Research Note

Influence of geometric shape of sponge iron used in induction furnace on metallurgical properties of produced steel

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Abstract

The geometric shape of the sponge iron particles (direct reduced iron, DRI) used in the induction furnace is very influential on the steel making process. In this paper, the effect of the geometrical deformation of DRI from spherical to other shapes on the final product quality and performance of the induction furnace is investigated. The results showed that the typical spherical shape of DRI melts over time and consumes more energy due to the air gap built between its particles. Long periods cause more oxidation and, consequently, more iron loss and lower iron production rates. Crushed DRI due to rapid melting, oxidation is much less and with high iron grade (94.9%) in steel, more molten weight and higher iron production rate (1.94 g/s) than other samples. Other geometric shapes, such as cylinders and cones, cannot be used industrially due to their high manufacturing costs, despite having mediocre results.

Keywords: Sponge Iron, DRI, Induction Furnace, Geometric Shape, Crushed Shape.

1. Introduction

Induction furnace steelmaking is expanding due to the reduction of initial investment costs, reduction of environmental pollution, reduction of production costs, the possibility of reaching the final capacity in several phases and other benefits. The induction furnace can produce a wide range of special alloy steels with controlled chemistry and successful de-oxidation processes. Of course, coreless induction furnaces are more important [1-3].

Although steel scrap is a custom input material for induction furnaces, due to problems such as its scarcity, its fluctuating price, its heterogeneous nature, and its higher content of impurities, direct reduced iron (DRI) or sponge iron is a suitable alternative [4, 5]. Since smelting and refining are performed simultaneously in the induction furnace, increasing the DRI ratio in the input charge increases the net melting rate and metal efficiency [3].

The physical, chemical, and thermal properties of input material affect the melting process of sponge iron. DRI is introduced with high porosity, low density, low thermal conductivity, high specific surface area, relatively high oxygen content, and moderate carbon percentage [6-8].

Therefore, in charging DRI (in the form of an ordinary sphere) to the induction furnace, its internal porous and air gap between its particles due to less electromagnetic field absorption reduces the production efficiency compared to scrap [4, 9, 10].

The geometric shape of the DRI is one of the most important factors affecting the performance of the induction furnace and the quality of the final product. The geometric shape of the DRI affects the bed porosity and the amount of air gap between the DRI particles. The usual shape of the DRI, which is almost spherical, reduces the melting efficiency due to the smaller surface-to-volume ratio and the empty spaces between the particles. In the

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previous work, the effect of changing the shape of DRI on the performance of the induction furnace was investigated [7]. In an induction furnace, by inducing a magnetic field from the coils to the furnace center (where the DRI is charged) and with the charge resistance to the field, the temperature increase and the charge will gradually melt. By changing the shape of DRI, due to the alert in the air gap between the particles, the efficiency and performance of the induction furnace and thus the melting rate is changed. The sample of crushed DRI consumes more power due to the smaller voids between the particles and melts in less time [7]. It was shown that crushed sponge iron had a 28% reduction in melting time and a 26% reduction in energy consumption due to the filling of pores between particles and a higher surface ratio than the spherical one, resulting in more absorption of the field [5, 7, 8].

Improving efficiency in steelmaking is closely related to melting time and can affect the quality of the output melt and reduce its oxidation. Accordingly, in this work, the effect of the geometric deformation of sponge iron on the quality and characteristics of the final product was investigated. Similar to the previous article, various shapes (conical, cylindrical, and spherical) were made. Then, the chemical composition of the final product and the production performance of the induction furnace were evaluated.

2. Materials and methods

To do this, the sponge iron prepared by Mianeh Sponge Iron Company, which contained 86.62% Fe_{total}, 83.16% Fe_{metal} and 4.2% silica, was transformed into various geometric shapes by pressing on metal molds (press pressure= 10-12 bar). In addition to ordinary spherical sponge iron (r: 7 mm), conical specimens (r: 7 mm and h: 27 mm) and cylinders (d: 14 mm and h: 9 mm) were also prepared (Fig. 1 and previous article [7]). For better comparison, a sample of crushed (broken) sponge iron and a mixed 4-shapes sample were considered.

The samples were melted together with 17 %wt of scrap (wire rod steel RSt34, DIN 2394) in a 5 kg induction furnace made by Tepka company with 450 Hz and 45 KV. Different samples were melted together with scrap in a cylindrical graphite crucible (capacity: 6 kg, height: 18 cm and diameter: 12 cm). After the end of melting, the chemical composition of the resulting steel and slag was determined by performing an X-ray fluorescence (XRF) analysis. Then, the effect of the geometric shape of DRI on the metallurgical properties of produced steel was investigated.

3. Results and discussions

Fig. 2 shows the field-emission scanning electron microscopy (FESEM) image of ordinary pressed sponge iron. As can be seen, porosity and cavities are reduced by pressing sponge iron and making different shapes. Increasing the particle density improves the induction of electromagnetic current in them and by absorbing more energy, it facilitates melting. Of course, in addition to particle porosity, the porosity of the charge bed is also effective. This has caused the crushed DRI and the 4-shaped sample (the mixture of spherical, cylindrical, conical and crushed DRI) to have better conditions for melting.

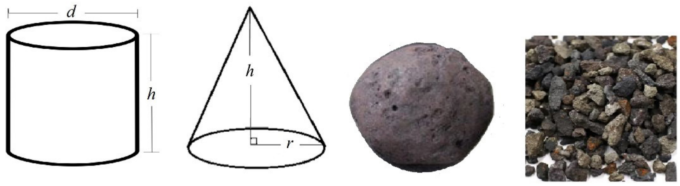

Fig. 1. Various geometric shapes of sponge iron.

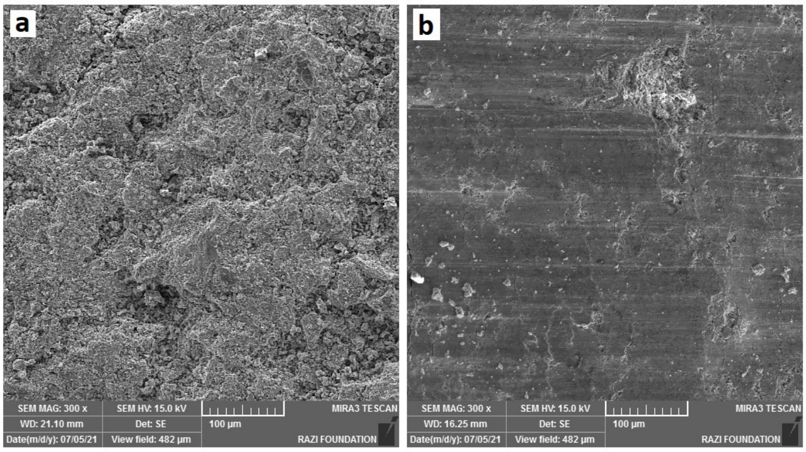

Fig. 2. FESEM images of sponge iron a) ordinary and b) pressed.

The analysis of smelts and slag from the melting of sponge iron with various shapes are given in Tables 1 and 2, respectively. For more detailed analysis, the chemical composition of all samples was determined. Because the samples were prepared at different times, their chemical composition is somewhat different. Steel made of molten sponge iron with 4-shapes has a higher iron grade. Of course, the amount of silicon is also high. The product steel of crushed sponge iron contains 94.9% iron and its silica impurity is lower than other samples (0.7%). One of the ways to reduce dissolved iron in slag is to improve the slag-metal reaction. So that oxygen of iron oxide is absorbed by impurities and iron returns to the metal phase. The slag-metal reaction can be improved by creating better stirring conditions in the induction furnace. Of course, special stirring conditions have not been provided, but the eddy current has done the charge stirring to some extent in the furnace.

The amount of iron loss varies in the produced slags. The lowest iron loss is due to the melting of conical DRI. Of course, iron losses in melting the crushed sample are not significantly different from conical geometry. Table 3 shows additional process information. Since the chemical composition of the slag has a considerable effect on the quality of iron and operating conditions, the basicity of slag has also been evaluated. The basicity of slag is calculated from various relationships. But its general formula for steelmaking is the weight ratio of CaO to SiO_2. However, depending on the amount of acidic and basic compounds, the desired formula can be selected for calculation [11]. In this study, due to the high percentage of MgO and Al_2O_3, the following equation was used to calculate the basicity:

$$B = \frac{CaO + MgO}{SiO_2 + Al_2O_3}$$

Basicity can be considered as a parameter along with reducing the melting process time by improving the phosphorus and desulfurization parameters. The higher the slag basicity, the lower the percentage of harmful elements (phosphorus and sulfur) in the molten steel [11]. Here, the cylindrical and then the crushed samples have the high slag basicity. Due to its lower alkalinity, the spherical geometry does not have a suitable ability to absorb sulfur and phosphorus elements, so it has the worst performance compared to other samples.

On the other hand, since steelmaking slag is an acidic material (silicate compounds), the presence of basic compounds and their adsorption from molten steel reduces the melting point and viscosity of the slag. This improves the interactions between the slag and the molten steel, resulting in better removal of impurities from the steel. In fact, for better removal of impurities, the slag basicity should be high (1.7-2.0). This requires the addition of basic compounds such as CaO to the system. Adding these compounds will increase the volume of slag. Because the study of the effect of DRI geometric deformation is the principal purpose of this work, the impact of lime has not been considered.

In primary steelmaking, oxygen is used to oxidize soluble impurities (such as C, Si, Mn, and P), however in induction furnace steelmaking, because oxygen does not enter the bath directly, the impurities are oxidized by FeO in the slag. Therefore, the presence of FeO can be significant [12].

Oxidation is one of the main issues in the storage and transportation of DRI and steel. This phenomenon can affect the quality and quantity of steelmaking. Further oxidation may occur in samples with particles having a higher surface-to-volume ratio. In the crushed DRI, oxidation was more than other geometries. However, the results show that despite the lower percentage of $Fe_{metalic}$ in crushed DRI, more Fe is produced. Melting of crushed DRI produces more melt weight, and the production rate (1.94 g/s) in it is higher than in other samples. This was due to the higher melting rate. The lowest rate of pure iron production is 1.31 g/s due to the melting the spherical geometry, which can be very important economically.

In the conical sample, oxidation is less due to its higher metallic iron percentage of $Fe_{metallic}$ (84.2%) compared to other geometries. While the purity of molten iron is less than the crushed sample. High silica content in this smelter can be a reason for the reduction of oxygen in molten steel and, consequently, the reduction of iron oxidation.

Cylindrical and conical samples have similar conditions in terms of %Fe in the melt, but due to the high

Table 1. XRF results for the chemical composition of the final product from the melting of sponge iron with different shapes.

wt%	Common spherical	Cylindrical	Conical	Crushed	4-geometries
Fe	93.5	94.7	94.7	94.9	96.1
Si	1.1	0.9	2.4	0.7	1.0
Al	3.7	2.3	1.4	2.2	1.5
Ca	0.3	0.3	0.3	0.2	0.1
Mg	0.3	0.2	0.7	0.3	0.4
S	<0.01				
P	<0.01				

melting rate, oxidation has occurred in the cylindrical sample. The spherical sample is melted in a longer time due to the surface-to-volume and air gap between the DRI particles inside the furnace. Therefore, the percentage of iron oxidation is high and also the percentage of iron purity is low.

In the 4-shape mixed sample, which used all the geometries equally, due to the mixing of the geometries and the effect of all parameters (surface-to-volume ratio, air gap between particles, density, etc.) at the same time, has better results in production rate after the crushed sample.

The X-ray diffraction (XRD) spectra of steel and slag obtained from smelting crushed DRI are shown in Fig. 3. As can be seen in the XRD pattern of steel, only iron peaks are seen. In fact, it confirms that its main phase is iron, and that because of their very small amount of impurity elements, their peaks have not been seen in the pattern. In the XRD pattern of slag, many peaks that are related to different phases can be seen. Its most important peaks are related to the SiO_2 phase and indicate that the slag is the product of a silicate base. In addition to silica, peaks of magnesia and alumina are also seen. Then, XRD pattern confirm the results of XRF analysis.

Table 2. XRF results for the chemical composition of the slag from the melting of sponge iron with different shapes.

wt%	Common spherical	Cylindrical	Conical	Crushed	4-geometries
Fe_2O_3+FeO	14.8	12.3	7.1	10.0	11.4
SiO_2	44.9	43.7	50.0	44.7	44.0
Al_2O_3	9.9	10.0	10.5	9.6	9.8
CaO	6.6	7.4	7.7	7.0	6.5
MnO_2	1.2	1.5	0.2	1.1	1.2
MgO	17.2	21.5	19.2	18.6	18.0
P_2O_5	<0.01				

Table 3. The influence of the geometrical shape of DRI on the production rate and characteristics of the output steel and slag based on the results of X-ray analysis.

	Common spherical	Cylindrical	Conical	Crushed	4-geometries
$\%Fe_{metal}$ in sponge iron	83.16	83.59	84.20	82.84	83.45
Basicity of slag	0.437	0.538	0.444	0.471	0.455
Melting time (s)*	361	343	330	259	293
Melt weight (g)*	507	517	523	531	520
pure Fe production rate (g/s)	1.31	1.43	1.50	1.94	1.70
* Reference [7]					

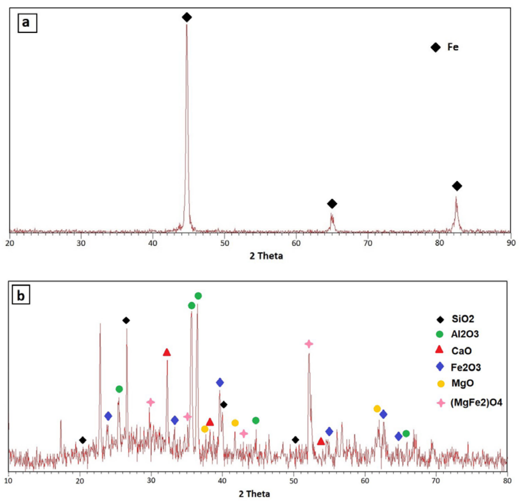

Fig. 3. XRD patterns of a) molten steel and b) slag.

4. Conclusions

In this paper, following the previous work, the effect of the geometric shape of DRI particles on the chemical composition of produced steel and the performance of the induction furnace in steel making was investigated. The output of induction furnace (steel and slag) was analyzed and the effect of geometric deformation was evaluated by determining their chemical composition. The results showed that Fe_{metal} in DRI of the crushed sample was less than other samples, but after melting due to rapid melting, oxidation occurred in it much less than other samples. As a result, with high iron grade (94.9%) in steel, melt weight was higher and iron production rate was higher (1.94 g/s) than other samples. However, in the spherical sample, due to the high melting time and oxidation, the Fe_{metal} melt (93.5%) and its iron production rate (1.31 g/s) were the lowest compared to all samples.

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