Improvement of steel cleanliness by controlling slag composition

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Abstract

The properties of slag are very important to improve steel cleanliness. Most of all, the value of (%CaO)/(%Al_2O_3), slag basicity, fluidity and Oxygen activity in the slag is considered to affect the steel cleanliness directly. To control these values effectively, the way of deoxidation and slag composition control by additives was changed. And the effect of oxygen content before tapping was investigated. Through the optimizing these factors, the total oxygen content of bearing steel was improved from 12ppm to 8ppm.

1. Introduction

Bearing unit applied to the junction of axis and so on is such a part that it causes the trouble of machinery after a certain lifetime because it received repeated stress. Therefore, it is needed to improve the quality of bearing steel so that it can be used during all the life of machinery. Generally the bearing steel used in most products is mainly composed of high Cr-C system and the bearing steel produced by POSCO is also composed of high Cr-C system as shown in table 1.

The factors affecting the life of bearing steel can be classified as nonmetallic inclusions, segregation etc. and among these factors, the effect of nonmetallic inclusions on bearing steel has been studied especially in the various methods. So from those studies it has been known that the nonmetallic inclusions are acting as the stress concentration point and finally cause the creation and grow up of fatigue crack.

The representative nonmetallic inclusions causing the crack are Al_2O_3, SiO2, TiO_2 etc. Fig. 1-(a)[1] shows that the life of bearing steel decreases with the increase of the sum of Al_2O_3 and SiO2 in the steel.

But as shown in fig. 1-(b), the sulfide, which exists as the form of MnS in the neighborhood of inclusion, decreases the tensile stress due to inclusions with the compressive stress acting itself, so gives the positive effects to the fatigue failure. However, considering general harmful effects caused by the sulfur, its contents should be limited under a proper range.[2]

2. Theoretical background

2-1. The effect of slag composition on the removal of Al_2O_3 inclusion

The main inclusion existing at the bearing steel is Al_2O_3 type, so it is needed to control the slag composition for the removal of Al_2O_3 type inclusion. The absorption ability of slag for Al_2O_3 can be improved by lowering Al_2O_3 activity or the melting temperature of slag to promote mass transport of Al_2O_3.

The range of slag composition satisfying these conditions should be near the binary system of Al_2O_3 and CaO considering the slag composition of bearing steel and reoxidation of molten steel by the SiO_2. If the former is considered to be more important, the proper composition range should be near the CaO saturation region marked as the region A in the figure 2. However, if the latter is considered to be more important the composition should be placed in the region B.

2-2. Reoxidation of molten steel by the low-grade oxide in the slag

As shown in equation (1), the low-grade oxides in the slag like FeO and MnO react with oxidant in the molten steel and create the nonmetallic inclusion.

$$3(FeO) + 2\underline{Al} = (Al_2O_3) + 3\underline{Fe} \qquad (1\text{-a})$$
$$3(MnO) + 2\underline{Al} = (Al_2O_3) + 3\underline{Mn} \qquad (1\text{-b})$$
$$3(SiO_2) + 4\underline{Al} = 2(Al_2O_3) + 3\underline{Si} \qquad (1\text{-c})$$

From the equation (1-a) and (1-b) when the contents of FeO and MnO in slag are high, the nonmetallic inclusions are created, therefore it is essential to decrease the FeO and MnO contents in slag. But as shown in fig. 3, the reoxidation behavior of SiO_2 is different from that of FeO and MnO because Si is stronger oxidant than Fe and Mn and if the basicity of molten slag is controlled over a certain degree, the reoxidation of molten steel by the SiO_2 in slag doesn't happen. Therefore if the slag basicity is controlled over a certain degree, we can prevent the reoxidation of molten steel by the SiO_2.

2-3. Effect of the oxygen content at the blow end of BOF on steel cleanliness

Since the oxygen content in the molten steel at the blow end of BOF is the origin of nonmetallic inclusion, it affects the cleanliness of steel. Therefore, the effect of oxygen content on the steel cleanliness should be considered.

3. Experimental procedure

Table 2 shows the steelmaking process in production of bearing steel at POSCO. As shown in this figure, the process consists of BOF-LF-RH-CC and the operation patterns at the unit process greatly affect the cleanliness of bearing steel. In this study three tests were carried out to remove the nonmetallic inclusion in molten steel. Those are change of deoxidation method, control of slag composition and decrease of oxygen content at the tapping.

3-1. Change of CaO/Al_2O_3 value

Al2O3 absorption ability of slag is different according to the slag composition. If the slag composition is in the CaO saturation region, the activity of Al2O3 inclusion becomes low and then better thermodynamic condition can be acquired. However, the absorption of the inclusion could be worse due to the higher melting temperature. When the slag composition is in the low melting temperature area, the absorption ability is increased but the thermodynamic equilibrium state is deteriorated. The slag composition was in the region of CaO saturation at the conventional method but the composition was change to the low melting temperature area at the improved method as shown at table 2.

CaO was added and small amount of CaF2 was also added to improve slagging rate before arc heating at the ladle furnace in the case of the conventional method. However, in spite of CaF2 addition the slag didn't melt completely and most of slag is solidified after arc heating. In this study to resolve this problem $CaO/\ Al_2O_3$ ratio was controlled from 1.7 to 1.8 by the addition of Al_2O_3 and decrease of CaO.

3-2. Change of deoxidation method at the tapping

As can be seen in the table 3, FeSi, FeMn and Al were added successively at the tapping by the conventional method. In this case, the oxides created during the deoxidation have the composition of SiO_2 and MnO and then when Al is added the oxides are changed to Al_2O_3 due to the difference of the affinity for oxygen. However, the composition of the oxides does not reach the thermodynamic equilibrium state. Therefore, the content of SiO_2 and MnO is higher than that of the thermodynamic equilibrium state and the slag basicity is low and the oxidation degree of slag is high.

As the method to improve the basicity and oxidation degree, Al was added first and then FeMn and FeSi was added. By this method the Al_2O_3 oxides are created first and then only a small part of the oxides are changed to SiO_2 and MnO. Consequently the main composition of the oxides should be Al_2O_3. As a result, the basicity is higher and oxidation degree of slag is lower than the conventional method.

3-3. Decrease of oxygen content at the tapping

As previously mentioned, it is beneficial for the improvement of steel cleanliness to decrease the oxygen content at the tapping because the oxygen at the tapping can be the origin of inclusions. However, when the oxygen content of BOF is decreased, dephosphorization is disturbed. Therefore, hot metal dephosphorization is required. In this study to decrease the oxygen content at the tapping, hot metal dephosphorization was carried out at HMPS(Hot Metal Pretreatment Station).

4. Result and discussion

4-1. The effect of (%CaO)/(% Al_2O_3)

The change of slag composition after RH is shown at fig. 4. By the conventional method the value of (%CaO)/(% SiO_2) (C/A) was widely spread from 2.0 to 4.4 but the C/A value was 1.2~2.0 by the improved method. The value of T.O was minimum at 1.7 regardless of the method. Therefore, in the case of bearing steel the C/A value at 1.7 gives best result to improve the steel cleanliness. The reason is that decrease of slag melting temperature is more efficient than control of slag composition to CaO saturation region.

Fig. 5 shows the comparison of slagmaking between the conventional and the improved methods after arc heating at the ladle furnace facility. As shown in this figure in the case of the conventional method much part of the slag is solidified but in the case of improved method the uniformly melted slag is spread on the top of ladle. Therefore, it can be confirmed that the slag melting temperature was lowered and inclusion absorption ability was increased by the improved method. The T.O could be reduced to 8ppm from 12ppm by the improved method.

4-2. Change of slag composition by the new deoxidation method

The slag compositions of the conventional and the improved method were compared at fig. 6. By the conventional deoxidation method slag basicity was in the range of 3.5~4.5 due to the oxidation of Si and Mn, but the basicity was 4.5~7.0 because Al was oxidized prior to Si and Mn by the improved method.

Fig. 7 shows the relation between slag basicity and T.O in bloom. Though the T.O was slightly decreased following the increase of basicity, slag basicity hardly affected T.O in comparison with other factor such as CaO/ Al_2O_3 ratio. To investigate these phenomena the SiO_2 stable zone was calculated using the bearing steel composition with equation (2). The composition of bearing steel used at the calculation was 0.99wt%C-1.3wt%Cr-0.3wt%Mn and the activity coefficient was calculated from these values.

$$3(SiO_2) + 4\underline{Al} = 2(Al_2O_3) + 3\underline{Si}\ ,\ \ \log K = -6.947 + 47{,}645/T \qquad (2)$$

Fig. 8 shows the result of equation (2). Sol. Al and Si contents of POSCO bearing steel, which are in the square of fig. 8, is 0.02~0.03wt% and 0.02% respectively. In this area if the basicity is more than 4, SiO_2 doesn’t act as an oxygen source. Therefore, the basicity doesn’t affect the steel cleanliness.

4-3. Decrease of oxygen potential at the tapping

As previously mentioned, hot metal dephosphorization was carried at HMPS facility

before BOF operation to minimize the oxygen content at the tapping.
This operation was adapted to both the conventional and the improved methods. Fig. 9 shows the relation between CD (carbon determinant) carbon and T.O in slab because the oxygen content at the end point of BOF couldn't be measured easily and the CD carbon shows very good relation with oxygen content. In the case of the conventional method T.O in slab showed similar value regardless of CD carbon. However, in the case of the improved method the T.O was decreased as the oxygen content was decreased. The relation between T.O in slab and CD carbon is present in equation (3).

$$T.O(ppm) = 11.2-0.0606(CD\ [C]\times 10^{-2} wt\%) \qquad (3)$$

Based on these results the difference between the conventional and the improved method is caused by the slag composition. The slag has a tendency to decrease inclusions in molten steel to a certain level and the time needed to reach at the level depends on the difference between current T.O and equilibrium T.O as shown at equations (4) and (5).

$$dO/dt = -k(O - O_e) \qquad (4)$$

O : present T.O content
k : T.O removal rate constant
O_e : equilibrium T.O at a given slag composition

$$O = (O_i - O_e)(O-O_e)^{-kt} + O_e \qquad (5)$$

O_i : initial T.O

From the equation (5), the time needed to reach at equilibrium T.O (equilibrium time) decreases when the initial T.O is low or equilibrium T.O is high. In the case of the conventional operation the equilibrium time is shorter than the steelmaking time regardless of initial T.O because the equilibrium T.O is high. However, in the case of the improved method the equilibrium time is longer than the steelmaking time because the equilibrium T.O is low. Therefore, when the CD carbon is low, the initial T.O becomes low and as a result effectiveness by the CD carbon is achieved.
In this study the O_e and k of the slag composition couldn't be calculated because the steelmaking process consists of some unit operation.

4-4. Key factors affecting the inclusion removal
Considering all the data, the C/A value affected steel cleanliness at every test. And the oxygen content affected the cleanliness selectively when the C/A value is lowered. Therefore, the C/A value should be controlled first to the proper range and then the initial T.O should be lowered.

5. Conclusions

1) The basicity of top slag does not affect the steel cleanliness on the removal of the inclusion in the bearing steel of which composition is 0.99wt%-1.3wt%Cr-0.3wt%Mn when the basicity is over 4 because SiO_2 is stable and does not react as an oxygen source.

2) The control of C/A is the most efficient method to remove the inclusions in bearing steel and the C/A value was most effective at 1.7~1.8. From this method the T.O could be reduced to 5~8ppm from 1~12ppm.

3) As the oxygen content at the tapping is decreased, the T.O of the bearing steel is decreased. However, when the C/A value is over 2.0 there is no substantial effect of oxygen content at the tapping since the equilibrium T.O is too high to reach equilibrium state within the steelmaking time.

6. References

1) Johnson, R. F. and Sewel, J. JISI, December, 1960, p.414
2) Brooksbank, D. and Andrews, K. W. JISI, December, 1972, p.246
3) Y. Fukuzaki et al, Steelmaking conference proceedings, 1992, p.397

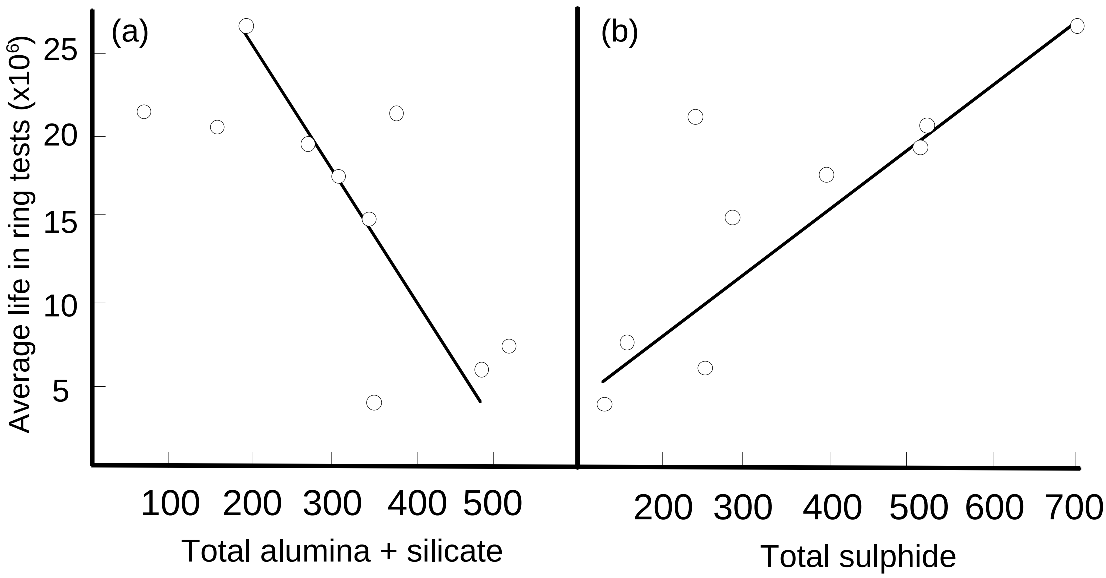


Fig. 1. Relationship between average life and inclusion content : counts based on total inclusions observed (×750) in 516 fields representing a total area of 9 .e

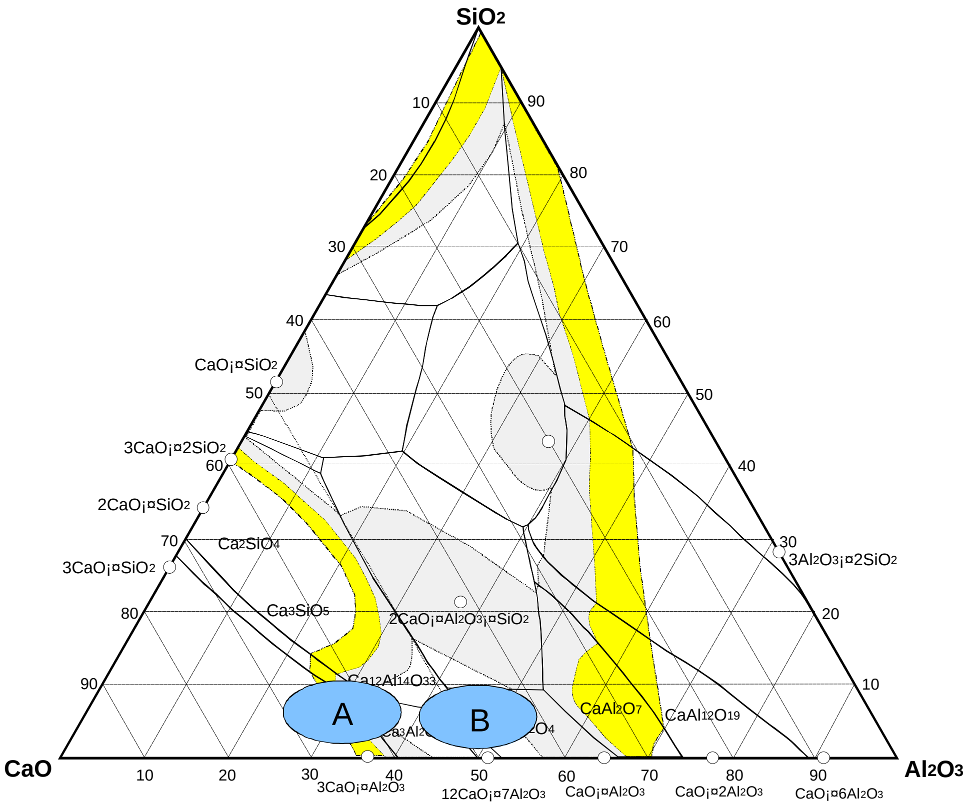


Fig. 2. Control of slag composition at bearing steel.

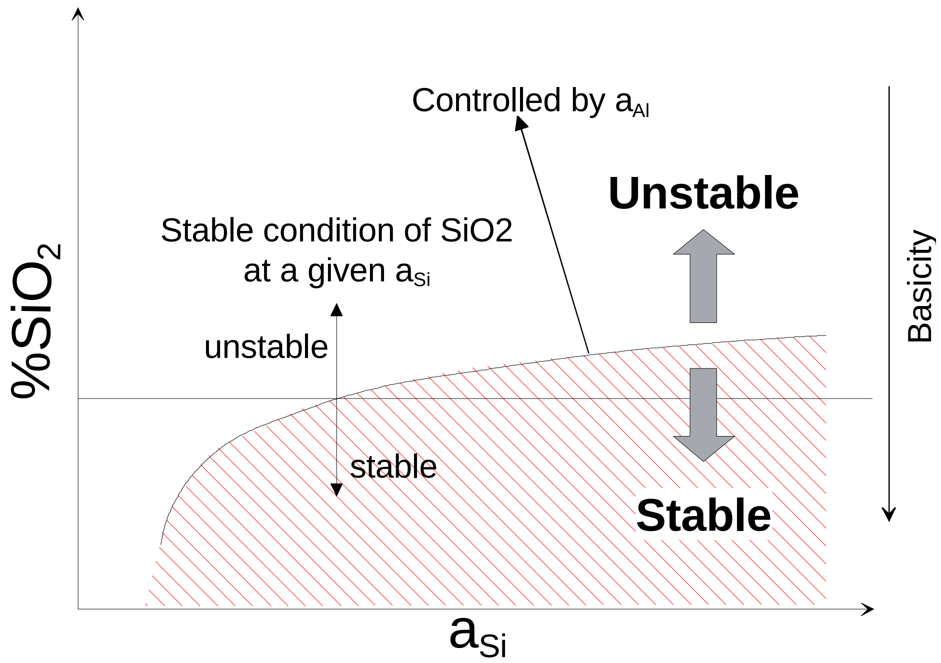


Fig. 3. Effect of slag basicity on the total oxygen contents in steel.

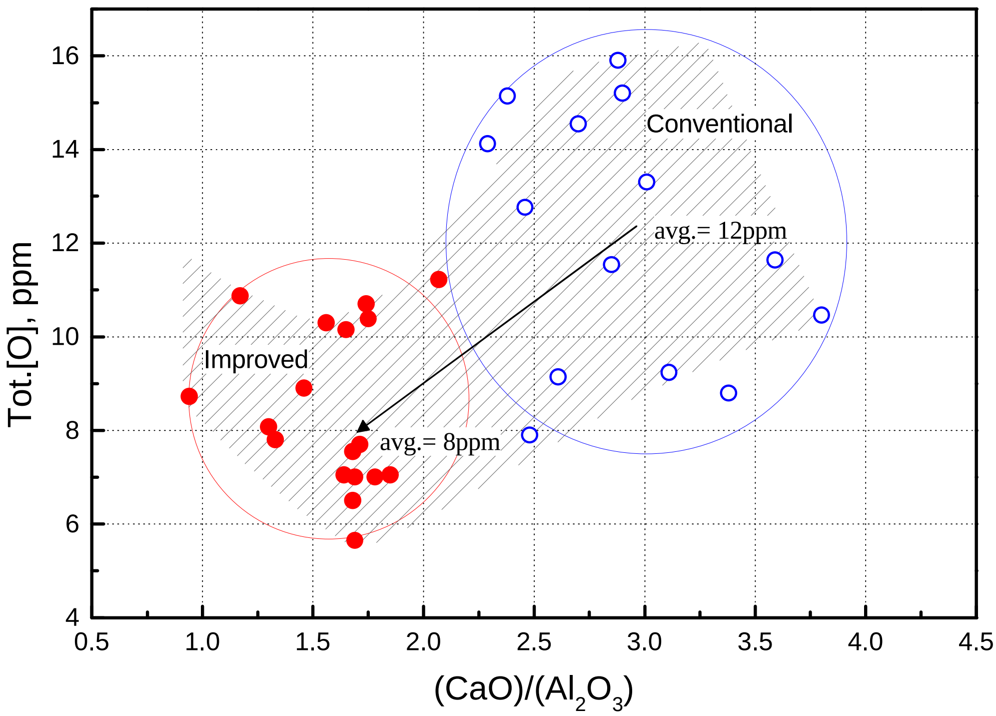
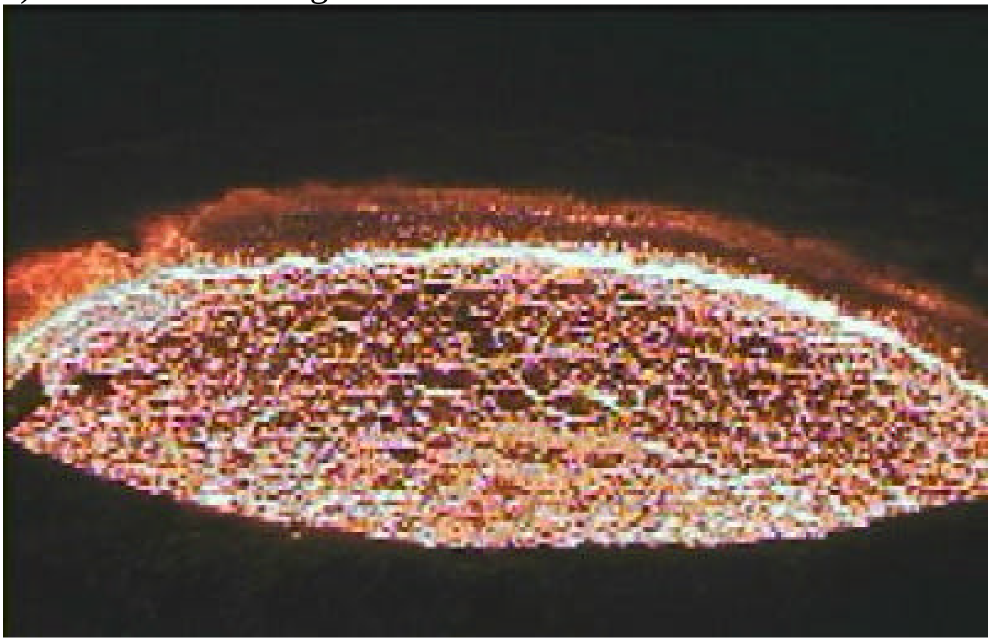


Fig. 4 Comparison T.[O] between the improbed and the conventional method at Bloom.

a) Nonfluid ladle slags : conventional method.



b) Fluid ladle slags : improved method.

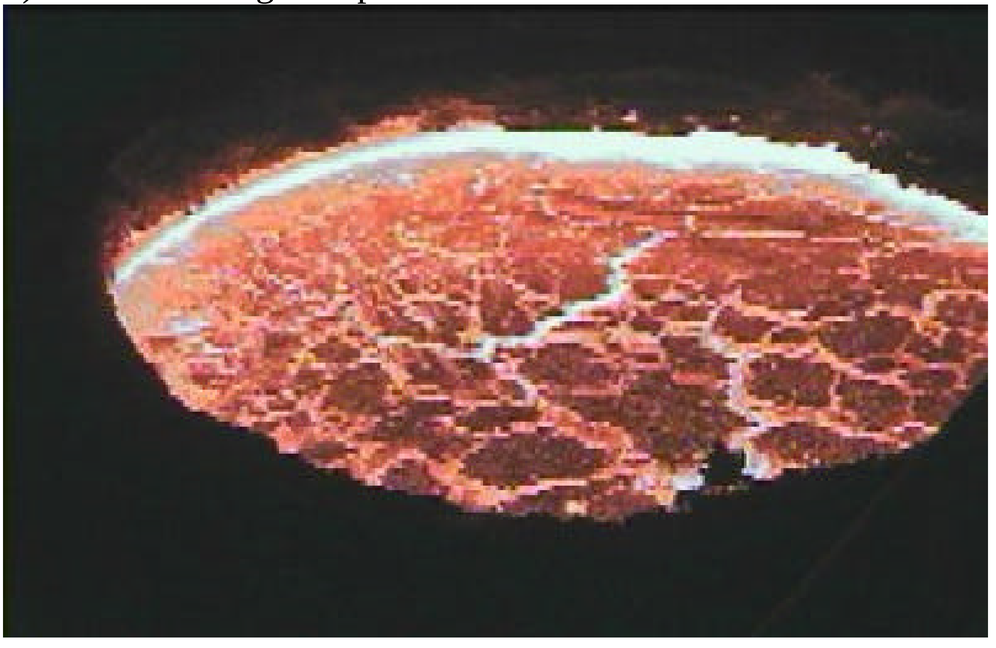


Fig. 5. Comparison of slag state after LF treatment.

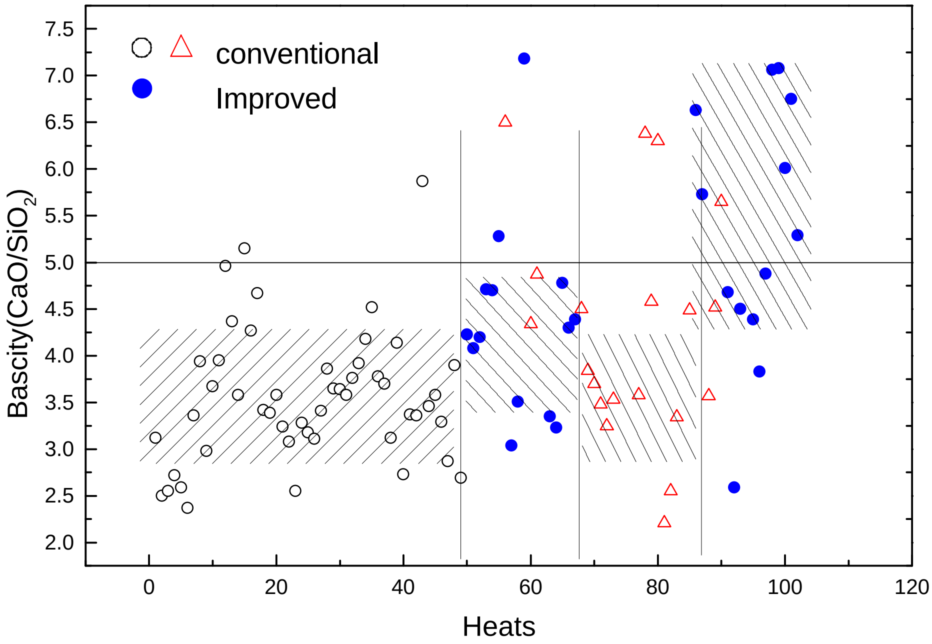


Fig. 6. Change of slag basiciy by improving deoxidation method and slag control.

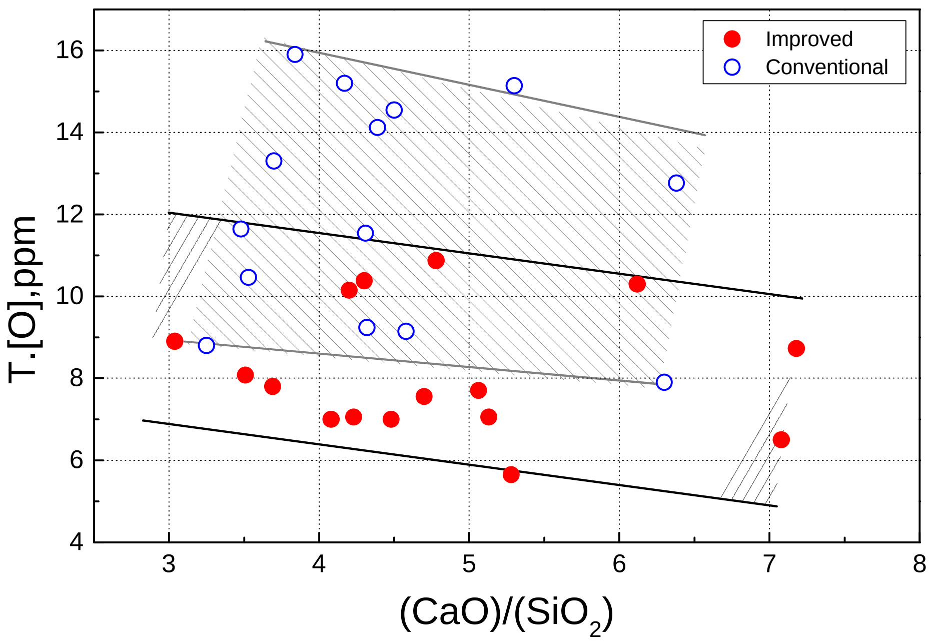


Fig. 7. Relationship between slag basicity and T.[O] of bloom.

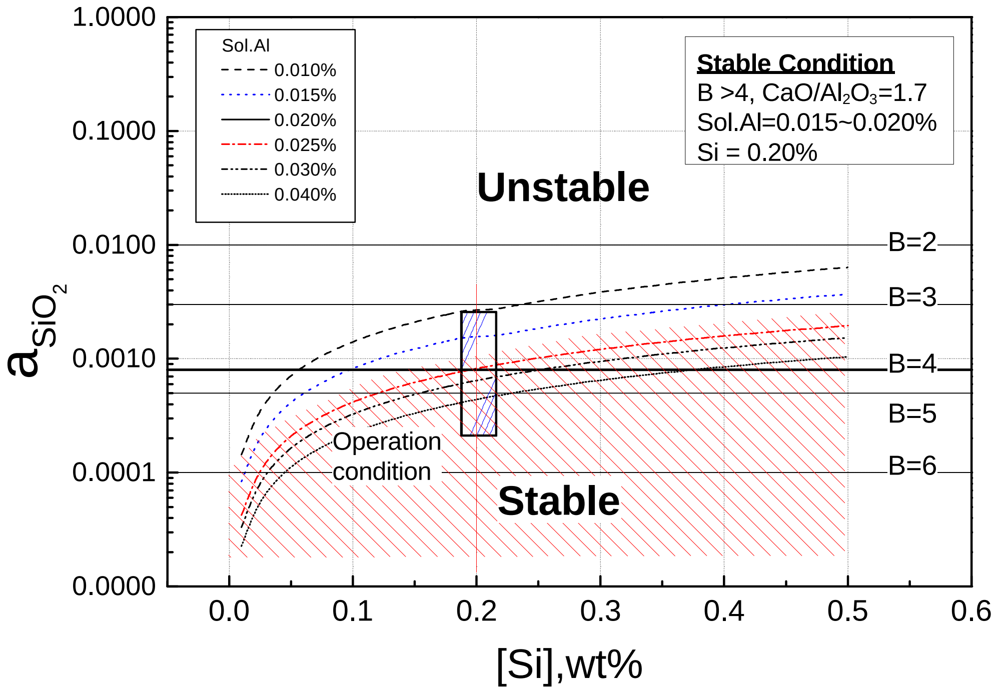


Fig. 8. Stable condition of a_{SiO2} in ladle slag at bearing steel production.

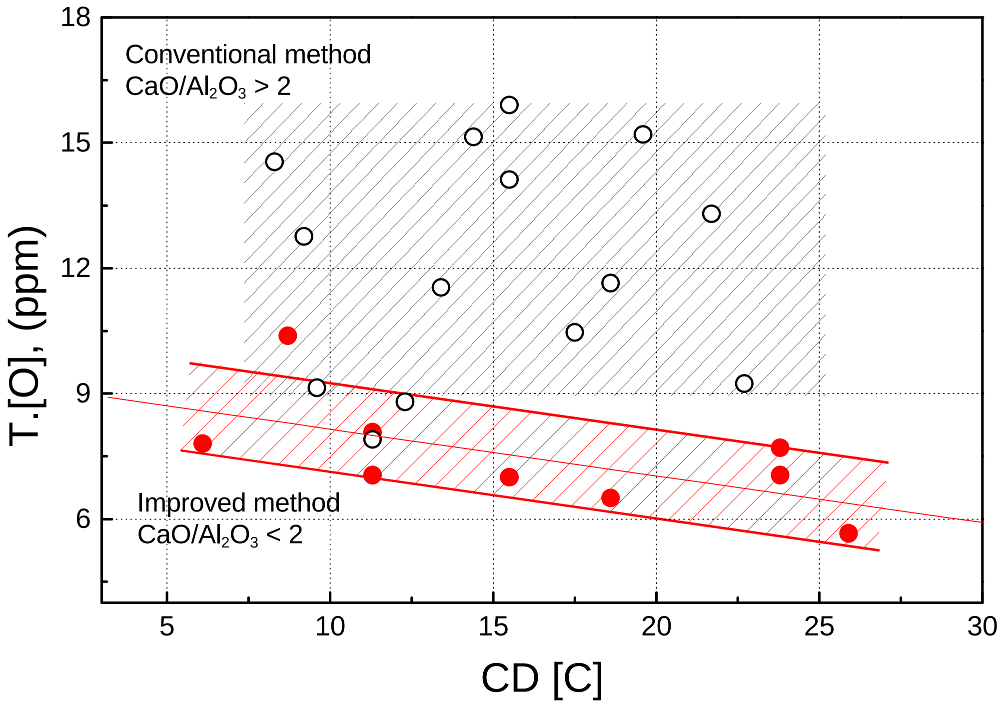


Fig. 9. Relationship between blow end CD [C] and T.[O] of bloom.

Table 1. The composition of bearing steel

Standard	Grade	Composition(wt%)					
		C	Si	Mn	P	S	Cr
J	SUJ1	0.95 1.10	0.15 0.35	<0.50	<0.025	<0.025	0.90 1.20
I	SUJ2	0.95 1.10	0.15 0.35	<0.50	<0.025	<0.025	1.30 1.60
S	SUJ3	0.95 1.10	0.40 0.70	0.90 1.15	<0.025	<0.025	0.90 1.20

Table 2. Change of characteristic temperatures

	Softening temp.	Melting temp.	Fluidizing temp.
Conventional	1468	1505	>1510
Improved	1347	1349	1368
Difference	121	156	142

Table 3. Comparison between the conventional and the Improved method

Conventional	Process	Improved
Deoxidation order : FeSi, FeMn, Al	Tapping 1. Deoxidation 2. Slagmaking	Deoxidation order Al, FeMn, FeSi
Arc heating CaO, CaF_2 addition	LF 1. Temperature adjustment 2. Slagmaking 3. Inclustion removal	Arc heating CaO, Al_2O_3 addition
Circulation : 25min	RH 1. Inclusion removal	Circulation : 25min
Bloom Casting	Continuous casting	Bloom Casting