EFFECT OF FURNACE TEMPERATURE ON IRON NUGGET PRODUCTION UNDER SEMI-FUSION CONDITIONS

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ABSTRACT

This study has been conducted to determine whether iron nugget having similar features to pig iron that can be obtained after a period of nearly 8 hours under blast furnace conditions, could be obtained in shorter period. In our previous study, iron nugget was produced using carbon composite pellets obtained from magnetite ore at furnace temperature 1330°C and furnace residence time 48 minutes. In this study the carbon composite pellets, produced using magnetite iron ore and coke through reduction at semi-fusion conditions, were used for production of iron nugget at furnace temperature 1410°C and residence time 8 minutes. The reduction was carried out under semi-fusion conditions in order to produce an iron nugget having physical and chemical features that are similar to high furnace pig iron at lower temperature and furnace residence time. The iron nugget was produced from pellets composed of iron oxide, coke, flux, and binder. Its characteristics are: micro hardness of 343.4 HV, apparent density of 6.786 and iron content of 92.7 %.

Keywords: *iron ore, pelletizing, cold bonded composite pellet, iron nugget.*

INTRODUCTION

Among the global iron and steel production methods, the most widely used one is blast furnace method. Nearly 60 % of global iron and steel production is realized with blast furnace and steel works integrated system. The purpose of blast furnace usage is to purify oxidized iron ores from their oxides chemically and to transform them to liquid iron being physically named as “hot metal”. In its wide definition, blast furnaces are smelting unites where ore gets in direct contact with the fuel.

Blast furnace is a giant steel mass being coated with brick having durability against fire, where iron ore, coking coal, and limestone are poured from upper part and from the bottom part, preheated air is flown into the furnace. Nearly 6 to 8 hours need for the raw materials being fed from upper part to come down in the furnace and to transform into final product in the form of liquid slag and liquid iron. These liquid products are emptied from the furnace at regular intervals. The effective temperature of furnace is between 1500 - 1600°C. Iron and steel production with blast furnace process continues under high temperatures, in long periods, and with a profit that gradually gets reduced. For this reason, searching began for new methods to increase profit by reducing temperature or production period. As a result, a method was developed by Kobe Steel and Midrex, were dust ores containing iron oxide were pelleted with thin coal nuggets and by reducing these pellets inside rotating furnace, it was made possible to realize the production of iron nugget having the quality of high furnace pig iron. In this process, iron oxide and reductive reagents are transformed into pellet together and the structure obtained is named as iron oxide-carbon composite pellet [1, 2]. This new iron production process was named ITmk3 [3 - 5].

Basicaly, in ITmk3 process the iron oxides are reducing in the structure into iron phase and afterwards are melting into carbon composite pellets. Slag phase composed of silicate and calcium oxides, because of high melting temperatures, remains in solid form. Since melting of slag phase is not required during the process, the iron mass is formed under relatively low temperature compared to the high furnace conditions. The process of obtaining completely melted iron phase, while slag phase under solid condition is obtained, can only be achieved with the production of carbon composite pellets. On the contrary to traditional pellets, in the production of composite pellets, calcium oxide and coke or coal, as being reductive reagents, are added to pellet mix in order to obtain slag formation. With the help of mixture being prepared, iron oxides are reduced into iron form. As slag phase is not transformed into liquid form and as iron phase is transformed into melting form during this process, this event is named as reduction process under semi-melting conditions. During the process, carbon composite pellets are reduced under relatively lower temperatures of 1350^{o}C - 1400^{o}C and they are melted and easily separated from the hot metal slag. As being different from traditional iron production methods, this method is realized at the stage when solid and liquid phases are present together. As slag phase is not melted, in refractories, FeO damage is not observed [6].

ITmk3 process has certain advantages as a simple process of selecting various iron ores and reductive reagents. This method is the advanced version of FASTMET process, which is sponge iron production method [7]. This process has the advantage of being a method that can be preferred to traditional iron production technologies due to reasons as minimizing energy loss during iron oxide reduction, observing reduction and slag separation together, not requiring to process at very high temperatures, and requiring low investment and low production costs. Besides, it is more environmental friendly with higher energy savings [8 - 11]. When carbon composite pellets are heated to high temperatures, first of all iron oxides in the structure are reduced and then metallic iron is formed. This metallic iron can be partially or completely melted depending on the temperature and the carbonate content. It is stated by Han et al. [12] that during the reduction of iron ore, one of the most important points is the carbon level of reduced iron as well as the slag composition.

The success of the process depends on the pellet structure, furnace temperature, type and quantity of reductive substance, pellet size, period of remaining in furnace, and content of gang, ash and binder in the mixture. Recently it was discovered that the addition of a coke inside pellet mixture provided better gas permeability and that it contributed to the melting features of iron [13, 14].

In this study, as being different from ITmk3 method, the coke was used instead of a coal. Experimental studies were realized in a laboratory high temperature furnace (1600^{o}C) instead of a rotating furnace. The aim of this study was to obtain iron nuggets from composite pellets in a laboratory high temperature furnace at semi-melting conditions in a short time. The most suitable furnace temperature for iron nugget production was determined.

EXPERIMENTAL

Materials

Magnetite concentrate was obtained from Divrigi Concentrated Facility (Turkey), with content of 95 % Fe_3O_4, 2.2 % SiO_2, 0.75 % Al_2O_3, 1.18 % CaO+MgO and 68 % Fe (80 % of which is below 45 microns). This concentrate was used for the production of carbon composite pellets. As a reducing agent, a coke containing 88.17 % free carbon, was used. Sodium carboxymethyl cellulose (CMC, 2 %) was used as a binding substance.

Methods

In this study in order to produce an iron nugget, having similar features to pig iron (obtained in nearly 8 hours in high furnace), for shorter period, 30 % coke and 2 % CMC were added to magnetite concentrate, and the pelleting process was realized for a period of nearly half an hour. Pellets being obtained were awaited for 8 minutes in Protherm branded laboratory scale high temperature furnace at temperatures of 1330^{o}C, 1370^{o}C and 1410^{o}C and they were subjected to reduction. The scheme of the process is illustrated in Fig. 1.

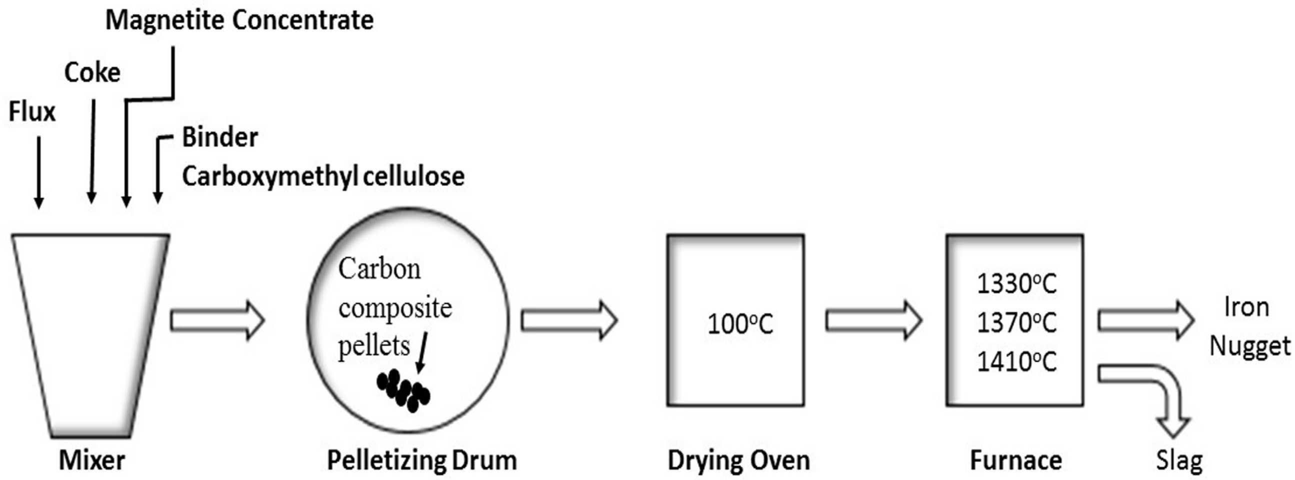

Fig. 1. Carbon Composite pellet production and reduction.

Characterization

In order to standardize a surface preparation procedure for all the experiments, an ASTM standard was chosen. The macro images of the obtained iron nuggets were taken, and their apparent densities were measured based on the volume of displaced distilled water method [15]. Abrasion, polishing [16] and inital etching [17] were applied to the cold molded iron nuggets with epoxy resin [16], and then the microstructure examination of the samples was performed by a scanning electron microscopy (SEM). In the following stage, Vickers hardness measurements (1 kg load), apparent density and chemical analysis of iron nuggets were done [15, 18, 19].

RESULTS AND DISCUSSION

Products after reduction

When composite pellets are heated for 8 minutes at different furnace temperatures (1330°C, 1370°C and 1410°C), a significant increase can be observed in metal formation. The obtained products are shown in Fig. 2.

As shown in Fig. 2, during the experiment made at the temperature of 1330°C, no metal formation occurred during 8 minutes in furnace.

With the temperature increase to 1370°C, after 8 minutes a metal formation and slag - metal separation began to occur. However, due to not sufficient time, metal particles can only gather as regional masses in the structure and the slag and the metal separation can

1330°C (Slag formation is not realized) | 1370°C (Partial metalization is realized) | 1410°C (Iron Nugget and slag separation is realized)

Fig. 2. Macro images of products obtained from carbon composite pellets treated for 8 minutes in different furnace temperatures.

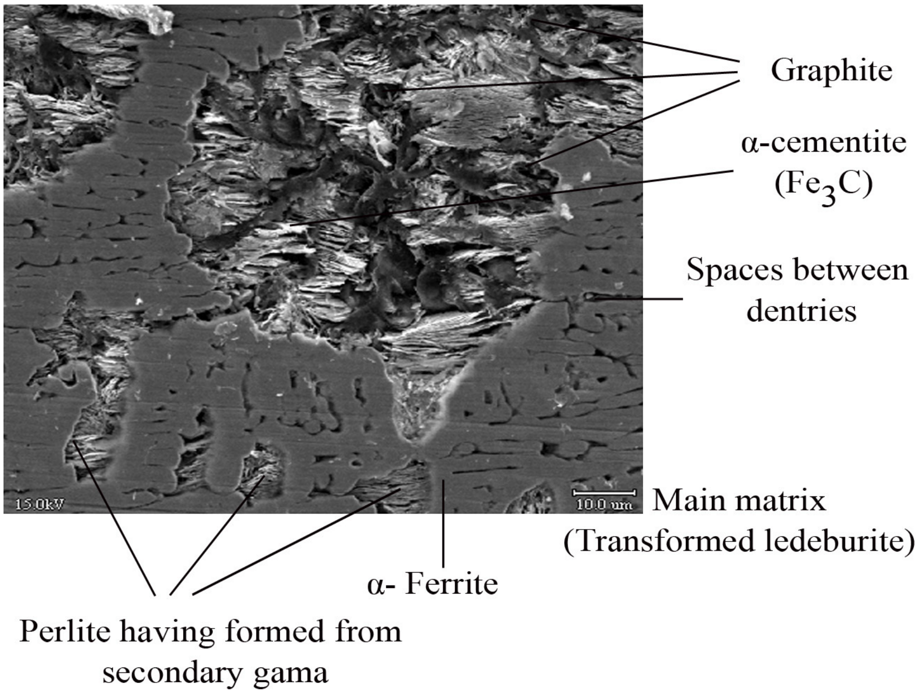

Fig. 3. SEM of enlarging carbon composite pellet after 8 minutes in the furnace at 1410°C, 1000 times (Nital Etching).

not be completely realized.

The fluidity of the liquid metal has increased with the increase of the furnace temperature and at 1410°C after 8 minutes, regional masses came out of slag and gathered as a whole. When the furnace temperature is increased and the eutectic point containing 4,3 % carbon is reached, the quantity of carbon diffusion in metal is also increased and the melting point of the metallic part gets reduced, then the formation of iron nugget takes place [20]. After 8 minutes at furnace temperature of 1410°C, it is clearly observed the formation of iron nugget and the separation of the metal and the slag. The carbon solubility within the structure is increased.

The micro-structure image of iron nugget was obtained by scanning electron microscopy (SEM) (Fig. 3).

From the Energy Dispersive X-Ray Spectroscopy (EDX) and SEM image (Figs. 3 and 4) it is obvious that the main matrix is the ledeburite structure, formed from the mixture of ferrite and secondary as being transformed. Small black dots, observed in the matrix, are spaces between dentrites. After reducing, the carbon coming from the coke, is observed as graphite phase in solid form as being undissolved. Graphite parts of coke are observed as sheet graphites (black stick formations). On the neighboring regions, sheet perlite structure has formed along the process as being composed of α-cementite mixture containing primary austenite being enriched with carbon from graphite through carbon diffusion. Sheet graphites and neighboring regions have been nested with graphite masses. Perlite being present in the matrix as small isles was formed as a result of ledeburite transformation. The data of chemical analysis obtained with the aim of having a general idea relating with formations of cementite (Fe_3C), graphite and perlite, are given in Table 1. XRD of the micro-structure is shown on Fig. 4.

Table 1. EDX analysis of iron nugget obtained from carbon composite pellet after 8 minutes in furnace at 1410°C.

Components	Fe (%)	C (%)	Components	Fe (%)	C (%)
Matrix	98.175	0.294	Pearlite	87.551	10.892
Graphite	9.736	89.853	Cementite	75.348	23.615

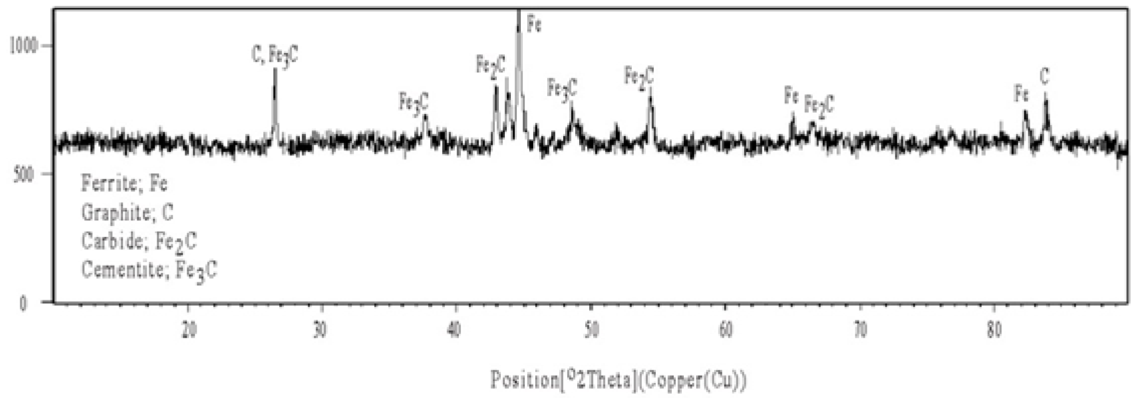

Fig. 4. XRD of iron nugget obtained from carbon composite pellet after 8 minutes in furnace at temperature of 1410°C.

Micro-hardness and apparent density measurements

Data for Vickers hardness measurements (1 kg load) and apparent density measurements for products obtained during the staying of 8 minutes in furnace at temperatures of 1330°C, 1370°C, and 1410°C with the aim to determine the impact of increase in furnace temperature on the iron nugget production, are given in Table 2.

When the data of Table 2 are reviewed, it is seen that as temperature is increased, micro-hardness and visible density values of the products also increased. It is found that these values were 343,4 HV and 6,79 g/cm^3, respectively, for iron nugget being obtained at temperature of 1410°C. As temperature increased, the molten carbon quantity in the products increased which also increased Vickers hardness values of these products. Furthermore, as furnace temperature increased, the visible density increased and as a result, while metallization degree and slag separation increased, porousness was reduced.

These results exactly correspond to the literature information. According to Lankford at al. [21] as furnace temperature increases, metallization degree and slag separation also increase and porousness is reduced.

In the pellets that remained for 8 minutes in furnace, while complete metallization can not be observed at 1370°C, as temperature was increased to 1410°C, metallization degree and slag separation increased and porousness was reduced. As a result, an iron nugget with highly visible density was obtained.

CONCLUSIONS

In this study different products were obtained depending on furnace temperature.

According to the results obtained from the experiments, as furnace temperature increases, an increase in carbon diffusion within metal was also observed. The increase in metallization reduced the porousity and the quantity of dissolved carbon in the metal was increased. The increase in metallization degree and decrease in porousity are indicators for the increase in the visible density. The increase in the quantity of dissolved carbon

Table 2. Micro-hardness and visible density measurements of products after 8 minutes in the furnace at different temperature.

Furnace Temperature (°C)	Vickers Micro Hardness (HV)	Apparent Density (g/cm^3)
1330	70,2	3,93
1370	115,3	4,94
1410	343,4	6,79

is an indicator of increase in micro-hardness values.

According to the results obtained, Vickers hardness increased with the increased quantity of dissolved carbon within metallized part. As Vickers hardness increased, product metallization and slag separation increased and porousity was reduced.

As a conclusion, carbon composite pellets being obtained by using 30 % coke and 2 % sodium carboxymethyl cellulose, was subjected to reduction in a furnace at semi-melting conditions at 1410°C for 8 minutes. The slag and metal separation was also observed. Iron masses thus produced have features and a composition that are similar to the ones obtained in high temperature furnace.

As a result of these experiments, the production of iron nugget usually obtained during a period of 48 minutes in the furnace at temperature of 1330°C, was realized for a shorter period in the furnace (8 minutes) by increasing the furnace temperature up to 1410°C. The production of pellet from carbon composite pellets under semi-melting conditions provided better working conditions compared with traditional pig iron production (1550°C and 8 hours).

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