Development of Dry Gunning Refractory with no Necessity of Drying Process

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ABSTRACT

Conventional monolithic refractories require drying process after installation and require lengthy drying period to prevent explosion. By eliminating the need for drying process, CO_2 emissions, fuel costs and downtime can be reduced, contributing to SDG 13: Take urgent action to combat climate and its impacts. In this study, we examined special new bond type material and developed dry gunning material that does not require drying process. It has already been applied to more than 40 furnaces in Japan and has been successfully used without going through drying process.

Keywords: Monolithic refractories, Drying process, SDGs, Carbon neutrality, CO_2, Incinerators, Non-ferrous processing furnaces

INTRODUCTION

Dry gunning method is broadly applied to installation of refractories in incinerators which burn general waste, industrial waste, biomass, etc. In dry gunning method, powder material is air-conveyed from a gunning machine through hose, and mixed with water sent by another hose at a nozzle portion to be gunned to objects.

General dry gunning refractories use alumina cement as binder, and use hydration reaction to develop strength. The hydrate of alumina cement forms dense structure, so it is excellent in strength. On the other hand, if the material is rapidly heated while still fully undried, a large steam pressure is generated inside structure, and when this exceeds strength of refractory, an explosion phenomenon occurs. The explosion of refractory may not only damage installation body, but may also cause damage to furnace and peripheral equipment. For this reason, drying process of removing moisture in refractory is essential before furnace operation.

In the drying process, it is necessary to raise temperature gently so as not to explode refractory, and it often takes more than dozens of hours. As a result, construction period becomes longer and it leads to loss of opportunities for customers. In addition, a large amount of CO_2 gas is emitted because fossil fuels such as heavy oil is burned by a burner.

In response to these problems, we have newly developed dry gunning refractory that eliminates the need for drying process and allows furnace to operate without explosion with rapid heating. This material has already been used at more than 40 actual furnaces in Japan. This paper describes outline of material development and an example of field application in actual furnace.

RESULTS AND DISCUSSION

1 Development of Gunning Material

1.1 Typical Properties of Materials

In order to realize a material which does not require drying, it is essential to improve dewaterability. For this reason, it is desirable not to use alumina cement which forms dense structure. Therefore, we have developed a material using new liquid inorganic binder that is easily dehydrated at a relatively low temperature.

Typical properties of the developed material is shown in Table 1. As a comparison, material with conventional cement binder and powder type inorganic binder are shown. Alumina-silica refractories are often used in general incinerators in Japan, thus alumina content is about 70% as a typical material.

Table 1: Typical properties of developed and conventional materials

Material Number	A	B	C
Type of Binder	Inorganic Liquid	Inorganic Powder	Alumina cement
Chemical composition / mass%			
Al_2O_3	71	73	70
SiO_2	20	17	23
CaO	—	—	4
Permanent linear change / %			
After firing 1400 °C, 3 h	-0.2	-2.7	-1.2
Cold crushing strength / MPa			
After drying 110 °C, 24 h	18	4	31
After firing 1400 °C, 3 h	73	81	49

1.2 Gunning System

In dry gunning method, as shown in Figure 1, powder and water are instantly mixed at a nozzle section and gunned. In this study, when in case of powder type binder, water amount tends to be excess. This is because nozzle mixing takes place in a faction of second and in such short time binder shall dissolve in water and mix with material powder. Therefore by application of liquid binder, it has become possible to optimize amount of water and improve strength.
It should be noted that developed material can be installed by conventional dry gunning equipment. Just switch from water to liquid binder and no special equipment is required.

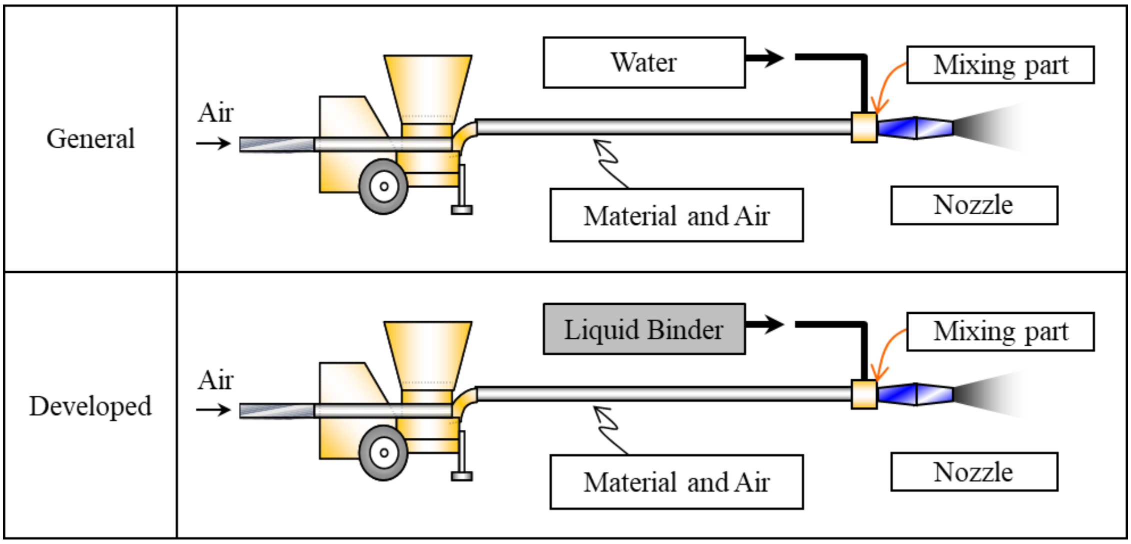

Figure 1 Comparison of dry gunning operation between general and developed materials

1.3 Dried Property

1.3.1 Permeability

As an approach of preventing explosion, it is possible to reduce steam pressure generated inside material by increasing permeability of material. The permeability of materials are shown in Figure 2. It can be seen that developed Material A has significantly higher permeability than cement-based Material C. This is presumed to be an effect of no reaction of calcium aluminate hydrate because of non-cement addition.

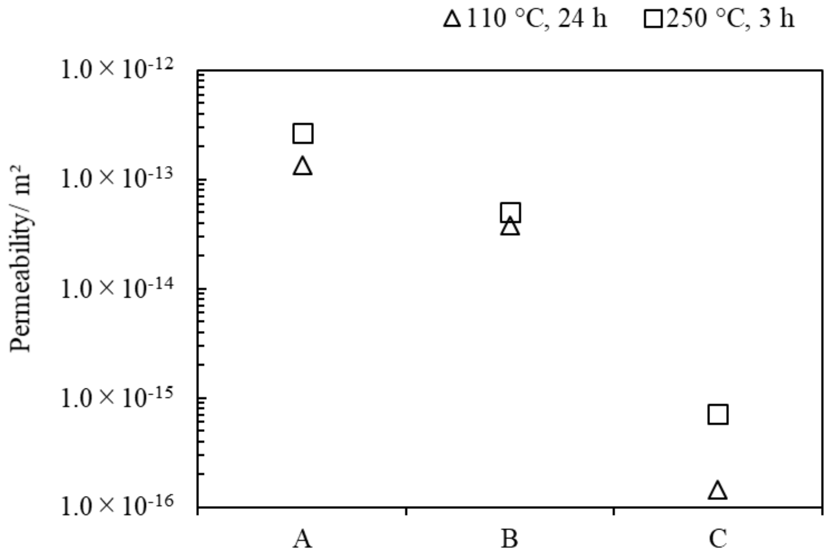

Figure 2 Comparison of permeability of materials

1.3.2 Internal Steam Pressure during Rapid Heating

For estimating internal steam pressure generated in Material A, rapid heating experiment was conducted. A schematic illustration for the rapid heating experiment is shown in Figure 3.

Thermocouple and electrode were embedded in the sample, and electric resistivity was measured by the electrode. When dehydration within the sample is completed, electrical resistivity increases sharply. The steam pressure generated internally matches saturated steam pressure until dehydration is completed.[1)] Therefore, while the electrical resistivity is low, saturated steam pressure at the internal temperature was used as the estimated steam pressure. [2)]

The sample was placed in a cylindrical wire-gauze, and heat insulating wool was attached to bottom and side so that it maximize heating from top surface. The temperature of electric furnace was set at 650 °C, and the sample was cured 24 hours at 20 ℃.

Result of rapid heating experiment is shown in Figure 4. Internal temperature of the sample is about 100 ℃ in 15 minutes from start of heating. At this time, the electric resistivity is low, indicating that the water is still contained. The electric resistivity increased from about 23 min., and it suggests that the peak of dehydration was passed in central part of the sample. At this time, the internal temperature is approximately 108 °C, and the estimated internal steam pressure is 0.03 MPa. This is very low pressure compared with strength of the material, and it is not high enough to cause an explosion. The sample was cut after the experiment to observe the cross section and no internal crack was confirmed.

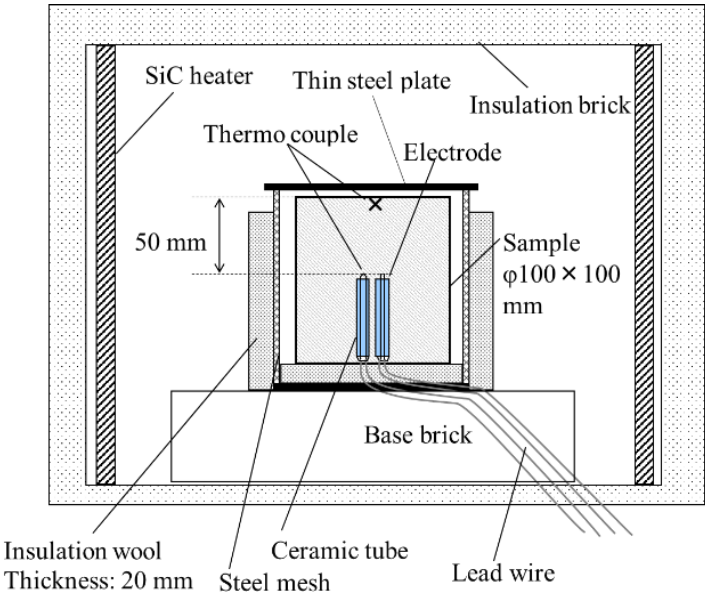

Figure 3 Schematic illustration for rapid heating experiment

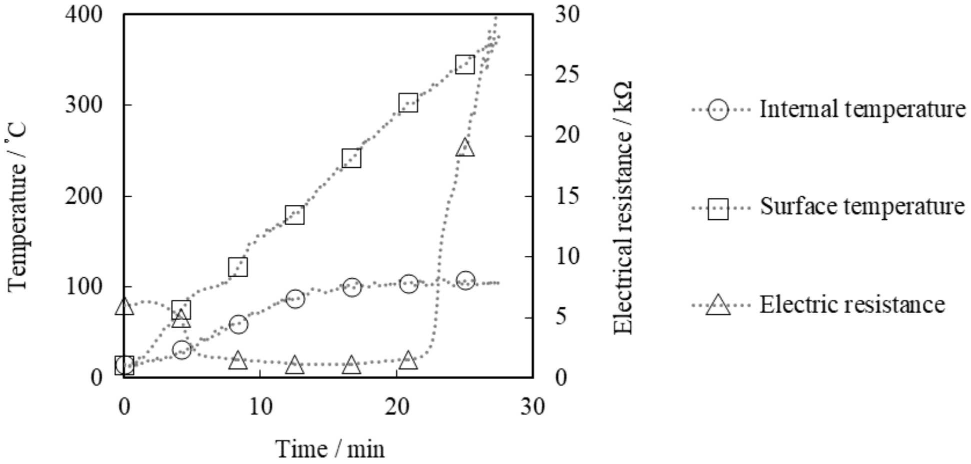

Figure 4 Result of rapid heating experiment

1.3.3 Scale-up Test for Explosion Resistance

Next, a large drying experimental furnace was used to conduct a test assuming an actual furnace from gunning to rapid heating about Material A (Shown in Figure 5 and 6). Installation thickness was 150 mm, and after 5 hours curing at ambient temperature, it was rapidly heated to 870 °C with 1 hour. Figure 7 shows the state of gunned body after rapid heating. It was confirmed that there was no explosion, and in addition, there was no crack and peeling in the gunned body, and that it was in a sound state.

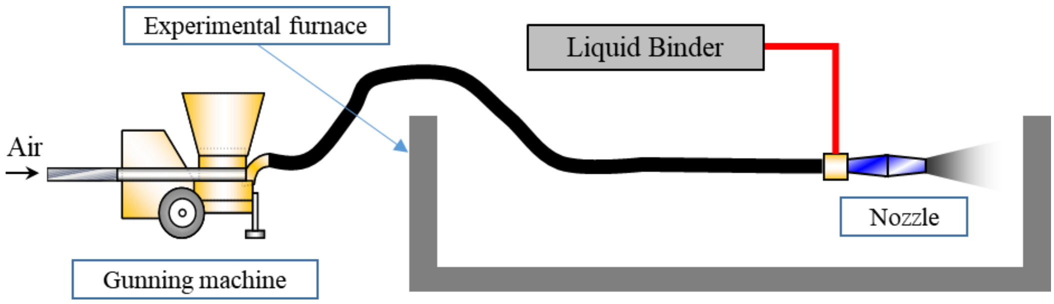

Figure 5 Schematic illustration of large scale rapid heating test

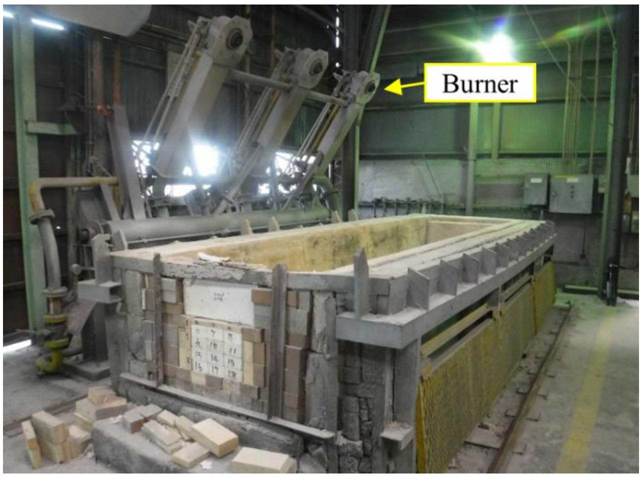

Figure 6 Exterior photograph of test furnace

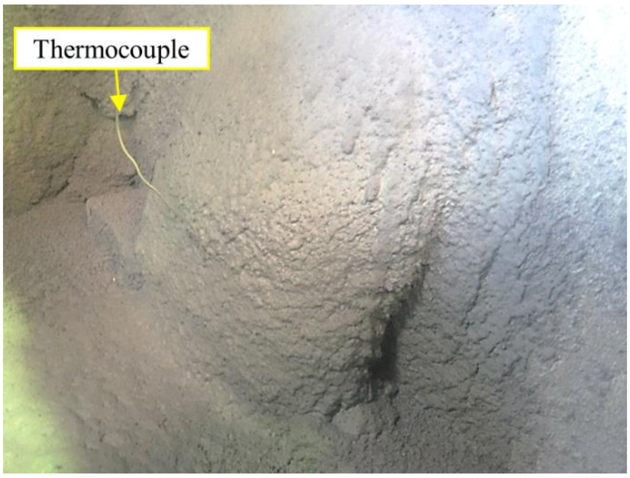

Figure 7 Appearance of after heating

1.4 Adhesion with Existing Materials

The dry gunning method is often used to repair locally damaged refractory materials by overlaying repair material. Therefore, adhesion with existing materials is also important.

To evaluate the adhesiveness, shear adhesive strength with alumina brick was measured using the device shown in Figure 8.[3)] A frame plate with a notch was attached to a brick composed of 60% Al_2O_3, and test materials were gunned within the notched frame. Gunned samples were dried at 110 °C for 24 hours and fired at 1000 °C for 3 hours.

The results are shown in Figure 9. Material A, which used liquid binder, had shear adhesive strength more than three times higher than that of cement-based Material C. Also, as shown in Figure 10, since Material A broke itself, not from joint surface, actual adhesive strength is presumed to be even higher. On the other hand, there was a lot of peeling at the adhesive interface of cement-based Material C. From these results, it can be expected that the developed material has superior adhesion compared to conventional cement-based materials, and can also improve the repair effect in localized repairs.

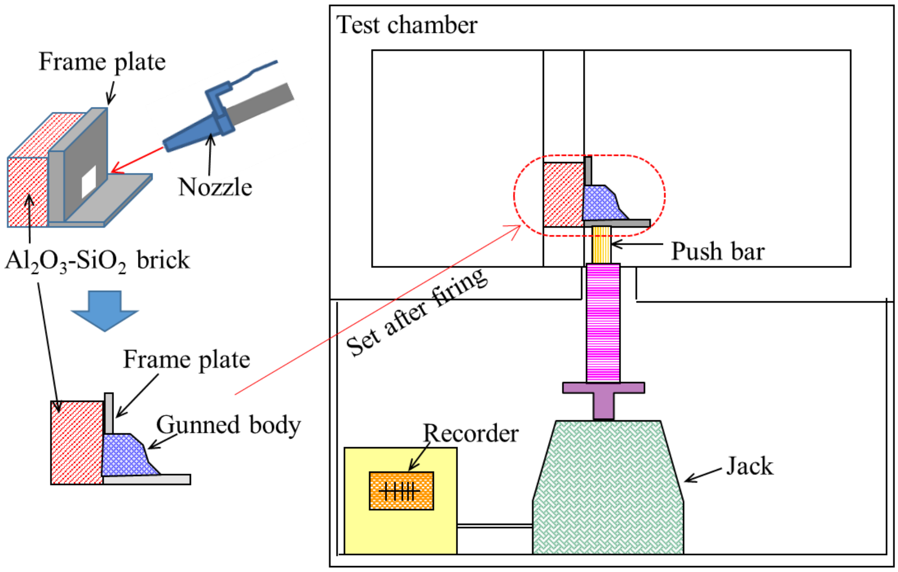

Figure 8 Schematic of adhesiveness test

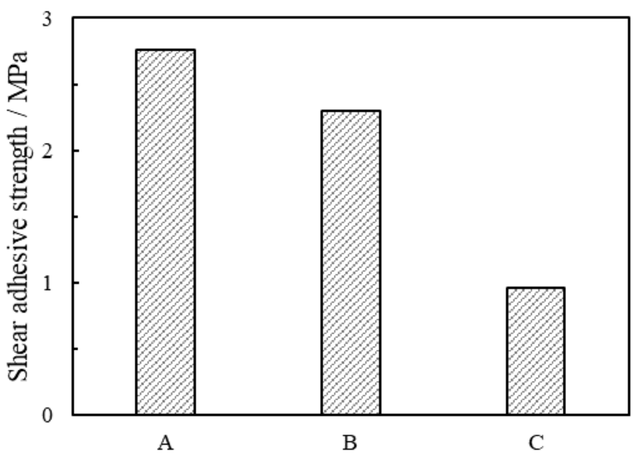

Figure 9 Results of shear adhesive strength

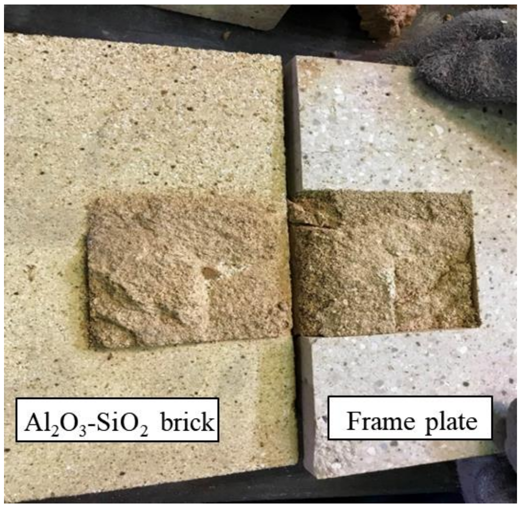

Figure 10 Appearance of after test of Material A

2 Results of Actual Furnace Application

2.1 Overview of Customer Z's Furnace

Customer Z owns two stoker furnaces, which are used to incinerate general and industrial waste. The incineration facility is located in the suburbs of city, and due to a large amount of waste being transported. Therefore it has become standard practice to operate under high temperature conditions exceeding 1500°C in order to increase processing capacity. Although refractory materials are repaired during biannual regular maintenance, sporadic emergency shutdowns due to early damage to the refractory materials have occurred. Each time, due to the repair and drying of the refractory materials, there was a significant opportunity loss arise from the shutdown of the furnace. Furthermore, because of using materials containing alumina cement for repairs, there were instances of refractory materials exploding during the drying process. To resolve these issues, we applied the Material A.

2.2 Cold Repair

During regular maintenance, we aimed to extend the lifespan by protecting the base material and applied it widely with installation thickness of 30-40 mm. The installation status is shown in Figure 11. The rebound loss of Material A is about 5%, which is superior in adhesion compared with the rebound loss of 10-15% of conventional cement-based gunning materials.

The gunned body was cured at room temperature for two days, and the drying process of the refractory was omitted. The operation was able to commence without any explosions, with only preheating of the furnace was carried out due to a rapid heating.

In addition, the durability status after six months of furnace operation is shown in Figure 12. Some of adhered slag had been peeled off, but there was almost no penetration of slag into the refractory. While most of the conventional cement-based materials would peel off after six months, there was hardly any peeling damage to Material A, which is presumed to be the effects of excellent adhesion.

Figure 11 Appearance of gunning Material A

Figure 12 Appearance of Material A after six months of furnace operation

2.3 Hot Repair

Due to changes in operating conditions of Customer Z, refractory materials in some of conventional materials peeled off, causing shell to become red-hot. As a result, operation of the furnace had to be urgently stopped, necessitating repair of refractory materials. As long time is required for cooling to enter the furnace, it was considered to repair it from outside the furnace using Material A in hot condition. Therefore, gunning nozzle was inserted from outside the furnace to the location where refractory material had peeled off, and Material A was gunned. The situation is shown in Figure 13 to 15. Although inside of the furnace was at a condition of 300 °C, adhesion of the material was good, and it was possible to install with a thickness of 100-150mm.

In conventional cement-based materials, hot installation was not chosen due to difficulty of adhering to the target. Therefore, a minimum of five days of furnace downtime was required, including cooling of the furnace and drying refractories. This time, by using Material A, it was achieved recovery within 24 hours from the furnace shutdown.

Figure 13 Appearance of refractory peeling

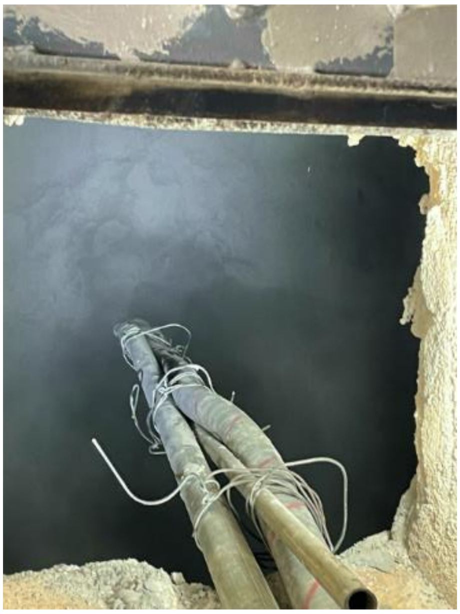

Figure 14 Appearance of gunning in hot condition

Figure 15 Appearance of after gunning

2.4 Effect of CO_2 Emissions Reduction

Figure 16 shows a comparison of drying and pre-heating time after cold repair using Material A or C at Customer Z. With conventional materials, 30 hours of drying was required, using 8.3 kL of A-type heavy oil as fuel. This corresponds to about 23 tons of CO_2 emissions when converted from the CO_2 emission factor (A-type heavy oil: 2.71t-CO_2・kL^{-1}) presented by the Ministry of Economy, Trade and Industry of Japan.[4)]

By applying Material A, the drying time of refractory material was eliminated, and only 15 hours were required for furnace pre-heating. The amount of A-type heavy oil used at this time was 0.26 kL corresponded 0.7 tons of CO_2. Therefore, considering one regular maintenance per year by the gunning material and two furnaces, the annual CO_2 reduction effect is 15.2 tons, and even more effect is expected when including emergency repairs.

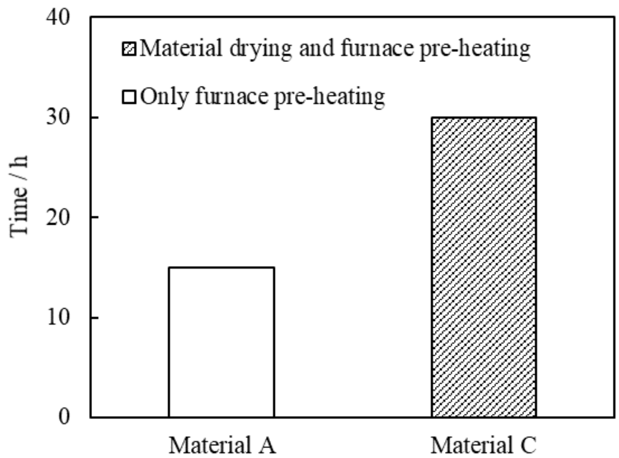

Figure 16 Comparison of drying and heating time between Material A and C

2.5 Application Results in Japan

The developed products have expanded their material range for each furnace and are broadening their applications within Japan. The application results are shown in Table 2. Not only for incinerators, but also for iron and non-ferrous kilns, the application has been expanded and can be used without any explosions even if the drying process is omitted. Furthermore, in incinerators, there have been results of improved durability, and there are many customers who are repeatedly using liquid inorganic binder type material while expanding range of application inside the furnace.

Table 2: Application results

Type of furnace	Number of applications
Various of Incinerator	Over 30
Power generation boiler	2
Electric arc furnace	3
Aluminum melting furnace	6

CONCLUSION

We have developed dry gunning material that eliminates the need for drying process, which can be used as an initial lining and repair material for incinerators and non-ferrous processing furnaces. We have been able to verify that there are no issues with its performance in actual furnaces. This has significantly reduced our customers' opportunity losses and CO_2 emissions, and we have now rolled it out to over 40 customers. Our customers include reheating furnaces and various ducts in the steel industry, and we expect to further expand its use not only in incinerators but also in the iron and steel/non-ferrous sectors in near future. We hope that this developed material will be widely used by customers both domestically and internationally, contributing to the preservation of the global environment through CO_2 emission reduction, and not only benefiting our customers but also achieving the Sustainable Development Goals (SDGs).

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