# Introduction of Imported Silica Brick to Hot-blast Stove Refractory in Kashima No.1 Blast Furnace

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# Abstract

We constructed three hot-blast stoves at Kashima No. 1 blast furnace, which started operation in 2004, and conducted a quality investigation of silica bricks, which were used in this hot-blast stove, made overseas. Four silica bricks from different manufacturers were investigated. One silica brick was selected by the results of some characteristics of four silica bricks and containing ratios of silica polymorph, result of compressive creep test. On the other hand, based on our policy of securing plural brick suppliers, we considered improving another silica brick which we decided to use. Then we developed a material with adjusted CaO addition and adopted it for the Kashima hot-blast stove.

# 1. Introduction

Among the lining and heat storage refractories (hereinafter referred to as checker bricks) of hot-blast stoves, silica bricks are used in large amounts in particularly hot areas of the hot-blast stoves. The lining refractories of the hot-blast stoves do not come into contact with molten iron or molten slag. Their damage is much less than that of the lining refractories of refining furnaces. For this reason, hot-blast stoves are normally operated for one campaign for every two campaigns of blast furnaces. On the other hand, increasing the hot-blast stove reline interval reduces the demand for silica bricks. Siliceous raw materials suitable for brick production are depleted in Japan. These conditions have forced us to use imported silica bricks for relining our hot-blast stoves. Nippon Steel Corporation installed three new hot-blast stoves for the Kashima No.1 blast furnace that started operation in 2004. The hot-blast stoves were constructed of imported silica bricks and have been operating successfully to date. In this report, we describe the history of quality investigation and improvement in the introduction of imported silica bricks.

# 2. Silica Bricks for Hot-blast Stoves

The hot-blast stove consists of a combustion chamber and a checker chamber. The combustion chamber is equipped at the base with a burner for mixing the fuel gas and air, burning the mixture, and producing high-temperature combustion gas. The checker chamber is constructed of many checker bricks stacked together to store the generated heat from the combustion chamber. Usually three or more hot-blast stoves are required per blast furnace. Hotblast stoves for large blast furnaces reach 40 m or more in height. The checker bricks of hot-blast stoves are constantly subjected to compressive stress under the weight of the brickwork.

In hot-blast stove operation, high-temperature combustion gas is generated in the combustion chamber and sent to the checker chamber to heat the checker bricks for a certain period of time. After that, cool air is sent by a blower in the direction opposite to that of combustion gas flow according to the timing of blowing the hot blast into the blast furnace, is heated to about 1200°C by the heat of the checker bricks, and is blown through the tuyeres into the blast furnace.

Figure 1 shows examples of refractory arrangement in three different types of external combustion hot-blast stove checker chamber.<sup>1)</sup> Each type uses silica bricks in the combustion chamber heated by the hot blast, in the pipe to connect the combustion chamber and checker chamber, and in the upper part of the checker chamber. Silica bricks are frequently used also in coke ovens. Since the temperature of the hot-blast stoves where silica bricks are used exceeds 1400°C, these silica bricks must have better creep resistance than those used in the coke ovens. For this reason, the silica bricks used in the hot-blast stoves have a higher SiO<sub>2</sub> content and a smaller amount of the liquid phase to cause creep than those used in the coke ovens.

The phase transition of  $SiO_2$  due to the dissolution and precipitation reactions<sup>2, 3</sup> through the liquid phase is less likely to occur in the silica bricks of the hot-blast stoves. Foreign silica rock contains larger quartz crystals than that produced in Japan. These large quartz

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Fig. 1 Refractories of various hot-blast stoves with external combustion chamber<sup>1)</sup>

crystals are less likely to undergo phase transition.<sup>4)</sup> As a result, quartz may remain in the silica bricks produced. The then Sumitomo Metal Industries had no experience of using imported silica bricks in hot-blast stoves and had to investigate the quality of imported silica bricks before introducing them. The investigation focused on the creep resistance and SiO<sub>2</sub> polymorph contents of the imported silica bricks.

# 3. Quality Investigation and Improvement of Imported Silica Bricks<sup>5)</sup>

#### 3.1 Quality investigation of imported silica bricks

**Table 1** shows the bulk density, apparent porosity and chemical composition of the silica bricks investigated and used as samples.<sup>5)</sup> The A, C, and D silica bricks are made from foreign silica rock and by different manufacturers. The B and C silica bricks are from the same manufacturer. The B silica bricks are manufactured in Japan from foreign silica rock. The C silica bricks are equivalent to the B silica bricks. These silica bricks were all fired in continuous kilns. **Table 2** shows the determined contents of SiO<sub>2</sub> polymorphs in the silica bricks.<sup>5)</sup> For comparison, the analysis results of silica bricks made from Japanese silica rock and used in the hot-blast stoves at the Kashima Area of the East Nippon Works are also shown in the

 Table 1
 Properties of investigated silica brick samples<sup>5</sup>

Sample No.	А	В	С	D
Bulk density / -	1.82	1.89	1.83	1.83
Apparent porosity / %	21.1	18.3	20.3	21.0
Chemical composition				
SiO <sub>2</sub> / mass%	96.5	95.6	96.1	96.2
CaO	1.9	2.8	1.9	2.2
Fe <sub>2</sub> O <sub>3</sub>	0.7	0.6	0.9	1.3
Al <sub>2</sub> O <sub>3</sub>	0.5	0.7	0.6	Trace
Production country	China	China	China	Europe

Table 2 Contents of SiO, polymorph in each silica brick samples<sup>5)</sup>

Sample No.	А	В	С	D	Conventional
SiO <sub>2</sub> content / mass%	96.5	95.6	96.1	96.2	95.6
Tridymite / mass%	61.7	73.1	75.2	42.8	69.5
Cristobalite	34.1	22.4	20.8	52.3	27.1
Quartz	0.7	Trace	Trace	1.1	Trace

"Conventional" column in Table 2. Quartz residues were recognized in the A and D bricks. The tridymite content of the B and C silica bricks was higher than that of the conventional silica bricks. Few quartz diffraction peaks were recognized in the B and C silica bricks.

The tridymite content of the A and D silica bricks was lower than that of the conventional silica bricks. Especially, the cristobalite content of the D silica bricks was higher than the tridymite content. In the compressive creep test, each specimen was heated under stress in an air atmosphere at a rate of 5°C/min to each test temperature for 50 hours. Then, the specimen was immediately freed from compression jigs and relieved of stress. Next, the specimen was furnace cooled to room temperature and measured for height. The strain of the specimen was determined from the difference in height before the test. Table 3 shows the strain of the respective bricks obtained after the compressive creep test.5) At 1500°C, the A, B, and C bricks contracted, but the D bricks expanded. At 1550°C, the C bricks contracted, but the A, B, and D bricks expanded. In the compressive creep test, the bricks do not change in height after the test or generally exhibit contraction. We thought that some structural change occurred in the material during the compressive creep test. Considering the silica polymorph contents described above, we decided to use the C silica bricks in two of the three hot-blast stoves mentioned first.

#### 3.2 Changes in silica polymorph contents

We investigated the causes as to why the silica bricks expanded after the compressive creep test. **Figures 2, 3, 4,** and **5** show the measured silica polymorph contents of the respective silica bricks before and after the test. The silica bricks differed in the silica polymorph contents after the test and in the polymorph transition behavior. The C and D silica bricks are almost the same in the tridymite and cristobalite contents before and after the 1500°C compressive creep test. The A and B silica bricks progressed in the transition from tridymite to cristobalite and increased in the cristobalite content after the 1500°C compressive creep test. All silica bricks increased in the cristobalite content after the 1550°C compressive creep test. This increase was about 10 mass% in the C silica bricks and 24 to 26 mass% in the A and B silica bricks. In the D silica bricks, the transition to cristobalite remarkably progressed and about 94 mass% of silica transitioned to cristobalite.

**Figure 6** shows the relationship between the strain and the change in the apparent porosity after the 1550°C compressive creep test. The change in the apparent porosity is expressed in percent difference in the apparent porosity before and after the test. The strain and the change in the apparent porosity showed a nearly positive correlation. The expanded A, B, and D bricks increased in the apparent porosity. The non-expanded C bricks did not appreciably change in the apparent porosity. Also considering the measured silica polymorph contents before and after the compressive creep test, we considered that the bricks expanded in the test because the transition from tridymite to cristobalite progressed and created voids during the test.

Table 3 Strains of each silica brick samples after creep test<sup>5)</sup>

Sample N	Jo.	А	В	С	D
~ / 0/	$1500^{\circ}\text{C} \times 50\text{h}$	-0.01	-0.07	-0.01	+0.03
8/70	1550°C×50h	+0.14	+0.15	-0.05	+0.41

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Fig. 2 Alteration of silica polymorph contents of brick A by creep test



Fig. 3 Alteration of silica polymorph contents of brick B by creep test



Fig. 4 Alteration of silica polymorph contents of brick C by creep test

#### 3.3 Improvement of silica bricks

We decided to use the C silica bricks but worked further to improve the silica bricks according to the policy of purchasing silica bricks from multiple manufacturers to ensure a stable supply. In the investigation in the previous section, we considered that the transition from tridymite to cristobalite was responsible for the expansion of the silica bricks in the compressive creep test. We then studied how to increase the tridymite content of the A silica bricks. The silica mineral phase of silica rock, a brick raw material, is quartz. The transition of quartz to tridymite or cristobalite is caused by: (1) firing at high temperature for a long time and (2) adding CaO, a transition accelerator. A silica brick manufacturer studied the method (1). They judged that they had to move brick cars in their continuous



Fig. 5 Alteration of silica polymorph contents of brick D by creep test



Fig. 6 Relationship between nominal strain and change of apparent porosity of trial bricks

Table 4 Properties of trial silica bricks

Sample No.	A (base)	2	3
Bulk density / -	1.82	1.83	1.83
Apparent porosity / %	21.1	20.7	20.3
Chemical composition			
SiO <sub>2</sub> / mass%	96.5	95.7	94.9
CaO	1.9	2.8	3.6
Fe <sub>2</sub> O <sub>3</sub>	0.7	0.7	0.7

kiln at the lowest possible speed to ensure the transition of quartz to tridymite in the manufacture of A silica bricks. They found that the firing time in the continuous kiln could not be extended further. Their batch kiln was shut down and could not be restarted. Given these considerations, we determined that the method (1) was impracticable. Instead, we studied the method (2) of increasing the CaO addition content.

Table 4 shows the bulk density, apparent porosity, and chemical composition of the two types of trial silica bricks. The No.2 and No.3 trial silica bricks increased in the CaO content by 0.9 and 1.7 mass%, respectively, with respect to the base silica bricks. The trial silica bricks showed no significant changes in the bulk density and apparent porosity. Figure 7 shows the relationship between the CaO addition content and the tridymite content for the A silica bricks and the No.2 and No.3 trial silica bricks. The tridymite content increased by increasing the CaO addition content. The tridymite content of the No.2 trial silica bricks with a CaO addition of 2.8% exceeded that of the conventional silica bricks in Table 2. The tridymite formation increased by increasing the CaO addition probably



Fig. 7 Relationship between CaO addition and tridymite content of trial bricks



Fig. 8 Comparison of trial bricks bending strength

Table 5 Strains of trial bricks after creep test

Sample N	lo.	А	2	3
e / %	$1500^{\circ}C \times 50 h$	-0.01	-0.01	+0.09
	$1550^{\circ}C \times 50 h$	+0.14	+0.01	+0.09

because the formation of the liquid phase composed of CaO and other impurities increased to facilitate the dissolution and precipitation reactions.<sup>2,3)</sup> If the formed liquid phase remains in excess, the hot bending strength is considered to decrease. We thus measured the hot bending strength of the trial silica bricks.

Figure 8 shows the measured 1400°C hot bending strength of the A silica bricks and the No.2 and No.3 trial silica bricks. In Fig. 8, the room-temperature bending strength of the A silica bricks is set to 100 and the bending strength of the No.2 and No.3 trial silica bricks is shown as the ratio to that value. The hot bending strength of all silica bricks decreased to about 50% of the room-temperature bending strength. The hot bending strength was not observed to decrease by increasing the CaO addition content. The hot bending strength was highest for the No.2 trial silica bricks with the CaO addition content of 2.8 mass%. The hot bending strength of the No.3 trial silica bricks with the CaO addition content of 3.6 mass% was lower than that for the No.2 trial silica bricks. Next, we conducted the compressive creep test of the trial silica bricks and investigated the strain at 1500°C and 1550°C and the silica polymorph contents before and after the test. Table 5 shows the strain of the No.2 and No.3 trial silica bricks after the test. Table 5 also shows the strain of the A silica bricks shown in Table 3 for comparison. The No.3 trial silica bricks exhibited expansion at 1500°C and 1550°C. The No.2 trial silica bricks exhibited little change in the strain at 1500°C and 1550°C.



Fig. 9 Alteration of silica polymorph contents of trial brick No.2 by creep test



Fig. 10 Alteration of silica polymorph contents of trial brick No.3 by creep test

The measured silica polymorph contents of the No.2 and No.3 trial silica bricks before and after the compressive creep test are shown in Figs. 9 and 10, respectively. In the A silica bricks, the transition of tridymite to cristobalite progressed even at 1500°C and the tridymite content decreased to about 20% at 1 550°C. In the trial silica bricks, the transition of tridymite to cristobalite was suppressed at both 1500°C and 1550°C. The tridymite content at 1550°C increased to about 30% for the No.2 trial silica bricks and to about 40% for the No.3 trial silica bricks. As compared with the base A silica bricks, the increase in the tridymite content was larger for the No.3 trial silica bricks with the 3.6 mass% CaO addition than for the No.2 trial silica bricks. The No.2 trial silica bricks had a higher hot bending strength and a smaller strain change in the compressive creep test. According to these results, we decided to adopt the No.2 trial silica bricks as improvement on the A silica bricks and for use in the remaining one hot-blast stove. The three hot-blast stoves built of the improved silica bricks have been operating without problems for 15 years. The improved silica bricks are also used in the hotblast stoves of the Wakayama No.1 and No.2 blast furnaces that later came into operation.

#### 4. Conclusions

In this report, we described the history of quality investigation and improvement of silica bricks imported and introduced for use in the hot-blast stoves of the Kashima No. 1 blast furnace put into operation in 2004. In recent years, it has become common to import and use high-alumina bricks and fireclay bricks in addition to silica

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bricks used in long-life furnaces such as hot-blast stoves and coke ovens. We are concerned that imported refractory bricks may present various problems, such as dimensional variabilities and breakage during long sea transport, in addition to the quality described in this report. While aware of these problems, we will continue to study engineering to make full use of imported refractory bricks.

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