

# 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 the recent years. The main problems are the work environment during installation and use of refractories, energy and natural resource conservation, and the global environment. Many kinds of refractories are used in the iron and steelmaking processes in the steel industry. The refractory waste generated when they are damaged and the production of steel becomes unstable when the refractories are replaced with new refractories. Therefore, we have made it our mission to achieve zero waste from spent refractories. The objectives of this research are to save energy and resources, maintain a site for spent refractories, and reduce the amount and cost of refractories.*

## 1. Introduction

In the ironmaking and steelmaking processes at steelworks, various types of refractories are used for the linings of furnaces for smelting, refining and conveying operations. When the degree of damage to the refractory lining of a furnace becomes such that stable operation of the furnace can no longer be ensured, the refractory lining is broken down and discarded. In recent years, there has been growing pressure to reduce the volume of waste refractories in the iron and steel industry.

In order to reduce the volume of waste refractories, it is necessary to cut back on their consumption by prolonging the life of furnace linings. On the other hand, it has become increasingly important to promote effective utilization of waste refractories. In the past few years, the individual steelworks of Nippon Steel have been pressing ahead with the recycling of waste refractories. This paper describes the recent improvements in refractory recycling technology and the company's activities to reduce waste refractories.

## 2. Problems in the Recycling of Used Refractories

Concerning the handling of used refractories, let us consider an

example at Nippon Steel's Oita Works (in 2001). Of the average monthly refractory consumption of 4,100 tons, 24% (1,003 tons) constituted waste refractories. Most of those waste refractories—about 750 tons—were reused as roadbed material or landfill (**Fig. 1**).

In recent years, Nippon Steel has been forcefully promoting the “Zero Emissions” concept as advocated by the United Nations University. This concept aims to completely eliminate waste material from within the production cycle in the industrial world and thereby

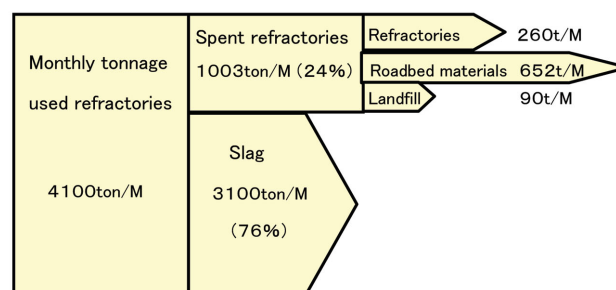


Fig. 1 Simplified flowsheet for used refractories in the steel works (2001 Oita Works)

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establish a recycling-based industrial system. In this context, the company has formulated a refractory recycling plan whereby waste refractories which accumulate daily at its steelworks can effectively be reused as resources within the steelworks, rather than simply sending them to be used as roadbed material or landfill outside the steelworks. However, when it comes to recycling waste refractories within the steelworks, there is the possibility that impurities (slag, base metal, etc.) which become mixed in with the waste refractories would cause inadequate wear resistance of any refractory lining made from recycled material. Thus, the success or failure of waste refractory recycling depends on whether they can be completely cleansed of degraded elements and impurities.

3. Concept behind the Recycling of Waste Refractories

As a means of achieving zero emissions, the 3 R's—Reduce, Reuse, Recycle—can be considered (see Table 1). “Reduce” refers to activities to reduce the consumption of refractories, such as by decreasing the burden of furnace operations on the refractory lining and increasing the durability of the refractory lining. “Reuse” means using waste refractories as auxiliary raw materials and slag modifiers, etc. “Recycle” means reusing waste refractories as materials for furnace linings. In particular, Nippon Steel pays special attention to converting waste refractories into monolithic refractories and using them as repair materials.

4. Technologies Required for Recycling Waste Refractories

Fig. 2 shows an outline of the typical refractory recycling process introduced by the steelworks at Nippon Steel.<sup>1,2)</sup> The technologies required of the individual steps in the process are described below.

4.1 Pretreatment technology

4.1.1 Collecting, sorting and categorizing used refractories

For any given furnace, several different types of refractory are used at different parts of the furnace. The old refractories that are torn down from the furnace are a mixture of different types of refractories. Therefore, simply collecting and using them directly as a recycled material is undesirable from the standpoint of refractory quality control. For this reason, when old refractories are torn down, they are sorted and categorized into MgO refractory, Al<sub>2</sub>O<sub>3</sub> refractory, carbon-containing refractory, and carbon-free refractory, etc. Even those refractories which have been sorted and categorized as mentioned above may have different types of refractories and large pieces of iron and slag mixed in them. In this case, it is necessary to break them down using heavy-duty machinery (see Fig. 3) and remove the

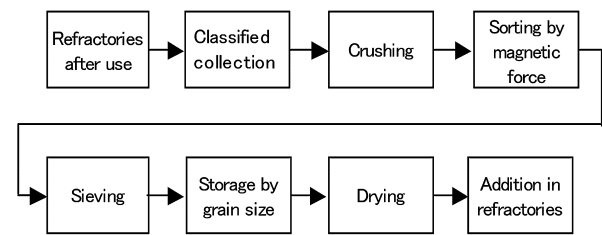


Fig. 2 Recycling process image of refractories



Fig. 3 Classified collection of spent refractories

different types of refractories and pieces of iron and slag manually or magnetically. In this process, the old refractories are roughly crushed into pieces of 200 to 400 mm so that they can easily be handled in the subsequent crushing/pulverization steps.

4.2 Technology to regenerate old refractories collected

4.2.1 Improving the efficiency of crushing/pulverization

In order to remove minute impurities from the old refractories that have been collected as described above and to render the refractory particles into a uniform size, the refractories are crushed and pulverized. According to the size and type of refractory, impact energy or compressive energy or shear energy is used to reduce the refractory particle size (see Fig. 4). Fig. 5 shows the equipment installed at Oita Works to crush and pulverize waste refractories. With this equipment, it is possible to crush waste refractories which have been roughly crushed down from sizes 200 to 400 mm to 20 mm or less, and recover them according to their particle size.

Fig. 6 shows the temporary storage conditions for old refractories which have been crushed and pulverized. Fig. 7 shows crushed and pulverized refractories which have been bagged for easy distri-

Table 1 Concept of 3R – reducing and recycling spent refractories –

Reduce	<ul style="list-style-type: none"><li>• Relaxation of operating condition Continuous operation, operation at lower temperature</li><li>• Lifetime extension of refractories High purity materials, optimum installation</li><li>• Lifetime extension by repairing Veneering repair, shotcrete, gunning</li></ul>
Reuse	Slag conditioners, raw materials used for refining, refractory sand, roadbed materials, etc.
Recycle	Reuse of SN plates, ladle shroud, spent brick, recycled products, landscape brick, unshaped refractories

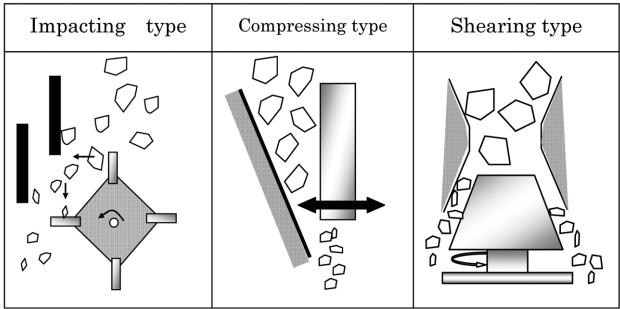


Fig. 4 Modes of crushing and milling



Fig. 5 Photograph of crushing and milling equipment



Fig. 6 Temporary place after crushing and milling



Fig. 7 State that was cut down in a container bag after crushing and milling

bution and addition to monolithic refractory at the work site. When recycled refractories are added to monolithic refractory while being mixed with water, it does not matter much if they contain water. However, when recycled refractories in the form of dry powder are pre-mixed with monolithic refractory, they need to be stored in bags to prevent the absorption of moisture.

#### 4.2.2 Removal of iron and slag

There are various methods of magnetically removing iron from waste refractories. Nippon Steel has adopted a magnetic suspension-type iron separation system which has proven performance in removing pieces of iron from raw materials for cement, glass, and coke (see Fig. 8). The type shown in Fig. 8(a) is suitable when the amount of iron to be removed is relatively small, while the type shown in Fig. 8(b) is suitable for larger iron pieces or when the iron removal process continues for many hours. Fig. 9 shows the relationship between the iron content of the refractory and the magnetic force required to remove the iron. A prescribed amount of iron pieces 5 to 10 mm in size were mixed in with ladle refractory particles of the same dimensions, and the mixture was subjected to magnetic separation.

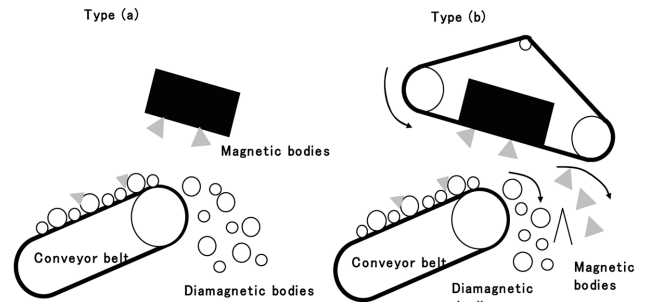


Fig. 8 Schematic image of sorting by magnetic force sieving

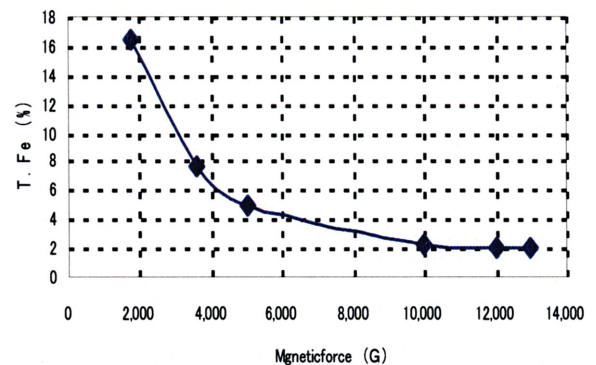


Fig. 9 Influence of magnetic force on the total Fe content in spent refractories

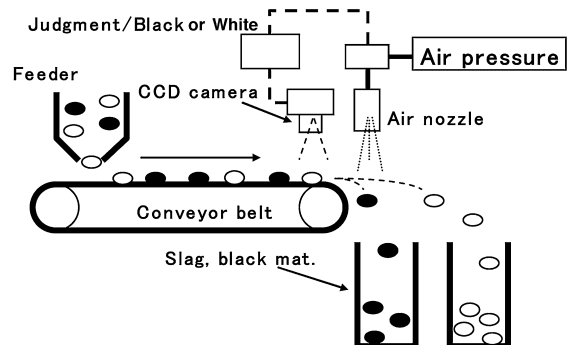


Fig. 10 Schematic view of a color-sorting device

As a result, it was found that the amount of T-Fe could be reduced to 2% or less by applying a magnetic force of 12,000 G or more. The individual steelworks of Nippon Steel select the most suitable magnetic separation system (Fig. 8(a) or (b)) and a suitable magnetic force according to the specific operational conditions and refractory type.

For the removal of slag, the company introduced a color-based sorting system, the configuration of which is shown schematically in Fig. 10.<sup>3)</sup> This system uses air pressure to sort materials with a strong contrast between black and white. It has proven performance in removing grit and other foreign matter from cereals, beans and other foodstuffs. The system is especially effective for removing the dark black iron pieces and slag from the light white-colored recycled  $Al_2O_3$  brick.

#### 4.2.3 Particle size management

When it comes to reusing recycled refractories which have been crushed, pulverized and cleansed of iron and other impurities, it is



best to sort and manage them according to particle size. Ordinary metallic mesh sieves are used to classify them. Mesh sizes are decided according to the purpose of classification. The largest mesh sieve is set at the top stage and the smallest at the bottom, with the intermediate mesh sieves set between them in order of mesh size. Since waste refractories waiting to be crushed are continuously loaded into the set of sieves, it is possible to classify large volumes of refractories by constantly vibrating the sieves. The company employs a vibrator which is capable of applying horizontal and vertical vibrations at the same time and which permits changing the mode of operation freely. By selecting the optimum operational mode for the vibrator according to the type and shape of the waste refractory, the efficiency of classification can be maximized.

4.2.4 Measures against dust

Dust is an integral factor in the process of crushing, pulverizing and classifying waste refractories to be recycled. This dust poses an environmental problem. Therefore, all the equipment used in the above process is completely covered so as to prevent the dust produced from spreading about. In addition, a dust-collecting system is installed to remove the dust. Dust is collected in a manner appropriate to the type of waste refractory to be recycled. Collected dust is used mainly as a raw material for landscape bricks,<sup>4)</sup> which are used to add to the aesthetic appeal of parks (see Fig. 11), and as flowerbed retainers in gardens, and so on.

4.3 Manufacturing refractory containing recycled material

4.3.1 Drying

When a recycled material is added to the monolithic refractory in the mixing process at the construction site, it need not be dried. However, there are some recycled materials, like that used for shot repair, which are pre-mixed with monolithic refractory and put in a tank for the shot repair machine at the construction site. In this case, if the recycled material contains any moisture, there is the distinct risk that it may harden through reaction with, say, a raw material with cement while in storage. Therefore, when a mixture of monolithic refractory and a recycled material is stored for many hours before use, it is necessary to dry the recycled material before it is mixed with the monolithic refractory. Fig. 12 shows a rotary kiln which is used to dry recycled materials.

4.3.2 Composition control technology

(a) Concept of addition of recycled material

The typical particle size distribution of a monolithic refractory material used at actual construction sites is shown in Fig. 13 (indicated by Curve A). A recycled material whose particle size distribution is on the large side (indicated by Curve B) is added to the mono-

lithic refractory material. The rate of addition of the recycled material is indicated by a ratio to the total of particle size distributions A + B. Fig. 13 shows an example of the addition of a recycled material to a castable. The particle size of the recycled material added to the castable is in the range 5 to 20 mm or 1 to 5 mm. In the case of wet gunning materials, the particle size of recycled materials added is in the range 1 to 5 mm. For dry gunning materials, recycled materials comprised of fine particles 1 mm or less are added.

Fig. 14 shows how the rate of addition of recycled materials influences the properties of castable. With the increase in the addition rate of recycled materials, the amount of water that must be added to maintain the same fluidity of the castable increases and the porosity of the castable increases at the same time. As a result, the wear resistance (durability) of the castable tends to decline. It is, therefore, necessary to determine the optimum rate of addition of recycled materials and the parts to which they are applied taking the above influences into consideration.

(b) Concept of application of recycled materials (“one rank down” method)

Recycled refractory materials are cleansed of iron and slag by magnetic separation and suchlike. Technically speaking, however, removing such impurities completely is impossible. As shown in Fig. 14, when 20% of recycled material is added to castable, the wear resistance of the castable decreases slightly. This was considered due to impurities contained in the recycled material. Therefore, with the aim of studying the influence of impurities contained in recycled materials on the properties of castable, we calculated the concentration of recycled materials against the increase in number of times of recycling (Table 2).



Fig. 11 Use of landscape bricks at bayside park in Oita City



Fig. 12 Appearance photograph of the rotary kiln

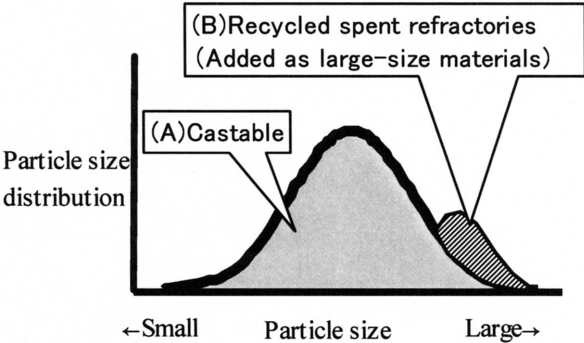


Fig. 13 Concept of the addition of recycled materials

It might be imagined that with the increase in the number of recycling cycles, the concentration of recycled materials would increase noticeably. Actually, however, since 80% of the refractory material used for refractory lining is always fresh new material, it may be said that the concentration of recycled materials does not increase much. Assume, for example, that recycled materials are added to castable a total of 20 times. In this case, the recycled materials added at the 20th time include some used in the actual furnace from the 1st through to the 19th time. Of them, more than half are recycled materials previously used in the actual furnace. Recycled materials used four times account for 98% of them. Thus, it was found that the proportion of recycled materials which are used five or more times and

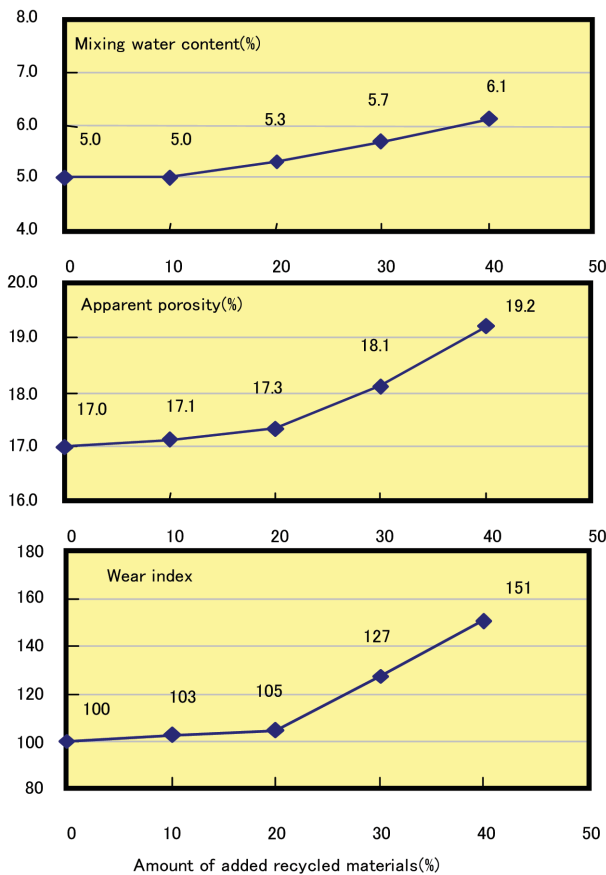


Fig. 14 Influence of amount of added recycled materials on the properties of castable

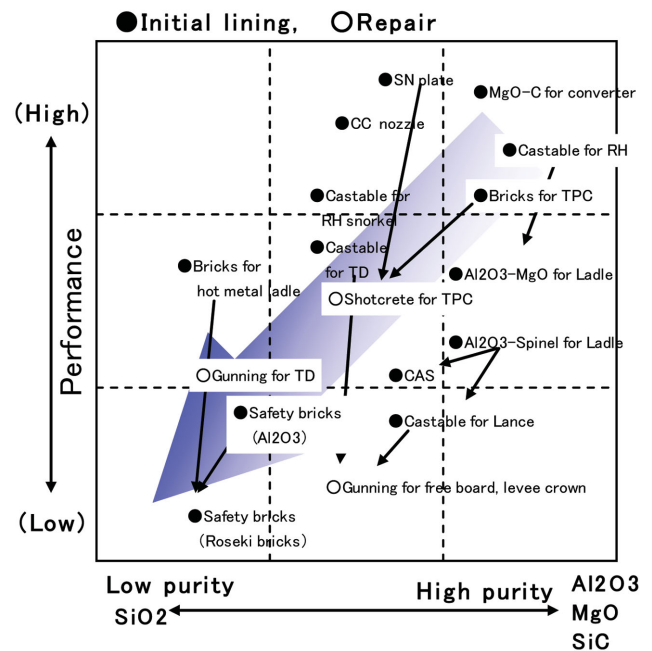


Fig. 15 Possible applications for spent refractories

which are therefore inferior in quality is negligible.

Even so, it is undeniable that the addition of recycled materials causes the castable's wear resistance to decline. The reason is considered to be that SiO<sub>2</sub> and CaO—components of slag contained in recycled materials in small amounts—tend to react with high-purity Al<sub>2</sub>O<sub>3</sub>, MgO and SiC from the fresh castable to form compounds with a low melting point. The refractory materials that are actually used in the furnaces of steelworks vary widely in grade according to the furnace parts to which they are applied. Therefore, we devised what we call the “one rank down” method in which recycled materials which have been added to a high-grade refractory material are next added to an intermediate-grade refractory, and then to a low-grade refractory (see Fig. 15). This approach is positively adopted at our steelworks.

## 5. Implementation Conditions for Recycling of Waste Refractories

Employing the refractory recycling technology as described so far, Muroran Works, Kimitsu Works, Nagoya Works, Yawata Works and Oita Works of Nippon Steel are recycling waste refractories in

Table 2 Concentration of spent refractories by repeating recycle (castable added 20% recycled spent refractories)

Recycling number	1st	2nd	3rd	4th	5th	10th	20th
virgin material (%)	100	80	80	80	80	80	80
Number of used refractories							
1		20	16	16	16	16	16
2			4	3.2	3.2	3.2	3.2
3				0.8	0.6	0.64	0.64
4					0.2	0.128	0.128
5						0.0258	0.0256
6						0.0051	0.00512
7						0.001	0.001024
8						0.0002	0.0002048
9						5.E-05	4.098E-05
10							8.192E-06

earnest. **Fig. 16** shows the change in recycling rate at Nippon Steel from 2001, when the company started its recycling activity, until 2005, when the company completed its improvements to its recycling technology. By continually improving our recycling technology, it has become possible to obtain high-quality recycled materials. As a result, the recycling rate has increased. In addition, as part of our activities to achieve zero emissions, the use of waste refractories as a roadbed material has been reduced significantly and the use of waste refractories as landfill, which poses an environmental problem, has been reduced to zero.

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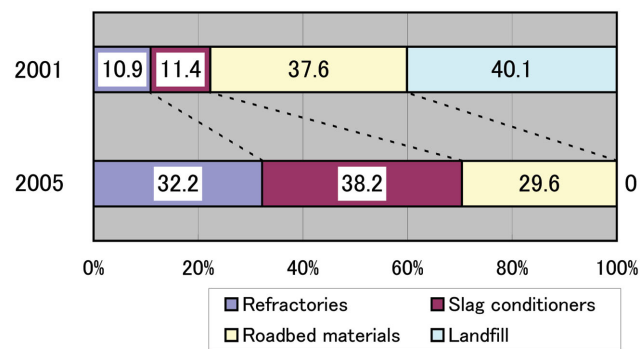


Fig. 16 Comparison of recycled refractories in 2001 and 2005



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