STRUCTURAL FEATURES INFLUENCING COKE DEGRADATION

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Introduction

During carbonisation in a coke oven fissures in the coke are generated due to stresses that arise from the 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, mainly transverse, fissures 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. The work presented in this paper is concerned with the characterization of these "secondary" fissures. Their importance for the mechanical properties of cokes, in particular their relation to the widely used Micum drum test, will also be discussed.

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] also 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 index 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]. 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. In view of the vast improvements in blast furnace cokes in recent decades, a method for fissure characterisation was therefore developed in order to re-examine the role of fissures and attempt to quantitatively assess their influence.

Experimental

After considerable testing of various procedures the following method was adopted as the most reliable and practical method. The coke lumps were prepared by being sliced into two halves with a diamond tipped saw. The flat surfaces were then polished with carborundum. The fissures were highlighted by using a white filler and were traced onto paper together with the lump outline. A large number of samples of the same coke had to be used to give statistically significant data relying on the random orientation and distribution of fissures within the lumps of coke. The traced images were subjected to image analysis, for which the capture system was modified to deal with images of that size. This was achieved by using a TV camera on the macro viewer of a Joyce-Loebl Magiscan 2A image analysis system. For each lump, the area, length and breadth of the two sectional faces were measured together with the number of fissures. If fissures were present in an image their length (L), breadth and perimeter (P) were also recorded. Two sets of cokes were used for the investigations. The first set comprised 6 cokes of blast furnace (iron-making) quality. They are referred to as cokes A to F in the following sections. The second set comprises two samples of the same domestic grade coke (G and H), two cokes used in zinc smelters (I and J) and a foundry coke (K). The samples were separated into 7 size fractions between 30 and >100mm.

Results and Discussion

For all the coke samples the average number of fissures was determined for all lump sizes. Smaller lumps tended to have no fissures or one fissure. For the smallest lumps (<50mm), more than 3 fissures in a lump was rare. For medium size lumps (50-80mm), lumps with multiple fissures occurred more frequently, but only for certain cokes. The differences between the cokes was considerable, e.g. for cokes F (a blast furnace coke) and H (a domestic coke) in the 70-80mm size range. Most lumps of coke F had no or very few fissures. In contrast all lumps of coke H had at least one fissure, most

frequently 3 or 4, and a few lumps as many as 9. Clearly and not unexpectedly fissuring is to a large extent dependent on the nature of the coke and two different cokes can show significant variations for the same lump size.

On the whole the deviations were smaller between lumps of different sizes of the same coke than between the different cokes. A clear numerical difference was be observed between the different types of coke. All the blast furnace and smelter cokes (A-F, I, J) had averages of 0.5 to 1.6 fissures per lump, the domestic coke (G,H) had on average 4 fissures per lump and the foundry coke (K) had 7.5 fissures per lump. It has to be taken into account though that the lump size of the foundry coke is much larger than for the blast furnace and domestic types. By way of overcoming the size distribution variations an estimate of the numbers of fissures per dm^3 of coke was made (Table 1). Considering the blast furnace and smelter cokes only, and excluding one very high result for coke E (in brackets in Table 1) the per unit volume results show a clearer trend than the per lump results. Although they tend to have fewer fissures than larger lumps, small lumps are seen to have a greater fissure density (fissures per unit volume). The trend also holds for the domestic cokes, but at higher values. This trend is significant in the way that it would make the occurrence of larger lumps appear to be generally more desirable from the viewpoint of resistance to size degradation, as their contribution to total fissure numbers per unit volume, or weight assuming similar densities, would be less than that of small lumps. The statement is restricted however to comparing similar cokes, blast furnace cokes in this case, and ignores the effect of fissure size. Comparing the averages for the blast furnace cokes with the foundry coke shows that the fissure density in the >100mm foundry coke lumps corresponds to that of blast furnace lumps in the 50-60mm size range.

The average length of the fissures in the different coke lump size ranges was also determined and these values are shown in Figure 1. As would be expected, the average fissure length increases with lump sizes, as the lump size must present a limit to the size a fissure can grow to before breakage occurs. The range of average length for each lump size is relatively large though, 5 to 10 mm between the coke with the longest and shortest fissures. To assess how the average fissure length compares to the lump size, the mean diameter of a sphere of the dimensions within the lump size range was divided by the average fissure length.

Table 2 shows that this works out at around 0.2 to 0.35. This puts the average fissure length at between a fifth and a third of the coke diameter. Again, no systematic variation with coke lump sizes is seen. The lump size therefore appears to be the only identified determining

factor for the fissure length, but as the scatter of the results indicates it is not likely to be the only one.

In addition to the number and length of fissures, a shape factor, defined as P/2L, was also determined. It gives an indication of regularity of the fissure geometry. A relatively straight, narrow fissure would have a factor close to 1. As the path of the fissure becomes more jagged or if the fissure is crossed by smaller fissures the value increases. A highly irregularly shaped fissure would have a shape factor approaching 2. The average shape factors are shown in Table 3. For most of the cokes the shape factor varied very little between the lump sizes. There was a weak tendency for higher shape factors in larger sizes, as all the higher values occur in the larger lump sizes. The exception was coke E, which had much larger shape factors than the majority of the cokes for all lump sizes. Most of the cokes had shape factors consistent with mildly jagged fissure paths or branching with much smaller secondary fissures. The shape factors for the domestic cokes were higher than those of the majority of blast furnace cokes, but not as high as the values for blast furnace coke E, which are only repeated once, in the largest lump size for the zinc smelter coke I.

On the assumption that the fissures are similar in shape in all cokes of all lump sizes the relationship between the shape factor and branching was explored. On the whole, even though there was some scatter, the shape factor increases from around 1.2 for 5% branching to around 1.5 for 30% branching.

As an additional piece of information on the fissure geometry it was determined what percentage of the fissures were external and internal, i.e. if they were touching the lump surface or if they were completely in the interior of the lump.

The majority of the fissures were external, but for some of the larger lumps sizes a considerable number (over 40%) did not touch the lump perimeter. Differences between the cokes were noticeable, for example coke E had a smaller percentage of fissures touching the lump perimeter than the rest of the cokes and coke H a particularly large percentage. As distinct from the branching there was no observed relation to the shape factor, so that it is unlikely that the shape of internal and external fissures varies significantly.

To test the relation between breakage and fissures, the number of fissures per lump was plotted against the M40 index in Figure 2a. For the blast furnace cokes the average number of fissures is greatest in the cokes with the highest M40 values, but that apparent relationship breaks down when the other cokes was included. Relating the average fissure length to the M40 index (Figure 2b) was equally inconclusive.

It has been suggested that the sum of the M40 and M10 index is a better indicator of breakage resistance [1]. The M40 indicates the amount of material > 40 mm, i.e. the

lumps which are unlikely to have undergone breakage. But not all material < 40mm is thought to originate by breakage. Adding the M10, which is percentage of material <10mm and thought to be created by abrasion, therefore gives a better measure of the amount of material that has not been affected by breakage. The sum of M40 and M10 was therefore also plotted against the average number of fissures per lump in Figure 3. The trend, for blast furnace coke only, remains the opposite of that predicted by the view that fissuring and breakage are linked. The amount of breakage during the Micum test decreases as the average number of fissures increases. Only a very small proportion of the fissures present actually lead to breakage. For the poorest blast furnace coke 10%wt is lost as breakage, but on average half of the coke lumps contain fissures. By the best coke less than 3%wt is lost by breakage, but on average all lumps have fissures, or more accurately, enough lumps have multiple fissures to average more than 1 fissure per lump.

Including the domestic and foundry coke, the picture looks a little different. Firstly, it can be seen how similar all blast furnace cokes are. Secondly, it becomes very clear that it is not the number of fissures, but the ability of the solid to contain them that determines breakage under Micum test conditions. Domestic cokes are comparatively weak, so they give the expected result that their average of about 4 fissures per lump cause breakage in over half of the lumps. That still leaves a sizable number of lumps with multiple fissures intact though. Foundry coke averages nearly 5 fissures per lump. Even with a lump size of >100 mm it is likely that if just 2 or 3 fissures per lump lead to breakage the remaining pieces will be below 40mm. But its combined M40+M10 is comparable to that of the best of the blast furnace cokes. It must therefore be much better at resisting fissure propagation. The strength as determined by the Micum test does not appear to be determined by the presence of fissures, but may possibly be found in the inherent material strength or in the ability of the porous structure to counter-act fissure growth.

It could be an indication that the material properties of coke have improved to such an extent that the Micum test is not severe enough to test it. Considering that the demands made on cokes in terms of the conditions under which they are used have also increased, a more severe method of testing may be worth considering.

Conclusions

Small coke lumps were seen to have a greater fissure density than larger lumps, even though they tend to have fewer fissures per lump. For resistance to breakage this would make the occurrence of larger lumps more desirable as their contribution to the total number of fissures in a unit volume, or weight assuming similar densities, is less than that of small lumps.

The average fissure length increases with coke lump sizes, but the range of average length for each lump size in different cokes is relatively large. Relating the average fissure lengths to the lump sizes showed that they fall between a fifth and a third of the hypothetical coke diameter. The lump size appears to a determining factor for the fissure length.

For most of the cokes the shape factor varied very little between the lump sizes. There was a weak tendency for higher shape factors in larger sizes, as all the highest values occur in the larger lump sizes. On the whole the shape factors were low, indicating fairly regularly shaped fissures. But there were some exceptions.

Fissuring did not relate to the Micum test in the expected manner. Even, or especially, in good cokes most lumps contained at least one fissure. The vast majority of fissures did not however lead to breakage of the lumps under Micum test conditions. Since the degree of fissuring has been related to the probability of fracture on impact [2, 4, 6, 7] in the past, it appears that blast furnace cokes have vastly improved in terms of resisting fissure propagation and breakage. This means that now either other structural parameters are needed to explain the remaining differences in Micum performances, or that more extreme tests are called for to account for the stronger cokes and increasing mechanical demands on them.

References

[1]   Loison, R.,Foch, P., Boyer, A., "Coke Quality and Production" , Butterworth, London, 1989

[2]   Mott, R.A., Wheeler, R.V., "Coke for Blast Furnaces", The Colliery Guardian Co, LTD, London, 1930

[3]   Tucker, J., Everitt, G. Hall, G., Ironmaking Conference Proceedings, 1991, 211

[4]   Nadziakiewicz, J., Coke and Gas, 1959, 21, 46

[5]   BCRA, Coke Research Report, 1961, No 10

[6]   Wallach, R.V., Sichel, H.S., J Inst Fuel, 1963, 36,421

[7]   Arima, T, Nishi, T., Okuhara, T., 2nd International Cokemaking Congress, 1992, 248

Table 1 Volumetric Fissure Density

Lump Size /mm	A	B	C	D	E	F	I	J	AV	G	H	K
30-40	18	22	39	24				24	25			
40-50	16		4	24	12		20	9	14			
50-60	12	7	6		[34]	14	17	6	10	55		
60-70					5	7	7	5	6	27	28	
70-80					9	5	8		8	13	20	
80-100							3		3			
>100												11

(Header above: No Fissures per dm^3)

Table 2 Average Fissure Length divided by Mean Coke Lump Diameter

Lump Size /mm	A	B	C	D	E	F	G	H	I	J	K
30-40	0.31	0.34	0.16	0.25						0.31	
40-50	0.28		0.20	0.31	0.33				0.31	0.21	
50-60	0.25	0.22	0.28		0.31	0.28	0.29		0.26	0.25	
60-70					0.28	0.33	0.27		0.26	0.27	
70-80					0.23	0.23	0.28	0.24	0.36		
80-100								0.28	0.25		
>100											0.23

(Header above: Fissure Length / Lump Diameter)

Table 3 Variation of the Fissure Shape Factor with Coke Lump Size

Lump Size/mm	A	B	C	D	E	F	G	H	I	J	K
30-40	1.23	1.13	1.27	1.15						1.26	
40-50	1.24		1.31	1.16	1.96				1.18	1.17	
50-60	1.25	1.13	1.21		1.86	1.32	1.37		1.18	1.18	
60-70					2.09	1.34	1.50		1.18	1.24	
70-80					2.05	1.32	1.72	1.35	1.37		
80-100								1.47	2.07		
>100											1.25

(Header above: P/2L)

Figure 1   Relation of average Fissure Length to Coke Lump Size

a)
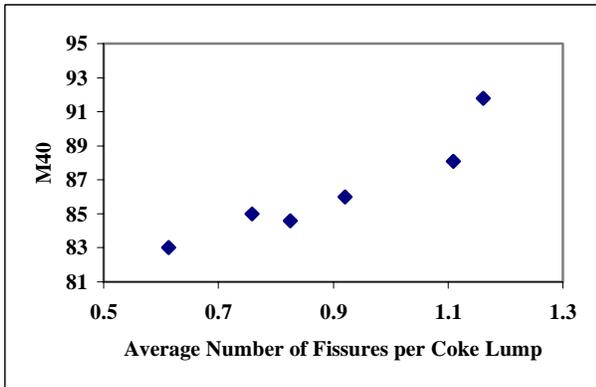
a)
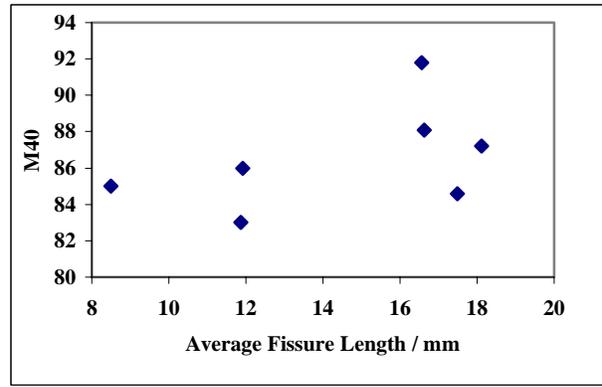
Figure 2   Relation of the M40 Index to a) the average Number of Fissures per Coke Lump
b) the average Fissure Length

a)
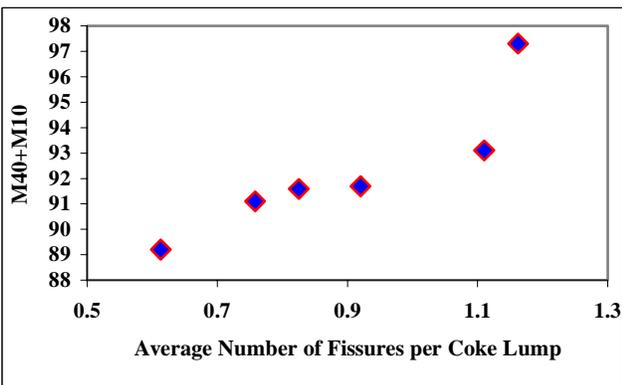
b)
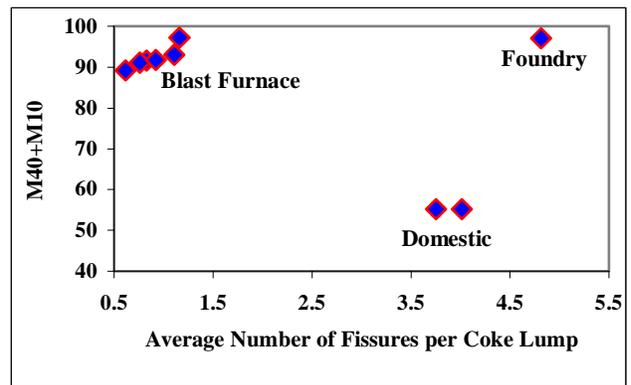
Figure 3 The relation of Fissuring to the Micum Test Results a)Blast Furnace Cokes only
b) Including Domestic and Foundry Coke