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Estimating the fusible content of individual coal grains and its application in coke making

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ABSTRACT

Quantification of the amount of inertinite that is fusible during coke making has long been a goal for many researchers and coke makers alike. This study has used matched halves of coal and coke to first determine the fusibility cut-off, and has then used CSIRO's CGA optical imaging system to obtain quantitative compositional information on individual coal particles at the size they are used for coke making.

The reflectance cut-off between fusible and infusible inertinite was determined by cutting coal lumps in half and coking one half. Comparison of matched structures in images of the coal and coke lumps allowed the fusible/infusible reflectance cut-off for inertinite to be determined for each of the coals. This study found that rather than there being a single reflectance cut off point between fusible and infusible inertinite for each coal there is a consistent difference (range) between the end of the vitrinite reflectance distribution and the fusible/infusible inertinite reflectance boundary for each individual particle within a coal.

This reflectance range was then used to estimate the amount of fusible and infusible inertinite in individual particles of coal which had been crushed for use as coke oven feed for six Australian coking coals (consisting of matched pairs of coals of similar ranks from different Australian coal measures). Also determined was size detail for the individual inertinite structures within each particle and the amount of infusible inertinite structures greater than 1.5 mm in length.

The CGA results obtained suggest that two of the coals (from the Rangal Coal Measures) contained a greater proportion of large infusible inerts than did the coals of comparable rank from other Australian measures. If this is proven, the information may assist coal producers to develop specific milling strategies for these coals.

1. Introduction

Coal petrographic information has been used since the 1950s to develop models which predicted coking performance. For coals of suitable rank some of the inertinite macerals as well as the vitrinite and liptinite macerals are fusible (fusibles) during coking and the remaining inertinite macerals and minerals do not fuse (infusibles). For coals of similar rank, the amount of fusible inertinite present in a coal may vary between coals extracted from differing coal basins/measures and even between coals from similar regions. Inertinite fusibility is related to reflectance, with low reflecting (fusible) inertinite being more reactive than high reflecting (infusible) inertinite. While it is known that the reflectance cut-off between fusible and infusible inertinites is rank dependent, it is still not established if this cut-off value is different between coals of different origin. A better understanding of these differences may explain why the initial model developed to predict ASTM coke stability values for vitrinite-rich North American coking coals does not apply correctly to Australian coals that contain significant proportions of highly reactive inertinites.

The uncertainty in the fusibility of inertinites from different sources and the impact of this on the resulting coke microtextures (coke microstructure, texture and the amount of fusible and infusible constituents) led Brown et al. (1986) to conclude that "coal maceral analysis alone cannot adequately characterise a coal for coke making". It is necessary to know the nature of the microtextures formed during the coking process in order fully understand the utilisation behaviour of the coke.

The size of infusible inertinite particles in the coke oven feed also impacts on coke strength. Kubota et al. (2008) established that large (approximately +1.5 mm) inertinite particles present in the coke oven feed coal may be a plane of weakness in the resultant coke, impacting adversely on coke quality. He therefore proposed that selective crushing based on inertinite size resulted in significant improvement in the resulting coke quality. The size of the fusible maceral structures in individual particles should also have a significant influence on coke microtextures. Therefore a better understanding of the fusibility of the inertinites in a coal which also provides detail on the fusible structures in coke oven feed coal, will improve the prediction of coke texture formation from the analysis of the parent coal.

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Coal is typically ground to 70% or more passing 3 mm in order to improve the contact between the different coal components and to improve distribution and mixing of the coal components in cokemaking. Although most coal particles in coke oven feed should be below 3 mm in size, particles up to 8 mm in size may be present. These large particles generally tend to be composite particles that can contain infusible inertinite components that may be larger than 1.5 mm in size and will therefore be detrimental to coking performance. As the large infusible inertinite material in coke oven feed can be present as either liberated particles or as a component of a larger particle, to accurately determine the size and abundance of infusible inerts requires an analysis method that can provide this information for single component and composite coal grains.

O'Brien et al. (2011) established that different milling strategies could alter the size distribution of the inert components (without altering the overall maceral composition) in coke oven feed and hence affect coke strength. This study used CSIRO's Coal Grain Analysis (CGA) system to obtain maceral composition information on individual particles of coke oven feed samples. A key feature of the CGA system is that it measures the reflectance fingerprint for each discrete particle and uses this information to determine the mineral, liptinite, vitrinite and inertinite abundances in each individual particle and then classifies each grain into a grain class. For coking coals, the CGA system was previously unable to separate inertinite in the individual particles into infusible and fusible inertinite or provide detail on the size of the fusible and infusible structures present in coke oven feed sized coal particles. Thus modification of the CGA system was undertaken to obtain this information to try and quantify the amount and size distribution of the infusible inerts present in coke oven feed samples.

2. Method

2.1. Selection of coals

For this study, three matched pairs of coal, two low rank (0.9–1.1% R_{Vran}), two medium rank (1.1–1.3% R_{Vran}) and two high rank (1.3–1.5% R_{Vran}) coking coals from different Australian coal basins were used (Table 1). Four of the samples were sourced from previous ACARP projects (O'Brien et al., 2011; Mahoney et al., 2013) and the additional samples were provided by coal producers and had been used in coke testing programmes.

Two coals came from the Rangal Coal Measures and one coal came from each of the Collinsville, Moranbah, Illawarra and German Creek Coal Measures (Table 1). Each coal was supplied as coke oven feed samples. In addition approximately 10 individual lumps from each coal, approximately 50 mm in size each were also supplied for making the matched surfaces.

These samples provided an opportunity to investigate if samples of comparable rank had similar size distributions of infusible inerts after they have been milled to produce coke oven feed and to determine if there are differences in amounts and size of infusible inerts from coals of similar ranks from different Australian coal basins.

Coals A and B contained nine size fractions, whereas the other coals contained four size fractions. For comparison the results obtained from the size analysis of all of the coals are shown on a mass percent basis in Table 2. Coals A, B, and C contained more material in the −0.5 mm fraction and less material in the +2 mm fraction than the other 3 coals.

Table 2
Summary of sizing data for the 6 coals for comparison.

	Coal A	Coal B	Coal C	Coal D	Coal E	Coal F
+2 mm	27.5%	25.0%	26.8%	33.1%	32.9%	38.1%
−2 + 1 mm	19.9%	21.4%	21.1%	22.7%	20.1%	19.9%
−1 + 0.5 mm	17.4%	21.0%	16.8%	14.6%	17.3%	15.6%
−0.5 mm	35.2%	32.6%	35.3%	29.7%	29.7%	26.3%

2.2. Preparation of individual matched surfaces

The method adopted was that used previously by Diessel (1983). Four to five of the large lumps of coal were cored (20 mm diameter cores, 20 to 25 mm long) and then cut (saw blade thickness of 0.5 mm) along the axis of the cylinder to produce two flat faces with the same distribution of macerals, only mirror images. One of the half-cylinders was mounted in polyester resin and lightly polished so that the reflectance distribution of the coal surface could be measured.

The other half of each particle was then "coked" using a laboratory furnace developed by the University of Newcastle (Mahoney et al., 2013) which enables single particles to be pyrolysed and cokes to be produced that are generally comparable with cokes produced using pilot scale equipment and commercial ovens.

The half-cylinder was mated to a hemi-cylinder of graphite, flat faces together and placed in a snugly fitting graphite crucible with a tightly fitting graphite lid secured in place using wire. The purpose of this procedure was to limit the movement of liquid material on the face of the hemi-cylinder during coking. The graphite crucibles were then packed inside a perforated steel box wrapped in aluminium foil (to act as an O_2 scavenger). The steel box was placed inside a controlled atmosphere muffle furnace (4 L/min Argon flow) and heated using the heating profile given in Table 3. This heating profile is the same that has been used previously with crushed coal in order to study the texture of carbon formed during pyrolysis and is similar to the heating profile used by previous studies (Diessel, 1983).

The cokes produced were then mounted in resin and lightly polished. The surfaces of the two halves (of coke and coal) were mirror images as shown in Fig. 1.

Of the six coals studied only five coals were able to produce cores from the lumps as the Coal C lumps crumbled each time when trying to produce a core. Of the five coals that were successfully cored only four formed successful cokes as Coal F produced such a fluid plastic phase that it could not be contained within the graphite crucible. In total matched surfaces for 4–5 lumps were able to be produced for Coals A, B, D and E.

2.3. Determining the fusible reflectance cut-offs

Imaging methods on the matching coal and coke surfaces were used to determine the fusible reflectance thresholds between fusible and infusible inertinites.

The coke samples were analysed by Pearson Coal Petrography using their in house method, which produces a map of the fused and non-

Table 1
Coal samples selected.

Reflectance (mean ran. vitrinite refl)	Coal measure	Sample name (reference)	Coal measure	Sample name (reference)
0.9–1.1	Collinsville	Coal E	German Creek	Coal F
1.1–1.3	Rangal	Coal D (Mahoney et al., 2013: Coal D)	Illawarra	Coal B (O'Brien et al., 2011: Coal B)
1.3–1.5	Rangal	Coal C (O'Brien et al., 2011: Coal C)	Moranbah	Coal A (O'Brien et al., 2011: Coal A)