CHARACTERISTICS OF CASTABLE REFRACTORIES FOR STEEL LADLE HEATED UNDER RESTRAINED CONDITIONS

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ABSTRACT

Alumina-magnesia castable materials used mainly in steel ladles form spinel at high temperatures heated under free conditions results in large permanent linear change and the material texture becomes porous. The materials are used as a structure in actual use and are bi-axially restrained by the surrounding structural members. This study investigated the influence of bi-axial restraint on the characteristics of alumina-magnesia materials. The other castable material with high strength was cast to the surrounding area of the aluminamagnesia castable to prepare bi-axially restrained specimens. As the result, it is suggested that the difference in the material strength between the hot face and the backside of the ladles will be more significant than the estimated under non-restrained conditions in laboratory, especially in case of alumina-magnesia materials which have large MgO contents.

Keywords: steel ladle, castable refractories; thermal behavior; spalling

INTRODUCTION

Alumina-magnesia castable refractories have been widely used for working linings of steel ladles. They are composed of alumina and magnesia raw materials [1]-[3], and spinel is formed by the following reaction (1).

$$Al_2O_3 + MgO \rightarrow MgAl_2O_4 \text{ (Spinel)} \cdots (1)$$

The formed spinel gives the good effects of high corrosion resistance and high slag penetration resistance.

Alumina-magnesia materials expand drastically at 1200°C-1400°C and the expansion remains after cooling under non-restrained conditions. The expansion causes an increase in apparent porosity and the material texture becomes porous. However, in actual use, the expansion is limited by the surrounding structural members and steel shell. In addition, the refractories show creep behavior at high temperature [4]. The material texture under restraint is considered to be denser than that under non-restrained conditions as in laboratory evaluations.

In the recent researches, heating tests under restrained conditions have been reported. Kitanaka et al. [5] carried out heating tests with the specimens fixed at both ends and reported that the specimens were cracked and buckled. Kamio et al. [6] conducted rapid heating tests with the specimens fixed at both ends and reported about the observations of crack-developing behavior. However the refractories used in actual steel ladles are under bi-axial restraint and are free in the direction perpendicular to the hot face. Examinations under uniaxial restraint, such as the above, do not fit the actual use conditions in steel ladles. Braulio et al. [7] conducted evaluation tests of specimens restrained by the castable material as the test under bi-axial restrained condition. It is reported that the texture of the specimens became denser, and the slag penetration was reduced.

In this study, we heated specimens under bi-axial constraint and investigated the change in the material characteristics, especially about spalling resistance.

Tab. 1: Specifications of sample castables and outer castable

		Sample Castable			Outer Castable
		(a)	(b)	(c)	
Chemical composition / %	Al_2O_3	87	91	95	57
	MgO	11	7	3	-
	SiO_2	1	1	1	39
Water content / %		5.5	5.5	5.5	6.5

METHODS AND MATERIALS

The castable specimens were prepared by casting into a 25mm×25mm×120mm mold and were cured over 24 hours. They were put at the center of another 120mm×25mm×180mm mold and the other castable material (hereafter “outer castable”) was cast to the surrounding area of the specimens which was to be restrained. They were cured over 24 hours and dried for 24 hours. For comparison, non-restrained specimens without outer castable were also prepared by the same curing and drying methods.

The specifications of the specimens and the outer castable are shown in table 1. The specimens were alumina-magnesia castable refractories containing 3% to 11% MgO. The outer castable had good spalling resistance and small permanent linear change.

The restrained and non-restrained specimens were heated at 1000°C, 1300°C and 1500°C for 3 hours in air.

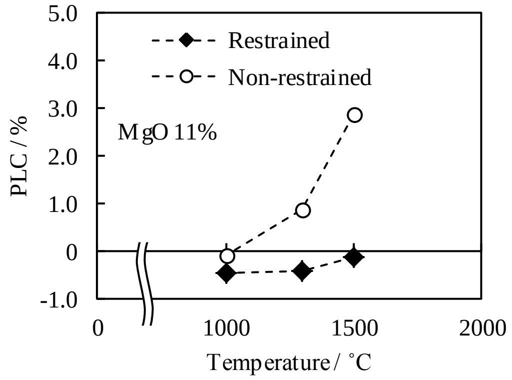

Fig. 1: Permanent linear change of restrained and non-restrained specimens at various temperatures.

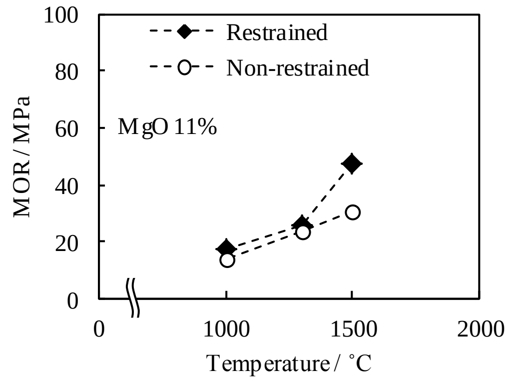

Fig. 2: Modulus of rupture of restrained and non-restrained specimens at various temperatures.

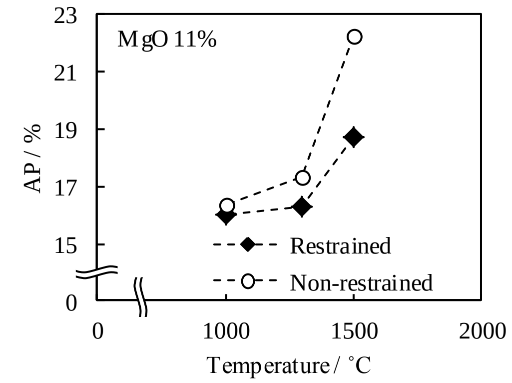

Fig. 3: Aparent porosity of restrained and non-restrained specimens at various temperatures.

RESULTS AND DISCUSSION

Results of heating test under restraint

Figure 1 shows the permanent linear changes of the restrained and the non-restrained specimens. The permanent linear change was measured in a longitudinal direction after removing the outer castable in the case of the restrained specimen. The expansion of the non-restrained specimens increased according to higher heating temperature. On the other hand, expansion of the restrained specimens was almost zero at all heating temperatures.

The alumina-magnesia refractories show large permanent linear change. However, the specimens heated under bi-axial restraint suppressed the expansion regardless of no stress relaxation by fracture behaviors such as cracks and buckling [5].

We evaluated various characteristics of the specimens heated under restraint and non-restraint conditions.

Physical characteristics of restrained and non-restrained specimens

The samples containing 11% of MgO (sample (a) in table 1) were heated at high temperature under restrained and non-restrained conditions. The characteristics were measured and evaluated.

Figure 2 shows the modulus of rupture (hereafter MOR) after heating. The MOR of both of them increased with the higher heating temperature. The MOR of the restrained specimens increased more especially when heated at 1500°C. The change in apparent porosity (hereafter AP) is shown in Fig. 3. The AP of both increased with temperature. The AP of the restrained specimens increased less than the non-restrained specimens, which means that the restrained specimens had a denser texture than the non-restrained ones.

Microstructures of restrained and non-restrained specimens

Figure 4 shows the compositional images of the specimens containing 7% of MgO heated at 1500°C Fig. 4 (a) is an image of the non-restrained specimen and Fig. 4 (b) is an image of the restrained specimen. The images were taken parallel to the restraint plane (Fig. 4 (c)). In the photos, the black area and dots indicate pores. The non-restrained specimens had more pores

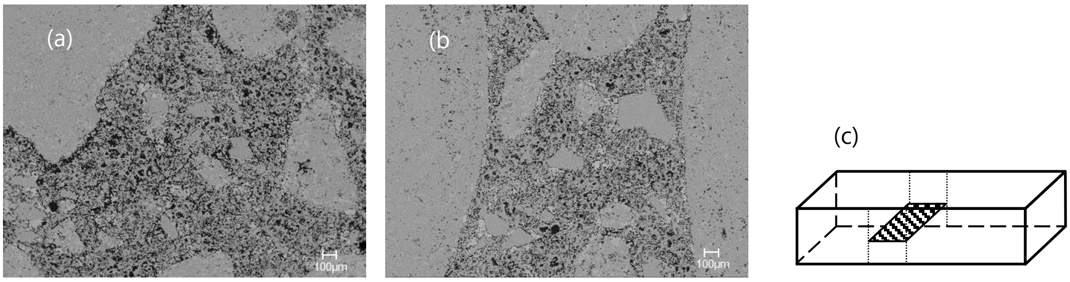

Fig. 4: Microscope image of (a) non-restrained specimen; (b) restrained specimen; (c) diagram of sampling position.

and a more porous texture. The restrained specimen had less pores and denser texture.

Discussion about change in characteristics under restraint

Outer castable suppressed the permanent linear change of the specimens. The specimens showed no cracks or buckling after heating under bi-axial restraint. Porosity reduction, pore refinement, and MOR increase were observed. It is considered that the texture densification caused by heated under restraint is considered to have been a result of MOR increase.

Influence of MgO content on permanent linear change

We evaluated the influence of MgO content on material characteristics after heating under restraint (Table 1 (a)-(c)). The change in permanent linear change (hereafter PLC) according to MgO content is shown in Fig. 5. The PLC after heating under non-restrained conditions increased as the MgO content increased. On the other hand, after heating under restrained conditions, the PLC remains about the same throughout the whole heating temperature range. The restrained specimens are considered to have been heated in enough restrained conditions. The specimens containing 3% MgO heated under both of restrained and non-restrained conditions showed almost zero PLC.

Influence of MgO content on physical characteristics

We evaluated the change in the physical characteristics against MgO content after heating under restrained conditions. Figure 6 shows the change in MOR. After heating under non-restrained conditions the MOR lowered as the amount of MgO increased. On the other hand, the MOR was not influenced by the content of MgO and remained almost the same after heating under restrained conditions. The restrained specimens show the same or higher MOR than the non-restrained one for each MgO contents. Figure 7 shows the change in AP. The AP of both the restrained and non-restrained specimens rose up as the content of MgO increased. The AP values of the non-restrained specimens rose up more significantly than those of the restrained specimens.

Discussion about influence of MgO content on physical characteristics after heating under restraint

The PLCs of the specimens containing 3% MgO were almost zero after heating under not only restrained but also non-restrained conditions. The physical characteristics did not show significant difference between the restrained and non-restrained specimens. On the other hand, the PLCs of the specimens containing 11% MgO after heating under restraint were larger than those under non-restraint resulting in a lower MOR.

The PLCs of the restrained specimens were approximately zero regardless of the increase in AP as the MgO content increased. The bi-axially restrained specimens are considered to have expanded in the direction perpendicular to the restrained axis, and the material texture became porous.

Influence of restraint in actual use

The MOR of the restrained specimens heated at high temperature significantly increased in comparison with those of the non-restrained specimens. The ratios of the MORs after heating at 1500°C and 1000°C are shown in Fig. 8. The ratios of the restrained specimen are larger than those of the non-restrained specimen throughout the whole MgO content range, and the difference became larger as the MgO content increased. This suggests that the difference of the material strength between the hot face and backside will occur and will be more significant than that estimated under non-restrained conditions in the laboratory. It is suggested that structural spalling could more easily occur in alumina-magnesia castables that have higher MgO contents.

The alumina-magnesia materials containing much MgO showed a very small PLC in the restrained directions, however,

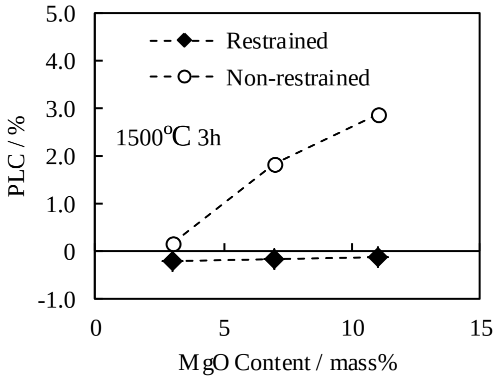

Fig. 5: Permanent linear changes of restrained and non-restrained specimens with various MgO contents.

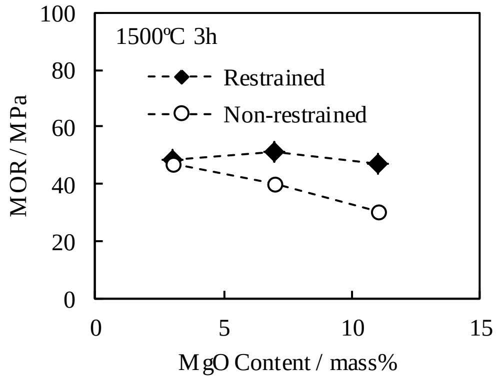

Fig. 6: Modulus of rupture of restrained and non-restrained specimens with various MgO contents.

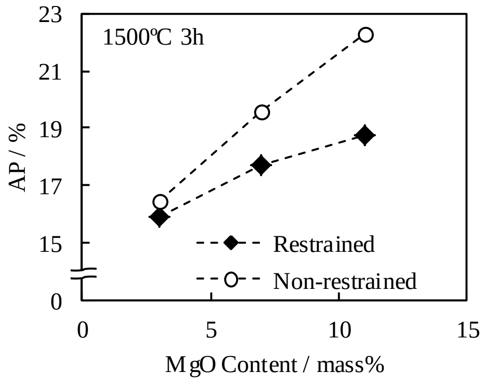

Fig. 7: Apparent porosities of restrained and non-restrained specimens with various MgO contents.

the AP increased. The materials are considered to have expanded in the direction perpendicular to restrained axis. Spalling can occur in actual use with materials that spalled in the uniaxial restraint tests [5], [6]. Corrosion resistance can be improved by increasing the content of MgO [1] and desification by heating under restrained conditions [7], but it is necessary to pay attentions to the significant difference in material strength between the hot face and backside of the ladles, and material

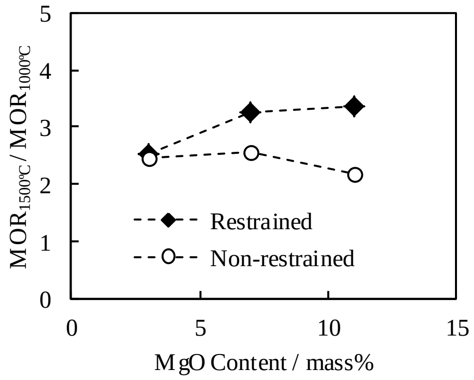

Fig. 8: The MOR ratios after heating at 1500°C and 1000°C

expansion in the direction perpendicular to the restrained plane.

CONCLUSION

In order to evaluate the characteristics of alumina-magnesia castable refractories in conditions similar to those of actual use, heating tests under bi-axial restraint were conducted. The PLC of the restrained specimens after heating was very small and the texture became denser. Along with that, it is suggested that the difference in the material strength between the hot face and the backside of the ladles will be large, so that structural spalling will easily occur, especially in case of materials which have a large MgO content.

REFERENCES

[1] M. Kobayashi, K. Kataoka, Y. Sakamoto and I. Kifune; Taikabutsu 1996; 48 (9): 486-487

[2] Y. Takakura, T. Yamamura, Y. Hamazaki and T. Kaneshige; Taikabutsu 1996; 48 (9): 488

[3] K. Yamamoto, H. Fujimoto, F. Hanada, T. OtaniY. Hamazaki, T. Kaneshige and Y. Takakura; Taikabutsu 1996; 48 (12): 656-657

[4] M. Ishikawa, N. Takahashi and C. Nishikawa; Taikabutsu 1999; 51 (3): 144-148

[5] M. Kiatanaka, M. Nishimura and S. Nishida; Taikabutsu 2015; 67 (7): 339-341

[6] H. Kamio, Y. Tsuji, Y. Kitazawa and H. Taira; Taikabutsu 2016; 68 (10): 466-476

[7] M. A. L. Braulio, E. Y. Sako, V. C. Pandolfelli; Proceedings of UNITECR 2013: 773-780