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START-UP AND SOME EXPERIENCE OF CAS-OB AT POSCO

PIERWSZE DOSWIADCZENIA Z PROCESU CAS-OB W POSCO

CAS-OB process was adopted in #2 steelmaking plant at Pohang works in 2005. Several factors affecting mixing time had been investigated by water model before CAS-OB start-up. Snorkel diameter, snorkel immersion depth, position of bottom bubbling and gas flow rate between top lance and bottom bubbling were considered. Splash in the snorkel and inclusion behavior during oxygen blowing were also investigated by water model. It was observed that snorkel immersion depth and bottom gas flow rate were critical to CAS-OB process.

Heating speed, bath composition change during oxygen blowing were compared between Al-killed steel and Si-Al-killed steel in plant test. Steel cleanliness was also compared with other process. CaO-CaF_2 flux injection was tried for desulfurization of Si-Al-killed steel.

[P] and [S] pick-up during oxygen heating were observed because of slag composition change in Al_2O_3 and Fe_{total} content. Adhesion of oxide to snorkel resulted in short snorkel life. Increase of lime addition during tapping and mixed production of various steel grades were helpful to relieve the problem. Additional improvement both in operation and in facilities will be continued in this process.

Keywords: Oxygen heating, snorkel life, [P] and [S] pick-up, water modelling

W 2005 roku w stalowni nr 2 w Pohang został uruchomiony proces CAS-OB. Przed jego uruchomieniem zbadano za pomocą wodnych modeli wpływ różnych czynników (średnica króćca, głębokość zanurzenia króćca, rozmieszczenie punktów dolnego wdmuchiwania, szybkość przepływu gazów pomiędzy górną oraz dolną lancą) na długość czasu mieszania. Na wodnym modelu zbadano również wielkość rozprysków w króćcu oraz zachowanie wtrąceń podczas wdmuchiwania tlenu. W wyniku tych testów ustalono, iż największe znaczenie dla procesu ma głębokość zanurzenia króćca oraz szybkość wdmuchiwania gazów.

Podczas badan porównano szybkość ogrzewania, zmiany skladu kapieli metalicznej podczas wdmuchiwania tlenu dla stali odtlenionej za pomocą Al lub Si-Al. Uzyskane wyniki zestawiono z wynikami uzyskanymi przy zastosowaniu innych procesów. Zbadano równiez wpływ dodatku topników CaO-CaF_2 na stopień odsiarczenia stali uspokojonej.

Wraz ze zmianami zawartości Al_2O_3 i Fe_{total} w żużlu, stwierdzono spadek [P] i [S] w kąpieli podczas świeżenia. Zaobserwowano również, że adhezja tlenków w króćcu powodowała zmniejszenie jego trwałości. Zwiększenie ilości dodatków wapna podczas topnienia oraz mieszania kąpieli metalowej w znacznym stopniu rozwiązuje ten problem w produkcji różnych gatunków stali. Ciągle jednak prowadzone są prace nad kolejnymi usprawnieniami procesu.

1. Introduction

In recent years, the demand for clean steel with precise compositional control has been increased. On the other hand, high price of raw material caused steelmaker to reduce production cost. Under these circumstances, #2 steelmaking plant at Pohang Works also needed to upgrade its facilities in order to improve productivity and metallurgical abilities. Those are KR in hot metal treatment and CAS-OB in secondary steelmaking, respectively. There were 4 bubbling stations, 3 on-lines and 1 off-line. The off-line bubbling station was in limited-use because the crane moved the ladle to the station and unfortunately, the station had no heating function. The off-line bubbling station was determined to change to CAS-OB which has desulphurization function with powder injection and heating function with oxygen blowing.

The CAS(Composition Adjustment by Sealed Argon Bubbling) process was started by NSC.[1] In this process, bottom bubbling gas creates an open eye in the

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slag layer and then refractory snorkel is lowered into the molten steel through the open eye. This makes alloy able to be added into the slag-free region so as to achieve higher yield.

To understand this process much better and to achieve optimum process conditions, several items had been investigated before CAS-OB start-up.

2. Determination of snorkel size and position

The snorkel diameter is critical to secure the slag-free region in the slag layer. It can be determined by knowing the diameter of open eye during bottom bubbling. The geometry of bubbling plume was investigated by several researchers. It has been recognized that the plume cone angle depends on gas flow rate. McNallan and King estimated the plume cone angle as a function of gas flow rate and found it to vary between 20 and 30 degree.[2] If the average value of plume cone angle, 25 degree is adopted to the ladle of #2 steelmaking plant, the diameter of open eye reaches ~1.7 m.(Fig.1) In recent years, Subagyo proposed the following equation by revaluating the result of Yonezawa.[3]

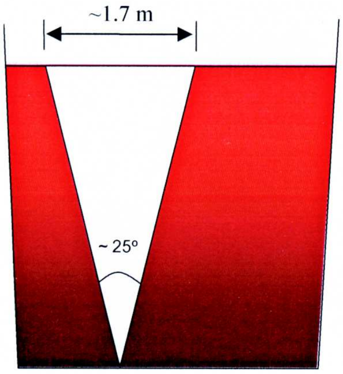

Fig. 1. Estimation of open eye in the ladle

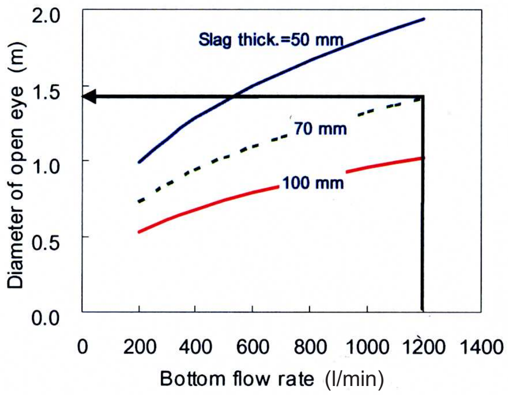

Fig. 2. Calculation of the diameter of open eye in the ladle with bottom flow rate

$$\frac{A_{es}}{(H+h)^2} = 0.02\left(\frac{Q^2}{gH^5}\right)^{0.375} \tag{1}$$

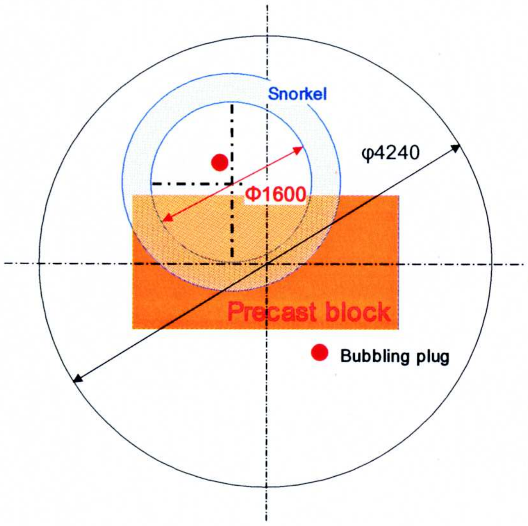

Fig. 3. Relative position of snorkel and bubbling plugs

We can calculate the diameter of open eye with bottom gas flow rate by using equation (eq1). In steelmaking ladle, the slag thickness is between 50 and 100 mm. If the average slag thickness is 75 mm, the diameter of open eye is about 1.5 m with maximum bottom gas flow rate, 1.2 Nm^3/min.(Fig2) Through consideration on the open eye above mentioned, the snorkel diameter is determined as 1.6 m.

In CAS-OB process, opening of bottom bubbling plug is important to secure open eye. To avoid the risk of failure of bubbling plug opening, snorkel position changing system was adopted. Snorkel position can be switched to good bubbling area. At the beginning of basic design, the bubbling plug position was recommended to align at the centre of snorkel. In this case, the bubbling plug is so close to the centre of ladle that it might show high erosion rate by poured steel stream. Finally, the bubbling plug is moved away from the centre of ladle so as to be aligned off the centre of snorkel. Relative position of snorkel and bubbling plugs in the ladle is shown in Fig. 3.

A quarter-scale acrylic model was constructed to investigate the mixing behaviour in CAS-OB process.(Fig.4) Splash and inclusion behaviour were also investigated. 95% mixing time is obtained by electric conductivity method.[4] Four electric probes were fixed to the acrylic ladle. Three probes were located at the ladle wall, one at the centre of ladle bottom. Inclusion behaviour was simulated by small plastic tubes with the density of 0.75 cm^3/g. The plastic tubes were added into the snorkel during experiment Inclusion removal rate can be calculated by counting the number of plastic tubes which were removed from inside the snorkel to outside. Dynamic similarity for bottom bubbling between model and actual facility was based on Froude Number.[5] On other hand, dynamic similarity for top blowing was based on Momentum Number.[6,7]

Fig.5 shows 95% mixing time of CAS compared with simple ladle bubbling. The mixing behaviour of CAS is inferior to that of simple ladle bubbling. Effect of snorkel immersion depth is shown in Fig.6. The deeper the snorkel immerses into the liquid, the longer the mixing time is; which is consistent with the early reports.[8,9] The snorkel diameter is not so critical as snorkel immersion depth.(Fig.7)

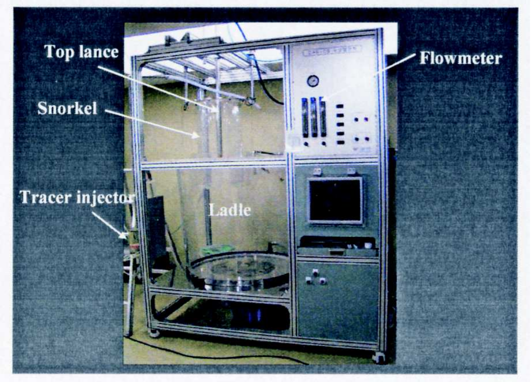

Fig. 4. Water model apparatus

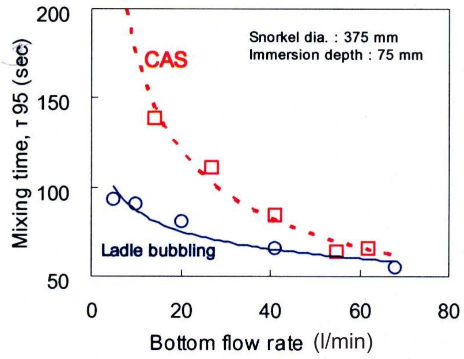

Fig. 5. Comparison between ladle bubbling and CAS

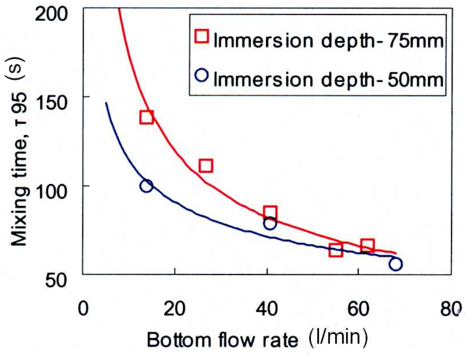

Fig. 6. Effect of snorkel immersion depth on mixing behaviour

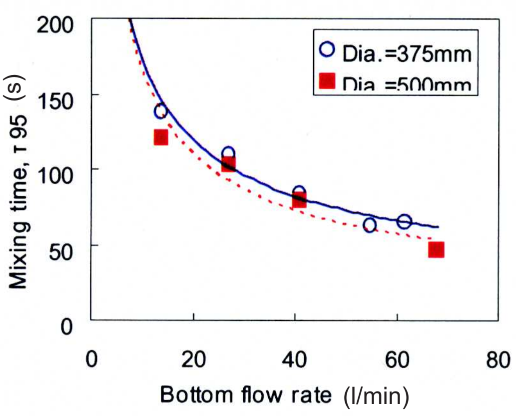

Fig. 7. Effect of snorkel diameter on mixing

Inclusion removal behaviour during oxygen blowing was simulated by varying top and bottom flow rate. Fig.8 shows the proportion of inclusion which is still remained inside snorkel with elapsed time. Although the tendency over certain bottom flow rate is not clear, it is found that the higher bottom flow rate is favourable to inclusion removal. Under the condition of fixed bottom flow rate, the higher top flow rate seems to retard inclusion removal rate.(Fig.9)

From the result of water model experiment, it is concluded that lower immersion depth of snorkel and higher bottom flow rate are important to achieve good metallurgical result in CAS-OB process.

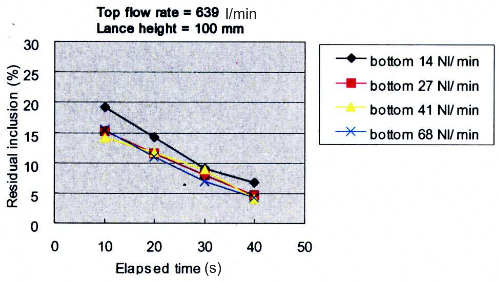

Fig. 8. Effect of bottom flow rate on inclusion removal rate

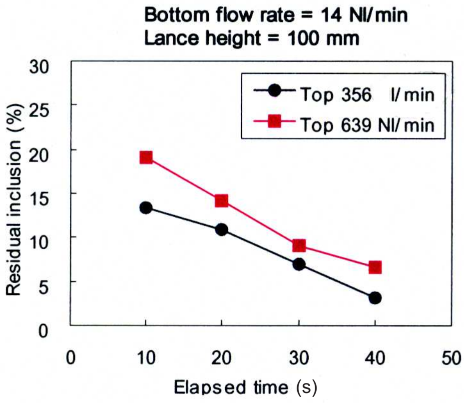

Fig. 9. Effect of top flow rate on inclusion removal rate

3. Operation result

Based on the result of water model experiment, hot test was started in 2005. Oxygen heating was main focus of steelmaking workers. Aluminium was added into liquid steel simultaneously with oxygen. The quantity of aluminium to oxygen was controlled according to steel grade. Fig.10 shows heating behaviour of CAS-OB. It is shown that net heating temperature is just related to total oxygen blowing quantity, regardless of oxygen flow rate. Reacted elements according to steel grade were compared during oxygen heating. Fig.11 shows that Mn and Si is burnt out during oxygen heating, especially in Si-Al killed steel. The amount of oxidised element was calculated by mass balance and used to predict the final composition of the bath.

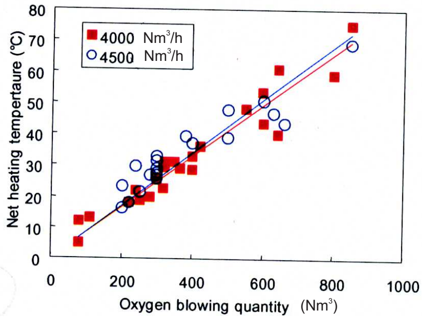

Fig. 10. Relationship between oxygen blowing quantity and heating temperature

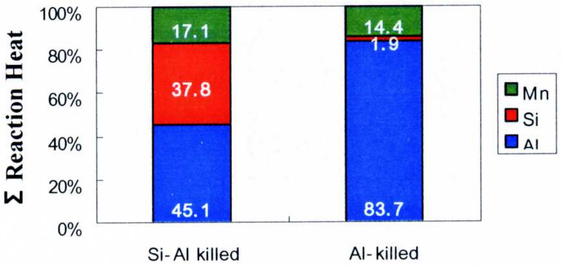

Fig. 11. Comparison of reacted elements between Si-Al killed and Al-killed steel during oxygen heating

During heating, [P] and [S] pick-up were observed. The changes of [P] and [S] composition before and after heating are shown in Fig.12. The amount of phosphorous pick-up extended to 30 ppm and that of sulphur to 20 ppm. Fig.13 shows the changes of slag composition before and after oxygen heating. Oxygen heating increases Al_2O_3, SiO_2, MnO, FeO content of slag. This lowers the activity of CaO, resulting in low phosphorous and sulphur partition ratio. Hopper restriction in CAS-OB limited lime addition during treatment. There was not enough space to be equipped with large-size lime hopper. Lime was added during tapping in BOF instead of addition during CAS-OB treatment.

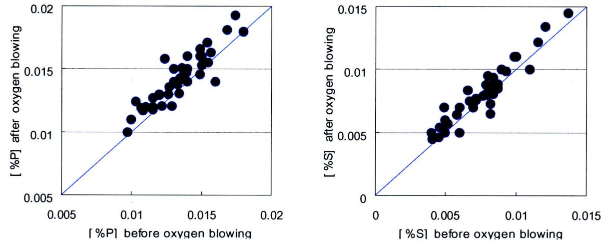

Fig. 12. Phosphorous and sulphur pickup during oxygen blowing

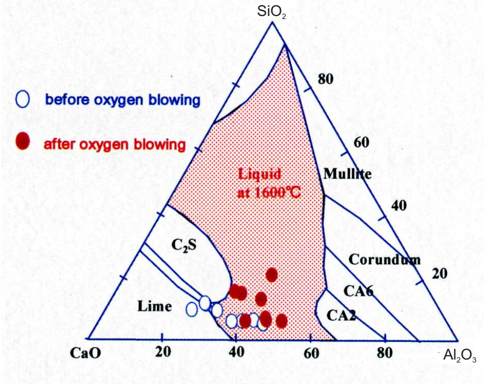

Fig. 13. Changes of slag compositions during oxygen blowing

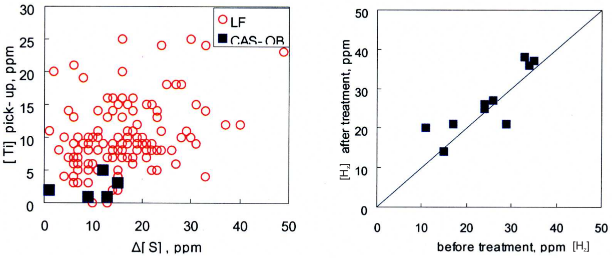

Fig. 14. [Ti] and $[N_Z]$ changes during CAS treatment

In CAS-OB process, mixing is retarded by snorkel which blocks the radial horizontal outflows along the free surface. On the other hand, the slag layer keeps quiescent; which is favourable to suppressing $[N_Z]$ pick-up and [Ti] pick-up. Of course, desulphurization through slag-metal reaction may not be available, thus desulphurization through transitory reaction by flux injection is essential. Fig.14 shows that [Ti] pick-up in CAS-OB is much lower than in LF at the same desulphurization value. $[N_Z]$ pick-up is negligible, as shown on the right figure in Fig.14. The heats corresponding to CAS-OB in this figure were treated by flux injection. Desulphurization in CAS-OB was not satisfactory because flux injection rate was very low which was 0.17 kg/t-min. Improvement in flux injection facility is now under consideration.

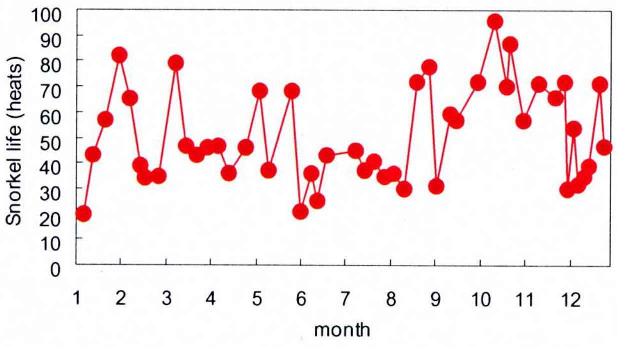

Fig. 15. Change of snorkel life after CAS-OB start-up

Steel cleanliness was also compared with other process by measuring tot.$[O_2]$ in slab. Total oxygen content of CAS-OB was nearly same to that of Bubbling, LF, somewhat inferior to that of RH. Flux injection was tried to improve the cleanliness of Al-killed steel. A little improvement seemed to be made but further test seemed to be needed to verify.

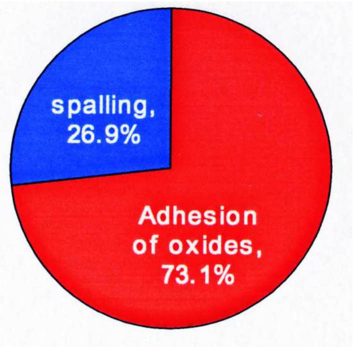

Fig. 16. Causes of early snorkel repair

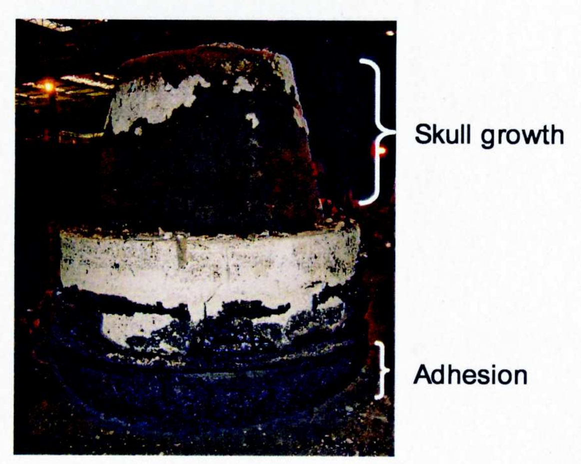

Fig. 17. Snorkel appearance after use

After CAS-OB process started, the target life of snorkel was over 50 heats. Many cases did not approach the target as shown in Fig.15. Causes of early snorkel repair consisted of adhesion of oxide and spilling of refractory.(Fig. 16) Appearance of snorkel after use is shown in Fig.17. While skull was attached to upper part of snorkel, some oxide material was attached to lower part. Oxide growth in lower part of snorkel causes clash with the rim of teeming ladle, resulting in snorkel break-down. The chemical composition of oxide material is shown in Table 1. The oxide material seemed to come from elements of steel bath during oxygen heating. The composition of oxide, i.e. combustion product can be calculated by mass balance and is shown in Fig. 18. While combustion product of Al-killed steel is nearly solid at steel temperature, that of Si-Al killed steel contains considerable liquid because of oxidation of [Mn] and [Si]. Increase of lime addition during tapping and mixed production of various steel grades were helpful to relieve this problem. On the other hand, refractory spilling of snorkel may be affected by thermal cycle. Fig.18 shows that productivity has an important effect on snorkel life. Further improvement both in operation and in facilities is needed in this process.

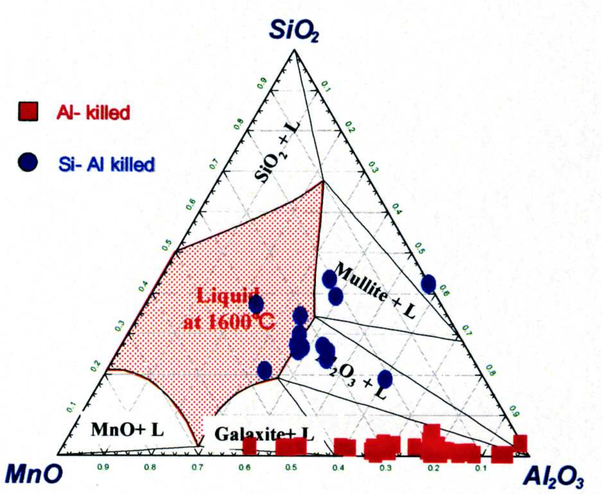

Fig. 18. Comparison of combustion products during oxygen blowing

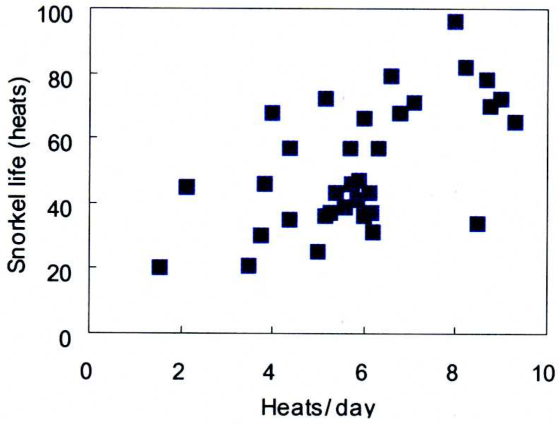

Fig. 19. Effect of productivity on the snorkel life

TABLE
Chemical composition of oxide material attached to lower part of snorkel

Al_2O_3	Fe_{total}	MnO	CaO	SiO_2	MgO	TiO_2
50.0	**21.7**	**13.3**	**4.6**	**0.95**	**1.14**	**0.13**

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