REPORT

Recent Technical Developments of Refractories and Ceramic Fiber Products for Reheating Furnace

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Abstract

Refractory materials used in the reheating furnace are outlined in this article, along with review of heat insulation technologies used for ceramic fiber products in the reheating furnace. By applying gunning plastic refractory and dry-gunning repair plastic refractory, marked labor saving is expected in refractory relining and maintenance work. Service life extension of refractories relined on the skid post and skid beam has been achieved by application of newly developed chemical bond castable refractory, which is characterized by improved thermal spalling resistance and erosion resistance to FeO. Marked heat loss reduction was realized by application of the developed ceramic fiber products with superior thermal properties and sufficient erosion resistance to FeO. Further development or optimization, such as optimization in applied technologies for reheating furnace operational conditions as well as developing heat insulation products combined with refractory and CF product, will be challenged.

1. Introduction

The reheating furnace is a facility to reheat semi-final steel products, such as slab or bloom, which are hot-rolled to thin steel sheet products, bar steel products with round or square sections or other shaped steel products at rolling mills in the steel industry. A schematic diagram of a reheating furnace is shown in Fig. 1. Semi-final steel products are transferred in a reheating furnace with the inner temperature kept at a specified temperature by reheating burners, and redly heated semi-final steel products are supplied to the hot-rolling mill. A walking beam system is usually applied for transferring semi-final steel products in reheating furnace. In the walking beam system, semi-final steel products are alternately held by a fixing beam and walking beam. The system repeats sequential cycle of ascending (lifting up semi-final steel product), advancing horizontal movement, descending (putting down semi-final steel product) and regressing horizontal movement (for returning to initial position) so as to forward semi-final steel products to discharge direction. In comparison with the old-fashioned pushing method, scratched defects on the semi-final steel product surface are prevented in the walking beam system.

The operation temperature of the reheating furnace ranges from a relatively low temperature of approximately 900℃ to a high temperature of over 1300℃. At maintenance works, refractories relined in the reheating furnace are cooled down from operation temperature to ambient temperature by mist spraying, resulting in exposure to large temperature fluctuation. In addition, chemical reaction between refractories and iron oxide components (usually FeO), which are generated as mill scale by surface oxidation of semi-final steel

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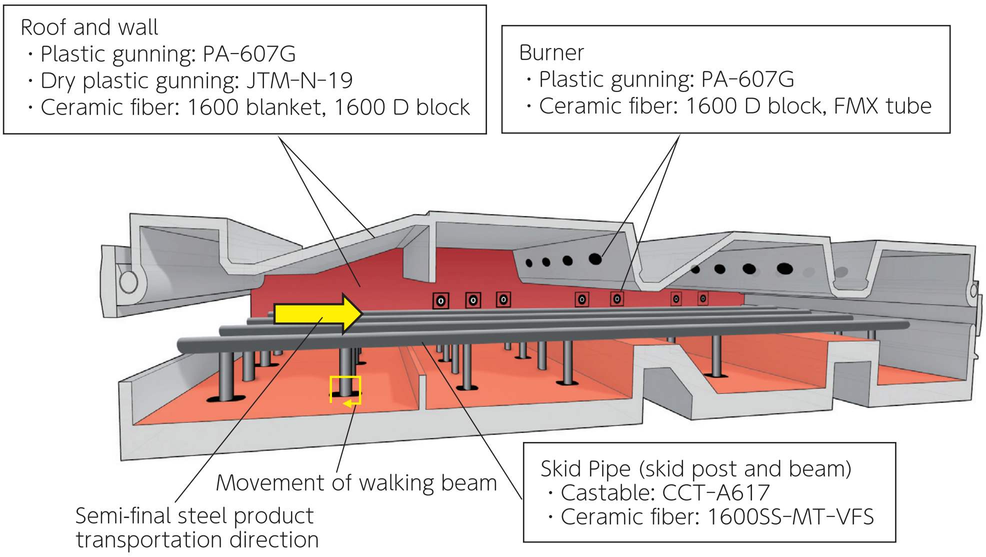


Fig. 1 Schematic diagram of reheating furnace.

products, ceaselessly takes place in the reheating furnace. In short, refractories in the reheating furnace are exposed to severe operational conditions. At the same time, since, from the standpoint of achieving a carbon-neutral society, it is quite important to minimize heat emission from the reheating furnace, intensification of reheating furnace thermal insulation is highly required. Meanwhile, since refractory relining and/or maintenance work are conducted with huge manpower under oppressive working conditions, laborsaving activities to reduce or lighten labor loads are also required.

Improvement of reheating furnace refractory performance, thermal insulation technologies utilizing ceramic fiber products and reducing labor in reheating furnace refractory relining work, which have been carried on by the authors' company and its group companies, are reviewed in this article.

2. *Gunning Plastic Refractory with Minimized Curing Shrinkage, PA-607G*

During the period from the 1960's to 1970's, in which a large number of reheating furnaces were constructed, refractory bricks were majorly applied as the relining refractory material of the reheating furnace[1]. Afterwards, in association with the increase in the number of reheating burners, the reheating furnace pressure was raised, accompanied by waste gas leakage from the joints of the relined bricks. As a countermeasure for such situation, ramming a plastic refractory with plasticity, one type of monolithic refractory, was developed and, as shown in Fig. 2, is applied by pounding with rammer[2,3]. In the 1980's, plastic refractory gunning construction method[4] was developed. In this construction method, granulated plastic refractory lumps in wet condition (appearances shown in Fig. 3) are pneumatically gunned on the relining wall surface as per Fig. 4. This construction method has following advantages, (1) 3-4 tons/hour of high relining efficiency, (2) good

Fig. 2 Scene of ramming plastic refractory installation onto wall surface.

Fig. 3 Appearance of gunning plastic refractory.

Fig. 4 Scene of gunning plastic refractory installation onto wall surface.

Fig. 5 Exterior view of gunning machine of gunning plastic refractory.

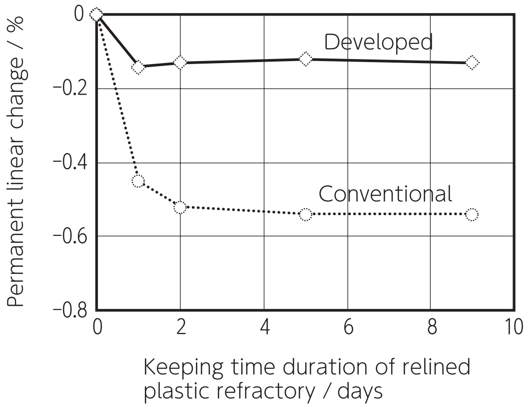


Fig. 6 Relation between keeping time duration of relined plastic refractory body and permanent linear shrinkage caused by curing.

working condition with little dust emission, (3) no necessity for assembling a molding frame, (4) easy relining on complex shaped surfaces, (5) operation with only compressed air as utility which does not require specialized skills for water or binder adjustment, (6) concise and easy cleaning after relining operation and (7) compactness of operation equipment which is shown in Fig. 5, hence the overall construction time period was remarkably shortened in association with labor reduction.

A confronting issue in this construction method is that relined plastic refractory body needs be cured with covering its whole surface with vinyl to prevent crack initiation caused by shrinkage induced by curing or drying. To eliminate such difficulty, gunning plastic refractory with minimized curing shrinkage, PA-607G, was developed. The typical characteristics of PA-607G are summarized in Table 1 in comparison with conventional gunning plastic refractory composed of around 60 % Al_2O_3.

Fig. 6 shows the relation between keeping time duration of relined plastic refractory body in ambient atmosphere after installation and permanent linear shrinkage caused by curing. Conventional gunning plastic refractory body exhibits marked shrinkage within one (1) day after installation, followed by further change to roughly −0.6% of permanent shrinkage. While, the developed gunning plastic refractory (PA-607G), for which clay raw material with a different level of wet condition was adopted, exhibits smaller than −0.2% of permanent linear shrinkage, which is equivalent to the curing shrinkage of conventional product cured with vinyl covering on its surface.

In order to evaluate the sensibility of crack

Table 1 Typical characteristics of PA-607G and conventional gunning plastic refractory

Product		PA-60G	PA-607G
Chemical Composition / %	Al_2O_3 SiO_2	58 35	60 35
Linear change / %	110℃-24 h 1000℃-3 h 1500℃-3 h	-0.19 -0.37 +0.07	-0.09 -0.31 +0.06
Modulus of rupture / MPa	1000℃-3 h 1500℃-3 h	1.1 6.8	1.8 6.8
Cold compressive strength / MPa	110℃-24 h 1000℃-3 h 1500℃-3 h	3 8 11	4 9 10
Apparent porosity / %	110℃-24 h 1000℃-3 h 1500℃-3 h	21.4 23.7 21.3	20.1 22.4 20.6
Bulk specific gravity / -	110℃-24 h 1000℃-3 h 1500℃-3 h	2.33 2.29 2.29	2.34 2.31 2.31
Maximum service temperature / ℃		1700	1700
Installation weight per unit volume / kg・m^{-3}		2,530	2,530
Notes		Conventional product	Gunning plastic refractory with minimized curing shrinkage

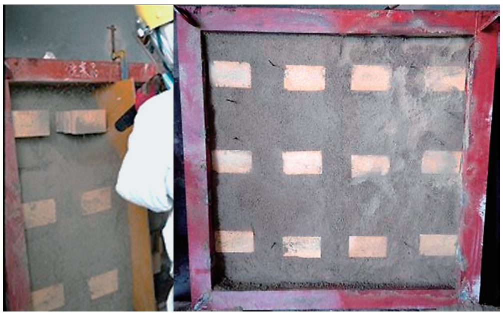
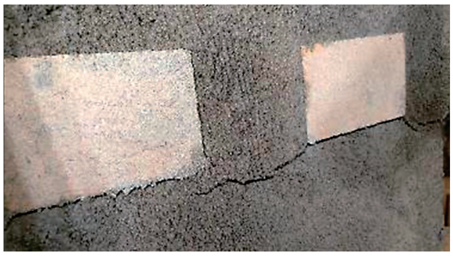
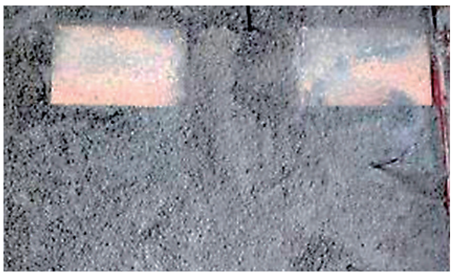


Fig. 7 Appearance of large-sized panel with anchor bricks used for simulative gunning experiment.



Conventional produc



Developed product

Fig. 8 Surface appearances of two types of gunning plastic refractory gunned onto large-sized panel and cured for 20 days.

initiation caused by curing shrinkage, a simulative experiment was conducted with conventional and developed gunning plastic refractory onto a large-sized panel in which, as shown in Fig. 7, anchor bricks were installed. The surface appearances of two types of gunning plastic refractories, which were gunned onto large-sized panels and cured for 20 days, are comparatively shown in Fig. 8. No

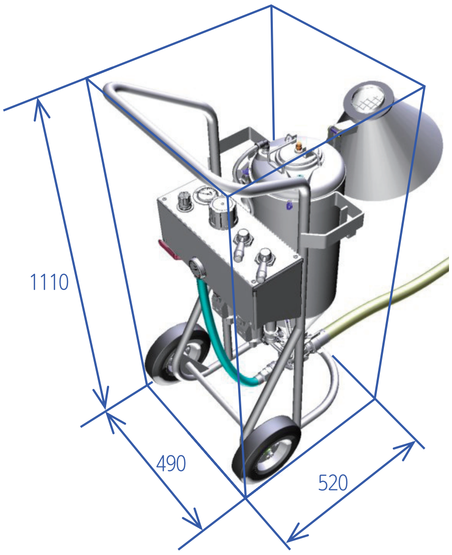


Fig. 9 Exterior view of lightweight portable dry-mix gunning machine, KOALA-mini[5].

Table 2 Typical characteristics of dry-gunning repair refractory material

Product		JTM-N-19
Linear change / %	110℃-24 h 1000℃-3 h 1400℃- 3 h	+0.01 -0.22 +0.12
Modulus of rupture / MPa	110℃-24 h 1000℃-3 h 1400℃-3 h	2.5 2.1 9.2
Apparent porosity / %	110℃-24 h 1000℃-3 h 1400℃-3 h	24.6 30.3 0.4
Bulk specific gravity / -	110℃-24 h 1000℃-3 h 1400℃-3 h	2.14 2.06 2.05
Chemical composition / %	Al_2O_3 SiO_2	55 35
Notes		Medium alumina

cracks caused by curing shrinkage were observed on the gunned surface of the developed gunning plastic refractory after 20 days of curing. Superior curing shrinkage property of the developed gunning plastic refractory, PA-607G, is affirmed in large scale simulative gunning experiment.

3. *Dry-gunning Repair Plastic Refractory, JTM-N-19*

Since reheating furnaces are operated for several decades, which is a lengthy time period, localized peel-off of relined gunning plastic refractory occasionally takes place. Based on half-yearly inspection work on the damaged condition of refractories relined in the reheating furnace, partial demolishing and repair work is conducted on locally damaged area. For minor repair work of quite localized damage, more convenient and easier repair method than plastic refractory gunning is preferable. In this regard, repair work with dry-gunning repair refractory using lightweight portable dry-mix gunning machine, KOALA-mini[5] (exterior view shown in Fig. 9), is highly recommended.

Fig. 10 Scene of gunning experiment of dry-gunning repair refractory material.

The typical characteristics of dry-gunning repair refractory material are shown in Table 2. By optimizing contents of clay raw materials and alumina cement, the blended compositions of dry-gunning repair refractories were designed so as to be equivalent to those of gunning plastic refractory, which is used for initial relining. Fig. 10 shows the scene of the gunning experiment of dry-gunning repair refractory material, in which, instead of KOALA-mini, a commonly applied gunning machine was used. Dry-gunning repair refractory, JTM-N-19, exhibits superior

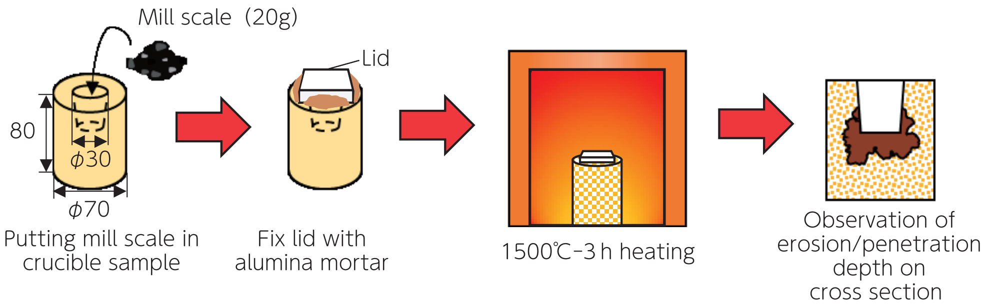
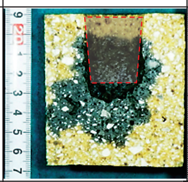
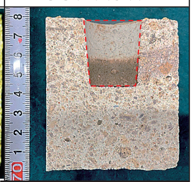


Fig. 11 Schematic diagram of crucible sample erosion testwith mill scale.

Table 3 Cross section of two types of castable refractory crucible sample specimens after erosion test

Sample	Cement castable CA-160	Chemical bond castable CCT-A617
Cross section of crucible sample after erosion test		
Penetration depth/ mm	25.0	0.5

adhesion property to secure roughly 300 mm thickness of gunned body with low dust emission in gunning operation.

4. Chemical Bond Castable Refractory with High Erosion Resistance to FeO, CCT-A617

The skid post and skid beam in the walking beam system are configured with a steel pipe in which cooling water is circulated and refractory material is relined on the outer surface of the steel pipe. The reheating furnace can be operated for lengthy time period by applying water cooling to prevent deterioration of steel materials used in the skid post and skid beam. Alumina-silica castable refractory has been used as a major relining material on the outer surface of the steel pipe. Castable refractory relined on the skid post and skid beam is damaged by mechanical impact caused by walking beam movement as well as by thermal shock induced by heating-cooling, resulting in crack initiation and, finally, peeled-off damage. In addition, the refractory is damaged by the FeO component in the generated mill scale, resulting in erosive damage and/or formation of an FeO infiltrated layer. Chemical bond castable refractory with better consistency between mechanical strength and erosion resistance, CCT-A617, was developed by applying colloidal silica in order to improving durability of castable refractory relined on skid post and skid beam.

A schematic diagram of the erosion test performed on the crucible specimen sample at 1500℃ for 3 hours with mill scale used as the erosive agent is shown in Fig. 11. As per Table 3, in which a cross section of the two types of castable refractory crucible specimen samples subjected to the erosion test is comparatively shown. Newly developed chemical bond castable refractory, CCT-A617, exhibits much better erosion resistance to FeO than conventional alumina-cement bond castable refractory, CA-160.

The major chemical and physical properties of two types of castable refractories, namely, CCT-A617 and CA-160, are shown in Table 4. The hot modulus of rupture of chemical bond castable refractory, CCT-A617, containing colloidal silica steadily increases with the elevation in temperature without the strength reduction at around 1000℃, which can be seen in conventional alumina-cement bond castable refractory, CA-160.

Practical application test of chemical bond

Table 4 Major chemical and physical properties of two types of castable refractories

Product		CCT-A617	CA-160
Chemical composition / %	Al_2O_3 SiO_2	70 28	46 44
Linear change / %	110℃-24 h 1000℃-3 h 1500℃-3 h	-0.01 0.00 0.43	-0.03 -0.10 0.50
Modulus of rupture / MPa	110℃-24 h 1000℃-3 h 1500℃-3 h	5.3 6.6 9.6	4.9 2.9 13.7
Installation weight per unit volume / $kg \cdot m^{-3}$		2640	2050
Binder		Colloidal silica	Alumina cement

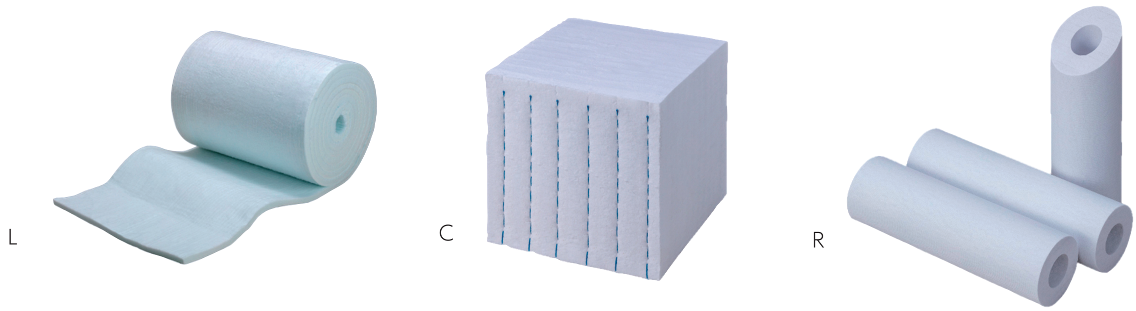


Fig. 12 Exterior appearances of CF products (L：Blanket C：Block R：VFS).

castable refractory, CCT-A617, for skid post and skid beam has been conducted, and it was affirmed that initiated cracks or peel-off damages were quite minor after over 4 years of reheating furnace operation.

5. *Ceramic Fiber Products for Reheating Furnace*

Due to its low bulk density, in comparison with cement castable refractory, ceramic fiber (hereinafter referred to as CF) is characterized by low thermal conductivity as well as small heat storage volume. Because of such advantageous thermal properties, CF has been applied as heat insulation refractory material for the reheating furnace since the 1980's[6], and a marked reduction in both heat loss from the reheating furnace and heat accumulation loss during reheating furnace operation has been clarified.

In a comparison with cement castable refractory, the major physical properties of several types of CF product applied for the reheating furnace, of which the exterior appearances are shown in Fig. 12, are summarized in Table 5. All the CF products cited in Table 5 exhibit better thermal properties than cement castable refractory. Their inferior physical property, erosion resistance to mill scale, can be improved by applying coating technology. Block shape CF products which have been used on the side wall and ceiling of the reheating furnace are recently applied to the partitioning wall, too. Application of CF products for other locations in the reheating furnace is proceeding. Typified examples of CF product application to the reheating furnace are outlined in the following sub-sections.

Table 5 Major physical properties of several types of CF products applied to reheating furnace

Material	1600 Blanket 100	1600 D Block 130	1600 SS-MT-VFS	Cement castable
Bulk density/kg·m^{-3}	100	130	230	2000
Thermal insulation capability Thermal conductivity/W·m^{-1}·K^{-1} at 1000℃	+++ 0.30	+++ 0.38	+++ 0.25	+ 1.0
Thermal shock resistance	+++	+++	+++	+
Scale resistance Coating technology application	+ +++	+ +++	++ +++	++ -
Handling · easiness	+++	++	++	+

+++: Excellent, ++: Good, +: Average, -: Out of scope

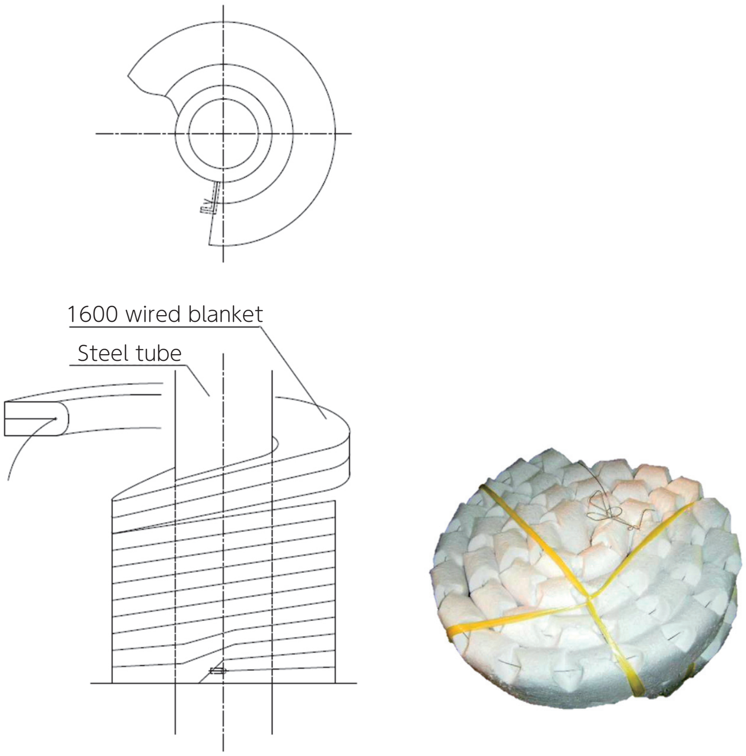


Fig. 13 Schematic installation view of 1600 wired blanket around skid post.

5. 1 Application of CF product 1600SS-MT-VFS to the skid post and skid beam

Since heat loss taken away by skid post cooling water occupies a large portion of the entire heat loss from the reheating furnace, a heat insulation structure with high application efficiency, in which CF blanket is rolled up on the outer surface of skid post forming a laminated structure, was firstly adopted. A schematic installation view of 1600 wired blanket around a skid post is shown in Fig. 13. 1600 wired blanket, which is CF blanket with wire reinforcement, is spirally built up tightly around the steel tube of the skid post so as to form a laminated structure. In comparison with castable refractory, 1600 wired blanket characterized by much smaller bulk density can materialize superior energy saving

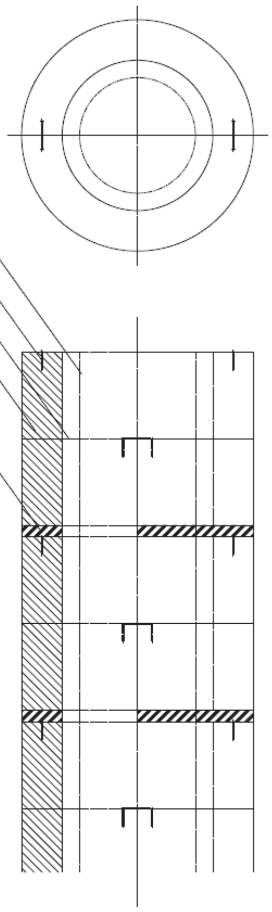
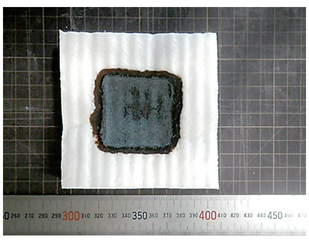
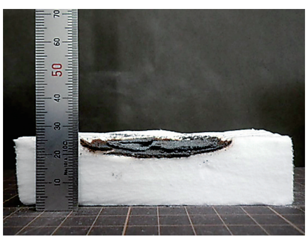
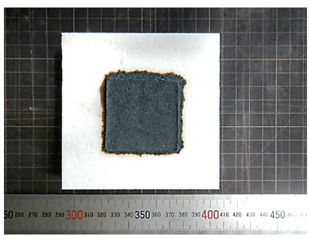


Fig. 14 Schematic installation view of 1600SS-MT-VFS around skid post.

efficiency by improved thermal insulation and small heat storage volume, and has been widely applied in various types of reheating furnaces. It is reported that, even though the outer surface of installed 1600 wired blanket is processed with coating material to compensate for its poor mechanical strength and inferior erosion resistance to mill scale, age deterioration caused by mill scale takes place on assembled CF blanket[7]. In order to improve such difficulty, tubular formed CF product with equivalent thermal properties of CF blanket and improved erosion resistance to mill scale, 1600SS-MT-VFS, was developed.

A schematic installation view of 1600SS-MT-VFS around skid post is shown in Fig. 14. As indicated in Table 5, 1600SS-MT-VFS exhibits almost double the bulk density of conventional CF blanket (1600 Blanket 100) with lower thermal conductivity. As per Table 6, in which results of the erosion test on 1600SS-MT-VFS and 1600 Blanket 100 at 1400℃ for 24 hours with mill scale as erosive agent are shown, 1600SS-MT-VFS exhibits well improved erosion resistance to mill scale. It is expected that damages caused by mill scale infiltration, such as

Table 6 Results of erosion test on 1600SS-MT-VFS and 1600Blanket 100 at 1400℃ for 24 hours with mill sale as erosive agent

	1600 Blanket100	1600SS-MT-VFS
Appearance surface side	 	 
Erosion thickness /mm	5	1

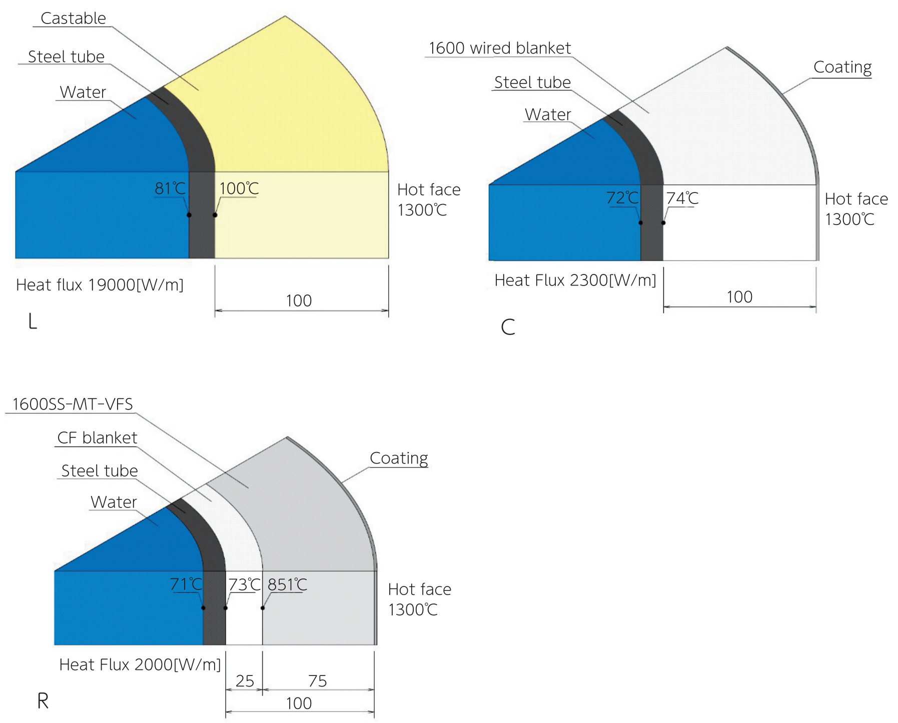


Fig. 15 Heat insulation structure configuration for steady state thermal transfer calculation (L : Castable refractory, C : 1600 wired blanket, R : 1600SS-MT-VFS).

drop-off of CF product or joint opening, observed in 1600 wired blanket laminated structure can be prevented by 1600SS-MT-VFS application.

To evaluate the improved thermal insulation efficiency by application of CF products, steady state thermal transfer calculation was conducted on three types of heat insulation structure configurations which are schematically illustrated in Fig. 15, namely, a conventional structure composed of castable refractory relined on skid pipe, a laminated insulation structure with 1600 wired blanket and insulation structure with CF blanket which situated between the skid post and 1600SS-MT-VFS. Since the major purpose of evaluation was relative comparison of thermal insulation efficiency by configuration of heat insulation structure, thermal transfer calculation was conducted with similar thickness of insulation material (with no consideration on influences of supporting fitting) under the same operational conditions, such as skid post water cooling conditions (inlet water temperature and flow rate). The results of thermal transfer calculation, namely, outlet cooling water temperature and heat flux, are summarized in Table 7. In comparison with heat insulation structure composed of castable refractory, outlet cooling water temperature was lowered by roughly 10℃ in a heat insulation structure composed of CF products in association with reduction of heat flux by around 90%. Taking into account the practical aspect in the relining process that, unlike a conventional heat insulation structure composed of castable refractory, the necessary number of supporting fittings is markedly lowered in a heat insulation structure with CF products. It is inferred that improved thermal insulation efficiency by application of CF products will exceed the calculation results because of reduction of heat loss by the supporting fittings.

Table 7 Thermal transfer calculation results on three types of heat insulation structure configuration

	Conventional	1600 wired blanket	1600SS-MT-VFS
Water temperature / ℃	81	72	71
Heat flux / $W \cdot m^{-1}$	19,000	2,300	2,000

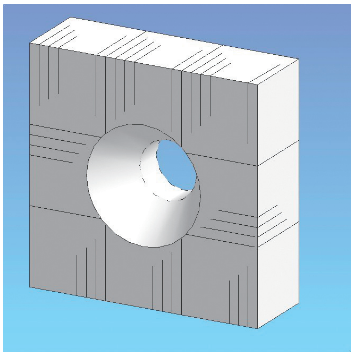


Fig. 16 Image of burner block manufactured with CF product.

Fig. 17 Exterior appearance of FMX tube made of highly densified CF product.

5. 2 Burner block, 1600D block and FMX tube

Because of requirements for appropriate heat resistance, thermal shock resistance and wind speed resistance, dense refractory material is usually applied for burner block installed around furnace reheating burner. When a CF product is adopted as the burner block material, a certain level of energy saving is expectable because of its smaller heat storage volume. An image of burner block manufactured with a CF product is shown in Fig. 16. To secure wind speed resistance, CF product burner block surface was processed with coating material and/or a highly densified CF product is adopted.

In the case of mainstream regenerating burner which is characterized by higher energy saving effect, wind velocity at exhaust heat recovery is much higher. When burner block composed of CF product is applied for regenerating burner, localized damage on the burner block is a concern. For such circumstance, adopting FMX tube made of a highly densified CF product, of which the exterior appearance is shown in Fig. 17, at the innermost layer is recommendable so as to secure consistency between thermal insulation efficiency and suppression of damages on CF burner block.

6. Future Activities

As reviewed above, reducing labor in reheating furnace refractory relining or maintenance work, improvement of durability of refractories used in the reheating furnace and intensification of thermal insulation of the reheating furnace with a variety of CF products have been carried on. Since it is prospected from recent viewpoint of global environment that efforts for further energy conservation are required, development or optimization of heat insulation technology for the reheating furnace is necessitated. By exerting our company's strengths, further development or optimization, such as optimization in applied technologies for reheating furnace operational conditions as well as developing heat insulation products combined with refractory and CF products, will be challenged.

7. Conclusion

As refractory products used in reheating furnace in steel industry, gunning plastic refractories, chemical bond castable refractories and CF heat insulation materials were reviewed in this article. By applying these products, labor reduction in reheating furnace refractory relining work, improvement of durability of reheating furnace refractories and reduction in heat loss from the reheating furnace can be realized. From the viewpoint of the global environment, further development of reheating furnace refractory products which would contribute to energy conservation shall be carried on.

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