

Experience of Salamander Tapping for Blast Furnace Relining in CSC

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The salamander tapping experience before the relining of two blast furnaces in CSC (China Steel Corporation) is described in this paper. In 2013, the total liquid metal received from the salamander tapping of No.4 BF was about 1150 tons and no dynamiting operation was done for the residual metal block in the hearth. In 2017, at No.3 BF, the total liquid received from the salamander tapping was about 168 tons. And, about 634 tons of the residual solid block was cut into 43 pieces by the wire cutting machine. Based on the experience, suggestions for successful salamander tapping are summarized as follows: First, the temperature monitoring for the carbon brick of the hearth is indispensable for estimating the profiles of the solidified line and the erosion line. Secondly, an appropriate operation strategy for maximizing the ratio between the liquid and the solid salamander is to make the productivity of the blast furnace as close to the highest productivity on record. It is inferred that when the temperature before relining is near the historical maximum temperature, the solidified line should be near the erosion line. Thirdly, more tapping holes are required for the complicated salamander consisting of coke, carbon brick and iron.

Keywords: Blast Furnace, Salamander Tapping, Core Drilling, Oxygen Lancing

1. INTRODUCTION

Salamander tapping of a blast furnace (BF) is the final tap after the furnace is blown down in order to drain the last liquid iron from the hearth bottom. The salamander includes liquid iron, molten slag and a mixture of solid iron, slag and coke. However, a large solid salamander left in the BF hearth is difficult to remove and could delay the schedule of the BF relining project by several days. Therefore, it is important to maximize the yield of the salamander tapping.

Several prerequisites are suggested by Danieli Corus for successful salamander tapping.⁽¹⁾ These include the maximum ratio between liquid and solid

salamander, high temperature of the liquids, correct angle and elevation of salamander tapping holes, and efficient salamander tapping activities. Typical liquefaction method includes to reduce the bottom and sidewall cooling, to target high productivity, to increase silicon content in iron, and to charge coarse coke, etc. The maximum temperature in the historical campaign can be utilised in estimating the wear profile by a computer model. Afterwards, multiple angles and elevations are defined at each salamander tapping position. The key parameters of salamander tapping operation, including the length and the maximum temperature of core drilling, time of oxygen lancing, are provided by Danieli Corus and listed in Table 1.

Table 1 Salamander operation parameters at Danieli Corus (D:Hearth Diameter)

Position	Hole/Position	Time of core drilling (hr/hole)	Length of core drilling (m)	Max. temperature of core drilling (°C)	Time of oxygen lancing (min)
1 (D<9m)					
2 (9m<D<12m)	3	1	2	800	60
3 (D>12m)					

The successful salamander tapping accompanied with higher productivity before relining was carried out at Gwangyang No.2 BF of POSCO. There was no any residual salamander left in the hearth. Two positions for the tapping were decided due to the large size of the BF with a 14m hearth diameter. The core drilling of two holes was completed within two hours. And, 15 minutes oxygen lancing for each hole was applied. Total time for the set-up of the drilling equipment, core drilling, oxygen lancing, and starting the salamander tapping was less than 3 hours. And, more than 1000 tons of hot metal was tapped within 5 hours.

The salamander tapping didn't yield any liquid iron before the relining of No.7 BF at Ispat Inland in 2003.⁽²⁾ The dynamiting operation was adopted in the removal of the solidified iron in order to blast the large iron block into pieces that were pulled out the hearth through the entrance of furnace shell. The removal of residual iron with 1200 tons extended the demolition schedule by thirteen days. Besides, a failure in salamander tapping was experienced at G BF of Tata Steel in 2013. In order to prevent stress from developing in the hearth shell after the BF blow-in, there was no liquid salamander tapped out.⁽³⁾

It is preferable for the salamander tapping that the drainage point is located at the lowest position where all liquid iron can reach in the blast furnace hearth. However, it is difficult to know the lowest level of liquid iron. The temperature of the carbon bricks and their maximum temperature in the campaign were used to estimate the profiles of the solidified layer and wear erosion of the hearth, respectively, for No.1 Blast Furnace at CSC.⁽⁴⁾ The multiple angles and elevations were decided on the base of both the solidified line and the erosion line. The salamander tapping experience of No.4 and No.3 BF of CSC will be described as below.

2. SALAMANDER TAPPING EXPERIENCE OF NO.4 BLAST FURNACE

2.1 Elevation of salamander tap

The design campaign life of CSC No.4 BF with a hearth diameter of 12.5m is 15 years. It came into operation in November, 1996. In order to understand the hearth status, the historical maximum temperature of carbon bricks was adopted to estimate the wear erosion of the hearth on 20 August, 2010. Figure 1 presents a hearth status with the solidified line of the salamander and the erosion line of carbon bricks. The daily average temperature on 20 August, 2010 and the historical maximum temperature at B211 measuring point were 211°C and 484°C, respectively. There are 4 layers of carbon brick at the bottom of the furnace, and the top 2 layers were eroded. Therefore, the elevation of salamander tapping was suggested to be close to the erosion elevation. Three presumed paths of the core drilling for the salamander tapping with 300 mm gap in elevation between holes are represented by three dotted lines in Figure 1. The elevation and angle of P1 hole was 6300mm above ground level and 10 degrees, respectively. The presumed depths of core drilling and oxygen lancing were 1500 mm and 4000mm, respectively.

2.2 Position of salamander tap

Two positions for salamander tapping were adopted in the successful experience of the salamander tapping. There were two salamander runners, one for charging into the torpedo car, and the other into the pit. Figure 2 shows the position of thermocouples for measuring temperature of the hearth bricks of No.4 BF. The measured temperatures at positions near the salamander tap were used to estimate the solidified line of salamander and the erosion line of bricks.

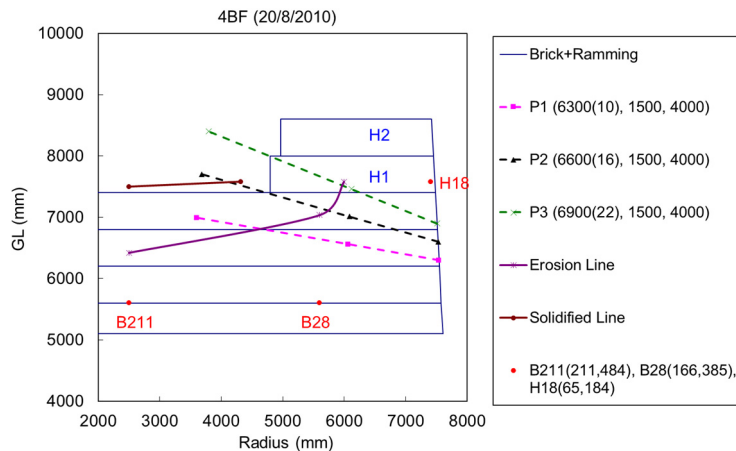


Fig.1. A hearth status with solidified line and erosion line and presumed core drilling paths

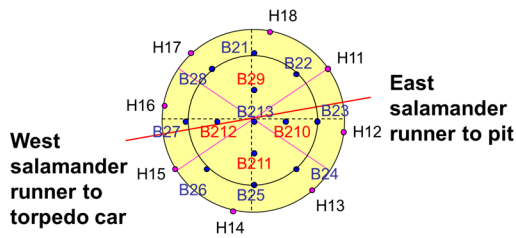


Fig.2. Position of thermocouples for measuring the temperature of hearth bricks in No.4 BF

2.3 Operation strategy

The relining of No.4 BF was scheduled on 31 August, 2013, based on the evaluated status of the hearth. In

order to increase the ratio of liquid to solid salamander, the higher productivity of above 2.3 thm/d/m³ and the lower cooling water flow rate at the bottom of the BF were pursued in the BF operation. Figure 3 shows the variation of productivity, hearth bottom temperature and cooling water flow rate before No.4 BF relining. On 13 August, 2013, the measured temperature of 376°C at B212 is close to the historical maximum temperature of 416°C and listed in Table 2.

2.4 Salamander tapping Operation

Based on the solidified line, the erosion line and previous experience, two salamander tapping paths with 300mm gap in elevation at the ramming mix were decided for the salamander tapping at the west of the BF as shown in Figure 4. The elevation and angle of the

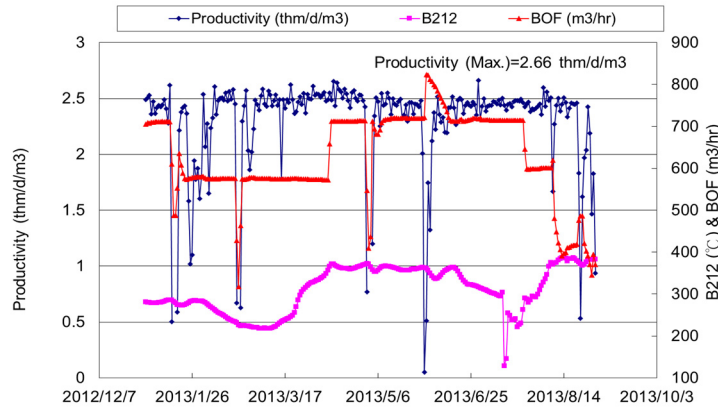


Fig.3. Productivity, bottom temperature and water flow rate before No.4 BF relining

Table 2 Measured temperatures at the hearth of No.4 BF

	B210	B23	H12	B212	B27	H16
Historical maximum temperature (°C)	448	350	252	416	324	218
Temperature on 13/8/2013 (°C)	374	Fail	121	376	272	198

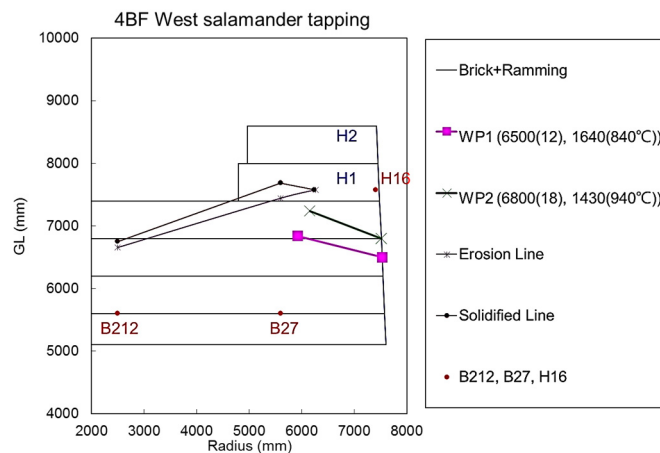


Fig.4. The salamander tapping operation at the west of No.4 BF

WP1 hole was 6500 mm above ground level and 12 degrees, respectively. The interim temperature measurement during the drilling process should be made for preventing liquid salamander suddenly flowing out from furnace. For safety, the core drilling was stopped when the depth of core drilling was 1640 mm when the measured temperature at the drilling forward end reached 840°C. After the completion of WP1 hole drilling, the WP2 hole was done at 6800 mm above ground level and with an angle of 18 degrees.

In the meantime, EP1 hole drilling was done at 6800 mm above ground level with an angle of 22 degrees at the east of the BF. The position of EP1 hole was higher than that of WP1 hole because the liquid salamander flowed through EP1 hole into the pit. The depth of core drilling and temperature were 1090 mm and 690°C, respectively.

After completing core drilling of three holes as mentioned above, oxygen lancing started from WP1

hole, the lowest hole. The liquid salamander began to flow into the salamander runner at 5 minutes after oxygen lancing. At 3.5 hours since the tapping started, the accumulated liquid salamander was about 1150 tons and is equal to the expected weight of the total liquid salamander in the hearth. Therefore, the oxygen lancing for EP1 and the dynamiting operation were cancelled due to the successful salamander tapping.

3. SALAMANDER TAPPING EXPERIENCE OF NO.3 BLAST FURNACE

3.1 Operation strategy

Based on the evaluation results of the shaft and hearth status, the second relining of No.3 BF was scheduled on 30 September, 2017. Figure 6 shows the variation of HM (hot metal) productivity of No.3 BF operation from 2010 to the date of blowing down for the relining. It also shows that the normal productivity was

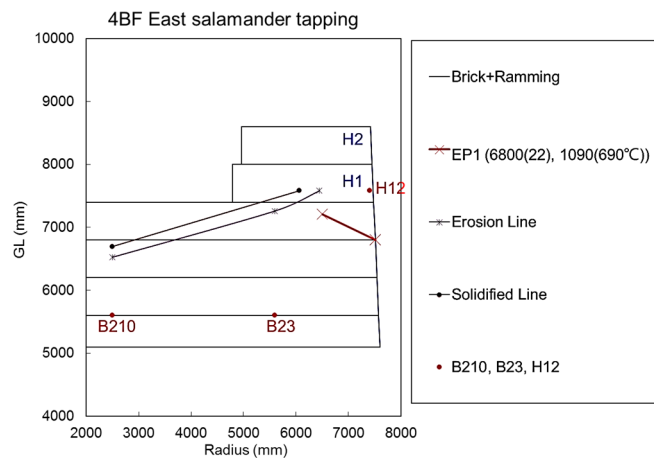


Fig.5. The salamander tapping operation at the east of No.4 BF

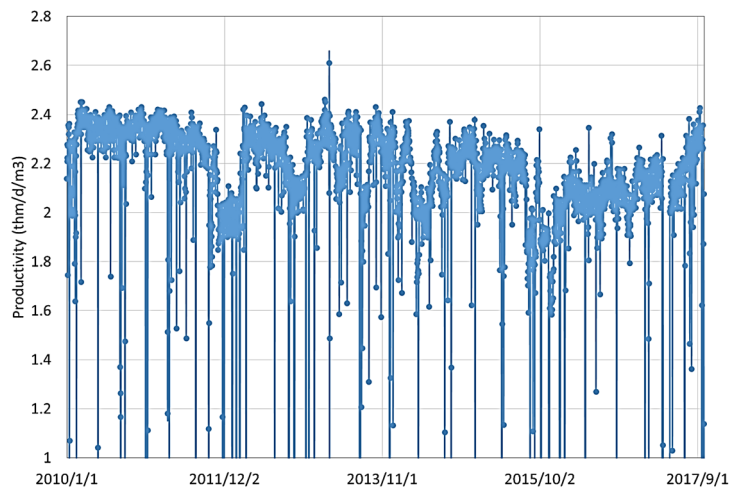


Fig.6. Variation of productivity from 2010 to relining at No.3 BF

around 2.4 thm/d/m³ in 2010. Due to the hot stove problem that occurred in 2016, the productivity decreased to and remained under 2.2 thm/d/m³. Although the productivity increased to 2.3 thm/d/m³ on 24 September, 2017, the measured temperature of B42 was 284.4°C, much lower than the historical maximum temperature of 904 °C (listed in Table 3). The large difference between these two temperatures means that there was a large amount of solid skull left in the hearth.

3.2 Salamander tapping Operation

Single position for the salamander tapping operation was adopted due to the restriction of soft water supply. Figure 7 shows the solidified line, the erosion line and two drilling paths in the hearth of No.3 BF. The elevation and the angle of P1 hole was 7700 mm above ground level at 10 degrees, respectively. Due to the difficulty to drill deeper, the core drilling was stopped at a

path depth of 1530 mm and a temperature of 358°C at the drilling face. After completion of drilling P1 hole, P2 hole was drilled at 8000mm above ground level and with an angle of 16 degrees. On consideration of the thicker solidified layer, the positions of these two holes were set higher than that of the holes at No. 4 BF.

Figure 8 shows photos of samples taken from the core drilling of P1 hole and P2 hole. It was noted that a segment of iron was found at the drilling end of each sample. Based on the lengths of carbon brick and iron segment, it was proven that the erosion line estimated by CSC is reliable enough for the salamander tapping operation.

The oxygen lancing started from P1 hole, the lower of two drilled holes. In fact, no liquid salamander was tapped out from the furnace at after 2 hours of oxygen lancing with the depth of 3600 mm, hence the P1 hole was abandoned. The liquid salamander drained out from

Table 3 Measured temperature of carbon bricks at the hearth of No.3 BF

	B106	B42	H204A	H303A
Historical maximum temperature (°C)	159	904	241	266
Temperature on 24/9/2017 (°C)	85.8	284.4	92.7	95.5

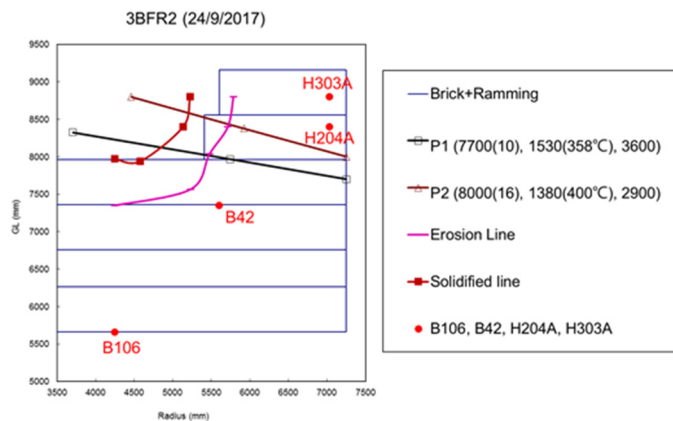


Fig.7. The salamander tapping operation at No.3 BF



Fig.8. Samples taken from the core drilling of P1 hole and P2 hole

P2 hole and accumulated about 168 tons at 50 minutes after oxygen lancing with the depth of 2900 mm.

3.3 Wire cutting of solid salamander

In CSC, this was the first experience of using the wire cutting machine for breaking a large solid salamander left in the hearth as to avoid the danger and pollution from a dynamiting operation. Figure 9 shows the investigation of the salamander tapping paths of P1 and P2 holes on the wire-cut solid salamander from No.3 BF. In Figure 9, it was clearly observed that the pathway of P1 hole was empty and that of P2 hole was full with slag with the composition listed in Table 4, labelled as sample no. 4. In order to investigate the compositions of the large salamander, five samples were collected at salamander 43 as shown on the right side of figure 9. The result of SEM-EDX analysis on these samples are listed in Table 4. Based on the chemical compositions, it is distinguishable that sample 1 is carbon brick, sample 2, 3,

and 5 are salamander, and sample 4 is slag. It was also observed that there were many pieces of coke and few pieces of carbon brick embedded in the large salamander block. Table 5 shows the fusion temperature of the samples. It indicates that the spherical, hemisphere and flow temperatures of salamander samples are higher than that of the slag sample. The flow temperatures of three salamander samples are between 1566°C and 1600°C. Hence, it is more difficult to melt the salamander than the slag.

First, the solid salamander block which weighted 634 tons in total, was cut into 43 pieces in order to remove it from the hearth. The small pieces of the salamander were slung and pulled out of the furnace via the shell door one by one. In the meantime, the sectional profile of the salamander block, shown in Figure 10, was sketched, based on the shape of the reassembled salamander block, the carbon brick level, and the original design drawing of the hearth geometry. In Figure 10, two



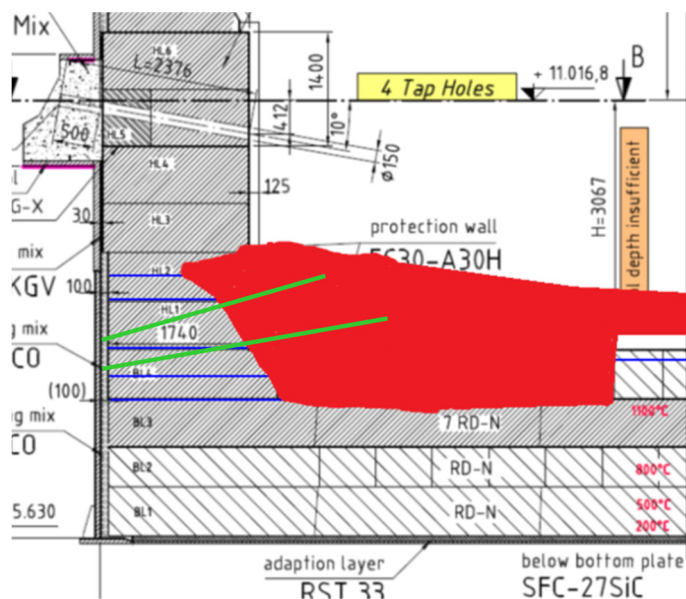
Fig.9. Investigation of the salamander tapping paths at No.3 BF

Table 4 SEM-EDX analysis of samples

Sample number	1	2	3	4	5
Main composition	Carbon brick	Salamander	Salamander	Slag	Salamander
C (%)	64.6	11.3	17.6	6.1	29
O (%)	5.2	1.6	-	13.8	3.9
Mg (%)	-	-	-	3.2	
Al (%)	0.1	-	-	6.1	1.2
Si (%)	0.5	0.3	0.4	15.1	2.2
S (%)	0.2	0.6	-	1.5	13.2
K (%)	0.5	-	-	1	1.9
Ca (%)	-	-	-	47.6	28.8
Fe (%)	28.9	85.1	82	5.6	20

Table 5 Fusion temperature measurement of samples

Sample number	2	3	4	5
Main composition	Salamander	Salamander	Slag	Salamander
Spherical temp. (°C)	1594	1540	1357	1506
Hemisphere temp. (°C)	1597	1560	1473	1534
Flow temp. (°C)	1600	1568	1565	1566

**Fig.10.** Sectional profile of solid Salamander block in the hearth of CSC No.3 BF

green lines stand for the drilling paths of P1 hole and P2 hole, respectively. The drilling forward end of P1 hole with path length of 3600mm was located in the solid salamander (the lower green line in Figure 10). And, the channel of the pathway was empty after drilling. The calculated solidified line, shown in Figure 7, was lower than the solid salamander level. That indicates that the thermal conductivity coefficient of a solid salamander used in the calculation was smaller than the real one. This is the reason why P1 hole drilling failed in the salamander tapping. In this work, it was also revealed that the elephant erosion occurred in the hearth of No.3 BF. Unexpectedly, the protected aluminum brick was still existing at the center of the furnace bottom.

4. CONCLUSIONS

In this study, the solidified line and the erosion line have been estimated for the salamander tapping of No.3 and No.4 BF. The experience of the salamander tapping can be summarized as below:

- (1) The temperature monitoring on the carbon brick of the hearth is important and it can be used to estimate

the solidified line and the erosion line.

- (2) An appropriate operation strategy for maximizing the ratio between the liquid and the solid salamander is to make the productivity of the blast furnace closure the highest productivity in the historical record. It is inferred that the solidified line should be near the erosion line when the temperature before relining is near the historical maximum temperature.
- (3) To ensure the success of tapping, more holes are required for the complicated salamander consisting of coke, carbon brick and iron.

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