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Full Length Article

Fractographic approach to metallurgical coke failure analysis. Part 2: Cokes from binary coal blends

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HIGHLIGHTS

- Failure profiles were constructed for cokes from single coals and binary blends.
- Fractography was used to examine and quantify the coke breakage behaviour.
- Non-linear effects were seen in the breakage behaviour of cokes from binary blends.
- The grain boundaries have a significant effect on the metallurgical coke strength.

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ABSTRACT

Metallurgical coke used in blast furnaces is the result of blending coals to achieve the optimum coke strength properties. Prediction of coke strength from coal properties relies primarily on statistical methods. Improvement of these models is desirable. We believe a better understanding of the fundamental factors controlling coke strength is required to achieve this.

In this second of a series of three papers, we apply our recently developed fractographic approach to examine and quantify the breakage behaviour and microstructural weaknesses in pilot oven metallurgical cokes from two series of single coals and binary blends of the coals. We have successfully applied fractography to perform an effective failure analysis of the complex, heterogeneous coke material. Summaries of the factors contributing to the failure of each coke studied have been presented as radar graphs. These graphs demonstrate that the failure profile of the cokes from blends is not simply a weighted average of the fracture behaviour of the cokes from the constituent single coals. Instead, non-additive effects are observed, and this may have implications for the mathematical models widely used to predict coke behaviour and strength in the blast furnace.

Trends between the various fractographic parameters have been identified, and preliminary relation of these to both the maximum compressive strength of each coke and basic properties of the original coals, has been completed. Enhanced understanding of how the fracture behaviour of each coke relates to the properties of the coal blend used will help facilitate better prediction of coke strength from coal properties and ultimately optimisation of the coal blending process.

1. Introduction

Our recent research work has aimed to better understand coke microstructural features determining coke strength as well as address the discrepancies in estimating coke strength from coal properties by applying a novel method to assess the factors impacting coke strength. Our approach uses the technique of fractography to break whole stabilised coke lumps analogous to those used in the blast furnace and then analyse the fractured surfaces to determine how and where the coke fractured, as detailed in the first of this series of three papers [1]. This technique allows for identification of the microstructural weaknesses and mechanisms by which the fractures propagate through the coke, and differs significantly to the largely statistical [2,3] and modelling based [4–6] approaches which have dominated coke strength research to date.

Our previous publication (Part 1) [1] examined the application of fractographic techniques widely used to understand the root cause of mechanical failure in other material systems such as metals and ceramics, to build a detailed picture of the contributing

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causes of the failures observed in lumps of a pilot oven metallurgical coke. This was achieved by decoding the fracture surface topography of the broken coke lumps, which led to the identification of the factors that contributed to the failure of the coke, as well as surface markings indicating the direction of failure and energy involved. This was the first example in which these features were comprehensively identified and used to establish the fracture origin(s), fracture path and the stresses the coke had been subjected to.

The failure mechanisms were detected by applying a three-step analytical approach in which the fracture surfaces were analysed on the macro, micro and submicron levels. Furthermore, the modes of failure and microstructural weaknesses, such as agglomeration of pores at the interface between the IMDC and RMDC, were quantified, and summarised using a radar diagram.

This current paper furthers this initial study and applies the technique to a range of cokes from both single coals and binary blends of these coals. The selected coals covered a wide range of properties, including rank, vitrinite content and coking behaviour.

2. Experimental

2.1. Metallurgical coal selection

The basic properties of the metallurgical coals chosen for this study are summarised in Table 1. These coals were selected to cover a wide range of rank, vitrinite content and coking behaviour. Two series of cokes were prepared using the coals and coal blends shown in Table 2.

2.2. Coke preparation

Cokes were prepared in a pilot coke oven. Two different pilot ovens were used; however, the same oven and conditions were used for each coke in a given set. The conditions are summarised in Table 1 of the previous paper [1] and Ref. [7].

Fractographic analysis was applied to the cokes after they had been stabilised, i.e. dropped from a height to represent their transport via material handling systems, and loading into the blast furnace. This allows a more accurate picture of the physical degradation mechanisms of metallurgical coke when subjected to mechanical stresses as well as determination of whether the dominant breakage mechanisms vary between cokes prepared from different coals and coal blends.

2.3. Fractography – impact testing

Fractographic analysis of coke samples was carried out by impact testing, using a method we have recently developed for effective failure analysis of metallurgical coke [1,8,9]. In summary the technique followed was:

- Large coke lumps were fractured by repeated drops onto a plate until the lump broke.
- Smaller lumps (45–63 mm) were fractured by compression in a universal tester, as detailed in Part 1 [1].
- Fracture surfaces were examined with no magnification, then under a stereomicroscope and finally using a scanning electron microscope to determine the factors controlling the fracture.

The technique is detailed in our previous publications [1,9].

Table 1
Basic properties of the metallurgical coals used.

Coal	Volatile matter (%, dry basis)	Vitrinite content (%)	Description
A	32.9	79	Coking coal
B	26.0	41	Soft coking coal
C	19.4	53	Coking coal
D	18.4	64	Coking coal

Table 2
Coal blending ratios used to prepare cokes in Set One and Set Two.

Set One	Set Two
Coal B – 100%	Coal A – 100%
Coal D – 100%	Coal C – 100%
Coal B – 50%/Coal D – 50%	Coal A – 50%/Coal C – 50%
Coal B – 25%/Coal D – 75%	

2.4. Failure of coke discs by compression testing

Coke cores were prepared from lumps of coke (typically the 50–63 or 63–75 mm size fractions) using a 16.9 mm diameter core drill, and cut into discs of approximately 10 mm thickness using a diamond saw. Discs were then gently ground flat using sandpaper. Compressive strength tests were conducted as for the coke lumps (Section 2.3). Load versus displacement graphs were recorded, and the maximum compressive strength was calculated from the maximum load at failure and the cross-sectional area of the coke discs.

A minimum of 7 tests were conducted for each type of coke, using discs obtained from cores of at least two different coke lumps. The mean maximum compressive strengths were calculated from the dataset of a minimum of 7 tests, with the highest and lowest values removed. The values obtained thus give an *indication only* of the maximum compressive strength and allow a comparison between the different cokes.

2.5. Fractographic analysis

A three-step approach was applied to analyse and quantify the modes of failure and microstructural weaknesses observed on coke fracture surfaces, using the method we reported previously [1]. The failure mechanisms were determined by analysing fracture surfaces on the macro, micro and submicron levels and identifying the structural features contributing to the failure. The analysis technique produced a scaled output for each of the contributing factors (see Table 3). For each coke, multiple lumps were fractured in each of several size ranges and all the lump results were combined for statistical analysis.

The overall mean for each coke, the standard deviation of the values between lumps (not shown) and the standard deviation of the overall mean were calculated and are shown in Tables 4 and 5. Properties were assumed to follow a normal distribution. The compiled data was used to generate radar diagrams to summarise the contributing factors to the failure of each coke.

3. Results

3.1. Fractography results

We will discuss the failure modes observed for the various cokes based on their fractographic analysis. Descriptions of the key failure mechanisms and microstructural weaknesses observed in coke are given in our earlier publication (Table 4) [1].

3.1.1. Coke Set One

Coke Set One consists of four cokes; one each from coals B and D and two from binary blends of these coals.