Durability Improvement of BOF Taphole Sleeves by Optimizing Refractory Material Design

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Abstract

The performance of taphole sleeves seriously influences the productivity of BOF operation. Excellent spalling resistance, constant duration of tapping and longer service life is increasingly requested to reduce the frequency of taphole repair. Taphole sleeves are damaged mostly by spalling, oxidation and corrosion by BOF slag. In pursuit of an appropriate balance between spalling resistance and anti-oxidation, we have developed two types of taphole materials. One is obtained by focusing on the prevention of gaseous oxidation without sacrificing the spalling resistance, and the other by enhancing oxidation resistance against Fe-oxide. MgO-C bricks of two types have contributed to realize high productivity of BOF operation for many customers.

1. Introduction

Recently every steel industry is pursuing higher productivity and the activity level of the BOF influences productivity of the steel making operation greatly. In order to reduce the down time of the BOF operation, improvements in the performance of the refractories, such as the longer service life of BOF linings or the shorter time for repair or relining, are requested eagerly. The performance of taphole sleeves also greatly affects the activity level of the BOF. Although the longer service life is, of course, desirable to reduce the frequency of taphole change, the spalling damage during tapping has to be avoided definitely in order to maintain a stable operation. Further it is required not only to shorten the tapping time, especially in the earlier stage of a service campaign, but also to maintain a stable tapping duration.

Furthermore, matching the properties of the taphole sleeve with the operating conditions cannot be disregarded. The conditions are different in each plant, so required properties also differ in each case. This paper reports an example of optimization in refractory material design to match taphole sleeves with the operating conditions.

2. Operating conditions and causes of damage

Fig. 1 shows a typical taphole sleeve with its operating conditions, various damages and their causes. The inner surface of the taphole sleeve is worn by the flow of molten steel, exposed to thermal shock by repetitive tapping and furthermore corroded by both slag and Fe-oxide. Also, the circular rim of the sleeve is damaged by the mechanical impact of the slag stopper at the end of tapping.

Fig. 2 shows operating conditions, causes of damage and required properties or improvements for a taphole sleeve. Generally excellent spalling resistance and excellent abrasion resistance are two contrary and incompatible characteristics. Each plant has its own conditions for the steel making process like the number of heats per day, the Fe-oxide content in the slag or the difference in damage between oxidation by liquid slag or that by air. In addition, there are several types of slag stopping devices such as slag stopping darts, slag sensing equipment or a pneumatic slag stopper (PSS).

These devices also influence the refractory material design for taphole sleeves. Moreover, considering the recent high-pressure operations, in repair a quick replacement of the taphole sleeve is desirable because long replacement times of a taphole sleeve cause a decrease of productivity. In each plant, the type of breaking machine and the

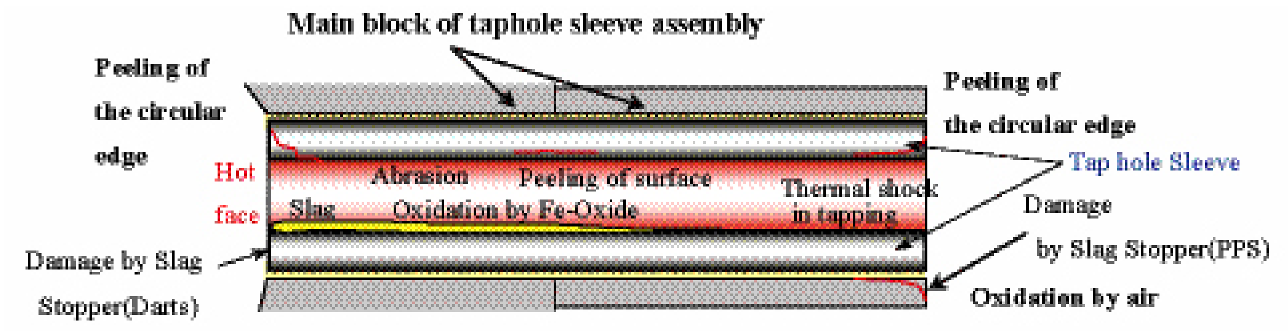

Fig. 1 A typical taphole sleeve with its operating conditions, various possible damages and their causes

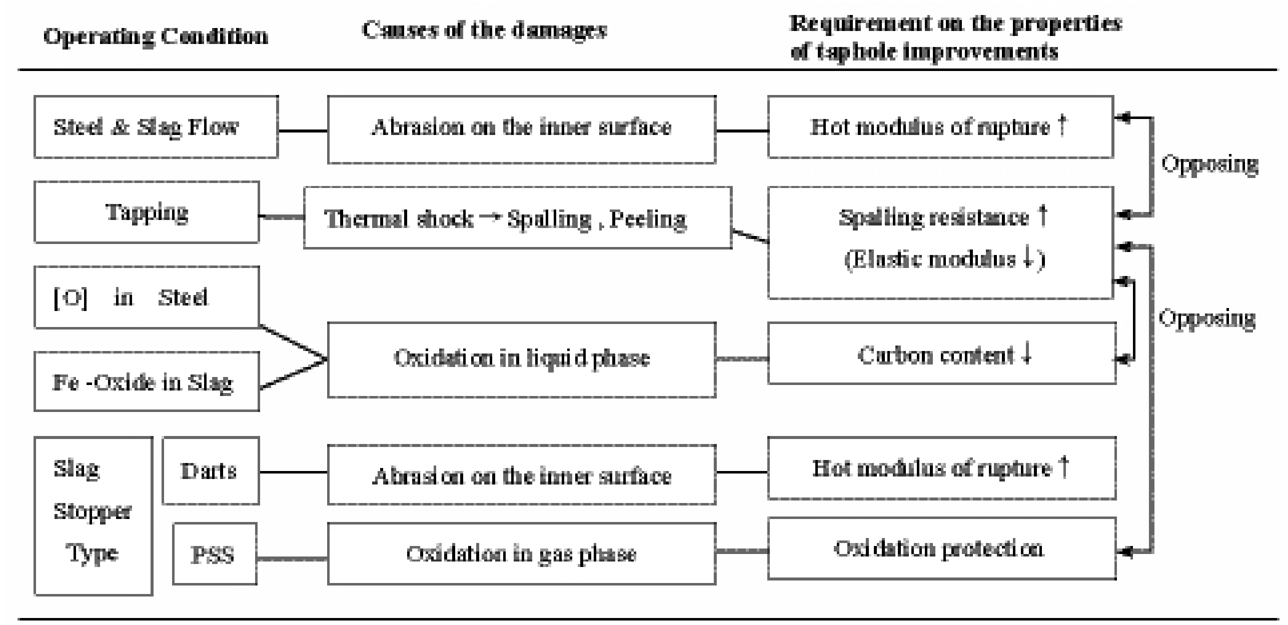

Fig. 2 Causes of the damages and requirement on the properties of taphole sleeves

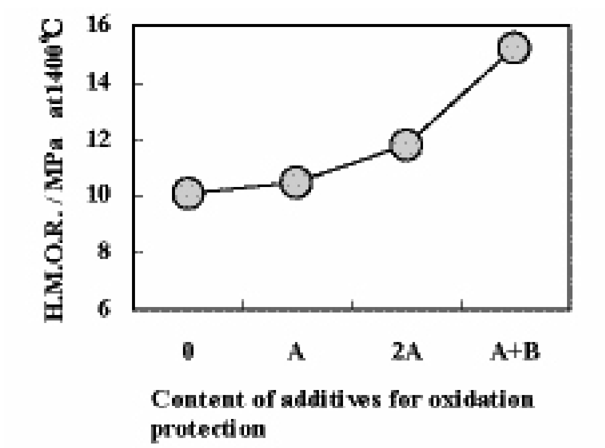

Fig. 3 Relation between amount of additives for oxidation protection and HMOR

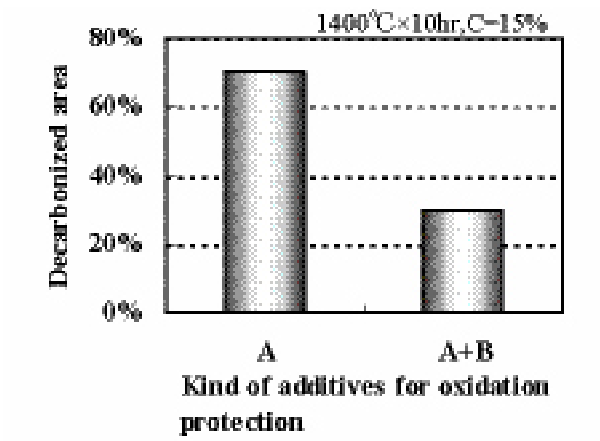

Fig. 4 Difference of the decarbonized area in MgO-C brick between two kinds of additives for oxidation protection

breaking method for the taphole replacement are different, so an appropriate material design matching with the repair conditions in each plant, especially suitable mechanical strength of the material, is required definitely.

3. Basic design of material for taphole sleeves

The properties of taphole materials are considerably influenced by their carbon content and the contents and kinds of additives for oxidation protection. As described above, the inner surface of taphole sleeves is in contact with a flow of molten steel and slag; therefore an improvement in abrasion resistance is essential to obtain excellent durability. An increase in the hot modulus of rupture is also effective[1]. **Fig. 3** shows the relation between the amount of additives for oxidation protection and the hot modulus of rupture (HMOR).

The HMOR is improved effectively by increasing the additives for oxidation protection. Furthermore, by heating two specimens, to which different kind of additives have been added for oxidation protection, in an oxidizing atmosphere, the decarbonized area is measured as shown in **Fig. 4**.

Generally the oxidation resistance in an oxidizing gas phase is improved effectively by adding plural additives for oxidation protection. It seems that gas phase oxidation proceeds violently during refining processes like slag-less blowing or less-slag outflows through a taphole. When much Fe-oxide is contained in the slag, the oxidation by the liquid phase proceeds rapidly. MnO also affects the oxidation similarly[2)3)]. **Fig. 5** shows the relation between Fe-oxide content in the slag and the wear index of MgO-C bricks with five different carbon contents.

The total content of Fe-oxide in the slag influences

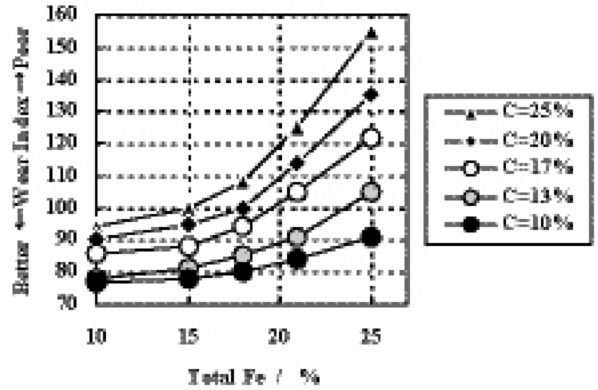

Fig. 5 Relation between Fe-oxide content in slag and wear index of MgO bricks of five different carbon contents

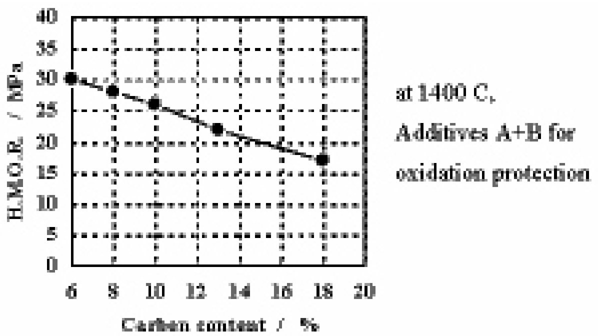

Fig. 6 Relation between carbon content and HMOR at 1400C

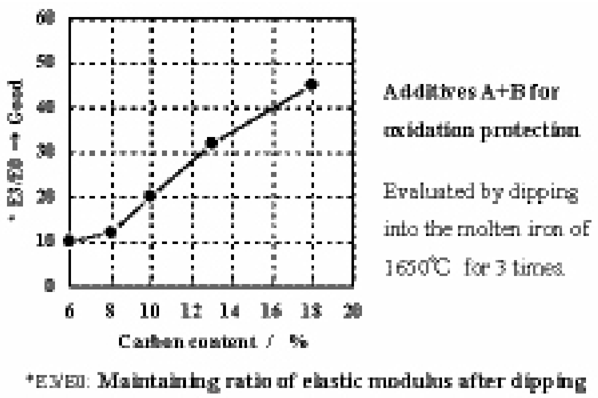

Fig. 7 Relation between carbon content and thermal shock resistance

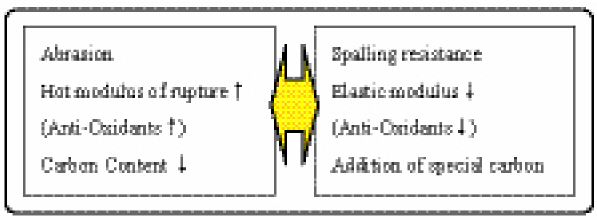

Fig. 8 Relation between various properties to be considered for optimal material design

considerably the damage on MgO-C bricks because Fe-oxide enhances decarbonization and produces micro pores in the brick matrix close to the hot surface and the MgO grains become exposed. As the countermeasure to this type of damage, decrease of the carbon content is effective. **Fig. 6** shows the relation between carbon content and HMOR.

By decreasing the carbon content the HMOR is raised, while the spalling resistance is diminished[5]. This relation is shown in **Fig.** 7. Similarly, the spalling-resistance deteriorates by increasing the content of additives for oxidation protection. To improve the performance of taphole sleeves, therefore, it is necessary to consider and adjust carefully the balance between various properties as shown in **Fig. 8**.

4. Typical examples of material design

Currently Krosaki Harima is supplying MgO-C bricks with a wide range of free carbon content, from 5 to 20mass%, to comply with the various operating conditions of our customers. Normally in overseas markets, excellent performance of taphole sleeves has been obtained by MgO-C bricks containing 10 mass % of free carbon, probably because the [O]-level of molten steel is higher in overseas steel plants than that in Japanese plants. Here we present two examples of material design with 10 mass % of carbon content. **Fig. 9** shows the examples A and B designed with that concept.

Both material designs, A and B, are pursuing the improvement of oxidation resistance under the condition in which the [O] level in molten steel is rather high and the content of Fe- oxide in the slag is also high. First the material of the design A is recommendable for the refining condition in which the influence of gas oxidation is dominant. The effect of special carbon added in the design

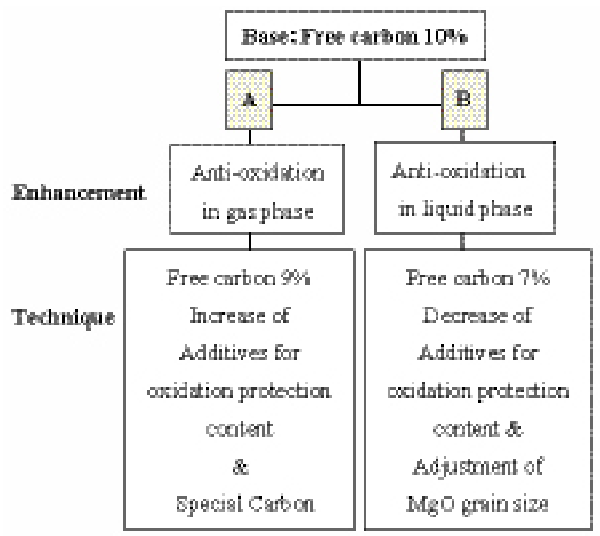

Fig. 9 Typical examples of material design

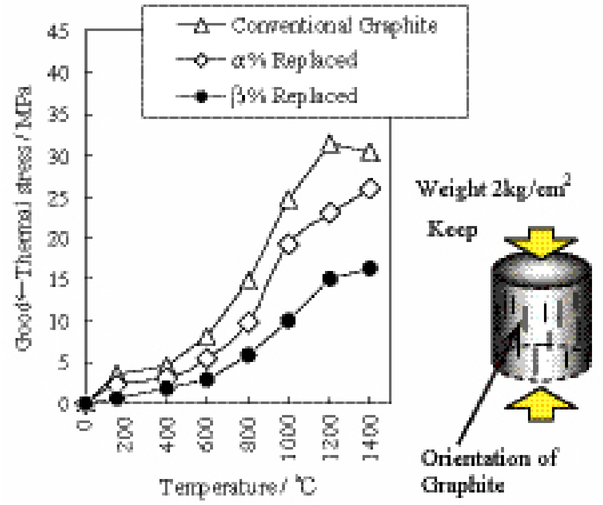

Fig. 10 Decrease of thermal stress in the brick by replacing a part of the graphite with a special carbon

Table 1 Typical properties of the improved materials A and B for taphole sleeves in comparison with the conventional one

Material	Conventional		A	B
Bulk density	2.92	3.01	3.00	3.05
Apparent porosity (%)	6.2	5.8	7.2	5.5
Crushing strength (MPa)	30	40	40	35
The largest grain size (mm)	2	3	3	5
H.M.O.R. (MPa) at 1400℃	18.1	20.0	22.1	14.0
Chemical composition (%)				
MgO	78.3	83	84	88
F.C.	17	10	9	7
Additive				
Anti-oxidation materials	***	**	***	**
Special carbon		*	**	

A is shown in **Fig. 10** and **Fig. 11**.

In spite of an increase of additives for oxidation protection, the thermal stress produced in the brick is controlled and sufficient spalling resistance is maintained due to the special carbon. Next the material of the design B is recommendable for the condition in which the content of Fe-oxide in the slag is rather high and the influence of liquid slag oxidation is dominant. The oxidation resistance in the liquid phase is enhanced with lower carbon content, and the spalling resistance is maintained by decreasing the kinds of and the amount of additives for oxidation protection. The material of the design B is durable in oxidation which especially occurs close to the brick surface. In the design B the durability against oxidation is obtained by optimizing the maximum grain size and grain distribution of MgO.

Typical properties of the improved materials A and B are shown in **Table 1** in comparison with the conventional one.

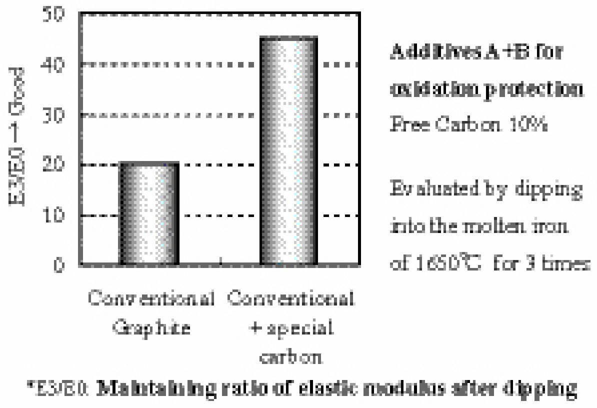

Fig. 11 Improvement of thermal shock resistance by adding a special carbon

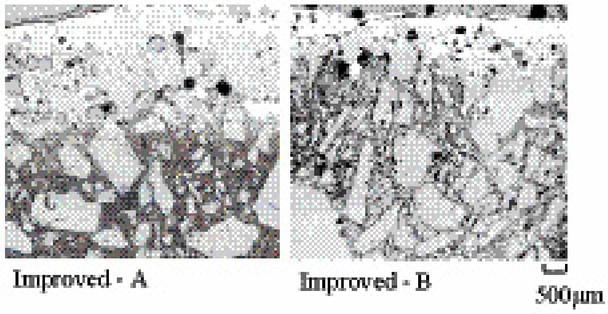

Fig. 12 Microstructure close to hot face of the improved materials A and B after the hot trial

5. Results of the trial in the steel converter and consideration on it

5.1 Observation of the taphole sleeve after the trial in the basic oxygen furnace

Fig. 12 shows the microstructure close to the hot face of the material A and B which were applied for the trial in the steel converter.

The left photograph in **Fig. 12** shows the microstructure of improved material A, which contains much additive for oxidation protection. The continuing layer connecting aggregates with the same color as MgO grain is observed close to the slag surface and the layer seems to protect the brick texture contributing to improve the durability[6]. On the other hand, the brick improved B, in which the carbon content is reduced and the MgO grain size distribution is changed, is observed in the right photograph of **Fig. 12**. The thickness of the layer with MgO grain color near the hot face is relatively small compared with that of improved A, due to the decrease of additive for oxidation protection. However, since the distance between each of the MgO aggregates is closer, it is thought that the durability is improved due to the slag adhesion layer which is maintained by the network structure of MgO aggregates.

Table 2 Performance record of BOF taphole sleeves of several customers

Customer	Capacity (heats/ton)	Carbon (mass%)	Performance/heats
A	300≦	17	75→90
B		7	150
C		9	80→100
A		9	150
D		17	200 with repair
E	250≦	9	65→70
F		10	80→90
B		7	200 with repair
G		10	80-100→130-150
H		10	50→100
B	200≦	17	100
I		10	100
J	150≦	9	70→90
K		7	100→120
L	≦100	9	90→100

5.2 Considerations

Table 2 shows the performance record of BOF taphole sleeves of the improved A material. Their durability has improved by 10% to 20% in comparison with that of the conventional ones of several customers.

It is considered that the material A is recommendable for the BOF condition of less slag on the surface of a taphole sleeve brick; in other words, the gas oxidation is dominant as observed often in plants using PSS for slag separation.

But the material A does not always show excellent performance under certain operating conditions e.g.

1) when the Fe-oxide content in the slag is rather high,
2) when the thick slag coat adheres often on the inner surface of the taphole, or
3) when the BOF operation is not so frequent.

In such conditions the material B shows rather better results than the material A. In case the Fe-oxide content in slag is high and slag adhesion is thick, the thick and dense layer close to the inner surface is easy to peel off and the inner diameter of the taphole (mm/heats) increases rapidly. Additionally the material B contains much additives for oxidation protection and the growth of the dense layer is controlled on the hot surface. Consequently the stable performance is obtained by the improved material B.

Besides the matrix is not sintered sufficiently because the additives for oxidation protection are inadequate. Therefore, in case a digging machine is not capable enough, the improved material B is recommendable.

6. Conclusions

In compliance with the BOF operating conditions of each customer, the optimal material for the taphole sleeves has been designed and supplied.

1) Recently the durability of taphole sleeves has been improved by 10% to 20% by increasing the contents of additives for oxidation protection and by replacing graphite with special carbon. The improved taphole shows better durability under the condition of gas oxidation dominance as observed, for example, in the plant using the pneumatic slag stopper (PSS).
2) On the other hand, under the condition that the slag contains much Fe-oxide and thick slag adhesion is observed on the brick surface, the improved material which contains less additives for oxidation protection and less carbon shows better performance than the material mentioned in 1) above. Due to relatively low mechanical strength sleeve bricks of this material are easy to be broken in furnace repair and contribute to improve productivity of the BOF plant.

The well-designed material for BOF taphole sleeve bricks contributes to improve the productivity of each BOF plant due to the excellent durability and the shorter repair time.

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