

Slag sampling and analysis from a lab-scale Electric Arc Furnace

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INTRODUCTION

Electric arc furnaces (EAF) are used in steelmaking to melt down raw materials such as steel scrap in order to produce new steels. Synthetic slags are used to refine and clean the molten steel in the steelmaking process.

It is beneficial that the slag composition can be known as early as possible in the EAF process, so that actions and decisions can be taken promptly for an efficient process control of EAF. However, this is still a challenge today, because no steel companies have yet incorporated direct slag composition data in an online process control system for the EAF process. Therefore, this work is part of an attempt to obtain a better understanding of change of the slag components, based on measurements in a lab-scale EAF. The ultimate goal of the work is to make it possible to measure the slag composition online with optical emission spectrometry (OES) in a full-scale EAF.

By testing the variations of slag levels and slag compositions, we can learn how these parameters affect the plasma measurements with optical emission spectrometry. The comparison between how slag level and compositions can affect OES measurement is still in progress. (OES measurement will be presented by participant from the University of Oulu.)

A large amount of energy is required by the electric arc furnace in the melting process. Light and heat are generated by the electric arc. The arc and plasma consist of a highly radiant mixture of free electrons, ions, atoms and molecules. A plasma occurs if a gas is heated strongly [1]. The electric arc provides this energy for the melting process in an industrial EAF.

MATERIALS AND METHODS

A lab-scale EAF at KTH with 10 kg capacity (Figure 1), was used for the trials. It was equipped with induction heating and an integrated water cooling system.

Experimental Procedure. A graphite crucible was lined with refractory material and allowed to dry and sinter before the melting of steel and slag formers. At the beginning of the trial, carbon steel (5 kg), carbon (200 g) were added into the graphite crucible. Thereafter, induction heating was employed in order

to achieve a sufficiently high temperature for the melting of carbon steel, carbon and slags. Slag formers of ca. 215 g per batch comprised of (in wt %) CaO 40, MgO 10, SiO₂ 35, Al₂O₃ 15 were added into the graphite crucible. Variations of slag levels were tested. Specifically, 3-5 batches of slag formers were added stepwise to vary the slag level from 15 mm, 20 mm and 25 mm in the crucible. An addition, 50 g CaO per addition were added twice after a 25 mm slag level had been reached. Thereafter, a ladle slag (79 g and 84 g respectively) were added in the end in order to increase the variation of the slag composition. Oxygen lancing was introduced into the steel melt to create a foaming which is similar to what is found in an electric arc furnace.

A welding power source, ESAB LHH400 was used to supply a 200-300A direct current (DC) to the two graphite electrodes in the lab-scale EAF. Also, a controller was used to adjust the height of the two graphite electrodes from the melt. This functioned not only as a height adjustment of the electrodes, but also as a means to initiate the arc.

The temperature of the steel melt was measured repeatedly with a S-type thermocouple via a lance (Heraeus Electro-Nite), before each slag sampling. Also, three different methods were tested to sample slag. Specifically, the slag samples were obtained by using rebars, slag rakes and quartz tubes.

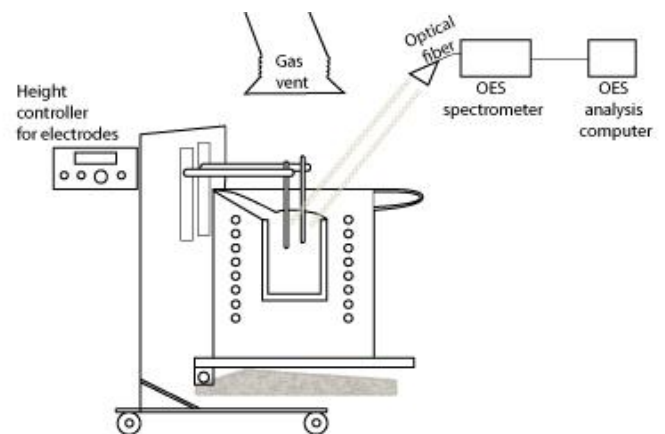


Figure 1. Lab-scale Electric Arc Furnace at KTH.

The composition of the slag samples were analysed with x-ray fluorescence (XRF). In total, 10 sets of slag samples were analysed with XRF. 10 grams from

each samples were first crushed into powder with a particle size <150µm and then 1 gram of each sample was analysed.

Characterization and semi-quantitative analyses of the slag samples were performed using a Hitachi TM3000 scanning electron microscope (SEM) equipped with an energy dispersive spectroscopy (EDS) analyser.

RESULTS AND DISCUSSIONS

The added slag formers had a basicity ($\text{CaO}+\text{MgO} / \text{SiO}_2+\text{Al}_2\text{O}_3$) of 1, where their weight percentage values are presented in Figure 2. Each batch of slag formers produced approximately a 5 mm slag level in the lined crucible. In 3-5 batches of slag formers the slag levels varied from 15 to 25 mm. A foaming of slag was tested with oxygen injection in trial number 10. The fraction of added ladle slag (containing Cr_2O_3 , FeO , MnO , SO_3 , TiO_2 , F , BaO) in number 8 constituted 0,9 wt % of the slag. For trials number 9 and 10 the fraction of ladle slag was increased to 1.7 wt %.

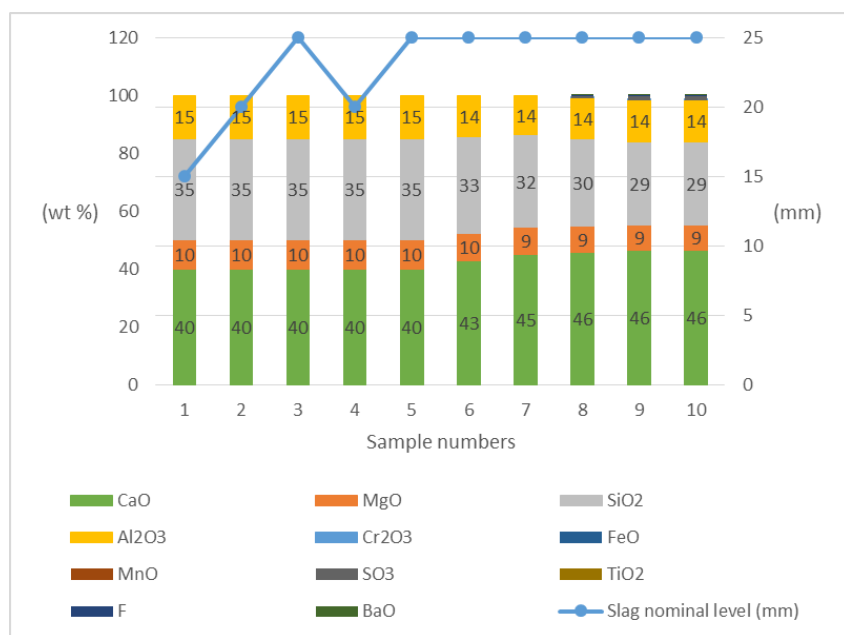


Figure 2. Slag formers added in wt % and normal slag level.

Temperature. Temperatures measured right before each slag samplings are shown in Table 1. The temperature was an important parameter because it can affect the slag characteristic and foaming ability [2].

Table 1. Temperature (°C) of the steel melt.

Sample	1	2	3	4	5	6	7	8	9	10*
Temperature	1595	1558	1553	1585	1566	1534	1404	1564	1644	1490

Note: 10* slag foaming

Slag foaming. Gas development in the slag phase created a condition for slag foaming. It was the purpose to create CO gas by adding carbon with the steel in the beginning of the experiment. Reaction between the dissolved carbon with the injected oxygen forms the reaction products CO (g) alternatively CO₂ (g) [2].

Sampling methodology. After tested, the different slag sampling methods had both advantages and disadvantages. With rebars and slag rakes, clean slag samples were obtained but the sample amounts were low. On the other hand, with quartz tubes a larger amount of slag sample could be obtained but the slag sample and the quartz tube wall adhered to each others. When separating the slag sample from the quartz tube material the slag sample was contaminated. Therefore, a new slag sampling method should be developed in order to obtain a large enough slag sample, such as by using a scoop or a ladle-like tool for slag sampling inside the crucible.

Slag analysis. The slag samples that were analysed with XRF and SEM showed a high content of MgO and it was higher than the MgO in the slag formers. This indicated that a dissolution of MgO from the lined refractory material occurred at the high temperatures. Therefore, the crucible should be lined with another type of material or a new crucible material should be used for further studies.

CONCLUSION

Ongoing work is in progress, to validate how well the analysed slag compositions correspond to the measurement data from the optical emission spectrometer (OES) measurements. If the OES results agree with our results, it indicates that the OES method has the potential to provide a fast feedback on slag composition changes which could be utilised in process control.

REFERENCES

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- [2] KTH, Institutionen för Materialvetenskap, Processmetallurgins Grunder, 2004.