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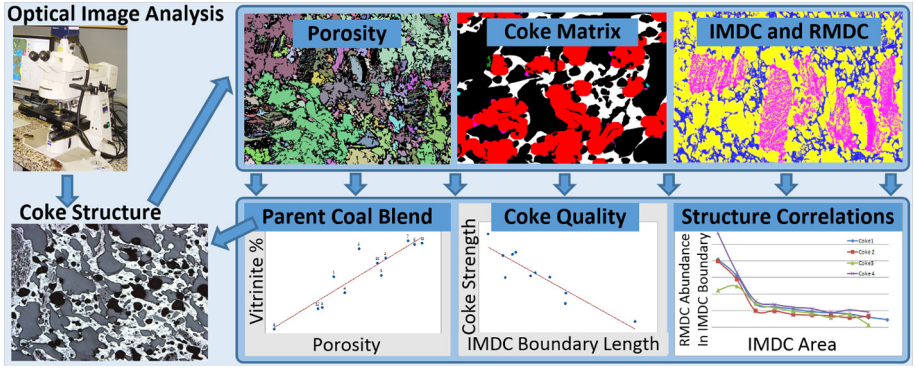
Novel optical image analysis coke characterisation and its application to study of the relationships between coke Structure, coke strength and parent coal composition

Eugene Donskoi [a,*], Andrei Poliakov [a], Merrick R. Mahoney [b], Oliver Scholes [c]

[a] CSIRO Mineral Resources, PO Box 883, Kenmore, QLD 4069, Australia
[b] University of Newcastle, University Dr, Callaghan, NSW 2308, Australia
[c] Vale International SA Route de Pallatex 29 1162 St-Prex Switzerland

GRAPHICAL ABSTRACT



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ABSTRACT

To better understand the connection between parent coal blend, coke structure, and coke strength novel structural identification and characterisation techniques for processing high resolution optical photomicrographs of coke were developed. Automated segmentation of inert maceral derived components (IMDC) and reactive maceral derived components (RMDC) allowed measurement of a broad range of parameters characterising coke structure. The characterisation included separate characterisation of IMDC and RMDC, IMDC boundaries including calculation of parameters characterising connections between IMDC and RMDC, coke porosity and, separately, IMDC porosity.

Several other novel approaches using image analysis software were investigated, such as:

- Separation of large porosity objects into individual pores (Separated Pores),
- Removal of weak walls and hence potential identification and measurement of Weak Areas,
- Identification of nodes (relatively thick agglomerations in the coke structure) and walls (part of the coke matrix connecting nodes),
- Measurement of Modified Wall Thickness (when only walls are taken into account), Wall Neck Thickness (weakest points in walls) and Specific Neck Thickness (sum of all necks per unit area).

* Corresponding author.
E-mail addresses: Eugene.Donskoi@csiro.au (E. Donskoi), Andrei.Poliakov@csiro.au (A. Poliakov), merrick.mahoney@newcastle.edu.au (M.R. Mahoney), oliver.scholes@vale.com (O. Scholes).

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Application of these novel characterisation techniques to a set of coke samples produced a substantial amount of data, which revealed many strong correlations between novel parameters characterising coke structure, and also between these parameters, coke strength indices and parent coal composition. This demonstrated the usefulness of the newly developed characterisation methodologies and gave a significantly improved understanding of coke structure and its connection with coke strength and parent coal blend. It should also be noted that these novel approaches to structural/textural characterisation can be applied to carbonaceous materials other than coke or other structural materials such as sinter, ore, and ceramics.

1. Introduction

One of the major tasks of the coke in blast furnace operation is to support the burden and ensure good permeability for gases and liquid phase drainage. Its other important tasks are provision of reducing gases, fuel for generating heat, and carbon for the hot metal. To fulfil these tasks the coke has to have certain characteristics such as proper reactivity, size distribution, high strength, and good abrasion resistance.

There is a strong interest in the industry towards parent coal blend cost reduction without significant impact on coke quality. Also, the availability of high quality hard coking coal used for metallurgical coke production is decreasing. As a result an increase of the amount of poorer caking coal in the coking blends is required [1], while maintaining coke quality.

To optimise parent coal blend formulation with the aim of producing high quality coke there should be an understanding of how maceral composition and the size distribution of parent coals, together with different blending, can affect coke properties. Many researchers have studied the dependence of coke strength and reactivity on different aspects of coke structure [1–8]. Three major factors were studied, i.e., porosity, the coke matrix, and the presence of large Inert Maceral Derived Components (IMDC). Therefore, simultaneous characterisation of all these factors is the key to the relationship of coke structure to coke strength. The most common method of such characterisation is Optical Image Analysis (OIA). For this, several samples from different parts of the coke oven are collected and embedded in epoxy resin or wax blocks. These blocks are then polished and imaged in air under reflected light.

Several distinct approaches to OIA characterisation of pore and coke matrix structure have been described [1,2,5,6]. The major aim of such distinct approaches was to find the most suitable descriptors that are highly correlated with strength measurements. CSIRO in its turn has also developed the unique Mineral4/Recognition4 OIA package, which is capable of identifying and characterising different structures (morphologies) in photomicrographs [9–12]. A number of processing approaches to coke characterisation and descriptors of coke images employed within this package are new and significantly different from those used in earlier studies. The main advantages of the new routines are: automated segmentation of IMDC from Reactive Maceral Derived Components (RMDC); automated characterisation of IMDC boundaries; segmentation of coke matrix into "Nodes" (relatively thicker, coalesced parts of the coke matrix and large IMDC) and "Walls"; measurements of the weakest parts of walls, etc.

The aim of this article is to introduce these new techniques and to demonstrate their applicability to coke characterisation by revealing the relationships between novel descriptors and other coke characteristics. To do so, a set of cokes produced within ACARP (The Australian Coal Association Research Program) research projects was imaged at ×100 magnification (1 pixel = 1.06356 μm) and analysed [13]. Even though not all strength and coal blend data were available for each coke, this set provided a good basis for study. Many correlations were significant at the 0.05 level. It should also be noted that Ro-max (mean maximum reflectance of vitrinite in oil) for all but two parent coal blends was in the range from 0.96% to 1.37%. Coke samples made from two parent coal blends significantly out of this range, with Ro-max = 0.87% and Ro-max = 1.56%, were also included as limiting cases. Unfortunately, in many coke strength correlations there were significant outliers connected with these two cokes (especially the coke made from parent coal blend with Ro-max = 0.87%), so data associated with these cokes were not considered in some correlations with coke strength. However, in correlations between coke structural characteristics, data for all cokes were taken into account (including the limiting ones).

2. Porosity characterisation

The effect of total porosity and different pore characteristics on coke strength has been studied by many authors [1,3–6]. Patrick and Walker [5] showed that there is a strong relationship between the coke tensile strength and total porosity. They also developed a relationship (1) connecting tensile strength (S) and coke structural characteristics, such as the number of pores per unit area (N), pore wall intercept size (W) and pore intercept size (p):

$$S * N = 10^5 * W * p^{-2} + 23 \quad (1)$$

Patrick and Walker [5] also showed that pore size and elongation, expressed as the Feret ratio, have a negative correlation with coke tensile strength. Grant et al. [3] showed that specimens obtained from regions close to the sole of the coke oven had lower porosity values and smaller pores, simultaneously having greater compressive strength than coke specimens situated higher in the oven. Grant et al. [3] concluded that the coke mechanical behaviour is largely governed by the pore structure.

Kubota et al. [1] came to the conclusion that coke strength is mainly determined by pores and cracks that cause fracturing of coke. They showed a high correlation between the total area and total perimeter of low roundness pores and coke strength ($DI_{6,}^{150}$ see [1]). In their work they neglected the pores with roundness higher than 0.2. However it is clear that even though such pores give less input to the coke's loss of strength, it would be preferential to take their impact into account as well.

Usually pores with low roundness are the relatively large tortuous pores (see Fig. 1) and vice versa, pores represented by relatively smaller numbers of pixels in the image tend to be more round than larger pores [9]. The smaller the pores are, the higher their abundance (altogether of 7907 recorded pores for this image, 5861 pores are less than 9 pixels and only 8 larger than 16,384 pixels with 69% of total pore area). If averaging by number, when the sum of measurements for each object divided by the total number of objects is reported, the result won't necessarily be representative. Roundness of pores in the 3–4 pixel size range is 0.9, while the roundness of pores larger than 16,384 pixels is less than 0.1. If the average roundness for all pores is calculated by number,