Fuel 200 (2017) 89–99

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Petrographic analysis and characterisation of a blast furnace coke and its wear mechanisms

Hannah Lomas [a,*,1], Richard Roest [a,1], Sushil Gupta [b], Richard A. Pearson [c], Robert Fetscher [a], David R. Jenkins [d], Robin Pearce [d,2], Riku Kanniala [e], Merrick R. Mahoney [a]

[a] *Centre for Ironmaking Materials Research, School of Engineering, The Newcastle Institute for Energy and Resources, University of Newcastle, Callaghan, NSW 2308, Australia*
[b] *School of Materials Science and Engineering, UNSW Australia, Sydney, NSW 2052, Australia*
[c] *Pearson Coal Petrography, 1-740 Discovery Street, Victoria, BC, Canada*
[d] *CSIRO Data61, 11 Julius Ave, North Ryde, NSW 2113, Australia*
[e] *SSAB Europe, Raahe, Finland*

HIGHLIGHTS

- Coke samples were retrieved from the tuyere drilling of an operating blast furnace.
- Petrographic analysis of the blast furnace feed and tuyere cokes was carried out.
- Tribological testing compared the wear behaviour of the feed and tuyere cokes.
- Mechanisms of coke wear varied with location from the blast furnace tuyere entrance.
- Coke wear modes were linked to coke microtexture and textural interfaces.

ARTICLE INFO

Article history:
Received 14 December 2016
Received in revised form 23 February 2017
Accepted 27 February 2017
Available online 27 March 2017

Keywords:
Blast furnace coke
Coke microtexture
Coke strength
Petrography
Tribology
Wear

ABSTRACT

Petrographic analysis of coke samples from the tuyere level of an operating blast furnace was carried out using a combination of advanced microscopy techniques including high resolution bireflectance and maximum reflectance measurements. A novel tribological approach was employed to investigate the wear mechanisms of the same cokes. The study showed that the wear mechanisms of coke are influenced by its microstructure and microtexture, as well as the strength and nature of the interfaces between the different coke textural constituents. The wear mechanisms of the cokes were found to vary with location from the tuyere entrance of the blast furnace and also differed to the feed coke. This is the first example of the application of petrographic analysis of cokes from an operating blast furnace to identify the difference in hardness and interaction strength of the distinct coke textural constituents. This research contributes towards improving understanding of the complex mechanisms of coke degradation in operating blast furnaces.

1. Introduction

Both the microstructure and microtexture of metallurgical coke are complex, a consequence of its inherent heterogeneous nature. Coke microtexture refers to the different forms of carbon present. Depending on whether the carbon came from material that fused during coking or material which did not they are classified into reactive maceral derived components (RMDC) and inertinite maceral derived components (IMDC) respectively. These distinct forms of carbon differ in their degree of optical anisotropy, with IMDC showing low anisotropy [1].

Petrography is an important tool in characterising and quantifying coke microtexture [2]. Although automated coke petrography has been used to characterise coke microtexture since the 1980s [3], recent advances [4–6], particularly to the algorithms used to classify the different forms of carbon based on their bireflectance (which depends on the degree of anisotropy) and mean maximum coke reflectance (which depends on coal rank) [7], have greatly facilitated the application of petrography for the characterization of various coke attributes [8,9]. In addition, a reliable link between

---

* Corresponding author.
E-mail address: Hannah.Lomas@newcastle.edu.au (H. Lomas).

[1] HL and RR contributed equally to this work.

[2] Current address: School of Mathematics and Physics, University of Queensland, St Lucia, QLD, Australia.

http://dx.doi.org/10.1016/j.fuel.2017.02.100

coke microtexture and its blast furnace performance has not yet been developed, thus there remains considerable interest from industrial operators regarding advances in this area.

Recently, we used a tribological approach to understand the mechanisms by which pilot oven coke samples are worn or damaged at room temperature [10,11]. Abrasion ('scratching' of the softer coke surface by the indenter), adhesion (transfer of material from the coke surface to the indenter) and delamination (subsurface cracks parallel to the surface) were identified as the main wear mechanisms applicable to coke strength at room temperature. The tribological experimental approach was found to be a highly effective as well as novel method to distinguish between textures of differing hardness (within both IMDC and RMDC) based on their relative resistance to abrasive wear. Moreover, it was possible to determine the strength and nature of RMDC-IMDC interactions based on the propensity of the IMDC to undergo adhesive and delamination wear. Poorly bonded IMDC were displaced from the boundary with the RMDC.

The mechanisms by which cracks propagated at the IMDC-RMDC interface were also clarified through the tribological tests and gave an indication of the strength and nature of the bonding at the inert interfaces. For example, cracks which propagated intergranularly, i.e. via the boundary of the inert, indicated that the inert was weakly bound to the RMDC, whilst transgranular cracks, i.e. cracks which propagated through the inert, implied either that the inert was 'weak'/'soft' and/or that the inert had a strong interaction with the RMDC. The roughness of the surface of cavities at which inert particles or RMDC material were removed from the microstructure during tribological testing also gave an indication of the strength and nature of the RMDC-IMDC interactions.

In this paper, we present the findings of petrographic and tribological analysis of cokes collected by tuyere sampling from an operating blast furnace. We compare the microstructural and microtextural features of the cokes, and their wear behaviour under tribological testing.

2. Experimental

2.1. Coke sample selection

Coke lumps from four selected locations in a tuyere core from an operating blast furnace with oil injection (BF#2 located at SSAB Europe, Raahe, Finland) plus the matched feed coke were used for this study. Further details of the tuyere drilling and blast furnace operations can be found in a previously published project report [12]. Fig. 1 [13] shows a diagram of the blast furnace with the bosh, raceway and deadman regions labelled, which are the regions of the furnace that the tuyere coke lumps were representative of. A blend of 5 coals plus petroleum coke (pet coke) (5%) was used to form the feed coke. Key strength indices of the feed coke, including its strength after reaction with carbon dioxide (CSR) index and IRSID tumble drum indices, are shown in Table 1. The ash chemistry analysis of the feed and each of the tuyere cokes is shown in Table 2. Proximate and ultimate analysis of the feed and each of the tuyere cokes is displayed in Table 3. Due to limited samples, two coke lumps greater than 19 mm in size were analysed for each test sample.

2.2. Sample preparation

Coke lumps were cut in half or into 10–20 mm thick slices using a diamond saw and embedded in rectangular polyester resin mounts. The coke blocks were then polished to a 3 μm finish and cut using a diamond saw into 50 × 50 mm blocks, with a maximum block height of 10 mm.

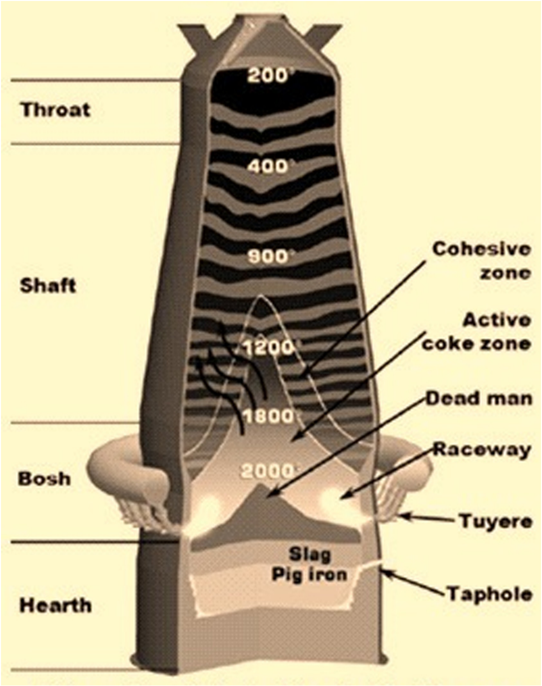

Fig. 1. [13] Diagram of the blast furnace, with the bosh, raceway and deadman regions labelled.

Table 1
Strength indices measured for the feed coke.

Coke strength index	Feed coke
Coke strength after reaction with CO_2 (CSR) index	66.4
Coke reactivity index (CRI)	21.2
I_{40} index	53.8
I_{10} index	19.0

2.3. Petrographic analysis

Coke petrographic analysis was carried out at Pearson Coal Petrography Inc. (Victoria, BC, Canada) using a previously established method [4]. Imaging was performed using a Zeiss reflected light microscope equipped with a rotating polarizer in the incident light path.

The number of image locations recorded per individual coke sample varied from 5395 for the smallest bosh coke sample (at a resolution of 0.9 μm per pixel) to 12,656 for the largest bird's nest coke sample (at a resolution of 1.1 μm per pixel). The individual images were then mosaicked together to produce an image of the entire sample. The maximum and minimum reflectance values for each pixel in the field of view were determined by rotating the polarizer on the microscope (18 times at 10° rotation per step) and recording the reflectance of each pixel at each step [4]. The bireflectance values for each pixel were then obtained by subtracting the minimum from the maximum reflectance values. The Anisotropy Quotient (AQ) was also calculated for each pixel, using the formula (bireflectance/$R_o$max) * 10 [5].

Quantitative identification of eight types of carbon was made from cross plots of coke bireflectance with coke $R_o$max reflectance, using algorithms developed at Pearson Coal Petrography to distinguish between the different types [4].

2.4. Tribological testing

Rotational ball-on-disk tribology experiments were conducted following our previously reported method [10]. A CETR tribometer