 Slag Treatment/Use Field

Slag related technical development in recent years has borne fruit in (1) reductions in the amount of slag generated, (2) techniques for recycling and reusing slag in the steel works, (3) treatment technologies for hard-to-treat slags, as represented by a technology for suppressing volumetric expansion due to hydration,[11,12] and (4) use of slag in materials for civil engineering and construction materials.

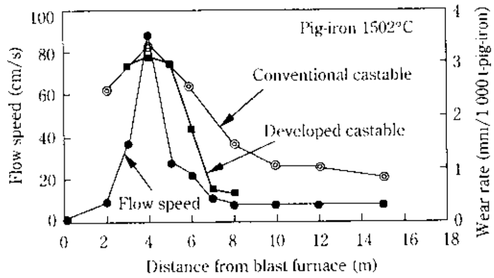


Fig. 1 Wear rate of castable and flow speed of pig-iron in trough at No. 6 Blast Furnace in Chiba Works

3 Results of Development in Refractory/Slag Fields

3.1 Refractory Field

As an iron- and steelmaker, Kawasaki Steel stands on the side of refractory users, and has therefore actively undertaken development in the fields of materials and installation technologies,[13,14] repair technologies, and use technologies. The following presents examples of development by Kawasaki Steel.

3.1.1 Development to flame gunning repair technology and application to coke oven

Flame gunning repair technologies for the coking chamber are of importance for extending coke oven life. The advantages of the flame gunning technology developed by Kawasaki Steel (**Table 1**)[6,15] are (1) LPG and metallic Si powder are used together as heat sources, and consequently, the construction of the burner is simple, and (2) the structure enables mixing of O_2, LPG, and the repair materials with good efficiency in the area near the burner discharge opening. As a result, a high capacity flame gunning technology (maximum gunning rate: 150 kg/h) of the world's highest level and short flame operation were realized. Moreover, by combining raw material and execution techniques, a gunned refractory with high durability was also realized. At Chiba Works No. 5 coke oven, this newly developed high capacity burner was mounted on a mechanical type flame gunning machine which had been developed separately, reducing repair time and realizing labor savings and high reliability in the flame gunning operation.

3.1.2 Development of graphite-containing monolithic refractory

Although the properties of graphite include excellent resistance to molten iron, slag, and thermal shock, graphite-containing monolithic refractories had not been applied to the iron manufacturing process. This was because the technology for overcoming (1) the hydrophobic property, (2) low fluidity, and (3) easy oxidation, which had been obstacles to the application of graphite, had not yet been developed. Kawasaki Steel developed a monolithic type material for runners by blending 10 mass% graphite in Al_2O_3-spinel refractory material.[16] It was possible to obtain an installed refractory with a fine structure and high corrosion resistance by applying techniques which included improved graphite dispersion using a dispersant developed by Kawasaki Steel, the Andreasen method of closed packing, and optimization of the particle size distribution based on a rheological analysis. As a result of using this developed material in the main trough at Chiba Works No. 6 blast furnace, it was possible to obtain excellent durability in comparison with the conventional non-graphite material, as shown in **Fig. 1**. This improvement in the wear rate was particularly noticeable in parts of the trough with lower pig iron flow speeds.

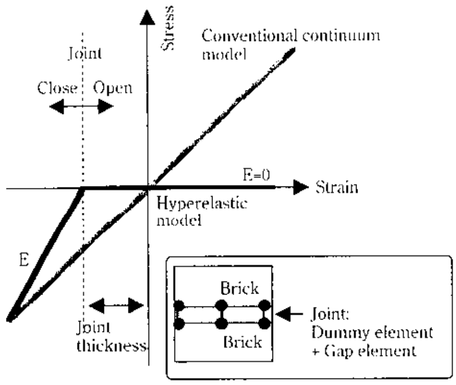


Fig. 2 Schematic illustration of hyperelastic model compared to the conventional continuum model

At present, efforts are being made to realize further improvement in these results, and to develop and apply practical graphite-containing monolithic refractories in the various steelmaking furnaces.

3.1.3 Contribution to extension of refractory life in steelmaking furnaces

As a result of recent progress in computer technology, it was possible to improve the accuracy of refractory installation design and slag design for steelmaking furnaces and expand the range of applications. One example is the development of a thermal-structural analysis method which improved the gap element method, as shown in **Fig. 2**.[7] At Kawasaki Steel, improvement of this method and use of a method which combines dummy elements with gap elements made it possible to simulate with good accuracy the phenomena of brick deformation, opening and closing of gaps, slipping, etc. in the installed refractory structure under non-steady temperature conditions. Using this analytic method, rational design of complex installed refractory structures, beginning with those of the Cr ore smelting reduction furnace and converter, has become possible, preventing problems caused by brick spalling and contributing greatly to longer furnace life.

Figure 3 shows the outline of a technology that reduces refractory wear by using thermodynamic calculation software,[17] which is capable of calculating the state diagrams of slag systems with multiple components, in the composition design of slag coatings. The conditions for stable forming of the slag coating are clarified in advance from three types of information, the analysis of the high temperature slag state by this method, measurements of high temperature slag fluidity in the laboratory, and the evaluation of the slag coating state in the actual furnace. Next, calculations are made to determine whether the coating slag satisfies the conditions for stable forming or not, based on the temperature and slag composition in the actual furnace.[18] On

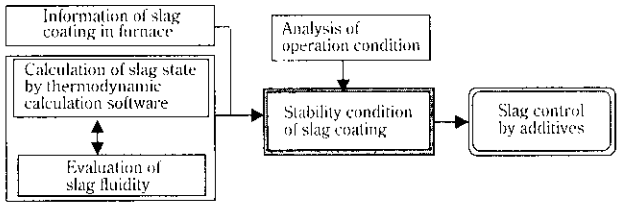


Fig. 3 Control system of slag coating by themodynamic calculation software

the basis of these results, setting materials, etc. are added so as to satisfy the conditions for stability. As a result of applying this improved slag coating method to the bottom of the K-BOP converters at Mizushima Works No. 2 steelmaking shop, it was possible to reduce converter bottom refractory wear by approximately 30%.[19] Similar methods have also been applied to slag control at other converters and ladles,[20] and are contributing to longer life.

3.2 Slag Field

In the field of slag, great effort was made in two areas, (1) reducing the generation of hard-to-treat slags and developing treatment technologies for such slags and (2) developing applications for generated slag. In area (1), techniques were developed mainly for steelmaking slag; these included prevention of dusting and suppression of volumetric expanision due to hydration, conversion of slag into road bed material, etc.[21-23] On the other hand, in area (2), efforts were directed manily at blast furnace slag, and included the development of new applications as material for civil engineering, material for concrete aggregate, and others. The following presents examples of development by Kawasaki Steel.

3.2.1 Use of slag from Cr ore smelting reduction furnace as road bed material

In addition to adopting a unique stainless steel smelting process comprising the Cr ore smelting reduction furnace—decarburization furnace—VOD furnace—continuous caster, Kawasaki Steel's Chiba Works has also installed a dust refining furnace with the aim of treating dust and other by-products. By using this process, it was possible to establish a technology for recycling and effectively using 100% of slag and dust. The flow of slag and dust recycling and effective use in this process are shown in **Fig. 4**. After all the generated slag has been recycled to the smelting reduction furnace or the dust refining furnace, it is finally used effectively mainly as road bed material. The two key points for using smelting reduction furnace slag as road bed material were (1) preventing dusting of the slag, which is caused by volumetric expansion due to modification of $2CaO\text{-}SiO_2$ during cooling, and (2) suppressing volumetric expansion due to hydration of the CaO or MgO contained in the slag.[24,25] Point (1) was solved by devel-

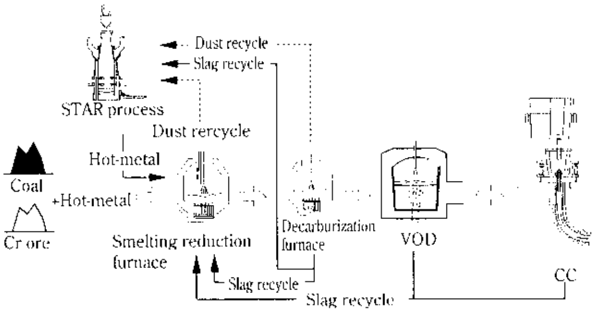


Fig. 4 Slag and dust recycle process for stainless steelmaing at Chiba Works

oping a technique of adding boron-containing ore to the molten slag. Point (2) was solved by developing techniques for suppressing expansion of the slag, suppressing melting of the refractories during blowing, and controlling the slag composition, which also promotes smelting reduction of the Cr ore, and particularly, for controlling the MgO concentration, CaO/SiO_2 ratio, and CaO/Al_2O_3 ratio during blowing and for accelerating melting. Although diverse materials are used in the smelting reduction furnace, newly developed technologies, beginning with those mentioned above, have made it possible to realize highly stable operation, and are also making an important contribution to environmental protection.

4 Conclusion

Refractories are an essential element which supports iron and steel production, and their importance will remain unchanged in the future. On the other hand, the Japanese steel industry must transform its existing plants into steel works which exist in harmony with the environment in order to maintain its international competitiveness in the coming years. One key element in this transformation will be the development of technologies which reduce the amount of generated by-products, as represented by slag, and enable treatment and effective use of such substances. Kawasaki Steel intends to contribute to the future growth of the steel industry and preservation of the global environment by carrying out even more rapid technical development in these fields.

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