THE CHARACTERISATION OF FISSURES IN METALLURGICAL COKES

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Introduction

In the commercial production of coke in a coke oven, fissures are generated in the coke due to stresses produced by differential contraction rates in adjacent layers of coke which are at different temperatures [1]. Typically they are longitudinal, i.e. perpendicular to the oven walls. Additional fissures, mainly transverse, are formed during pushing [2, 3]. These fissures determine the size distribution of the product coke by breakage along their lines during subsequent handling. But not all the fissures lead to breakage at this early stage, so that a number of them remain in the coke lumps.

In an early study Mott and Wheeler [2] showed that the greater the number of initial fissures in a piece of coke, the weaker it was in a shatter test. They also noted that the degree of penetration of the fissures affected the strength of the coke. Nadziakiewicz [4] concluded that a clear relationship exists between mechanical strength and fissures and that, furthermore, pore structure and inherent material strength of the coke have little influence on the Micum 40 index, an industrial measure of resistance to fracture. The average separation of the fissures has also been related to the amount of material remaining above a 40mm sieve after a small drum test [5] whilst Wallach and Sichel [6] suggested that the coke degradation phenomena in the drum test can be divided into two independent processes, abrasion and breakage on impact. Loison et al [1] confirm this view by stating that brittle fracture impact is due to the extension of fissures already present in the coke. Arima et al [7] showed that the size distribution of coke lumps after testing is not strongly influenced by abrasion, but mostly determined by the initial size distribution and by volumetric breakage, which they also believe to depend on the degree of fissuring.

Even though volumetric breakage has been linked to the fissures present in coke by several workers [2, 4, 6, 7], few studies have been undertaken in recent times to directly and quantitatively relate coke quality to fissuring. In part this is due to the difficulty of defining and measuring the degree of fissuring. A method for image analysis based characterization of fissures has been developed and reported [8], and the present work has continued to improve sample preparation methods and gather additional data.

The Fissure Analysis Method

The fissure analysis method is based on slicing a large number of coke lumps, recording the occurrence of fissures and subjecting the coke slices to image analysis. The weight of each coke lump was recorded prior to slicing to enable a comparison between cokes on a number of fissures per kilogram coke basis. The lumps were then cut into roughly 20 mm thick slices. Slices containing fissures were cleaned and fissures highlighted by filling with a thin white plaster mixture. Image analysis was carried out on digital images of the coke slices using Optimas software. The dimensions of the slice and of all highlighted features above a pre-selected minimum perimeter were recorded. Using manual editing, the slices were traced to define the area of interest, editing out shadows and relief. Fissures varied considerably in width, some appearing almost like a collection of independent features, with others being comparatively short and quite wide for their length.

Fissure Width and 'True Fissure Length'

Some image analysis parameters are suitable for all shapes of objects, others may be more suited to some than to others. In the case of the fissures, the basic parameters recorded were area, perimeter, breadth and length. Area and perimeter rely on counting the pixels in a chosen object and those on the line surrounding it. They should not be influenced by shape, no matter how oddly shaped an object is. Circularity is calculated from them, and thus equally unaffected. Length and breadth, however, are measured with a more regular shape in mind. Figure 1 shows an approximation of the major axis length and breadth measurements. The major axis length represents the longest straight dimension along which the fissure stretches. Breadth is measured by adding together the longest straight dimensions perpendicular to the major axis length on either side of it. Clearly, this is a good way of measuring the dimensions of a round-ish object, but does not represent well the type of objects fissures belong to. The major axis length will differ from the true length of a fissure unless it is perfectly straight, and the more 'torturous' the fissure path becomes, the greater the discrepancy. The breadth is more of a measure on how great the sweep of the path is, and will be completely unusable for branched fissures. It was thought that a more truthful representation for a fissure could be a long, thin rectangle with the longer side L representing the length of the fissure if it was unraveled and straightened. The small side x would be an average value of the fissure width. Such dimensions could be calculated from the area A and the perimeter P.

For a long, thin rectangle with the dimensions L and x

$P = 2(L+x)$ and $A = Lx$ which combine to give the quadratic equation

$$2L^2 - PL + 2A = 0$$

This can be solved as

$L = P/4 \pm \sqrt{P^2/16 - A}$ provided $P^2 > 16A$

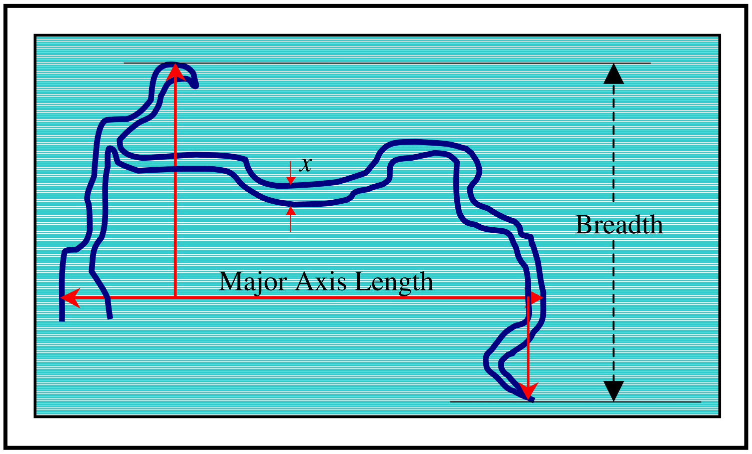

Figure 1 Major Axis Length and Breadth

The calculated fissure widths are shown in Figure 2 as percentage distributions for the two cokes. They range from 0.4 to 1.7 mm, centering around 1 mm. This is much more in line with the appearance of the fissures than the original breadth measurements. The 'true length' was determined as being on average around 1.36 times that of the major axis length. In a few extreme cases the true length was over double that of the major axis length.

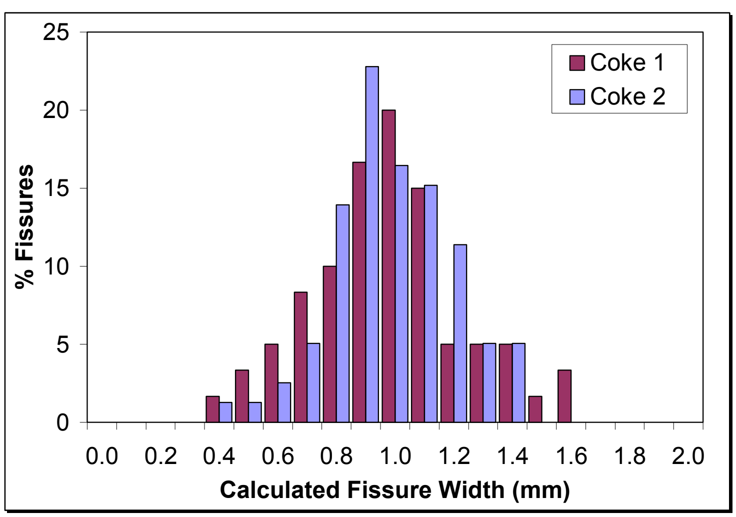

Figure 2 Calculated Average Fissure Width

Having more realistic values for the length and width dimensions, the aspect ratio was calculated. On average, the width was less than a 20th of the 'true length' and there were few fissures with aspect ratios about 0.1, and none about 0.14. Subjecting the data for the pores to the same treatment showed that 97.5% of the pores had aspect ratios above 0.3 when the major axis length and associated breadth were used to calculate them. Fitting the pores into rectangles is not a good approximation, or a meaningful action to take, unless it would serve that by their different results the pores could be distinguished from the fissures. As Figure 3 shows, this is not the case, so that this exercise could be deemed only partially successful.

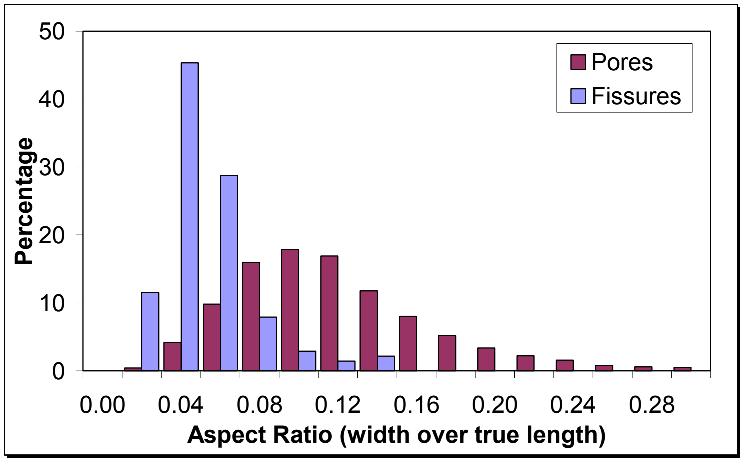

Figure 3 Aspect Ratio for Fissures and Pores

Testing the Calculated Fissure Width

Measuring the true fissure length would be difficult, but an estimate for the fissure width can be obtained using image analysis. The width is not uniform, and such an estimate would be an average of measurements taken at regular intervals. For this analysis, the image of the fissure was binarised and isolated from the remainder of the coke by manual tracing. Lines were then drawn across the fissure at regular intervals and the lengths of those lines recorded. The method was applied to a smaller sub-sample of the cokes and the average widths for the fissures are plotted against the calculated values in Figure 4. It appears that for the thinner fissures the calculated value tends to be higher, but that for some very wide fissures it is lower than the measured values. But on the whole, the two methods produce fissure width in the same range of values. On average the largest measurement was 7.5 times greater than the smallest, but for 20% of the fissures it was in excess of 10 times, for some as high as 30 times higher. With such variations arriving at a satisfactory average is not easy.

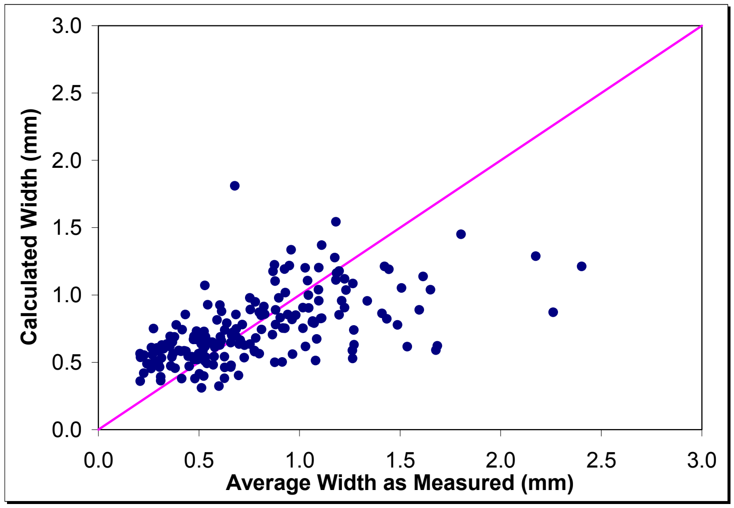

Figure 4 Comparing the Average Measured and the Calculated Fissure Width

The Third Dimension – Fissure Depth

Fissures are three dimensional entities in three dimensional lumps of coke. By slicing the coke lumps two-dimensional surfaces are created, and only two dimensions of the fissures have so far been considered, the length and width. These two dimensions differ greatly in size, as the aspect ratio distribution in Figure 3 shows. Typically, fissures are 20 times longer than wide. Making an assumption about the third dimension, depth, on the basis of either of these would lead to a very different perception of the fissures and their occurrence. If the depth is akin to the width, typically some 0.5-1.5 mm, fissures would be hard to detect by slicing, and for each uncovered fissure there would be many unseen ones. A slice would have to be in a very precise plane to slice through any length of fissure, and any slight change in direction would remove the fissure from the plane, making it likely that only fissure segments are seen, and that fissure length is grossly underestimated. On the other hand, assuming the depth and length to be of similar values, some 25-75 mm, would give fissures a wedge-like appearance. Slicing the lump in any direction other than exactly parallel to the wedge surfaces is likely to make at least part of the fissure appear. The fissure count, in this case, should be reasonably accurate, even if the fissure dimensions seen would very much depend on the angle of the slicing relative to the fissure. Depending where it is cut, the same fissure could look short and wide or quite long and narrow. The only way to get a true picture of fissure geometry would be to look at fissures in all three dimensions, but what can be done using 'two-dimensional technology' is to explore the likelihood of either of these cases. A sub-set of prepared samples was sliced again at right angles to the original fissure. The new surface was also prepared for image analysis and the results for the two surfaces were compared. If depth and width are similar, little evidence of the fissure should be found at the new surface. If the depth is larger, i.e. the fissure shape wedge-like, the image of a fissure should be apparent at the majority of the new surfaces, and should traverse the entire slice in a significant number of them.

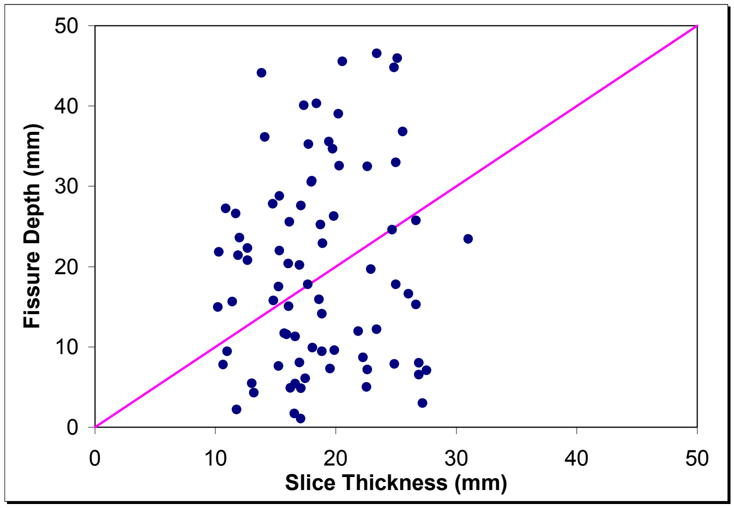

Figure 5 Coke Slice Cross-Sections perpendicular to the observed Fissures: Fissure depth relative to the Slice Thickness

Figure 5 shows the 'fissure depth', the length of the fissure in the new surface, plotted against the thickness of the coke slice. The thickness is scattered around 20mm, the nominal slice thickness, and the fissures running through the slices, at right angles to the originally observed fissures, varies considerably. In a few cases it matches the slice thickness, in some it is longer, indicating that it does not take the shortest path through the slice, in others it is shorter indicating incomplete penetration. There were few cases where the 'fissure depth' was in the same range as the fissure width, which was found to be below 2 mm. The results are consistent with a fissure of a depth similar to the fissure length observed, being randomly sliced.

Conclusions

A method for image analysis on residual fissures in coke lumps originally developed at Loughborough University has been improved more recently at the University of Nottingham. It provides data that permit the degree of fissuring to be compared between cokes. The average number of fissures per coke lump or per kilogram of coke can be compared, but this could easily be done without the aid of image analysis. Image analysis can collect more detailed information about the size and shape of the fissures. It was intended that this could be used to derive a scientific, quantifiable definition of a fissure. This has proved to be more difficult than expected, considering how easily fissures can be identified by the human eye. A combination of the fissure properties and those of some large, irregularly shaped pores makes it impossible to define clear cut-off values between them. There may be a case to move from fissure analysis to the analysis of all features above a certain size that are not included in other structural characterization methods.

A method has been developed to give a more accurate estimation of the fissure width by calculating it from the area and perimeter of the fissure. It was verified by comparing the calculated values with measured averages. Some evidence was collected about the third, unseen fissure dimension. This led to the conclusion that fissures are ‘wedge’ shape, which makes them relatively easy to detect by slicing through the coke lumps. The fissure count used for comparing cokes is therefore likely to be reasonably accurate.

Acknowledgements
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