NIPPON STEEL TECHNICAL REPORT No. 98 JULY 2008

Technical Review

UDC 666 . 7

Recent Technology of Refractory Production

Tsuneo KAYAMA* Keisuke ASANO
Hiroshi EBISAWA Kazuyuki UENO

Abstract

In order to follow the technical innovation of domestic iron and steelmaking industry which has advanced very fast, the refractory suppliers have also made their effort to innovate their material and manufacturing technology. As the result, according to the change of steelmaking operation, they have developed new optimal materials. Furthermore, they have much progressed their technology to stabilize the quality of refractory products and to improve their productivity. In this paper, the improvements of quality control and productivity at each manufacturing process of refractory are both reported.

1. Introduction

In the iron and steel industry, refractories are used in all sorts of furnaces, ranging from the blast furnace, hot stove and coke oven in the ironmaking process, to the converter, secondary refining furnace and continuous caster in the steelmaking process, and the reheating furnace in the hot rolling process. They are also used in many other industries, such as the nonferrous metal, cement and glass industries, in all those parts of kilns, incinerators, melting furnaces, etc. which are exposed to high temperatures.

When classed by form (shaped or unshaped), material (acidic, neutral, basic or composite), shape, etc., several thousand types of refractories are used at a single steelworks. For want of space, describing the manufacturing techniques for all those refractories, even briefly, is extremely difficult. In this paper, therefore, we shall confine ourselves to discussing the latest refractory manufacturing technology from two aspects—improvement in quality control and improvement in productivity in the individual production processes.

2. Refractory Production Flow

As shown in **Fig. 1**, the flow of refractory production differs according to the form of refractory.

Strictly speaking, unshaped refractory as shipped from the refractory manufacturer is not a refractory; it only becomes a refractory after it undergoes mixing, forming, aging, drying, preheating, etc. at the site of use. According to custom, however, the unshaped

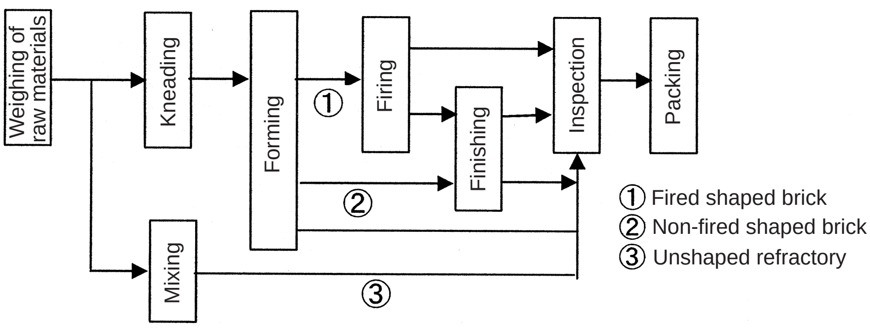

Fig. 1 Typical production flow of refractories

* Director, R&D Div., Krosaki Harima Corporation
1-1, Higashihama-machi, Yahata-nishi-ku, Kitakyushu-shi, Fukuoka-ken

refractory is treated in the same manner as the shaped refractory.

3. Present State of Refractory Manufacturing Processes

3.1 Weighing

Formerly, it was common practice for the refractory makers to purchase the raw materials, crush them into suitable grain sizes, then screen and store them in large tanks according to the grain size. Workers had to manually collect the required amount of raw materials using a weighing car which ran under the tanks. In the days when only a few different products were mass-produced, productivity was fairly high even using this method. However, as inexpensive refractories began to be imported in large quantities in the wake of the oil crisis and the yen's appreciation in the early 1970s, Japanese refractory makers found it imperative to turn their attention toward higher value-added and small volume production in a wider variety of sizes and grades.

With such small volume production in such a wide variety of sizes and grades for these high value-added refractories, the required number of weighings (by kind and grain size of raw material) increased while at the same time, the size of each lot weighed became smaller. Therefore, many refractory makers abandoned crushing the raw materials by themselves and decided to purchase screened ones from raw material suppliers to improve the efficiency of their manufacturing operations. The increased number of weighings per variety and the decreased size of each lot meant an increase in storage tanks to be prepared. Under those conditions, with manual weighing of raw materials, productivity declined markedly. Therefore, the refractory manufacturers pressed ahead with automated weighing and laborsaving operations. This, together with the spread of information technology (IT), has contributed much to improve productivity. At a company manufacturing unshaped refractories, you will find more than 100 large and small tanks for raw materials, beneath which an unmanned computer-controlled weighing car moves (see **Photos 1 through 4**).

In the future, enhancing the value and stabilizing product quality still further will be even more of a necessity than ever. In view of this and from the standpoint of quality assurance, it is considered indispensable to fully automate the weighing operation and implement production/quality controls to make the most effective use of IT.

3.2 Mixing/kneading

Mixing (and kneading) the raw materials is an extremely important process that largely determines the refractory performance, and each individual refractory manufacturer employs its own know-how for the process. Recently, more and more refractory makers are using not only coarse grains, medium-sized grains and fine particles, but also extra-fine particles of submicron order, from the standpoint of achieving the optimum material design. At present, however, it is difficult to disperse those extra-fine particles evenly within the compound. Therefore, it is important to select the optimum mixer or kneader that permits obtaining a compound of various kinds of particles of varying size which is as uniform as possible.

The mixers that are most popular today are the Omni-mixer (**Fig. 2**) and Nauta mixer (**Fig. 3**). As representative kneaders, the MKP mixer (**Fig. 4**) and Eirich mixer (**Fig. 5**) may be cited. In addition to these, there are many other different types of mixers or kneaders. A suitable one is selected from among those available according to the types of raw materials used and the purpose of use. From the standpoint of product quality, there are two important points to consider when selecting a mixer or kneader. They are: "How can the raw materials be mixed uniformly?" and "How can the effect of kneading be enhanced?" In terms of productivity, the Eirich mixer equipped with high-speed rotary blades is superior.

In order to ensure that all of the raw materials are mixed uniformly and that a coating layer made up of fine particles, extra-fine particles and binder is properly formed around coarse and medium-sized grains, the refractory makers have worked out various measures, such as subjecting the fine and extra-fine particles to premixing treatment and optimizing the charging sequence of raw materials in varying particle sizes and the timing of charging of the binder. It is

Photo 1 Raw material tanks

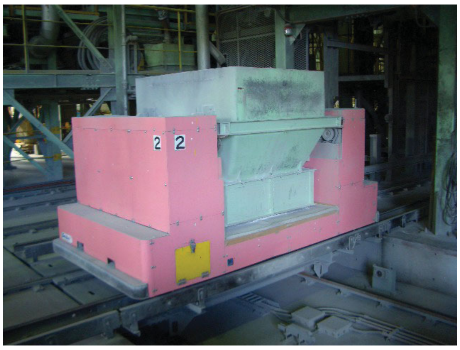

Photo 2 Automatic weighing car

Photo 3 Intensive control room

Photo 4 Monitoring screen in control room

Fig. 2 Omni mixer (by Chiyoda Machinery Co., Ltd.)

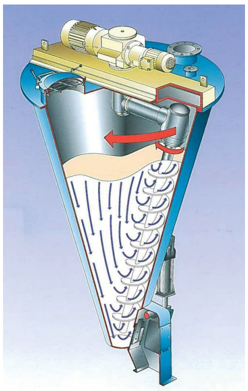

Fig. 3 Nauta mixer (by Hosokawa Micron Corp.)

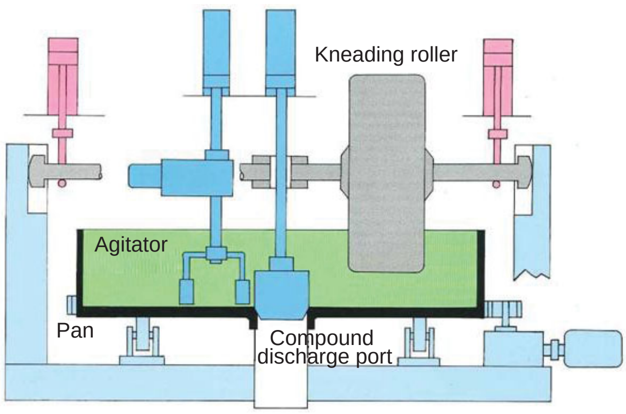

Fig. 4 MKP mixer (by Mitsuishi Fukai Co., Ltd.)

Fig. 5 Eirich mixer (by Nippon Eirich Co., Ltd.)

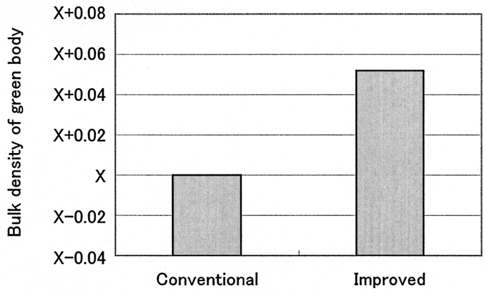

Fig. 6 Comparison of bulk density by improving mixing

considered that a green body made from compounds which have been mixed properly has a high bulk density.

By way of suggestion, **Fig. 6** compares the bulk density of green body before improvement (a batch of raw materials of varying particle sizes and binder charged together) and after improvement (the fine particles having been subjected to premixing and the charging sequence for the raw materials and binder optimized). Each of the samples used for the comparison was obtained by mixing the same raw materials for a certain period of time and then compressing the compound under a certain load. The binder is sensitive to temperature, and its viscosity varies significantly according to temperature. Therefore, by implementing proper temperature control of the binder, as well as the raw materials and the mixer, it is possible to mix the binder and raw materials under the same conditions throughout the year. This helps stabilize the product quality. Since some binders are susceptible to deteriorate with age, it is necessary to pay special attention when handling the binder. In the case of unshaped refractory materials which are mixed at the site of use, the binder is carefully kept packed separately from other materials till it is used.

Another problem in the kneading process is the difficulty involved in judging the end point. In the past, experienced workers could accurately judge the end point by gripping the compound. In recent years, however, the process has become highly automated, making such judgment by hand difficult. Under that condition, the kneading time, compound temperature, mixer power requirements, etc. are used as parameters to judge the end point. Even so, really dependable criteria have yet to be established. Thus, expectations are entertained of the discovery of new measurement items and the development of new analytical techniques in the future.

Further problem is that the small volume production in a variety of sizes and grades calls for frequent changes in the types of raw materials to be mixed. Under that condition, the mixer needs to be cleaned before every compound change and any residue on the inside of the mixer easily removed.

3.3 Transportation of compound

As mentioned above, in the mixing process, various new ideas have been incorporated to obtain a homogeneous compound of raw materials. This compound is transported from the mixing process to the forming process. Since the compound is an aggregate made up of particles which vary widely in size, from coarse to extra-fine particles, it is subject to segregation under the influence of gravity during transportation. To prevent the efforts made in the mixing process from coming to naught, it is necessary to devise effective ways to prevent segregation of the compound during transportation between processes. Specifically, it is important to devise appropriate methods of discharging and weighing the compound so that any difference in level along the transportation route is made as small as possible and that the flow of the compound in the direction of gravity is minimized. In some cases, equipment is installed to re-agitate and re-mix the compound just before forming.

3.4 Forming

The representative forming machines used for manufacturing shaped bricks are as follows.

(1) Dynamic pressure press (e.g. friction press)
See **Fig. 7** and **Photo 5** (by Mitsuishi Fukai Co., Ltd).

(2) Static pressure press (e.g. hydraulic oil press)
See **Fig. 8** and **Photo 6** (by Mitsuishi Fukai Co., Ltd).

(3) Isostatic press (cold isostatic press: CIP)
See **Fig. 9** and **Photo 7**.

Since each of the forming machines shown above has different advantages and disadvantages, an appropriate type is selected according to the kind of product and production volume, etc. Types (1) and (2), which are mechanical single-axis presses using dies, are widely used to manufacture ordinary refractory bricks. Type (3), which is an infinite multi-axis press using a rubber mold, permits obtaining homogeneous products even when their length-to-diameter ratio is considerably large. Specifically, this type of press (CIP) is used to manufacture shaped refractories for the steelmaking processes, such as long tubes for continuous casting and converter tapholes.

In recent years, flaky graphite, fine and extra-fine particles, etc. have increasingly been used as raw materials for refractories. When a compound of those and other raw materials is formed using a mechanical single-axis press, the generation of lamination (laminar void defect) increases. In order to resolve this problem, a vacuum press which permits degassing the compound in the die mold during the forming operation has been developed. This vacuum press is becoming widespread. In some cases, an existing press is modified to allow the above vacuum processing capability. The introduction of a vacuum press has even enabled the manufacture of large bricks exceeding 1 m in length.

According to the increase in product size and bulk density, larger forming machines are being used. As a result, it is difficult to operate these manually. In order to reduce the heavy muscular work involved in the forming process, automatic forming machines are becoming more widespread. According to the progress of hydraulic technology in recent years, the conventional friction press is being replaced by the hydraulic oil press. The introduction of a hydraulic oil press facilitates controlling the product dimensions and pressing force. Therefore, the accurate automatic control of product dimension and bulk density has become widespread. These improvements have dra-

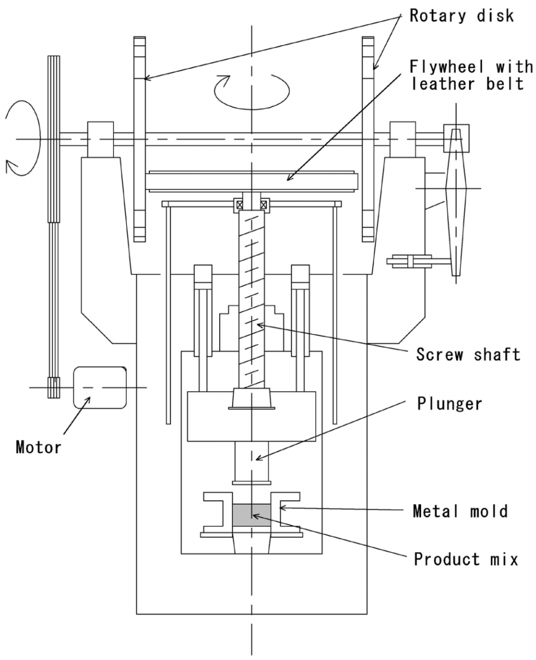

Fig. 7 Section of friction press

Photo 5 Appearance of friction press

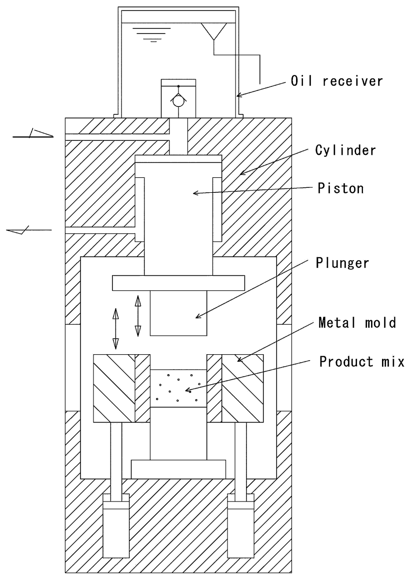

Fig. 8 Section of hydraulic oil press

Photo 6 Appearance of hydraulic oil press

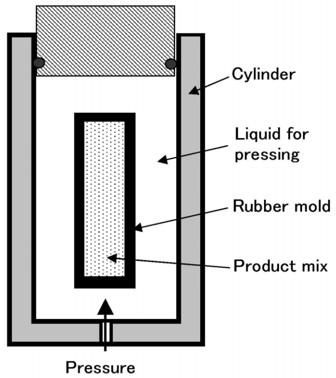

Fig. 9 Section of CIP

Photo 7 Appearance of CIP

matically shortened the forming cycle time and have increased productivity.

In addition, thanks to the progress of robotics and a decline in the cost of robots, the handling of formed bricks has been appreciably automated. Recently, the in-process inspection of product dimensions and bulk density just after forming has also been automated. Today it is not unusual to see a refractory manufacturing plant where the forming of bricks is fully automated.

As mentioned earlier, a typical example of application of the cold isostatic press (CIP) is the tube that is used in continuous casting of steel. Since this tube is an important shaped refractory that largely determines the quality of cast steel, it is subject to exceptionally strict quality control. One example of this is the strict air conditioning of the forming process environment. Since a slight change in ambient temperature or humidity significantly influences the plasticity of the compound, strict air conditioning is requested to ensure uniform product quality. Thus, strict air conditioning makes it possible to manufacture the shaped refractory with minimum fluctuation in quality. As a matter of fact, the changeover from simple air conditioning to strict air conditioning has improved the standard deviations of such quality indexes such as bulk density and porosity by 20% throughout the year.

Furthermore, ordinary refractories are controlled in mixing batches of compounds (500 to 1,500 kg). However, in the case of refractory tubes used in continuous casting of steel, they are controlled piece by piece for the reasons mentioned above. Each of the tubes goes through the entire process, from forming to shipment, with an ID card attached to it. Recently, in order to eliminate or minimize any additional processing from the standpoint of cost reduction and environmental protection, near-net forming technology based on optimum rubber mold design has been developed. In this connection, unlike other furnace bricks, the tube used in continuous casting of steel is subject to optimization of its shape based on the flow of molten steel simulated by a water model experiment or fluid analysis using a computer system.

3.5 Firing

The firing furnaces are divided roughly into continuous firing furnaces (tunnel kilns: **Photo 8**), which are suitable for mass production of bricks, and batch firing furnaces (shuttle kilns: **Photo 9**), which are versatile.

The firing temperature, which varies according to the kind of brick, is in the range 1,000℃ to 1,800℃. From the standpoint of quality control, it is necessary to heat up and cool down bricks according to the firing temperature curve established for each kind of brick. Improper heating or cooling may cause cracks in the bricks. Needless to say, it is desirable that the temperature inside the kiln should be uniform. Actually, however, because of the physical size of the kiln, the temperature inside the kiln varies somewhat from one part to another. In particular, the differences in temperature between the upper and lower parts of the kiln and between the sides and the center of the kiln cause problems. The refractory makers have worked out a number of measures and made various improvements to minimize the temperature differences mentioned above.

The improvements that have been made to firing furnaces from the standpoint of production largely focus on three points—changeover to new fuels, saving of energy, and automation of furnace operation. Concerning the fuel used in firing furnaces, coal had been replaced by heavy oil to allow for better temperature control. Later, heavy oil was replaced by natural gas in order to reduce CO_2 emissions and fuel costs. The use of natural gas also made it possible

Photo 8 Appearance of tunnel kiln (by Mino Ceramic Co., Ltd.)

Photo 9 Appearance of shuttle kiln (by Mino Ceramic Co., Ltd.)

to control the furnace temperature more accurately. With respect to saving energy, much had been done to use energy-efficient burners and make effective use of waste heat since the oil crisis. As a result, the specific energy consumption per unit brick weight had decreased dramatically. In recent years, however, it should be noted that specific energy consumption is no longer decreasing, and may even be increasing due to higher firing temperatures, more frequent changes in the firing temperature, and smaller quantities of products loaded on each firing car, etc.—all of which are necessary to enhance the value added to bricks and implement small volume production in various sizes and grades.

With respect to the automation of furnace operations, remarkable progress has been made. With the improved reliability of furnace equipment, it has become possible to automate the pushing-in, drawing-out and forwarding of the firing cars. In addition, the control of furnace temperatures and the watch for accidental fires that were formerly implemented by shift workers round the clock have been automated. Today most firing furnaces operate unattended.

One task that still remains to be tackled is to automate the work of loading bricks on the firing car. In the case of bricks for cement kilns which are standardized and similar in shape and which are produced in large quantities, they are automatically loaded onto the firing cars by robots. For other types of bricks, which vary widely in shape, loading by hand is still common.

3.6 Finishing

Following the work process, there is a machining process to obtain bricks of the correct dimensions and surface accuracy and an assembly process in which bricks are fitted in metal casings, etc. Generally, bricks are worked on manually using relatively small general-purpose machines. This is considered to be due to the large number of operational steps compared to the production volume of bricks of the same type and shape, because bricks demanded by customers vary widely in shape. At present, the refractory manufacturers, following the example of Toyota's production system, employ multi-faceted workers, U-shaped production lines, and cell production systems, etc. in order to enhance productivity while depending largely on manual labor. Under the prevailing environment of small volume production in a variety of sizes and grades, however, the U-shaped production line and cell production system have to be based on manual work. Hence, it seems difficult to completely automate the finishing process.

4. Summary of Improvements in Quality Control and Productivity

What has been described so far can be summarized as follows.

○ Improvements in quality control
- Uniform dispersion of fine and ultra-fine particles as raw materials
- Prevention of segregation of material compound
- Stabilization of compound plasticity by strict air conditioning
- Breakaway from dependence on operator's skill by automation
- Improvement in traceability by introduction of IT

○ Improvements in productivity
- Reduction of cycle time and lead time
- Smoothing the flow of semi-finished products
- Automation and saving of labor by effective utilization of IT

Unlike metals, most refractories are made from particles without being passed through a melting process. This means that once any impurities are mixed into compound, they cannot be removed. Besides, there is no effective measures for remedying cracks or internal defects, etc. which can occur in bricks in the forming or firing process. It is, therefore, extremely important to implement strict quality control in each of the processes. To that end, the refractory makers have introduced in-process inspections using various types of sensors. Nevertheless, there are still many improvements to be made. In terms of productivity, they seek stable production by streamlining the discrete processes.

5. Conclusion

The refractory industry has made every possible effort to press ahead with technological innovations in order to follow up the rapid changes in the steelmaking processes and enhance the value added to refractory products. On the other hand, refractory makers have developed and improved various manufacturing processes not only to create new materials, but also to further stabilize product quality. What has been described in this paper represents only part of those efforts. We believe that in the future, R&D in the refractory industry will be spurred on as the results of use of its products by customers are fed back and checked against the history of manufacturing the products.

With regard to environmental problems, including recent concerns about global warming, the refractory industry recognizes these as important challenges to be met in the future. In this context, we think that the industry must press ahead not only with the recycling and reuse of waste refractories to help reduce industrial waste, but also with studies into a changeover from the present bricks fired at high temperatures to bricks fired at lower temperatures or non-fired bricks and on the promotion of unshaped refractories to help reduce CO_2 emissions.

As described so far, we will continue making every possible effort to enhance the value added to refractories and assure stable supply of high-quality refractory products while paying due attention to the environment at all times.

Reference

1) Technical Association of Refractories, Japan: Taikabutsu Notebook '97

Tsuneo KAYAMA
Director of Technical Research Laboratories, Krosaki Harima Corporation
1-1, Higashihama-machi, Yahata-nishi-ku, Kitakyushu-shi, Fukuoka-ken

Keisuke ASANO
Technical adviser, Krosaki Harima Corporation

Hiroshi EBISAWA
Executive councilor & director of Production Technical Center, Technical Dept., Krosaki Harima Corporation

Kazuyuki UENO
Manager of Technical Dept., Krosaki Harima Corporation