Reduction Behavior of Cold-bonded Briquettes under Simulated Blast Furnace Conditions

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Recycling of fine sized iron-rich by-products back to blast furnace (BF) process in the form of cement-bonded briquettes has become a common procedure in steel plants. Replacing part of the cement by Ground Granulated Blast Furnace Slag (GGBFS) is also a common method to reduce cement consumption. When the briquettes are subjected to high temperature and reducing atmosphere in the BF, the cement phases decompose and the iron oxides undergo a series of phase transformations. To avoid early disintegration and to improve the performance of the briquettes, it is necessary to study these reactions during the reduction. In the present study the reduction behavior of the BF briquette samples was studied by experimental methods in a laboratory scale furnace, which simulates the conditions of the BF shaft in a CO–CO2–N2 atmosphere. With interrupted experiments the composition of the briquette was studied in different reduction stages of the BF shaft. The effect of GGBFS as a binder material on the reduction was studied with GGBFS containing briquette samples. The reduction of briquettes was compared to an olivine pellet which was used as a reference sample. Considerably higher reduction rate was detected with the briquettes compared to the pellet at 1 100°C when reduced to metallic iron. 25–50 vol-% swelling in the briquette samples was detected during the wüstite-iron reduction step at 900–1 000°C. X-ray diffraction (XRD) was used to observe the phase transformations in the Fe–Fe2O3–CaO system of the briquette and the results are in agreement with the theory.

KEY WORDS: reduction; cold-bonded briquettes; swelling; carbon monoxide; carbon dioxide; nitrogen; non-isothermal; blast furnace.

1. Introduction

Large amounts of recyclable by-products are generated in the steel plants worldwide. The by-products are formed in different stages of the steel production chain and the most of them are dusts and other materials with small particle size which cannot be charged in the Blast Furnace (BF) process without increasing the particle size. Agglomeration of dusts and other materials into briquettes, where cement is used as a binding material, is a commonly used method to enable by-product charging to the BF.1–5) Replacing cement partly by Ground Granulated Blast Furnace Slag (GGBFS) is a feasible option.6–9) Mechanical properties of the briquette are achieved by sufficiently long curing time periods. The briquette is usually rich with carbon, iron oxides and calcium oxides and the decomposition reactions of the cement phases, the gasification of the carbon and the reduction of iron oxides take place in the BF. This leads to various phase transformations and metamorphosis in the briquette.10,11) The durability of the briquette is dependent on these phase transformations, which makes the reduction behavior experiments necessary.

The briquettes have been recently introduced to the BF process together with iron ore pellets in Ruukki’s steelworks in Raahes, Finland. The mechanical properties of the briquettes have already been studied9) but the reduction behavior still needs further investigation. Since there is no standardized reduction test available for the briquettes yet, in this study the briquettes were reduced under a dynamic reduction program, which has been previously used to study the reduction behavior of iron ore pellets.12,13) Experiments were conducted in a laboratory scale furnace, which simulates the BF shaft conditions up to 1 100°C in CO–CO2–N2 gas. Dynamic programs were used to study the reduction and phase transformations in the briquettes when the iron oxides are reduced to magnetite, wüstite and iron. Portland Cement (PC) was used as a binder material in the briquettes and two of the samples contained GGBFS as a replacement. The reduction of the briquette was compared to an olivine pellet which was used as a reference sample.

2. Experimental

A Blast Furnace Simulator (BFS) presented by Iljana et al.12) was used in the laboratory experiments. A video cam-

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era was placed on top of the BFS and focused on a sample basket via a mirror. The video camera was set to capture images during the experiments at 30 s time intervals and the images were stored on a computer, to which the camera was connected. The briquette samples were prepared for the experiments by cutting an industrial scale cold-bonded briquette in 12 triangle-shaped pieces, each weighing between 35–45 grams as seen in Fig. 1. The briquette samples, labeled as 0, 3 and 6 were placed on a BFS sample basket together with an olivine pellet, which was used as a reference sample. Sample 0 represents briquette without GGBFS addition and it was introduced twice in the experiments for the sake of comparison. Samples 3 and 6 represent briquette samples with 3 and 6 wt-% GGBFS additions, respectively. A full BFS sample basket is shown in Fig. 2 and Table 1 shows the binder materials of the briquette samples. Chemical compositions of the briquette, the reference pellet and the GGBFS are shown in Tables 2–4, respectively. All samples were kept in a temperature cabinet at 110°C to prevent moisture absorption from air.

Two dynamic experiments, named “Iron 1” and “Iron 2”, were conducted on the phase stability area of metallic iron, the only difference between these two experiments being that the latter one was continued isothermally for 60 minutes. Furthermore, two interrupted experiments, the first taking place up to the “Magnetite” stage and the second up to the “Wüstite” stage, were performed to study the phase transformations in hematite-magnetite and magnetite-wüstite reduction steps. Gas atmosphere and temperature profiles as a function of time, beginning from ambient conditions and terminating at 1100°C, are shown for each dynamic test in Fig. 3. Reducing conditions in the experiments are presented in a Fe–O–CO–CO₂ phase diagram in Fig. 4. The total gas volume flow rate was 10 l/min in each experiment. All samples were cooled under N₂ flow to prevent oxidation of the samples in the cooling phase.

Each sample was weighed before and after the experiments. The Reduction Degree (RD) of the reference pellet was calculated according to Eq. (1). The RD was not calculated for the briquette samples because the samples contained several iron-containing components and carbon that is at least partly gasified in the tests and this might lead to a quite high inaccuracy in the RD values. In order to observe the swelling behavior of the reduced samples, the volumes of the briquettes and the pellets were measured before and after the experiments. Change in the volume of the samples

![Fig. 1. Illustration of the briquette sample preparation.](image1)
![Fig. 2. BFS sample basket with 4 briquettes samples and a reference pellet.](image2)
![Fig. 3. Gas atmosphere and temperature profiles presented as a function of time in the experiments.(12)](image3)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Binder material (wt-%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0, 00</td>
<td>10% Portland Cement</td>
</tr>
<tr>
<td>3</td>
<td>8% Portland Cement + 3% Ground Granulated Blast Furnace Slag</td>
</tr>
<tr>
<td>6</td>
<td>8% Portland Cement + 6% Ground Granulated Blast Furnace Slag</td>
</tr>
</tbody>
</table>

Table 1. Binding materials used in the briquette samples.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Binder material (wt-%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10% Portland Cement</td>
</tr>
<tr>
<td></td>
<td>8% Portland Cement + 3% Ground Granulated Blast Furnace Slag</td>
</tr>
<tr>
<td></td>
<td>8% Portland Cement + 6% Ground Granulated Blast Furnace Slag</td>
</tr>
</tbody>
</table>

Table 2. Chemical analysis of the cold-bonded briquette (wt-%).

<table>
<thead>
<tr>
<th>H₂O</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>S</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>SiO₂</th>
<th>CaO</th>
<th>Ti</th>
<th>V</th>
<th>Mn</th>
<th>Fe_ox</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.68</td>
<td>0.18</td>
<td>0.23</td>
<td>0.3</td>
<td>1.12</td>
<td>1.44</td>
<td>7.13</td>
<td>13.86</td>
<td>0.21</td>
<td>0.16</td>
<td>0.57</td>
<td>49.25</td>
<td>10.75</td>
</tr>
</tbody>
</table>

Table 3. Chemical analysis of the reference pellet (wt-%).

<table>
<thead>
<tr>
<th>Fe_ox</th>
<th>FeO</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>SiO₂</th>
<th>CaO</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>66.79</td>
<td>0.4</td>
<td>1.3</td>
<td>0.36</td>
<td>1.84</td>
<td>0.41</td>
<td>0.208</td>
</tr>
</tbody>
</table>

Table 4. Chemical composition of the GGBFS (wt-%).

<table>
<thead>
<tr>
<th>CaO</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MgO</th>
<th>S</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>MnO</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>34.4</td>
<td>9</td>
<td>0.5</td>
<td>12.3</td>
<td>1.7</td>
<td>0.5</td>
<td>0.8</td>
<td>0.3</td>
<td>1.3</td>
</tr>
</tbody>
</table>
was calculated by Eqs. (2) and (3), respectively. For the pellet the RSI method was used which is presented in Eq. (3). Phase transformations were observed with X-ray diffraction (XRD) analyses made with Siemens Kristalloflex D 5000. Briquette samples were ground and sieved to a particle size smaller than 500 μm for the X-Ray diffraction (XRD) analysis. It should be noticed that the metallic iron (Fe) of the raw sample could not be ground to a fine size and therefore it is not seen in the XRD analysis.

\[
\text{Reduction(\%)} = \frac{\text{Weight removed from sample}}{\text{Weight removable from iron oxides}}
\]

\[
\Delta V_{\text{briq}} = \left( \frac{A_1 h_1 - A_0 h_0}{A_0 h_0} \right) \times 100\%
\]

\[
RSI = \frac{V_1 - V_0}{V_0} \times 100\% = \left[ \left( \frac{d_1}{d_0} \right)^3 - 1 \right] \times 100\%
\]

3. Results

The phases which were identified in the briquette samples with the XRD are shown in Table 5. Figure 5 shows the XRD peaks for the briquette sample 0. Because very few differences were detected between the XRD analyses of the different briquette samples, only the peaks of the sample 0 are presented in a figure. In Fig. 6 are shown the Light Optical Microscope (LOM) images of the structure of the briquette sample in “Magnetite”, “Wüstite” and “Iron 2” experiments. Only very small differences were detected between the raw sample and “Magnetite” sample as well as between the “Iron 1” and “Iron 2” samples. Therefore the
LOM images of only three experiments are presented here.

In Fig. 7 is shown the weight losses of the samples in the experiments. The calculated reduction degree (%) of the reference pellet and swelling (vol-%) of the samples are shown in Figs. 8 and 9, respectively. The two 0 samples are labeled as 0 and 00 in the figures.

Figure 10 shows the swelling of the briquettes by video camera images. These images show that the swelling of the briquettes takes place during the wüstite-iron reduction step at 900–1000°C. In Fig. 11 is shown the Fe–Fe₂O₃–CaO phase system in CO–CO₂.

Table 5. Identified phases in the XRD analyses.

<table>
<thead>
<tr>
<th>Briquette sample</th>
<th>Briquette before exp. (25°C)</th>
<th>Briquette before exp. (25°C)</th>
<th>Briquette before exp. (25°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw sample</td>
<td>Fe₂O₃, FeO, Fe₂O₅, Ca(OH)₂,</td>
<td>Fe₂O₃, FeO, Fe₂O₅, Ca(OH)₂,</td>
<td>Fe₂O₃, FeO, Fe₂O₅, Ca(OH)₂,</td>
</tr>
<tr>
<td>“Magnetite” (480°C)</td>
<td>C and CaCO₃ *</td>
<td>C and CaCO₃ *</td>
<td>C and CaCO₃ *</td>
</tr>
<tr>
<td>“Wüstite” (780°C)</td>
<td>CaCO₃, C, Fe₂O₅, Fe₂O₅, and FeO *</td>
<td>CaCO₃, C, Fe₂O₅, Fe₂O₅, and FeO *</td>
<td>CaCO₃, C, Fe₂O₅, Fe₂O₅, and FeO *</td>
</tr>
<tr>
<td>“Iron 1” and “Iron 2” (1000°C)</td>
<td>Fe, Ca₂Al₂SiO₇, CaO, and MgO</td>
<td>Fe, Ca₂Al₂SiO₇, CaO, and MgO</td>
<td>Fe, Ca₂Al₂SiO₇, CaO, and MgO</td>
</tr>
</tbody>
</table>

* Sample contains metallic iron (Fe) which could not be ground to a fine size needed for the XRD.
3.1. “Magnetite” Experiment

A slight reduction of iron oxides occurred in the “Magnetite” experiment since the reference pellet loses about 1% of its weight as seen in Fig. 7. Weight loss of the pellet indicates approximately 3.1% RD as seen in Fig. 8, whereas the calculated complete RD of magnetite would be approximately 11.6%. In the conditions of the “Magnetite” experiment, hematite to magnetite reduction takes place according to Eq. (4).

\[
3 \text{Fe}_2\text{O}_3 + \text{CO} = 2 \text{Fe}_2\text{O}_4 + \text{CO}_2
\]  

(4)

In Fig. 6 the structure of the briquette sample after the “Magnetite” experiment is shown. The LOM image shows the various iron oxides which differ from each other by color. Weight losses of the briquette samples are equal to the pellet as it can be seen in Fig. 7. Figure 5 shows that hematite (Fe₂O₃) and portlandite (Ca(OH)₂) have disappeared from the briquette samples at temperatures below 480°C and the peaks of magnetite (Fe₃O₄) and calcium carbonate (CaCO₃) have increased. In the presence of CO₂, calcium carbonate is formed from the portlandite according to Eq. (5).

\[
\text{Ca(OH)}_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}
\]  

(5)

The calculated total decomposition of portlandite would cause about 0.3% weight loss to the briquette sample. The released water vapor may have an effect on the reduction of iron oxides through the water-gas or the water-gas shift reactions shown in Eqs. (6) and (7), respectively.

\[
\text{C} + \text{H}_2\text{O} = \text{CO} + \text{H}_2
\]  

(6)

\[
\text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2
\]  

(7)

In addition to the hematite to magnetite reduction, the metallic iron in the briquette may be oxidized either by Eqs. (8) or (9). It can be seen in Fig. 5 that the amount of the metallic iron in the briquette sample is not sufficiently high to be detected with the XRD. Reduction causes weight loss and oxidation increases the weight of the sample. The weight loss of the briquette is probably affected by various reactions in the “Magnetite” experiment.

\[
\text{Fe} + \text{CO}_2 = \text{FeO} + \text{CO}
\]  

(8)

\[
\text{Fe} + \text{H}_2\text{O} = \text{FeO} + \text{H}_2
\]  

(9)

3.2. “Wüstite” Experiment

The XRD peaks in Fig. 5 show that magnetite is reduced to wüstite in the samples at 780°C. The reduction of magnetite has taken place according to Eq. (10).

\[
\text{Fe}_5\text{O}_4 + \text{CO} = 3 \text{Fe}_2\text{O}_3 + \text{CO}_2
\]  

(10)

The weight losses of the samples presented in Fig. 7 show about 5–6% weight losses for all the samples and slightly higher weight losses on the briquette samples (+0.5–1%) than on the pellet. In Fig. 6 the structure of the briquette sample after the “Wüstite” experiment is shown. Trivalent iron can no longer be detected in the sample with the LOM. The weight loss of the reference pellet indicates about 18% RD, when the calculated complete RD of wüstite would be about 33%.

At 780°C, the amount of calcium carbonate (CaCO₃) phase has decreased in comparison to lower temperature, whereas di-calcium ferrite (Ca₂Fe₂O₅) phase has appeared in the briquette samples according to the XRD peaks presented in Fig. 5. This indicates that part of calcium carbonate has decomposed and formed di-calcium ferrite together with the iron oxides in a complex series of reactions shown in Eq. (11). This reaction series has been proposed to occur approximately at 750°C by Robinson et al.¹⁰

\[
\text{Fe}_5\text{O}_4 + 3\text{CaCO}_3 + 2\text{Fe} = \text{Ca}_2\text{Fe}_2\text{O}_5 + 3\text{FeO} + \text{CaO} + 2\text{CO} + \text{CO}_2
\]  

(11)

3.3. “Iron 1” and “Iron 2” Experiments

In “Iron 1” and “Iron 2” experiments divalent iron is reduced to metallic according to Eq. (12).

\[
\text{FeO} + \text{CO} = \text{Fe} + \text{CO}_2
\]  

(12)

Figure 6 shows that the structure of the briquette sample is considerably more porous when reduced to iron in comparison to other experiments. The weight losses of the briquette samples are from 27 to 31% in the experiments as it can be seen in Fig. 7. It is notable that weight losses of briquette samples in “Iron 1” and “Iron 2” experiments are equal which indicates 100% RD already in the “Iron 1” for the briquette samples. The weight losses of the pellets are 22% and 27% in “Iron 1” and “Iron 2” which indicate about 75.5% and 92% RDs, respectively. The effect of the 60 min time extension in “Iron 2” leads to markedly higher RD with the pellet. The higher reduction degree of the briquette in “Iron 1” is probably achieved by the self-reducing effect of the carbon which reacts according to the Bouduard reaction (Eq. (13)). The CO formed in the Bouduard increases the reduction rate of the briquette.

\[
\text{CO}_2 + \text{C} \leftrightarrow 2\text{CO}
\]  

(13)

In the briquettes, the remaining calcium carbonates have decomposed through the thermal decomposition by Eq. (14) at around 840°C. The di-calcium ferrite phase (Ca₂Fe₂O₅) has been reduced to Fe and CaO by Eq. (15) at about 950°C. Metallic iron and some calcium silicates, periclase (MgO) and lime (CaO) phases are present in the sample after reduction as shown in Fig. 5.

\[
\text{CaCO}_3 = \text{CaO} + \text{CO}_2
\]  

(14)

\[
\text{Ca}_2\text{Fe}_2\text{O}_5 + 3\text{CO} = 2\text{Fe} + 2\text{CaO} + 3\text{CO}_2
\]  

(15)

4. Discussion

4.1. Reduction

Thermodynamic computations¹⁴ were used to determine the equilibrium state for a system with a composition similar to the briquette samples. The average contents of the major components of the briquettes were used as initial values and temperature was varied between 25 and 1 100°C. The results showed complete reduction of iron oxides at higher temperatures, which led to approximately 27% weight loss, whereas the experimental weight losses were between 28 and 31%. These results support the assumption of complete reduction of iron oxides and vaporization of assumed com-
ponents at 1100°C.

The weight losses in “Magnetite” and “Wüstite” experiments did not show significant differences between the reduction behavior of the reference pellet and the briquette samples. However, a notable difference in the reduction behavior of briquette samples and the pellet was detected in the “Iron 1” and “Iron 2” experiments. The briquette reduced notably faster than the pellet in “Iron 1” experiment, which was an interrupted experiment up to 1100°C.

The briquette samples contain about 10 wt-% carbonaceous material, mainly in a form of coke dust. It has been shown in the literature that at high temperatures (>800°C) the high carbon gasification with CO₂ causes strong CO formation, which accelerates the reduction of the iron oxides considerably. The reduction of iron oxides in direct reduction system is known to occur in gaseous phases. In the case of coke dust the gasification occurs at 750–850°C in CO₂ gas, depending on the surrounding materials, which may act as catalysts. In the present study coke dust showed no significant effect on the at temperatures below 780°C in CO–CO₂–N₂ gas which is in agreement with the results of other authors.

In the literature, the self-reducing effect of the briquette achieved by carbon has been shown to lead to hematite to magnetite reduction at 500–600°C, magnetite to wüstite at 640–850°C and wüstite to iron at 850–1000°C in an inert atmosphere. With sufficiently long heating times, a briquette has been shown to reach a 100% RD with the self-reduction in an inert atmosphere. In the present experiments these reduction steps were reached in the briquette samples containing about 10 wt-% coke with interrupted reduction experiments, which simulated the BF conditions at 480, 780 and 1100°C, respectively. The reference pellet did not reach these reduction steps completely in the same experiments which can be explained by the direct reduction system achieved by the coke of the briquette. It should be noticed that the reduction rate of the briquette is also increased by the higher porosity caused by the decomposition of the hydrates and the carbonates of the cement.

In the literature, the self-reducing effect of the briquette was studied in the present experiments under simulated BF conditions and the briquettes can be predicted to have similar reduction behavior in an actual BF. However, it must be noticed that actual BF contains also H₂ and H₂O gases and circulating hydrates and the carbonates of the cement.

The self-reducing effect of the briquette compared to the pellets may need further consideration from the viewpoint of the briquette durability in the pressure of the BF shaft. The strength of the briquette samples were not tested after the experiments in this study.

4.2. Phase Transformations

Raw briquette samples consist mainly of divalent and trivalent iron oxides, portlandite Ca(OH)₂, carbon (C) and calcium carbonate (CaCO₃) at room temperature as shown in Fig. 5. Raw samples also contain larger particles of metallic iron (Fe), which is not shown in the XRD because of the sample preparation, for which they could not be ground to a fine particle size. The XRD peaks in Fig. 5 show the phase transformations in the briquettes during the reduction.

In “Magnetite” experiment at 480°C, the decomposition of hydrates has occurred when portlandite has disappeared from the sample. Peaks of hematite also have disappeared at this point.

In “Wüstite” experiment at 780°C, di-calcium ferrite (Ca₂Fe₂O₅) phase has appeared in the briquette sample whereas peaks of calcium carbonates have decreased. This indicates the decomposition reaction of calcium carbonate which has been proposed to occur at about 700°C. In the conditions of the “Wüstite” experiment calcium carbonate and wüstite have formed di-calcium ferrite in Fig. 11. It is shown the Fe–Fe₂O₃–CaO phase stability system in CO–CO₂ gas. The phase stability system shows that the di-calcium ferrite phase is a stable phase in the conditions of “Wüstite” experiment.

Figure 5 shows that in “Iron 1” and “Iron 2” experiments at 1100°C, carbon, calcium carbonate and di-calcium ferrite phases have disappeared. Carbon has gasified and calcium carbonate and di-calcium ferrite have decomposed through thermal decomposition and reduction, respectively. All iron is reduced to metallic and the samples contain some larinit (Ca₅SiO₅), gehlenite (Ca₂Al₂SiO₅), iron (Fe), lime (CaO) and periclase (MgO). The Fe–Fe₂O₃–CaO phase stability system in CO–CO₂ gas shown in Fig. 11 indicates that metallic iron and lime are the stable phases at the conditions of “Iron 1” and “Iron 2” experiments.

According to the present results, the phase transformations and metamorphism of the briquette samples follow the path of the compositions of the phase stability system shown in Fig. 11. The results show that briquettes reach the stable phase compositions in the interrupted reduction experiments.

4.3. Swelling

In the present experiments an increase of 25–50% in the volume of briquettes were detected during the wüstite-iron reduction step at 900–1000°C. GGBFS addition had a slight increasing effect on the swelling of the briquettes. The effect was more pronounced with 3% addition than with 6% addition. In the literature the swelling of cold-bonded briquettes has been detected at the same temperature range and it has been explained to be caused by the popping up of individual pellet fines during the conversion of wüstite to iron.

Singh et al. have reported equal amount of swelling (approximately 31 vol-%) with cold-bonded briquettes under quite similar reduction conditions. They conducted the laboratory experiments under simulated BF conditions in N₂–CO–CO₂–H₂ gas at 10 l/min flow rate. They also found that in an experimental BF the amount of swelling was at lower level. (< 15 vol-%).

Singh et al. detected catastrophic swelling (>100 vol-%) of cold-bonded briquettes in the experiments which were conducted under isothermal conditions at 950°C using N₂–CO (60:40). They suspected that the catastrophic swelling takes place in three steps: disintegration of pellet fines particles, formation of slag with low melting point and generation of localized high gas pressure owing to formation and oxidation of metastable iron carbide. Formation reaction of Fe₃C is shown in Eq. (16).

\[
3FeO + 5CO = Fe₃C + 4CO₂ \quad \text{............. (16)}
\]
The Fe₃C phase was not identified in the XRD analyses of this study, which explains the lack of catastrophic swelling due to formation of metastable iron carbide.

The cause of catastrophic swelling in iron ore pellets is known to be due to growth of iron whiskers in wüstite reduction. The growth of iron whiskers has been shown to be increased in certain conditions and in the presence of CaO. The mechanism of whisker growth should be also considered for the cause of swelling of the briquettes in the present experiments because they consist of these raw materials. The GGBFS addition in the briquette basically increases the amount of CaO and decreases the amount of iron oxides which might have an effect on the swelling behavior.

5. Conclusions

The reduction behavior tests were made on cold-bonded by-product briquettes under simulated BF conditions. The following conclusions were made from the experiments:

1. The briquettes showed significantly faster reduction compared to a reference pellet when reduced to metallic iron at 780–1100°C temperature. The self-reduction effect is probably achieved by the coke and the increased porosity due to decomposition reactions.

2. An increase of 25–50% in the volume of briquettes was detected during the wüstite-iron reduction step at 900–1000°C.

3. GGBFS addition had a slight increasing effect on the swelling of the briquettes. The effect was more pronounced with 3% addition than with 6% addition.

4. Phase transformations occurring in the briquette are in agreement with the theory and briquettes can be predicted to follow the phase transformation path in the actual BF process.

5. The structure of the briquette does not disintegrate in the BF conditions even though the cement phases decompose in the high temperature of the BF process. The phase transformation of Ca(OH)₂ first to CaCO₃ and secondly to Ca₂Fe₂O₅ may have an effect on this behavior.

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