IMPROVEMENT OF MgO-C BRICKS ABRASION WEAR RESISTANCE FOR BOF SCRAP IMPACT AREA

Ryoma Fujiyoshi, Masaazu Iida, Atsuhisa Iida, Atushi Torigoe
Shinagawa Refractories Co., Ltd., Bizen, Japan

1. INTRODUCTION

As is generally accepted, reduction of greenhouse gas emission is one of the most important tasks for all industrial sectors. For integrated steel mills, increase in steel scrap as raw material is an effective measure since it decreases use of hot metal from the blast furnace which emits large amount of CO_2 gas. Therefore, the amount of scrap charged to the Basic Oxygen Furnace (hereinafter, referred to as BOF) has been increasing. The increase in steel scrap charging accelerates the wear of the scrap impact area. As shown in **Fig. 1**, the charging pad of the BOF is the part to which the charged scrap and molten iron collide. Particularly, heavy scrap charging seriously damages MgO-C bricks installed on the charging pad. Thus, it is obvious that mechanical abrasion is the dominant factor of refractory wear there.

In order to reduce the wear caused by mechanical abrasion, improving refractory strength had been considered to be the most effective measure[1]. Therefore, we have evaluated the effect of various strength-improving technologies on abrasion resistance by sand blasting abrasion experiment. Through the numbers of laboratory investigations, however, it was found that the results of the sand blasting experiment didn't always agree with the strength evaluation results. We thought that if the sand blasting abrasion resistance was more accurate parameter than strength, there might be more effective measures to reduce wear of charging pad of BOF.

In this article, the development of a superior abrasion resistant MgO-C brick for the charging pad of the BOF, according to detail investigations of mechanical abrasion wear, is described.

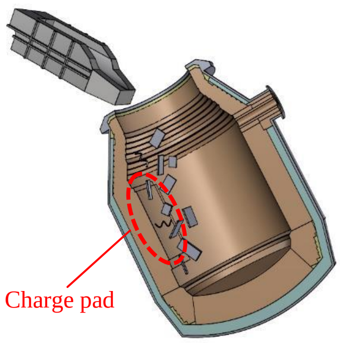

Fig. 1 Schematic illustration of scrap impact damage of BOF charge pad.

2. THE PROPERTY INFLUENCING ON SAND BLASTING ABRASION RESISTANCE

As mentioned above, it was found that strength is not the most significant property for sand blasting abrasion resistance. In order to identify the dominant factor, three materials, which had shown large deviation between sand blasting abrasion resistance and strength, were selected empirically. Various properties of these three materials were evaluated, followed by comparison to sand blasting abrasion resistance.

The accuracy of the sand blasting abrasions experiment was validated by comparing the status of the specimen after the sand blasting experiment and the specimen on which steel block had been experimentally dropped down.

While evaluation under hot condition is suitable, all evaluations in this section were carried out at room temperature since the steel block drop impact experiment under hot condition was impossible.

2.1. Experimental Procedure

The typical properties of the selected MgO-C bricks are summarized in **Table 1**.

Table 1 Properties of MgO-C bricks for evaluation

	Sample A	Sample B	Sample C
MgO / mass%	71	77	79
F.C. / mass%	26	16	17
Bulk specific gravity / -	2.73	2.99	3.03
Cold crushing strength / MPa	44	50	30

These materials were heated at 1200 °C in a coke breeze-filled saggar for 3 h utilizing an electric furnace followed by property evaluations. The Archimedes method was employed to determine the apparent porosities and bulk specific gravities. The modulus of rupture (hereinafter referred to as MOR) and dynamic elastic modulus were measured for rectangular specimens of 40 × 40 × 160 mm by three point bending method and grind sonic method, respectively.

Fracture energies of each material were evaluated for specimens in the shapes of 40 × 15 × 150 mm without notches by three point bending method. The thinnest plane of the specimen was put on the two supporting pins set in the span of 100 mm. A vertical bending force was loaded on the center of the specimen, at a rate of 0.1 mm/minute gauging bending displacement. Fracture energies were evaluated from the integral of the load-displacement curves.

The sand blasting abrasion experiments were carried out with 114 × 114 × 65 mm specimens according to JIS R 2252-1. 1 kg of SiC particles between 350 and 850 μm were blasted to the specimens' surfaces with a sufficient amount 350 kPa of compressed air for 7.5 minutes followed by abraded volume evaluation. The details are described in our previous work [2]. Additionally, microstructures of post abrasion experiment specimens were observed by optical microscope.

The state of the brick to which charged steel scrap collided was verified by steel block drop impact experiment. **Figures 2 and 3** show a schematic illustration of the experiment and appearance of apparatus, respectively. 20 100 × 80 × 400 mm bricks in size of were assembled in a steel box and screwed up tightly. Onto the brick-assembled structure that tilted for 30 º from the horizontal, a steel block of 12 kg was dropped from 2 m height followed by observation of the brick to which steel block was collided. Sample B was subjected to the steel block dropping experiment.

2. 2. Result

Table 2 summarizes the evaluated properties and **Fig. 4** shows the appearances and cut surfaces of the specimens after the sand blasting abrasion experiment. The wear volume of sample A was the smallest, and the abrasion volume increased in sample B, and increased more in sample C.

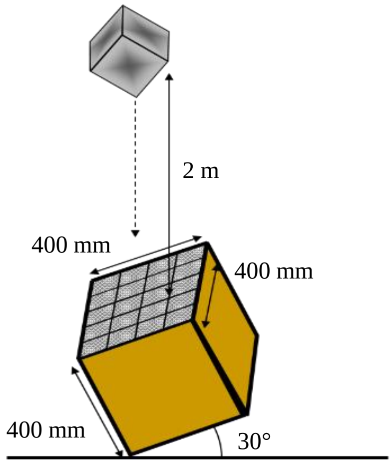

Fig. 2 Schematic illustration of steel block drop impact test.

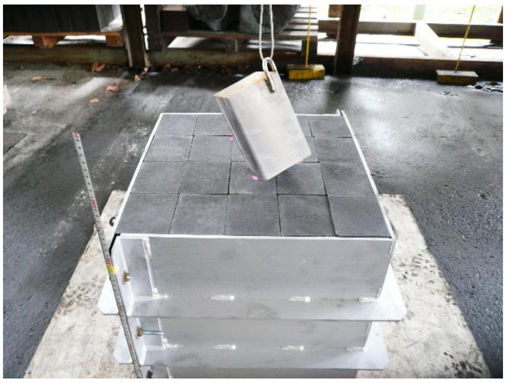

Fig. 3 Appearance of steel block drop impact test.

Table 2 Evaluated properties of MgO-C bricks after heating at 1200 °C in coke breeze for 3 h

	Sample A	Sample B	Sample C
Apparent porosity / %	8.8	7.3	8.5
Bulk specific gravity / -	2.92	2.73	2.97
MOR / MPa	8.9	10.7	5.1
Elastic modulus / GPa	8.5	18.6	7.0
Fracture energy / J	0.38	0.25	0.19
Abrasion index / -	100	173	241

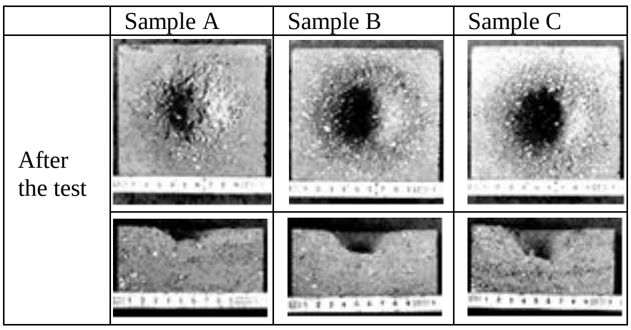

Fig. 4 Appearance and cut surface after the sand blasting abrasion experiment.

Figures 5 and 6 show the influence of the MOR and fracture energy on the sand blasting abrasion volume associated with the result of regression analysis, respectively. While negative slopes were determined for the scatter plot of the abrasion index for the MOR, the determination coefficient (R^2) was smaller. On the other hand, strong correlation was recognized for the relation between abrasion index and fracture energy.

Correlations of the abrasion indexes between each property are summarized in **Table 3**. Obviously, the abrasion index showed strongest susceptibility to fracture energy.

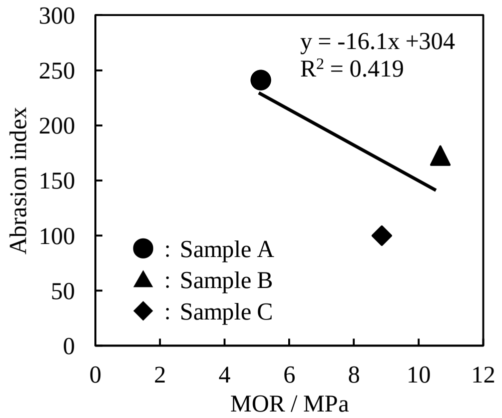

Fig. 5 Relationship between the abrasion index and MOR.

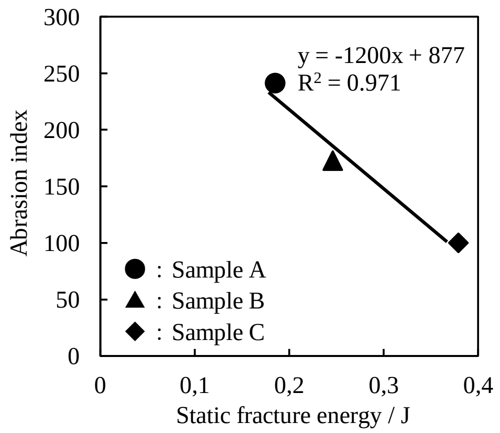

Fig. 6 Relationship between abrasion index and fracture energy.

Table 3 Results of regression analysis for scatter plot of abrasion index for each property.

Properties	regression line	Coefficient of determination
Elastic modulus	y = -1.13x + 184	0.013
Modulus of rupture	y = -16.1x + 304	0.419
Apparent porosity	y = -18.3x + 321	0.588
Bulk specific gravity	y = 100x - 118	0.908
Fracture energy	y = -1200x + 877	0.963

Figure 7 shows the microstructure of the abraded surface of the specimens after a sand blasting abrasion experiment. Initiation and propagation of micro cracks were confirmed.

Figures 8 shows the appearance of the specimen on which the steel block dropped down. The steel block collided part is scraped off and a defect was observed. The state of the side surface of the steel block collided part is shown in **Fig. 9**. Crack propagation from the scraped area was observed.

2. 3. Discussion

According to the regression analysis, a strong correlation between abrasion resistance and fracture energy was confirmed. It is well-known that fracture energy corresponds to overall energy consumption for the creation of a new surface by cutting the bond formed in the brick structure. Since the creation of a new surface is equivalent to crack propagation, fracture energy is the parameter for crack propagation resistance.

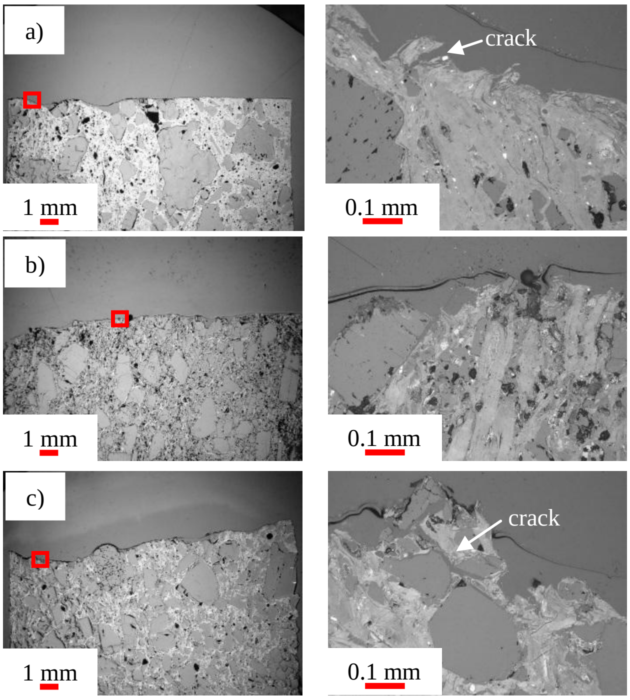

Fig. 7 Micro structure of wear surface of sample after sand blasting test. a) Sample A, b) Sample B, c) Sample C

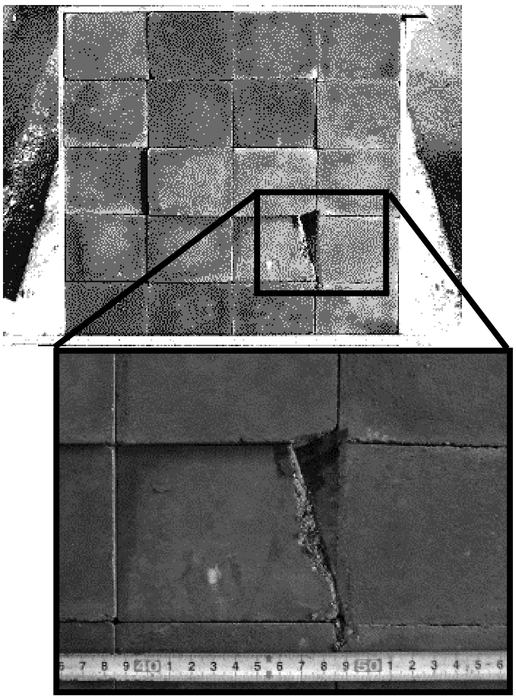

Fig. 8 Photos of surface after test.

Hence, it was concluded that the critical factor of brick abrasion caused by sand blasting is crack propagation occurring in microscopic scale. During the sand blasting experiment, abrasive particles continuously hit the brick surface, resulting in crack initiation and propagation. The part surrounded by propagated cracks would remove from brick body.

On the surface of the specimen that was subjected to the steel block dropping experiment, crack propagation was observed at a microscopic scale. If numbers of steel block hit the brick continuously, cracks might propagate and link together. This is how the charging pad of a commercial BOF wears. Therefore, crack propagation is considered to be essential for BOF charging pad wear.

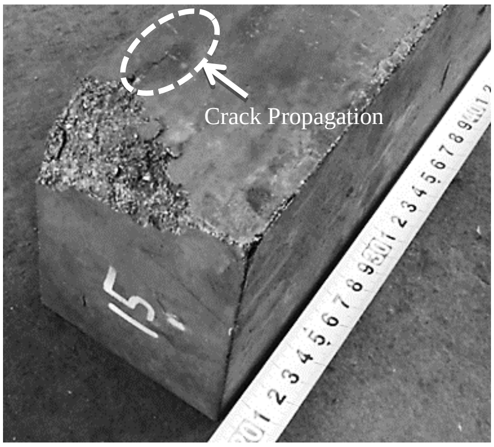

Fig. 9 Appearance of bricks after test.

For both cases, i.e., the sand blasting experiment and scrap charging, crack propagation is significantly important. Thus, it is acceptable to assume that sand blasting abrasion experiment is an accurate method to reproduce the wear of the BOF charging pad. Accordingly, it is predictable that increasing fracture energy is effective for improving abrasion resistance of bricks for charging pad.

3. DEVELOPMENT OF HIGH ABRASION RESISTANCE BRICK FOR BOF CHARGING PAD

Based on the above discussion, improvement in the MgO-C brick fracture energy was attempted by laboratory experiment. Through a series of experiments, two effective methods were newly developed; one was to reinforce the matrix by special microstructure optimizing technology and the other was to enhance the carbon bond by applying novel processing technology.

Table 4 provides properties of bricks for the BOF charging pad. Conventional material was designed to achieve high hot modulus of rupture (hereinafter, referred to as HMOR) measured at 800 °C. New technologies were applied to two developed bricks. Since these are the materials for commercial application, fracture energies were evaluated at 800 °C in an argon gas flow.

Table 4 Properties of MgO-C bricks for field trial

	Base	1st step	2nd step
Remarks	Conventional	Matrix reinforced	Carbon bond enhanced
MgO / mass%	77	79	79
F.C. /mass%	15	13	14
Bulk specific gravity / -	2.99	2.97	2.92
Cold crushing strength / MPa	50	54	52

HMOR at 800 °C / MPa	16	11	13
Fracture energy at 800 °C / J	0.26	0.40	0.49

Figure 10 shows load-displacement curves of the materials. The Evaluating conditions were identical to the conditions described in subsection 2.1. except for temperature and atmosphere. The HMORs and fracture energies shown in **Table 4** were obtained from **Fig. 10**. While the HMORs of two developed materials were smaller than the conventional one, noticeable improvement of fracture energies were evaluated.

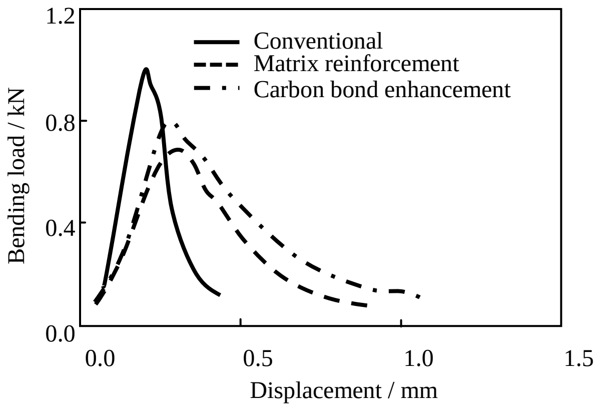

Fig. 10 Load-Displacement curve obtained from three-point bending test.

These materials were applied to a commercially operating BOF. Chronologically, matrix reinforced material was developed prior to the development of carbon bonding enhanced material. As a consequence, matrix reinforced material, which had showed relatively lower fracture energy compared to carbon bonding enhanced material, had been used for commercial application.

As shown in **Fig. 11**, superior abrasion resistances were recognized for the developed materials, particularly for carbon bonding enhanced materials. **Figures 12 and 13** show influences of the HMOR and fracture energy on the wear rates of a BOF charging pad, respectively. As is obvious, fracture energy showed strong correlation to the wear rate of a commercially operated BOF charging pad.

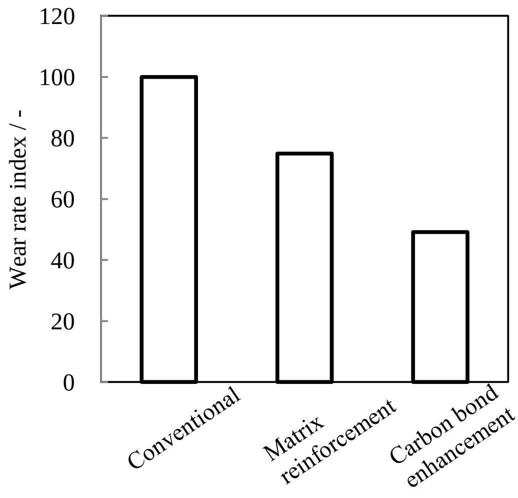

Fig. 11 Wear rate index.

Hence, the folloing assumptions, (1) the sand blasting abrasion experiment is an accurate method for reproducing the wear of the BOF charging pad, and (2) increasing the fracture energy is effective for improving the abrasion rsistance of bricks for the charging pad of BOFs, were validated by commercial application. According to the investigations, high fracture energy material that applied novel carbon bonding enhancing technology is reccomendable for the BOF charging pad.

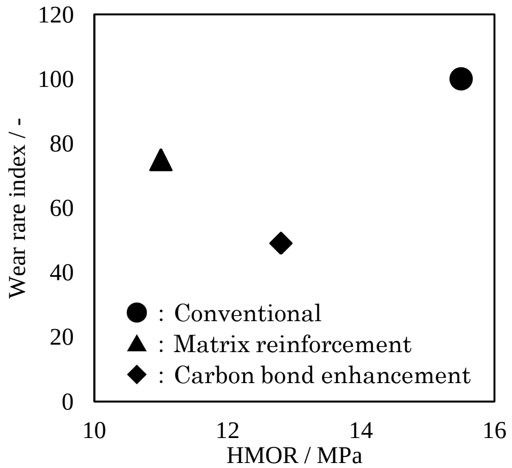

Fig. 12 Relationship between wear rate index and HMOR.

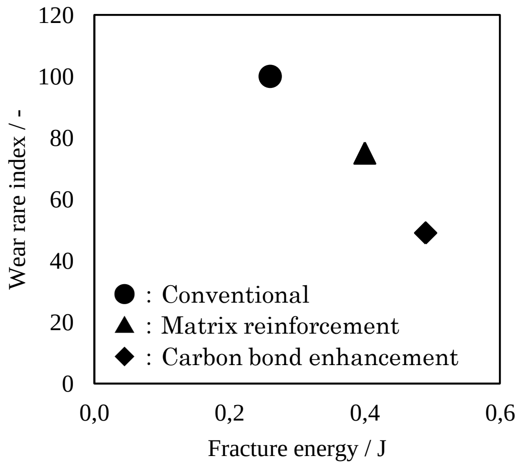

Fig. 13 Relationship between wear rate index and fracture energy.

4. CONCLUSION

In order to reduce mechanical abrasion wear of the BOF charging pad caused by charged scrap collision, a detailed investigation for abrasion wear was carried out. As a result of the investigation, it was clarified that crack propagation is essential factor both for charging pad abrasion and sand blasting abrasion. Therefore, the sand blasting experiment was assumed to be an accurate method for reproducing charging pad abrasion. Based on that assumption, the high fracture energy materials, which show superior sand blasting abrasion resistance, were developed by applying novel carbon bonding enhancing technology. These assumptions were validated by commercial application.

REFERENCE

[1] Inukai K, Moriwaki K, Ogata M, Iida E, Abrasion Resistance Evaluation of SV Plate Materials: TAIKABUTU; Vol. 60, No. 3 p. 132 (2008).

[2] Fujiyoshi R, Iida A, Torigoe A, Yoshioka H, Reduction of wear rate of B.O.F. Charging pad by Application of high fracture toughness: Proceedings of the 10th UNITECR; Dresden; 2007. p. 470-73.

[3] Iida A, Kakihara M, Suto M, Tada H. Improvement of MgO-C bricks for BOF based on microstructure investigation: Shinagawa Technical Report Vol. 59, p. 85-100, (2016).