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Technical Report

Analysis of Factors that Influence Coke Pushing Force

Sadayoshi AIZAWA* Masato SUGIURA
Michitaka SAKAIDA

Abstract

The excessive pushing force of discharging coke from an oven chamber causes operational problems, for example pushing clogging, and excessive load on the oven wall increases oven wall damage. Scraping clogged coke and oven wall repair reduce the coke oven productivity and stable production of coke becomes difficult. Pushing force is controlled in the daily operation of commercial coke ovens, but as there are many factors that influence such force, operation control based on such factors is required.

1. Introduction

Nippon Steel Corporation is in the process of replacing aged coke ovens; however, it still has many aged coke ovens that have been used for more than 40 years. Extending the oven life and managing oven bodies are important tasks in the coke production process. In addition, extreme increase in the pushing force and pushing clogging when coke is pushed out from coke-oven chambers, in particular, apply excessive loads on the coke-oven chamber walls and that damages the oven walls. Therefore, clarifying the causes that affect the coke pushing force is very important.

Coke in a coke-oven chamber is referred to as “coke cake” and it is an agglomerate of coke lumps divided by cracks vertical or horizontal to the oven wall. When coke cake is pushed, the cake is compressed in the oven length direction and swells in the oven width direction at the same time, which applies a load to the oven wall. The coke pushing force is expressed as the sum of the frictional force to the oven wall and that to the oven bottom in a coke-oven chamber:

$$F = 2Fw \cdot \mu w + Fs \cdot \mu s \quad (1)$$

Where, Fw is the load working on the oven wall, Fs is the load working on the oven bottom, μw is the oven wall friction coefficient, and μs is the oven bottom friction coefficient. Fs is mainly the weight of the coke itself, so it is almost determined by the capacity of the coke-oven chamber and the charging density of the coal.

Each friction coefficient is affected by the degree of damage to the oven wall or oven bottom, but in aged ovens, the influence of damage on the oven walls is greater. In addition, the load working on the oven wall is determined by the deformation degree of the coke cake toward the oven wall when compressed and also by the gap length between the oven wall and coke cake at the end of carbonization that is formed due to contraction of the coke during the carbonization (hereinafter, referred to as lateral shrinkage). Factors that affect coke pushing force are broadly divided into those originating in carbonization conditions, coal properties, or oven body state. This report shows the results of a laboratory-scale study of the influence of these factors on the pushing force along with oven wall displacement behavior measured during carbonization using a commercial aged oven.

2. Main Disclosure

2.1 Influence of carbonization conditions and coal properties on pushing force

2.1.1 Factors that affect the Rankine coefficient

(1) Experimental procedures

For a coke cake compression test, a movable-wall carbonization test oven with a coke-oven chamber width of 450 mm, height of 1 100 mm, and length of 1 050 mm was used. After carbonization completion, with the CS (side opposite to the coke pusher) oven door supported from the rear, a load was applied to the coke cake with the extruder to measure the pushing force and loads on the movable wall and CS oven door continuously. **Figure 1** illustrates an outline of the test. As the coal, blended coal with a mean reflectance of 1.18 to 1.21% and a fluidity log (MF/ddpm) of 2.4 to 2.6 was used. The oven temperature was 1 100 to 1 350°C.[1)]

(2) Experimental results

(2)-(i) Coke cake behavior during compression

Figure 2 shows an example of coke cake behavior during compression. Immediately after the pushing force started working, the coke cake started compressing and a load was applied to the oven wall. This is because although a gap was formed between the coke cake and oven wall due to contraction of the coke during the carbonization, the projections and depressions on the coke surface varied and some sections had been in contact with the oven wall from

* Senior Researcher, Ironmaking Research Lab., Process Research Laboratories
20-1 Shintomi, Futtsu City, Chiba Pref. 293-8511

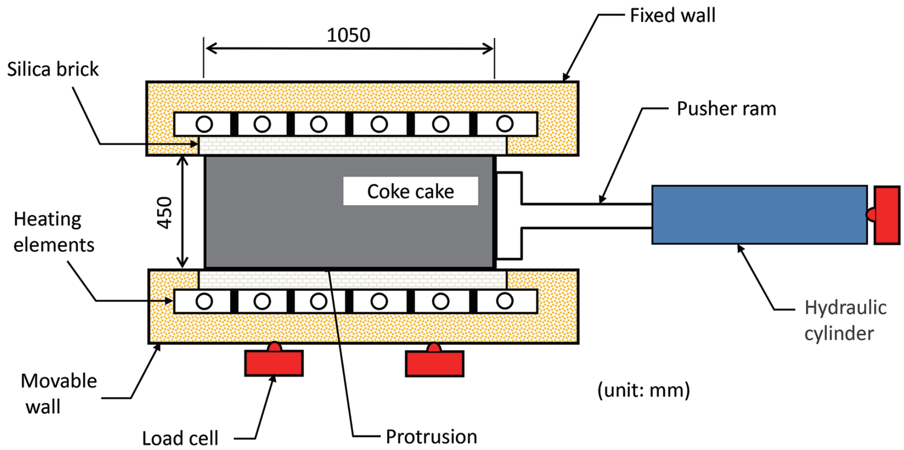

Fig. 1 Experimental apparatus for coke cake compressing test

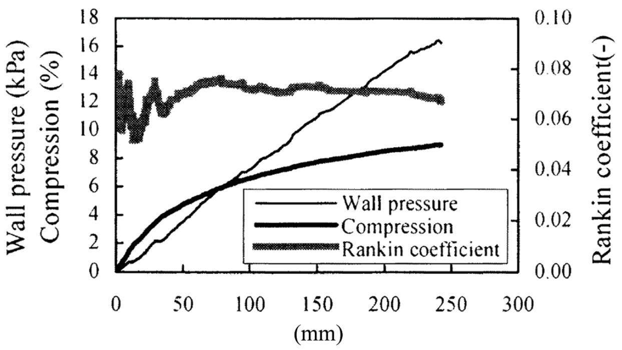

Fig. 2 Behavior of coke cake compressing

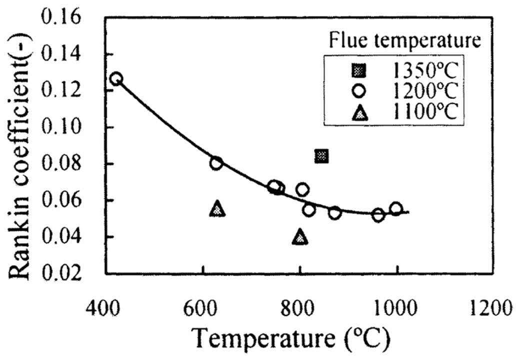

Fig. 3 Effect of coke temperature on Rankin coefficient

the beginning.

The wall pressure increases almost in proportion to the pushing force. The Rankine coefficient K defined by Equation (2) was calculated based on the relationship between the wall pressure and pushing force in Fig. 2, where the pushing force is P and the wall pressure is Pw:

$$K = Pw / P \quad (2)$$

The Rankine coefficient is also referred to as the lateral pressure conversion ratio. As the coefficient is higher, the pressure on the oven wall is higher and thus in turn the pushing force is larger. Although the variation is large in the early stage of the compression, the coefficient becomes almost constant after that. In the case shown in Fig. 2, K≈0.08.

(2)-(ii) Influence of oven temperature and coke temperature on the Rankine coefficient

Figure 3 shows the relationship between the Rankine coefficient and coke temperature at the end of carbonization that was changed from 420 to 1000°C. The low coke temperature indicates that the contraction at the center in the oven width direction is not sufficient and the lateral shrinkage volume becomes smaller. **Figure 4** shows the results when the data in Fig. 3 was organized with the lateral shrinkage. When the oven temperature is constant, there may be no significant difference in crack formation or coke particle size: The lower the lateral shrinkage, the higher the Rankine coefficient. The differences in the Rankine coefficient due to the differences in the oven temperature tend to deviate from the relationship organized only with lateral shrinkage: When the lateral shrinkage volume is the same, the higher the oven temperature, the larger the Rankine coefficient. This may be because when the oven temperature is high, more cracks are formed and the coke cake tends to deform in the oven width direction during compression. Similar results were obtained in a measurement test of the apparent Poisson ratio of the coke cake (physical property equivalent to the Rankine coefficient when the lateral shrinkage is 0 mm in cold working) where the coke temperature was constant and the oven temperature was varied.[2]

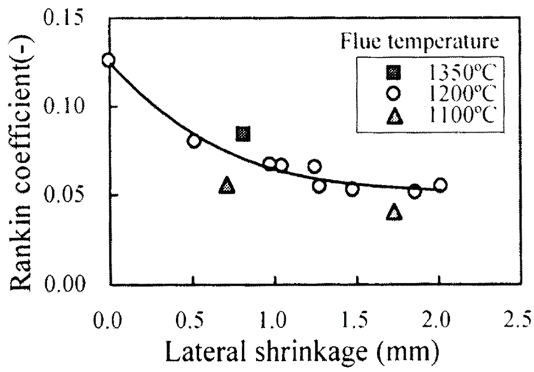

Fig. 4 Effect of lateral shrinkage on Rankin coefficient

To examine the influence of lateral shrinkage only, a movable wall on one side was moved by 1 to 3 mm in a compression test to enlarge the gap between the coke cake and oven wall. **Figure 5**

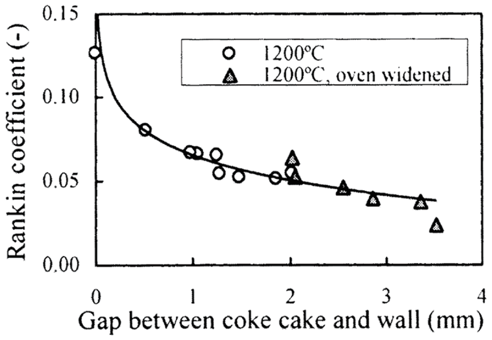

Fig. 5 Effect of gap between coke cake and wall on Rankin coefficient

shows the measurement results under such conditions along with the data at an oven temperature of 1200°C in Fig. 4. The extended oven width during the compression decreases the Rankine coefficient. Increase in the Rankine coefficient due to decrease in the coke temperature may be mainly due to decrease in the lateral shrinkage. Therefore, for aged ovens, in particular, operation and oven body management to prevent the coke temperature from lowering due to insufficient carbonization is important, for example, by securing sufficient soaking time and avoiding damage to combustion chambers appropriately.

2.1.2 Oven wall displacement behavior at aged ovens during carbonization

Lateral shrinkage is caused by the contraction of coke in the oven width direction during carbonization. Examples of factors that affect coke contraction are the volume of volatile matter in coal and charge bulk density. Previous carbonization tests using test coke ovens show that as the volatile matter volume is lower and as the bulk density is higher, the contraction volume is lower.[2, 3] However, these results were obtained in measurements where the oven walls were completely secured and thereby no displacement occurred. In commercial coke ovens, the situation may be different.

When coal is carbonized in a coke-oven chamber, the pressure that occurs when the plastic coal layer contains the generated gas (hereinafter, gas pressure) applies force to the oven wall via the coke layer. This pressure is called coking pressure. Although the gas pressure of a plastic coal layer varies depending on the coal properties, bulk density, and other factors, when the coking pressure is high, the oven wall (brick structure) moves in a bending-like fashion. Oven wall displacement due to the coking pressure from the neighboring oven may decrease the lateral shrinkage, which may increase the Rankine coefficient and in turn increases the pushing force as described in the previous section.

The rigidity of the wall of an aged oven against loads has been decreased due to lowered oven-tightening force and the swelling of the oven body in the oven length direction. Therefore, even when the same coking pressure is applied, the walls of aged ovens tend to deform more compared to new ovens and its influence on the pushing force may be different. Wall displacement of a commercial oven during coal carbonization was continuously measured and the relationship between the pushing force and oven wall displacement due to coking pressure was evaluated in this study.[4]

(1) Experimental procedures

Oven wall displacement was measured using coke oven 6 at Hokkai Iron & Coke Corporation (currently, Nippon Steel Muroran Works). Coke-oven chamber No. 46 for which all the oven wall bricks had been replaced one year ago and chamber No. 72 that had been used for 26 years were used. **Figure 6** shows an outline of the measurement. A water-cooled probe that was designed such that the tip would be at the center of the oven height was inserted into the oven next to the measurement target oven. The entire probe was suspended in a pivot style. The displacement from the neighboring oven where the carbonization proceeded was obtained by reading the location of a blip that is shown, on the light receiving plate, by beams from a laser oscillator installed at the upper end of the probe. In addition to the oven wall displacement, the gas pressure during the carbonization was measured with a stainless steel tube probe with an inner diameter of 1 mm and outer diameter of 2 mm inserted at the center in the oven width direction.

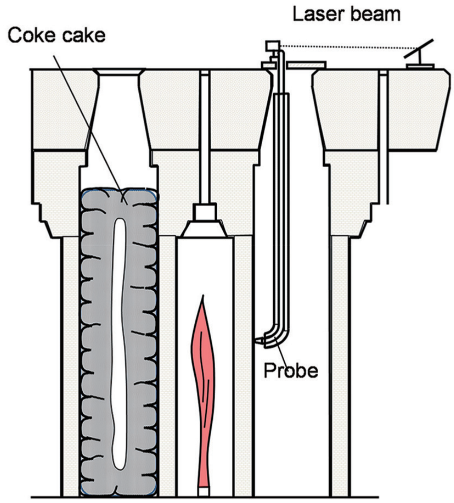

Fig. 6 Side view showing determination of wall displacement

As coal blending, aiming at increasing the gas pressure in the coal from 8 to 10 kPa, which is regarded as the collapse limit of an oven wall, the blending ratio of high-coking pressure coal was changed during the measurement period (one week). Coke-oven chamber No. 46 for which all the oven wall bricks had been replaced one year ago was used for the measurement of two levels and chamber No. 72, which had been used for 26 years, was used for the measurement of three levels.

(2) Experimental results

Figure 7 shows some measurement results of the oven wall displacement and coal gas pressure during the carbonization (coke-oven chamber No. 46). In the upper figure in Fig. 7, the positive displacement values in the oven wall displacement measurement indicate that the oven wall of the measurement target was pushed out toward the center in the oven width direction due to displacement from the neighboring oven (oven with the charged coal). The oven wall significantly deformed when the coal was charged into the neighboring oven and then gradually recovered; in approximately nine hours after the coal charge, it started deforming again, showing a peak. At the time point approximately nine hours after the coal charge, the coke temperature is in the softening and melting temperature range and the coal gas pressure is at the maximum. This indicates that the oven wall displacement at this point was caused by the coking pressure.

Figure 8 shows the relationship between the maximum coal gas pressure at which the temperature of the coal center reaches the softening and melting temperature during the carbonization and the corresponding oven wall displacement volume. The oven wall displace-

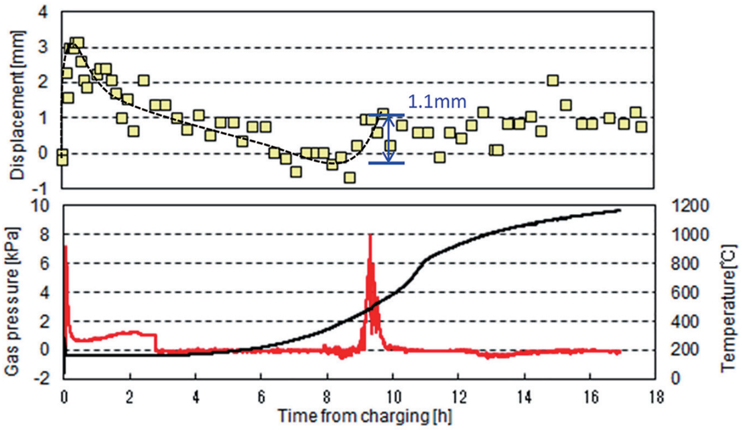

Fig. 7 Profile of gas pressure, temperature and wall displacement during carbonization (Chamber No. 46)

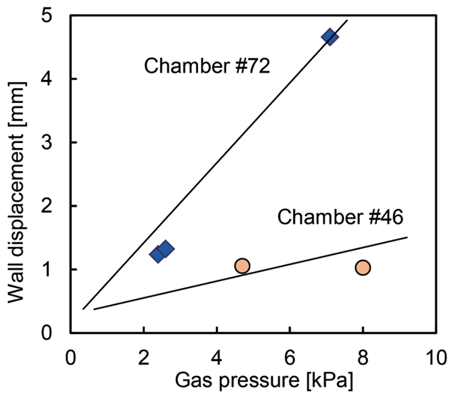

Fig. 8 Relationship between maximum gas pressure and wall displacement

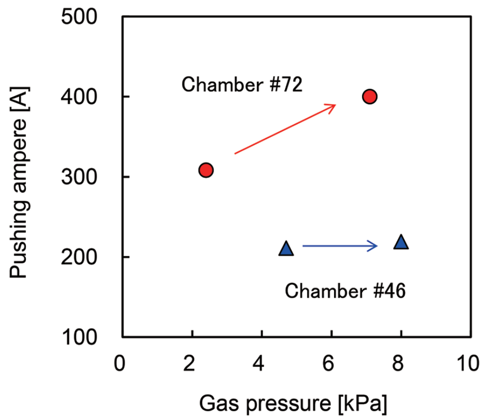

Fig. 9 Relationship between maximum gas pressure and pushing ampere of coke cake

ment volume increases almost linearly to the coal gas pressure. The oven wall displacement volume per the unit gas pressure calculated from the inclination was 0.67 mm/kPa for coke-oven chamber No. 72 (aged oven) and 0.14 mm/kPa for coke-oven chamber No. 46 (sound oven). The value in the case of the aged oven was approximately 5 times larger than that of the sound oven. These results show that the rigidity of the oven wall of the aged oven against loads had been lowered due to decreased oven-tightening force and swelling of the oven body in the oven length direction as previously described.

Figure 9 shows the influence of the gas pressure on the pushing resistance. The graph uses the maximum ampere of the coke pusher motor that is equivalent to the pushing resistance of the coke. The absolute value of the pushing ampere is larger in the case of coke-oven chamber No. 72 (aged oven). The increased gas pressure hardly affects coke-oven chamber No. 46 (sound oven) while in the case of coke-oven chamber No. 72 (aged oven), the current significantly increases. This may be because the influence of swelling of the neighboring oven wall that works to decrease the lateral shrinkage is larger in the case of the aged oven as described previously. In addition, it may be affected because the contraction start point of the oven itself after the coking pressure is removed is located outside of the original position and thereby the lateral shrinkage is smaller for that amount. In any case, for aged ovens, to secure sufficient lateral shrinkage, coal blending for maintaining the coking pressure at a low level and appropriate operation management (e.g., bulk density setting) are required.

2.2 Influence of oven body state on pushing force

The previous section has described the influence of the carbonization conditions and coal properties on the pushing force. In addition to these, the oven body state also affects the pushing force significantly. The oven body state is determined by fairly broad items for coke ovens. In this report, this state means the oven wall state. For aged coke ovens, many flaws are seen on the surface of coke-oven chamber walls and carbon adhered to damaged bricks turns into protrusions that remove the fineness of the oven walls, which tends to increase projections and depressions. Such projections and depressions work as resistance when coke cake is pushed out, causing pushing clogging and other problems. In addition, they increase loads toward the oven walls, which further damages them. Technologies to repair coke-oven chamber walls are described in another report.[5)] In this research, we quantitatively studied the influence of projections and depressions formed on oven walls on the coke pushing force as well as coke cake behavior when the coke cake passes sections with projections and depressions. This section describes the results obtained in a laboratory-scale test.[6, 7)]

2.2.1 Influence of the shape of projections and depressions made on oven walls on coke pushing force

(1) Experimental procedures

Figure 10 illustrates an outline of the tester. Coal charged into a pail with a width of 420 mm, height of 400 mm, and length of 610 mm was carbonized to produce coke cake. Hydraulic cylinders were placed on the front and rear side of the coke cake. The pushing force was measured while certain reaction force was applied. To simulate projections and depressions on the oven wall, a protrusion with a cross section as shown in **Fig. 11** was installed on one inside wall of the apparatus to form a narrower section. The length of the flat section equivalent to the short base of the cross-sectional trapezoid was constant at 220 mm. The protrusion thickness H or the inclination angle θ was changed as shown in **Table 1**. The length of the protrusion chamber in the height direction was the same as that of the coke cake at 400 mm. The pushing rate was 140 mm/s and the maximum stroke was 500 mm.

(2) Experimental results

Figure 12 shows some changes in the various loads against the pushing length (when the protrusion thickness is 40 mm). When the pushing length exceeds 100 mm, a load is generated. The reaction force remains constant at 20 kN while the pushing force and the load on the wall continue to increase, and becomes constant at approximately 430 mm. This value may be the force required for the coke cake to pass through the section narrowed by the protrusion on the oven wall. **Figure 13** shows the pushing force measured when the protrusion thickness H was varied. The pushing force exponentially increases as the protrusion thickness increases, and these results show that the influence is large. **Figure 14** shows the pushing force and load on the wall measured when the slope angle of the protrusion was changed while the protrusion thickness H was constant at 30 mm. As the slope angle increases, the pushing force lin-

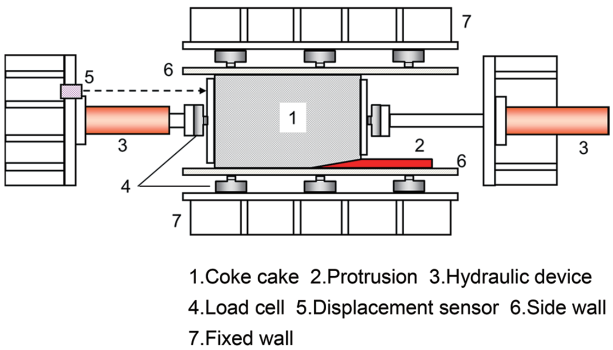

Fig. 10 Experimental apparatus for pushing force measurement

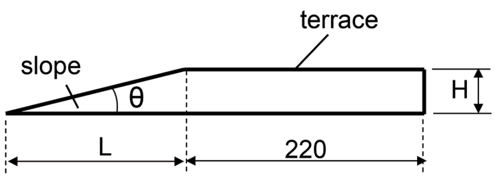

Fig. 11 Profile of protrusion

Table 1 Protrusion profile conditions for pushing test

H [mm]	L [mm]	θ [deg]
0	180	0
10	180	3.2
20	180	6.3
30	180	9.5
40	180	12.5
50	180	15.5
30	90	18.4
30	45	33.7
30	30	45.0

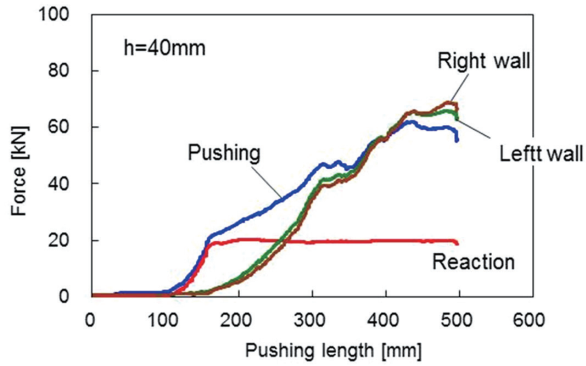

Fig. 12 Profiles of pushing force, load on wall and reaction force

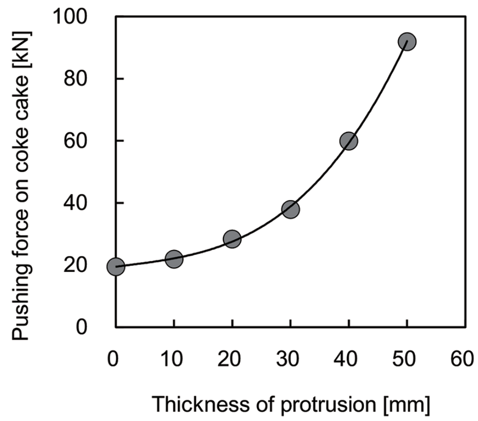

Fig. 13 Influence of protrusion thickness on pushing force

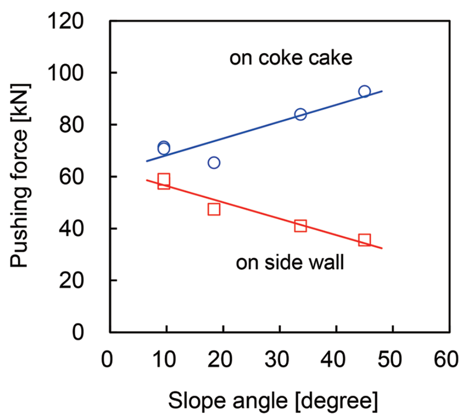

Fig. 14 Influence of protrusion slope angle on pushing force

early increases while on the contrary, the force working on the wall decreases. This may be because the load working on the protrusion slope is distributed more toward the wall side as the protrusion slope angle is smaller; and the fact that as the slope length L became longer, the region where the coke was in contact with the enlarged slope may also have affected the results.

2.2.2 Influence of gap length in the oven width direction on pushing force when oven walls have a protrusion

(1) Experimental procedures

Figure 15 illustrates a state where coke cake passes through a section narrowed by a protrusion in the oven width. Gaps in the oven width direction are broadly divided into that between the coke cake surface and oven wall (due to lateral shrinkage) and a large one inside the coke cake in the oven length direction at the center of the coke-oven chamber. As explained in the Introduction, since lateral shrinkage is formed by coke contraction in the oven width direction, it is affected by the coal properties or operation conditions. This also applies to a gap at the coke-oven chamber center. When coke cake passes through the narrow section, it transcends the protrusion as its behavior. Therefore, how easily the coke cake can move in the oven width direction, that is to say, the gap length may affect how easily the coke cake can transcend the protrusion and in turn it may affect the pushing force.

A tester shown in Fig. 10 was used to measure the pushing force when the protrusion thickness was changed from 0 to 50 mm. The length of the flat section was constant at 220 mm and the slope length was constant at 180 mm. The coal properties or the distance between the tester walls was changed to vary the gap length in the oven width direction. The gap length in the width direction was calculated based on X-ray CT images of the coke cake as shown in **Fig. 16**.

(2) Experimental results

Figure 17 shows the influence of the total gap length in the width direction on the force required for the coke cake to transcend the protrusion when the protrusion thickness H was 30 mm. The force required to transcend the protrusion is expressed with the force that is obtained by deducting the reaction force from the pushing force. The force required to transcend the protrusion, that is to say, to pass through the narrow section, has good correlation with the total gap in the oven width direction. The ratio of the gap at the center of the coke cake to that on the wall side is different; however, the data could be uniquely organized by the total gap and that may indicate that the influence of the gap at the center is almost equal to that of the gap on the wall side. Although the data in Fig. 17 was obtained when the protrusion thickness H was constant at 30 mm, the addition of the data obtained when the protrusion thickness H was changed results in, for the same total gap in the width direction, the larger the protrusion thickness H, the higher the pushing force, and thus the data cannot be uniquely organized. Therefore, based on the concept that the force required to transcend the protrusion increases as the protrusion thickness H increases and as the total gap w decreases, the following index Qn was defined:

$$Qn = \{100\,(H-w)/L\} \qquad (3)$$

Figure 18 shows the relationship between the index Qn and force to transcend the protrusion when H, w, and L were changed. The index Qn is in good correlation with the pushing force. The protrusion thickness H and distance between the oven walls L originate in the oven body and the total gap w originates in the coal or coke cake, so it can be considered that they could be organized with

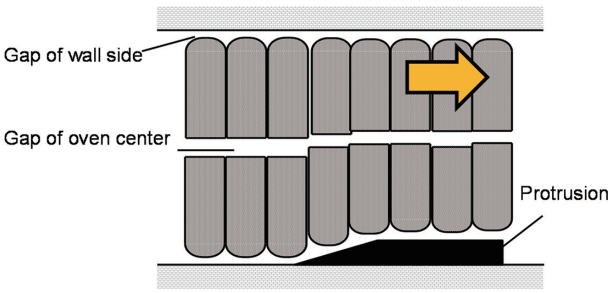

Fig. 15 Schematic view of coke cake passing the narrow district

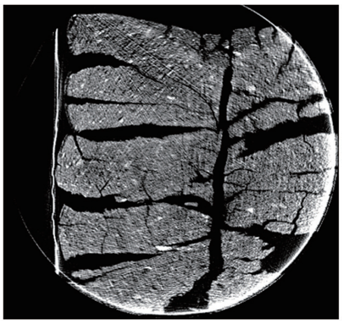

Fig. 16 X-rays CT image of the coke cake

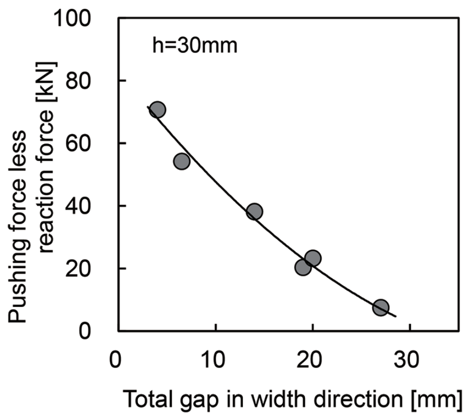

Fig. 17 Influence of total gap in width direction on pushing force less reaction force

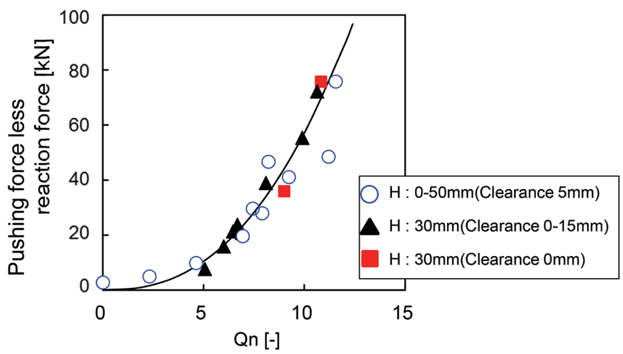

Fig. 18 Relationship between index Qn and pushing force less reaction force

the index Qn consisting of the various factors that affect the force to transcend the protrusion.

3. Conclusion

This report has described the influence of the various factors that affect the pushing force for coke cake originating in carbonization conditions, coal properties, and oven body state evaluated quantitatively. Based on the findings, the upper limit on the coking pressure is determined in actual operation using commercial ovens in order to secure lateral shrinkage to manage coal blending and operations. In addition, projections and depressions on oven walls have been properly repaired (details will be presented in another report) and operation is managed while continually securing the total gap for coke cake. Furthermore, the application of X-ray CT has enabled observing the shape inside coke cake that used to be impossible and has made it possible to evaluate the characteristics of coke cake more quantitatively. However, the causes of problems with pushing (e.g., pushing clogging) have not been fully clarified. Therefore, Nippon Steel will also work to clarify the coke pushing behavior based on the understanding and mechanism of phenomena in the future.

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Sadayoshi AIZAWA
Senior Researcher
Ironmaking Research Lab.
Process Research Laboratories
20-1 Shintomi, Futtsu City, Chiba Pref. 293-8511

Masato SUGIURA
Senior Researcher, Ph.D
Instrumentation & Control Research Lab.
Process Research Laboratories

Michitaka SAKAIDA
General Manager, Coke making Plant Engineering
Plant Engineering Div.
Plant Engineering and Facility Management Center