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Texture-Based Identification of Inert-Maceral Derived Components in Metallurgical Coke

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Abstract: As part of a comprehensive approach to understanding the relationship between the properties of metallurgical coke and its microstructure, we present methods and techniques for the identification of inert-maceral derived component (IMDC) grains in metallurgical coke. Detecting the presence of IMDC grains, delineating their extent and quantifying their density and spatial distribution assist in predicting the quality of the bulk coke. In order to overcome the inadequacy of the more common image analysis techniques, our methodology tackles visual texture in 3D. It is centred on mimicking human visual inspection of the mineral texture from two or more angles, and as such is based on a biologically inspired approach. In this paper we briefly describe the methodology as well as associated processing techniques that play a support role. Preliminary results are presented for a range of cokes produced from different coals. The methods have been incorporated into our overall approach to analysis of the quality of coke from its microstructure. We are working towards a framework in which 3D image analysis constitutes an integral part of the assessment of the quality of coke made from specified coals under given processing conditions.

Keywords: *Metallurgical coke, image analysis, Gabor filter*

1. INTRODUCTION

Metallurgical coal is a major Australian commodity export, worth more than A$20b per annum. It is used to make coke, a vital component in steelmaking. High quality coke is important for successful operation of modern ironmaking blast furnaces. Crucial to coke quality is the strength and reactivity of this porous composite material. There is a close relationship between coke quality and its microstructure, which varies at micron scale. The solid phase of the coke can be partitioned into Reactive Maceral Derived Components (RMDC), Inert Maceral Derived Components (IMDC) and mineral matter. Detecting the presence of IMDC grains, delineating their extent and analysing their density and spatial distribution assist in predicting the quality of the bulk coke. IMDCs are often not distinguishable by standard image processing techniques in images acquired with Micro-CT (μCT), as they have very similar X-ray absorption properties to RMDC. However, due to their material composition and formation history, they do exhibit characteristic 2D and 3D patterns, which make them distinguishable under visual examination from the rest of the coke. While these patterns are sometimes accompanied by image intensities that are also different from the surrounding RMDC, we have found that intensity alone is not always a sufficient feature for the reliable detection and delineation of IMDCs.

Since we have determined that visual inspection can readily reveal the existence and extent of IMDCs, we have chosen the biologically inspired Gabor filters to be our basic processing units. Gabor filters have consistently demonstrated a potential in automating visual inspection tasks. This work forms a part of an on-going research effort into understanding the relationship between coke microstructure and coke quality properties, such as strength and reactivity, as reported elsewhere (Mahoney *et al*, Steel *et al*, Jenkins *et al*).

2. DATA COLLECTION

2.1. Preparation of coke samples

Coke cores were prepared from lumps of coke using a 16.9 mm diameter core drill, and cut into discs of approximately 10 mm thickness using a diamond saw. Discs were placed at 40°C in an oven overnight. They were then gently ground flat using sandpaper and wrapped in sellotape to avoid crumbling of the coke during the compression tests. Samples were glued onto aluminium sample mounts designed to fit tightly into the head of the goniometer on the beamline. Figure 1 shows a coke disc glued onto a sample mount.

Figure 1. Photograph of a coke disc (16.9 mm diameter) used for imaging on the synchrotron beamline.

2.2. Image collection at the Australian Synchrotron

Micro-CT of the coke samples was carried out at the Australian Synchrotron Imaging and Medical Beamline, at an X-ray energy of approximately 30keV with 1800 images acquired as the sample was rotated over 180 degrees. Due to the gap between the sample and detector the images benefited from a modest amount of phase-contrast which enhances the visibility of edges, boundaries and small features. The image data was treated with a phase-retrieval algorithm prior to phase-retrieval in order to make best use of the phase contrast and improve the quality of the final images.

The zooming 'Ruby' X-ray imaging detector was used, set to 7.65 µm per pixel. At 2560 pixels across the detector, this gave a 19.5mm field of view well suited to the 16mm diameter samples. Figure 2 shows photos of the beamline facility and of a sample mounted on the instrument in preparation for imaging.

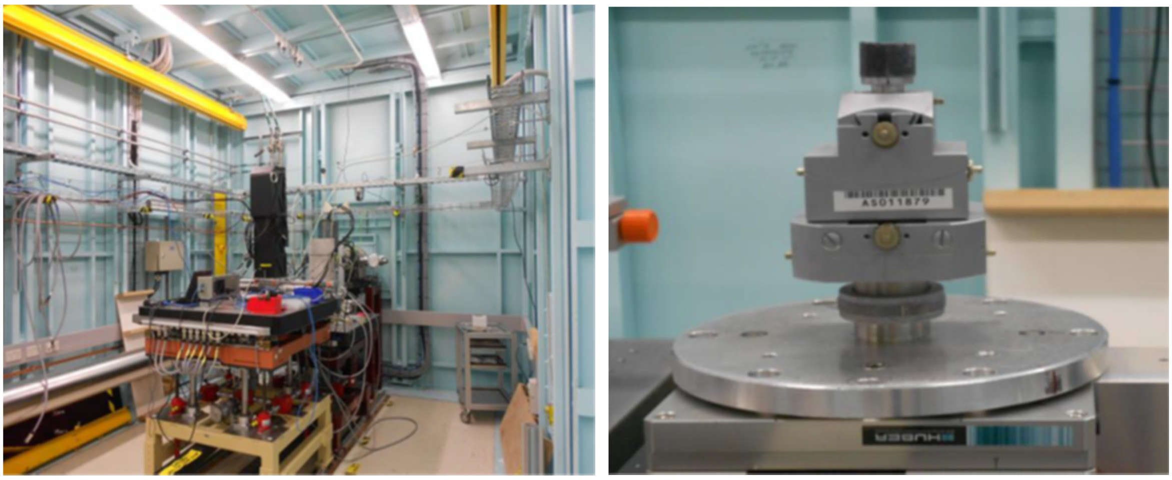

Figure 2. Photographs of the Australian Synchrotron Imaging and Medical Beamline. Left: overview of the facility; Right: a coke sample mounted on the imaging stage.

3. METHODS

Apart from the IMDCs, the mineral components are of interest for our study. These show up with high-intensity under X-ray imaging. Some of the IMDCs, as well as all or most minerals, can be captured based on the voxel intensities and the sizes of the connected components, in combination with morphological analysis. IMDCs not amenable to intensity-based measures can be effectively segmented with texture features.

Our main methodology for the texture based approach is centred on mimicking human visual inspection of the IMDC texture, and as such is based on a biologically inspired approach. The central unit in our processing pipeline is a bank of Gabor filters. Historically employed in studies of the biological visual system (Caelli and Moraglia, 1985), each Gabor filter is designed to respond maximally to a particular type of visual textural stimulus – one that exhibits oriented patterns at specific spatial scales (Gabor, 1946; Fogel and Sagi, 1989; Haghighat et al., 2013). This double orientation and scale selectivity has been shown to resemble the electrophysiological responses of a class of neurons in Visual Cortex Area 1 (V1) of primates.

Our method further incorporates a double-pass convolution. The results of the convolution are individually cleaned up by morphological opening, and are subsequently fused together before being median-filtered and thresholded. A connected component analysis is then applied, where voxels that are connected to any of its 26 neighbours in 3D are considered to be forming part of a common block with the connected neighbours. Blocks that are too small to be considered likely IMDC grains are removed.

Due to the sheer size of the raw 3D images to be processed, accelerated-computing techniques have been employed, including the above-mentioned double-pass convolution with orthogonal 2D kernels in place of brute-force convolution with a 3D kernel, as well as parallelized computation.

4. RESULTS

Segmentation results using intensity-based thresholding, connected component analysis and other morphological analysis are shown in Figure 3. In this particular example, there are many small pieces of mineral component and a few larger pieces of IMDC that have been identified. A limitation of IMDC identification in this way is that often only part of a single piece of IMDC can be identified. A visual inspection of the sample generally shows this to be the case, as well as there being other (complete) pieces of IMDC not identified.

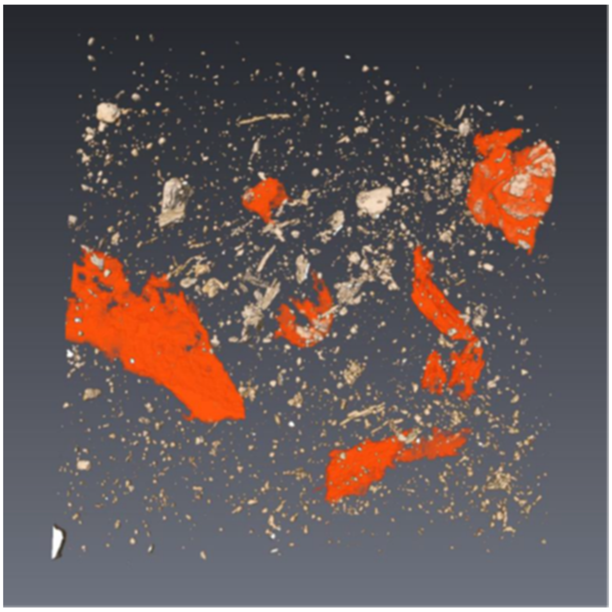

Figure 3. Segmentation results using intensity-based thresholding, connected component analysis and other morphological analysis. The white components are minerals and the orange components are IMDCs.

That is, there are generally many more IMDC components in the sample than can be obtained in this way. Once the texture based approach is added, we are able to locate most, but not all of the IMDCs in the samples. Figure 4 shows examples of IMDC and mineral component identification in four different coke samples, obtained using the combination of intensity based approach with the texture based approach. These are presented as composite images, where the IMDC and mineral components are highlighted using colour, superimposed upon the original greyscale images obtained from the μCT imaging. It is quite clear that there is considerable difference in the fraction of IMDC components in the samples. This occurs because the different cokes have been produced using coal from different coal mines. As a result, the different properties are associated with the complexities of the geological formation of the coals from different regions, combined with the effects of the transformation of the coal into coke.

It is reasonable to expect that the different amounts of IMDC in the samples could affect the coke quality. One sample in particular, shown in Figure 4(c), has a very high loading of IMDC and is likely to have low coke strength. One possible reason for this is the minimal amount of RMDC material between IMDC component, which can act to bind the material together. It is apparent in this image that the boundary between (what appear to the eye to be) separate pieces of IMDC within the sample tend to merge into a single mass using our approach. In order to better understand the coke strength properties, it is desirable to take our analysis a step further in such cases, by being able to distinguish a delineating surface between two such neighbouring pieces of IMDC. At this stage of development, that is not always possible, so it is clear that further development of the technique is required.

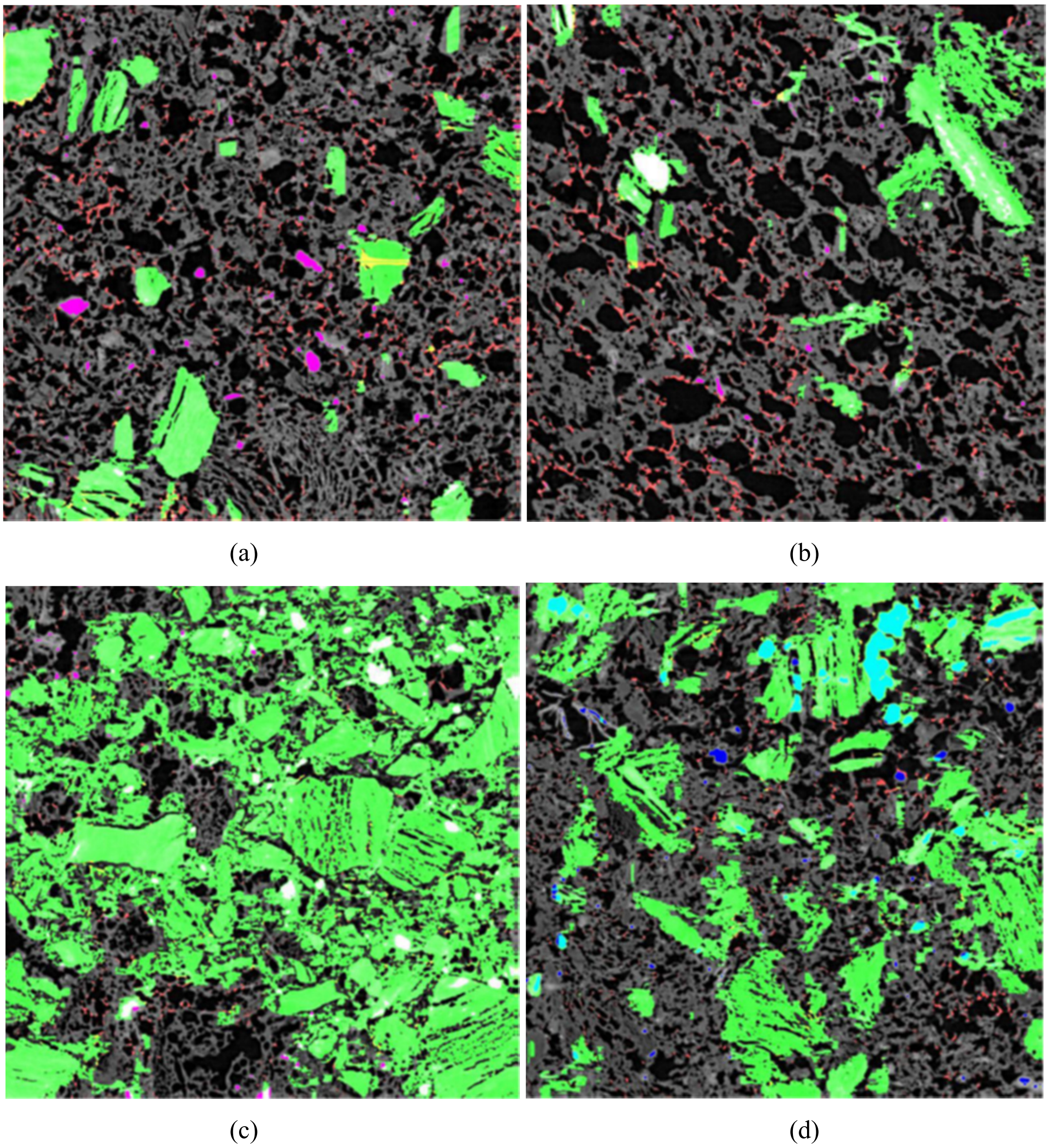

Figure 4. Snapshots of a single layer of composite images identifying minerals (magenta) and IMDC (green) for four different coke samples. The red regions are further processing features not considered in this paper.

It is important to remember that the images in Figure 4 are single slices from a 3D representation of coke microstructures. Adding of the third dimension allows a great deal of advantage to the IMDC identification, due to the effect of connectivity between individual slices. It also aids significantly in visualization, where animations of the whole 3D geometry can show the shape and size of the individual components.

5. DISCUSSION AND CONCLUSION

We have presented methods and techniques for the segmentation of inert-maceral derived component (IMDC) grains in metallurgical coke. By analysing the voxel intensity profile, connectedness with nearby voxels of similar intensities, and the extent with which a coherent block of voxels can be formed, the mineral components and some of the IMDCs have been demonstrated to be straightforward to identify. The more challenging remainder must be dealt with using texture-based methods.

Our methodology is centred on mimicking human visual inspection of the mineral texture, and as such is based on a biologically inspired approach. We have briefly described the approach and associated processing techniques that play a support role. Preliminary results have been shown and the strengths and limitations of the approach were discussed. The proposed methods have been utilised as part of an overall approach aimed at relating the quality of the bulk coke to its microstructural features.

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