HIGH SPALLING RESISTANT BASIC BRICK FOR STEEL CASTING SLIDE VALVE PLATE*

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Abstract

In order to improve the thermal spalling resistance of carbonaceous material-containing basic brick for the slide valve plate of facilities for the steel continuous casting process, spinel addition was investigated. Spinel is a favorable material in terms of thermal spalling resistance since it exhibits lower thermal expansion than MgO. However, corrosion resistance is inferior to MgO since the reactivity of spinel is higher than MgO. Thus, the grain size and fraction of spinel were optimized by laboratory experiment. In the series of experiments, a corrosion experiment and thermal spalling experiment were carried out. As a result, it was verified that utilization of coarse grain spinel is effective for minimizing corrosion resistance deterioration. This is attributable to lower surface area of spinel. On the other hand, no significant influence of spinel grain size on thermal spalling resistance was detected. Hence, thermal spalling resistance is considered to be governed by overall physical properties. Therefore, it was assumed that containing adequate amount of coarse spinel is desirable. The assumption was validated by numbers of commercial applications.

Keywords: Refractory; Steel casting; Slide valve plate; thermal spalling

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1 INTRODUCTION

For many decades, continuous casting has been widely adopted by most of the steel makers as the molten steel solidification methoddue to its sufficient efficiency. **Figure 1** schematically shows the process. Molten steel in the steel ladle, which had been refined through metallurgical process, is poured into the tundish that stabilizes the liquid flow and delivers molten steel to the caster entry positons.

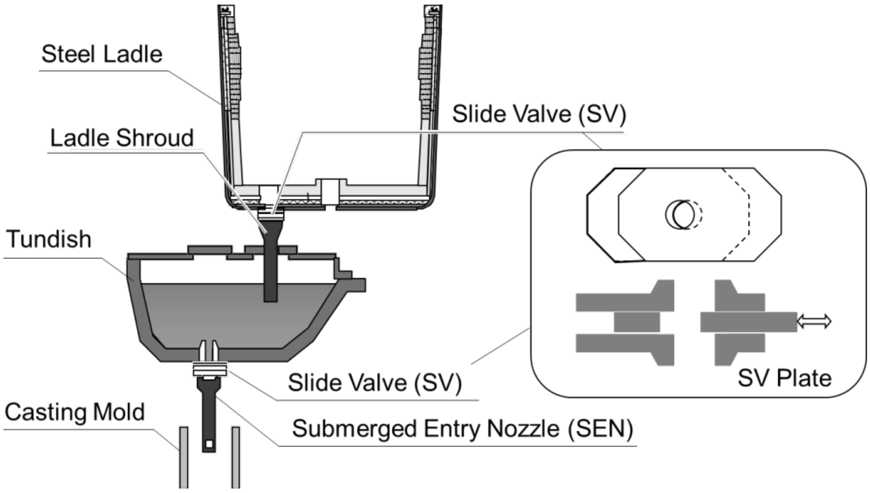


Figure 1. Schematic illustration of continuous casting process.

In this process, accurate flow rate control is one of the key factors to maintaining stable operation and theslide valve (SV) system is one of the effective methods for achieving it. As shown in **Figure1**, the SV system controls the flow rate by adjusting the positions of liquid drainingbore, which are installed on the refractory plates.Inmost cases, burnt Al_2O_3-C material containing additives is suitable for the SV plate.
The SV plate tends to be damaged according to severeoperating conditions. Typical damage includes the following:bore diameter increase due to corrosion, thermal spalling caused by thermal shock according tosteel flow, surfacedeteriorationresulting from reactions between refractory components and molten steel, and edge chipping due to thermal stress [1]. In order to develop countermeasures for the above mentioned phenomena, much research has been carried out to improve refractory materials.
Predictably, steel composition strongly influences SV plate refractory damage [2,3]. It is widely accepted that Ca-treated high cleanliness steel is so corrosive that excessive bore diameter increase and/or surface deterioration tends to occur [4]. With respect to steel refining, injection of a Ca-bearing alloysuch as Ca-Si alloy improves steel cleanliness effectively. Cais alow boiling point high vapor pressure element and the solubility of Ca in molten steel is low. Thus, it easilycontacts the oxygen in the air suctioned through the interface between the plates to form calcium oxide during the casting. According to the eutectic reaction between CaO and Al_2O_3 in plate refractories, a small portion of liquid phase is formed in refractory plate structure resulting in promotion of corrosion.
In terms of reactions with CaO, a basic oxide such as MgO is a favorable compound since eutectic temperature is sufficiently high. High thermal expansion of MgO considerably deteriorates thermal spalling resistance. Hence, improvement of basic bricks used for the SV plate was investigated.

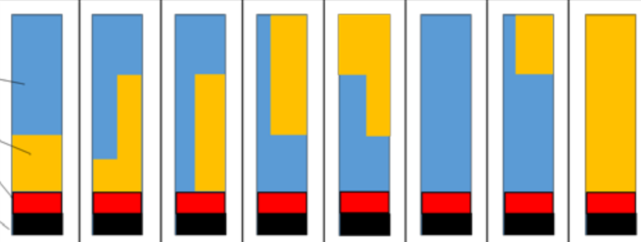
2 MATERIALS AND METHODS

2.1 Laboratory Evaluation

In order toimprove thermal spalling resistance, we focused on the utilization of spinel. Spinel is a mineral that shows a wide range solid solution consisting of various kinds of metallic oxides such as MgO, MnO, FeO, Al_2O_3, Cr_2O_3, and so on. For refractory grade, MgO·Al_2O_3 is commercially available. While low thermal expansion of spinel is desirable from the view point of thermal shock resistance, corrosion resistance is poorer compared to MgO. Thus, influences of combined application of MgOon properties were evaluated.

Table 1is the schematic image of the evaluated material compositions.The grain size and amount of spinel were optimized. The grain size distribution of spinel and spinel fraction in oxide raw materials were varied in material series A1 to A5 and B1 to B5 respectively. In series B, spinel replaced coarser grainMgOaccording to the evaluation results of series A. The equivalent amount of metallic additives and carbonaceous materials were included in all specimens.

Table 1. Schematic image of evaluated material composition

Specimen I.D.	A1	A2	A3	A4	A5	B1	B2	B3
Material composition MgO Spinel Metallic additives Carbonaceous materials								
Spinel/(Spinel+MgO)	0.5	0.5	0.5	0.5	0.5	0,0	0.2	1.0
Grain size index of spinel	1.0	1.7	2.6	6.0	7.2	-	-	-

Upper side of the materialcompositioncolumnindicates coarse grain.
Lower side indicates fine powder.

The prepared raw materials were mixed withphenolic resin in a mixer. Mixtures were pressed in a rectangular shape by vacuum hydraulic press at 150MPa and cured at 200 ºC followed by burning at a temperature under 1,000 ºC in a reducing atmosphere. The specimens were cut into specific shapes and subjected to property evaluations.

Table 2summarizes the evaluation method.

Table 2. Evaluation method

Evaluation	Specimens	Methodology
Apparent porosity(ε) and Bulk density (BD)	All	Archmedes Method
Modules of rupture (σ_{MOR})	All	Three point bending
Young's Modulus (E)	All	Gring sonic method
Thermal expansion	All	R.T. to 1500 ºC, in Ar
Corrosion resistance	All but A5	Rotary method, 1650 ºC for 5h, Slag: CaO/Al_2O_3=1, FeO 30%
Spalling resistance	A2, A3, A4	Dipping bore-installed platey

B1, B2, B3	specimen in molten pig iron

Along with the physicalproperty evaluation, corrosion resistance and spalling resistance were directly evaluated. **Figure 2** shows aschema of the corrosion experiment. The specimens were assembled in box shape and the inside of the box was heated by oxygen-propane burner with rotation. Slag was poured in the box and the corrosion depth of each specimen was measured. In order to maintain the corrosion ability of the slag, it was exchanged every one hour. Inevitably, deviation of corrosion depth between experimental batches is recognizable, The corrosion depth was expressed by an index normalized by the corrosion depth of standard material.

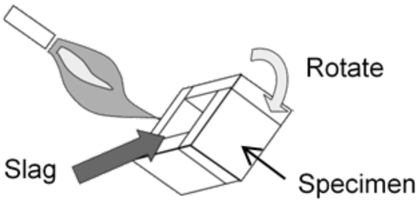


Figure 2. Schematic image of corrosion experiment.

Figure 3demonstrates the shape of the spalling experiment specimens.Ogata et. al [5] demonstrated that accuracy of result of spalling experiment can be improved by applying the hole-installed specimen. In this study, therefore,a hole was installed on the specimen. Specimens were dipped into the molten pig iron melted in a high frequency induction furnace for one minute followed by natural cooling. The external appearances and cut sections of post-experiment specimens were observed.

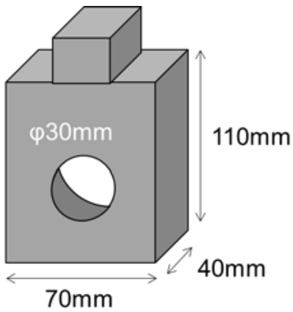


Figure 3. Specimen for spalling evaluation.

2.2 CommercialApplication

Material A4, which had been concluded to be optimal, was used for three steel mills, A, B, and C. In steel mills A and B, it was used for the SV plate of the steel ladle. In steel mill A, both Ca-treated steel and general steel were cast and in steel mill B, only Ca-treated steel was cast. In steel mill C, it was applied to the SV plate for tundish and only Ca-treated steel was cast. In steel mill B and C, spinel-excluding material B1 was also evaluated. The external appearance of the product used for steel mill B was observed and cross sectional observation of the specimens after use in steel mill C was carried out.

3 RESULTS

3.1 Laboratory Evaluation

Table 3 provides the apparent porosity (ε) and bulk density (BD) of the specimens.ε and BD of all specimens indicates that no significant deterioration in the specimens was recognized.

Table 3. Properties of specimens

	A1	A2	A3	A4	A5	B1	B2	B3
ε / %	9.9	9.3	11.1	10.3	11.2	10.2	10.7	9.4
BD / $kg{\cdot}m^{-3}$	2990	3000	2950	2960	2940	2960	2950	3000

Figure 4 shows the Influences of Spinel grain size and spinel fraction on Young's modulus (E). E increases as spinel grain size increases and spinel amount decreases.

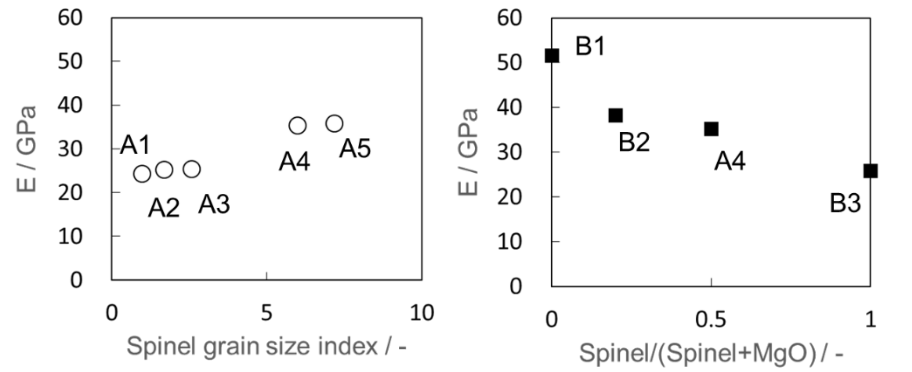


Figure 4. Variations in Young's modulus (E) as functions of grain size andspinel fraction.

Figure 5 shows the Influences of spinel grain size and spinel fractionon themodulus of rupture (σ_{MOR}). While little influence is recognized for spinel grainsize, theσ_{MOR} decreases linearly to the spinel fraction.

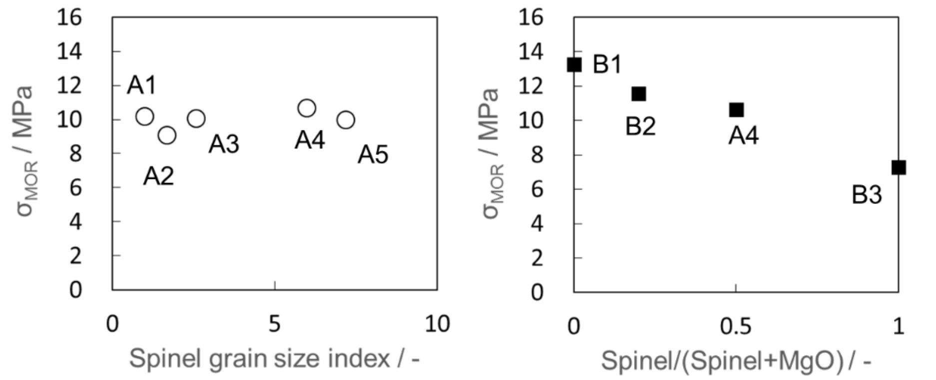


Figure 5. Variations in modulus of rupture(σ_{MOR}) as functions of grain size and spinel fraction.

Figure 6 shows the Influences of Spinel grain size and spinel fraction on thermal expansion at 1500 ºC ($\Delta L/L_{1500}$). Similar to theσ_{MOR}, little influence is recognized for the spinel grainsize and $\Delta L/L_{1500}$ decreases linearly to the spinel fraction.

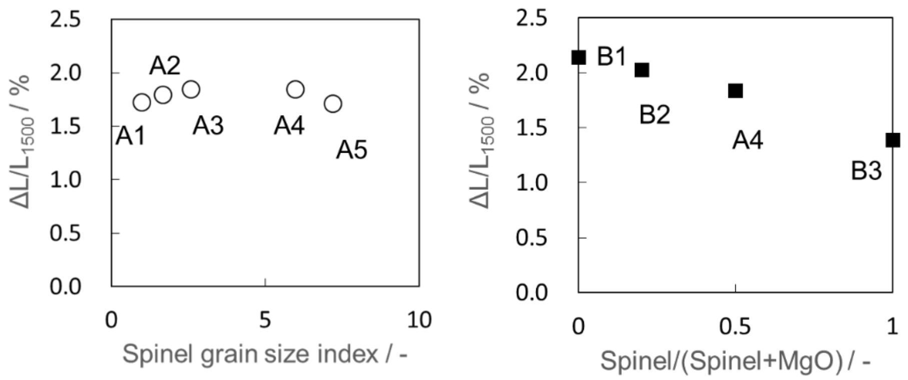


Figure 6. Variations inthermal expansion at 1500ºC ($\Delta L/L_{1500}$) as functions of grain size and spinel fraction.

Figure 7 shows the Influences of Spinel grain size and spinel fraction on slag corrosion. Corrosion resistance deteriorates as spinel grain size becomes fine and the spinel fraction increases.

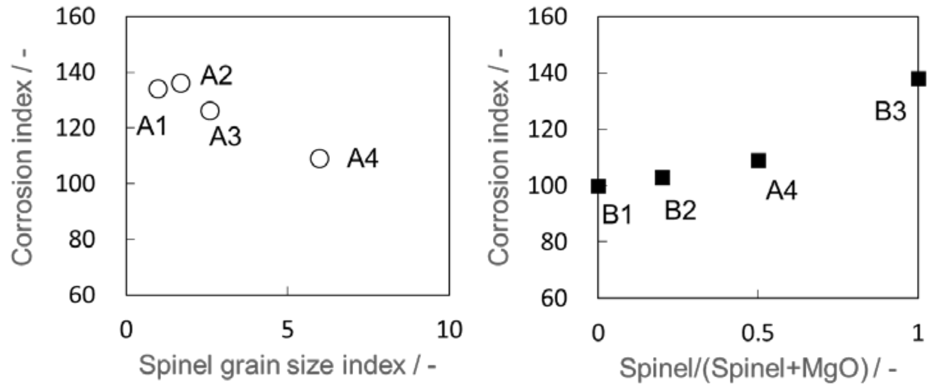


Figure 7. Variations incorrosion index as functions of grain size and spinel fraction.

Figures 8and **9**are the influences of grain size and spinel fraction on theresults of the spalling experiment, respectively.

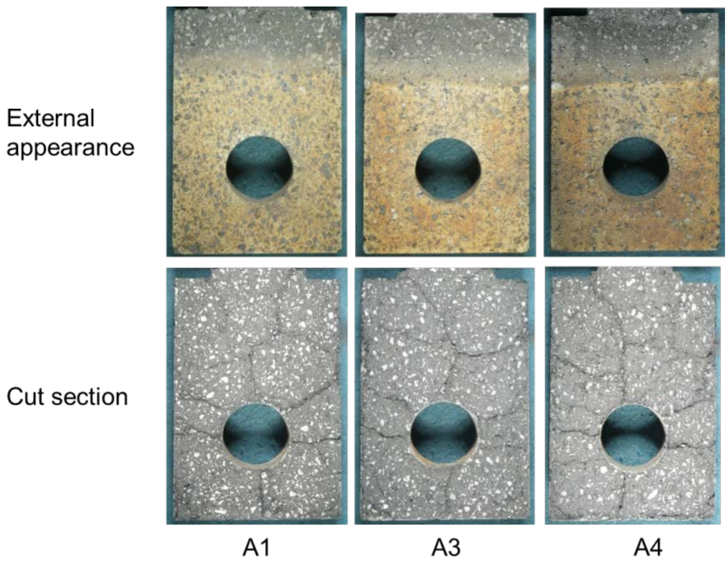


Figure 8. Cracking status of post-spalling experiment specimens in which spinel grain size was varied.

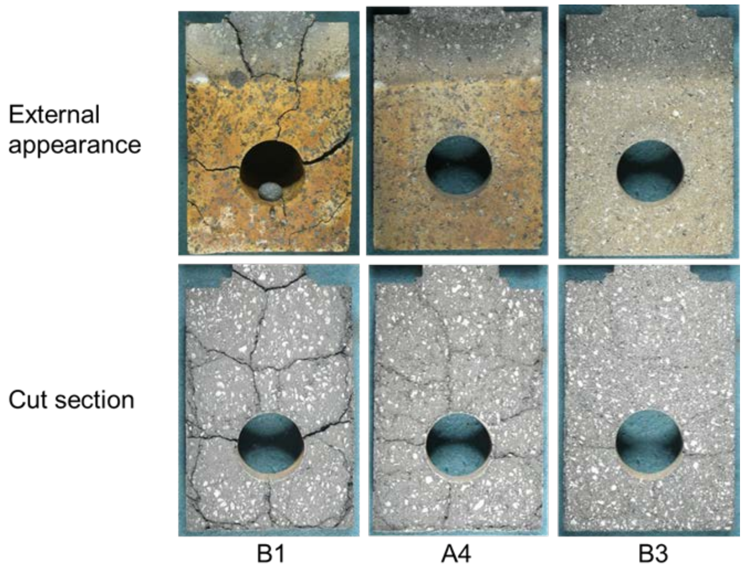


Figure 9. Cracking status of post-spalling experiment specimens in which spinel amount was varied.

On the cut surfacesof the post-spalling experiment specimens, the crack lengths were measured. A summation of the crack length of each specimen is given in **Figure 10**. While slight deterioration in spalling resistance is observed for the specimen including coarse spinel, considerable influence of spinel fraction on spalling resistance was recognized.

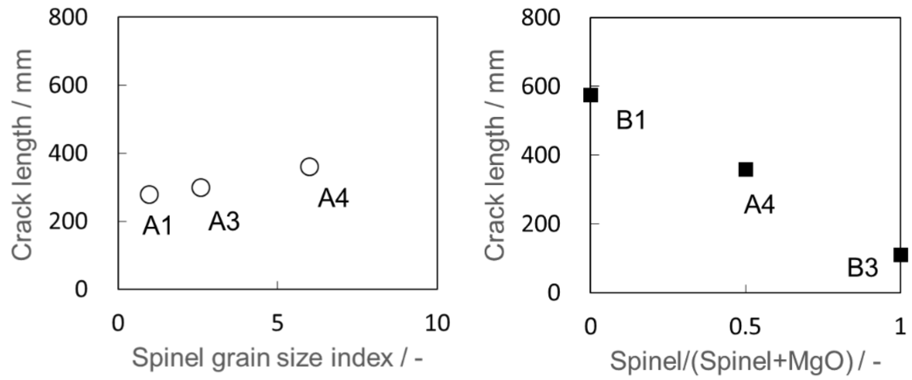


Figure 10. Variations incrack length as functions of grain size and spinel fraction.

3.2 CommercialApplication

According to the above mentioned laboratoryevaluation results, A4 was selected to subject to commercial application. **Table 4** provides the application results obtained from steel mills A, B, and C.

Table 3. Commercial application results for A4

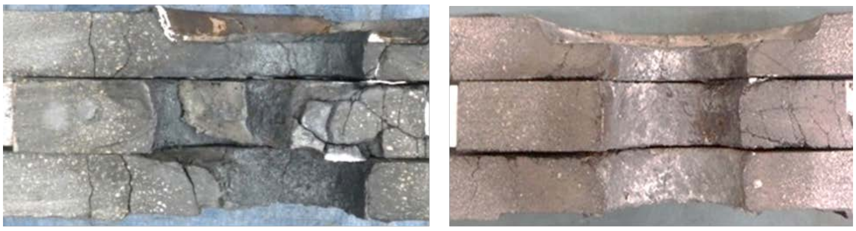
Steel mill	Facility	Bore diameter	Casting duration	Steel grade	Heats
A	Steel ladle	90 mm	30-40 min,	Ca-treated / general	5
B	Steel ladle	38 mm	-	Ca-treated	2
C	Tundish	80 mm	40-50 min.	Ca-treated	6

A4 was satisfactorily applied to these four steel mills.

Figures 11 and **12** show comparisons of the cracking status of SV plate after commercial applications. Obviously, considerable improvement of spalling resistance was recognized for material A4.

B1 **A4**

Figure 11. External appearances of SV plates after commercial applications at steel mill B.



B1 **A4**

Figure 12. Cut surfaces of SV plates after commercial applications at steel mill C.

4 DISCCUSION

Figure 7 verifies that including spinel significantly deteriorates corrosion resistance. In the case of corrosion resistance, however, adjusting spinel grain size is effective for suppressing deterioration, that is, using coarse spinel grain gives better results. Surface area is a key factor to understanding the resultsof complex refractory ceramic microstructures. Dissolution reaction of oxide grain into molten slag occurs at the particle surface. Thus, when a high reactivity surface occupies a larger fraction of whole particle surface, rapid dissolution is expected. Hence, reduction of high reactivity spinel surface area by using course spinel grain is desirable in terms of corrosion resistance improvement.
On the other hand, only a little influence of spinel grain size on thermal spalling resistance was evaluated as indicated in **Figures 8, 9**, and **10**. Unlike chemical reactions such as corrosion, physical phenomena is considered to be governed by overall physical properties.
According to Hasselman [6], thermal stress fracture resistance parameter “R” of brittle refractory ceramics is expressed by the following equation.

$$R=\sigma_f(1-\nu)/\alpha E \quad (1)$$

Where σ_f, ν, α, and E are fracture strength, Poisson’s ratio, thermal expansion coefficient and Young’s modulus, respectively. Since it is acceptable to assume that Poisson’s ratio is equivalent for all specimens in this study, $\sigma_{MOR}/\alpha E$ should be a reasonable parameter to evaluate thermal spalling resistance. Therefore, the $\sigma_{MOR}/\alpha E$ of the materials were calculated and the results are shown in **Figure 13**.The $\sigma_{MOR}/\alpha E$ increases as spinel grain size decreases and spinel fraction increases.

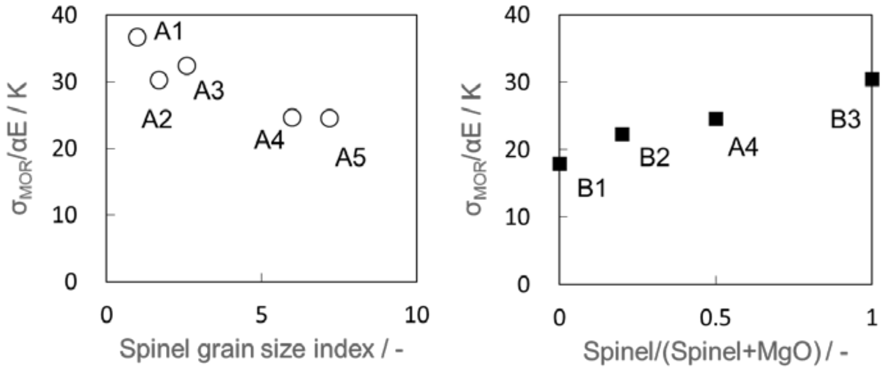


Figure 13. Variations inthermal spalling resistance parameter $\sigma_{MOR}/\alpha E$as functions of grain size and spinel fraction.

Figure 14shows the influence of $\sigma_{MOR}/\alpha E$ on the crack length of the post spalling experiment specimens. In each material series, the $\sigma_{MOR}/\alpha E$was regarded as the predictable parameter of thermal spalling resistance. However, susceptibility of thermal spalling experiment result to $\sigma_{MOR}/\alpha E$ differedwith each series of experiments.The reason of the difference in the susceptibility is unclear.

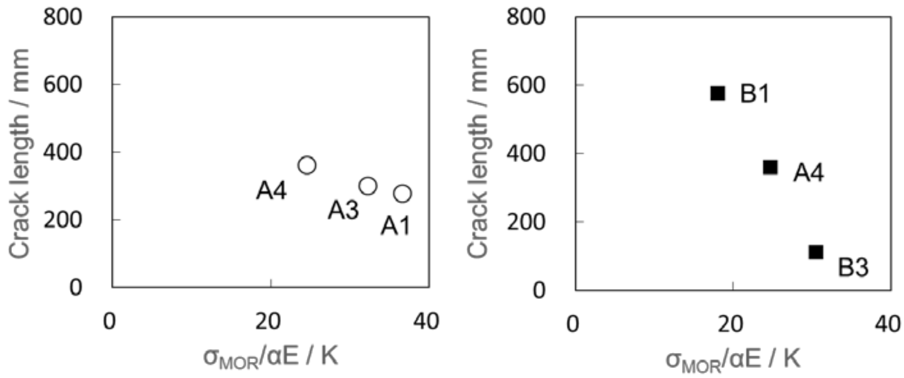


Figure 14. Variations in crack length after spalling experiment as functions of $\sigma_{MOR}/\alpha E$ and α.

In spite of the strange behavior in detail analysis, the commercial application results demonstrated in **Table 3** and **Figures 11** and **12**qualitatively agreed with the experimental results. Thus, it is necessary to evaluate the various properties and regard experimental results from a holistic point ofview.

5 CONCLUSION

In order to improve the thermal spalling resistance of basic brick used for slide valve platesin the continuous casting process, spinel addition was investigated. As a result, it was verified thatutilization of coarse spinel is effective for minimizing corrosion resistance deterioration. This is attributable to the lower surface area of the reactive spinel. On the other hand, no significant influence of spinel grain size on thermal spalling resistance was evaluated. Hence, thermal spalling resistance is considered to be governed by overall physical properties.
On the basis of the laboratory experiments, spinel grain size and spinel fraction were optimized and subjected to the commercial application.Successful results were obtained.

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