China Steel Technical Report, No. 32, pp.8－11, (2019)

Development of High-Efficiency Melting Technology for Recycling Desulfurization Slag in an Electric Arc Furnace

YU-LUN HUANG, MING-HUI TSENG and YUNG-LIN CHIU

Metallurgical Department,
Dragon Steel Corporation

With the rising awareness of environmental protection, CSC Group has been committed to recycling steelmaking slag in recent years. Desulfurization slag is one kind of the steelmaking slag which is produced from the BOF pre-desulfurization treatment process. Dragon Steel Corporation is responsible for recycling CSC group's desulfurization slag by use of the electric arc furnace (EAF). However, recovering the desulfurization slag by the EAF shows low efficiency, such as low iron recovery and high energy consumption. A modified steelmaking process and scrap-added technology have been developed to improve the melting efficiency of the desulfurization slag when immersed in the liquid steelmaking slag, and the results also show higher efficiency of dephosphorization. It also shows that the T.Fe in the slag is reduced from 22.4% to 16.1%, and the amount of slag is reduced from 20.1% to 14.9%. The results showed a significant increase in yield, increasing from approximately 85.7% to 90.2%. The estimated benefit growth is more than NT$600 million per year.

Keywords: Recycled Slag, Electric Arc Furnace, Recovery, Dephosphorization, Steelmaking

1. INTRODUCTION

The modern electric arc furnace (EAF) steelmaking process uses high voltage and the long arc operation[1,2]. It mainly uses scrap as raw material and alloy to adjust chemical composition. It is primarily used to produce high quality structural steel, tool steel and alloy steel. The main processes of the electric arc furnace includes melting, heating, dephosphorization and decarburization, and the remaining refining tasks are moved to a secondary refining process to accelerate the steelmaking efficiency. The early stage of this process is the melting period where the high temperature arc generated by the electrodes gradually melts the scrap, oxygen is then blown for the melting and decarburization reaction, and then carbon injection is performed at an appropriate timing to form the foaming slag. After the scrap is completely melted, it continues the refining period where the dephosphorization reaction of the component is controlled and adjustment of the molten steel to a desired temperature are mainly performed. In addition to the scrap and raw materials used in the electric furnace in Dragon Steel Corporation (DSC) it also contains molten iron, and the proportion of this addition is about 30~55%.

Besides, in order to protect the environment by reusing the by-product produced in the steelmaking process. DSC recycles the desulfurization slag as raw material, and puts it back into the electric furnace again for smelting to recover the iron in the slag and re-use CaO as a dephosphorization agent. The desulfurization slag is a by-product of the desulfurization steelmaking process. It is mainly composed of a mixture of slag and iron randomly interlaced. The melting point of the slag phase is higher than 1900°C according to the composition, and the melting point of the iron phase is about 1200°C. With respect to the operation temperature in an EAF of 1500~1650°C, it takes a lot of electrical energy to increase the temperature of the molten steel to melt the slag. Therefore, the high melting point of the slag phase is the primary object that must be overcome to improve the melting efficiency of the slag. Figure 1 shows the temperature simulation results of steel balls and slag balls placed in molten iron at 1400°C. The steel balls can reach the temperature of the molten iron in about ten minutes. But even if the slag balls are in place for 30 minutes, the temperature of the slag is still lower than 1200°C, which shows that the heat transfer efficiency of the slag is extremely poor, and so is not easy to melt. Therefore, it is known that the heat transfer of the recovered slag iron is very poor, and cannot be handled by means of accelerated heat transfer. One of the strategies is to change the melting point of the recovered slag iron.

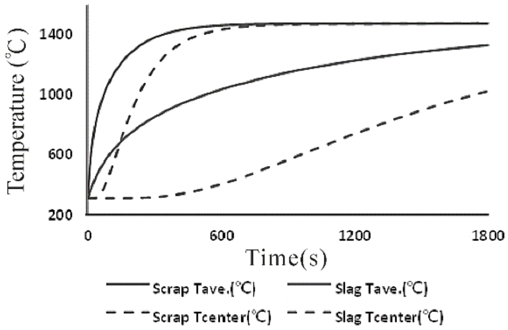

Fig.1. The temperature simulation of steel balls and slag balls immersed in molten iron at 1400°C

2. EXPERIMENTAL METHOD

2.1 Thermophysical properties analysis

In order to find a countermeasure to improve the melting efficiency of the desulfurization slag, a numerical simulation was carried out using Fluent to study the heat transfer coefficient of the slag. In the simulation, a scrap ball and a slag ball, with initial conditions were set as 20 cm in diameter and 40°C, were respectively immersed in 1400°C molten iron. Figure 1 shows the average and center temperature curve of the slag and the scrap. The solid red line is the average temperature of the slag, the red dotted line is the center temperature of the slag, the solid blue line is the average temperature of the scrap, and the blue dotted line is the center temperature of the scrap.

As the results show, the temperature of the scrap ball can be balanced with the temperature of the molten iron in about 10 minutes. However, after the slag ball has been immersed in the molten iron for 30 minutes, the average and center temperature were only about 1200°C and 900°C, respectively. The temperature is much lower than the melting point of the slag. It is concluded that the heat transfer of slag is much slower than that of scrap, which means that the efficiency of preheating of the slag is relatively lower.

2.2 Melting mechanism

An experiment on the melting behavior of scrap[3] was carried out for this research. A low carbon steel (LCS) ball with a melting point of about 1530°C was immersed in molten iron with a carbon concentration of 3% but at a different temperature. The relationship between the size of the ball and time is shown as Fig.2. Under the condition that the molten iron temperature was 1600°C, the melting rate of the steel ball was 30 mm/min because the environment temperature was higher than the melting point of the LCS ball. However, under the condition of a molten iron temperature of 1450°C, even though the environment temperature was lower than the melting point of the LCS ball, the surface of the LCS ball still continued to melt layer by layer due to the decrease in the melting point of the surface. The decrease came from the diffusion of carbon in the molten iron, which motivated the melting speed to 5 mm/min. Finally, under the condition of a molten iron temperature of 1300°C, the environment temperature was much lower than the melting point of the LCS ball. Carbon in the molten iron diffused to the surface of the LCS ball for a long time Figure 2 shows the dimensional changes of a low carbon steel ball immersed in molten iron at different temperatures over 5 minutes, and the melting point of the surface of the LCS ball dropped to a value less than the temperature of the molten iron. So the melting rate of the steel ball was 0.3 mm/min under gradual melting. The result of this experiment revealed that the melting point of the new component lowered by changing the composition of the material surface could effectively improve the efficiency for melting of the substance. As a result, the chemical method for lowering the melting point by slagging is an effective way, rather than the traditional physical method of increasing the temperature be elevating electric energy.

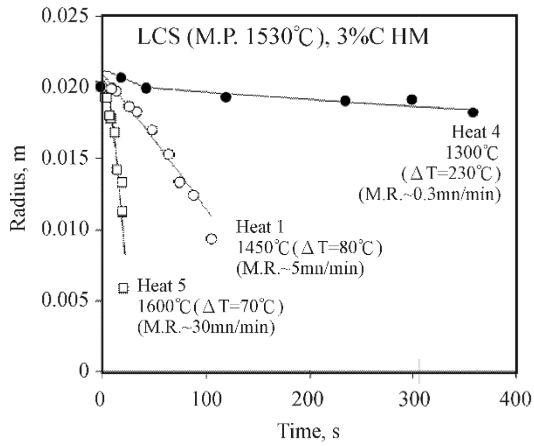

Fig.2. Melting rate of a low carbon steel ball

2.3 Strategy of increasing melting efficiency

From the these experiments, the factors that really affect the melting efficiency are the melting point of the substance, not the heat transfer efficiency. Therefore, the focus of the research strategy is to deal with the melting point of the slag. According to the ternary phase diagram of the slag in figure 3, the composition can effectively change the melting point of the slag, especially the ratio of FeO in the slag. Therefore, the focus of this study is to improve the slagging effect and reduce the melting point of slag to enhance the melting efficiency. The countermeasure for improving the slagging effect is to control the slag when it remains in a liquid state and to effectively increase the reaction probability by the adding of slag as a raw material to the forming slag in the EAF.

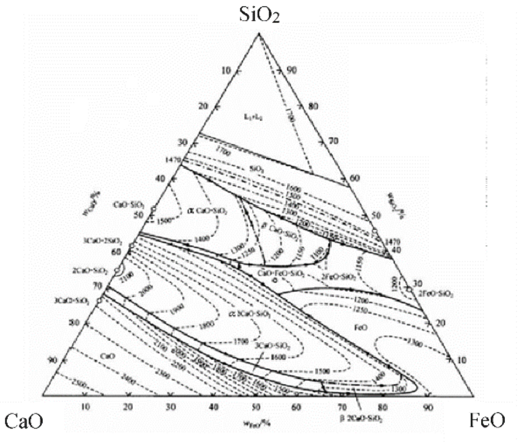

Fig.3. The ternary phase diagram of the slag

The blowing pattern of the EAF was adjusted to control the slag formation process for this study. A modified appropriate blowing pattern was developed at the beginning of the process. Thereby the increment of FeO in the EAF slag can make the melting point of the slag decrease to keep it in a liquid state, and promote the slagging reaction in contact with the adding of recycled slag. Figure 4 is the predicted carbon content in the molten steel and the change of total Fe (T.Fe) in the EAF slag. The initial increasing FeO can also increase dephosphorization efficiency.

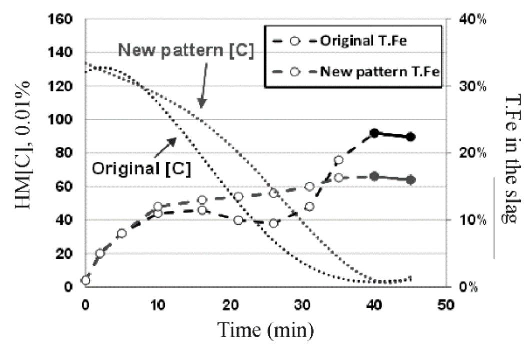

Fig.4. Comparison of original and new pattern

In addition, it is not necessary to deliberately increase the proportion of FeO during the refining period to ensure dephosphorization efficiency. It helps to increase productivity because the original mode is excessive peroxidation. It will cause more iron to enter the slag and cause a drop in recovery. The peroxidation of the molten steel in the new blowing pattern is lowered, so that not only the recovery rate is increased, but also the total slag amount is simultaneously lowered.

3. RESULTS AND DISCUSSION

3.1 The improvement of yield

Due to the modified blowing pattern, the T.Fe in the slag is reduced from 22.4% to 16.1%, and the amount of slag is reduced from 20.1% to 14.9%. The reduction in the amount of slag and T.Fe in the slag show the lower iron loss. Not only is the reduction in T.Fe in the slag, but the yield of desulfurized slag iron is increased from 30% to 70%, both of which contribute significantly to total yield. Figure 5 shows a significant yield increase from approximately 85.7% to 90.2%. The initial estimate of the increase in yield is more than 600 million NTD per year.

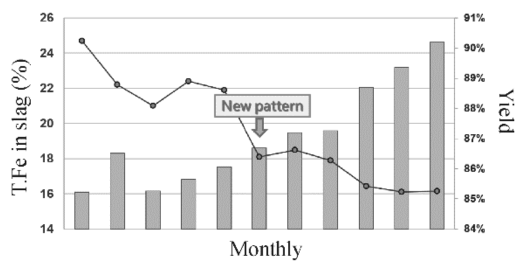

Fig.5. Monthly yield of DSC EAF

3.2 Dephosphorization efficiency

The modified blowing pattern controls the lower T.Fe in the slag at the end stage of the smelting process (refining period) to reduce the peroxidation of the molten steel. So that the yield improves naturally, but the slag of lower T.Fe is theoretically detrimental to dephosphorization. However, the modified blowing pattern which deliberately increases T.Fe in the slag during the initial stage of the smelting process is helpful for dephosphorization. Therefore, the final result indicates that it does not affect the overall dephosphorization efficiency.

Figure 6 shows the results of the EAF heats before and after the change of the blowing pattern. The horizontal axis in the figure is the T.Fe in the slag, and the vertical axis is the final phosphorus in the molten steel. The Steel grade of DSC EAF products are usually targeted at 0.02% of final phosphorus. The final results of the EAF heats are divided into three zones: (I) high phosphorus zone, (II) high-efficiency zone and (III) peroxidation zone. The T.Fe in the slag is less than 20% in zone (I) and (II), which represents a higher yield of steel, but the lower T.Fe may cause lower dephosphorization efficiency more easily. Some of those heats' final phosphorus content will more than the limit (0.02%), such as zone (I). The zone (III) is a lower yield area because of the high T.Fe in the slag. The operation target is to increase the heats number proportion of the (II) zone: high-efficiency zone. The results show that the modified blowing pattern helps to increase the heats proportion of zone (II) from 24.8% to 83.8%. The area (I) where phosphorus is over limit decreased from 5.9% to 0.6%. It shows that in addition to the high yield, the modified blowing pattern can also takes into account the dephosphorization efficiency.

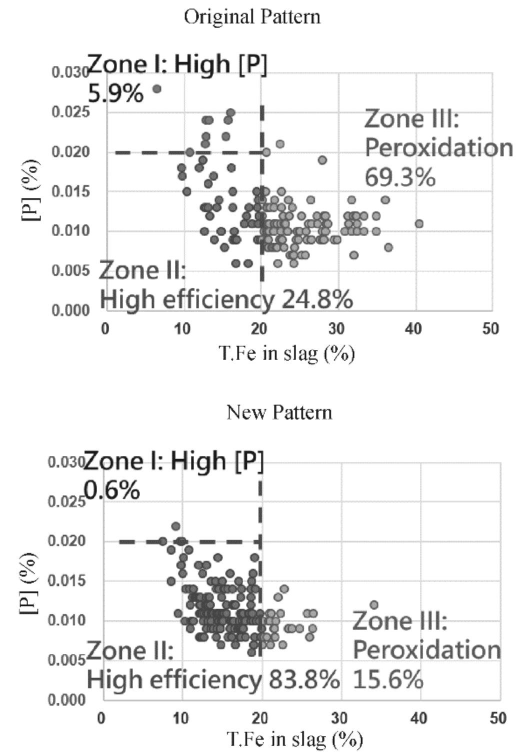

Fig.6. The results between the original and modified blowing pattern

4. CONCLUSIONS

In order to protect the environment by reusing the by-product produced in the steelmaking process, DSC developed environment-friendly processes for slag recycling. A modified appropriate blowing pattern was developed to promote the slagging of the recycled slag in the early stage and improved the melting efficiency. Due to the modified blowing pattern, T.Fe in the slag is reduced from 22.4% to 16.1%. It also reduces the amount of slag. The reduction in the amount of slag and T.Fe in the slag show the lower iron loss. The results show a significant yield increase from approximately 85.7% to 90.2%. The initial estimate of the increase in yield is more than 600 million NTD per year. In addition, it also take into account the dephosphorization efficiency.

REFERENCES

1. Cobb, H. M., Dictionary of Metals, Appendix I: Metals History Timeline, ASM International, Materials Park, OH, USA, 304 (2012).
2. Lüngen, H. B.; Peters, M.; Schmöle, P., Measures to Increase Efficiency and to Reduce CO_2 Emissions in Iron and Steelmaking in Germany and Europe. AISTech 2012 Proceedings, 109-119 (2012).
3. Sun, H. P. et al., Scrap and DRI Melting in Hot Metal Part II: Analysis of Scrap Melting Rate in Hot Metal, Progress Report in R&D department in CSC, No. 33 (2013).
4. Francesco, M.; Carlo, M.; Marta, G., Recycling of ladle slag in the EAF: A way to improve environmental conditions and reduce variable costs in steel plants, Iron and Steel Technology, Vol. 4, No. 2, pp. 68-76 (2007).
5. Yoshie, N.; Naoki, K.; Maki, I.; Seiji, N.; Yasuo, K., Development of Slag Recycling Process in Hot Metal Desulfurization with Mechanical Stirring, Steel Research International, Vol. 80, No. 10, pp. 727-732 (2009).
6. Suito, H.; Inoue, R., Phosphorus Distribution between MgO-saturated CaO-FetO-SiO_2-P_2O_5-MnO Slags and Liquid Iron, Trans. Iron Steel Inst, Jpn, 1984, 24, 40–46.