Development of high toughness refractory utilizing metal fiber

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1. Abstract

The molten pig iron tapped out from the blast furnace contains the slag. Then the pig iron separates from slag in the main trough, and passes through the iron runner and pours from the tip of iron runner into the tilting trough. If cracks develop at the tip of the iron runner, repair work with the dismantling lining work are required, which imposes a heavy burden on the blast furnace operation.

Regarding the structural examination, we presented a report at UNITECR 2019 (“The effort to prevent cracks by changing the runner structure at the tip of iron runner”).

For this report, we examine the countermeasures against cracking from the refractory side, and report on the countermeasures that consider effective and the results of application to the actual operation.

2. Introduction

In Japan, 21 blast furnaces of smaller to larger sizes are in operation (as of October 2021). When operating a blast furnace, it is required to be durable enough to withstand heavy load conditions, and specifically, it is important to suppress wear, cracks, peeling, and etc.

In addition, since the shape of the runner differs for each customer, it is important to design the refractory material according to the condition.

3. Task

After installing the refractory to the main trough, iron runner and slag runner, a drying process applies with burners for the purpose of dehydration and removal of pitch volatile matter. Since cracks appeared at the locations shown in Fig. 1 at the initial stage of the drying process and operation, we discussed and examined in this report the development of a high toughness refractory using metal fiber which we can expect improving effect at the initial stage of strength exhibition.

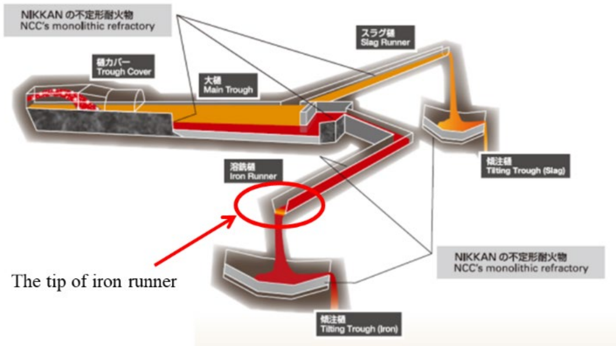


Fig.1. Diagram of runner structure

4. Development of high toughness refractory

(1) Basic evaluation of metal fiber

It is important to select metal fibers for refractory from the viewpoints of application, availability and heat resistance, and the metal fibers shown in Table I are generally distributed.

Prior to the refractory development, we evaluated the metal fiber type and workability, and excluded the wave type from the subsequent evaluations because it could not secure sufficient fluidity when the added amount was increased.

In addition, since there was no significant difference in fluidity between the straight and the rivet types, we made the subsequent evaluation with the rivet type because we expected rivet type has higher toughness.

Table. I. Metal Fiber Type

Shape	Straight	Rivet	Wave
Appearance			
Fluidity	○	○	○～△

(2) Heat resistance evaluation of metal fiber

Generally, steel and stainless steel types are distributed and the heat resistance is different due to the characteristics of the metal fibers. In Table. II., we conducted heat resistant temperature investigation based on the types.

Table. II. Heat resistance evaluation result of metal fiber

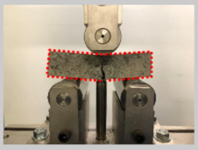
Metal Fiber Type (Rivet)	Steel	Stainless
1000℃ × 12hr Oxidation		
1200℃ × 12hr Oxidation		

The surface of steel fiber oxidized at 1000℃. For the heat resistance evaluation, stainless fiber was less likely to be fragile.

(3) Effect of metal fiber on strength exhibition

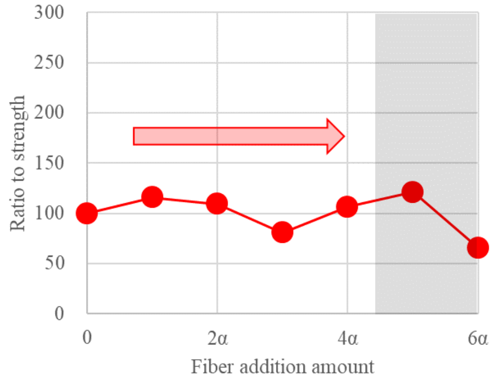
We measured bending, compression, and split tensile strength of metal fibers in order to investigate how metal fibers affect strength exhibition. The sample was prepared at 110℃ for 24 hours. Table. III. shows the shape and test method.

Table. III. Comparison of strength exhibition with metal fiber

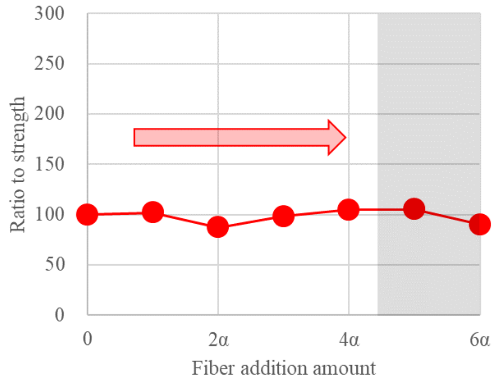
	Bending/Compressive Strength	Split Tensile Strength
Shape	40 × 40 × 160㎜	Φ80 × 80H
		
Picture at the test		

For the bending test (Graph.1.) and the compression test (Graph.2.), there was no sign of strength improvement even if the added amount of metal fiber was increased.

Graph.1. Bending Strength

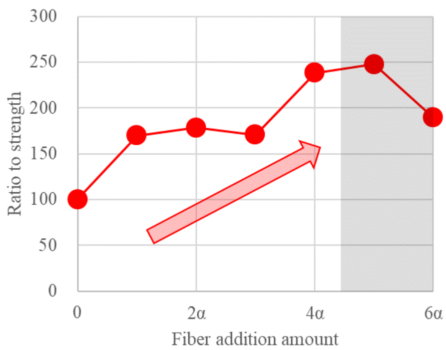


Graph. 2. Compression Strength



In the split tensile test (Graph.3.), the strength increased as the added amount of metal fiber increased. With the addition of 4α, the strength ratio became more than twice as much as the case of no addition.

Graph. 3. Split Tensile Strength



However, when the adding amount of metal fiber exceeded 4α, the metal fiber became tangled and the normal workability could not maintain.

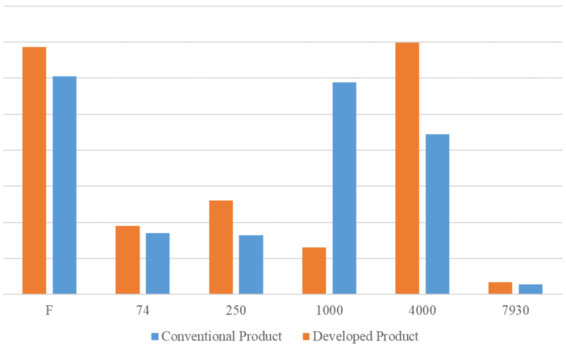
The test results in the table is just only for the reference values after 5α.

We confirmed that the addition of metal fibers increased the splitting strength and it was effective means for improving toughness.

(4) Examination of further toughness

Based on the conventional refractory design, the fluidity deteriorated when the added amount of metal fiber was increased. Therefore, we reviewed the formulation amount of 8-1 mm aggregate that interferes with metal fibers. (Graph. 4.)

Graph.4. Formulation ratio for each particle range



We attempted to increase the allowance for metal fiber addition by increasing the 8-4mm aggregate and decreasing the 4-1mm aggregate.

(5) Fluidity evaluation of developed refractory

Table. IV. shows evaluation of the fluidity of the conventional and the developed refractory by ○, △, or × for each added amount of metal fiber.

By changing the amount of aggregate that the metal fibers interfere with in the developed refractory, the fluidity improved compared to the conventional refractory, and it made possible to mix more metal fibers.

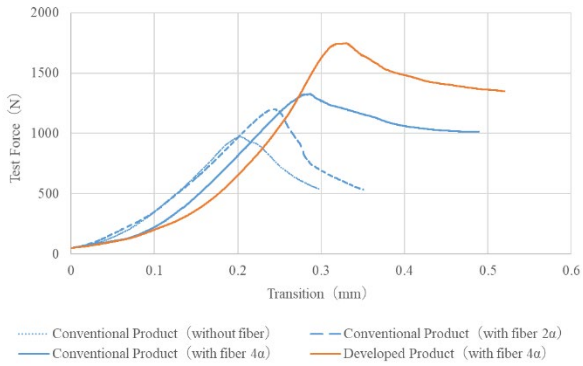
Table. IV. Fluidity evaluation for conventional and developed refractor

Fiber Addition amount	Conventional Product	Developed Product
2α	○	○
4α	△	○
6α	×	△
Condition At 4α addition		

(6) Toughness improvement evaluation of developed refractory

With the bending tester, the displacement of the sample fired at 600°C and the change in the maximum test force were investigated (Graph. 5.)

Graph.5. Toughness evaluation of conventional and developed refractories



Judging by the results of the conventional refractory, we confirmed that as the added amount of fiber increased, the change until fracture and the test force increased.

For the developed refractory, the change and test force increased more compared to the conventional refractory with metal fiber addition 4α, and the fiber addition effect became more remarkable.

In addition, the load of the conventional Sample without fiber and with fiber added 2α decreased immediately after fracture, but the strength of the sample with fiber added 4α gradually decreased. We consider this movement has an effect that can prevent enlarging the cracks even if the refractory has them.

For the conventional refractory, it was not possible to secure sufficient fluidity by adding 4α of fiber, but the developed refractory made the amount of fiber added 4α possible and the toughness improved.

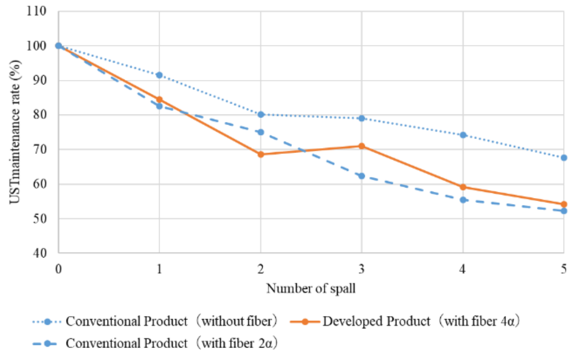
(7) Spalling property evaluation

Since the particle size composition of the conventional refractory was changed, we conducted confirmation test on the spalling property during operation at high temperatures.

Sample size was 40x80x160mm, processing conditions were 1000 ℃x 3hr reduction firing.

After heating at a test temperature of 1450℃ for 30 minutes, we performed forced air-cooling for 30 minutes. We repeated this 5 times, and the UST maintenance rate was measured for each heating / cooling cycle, and the transition of the maintenance rate when the initial value before the test was set to 100 was investigated. (Graph. 6.)

Graph.6. Change in UST maintenance rate for each heating and cooling (initial value 100)



The UST maintenance rate was reduced by adding 2α of fiber to the conventional refractory. Even if 4α of fiber was added to the developed refractory, the result was equal to or better than that of the conventional refractory (2α with fiber addition).

It is considered that the progress of internal defects could be suppressed by changing the particle size composition of the conventional product and forming a stable structure even when fibers were added.

(8) Summary

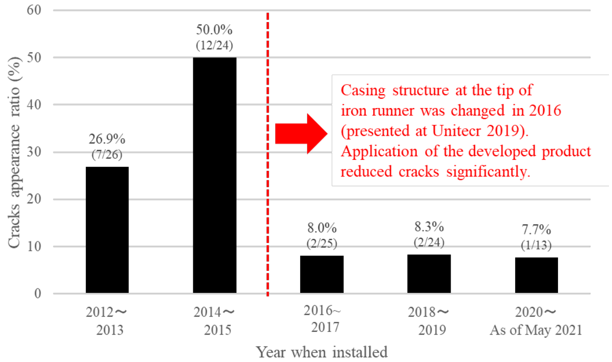
In order to increase the toughness of refractories, we selected metal fibers and tried to increase the amount, but for the conventional refractory, the amount of 2α added was the limit in order to secure normal fluidity. For the developed refractory, we could secure sufficient fluidity even if 4α addition by changing the particle size composition. Due to the ability of 4α addition of fiber, the test force and change until fracture increased for the bending test. In addition, we could suppress the sudden decrease in strength after fracture, and we could provide the function of suppressing through cracks. In terms of spall property, it had the characteristics equal to or better than the conventional refractory with fiber addition, and we considered that we optimized the particle size configuration.

This developed refractory with improved toughness of the conventional refractory and maintained spalling properties, we applied them to the actual furnace.

5. Result of application to actual furnace

The crack appearance rate at the tip of iron runner of the conventional and the developed refractories over the past 10 years summarized every two years (Table. V.).

Table. V. Cracks appearance rate at the tip of iron runner for the conventional and the developed refractories



*The numbers in parentheses are the number of cracks / the number of constructions.

Until 2016 when the developed refractory was applied to the actual furnace, cracks appeared at the tip of runner once every 2 to 4 times of refractory installation. After that, in 2016 the runner casing structure was remodeled to strengthen the structure (reported at UNITECR 2019), and the application of the developed refractory was started.

After application, the crack appearance rate decreased sharply, demonstrating a high improvement effect.

6. Conclusion

For a blast furnace operation, cracks on refractories impose a heavy burden on the operation, so both measures are applied to strengthen the structure (reported in 2019) and developed the refractory.

As for the improvement effect, even now, about 5 years have passed since the application started, the cracks appearances have decreased sharply, and it has contributed greatly to the stability of operations.