INVESTIGATION OF COKE PROPERTIES WHILE DESCENDING THROUGH AN EXPERIMENTAL BLAST FURNACE

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Abstract

A high and a low CRI coke were tested in the LKAB’s Experimental Blast Furnace (EBF) at Luleå. Frequent probe sampling from two shaft probes and an inclined probe going through the cohesive zone area was done. In addition to this, one tuyere core drilling took place for each coke quality. Process differences were recorded and analysed. The evolution of physical and chemical properties of the sampled coke were analysed by XRD. The inorganic phases of the EBF cokes was analysed by XRF. The CO₂ reactivity of the coke samples was measured under non-isothermal conditions (1300°C) using Thermo Gravimetric Analysis (TGA). The anisotropic/isotropic relation of the coke carbon texture was measured by a light optical microscope. The tuyere core sample was divided into four segments and analysed, with use of above mentioned methods, as well as porosity studies by light optical microscope.

The order of carbon structure and the concentration of alkali species were increased as coke passed through thermal reserve zone to the cohesive zone of the EBF. The alkali concentration of the EBF coke was increased with increasing depth until the coke reached tuyere level. There was a higher alkali uptake for the high CRI coke. The CO₂ reactivity of coke was found to increase with increasing depth of the EBF from top, and was related to the catalytic effect by increased alkalis in coke. The TGA test indicated only small differences between high quality and poor quality coke. Starting from different levels of anisotropy of the feed cokes, the isotropic carbon texture of both coke types increased during its descent in the EBF. The main result of these measurements is that the isotropic coke carbon components are more metallurgical treatment resistant under load of the EBF.

Introduction

Blast Furnace (BF) is the most dominant process of iron making worldwide. In addition to ferrous burden coke is the raw material charged into the BF which has a strong influence on the process efficiency and hot metal quality. Both economic and environmental pressures demand a reduction in coke consumption in blast furnace process. At present there is an increasing focus on replacing coke by injecting cheaper coal or other reductants through tuyeres. At low coke rate operation, less amount of coke is available in the BF for melting of ferrous burden, providing gases for iron oxide reduction and to maintain the gas/liquid permeability. Therefore, the optimised coke quality is becoming increasingly critical for the efficient operation of a blast furnace.

A range of quality tests have been developed to characterize degradation potential of coke in a blast furnace. Today the Coke Reactivity Index (CRI) and the Coke Strength after Reaction (CSR), developed by Nippon Steel Corporation (NSC), Japan is the most widespread test to
assess the effect of solution loss reaction on coke strength. The CRI/CSR test is adopted by ASTM and is also being considered for ISO standard\textsuperscript{11,2}. High CSR coke is believed to prevent the coke from breaking down, improve the permeability of gas and liquid and increase the productivity as well as decrease the specific coke consumption\textsuperscript{3}. During the test, 200 g of coke crushed to 19-22.4 mm, reacts with CO\textsubscript{2} gas at 1100 °C during 2 hours. CRI is defined as the mass loss after gasification reaction. CSR is measured in “CSR drum” rotating the reacted coke at 20 revolutions per minute during 30 min. CSR is defined as the weight percentage of coke over 10 mm after the rotation. The main factors affecting negatively coke CSR are obtained to be an increase in carbon texture isotropy and ash basicity.

As the coke moves towards lower zones of a blast furnace, it degrades and generates fines, which in each separate case weakens BF permeability and process efficiency. Blast furnace tuyere core drillings during the monthly stoppages of industrial blast furnaces have given new information about coke degradation at higher temperatures than 1100 °C. At tuyere level there is a pronounced influence of thermal impact on coke\textsuperscript{5}. Reactions combined with breakdown of silicate minerals generate new micro-void in carbon textures and is believed to weaken coke resistance. With an increase in temperature carbon textures begin to decompose by graphitization. Speed of texture graphitization is in turn catalysed by molten iron and also slag accretions\textsuperscript{6}.

An exact alkali role on coke degradation has far remained unclear. Alkalis sublimate into coke without affecting its size or strength in an operating blast furnace at temperature range of 800-850°C\textsuperscript{6}. Alkali impregnation is known to speed-up the solution loss reaction such that the CRI values for coke have significantly increased depending on free potassium content and coke properties\textsuperscript{8,9}.

The potassium content of coke varies at different locations of an operating blast furnace, e.g. at tuyere level alkalis are completely vaporised at high temperatures of the raceway but deadman coke ash in the BF centre could contain up 30 % of potassium oxide \textsuperscript{8,11,12}. First of all alkalis are fixed in aluminosilicates\textsuperscript{13}.

The free potassium adsorption is believed to be a function of carbon textures in coke as well as temperature\textsuperscript{14}. For example, potassium penetration into isotropic textures, compared to high anisotropic domains, is shown to be greater with temperatures 1000 -1200 °C and is related to macropore size and surface area\textsuperscript{14}. Generally, alkalis are believed to cause breakage of coke by the selective reactions with different ordered carbon forms.

The main focus of this investigation is to study different coke qualities in an experimental blast furnace. The measurements of texture and porosity distributions with the ash chemistry of the EBF coke samples from several locations are presented. Changes in low and high CSR cokes formed during passage in the EBF are compared with each others. The differences in the process were also studied.

**Experimental**

**Experimental Blast Furnace**

The EBF has a working volume of 8.2 m\textsuperscript{3} and a hearth diameter of 1.2 m and is 6 m high from stock line to tuyere. It has been described in details elsewhere\textsuperscript{15-17}.
EBF trial with poor quality coke

The trial took place in the spring of 2004 and consisted of two parts i.e. a two days reference period with a low CRI coke followed two days of operation with high CRI coke.

Figure 1 Illustration of the Experimental Blast Furnace and the approximate positions of the probes

Solid sampling occurred at three positions, i.e. upper shaft, lower shaft and through the cohesive zone, see Figure 1. In addition a tuyere core drilling was done.

The sampled coke material was separated from slag fluxes and pellets. Prior to x-ray diffraction, XRF and TGA reactivity measurements, small coke lumps (approximately 6-8 cm³) were selected from each probe and crushed to powder (< 75 micron).

The tuyere drill core was divided in four equally large segments and labelled Centre, Mid 1, Mid 2, and Wall. Thereafter the samples were sieved to fractions of -19 mm, 19-22.4 mm and +22.4 mm. The samples labelled Centre thus represent coke from the centre of the furnace at tuyere level.

The process parameters were altered as little as possible when reductant changed. Same amount of coal injection was used. The cokes were very different in quality, as can be seen in Table I.
Table I: Properties of the feed coke used in the current study

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Low CRI coke</th>
<th>High CRI coke</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRI</td>
<td>19</td>
<td>48</td>
</tr>
<tr>
<td>CSR</td>
<td>72</td>
<td>35</td>
</tr>
<tr>
<td>Fe</td>
<td>0.35</td>
<td>1.05</td>
</tr>
<tr>
<td>SiO₂</td>
<td>6.14</td>
<td>4.72</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.022</td>
<td>0.053</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>2.82</td>
<td>2.26</td>
</tr>
<tr>
<td>MgO</td>
<td>0.04</td>
<td>0.2</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.04</td>
<td>0.11</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.14</td>
<td>0.22</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.18</td>
<td>0.1</td>
</tr>
</tbody>
</table>

**XRD of Cokes**

A Siemens 5000 X-ray diffractometer was used to measure the carbon structural parameters including degree of coke graphitisation. XRD patterns were obtained by recording the scattering intensities by using Copper Kα radiation (30 kV, 30 mA) as the X-ray source. Coke powder was packed into an aluminium holder and scanned over an angular range from 5-105° using a step size of 0.05° and collecting the scattering intensity for 5 seconds at each step. Carbon structure of coke is often related to the reactivity as well as graphitization. Graphite structure can be described as regular, vertical stacking of hexagonal aromatic layers. Graphitization degree of the EBF cokes was characterized by the crystallite height of coke carbon (Lc), and was evaluated by analysing the 002 carbon peak of the XRD pattern. The XRD data was processed to obtain the crystallite height (Lc) of coke carbon. Average stack height (Lc) of the 002 carbon peak was calculated using Scherrer’s equation by using K = 0.89.

A sharper 002 peak indicates a larger carbon crystallite and a greater degree of ordering of the carbon structure of coke or graphitisation.

**TGA Reactivity of Cokes with CO₂**

Non-isothermal reactivity was measured by using 60~80 mg of coke powder in an Al₂O₃ crucible with the help of Netzsch STA 409 Thermal Gravimetric and Differential Thermal Analyser (TGA/DTA). All the EBF cokes were reacted under dynamic heating up to 1300 °C with a heating rate of 10°C/minute and a CO₂ flow rate of 100 ml/min.

**Micro texture measurement**

The change in the coke microstructure passing the EBF was measured by an automated microscopic measuring procedure developed at TKS to quantify the ordering of the coke carbon microstructure. This measuring procedure is based on the optical physics of the bi-reflectance. The dimension of the bi-reflectance is recorded using a linear polarising filter in the reflected light of the sample at various polarisation degrees.

The microscope employed is equipped with a scanning stage, an auto focus system and a power-driven polarizer in the reflected microscopic light. An adapted image analysing system enables quantification of quantify the degree of anisotropic and isotropic components calculated from the optical bi-reflectance.
Using this method at both coke operations (high and low level CRI) the feed cokes were investigated in comparison to the tuyere coke material sampled by the tuyere probe. The material of each tuyere core drilling was split radially into four segments. The material of each segment was screened into three fractions (<19 mm, 19-22.4 mm and > 22.4 mm) and then separated into coke, metal and slag components. From the crushed feed coke and each tuyere coke material a polished section was prepared for determination by this microscopic measurement technique.

Porosity measurements

Variation in porous structure was measured by using the analySIS 3.2 program and Olympus microscope with 520 magnifications. Coke porosity is calculated as the average value of the pieces measured for the tuyere segment.

Results & Discussion

In the EBF, coke undergoes many modification such as carbon structure and constituent minerals including alkali phases and porosity as discussed below. Each coke property could influence the coke behavior in an operating blast furnace particularly its strength. The trial with 100% high CRI / low CSR coke lasted for two days and was unique of its kind. With such poor quality regarding strength, it would have been very difficult, if not impossible, to try this in a full scale blast furnace. But it was possible to try it in the EBF and the interesting aspect was the high CRI value.

Process analysis

Operational data, compared to a reference period with low CRI coke, is shown in Table II.

<table>
<thead>
<tr>
<th>Blast parameters</th>
<th>Reference low CRI</th>
<th>Trial high CRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>blast volume</td>
<td>nm3/h</td>
<td>1595</td>
</tr>
<tr>
<td>oxygen addition</td>
<td>%</td>
<td>1.3</td>
</tr>
<tr>
<td>blast moisture</td>
<td>g/nm3</td>
<td>23</td>
</tr>
<tr>
<td>Reductants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>coke rate</td>
<td>kg/thm</td>
<td>436</td>
</tr>
<tr>
<td>coal rate</td>
<td>kg/thm</td>
<td>103</td>
</tr>
<tr>
<td>reductant rate</td>
<td>kg/thm</td>
<td>539</td>
</tr>
<tr>
<td>Hot Metal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>%</td>
<td>4.39</td>
</tr>
<tr>
<td>Si</td>
<td>%</td>
<td>1.99</td>
</tr>
<tr>
<td>S</td>
<td>%</td>
<td>0.022</td>
</tr>
<tr>
<td>temperature °C</td>
<td></td>
<td>1451</td>
</tr>
<tr>
<td>Slag</td>
<td></td>
<td></td>
</tr>
<tr>
<td>volume</td>
<td>kg/thm</td>
<td>147</td>
</tr>
<tr>
<td>CaO/SiO2</td>
<td></td>
<td>0.98</td>
</tr>
<tr>
<td>Top gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>temperature °C</td>
<td></td>
<td>188</td>
</tr>
<tr>
<td>Eta CO</td>
<td></td>
<td>0.46</td>
</tr>
<tr>
<td>Flue dust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>amount</td>
<td>kg/thm</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>%</td>
<td>41</td>
</tr>
<tr>
<td>Fe</td>
<td>%</td>
<td>20</td>
</tr>
</tbody>
</table>
The most important results are summarised as follows:

- The coke rate was increased by more than 30 kg/thm.
- Even with the much higher reductant rate it was not possible to keep an acceptable hot metal heat level. Silicon content and hot metal temperature was significantly lower and sulphur content much higher. Surprisingly, the carbon content was not so much influenced.
- The gas utilisation was significantly increased, although with very high fluctuations, as shown in Figure 2. The same phenomena occur in the EBF when operating with a ferrous burden with a high degree of swelling and disintegration.
- Higher slag volume and lower basicity, because of lower silicon content in the hot metal.
- The temperature distribution in the EBF was changed in such a way that the temperature in the lower shaft became much higher. The cohesive zone moved upwards which was also verified from shaft pressure measurements.
- The amount of flue dust was almost tripled, but the carbon content only increased by 30%, indicating a more irregular gas flow, also causing also more iron units to leave the furnace with the gas.

![Figure 2 Gas utilization for the reference and trial period. The arrow corresponds to the change from reference coke to the trial coke](image)

Evolution of Carbon Structure

Figure 3 and 4 compares the XRD patterns of cokes from four representative locations of the EBF. It is seen that the width of the 002 carbon peak becomes sharper as the coke descends. The background intensity of lower zone coke samples (e.g. tuyere level) are less than those of coke samples from the upper part of the EBF (upper shaft samples). Low background intensity is indicative of less proportion of amorphous carbon. The amorphous carbon of coke was found to decline sluggishly up to the cohesive zone, and changed rapidly as the coke descended in the hearth regions of the EBF. This means that coke carbon becomes increasingly ordered as the coke passes from thermal reserve zone to bosh region while amorphous carbon is increasingly depleted.

The comparison between the high and low CRI coke reveals that the temperature profiles have been different. It verifies the fact that the cohesive zone was shifted upwards during the trial period with high CRI coke.
The so-called Lc value was calculated using Scherrer’s equation:

\[ Lc = \frac{0.89 \times \lambda}{\beta \times \cos(\theta)} \]

where \( \lambda \) is the wavelength x-ray radiation, \( \beta \) is the FWHM (Full Width at Half Maximum) and 2\( \theta \) is the centre of the 002 carbon peak.

![Figure 5 Calculated Lc values from x-ray diffraction spectrum](image)

The Lc increases as the coke descends which can be seen in Figure 5. The lower Lc value generated from the trial coke from the tuyere core centre can be explained by the lower hot metal
temperature i.e. lower heat level in the hearth. The Lc value is higher for coke found in the centre than for coke found at the wall side, thus indicating higher temperature at the centre.

Evolution of Coke Ash Chemistry

The XRF analyses of the EBF coke samples are provided in Table III. In addition to carbon structure, coke ash chemistry is also continuously changed in the EBF for both coke qualities.

Table III: Chemical composition. The reference low CRI coke corresponds to number 1 and the high CRI trial coke corresponds to number 2. C stands for Centre, and W for Wall

<table>
<thead>
<tr>
<th>XRF</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe</th>
<th>CaO</th>
<th>MgO</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>TiO₂</th>
<th>P₂O₅</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed 1</td>
<td>4.66</td>
<td>0.35</td>
<td>0.08</td>
<td>0.15</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed 2</td>
<td>4.72</td>
<td>1.05</td>
<td>0.62</td>
<td></td>
<td></td>
<td>0.22</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper 1</td>
<td>4.07</td>
<td>2.54</td>
<td>1.04</td>
<td>0.50</td>
<td>0.25</td>
<td>0.18</td>
<td>0.09</td>
<td>0.16</td>
<td>0.10</td>
<td>0.53</td>
</tr>
<tr>
<td>Upper 2</td>
<td>5.79</td>
<td>2.68</td>
<td>0.76</td>
<td>0.28</td>
<td>0.13</td>
<td>0.23</td>
<td>0.09</td>
<td>0.13</td>
<td>0.04</td>
<td>0.74</td>
</tr>
<tr>
<td>Lower 1</td>
<td>3.92</td>
<td>2.62</td>
<td>0.81</td>
<td>0.40</td>
<td>0.23</td>
<td>1.03</td>
<td>0.26</td>
<td>0.14</td>
<td>0.11</td>
<td>0.55</td>
</tr>
<tr>
<td>Lower 2</td>
<td>5.42</td>
<td>2.47</td>
<td>1.54</td>
<td>0.60</td>
<td>0.22</td>
<td>0.89</td>
<td>0.19</td>
<td>0.10</td>
<td>0.06</td>
<td>0.82</td>
</tr>
<tr>
<td>Inclined 1</td>
<td>4.15</td>
<td>2.50</td>
<td>0.73</td>
<td>0.38</td>
<td>0.21</td>
<td>1.47</td>
<td>0.26</td>
<td>0.14</td>
<td>0.08</td>
<td>0.55</td>
</tr>
<tr>
<td>Inclined 2</td>
<td>5.82</td>
<td>2.49</td>
<td>1.46</td>
<td>1.45</td>
<td>0.41</td>
<td>2.95</td>
<td>0.62</td>
<td>0.09</td>
<td>0.07</td>
<td>0.77</td>
</tr>
<tr>
<td>Tuyere 1 C</td>
<td>2.91</td>
<td>2.87</td>
<td>0.98</td>
<td>3.42</td>
<td>1.30</td>
<td>0.10</td>
<td>0.01</td>
<td>0.23</td>
<td>0.06</td>
<td>0.40</td>
</tr>
<tr>
<td>Tuyere 2 C</td>
<td>1.93</td>
<td>2.58</td>
<td>1.42</td>
<td>1.18</td>
<td>1.20</td>
<td>0.69</td>
<td>0.16</td>
<td>0.12</td>
<td>0.015</td>
<td>0.40</td>
</tr>
<tr>
<td>Tuyere 1 W</td>
<td>8.47</td>
<td>4.83</td>
<td>0.54</td>
<td>0.67</td>
<td>0.20</td>
<td>0.35</td>
<td>0.09</td>
<td>0.24</td>
<td>0.008</td>
<td>0</td>
</tr>
<tr>
<td>Tuyere 2 W</td>
<td>6.31</td>
<td>4.12</td>
<td>1.40</td>
<td>2.17</td>
<td>0.40</td>
<td>1.02</td>
<td>0.24</td>
<td>0.18</td>
<td>0.02</td>
<td>0.50</td>
</tr>
</tbody>
</table>

The alkali uptake is higher for the high CRI coke as can be seen in Table III and Figure 6a). It is clear that the increase of potassium and sodium is proportional. However, the amount of potassium is much higher for all samples. Figure 6b) reveals the alkali distribution in the tuyere core probe. It can be seen that the highest amount of alkali is found at the wall side of the EBF. Further, the low CRI coke had very little sodium and potassium when compared with the high CRI coke. The reason to this could be the much different temperature profile in the hearth which is verified by the Lc measurements.

![Figure 6a) Alkali in coke as a function of samples b) Alkali distribution in tuyere core.](image-url)
Because of the different size distribution between the drill cokes, the amount of -19 mm trial coke and +22.4 mm reference coke were enough for ash chemical analysis. Iron catalyses noticeable carbon gasification, independent of texture type. A decrease in SiO₂/Al₂O₃ ratio in ash, see Figure 7, refers to an intensive silica vaporisation of silicates from furnace wall to centre. It is clear that with higher temperature there is an increase in the coke porosity. Silicate breakdown catalysts dissolution of surrounding carbon and mosaic textures starts to change color as an indication of graphitization. Proportion of carbon textures, which are enriched in silicate dissemination and secondary graphite, should be decreasing, not necessarily isotropic texture reacting easy with CO₂.

Alkalis are known as a low temperature indicator when connected with silicates. For the high CRI coke the increased alkali seems to be connected with the carbon textures. The more of isotropic carbon phases in the coke, the higher the potassium uptake and, maybe, abrasion of the coke. An influence of alkalis on carbon disappearance is not clear in any way. Even gasified areas inside fused isotropic textures are detected. At the tuyere level there seems to be a more dominant relationship between silica vaporization from silicates and increased coke porosity. However, there seems to be a positive relationship between increased gasification spots of isotropic texture and coke porosity. A small decrease of the high CRI coke porosity with an increase with alkali content can be seen.

![Chemical differences of tuyere coke ash](image)

Figure 7 Silica and aluminium oxide and alkali content in coke found in tuyere core

**Evolution of Coke Reactivity in the EBF**

A TGA comparison between feed, upper, lower, inclined probes, as well as tuyere core probe for both high and low CRI coke was done. Figure 8 to 10 compares the non-isothermal reactivity of the EBF coke. The weight losses of lower zone cokes are consistently higher compared to upper zones coke samples. This implies that the reactivity of coke increases as it descends into the EBF. The coke reactivity is often related to the carbon structure, surface area and coke minerals. In previous section it was seen that carbon structure of lower zone EBF cokes was increasingly ordered. Therefore, the carbon structure alone could not be responsible for increased reactivity of lower zone coke samples as increased crystalline order of carbon is believed to retard the reactivity.

Figure 8a compares the feed of the high and low CRI cokes. The solution loss reaction starts earlier for the high CRI coke and at 1300°C the weight loss is 53 % for the trial coke and 46 % for the reference coke. However, the trial coke had approximately 5 % higher moisture content.
In Figure 8b) the upper probe samples of the reference and trial coke are compared. It is interesting to notice that the low CRI coke actually reacts faster than the high CRI coke. The mass change is 64 % and 37 % respectively. The same pattern is seen in Figure 9a) and b). At tuyere level the high CRI coke does react faster and has a greater mass loss, see Figure 10a) and b). However, it is a little difference and one would expect a much larger difference.

![Figure 8: Reference and trial coke from upper probe](image1)

![Figure 9: Reference and trial coke from lower probe](image2)

![Figure 10: Reference and trial coke from tuyere level](image3)
The TGA study implies that the CRI value have little influence when the coke have been crushed, thus suggesting that structure plays a dominant role.

**Isotropic / anisotropic changes in the coke carbon microstructure**

In Figures 11a) and 11b) the results are presented as reduced to the Anisotropic\textsubscript{total} and Isotropro\textsubscript{total} components as mean values of the different fractions. With respect to the measuring method the Anisotropics and the Isotropics are detected in close correspondence, i.e. the sum always results in 100%.

The measurements of the feed cokes result in very different levels of the detected anisotropy. The high quality reference coke contains 79 vol.% Anisotropics corresponding to 21 vol.% Isotropics, the low quality high CRI coke is 62 vol.% of Anisotropics and 38 vol.% Isotropics. This result reflects a very different origin of the coals (coal blends) used for the coke types determined.

With respect to the coke texture of the tuyere coke at both operations the Isotropics increase towards the centre of the EBF. In the case of the high CRI coke at the centre an increase of 10% in the Isotropics is corresponding to a 10% decrease of the Anisotropics towards the centre. The changes in the high quality reference coke are less, in the Isotropics an increase of up to 5% corresponds with a 5% decrease in the Anisotropis.

With respect to the behaviour of these cokes during descending in the EBF it can be concluded, that the isotropic carbon components are more metallurgical treatment resistant under load of the EBF compared to the anisotropic components. Apparently the gasification attacks the anisotropic carbon components more than the Isotropics.

**Porosity differences**

The tuyere drill core was divided in four segments, i.e. Centre, Mid 1, Mid 2, and Wall. It was then sieved to fractions of -19 mm, 19-22.4 mm and +22.4 mm. Variation in tuyere coke porosity by the image analysis was measured using 19-22.4 mm drill coke. The 50 g image analysis sample of about 10 coke pieces is constructed at the same weight distribution as inside the 19-22.4 mm drill core.

Variation in porous structure was measured for two sets of tuyere coke, low and high CRI, see Figure 12 and 13. Coke porosity is calculated as the average value of the pieces measured for the tuyere segment. The image analysis shows a greater porosity percent for low CRI coke which
gently increases towards the EBF centre, see Figure 14. A similar increasing porosity line is true for the high CRI coke but an opposite downward trend in the EBF centre.

![Low CRI coke porosity versus pore area](image)

Figure 12 Pore area vs. porosity for the reference coke

![High CRI coke porosity versus pore area](image)

Figure 13 Pore area vs. porosity for the trial coke

![Tuyere coke porosity versus pore area](image)

Figure 14 The tuyere coke porosity vs. pore area for both of the coke types
Conclusions

A test with a poor coke quality (high CRI/low CSR) was conducted in an experimental blast furnace. Comparison was made with a reference period using high quality coke (low CRI/high CSR). Evolution of coke properties particularly carbon structure and alkali uptake were related to CO₂ reactivity. On the basis of this study, following conclusions were made.

1. Process: The cohesive zone was shifted upwards during the high CRI coke trial. The gas utilization was higher but more fluctuating during the trial period. Despite a much higher reductant rate, hot metal temperature was too low. Flue dust generation was significantly higher for the trial period.
2. Graphitisation: The graphitisation increased as the cokes descended through the EBF. The degrees of graphitisation were different for the high and low CRI cokes when comparing feed and tuyere samples which verify different temperature profiles.
3. Alkali uptake is higher for high CRI coke. This could be explained by a higher specific surface area for the high CRI coke.
4. TGA with CO₂: The CO₂ reactivity of coke was found to increase during progressive movement of the coke from thermal reserve zone to cohesive zone of the EBF, and was related to the catalytic effect of increased alkali concentration in coke. This was the same for both cokes. CRI plays little role when comparing reactivity with CO₂ of crushed sample in TGA.
5. Porosity: The tuyere drill results indicate a higher porosity and larger pores for both cokes at the centre where the temperature has been higher. The reference coke has a higher porosity but smaller pores.
6. Isotropic/anisotropic changes: Starting from different levels the anisotropic coke carbon components decreased and the isotropic components correspondingly increased as the coke descended through the EBF. Thus the isotropic coke components seem to be more metallurgical treatment resistant.

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