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*Technology*

# Recent Improvement of Recycling Technology for Refractories

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## Abstract

***The environmental problems caused by refractories have become an increasingly important issue in recent years. Many types of refractories are used in the iron and steelmaking process in the steel industry. Refractory waste is generated when the refractories are damaged and the production of steel becomes unstable. Most of the used refractories end up in landfill without recycling. However, there is a growing need for recycling from the viewpoint of reducing the costs of disposal by landfill outside a steelmaking mill and the purchase of new refractories. Therefore, we have developed a selection technology and voluminous recycling technology, and discovered a new use for used refractories.***


## 1. Introduction

Many of the ironmaking and steelmaking processes use refractories adapted to the operating conditions of furnaces and ovens. When the damage to refractories progresses to such an extent that the refractories can no longer perform their intended functions, they are dismantled. **Figure 1** shows the refractory recycle flow. The dismantled refractories are sorted, crushed, magnetically separated, classified, and dried as required. They are then recycled as refractories or used as submaterials (converter flux, for example). If the used refractories do not meet the quality required to be recycled as refractories or submaterials or their recycling is not economically viable, they are sold, used as base course materials, or landfilled. Given the mounting interest in environmental problems and the skyrocketing prices of refractory raw material in recent years, Nippon Steel Corporation has worked to reduce the landfill volume and to develop recycle applications with high economic viability. In this report, we describe the initiatives we have taken to recycle used refractories with the highest economic viability.[1)]

## 2. Issues with Refractory Recycling

### 2.1 Conventional refractory recycling technologies and issues

Among the used refractory recycling technologies reported in the past are the technology for reconditioning used sliding nozzle plates,[2)] reconditioning used bricks,[3)] applying used refractories as refining fluxes,[4)] and adding crushed particles of particular used bricks to monolithic refractories.[5)] Many of these technologies, however, were employed in limited applications and could handle at most a maximum of about 20% of the used refractories generated.

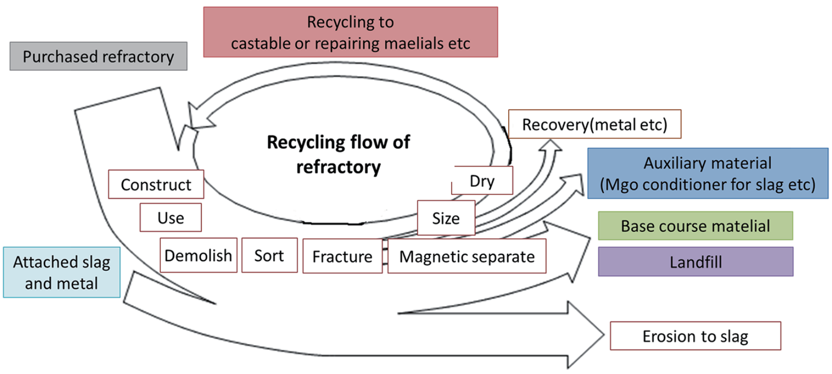


**Fig. 1 Schematic flow of refractories**

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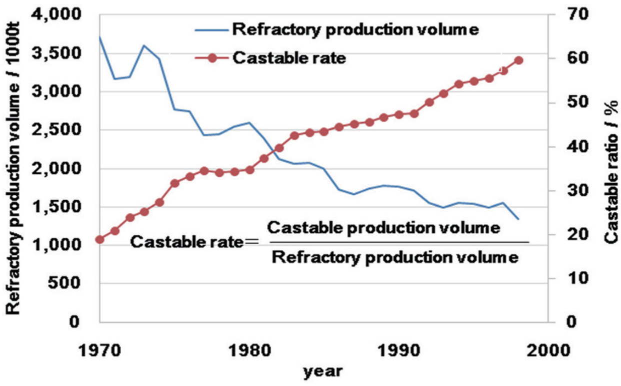


Fig. 2 Changes in refractory production volume and castable rate

Most of the remaining used refractories were landfilled or otherwise disposed of.

### 2.2 New issues in changing environment

In the past, many of the unrecycled used refractories were landfilled on the premises of steelworks or used as base course materials. In the 1990s, the landfilling of the premises was completed at one steelworks after another. Each steelworks was then faced with the mounting need for the volume reduction of used refractory waste. Recycling of used refractories changed from individual used refractories to all of the used refractories generated.

**Figure 2** shows the changes in the refractory production and the ratio of monolithic refractories among all refractories.[6] The refractories used in the ironmaking and steelmaking processes were switched from bricks to monolithic refractories. Bricks were used in furnace lining areas subjected to severe operating conditions and serious damage. Especially, permanent bricks came to be used as the last defense against molten steel leaks. Higher purity and performance were required of the refractory raw materials. These trends severely limited the recycle applications of used bricks and other used refractories. To expand the recycling of used refractories, it became essential to establish the technology for sorting monolithic refractories for recycling and the technology for using larger amounts of recycled refractory raw materials than in the past.

## 3. Developed Technology

### 3.1 Sorting technology

**Figure 3** shows an example of refractory recycling at a steelworks. Crushing, sorting, and classifying are the refractory processing steps performed traditionally. The technologies introduced to increase the recycling of refractories in recent years are described below.

3.1.1 Needs for and issues with sorting technology

Used refractories contain metal, slag, and other components harmful to refractories. To recycle the used refractories as refractory raw materials, it is necessary to remove these harmful components. As an example of the need for removing harmful components, the relationship between the content of FeO as a harmful component in refractory aggregate components and the melting point of the refractory aggregate components was examined (**Fig. 4**). As the FeO content increases, each refractory raw material decreases in refractoriness. In addition, the volume expansion from the oxidation of contaminating FeO and the reaction of contaminating FeO with the slag components cause cracks and abnormal damage to the refractories.

Conventional sorting methods mainly involved the attraction and removal of iron materials with a lifting magnet installed on a heavy machine or conveyor, and sorting with eyes and hands. These methods were unable to sort out weakly magnetic iron components mixed in refractories or imposed a heavy load on recycling workers. Monolithic refractories without particular shapes must be crushed into appropriate sizes for sorting. Regardless of the size of crushed pieces, the used refractories contain penetrated layers of FeO, slag, and other harmful components. Such harmful components must be visually sorted out from very fine crushed particles. This is a difficult piece of work. Particularly, the thickness of slag penetrated layers in carbon-free monolithic refractories is larger than in carbon-containing monolithic refractories. This makes it more difficult to remove harmful components. Carbon-containing monolithic refractories have little change in color with slag penetration and are difficult to sort out visually.

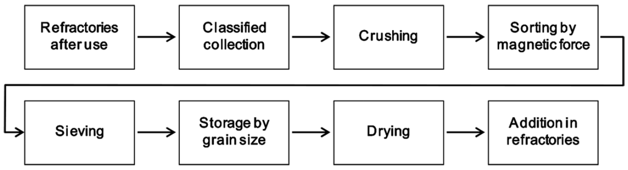


Fig. 3 Recycling processing flow of refractory after use

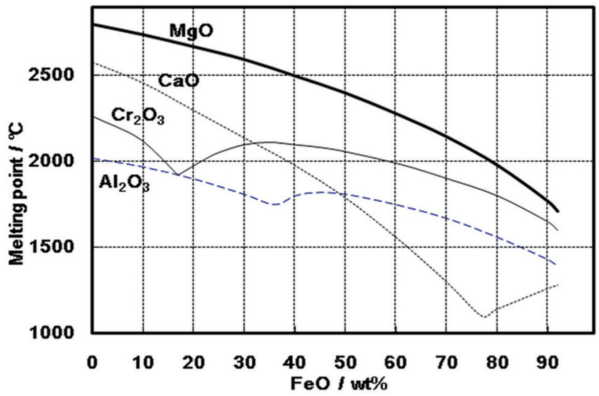


Fig. 4 Relation between FeO mixture amount and melting point of refractory

3.1.2 Introduction of high magnetic separators

**Figure 5** schematically illustrates a magnetic separator. Conventional magnetic separation is often performed with a suspended magnetic separator installed on a sorting conveyor. The conventional magnetic separator could efficiently remove skulls and other ferromagnetic materials built up on used refractory particles. Because its magnets were located distant from the material to be separated, however, it was not suitable for separating minute iron components, weak magnetic slag, and similar materials mixed in used refractory particles. Given this situation, a pulley-type magnetic separator with a minimum distance to the material to be separated out was adopted next. A high magnetic separator with a magnetic force of over 10000 G was introduced for thorough separation and removal of crushed magnetic particles. Small crushed magnetic particles difficult to sort out visually could now be separated from non-magnetic particles with this high magnetic separator.

A non-carbon-containing used refractory with a relatively high impurity content was crushed, separated into 5 to 10 mm particles, and magnetically sorted out. The results are shown in **Fig. 6**. Magnetic separation with the magnetic force of over 10000 G could reduce the total iron content, including iron oxides and compounds, to

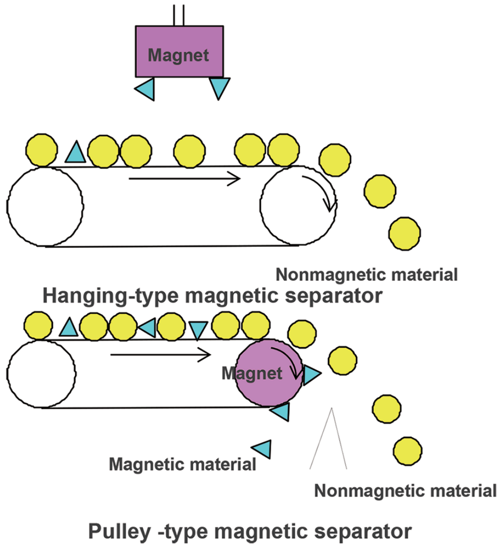


**Fig. 5 Schematic illustration of magnetic separator**

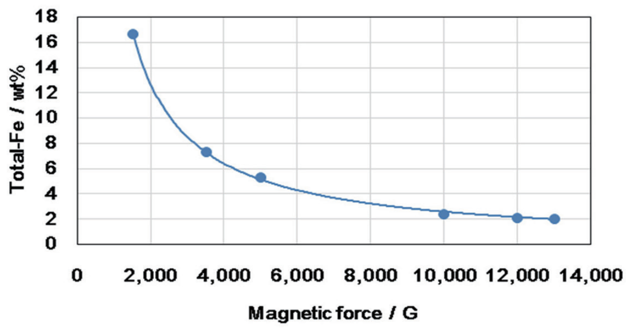


**Fig. 6 Relation between magnetic force and total-Fe amount in refractory**

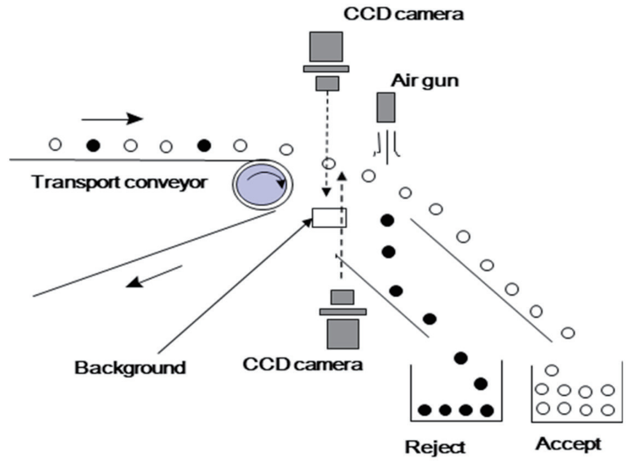


**Fig. 7 Schematic illustration of color sorting process**

| Particle size | Before sorting | After sorting |
|---|---|---|
| 10-20mm |  |  |
| 5-10mm |  |  |

**Fig. 8 Recycling refractory before and after color sorting process**

a low level of about 2 wt%.

It is advisable and effective to introduce a suspension-type magnetic separator together with a pulley-type magnetic separator. First, skulls and other ferromagnetic materials are removed by the suspension-type magnetic separator with superior processing capacity. Next, weak magnetic materials are removed by the pulley type magnetic separator with superior sorting accuracy.

3.1.3 Introduction of color sorters

Besides the aforementioned high magnetic separators, color sorters were introduced for removing nonmagnetic harmful slag components from non-carbon-containing refractory particles that readily change in color with the penetration of impurities. **Figure 7** shows a schematic illustration of color sorting. Refractory particles before and after color sorting are shown in **Fig. 8**. The color sorter is mainly intended for non-carbon-containing monolithic refractory particles and preset with the colors of virgin refractory particles in the background. The color change of refractory particles with slag penetration is distinguished with a CCD camera. Non-matching refractory particles are blown with air from an air gun to change their flight distance and are sorted out. This separation of non-slag-penetrated recycled refractory raw materials from slag-penetrated recycled refractory raw materials makes it possible to sort out higher-grade recycled refractory raw materials.

The air guns of some color sorters do not have sufficiently high capacity to blow off larger refractory particles and the sorting accuracy consequently suffers. In such a case, it is necessary to set the sorter capacity to the grade of recycled refractory raw materials to be handled or to re-crush the recycled refractory raw materials into appropriate particle sizes.

We have described above the methods of sorting out and removing harmful components mixed in used refractory particles and of recovering good-quality recycled refractory raw materials. If the threshold for good refractory particles is set too high, the volume of recycled refractory raw materials to be reused naturally decreases. It is thus important to change the sorting threshold to meet the refractory applications described later and to make and manage plans for producing recycled refractory raw materials to the desired grade.

## 3.2 Technology for applying large amount of recycled refractory raw materials

With the conventional technology for adding a large amount of recycled refractory raw materials to monolithic refractories, recycled refractory raw materials outside the large end of the particle size range of the original refractory raw materials are added to the original refractory (**Fig. 9**). This is generally called the "outer percentage addition" method.

This method had an upper limit set for the amount of recycled

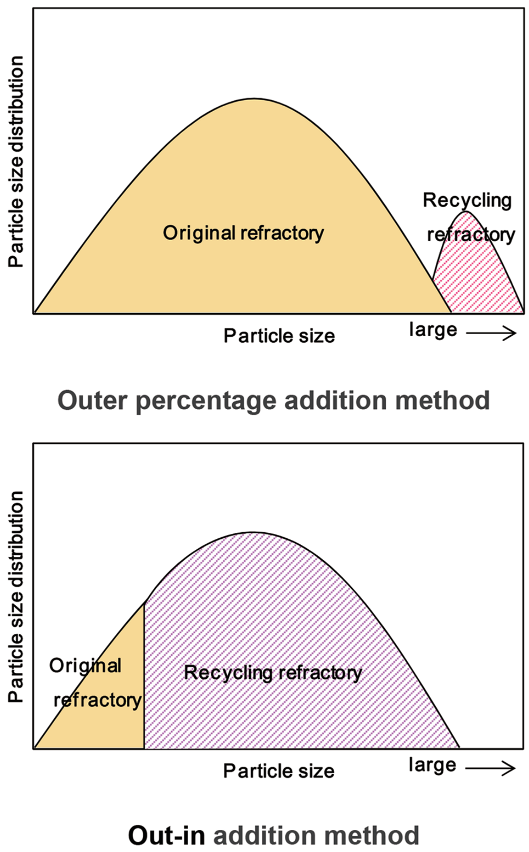


**Fig. 9 Schematic diagram of recycling refractory addition method**

refractory raw materials added by grade to maintain the packing capacity of the original refractory. It was thus difficult to use a large amount of the recycled refractory raw material. Also, because the applicable particle size was limited to the large end of the particle size range and the refractory installation method was limited to casting, the applications were severely restricted. In other words, to use a larger amount of recycled refractory raw materials, technology was required for doing so within the particle size composition without sacrifice to the properties of monolithic refractories.

For this reason, the "out-in addition" method was devised to increase the usage of recycled refractory raw materials.[7] According to this method, the recycled refractory raw material is added in specific size fractions of the monolithic refractory by referring to the appropriate particle size composition as an index, such as that defined by Andreasen's continuous particle size distribution equation.[8] The appropriate particle size composition is achieved by using the virgin raw materials. The out-in addition method can use the recycled refractory raw materials not only for castable refractories, but also for other monolithic refractories such as gunning and troweling repair refractories. The applications of recycled refractory raw materials have been significantly expanded by the out-in addition method.

### 3.3 Development of recycled refractory applications

As the application range of recycled refractory raw materials is expanded, recycled refractory raw materials are included among the used refractories to be recovered and are repeatedly used. This condition was feared to concentrate harmful components little by little in refractory raw materials. Against this possibility, a "one rank down" method was conceived. Recycled refractory raw materials are classified by application areas into high-grade, medium-grade, and low-grade refractories. The recycled refractory raw material is sequentially added and used as high-, medium-, and low-grade refractories.[9] **Figure 10** shows the relationship between the added amount of recycled refractory raw materials and the durability of refractories made with the addition of the recycled refractory raw materials.

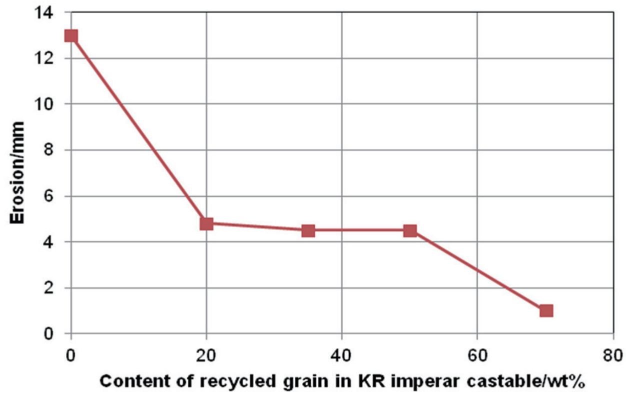


**Fig. 10 Relation between addition amount of recycling refractory and resistance properties of castable**

When crushed particles of used sliding nozzle plate bricks were added as high-grade recycled refractory raw materials to monolithic refractories composed of medium-grade raw materials, the durability of the resultant monolithic refractories was confirmed to have improved and their operating life improved more than 20% on real equipment as compared in the past.[10]

Low-grade used refractories are intended for use as gunning repair materials and are utilized in an increasing amount in this application. Dedicated machines such as continuous kneaders for recycled refractory raw materials are developed to improve the ease of operation.[11]

A new application is developed for recycled refractory raw materials as protectors for the hearth bricks of hot rolling reheating furnaces.[12] In the past, when built-up scale penetrated and adhered to the hearth bricks of reheating furnaces, they had to be removed together with the hearth bricks. A recycled refractory raw material of appropriate particle size composition was spread as protector on the hearth bricks. This application sharply reduced the dismantling labor and the repair cost of reheating furnace hearth bricks.

In recent years, technology has been developed for recycling ceramic fibers frequently used in long-life equipment such as hot rolling reheating furnaces. Used ceramic fibers are different from the lumpy used refractories described so far. Due to their low bulk specific gravity, much labor and money is required to dispose of them. When used ceramic fibers are defibrillated and formed, they can be recycled.[13]

## 4. Summary and Future Prospects

In recent years, the development of new technologies for the recovery, sorting, and application of used refractories has advanced. The recycling of refractories was limited to particular refractories in the past but has now progressed into the recycling of all of the used refractories generated in the iron and steel recycling processes. Sharp reduction in the final disposal volume is reported at the production facilities of ironmaking and steelmaking processes.[14] We will continue to develop new refractory recycling technology to contribute to our environmentally friendly society while adapting to changes in refractory recycling technology.

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