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Development of a tundish coating mix with excellent drying and dismantling properties

After relining with a coating mix, the tundish is usually preheated quickly. To prevent incidents caused by quick preheating, such as explosive spalling, adequate drying properties are provided to the tundish coating mix by blending fibre. We establish a fibre blending technique for blending large amounts of fibre to accomplish a reduction in thermal conductivity of the coating mix of roughly 40%. Improved drying and dismantling properties were developed by utilizing a fibre blending technique for the tundish coating mix, gunning and trowelling coating mixes.

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INTRODUCTION

The tundish used in continuous casting operations is an intermediate vessel which transfers molten steel from the teeming ladle to a mould. It has the roles of storing molten steel temporarily, distributing molten steel to each mould at a stable supply rate, and promoting floatation and separation of nonmetallic inclusions. As is schematically illustrated in *Figure 1*, the permanent brick back lining, brick or castable refractory wear layer, and MgO coating mix are relined in a sequential order in the tundish. Due to the necessity for removing the remaining molten steel and slag after a continuous casting operation, a coating mix is relined on the working surface of the wear layer refractory, so that the remaining molten steel can be easily removed without damaging the wear layer refractory.

The coating mix, which is generally composed of MgO to ensure clean, molten steel in the tundish, is relined by gunning or trowelling

before every casting campaign. The required properties of the tundish coating mix are cited as:

1. Good drying properties for quick preheating operations without incidents such as explosive spalling.
2. Adequate workability for relining operations
3. Easy dismantling properties with minimized sticking to the wear layer refractory.

Newly developed tundish coating mixes, JTM-M-629 (gunning) and SCOAT-M-71 (trowelling), with such required properties appropriately improved, are introduced in this article.

CHARACTERISTIC FEATURES OF TUNDISH COATING MIX

The operation cycle of the tundish is shown in *Figure 2*. After completion of continuous casting, the coating mix is dismantled, usually along with removal of the remaining metal in

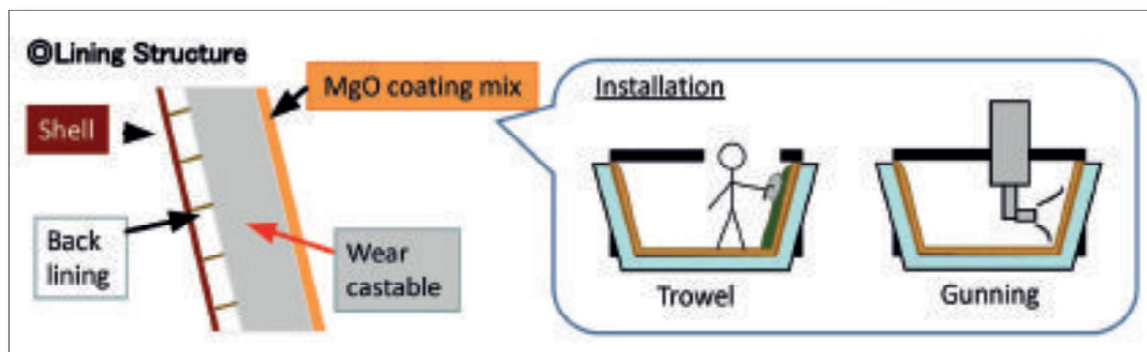


Fig 1 Tundish refractory relining specifications and two coating mix application methods

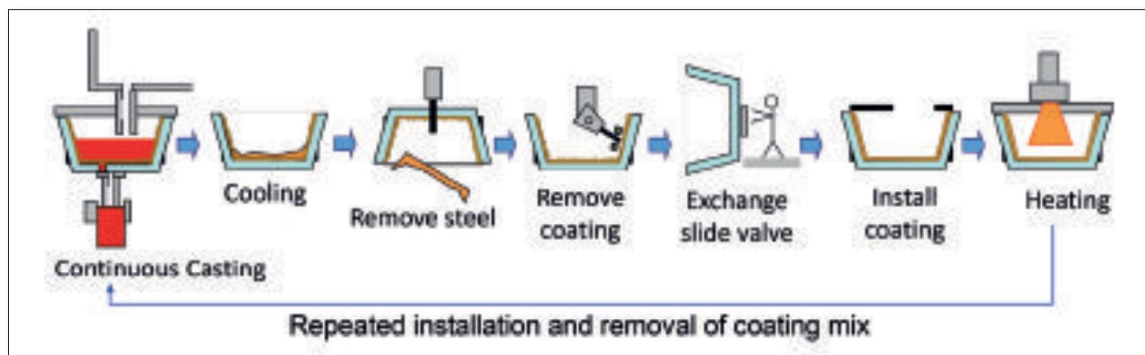


Fig 2 Operation cycle of tundish

the tundish. After a cycle of tundish refractory maintenance work, the coating mix is relined again. Before use in continuous casting operations, the tundish is preheated quickly. To prevent explosive spalling during quick preheating, fibre is generally blended to secure permeability of the relined coating mix body.

When large amounts of fibre are blended, however, transportation efficiency of the coating mix is reduced in gunning operation, resulting in an unstable gunned coating mix body. When large amounts of fiber are blended into the troweling coating mix, the troweled coating mix tends to slip down because of insufficient adhesiveness. Consequently, a fibre blending technique which includes selection of an appropriate fibre material and fibre shape is important to suppress and minimize negative influences of fibre blending on coating mix properties. By utilizing an elaborately improved fibre blending technique, new coating mixes, JTM-M-629 (gunning) and SCOAT-M-71 (trowelling), were developed. Features of these coating mixes are introduced in the following sections.

FEATURES OF GUNNING COATING MIX, JTM-M-629

The thermal conductivity of the newly developed coating mix, JTM-M-629, at 1000°C is shown in Figure 3. Compared with a conventional coating mix, by blending large amounts of fibre, the gunned body structure of the newly developed coating mix becomes more porous, resulting in a reduction in thermal conductivity at 1000°C by roughly 40%. A lower thermal conductivity means that the temperature at the interface between the wear layer refractory and the coating mix is lowered, suppressing sticking of the coating

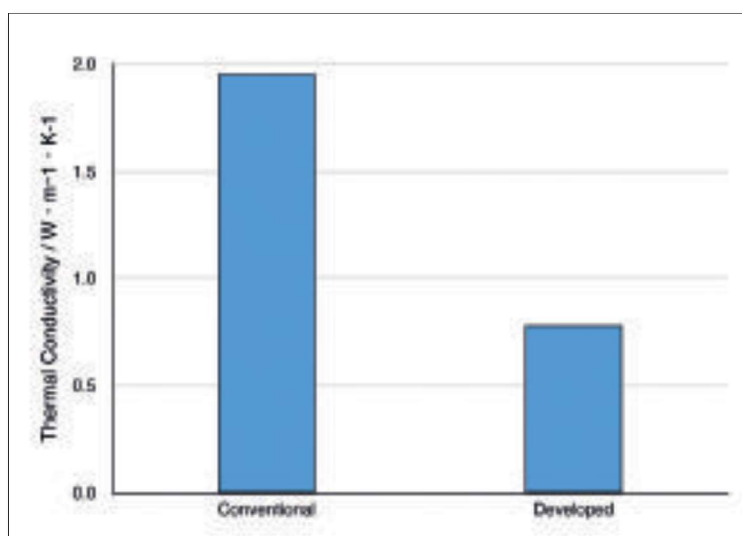


Fig 3 Comparison of thermal conductivity of gunned coating mix body at 1000°C

mix to the wear layer refractory. Figure 4 shows how the permeability of the gunned coating mix body compared between the conventional and developed product. Large amounts of fibre blending contribute to an improvement in the permeability of the gunned coating mix body. It is inferred that improved permeability of the gunned coating mix body positively influences suppression of explosive spalling. It is noted that, despite the large amount of fibre blending, the transportation efficiency of the developed coating mix during gunning operations has been adequately secured, by an improved fibre blending technique.

FEATURES OF TROWELLING COATING MIX, SCOAT-M-71

Large amounts of fibre were blended into the newly developed trowelling coating mix, SCOAT-M-71, as was the case with the →

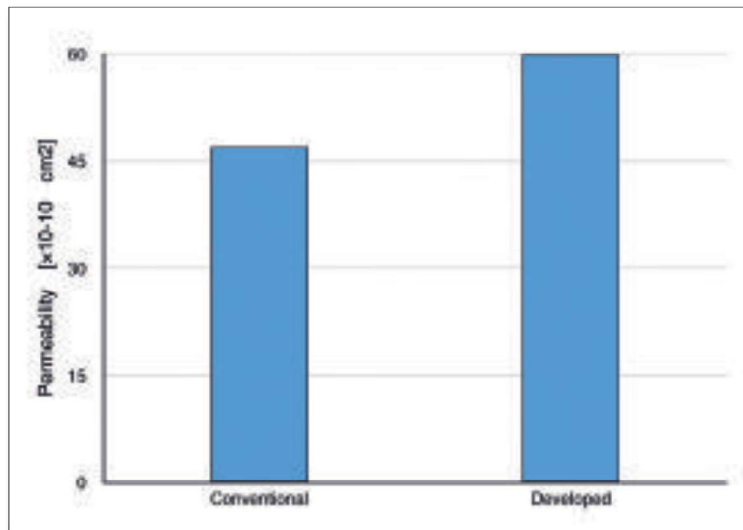


Fig 4 Comparison of permeability of gunned coating mix bodies

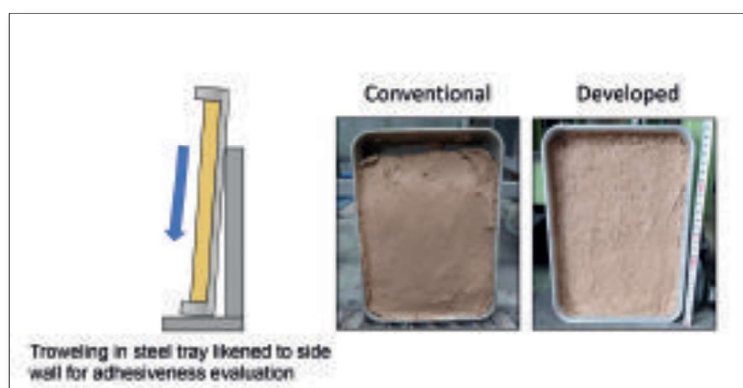


Fig 5 Test method for evaluating adhesiveness of trowelling coating mix

		JTM-M-629	SOOAT-M-71
Chemical composition / %	MgO SiO ₂	87 5	88 5
Permanent linear change / %	1000°C-3h	-0.01	-0.30
	1500°C-3h	-3.48	-2.87
Modulus of rupture / MPa	110°C-24h	1.2	1.5
	1000°C-3h	0.8	1.0
	1500°C-3h	4.4	5.7
Added amount of water / %		18~22	15~18
Installation weight per unit volume / kg · m ⁻³		1,900	1,900
Notes		Gunning mix	Trowelling mix

Tale 1 Typical characteristics of gunning and trowelling coating mixes

gunning coating mix, JTM-M-629. This acts to suppress sticking to the wear layer refractory. In addition, shape retainability of the relined coating mix body, i.e. workability in the trowelling operation, has been realized by using an additive agent with high viscosity and quick setting characteristics.

Figure 5 shows the test method for evaluating the adhesiveness of the trowelling coating mix and the appearance of the conventional and newly developed coating mix, when trowelled into a steel tray. The coating mix was troweled into a steel tray at 80 degrees of tilt angle, so as to liken it to a tundish side wall, for evaluating workability and adhesiveness. As is observable by the appearance of the trowelled coating mix bodies shown in Figure 5, the newly developed coating mix exhibits almost no slip-down in its relined body, namely, better shape retainability and adhesiveness.

Typical characteristics of the newly developed gunning and trowelling coating mixes are summarized in Table 1. Both coating mixes are composed of magnesia and have been used in both integrated steel plants and electric furnace steel shops with a good reputation.

CONCLUSION

Gunning and trowelling coating mixes with improved drying, workability and dismantling properties, were developed by establishing a fibre blending technique for the tundish coating mix. These coating mixes have been used in practical operations with a good reputation for their performance. **MS**

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High-durability trowelling repair refractory material, CCT-A620T, for reheating furnace skid pipe

By applying clay with a good swelling property, a high durability trowelling repair refractory material has been newly developed, in which colloidal silica is used as binder. Similar to conventional cement blended trowelling repair refractory, the newly developed trowelling repair refractory, CCT-A620T, is applicable for repair work on the reheating furnace skid pipe. Since damage caused by cracking and peeling off is reduced through the use of CCT-A620T, a reduction in repair refractory consumption is achievable.

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INTRODUCTION

The reheating furnace is a facility in which semi-finish steel products, produced in a caster, are heated up for the hot rolling mill. Thermal spalling resistance and erosion resistance to FeO are required for reheating furnace refractories, as they are exposed to high temperatures for a long period of time, and may react with mill scale generated by surface oxidation of semi-finished steel products. Application of ceramic fibre, or CA6 castable refractory in a reheating furnace has increased, because of the importance of reducing exhaust heat from the reheating furnace as a means of achieving carbon neutral operations. However, this leads to a problematic increase in the frequency of repair work, because of deterioration of ceramic fibre durability, caused by FeO attack, or mist cooling applied during periodical maintenance work. For this reason, better durability of reheating furnace refractories is still required.

The authors' company developed a chemical bond castable refractory for skid pipes, utilizing colloidal silica^[1], which has been used with good results and for a long service life, without severe cracking, or peel-off damage. The skid pipe, which is relined with a conventional cement castable refractory, can be severely damaged by thermal shock and erosion by FeO derived from mill scale. Damaged skid pipe refractories are dismantled and repaired with new castable refractory during periodical maintenance. When the time available for maintenance is too short to repair the skid pipe by relining with new castable refractories,

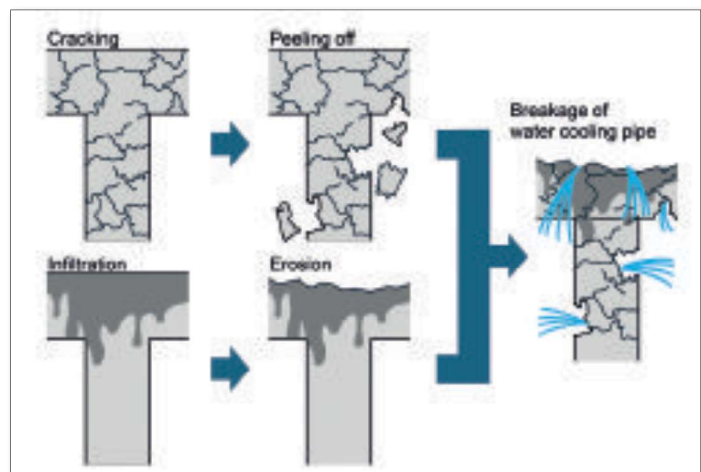


Fig 1 Damage patterns of reheating furnace skid pipe refractory

repair work is carried out with trowelling repair material. For such occasions, a high durability trowelling repair refractory is required.

This article introduces the newly developed trowelling repair refractory, CCT-A620T, which can have a long service life at the repaired position in reheating furnace skid pipes.

DAMAGE PATTERNS OF REHEATING FURNACE SKID PIPE REFRACTORY

The operating temperature of the reheating furnace is in the range from roughly 900°C to over 1300°C. Since relined refractories are cooled down by mist cooling during periodic maintenance work, they are exposed to large temperature fluctuations. In addition, reheated furnace refractories are exposed to a harsh environment where iron oxides, such as FeO, called mill scale, is constantly being generated →

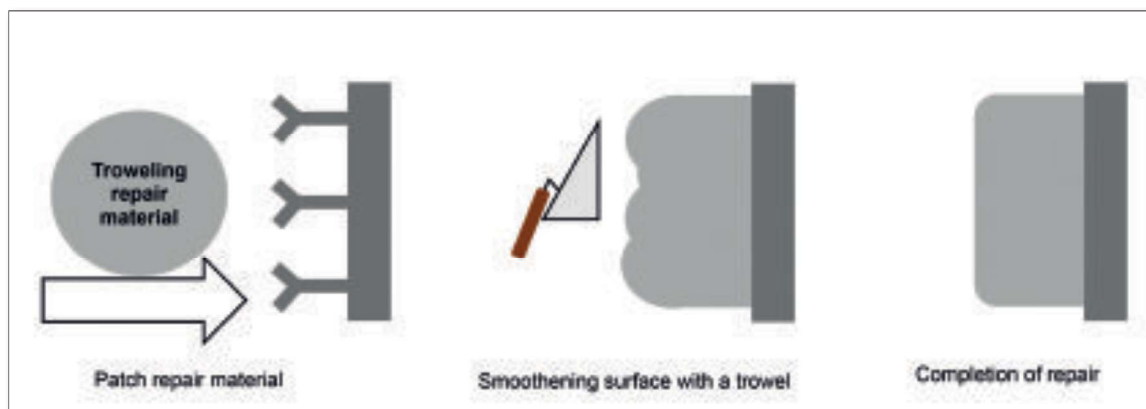


Fig 2 Schematic diagram of trowelling repair refractory application on skid pipe

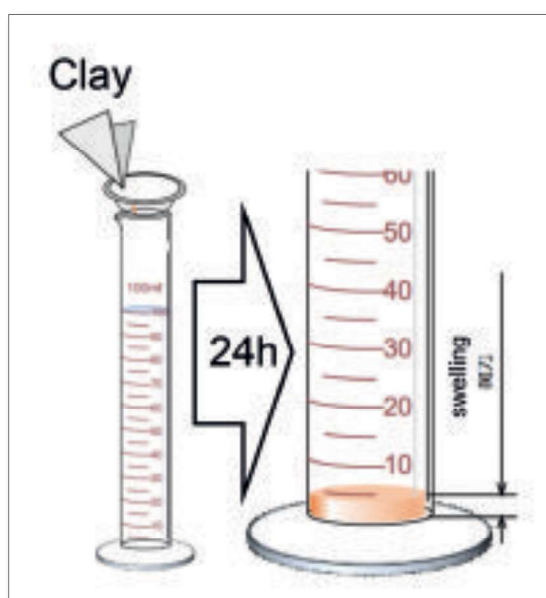


Fig 3 Water dipping test to evaluate the swelling property of clay

by surface oxidation of steel semi-products. As per *Figure 1*, refractories relined on a skid pipe are damaged by cracks induced by thermal spalling, peeling-off caused by elongation of cracks, and infiltration of chemical compounds, generated by reaction with iron oxides. When a refractory is severely damaged, the water-cooling pipe in the skid pipe is broken. Therefore, repair work on skid pipe refractories is necessitated during periodical inspections.

RELINING OF TROWELLING REPAIR REFRACTORY ON SKID PIPE

Figure 2 is a schematic diagram of trowelling repair refractory relining on a skid pipe. First, the trowelling repair refractory is kneaded to a

relatively high hardness and then patched onto the skid pipe surface by hand. After patching, its surface, wet with water, is smoothed with a trowel. Sufficient shape retaining properties, good adhesiveness and adequate water holding properties to suppress drying during relining work, are required of trowelling repair refractories. Thus, appropriate selection of the clay which is blended into the trowelling repair material is important to secure these three characteristics.

SELECTION OF APPROPRIATE CLAY

Clay, a common natural resource, generally exhibits a plastic property with a moderate amount of water addition, as well as increased hardness as it dries. In the firing process, clay plays the role of binding blended raw materials through the silica components generated by decomposition. Clay is used as a fine raw material to secure moldability as well as shape retention of the green body. The swelling property is cited as one of the characteristics to evaluate clay material quality. Swelling is volume expansion behavior induced by water absorption. Clay with a good swelling property indicates that a large amount of water can be absorbed and held in the clay material.

The swelling property of three kinds of clay were evaluated with the water dipping test shown in *Figure 3*. In the example, 2g of clay sample were dipped into 100ml of water in a measuring cylinder. After keeping the clay in the water for 24 hours, the expanded volume of dipped clay sample was measured to quantify swelling behavior. The chemical compositions of three kinds of clay are shown in *Table 1*. As per *Figure 4* in which the degree of swelling of

each clay is compared, clay sample C exhibits the highest degree of swelling.

Figure 5 schematically shows the crystal structure of clay and the mechanism of swelling. Clay is composed of laminated plate crystal layers of approximately 1nm thickness. Since the interlayer between plate crystals is charged with negative polarity, a variety of exchangeable cations, namely, Na^+ , K^+ , Ca^{2+} and Mg^{2+} , are absorbed. Clay largely containing Na^+ ion crystal interlayers is called Na-type clay. When water molecules infiltrate into the interlayer of clay, as illustrated in Figure 4, the interlayer between the clay unit crystals expands, resulting in volume expansion, otherwise referred to as swelling. It is acknowledged that Na-type clay mineral exhibits a better swelling property associated with a high thickening property, increased viscosity and good dispersibility in water. The results evaluated with the water dipping test are consistent with such knowledge.

FEATURES OF NEWLY DEVELOPED TROWELLING REPAIR MATERIAL, CCT-A620T

Working life

One problem caused by the use of colloidal silica is quick drying of the refractory body surface. For this reason, the working time for trowelling the refractory at the experimental stage was only 2 hours. When clay with a good swelling property was blended, the water component held in the refractory body notably increased, resulting in suppression of quick drying of the refractory body surface with improved shape retaining property. As shown in Figure 6, newly developed trowelling repair material, CCT-A620T, realized a 5-hour working life, over two times that of its prototype product. In practical repair operations, CCT-A620T exhibits good workability with sufficient working life.

Physical properties

The permanent linear change and modulus of rupture of the newly developed trowelling repair material, CCT-A620T, in which colloidal silica is used as binder is compared with that of a conventional cement blended trowelling refractory in Figure 7 and Figure 8, respectively. Because of the use of colloidal silica as binder, CCT-A620T exhibits a steady increase of mechanical strength in accordance with elevated →

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
Clay A	64.1	17.6	5.7	1.0	0.8	1.2	2.7
Clay B	67.2	17.4	3.8	0.7	1.4	1.8	1.3
Clay C	70.4	15.5	2.0	1.6	2.4	2.3	0.3

Table 1 Chemical compositions of three types of clay

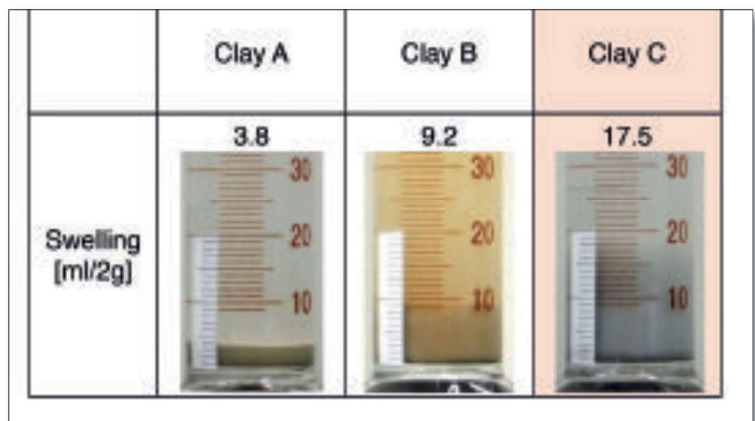


Fig 4 Degree of swelling of each clay sample

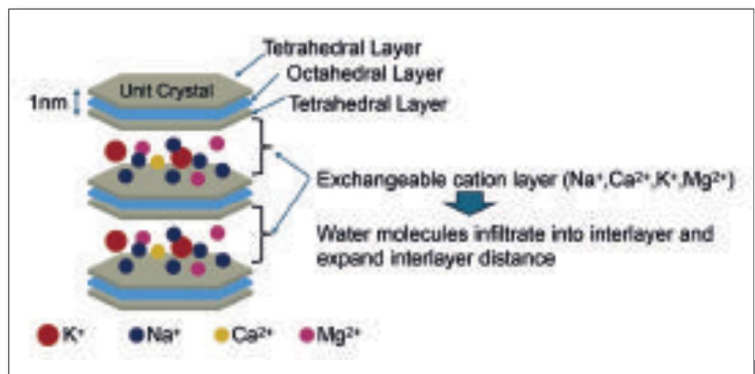


Fig 5 Schematic illustration of crystal structure of clay mineral and mechanism of swelling

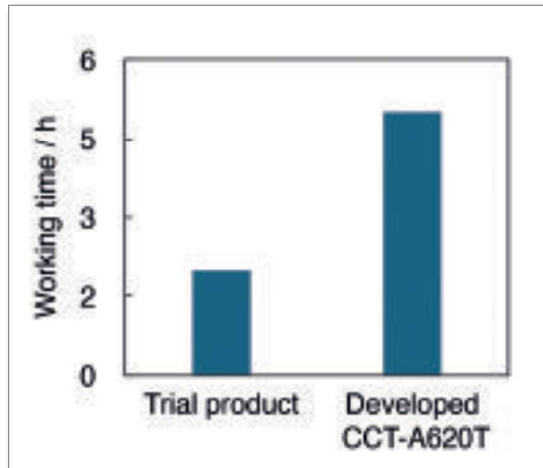


Fig 6 Comparison of working time

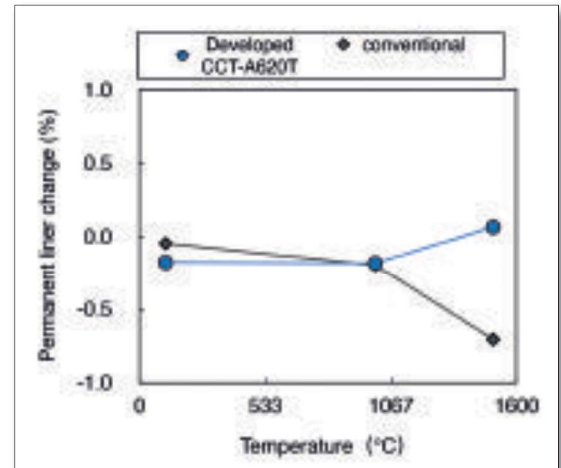


Fig 7 Comparison of permanent linear change

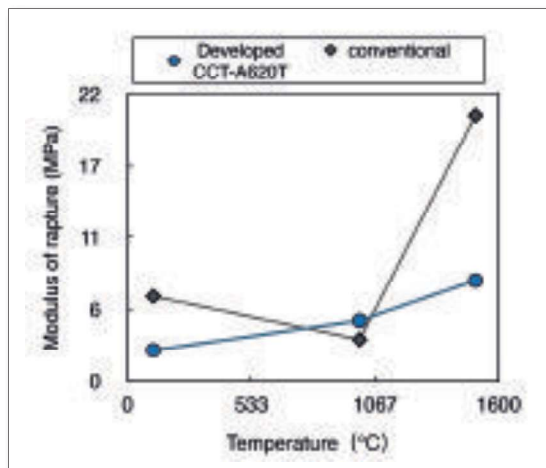


Fig 8 Comparison of modulus of rupture

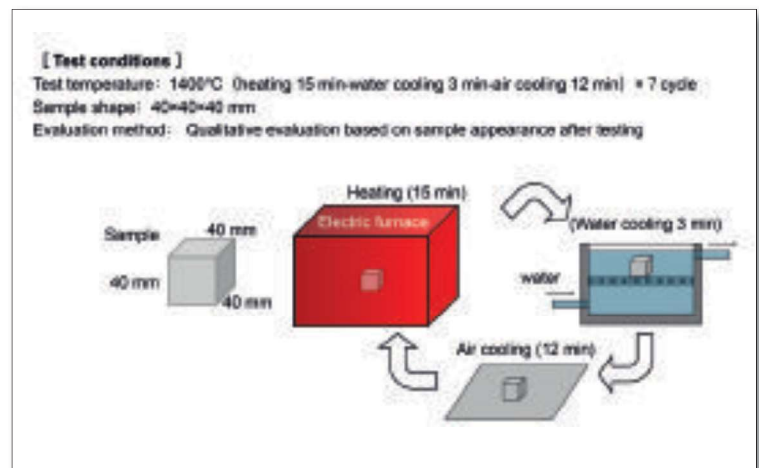


Fig 9 Schematic diagram of thermal spalling test

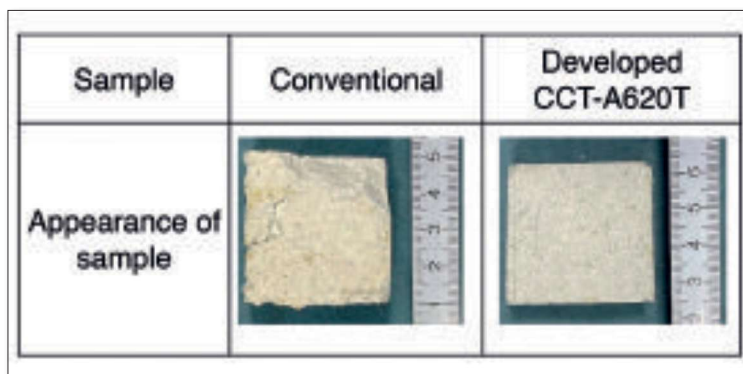


Fig 10 Appearance of thermal spalling test specimen

heat treatment temperature with no strength reduction at around 1000°C, which is generally observed in cement blended refractories.

Thermal spalling resistance

A schematic diagram of the thermal spalling test is shown in Figure 9. A heating and cooling cycle in which a 40mm cubic sample specimen was heated at 1400°C for 15 minutes in an electric furnace and cooled down in water for 3 minutes, followed by air cooling for 12 minutes, was repeated seven times. After completion of the thermal spalling test, the degree of crack initiation was observed for evaluation. A comparison of the appearance of the thermal spalling test specimens is shown in Figure 10.

In comparison with the conventional cement blended trowelling refractory, CCT-A620T exhibits superior thermal spalling resistance. It is

inferred that smaller fluctuations in mechanical strength and volume change by elevation of heat treatment temperature contributed to the improved thermal spalling resistance of CCT-A620T.

EROSION RESISTANCE TO FEO

A schematic diagram of the erosion test is shown in *Figure 11*. Mill scale was put in crucible samples made of CCT-A620T and a conventional trowelling refractory. Then, the crucible samples with a firmly fixed lid were heated at 1500°C for 3 hours. After heating, the crucible samples were cut into halves to observe erosion by FeO as well as the FeO penetration depth in the trowelling refractories. A cross-section of the crucible sample after the erosion test is shown in *Figure 12*. In comparison with the conventional trowelling refractory, CCT-A620T exhibits improved erosion resistance to FeO.

The chemical and physical characteristics of CCT-A620T and those of a conventional trowelling refractory are compared in *Table 2*. Application of colloidal silica as a binder has enabled the advantageous blending design of CCT-A620T, to increase Al_2O_3 content in association with lowering of the CaO component to almost zero. It is inferred that the reactivity of CCT-A620T with FeO is lowered by such change in chemical composition.

CONCLUSION

High-durability trowelling repair refractory material, CCT-A620T, was developed for the skid pipe in a reheating furnace, by applying clay with a good swelling property to suppress quick drying of the refractory body surface, which is one of the difficult points caused by the use of colloidal silica. CCT-A620T is applicable for both patching and trowelling repair work. **MS**

REFERENCE

[1] S. Komori, K. Komatsubara and S. Suetake (2023). *Shinagawa Technical Report*, 66, 16-29.

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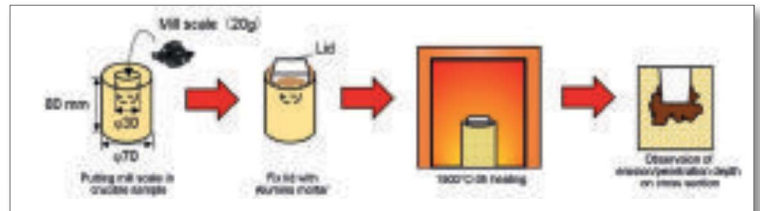


Fig 11 Schematic diagram of crucible sample erosion test with mill scale

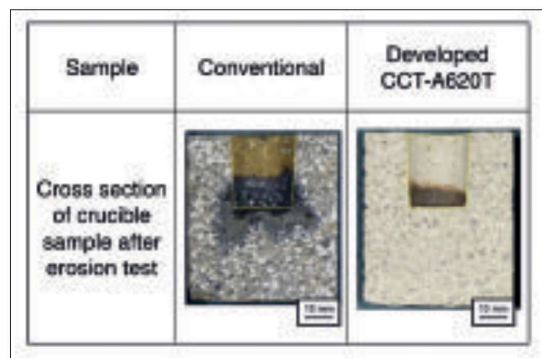


Fig 12 Cross section of crucible sample after erosion test

Product		Conventional	Developed CCT-A620T
Chemical composition [%]	Al_2O_3	60	70
	SiO_2	34	27
	CaO	4	0
Linear change [%]	110°C-24 h	-0.05	-0.18
	1000°C-3 h	-0.20	-0.19
	1500°C-3 h	-0.71	0.06
Modulus of rupture [MPa]	110°C-24 h	6.5	2.4
	1000°C-3 h	3.2	4.6
	1500°C-3 h	20.4	7.7
Binder		Alumina cement	Colloidal silica

Table 2 Typical characteristics of CCT-A620T and conventional trowelled refractory