Analysis of Technologies for Improving Steel Purity by Controlling Slag Content

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Abstract: This article analyzes the composition and reactions of slag formed during steel melting, as well as the influence of liquid slag on the quality of cast products. The importance of using slag-forming fluxes and accelerating the oxidation process of elements in the process of melting the alloy is mentioned. By adding flux to the liquid metal, the slag was completely separated from the liquid metal by accelerating the formation process. In addition, the quality of cast products was improved by separating them from the liquid metal, since the addition of slag during the process of pouring liquid metal into the ladle and casting mold affects the quality of the casting.

1 INTRODUCTION

Improving the quality of steel requires the reduction of harmful elements, mirrors and gas pores in its composition, as well as the prevention of liquid metal fluidity and the formation of cracks, as well as obtaining high-quality cast products. Improved quality of bulk products ensures long – term use. Generally, the steels used in most products have a high Cr – C system content, and the steel grades produced by the researchers are no exception, can be seen in the table 1. Factors affecting the service life of steel are: non-metallic inclusions, segregation, etc. Among these factors, the effect of non-metallic additives on steels has been studied using various methods (Saidmakhamadov, 2024; Patrik, 1997; Kholmirzaev et al., 2023; Nodir et al., 2021). In these studies, non-metallic inclusions play the role of fatigue concentration points and finally lead to the initiation and growth of fatigue cracks (Saidmakhamadov, 2024). Non – metallic inclusions such as Al_2O_3, SiO_2, TiO_2, etc. can cause the casting to crack. As shown in Fig. 1 – a, Al_2O_3 and SiO_2 additions in steel reduced the service life of the bearing steel. At the same time, the sulfide present in the form of MnS as inclusions reduced the strength of the casting due to the inclusions and therefore negatively affected the working time of the part (see Fig. 1. b). However, taking into account the general harmful effects of sulfur, its presence in steel should be limited to an appropriate range (Nosir & Bokhodir, 2023; Kholmirzaev et al., 2024a).

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2 MATERIALS AND METHODS

Thefore, it is necessary to control the slag content to remove Al_2O_3 inclusions from steel. The adsorption capacity of slag for Al_2O_3 can be improved by reducing the activity of Al_2O_3 or the melting temperature of the slag, which contributed to the mass transport of Al_2O_3 (Kholmirzaev, 2023; Nodir v et al., 2022; Tursunbaev et al., 2023; Tursunbaev et al., 2024; Kholmirzaev et al., 2024b).

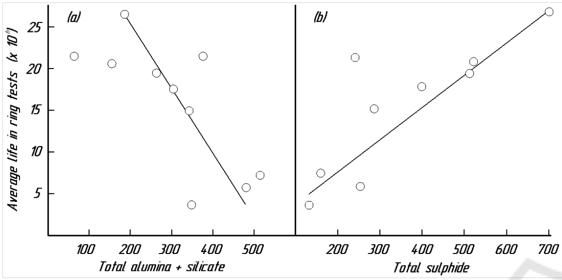

Figure 1: Correlation between mean lifetime and inclusion content: calculations based on total inclusions (x 750) observed in 516 fields with a total area of ~9 mm^2.

The slag composition range satisfying these conditions should be close to the Al2O3 – CaO binary system. The composition of the slag used with steel must also take into account the re – oxidation of the steel being liquefied by the SiO2 in the slag. If the former is considered more important, the relevant composition range should be close to the saturation region of CaO, marked as region A in Fig. 2. However, if the latter is considered more important, the composition should be located in region B. The chemical composition of the tested steels as a sample is presented in Table 1.

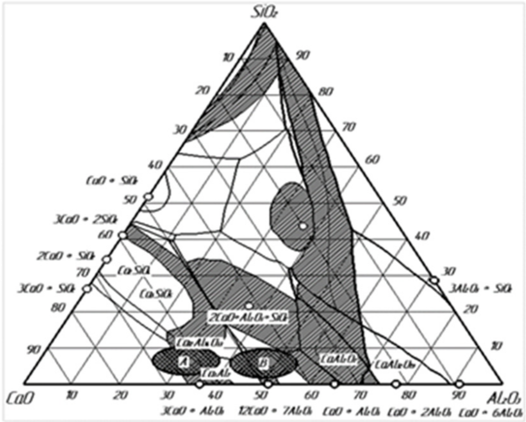

Figure 2: Control of slag content of steel.

Reoxidation of molten steel with low oxide in slag

As shown in the following equations, low-grade oxides such as FeO and MnO in the slag reacted with the oxide former in the molten steel to form non-metallic inclusions.

$$3(FeO) + 2\underline{Al} = (Al_2O_3) + 3\underline{Fe} \quad 1\ a$$

$$3(MnO) + 2\underline{Al} = (Al_2O_3) + 3\underline{Mn} \quad 1\ b$$

$$3(SiO_2) + 4\underline{Al} = 2\ (Al_2O_3) + 3\underline{Si} \quad 1\ c$$

From the equations (1 a) and (1 b), when the amount of FeO and MnO in the slag is high, non – metallic inclusions are formed, so it is very important to reduce the content of FeO and MnO in the slag. However, as shown in Figure 3, the reoxidation behavior of SiO_2 is different from that of FeO and MnO because Si is a stronger oxidizing element than Fe and Mn. Consequently, if the basicity of the molten slag is controlled to some extent, reoxidation of the molten steel by SiO_2 in the slag does not occur and can therefore be prevented by controlling the slag composition.

Table 1: Chemical composition of steel, weight – %.

Standard/grade	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

Effect of oxygen content at end of blow in BOF on steel cleanliness. Since blowing in BOF (basic oxygen furnace) reduces the amount of oxygen in the molten steel from the formation of non – metallic inclusions, it affects the purity of the steel and should therefore be taken into account. Table 2 shows the production process of bearing steel in an electric arc furnace. The process consists of BOF – ladle furnace -RH degassing – continuous casting, and the operation schemes of the technological units greatly affected the purity of the bearing steel. In this study, the following three tests were conducted to remove non – metallic inclusions from molten steel: changing the deoxidation method, controlling the slag composition, and using the oxygen content efficiently.

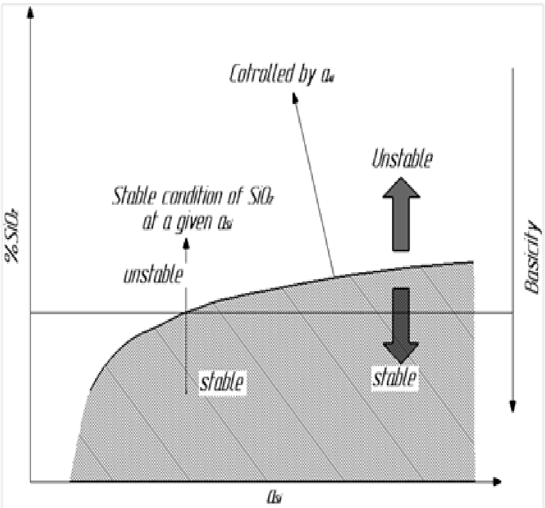

Figure 3: Effect of slag base on SiO_2 and total oxygen content of steel.

Table 2: Comparison of traditional and improved methods.

Process	Traditional	Improved
Chemical process		
Oxidation	Oxidizing order: FeSi, FeMn, Al	Oxidizing order: Al, FeMn, FeSi
Slag formation		
Electric arc furnace		
Temperature control	Heating the furnace	Heating the furnace
Slag formation	Addition of CaO, CaF_2	Addition of CaO, Al_2O_3
Remove attachments		
Degassing	Usage: 25 min	Usage: 25 min
Remove attachments		
Continuous pouring	Cast formation	Cast formation

Change of CaO/Al_2O_3 value**.** Al_2O_3 absorption capacity of slag changed depending on its composition. If the slag composition is saturated with CaO, the activity of Al_2O_3 additions decreases, and thus improved thermodynamic conditions have appeared. However, additives may be less effective due to higher melting temperatures. When the slag composition is at a low melting temperature, the absorption capacity is increased, but the thermodynamic equilibrium condition is worsened.

In the traditional method, the slag composition was in the CaO saturation region, but the improved method changed the composition to the low melting temperature region, as shown in Table 3. In the traditional method, before heating the arc in a slag furnace, CaO and a small amount of CaF_2 are added to accelerate the slag formation process. However, despite the addition of CaF_2, the slag was not completely melted and most of the slag solidified after arc heating. In this study, in order to solve this problem, the following ratio was controlled between 1 · 7 and 1 · 8 by slightly increasing the addition of %CaO/%Al_2O_3 and decreasing the addition of CaO.

Change the oxidation method. In the traditional method, FeSi, FeMn and Al were added sequentially during the charge loading (see Table 2). In this case, the oxides are 3(MnO) + 2Al = (The oxides formed during the oxidation of Al were SiO_2 and MnO, but when Al was added, the oxides changed to Al_2O_3 due to the closeness of Al to oxygen. However, the composition of the oxides did not reach the state of thermodynamic equilibrium.

Therefore, the composition of SiO_2 and MnO higher than the thermodynamic equilibrium state and the slag alkalinity was low and the slag oxidation level was high. Al, then FeMn and FeSi were added in the new method to improve the basis and degree of oxidation. By reversing the addition order, Al_2O_3 oxides are formed first and then only a small fraction of the oxide composition should be Al_2O_3. As a result, the basicity is higher and the oxidation level of the slag is lower than in the traditional method.

A decrease in the amount of oxygen during infusion. Reducing the amount of oxygen in the liquid metal during casting to improve steel purity has reduced gas voids in the casting. Because it can be the main source of additives. However, when the amount of oxygen decreased, the dephosphorylation process was disrupted.

Therefore, liquid metal dephosphorization was required. In this study, liquid metal dephosphorization was performed in a liquid metal pretreatment station, before the BOF (basic oxygen furnace) operation, to reduce the oxygen content during casting.

Table 3: Temperature change.

	Softening temperature	Melting temperature	Liquefaction temperature
Traditional ^{0}C	1468	1505	>1510
Improved ^{0}C	1347	1349	1368
Difference, K	121	156	~142

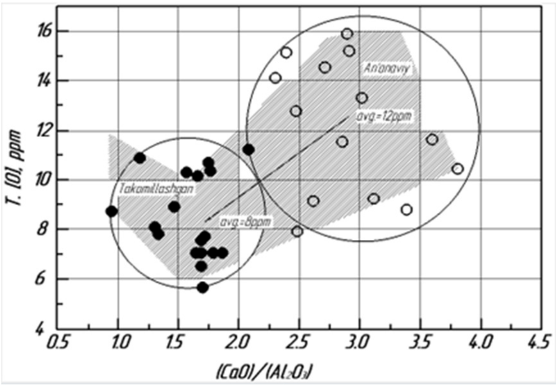

Figure 4: Comparison of total oxygen T.[O] between improved and conventional methods of liquefaction.

3 RESULTS AND DISCUSSION

Effect of $\%CaO/\%Al_2O_3$ ratio on casting quality. The change in slag composition after RH degassing is shown in Figure 4. The $\%CaO/\%Al_2O_3$ (C/A) value in the conventional method was 2 · 0 to 4 · 4, but the C/A ratio was 1 · 2 to 2 · 0 in the improved method. Total oxygen value was minimum at C/A=1 · 7 regardless of T. [O] method. Therefore, in steels, a C/A ratio of 1 · 7 gave the best results for improving steel purity. This is because lowering the slag melting temperature is more effective than controlling the slag composition to reach the CaO saturated region. Figure 15 shows a comparison of slag formation between conventional and improved methods after arc heating in an electric arc furnace. As shown in this picture, in the traditional method, most of the slag is solidified, but in the improved method, the molten slag is spread uniformly over the top of the furnace.

During operation (cycling and storage) LIA the most significant changes occur on electrodes made of lithium-manganese spinals.

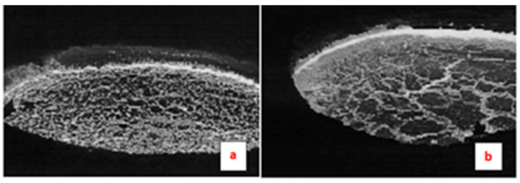

Figure 5: Comparison of slag condition after treatment in an electric arc furnace. a) solid slag, traditional method; b) liquid slag, improved method.

Therefore, it can be confirmed that the melting temperature of the slag has decreased and as a result, the absorption capacity of the inclusion has increased with the improved method.

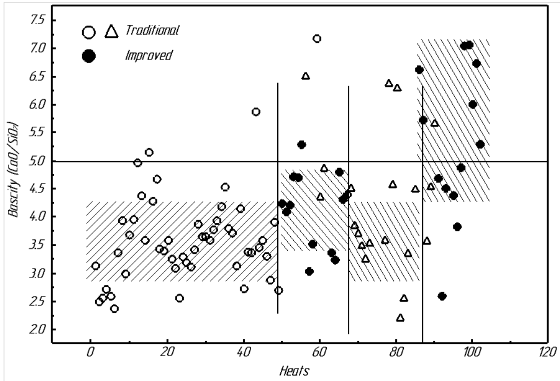

Figure 6: Modifying slag basicity by improving reoxidation method and slag control.

Total oxygen T.O can be reduced from 12 to 8 ppm using the improved method over the conventional method (see Figure 4).

Changing the composition of slag with a new reoxidation method. The slag composition of traditional and improved methods can be compared in Figure 6. In the conventional reoxidation process, the slag basicity was in the range of 3 ·5 – 4 · 5 due to oxidation of Si and Mn, but in the improved method, the basicity was 4 · 5 – 7 · 0 because Al was oxidized before Si and Mn. Figure 7 shows the relationship between slag basicity and T.[O] for solidification. Although T.[O] decreased slightly after increasing basicity, slag basicity had little effect on T.[O] compared to other factors such as C/A ratio.

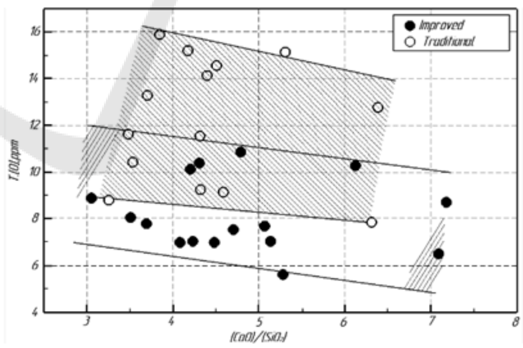

Figure 7: Rectangle.

To investigate these processes, the SiO_2 stability zone was calculated using the bearing steel composition with the following equations.

$$3(SiO_2) + 4Al = 2(Al_2O_3) + 3Si \quad (2\text{ a})$$

$$\log K = -6 \cdot 947 + 47645/T \quad (2\text{ b})$$

Calculation – the composition of the steel used in the books is 0 · 99C – 0 · 3Mn – 1 · 3Cr (wt – %) and

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the activity coefficient was calculated from these values: the results are shown in figure 1.7. The soluble Al and Si content of steel, i.e. 0 ·02 – 0 · 03 wt – % and 0 · 20 wt – %, respectively, fall into the rectangle shown in Fig. 7. In this area, if the basicity is greater than 4, SiO_2 does not act as an oxygen source. Therefore, basicity does not affect the purity of steel.

4 CONCLUSIONS

1. When removing inclusions from bearing steel containing (wt. – %) 0 · 99C – 0 · 3Mn – 1 · 3Cr with a slag basicity higher than 4, steel purity is not affected because SiO_2 is stable and oxygen does not act as a source.
2. Controlling the $\%CaO/\%Al_2O_3$ ratio is the most effective method for removing inclusions from bearing steels, and its value was most effective at 1 · 7 – 1 · 8. Using this method, total oxygen T.[O] can be reduced from 10 – 12 ppm to 5 – 8 ppm.
3. T.[O] of the bearing steel is reduced due to the reduction of oxygen content due to the moving contact of the liquid metal during casting. However, when $\%CaO/\%Al_2O_3 > 2 \cdot 0$, the amount of oxygen at impact does not have a significant effect because the equilibrium T.[O] is too high to reach equilibrium during steelmaking.

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