COKING PRESSURE AND ITS RELATION TO FISSURE FORMATION

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Introduction

The danger excessive coking pressure poses to the integrity and longevity of coke ovens has been recognized for many years [1-7]. 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 [8]. Typically they are longitudinal, i.e. perpendicular to the oven walls and extending inwards from the oven wall to the charge center. Traditionally any link between the larger structure of the coke in the oven, in terms of fissure network development, and coking pressure was dismissed. This was challenged by the finding that the internal gas pressure measured in a movable wall oven depended on the distance between the nearest fissure and the measuring probe [9.10]. This would imply that gas can penetrate the semi coke to some extent, but with increasing difficulty as the continuous layer of semi-coke grows thicker. Effective gas release would then depend on fissures being present in sufficient number and proximity to the area of gas release. These fissures would need to be in place while gases are being evolved, so that the speed with which fissures form and propagate would be of paramount importance.

Experimental Work

For this investigation the coking behaviour of some selected coals was characterized with particular emphasis on the fluid properties, gas release and fissuring in the semi-coke. Coking pressure data was used in conjunction with viscosity and thermogravimetric data. Two sets of experiments were carried out: A small coking pressure experiment and fissuring experiments in a larger box furnace.

The Coals

Rather than using commercial coal blends, which are carefully balanced to meet the requirements of coke ovens, four single coals were used for the investigation. Two pairs of coals at the extreme ends of coking behaviour were selected: Two high volatile, high fluidity coals A and B, and two low volatile, low fluidity ones, C and D. The wall pressures recorded, together with some of the characterization data are given in Table 1.

	Coal:	**A**	**B**	**C**	**D**
Pressure recorded in 250 kg pilot oven	kN/m2	48.4	15.9	3	2
Volatile Matter	% wt dmmf	17.9	19.3	32.8	32.1
Gieseler Max. Fluidity	ddpm	37	37	29783	26810

Table 1 Data on the Coals

The Small Coking Pressure Experiment

The internal gas pressure generated during coking was tested in a small scale laboratory experiment. A retort filled with 20g of coal (8% wt moisture and a bulk density of about 740 kg/m^3) was heated inside a split furnace at 3^{o}C/min.

During the carbonization 120 ml/min of nitrogen flowed through the retort. This quantity of gas is large compared with the amount of volatiles released, so that relative to the nitrogen collecting inside the retort, the influence of the volatile matter content of the coal is negligible. The furnace temperature gradient provided a temperature gradient across the coal charge. One end of the coal charge, the higher temperature end or 'coke-side' was lined up with the furnace centre line. The lower temperature end or 'coal-side' was connected to an empty section of the retort, in which the gas pressure was monitored. The sample temperature was recorded at both ends using thermocouples inserted into the nitrogen injection tube running through the centre of the sample. The absolute gas pressures generated in the small coking experiment are shown in Table 2. The repeatability for the two coals which generate appreciable pressures is low. However, coals C and D, which generate no pressure in the pilot-scale oven, develop considerable gas pressure in the small experiment, whereas coals A and B, which generate excessive pressure in the pilot-scale oven, develop very little gas pressure in the small experiment.

kPa	Test 1	Test 2
A	4.0	3.6
B	2.0	2.4
C	297.6	578.6
D	311.8	79.6

Table 2 Gas Pressures Generated in the Small Coking Experiment

The gas pressure data in conjunction with the temperature profiles were considered in relation to the Gieseler fluidity data.

The general picture provided by this comparison implied that, at the onset of the pressure build-up, the coal charge had not softened at the cold side but had reached a temperature near to that of maximum fluidity at the hot coke side (Table 3). When peak pressures were recorded, the whole sample had reached the softening temperature with the hot coke side at the re-solidification temperature.

Unlike the commercial coke oven situation, the direction of gas escape from this system is unambiguous, the injected gas flow from the injection point to the gas outlet at the hot side of the charge. If resistance to gas flow is set up in this region, gas collects at the cold end of the retort and the pressure is measured. With this in mind, the results are consistent with the lowest permeability to the injected gas occurring in the late stages of the fluid stage for the high volatile coals C and D and the early stages of semi-coke formation for the low volatile coals A and B.

Coal		Coking Pressure Temperatures, °C		Gieseler Fluidity Temperatures, °C		
		Coal Side	Coke Side	Softening	Max. Fluidity	Resolidification
A	Pressure on-set	425	474	440	479	507
	Peak pressure	468	516			
B	Pressure on-set	405	458	439	473	500
	Peak pressure	445	498			
C	Pressure on-set	403	452	387	448	489
	Peak pressure	444	493			
D	Pressure on-set	378	439	381	443	486
	Peak pressure	428	493			

Table 3 Temperatures of Gas Pressure on-Set and Peak Pressure

Fissure Formation

A fissure pattern was obtained for the four coals using a method based on that used by Sato [11]. 3.6 kg of coal were carbonized in a sealed steel box (440 x 340 x 30 mm). The charge density was around 800 kg/m^3 and the moisture content of the air-dried coal was adjusted to 7% wt. The resulting coke layers are shown in Figure 1. A difference can clearly be detected between the two low volatile, low fluidity coals and the two coals with a high volatile matter content and high fluidity. The high fluidity, high volatile coals C and D formed cokes with an extensive fissure network, which separated the coke layer into distinct pieces. The low volatile coals A and B formed fairly intact layers of coke with fewer fissures, which did not link up to form a network. The fissures were mostly unbranched and ran in a direction perpendicular to the heated walls in the direction of the temperature gradient.

Digital images of the fissure pattern were analysed using Optimas image analysis software. A certain degree of editing of the resulting binary images was required, and the data obtained should therefore be taken as a comparative guide rather than as absolute values. For the highly fractured cokes it was difficult to highlight individual fissures, which resulted in a misleadingly low fissure count. The entire central region of a fissure network, including coke pieces in it, would be counted as one giant fissure. A more indirect route was therefore adopted. The images were inverted and the number and size of coke pieces was counted instead of the fissures separating them. The area of the separating fissures was obtained by subtracting the sum of the area of the pieces from the total area. It was then added to the area of the non-separating fissures to obtain the total fissure area. A numerical expression for the degree of fissuring was thus arrived at, which corresponds well with the impression given by the images of the fissure pattern. The coking pressure data was plotted against the degree of fissuring in terms of the percentage of the coke area taken by the fissures (Figure 2). There appears to be an inverse relationship with the cokes that develop extensive fissuring generating little coking pressure, whereas those that generate coking pressure developed few fissures.

A second set of experiments was carried out on coals B and D only. They were ‘interrupted’ fissuring experiments with the view to assessing fissuring at different stages of the coking process. For this purpose the temperature was monitored at different positions of the charge by inserting thermocouples into the coal. As the experimental set-up was not designed for this type of experiment, the final temperatures could not be accurately predicted. The temperature at the charge center continued to rise considerably after the temperature outside the box had started to fall, which occurred almost immediately after the heating elements were switched off. The temperature profiles across the charge box were therefore assessed. On the whole, coking was found to proceed to match the maximum temperatures attained, despite the very slow rate with which the residual temperature gradients leveled out after the furnace was switched off. Even on that basis, more semi-coke was formed than would be expected if only the parts of the charge that were heated beyond the resolidification temperature emerged as fused material.

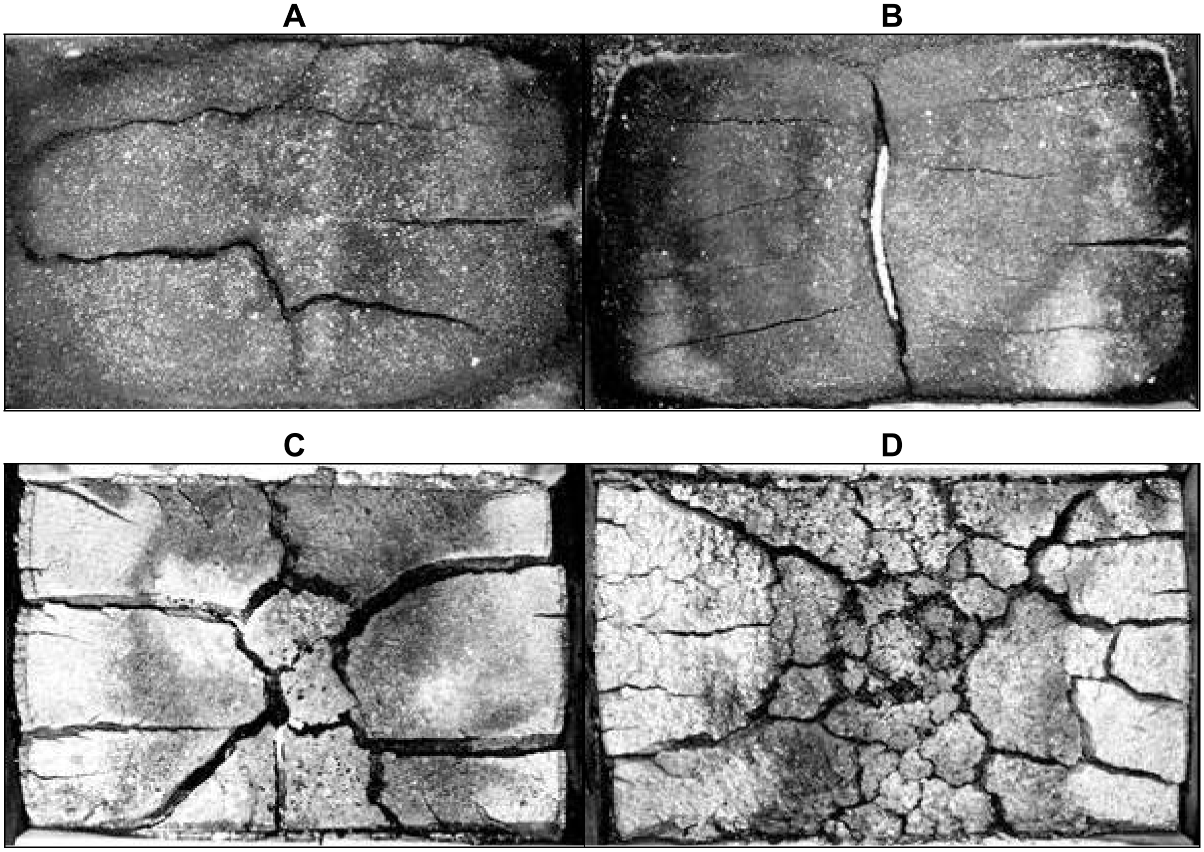

Figure 1 Coke Fissure Pattern

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Figure 2 Degree of Fissuring and Coking Pressure in the MWO

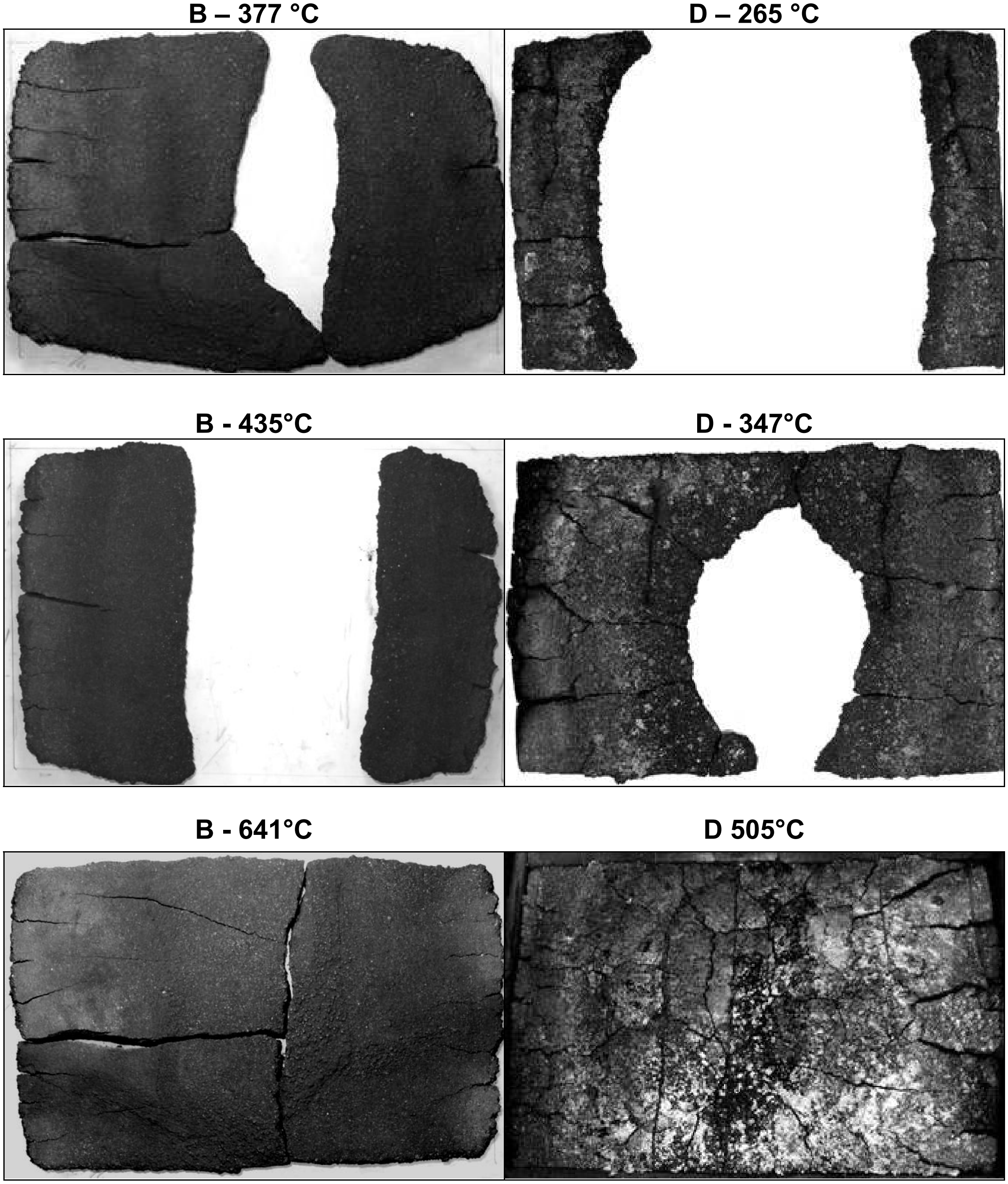
In Figure 3 three cokes from each coal are ordered by the extent of carbonisation they have experienced. As a rough guide to the extent of coking, the maximum centre line temperature is indicated. The difference in the extent of fissuring between the cokes of the two coals is evident at all stages of development. Whereas coal D has developed fissures that extend all the way from the wall to the leading edge of the forming coke when only a quarter of the charge has been transformed into semi-coke, coal B still has no such fissures when half or more of the charge has become semi-coke. By the time coal D is more than half converted to semi-coke, fissures can be observed to branch out and become linked to one another. By the time all the charge of coal D has been transformed into semi-coke, an extensive network of fissures is in place. For coal B a few fissures extending from the wall to the centre are eventually established after all the charge is transformed into coke, but the majority of fissures extend just a short distance inwards from the walls. At higher temperatures additional fissures develop along the wall-centre line, but they tend to neither touch the wall-side edge, nor extend to the central void.

In summary, not only are more fissures formed for coal D than for coal B, they appear to be formed earlier in the development of the coke and extend across the entire emerging coke right to the leading edge where new coke is formed. For coal D fissures commence to branch and connect when coal B fissures barely extend through half of the coke that has formed. When the entire charge has been transformed, coal D has a network of fissures in place, whereas for coal B a few fissures just about extend through the whole oven half-width as isolated, straight fissures.

Conclusions

Coking pressure potential was compared for four coals, two low volatile, low fluidity ones and two high volatile, high fluidity ones. Pilot scale oven testing identified the low volatile coals as potential coking pressure generating coals. Conversely, in a small, sealed coking retort, the high volatile coals led to pressure build-up. Comparing the pressure curves from the small experiment with the Gieseler fluidity temperature range suggests the likelihood of low permeability occurring towards the end of the fluidity range, or just beyond it, for all four coals. This would place an area of low permeability at the coke-side of an advancing plastic layer. There the low permeability area would benefit from fissures extending into its vicinity, which would reduce the distance evolved gases have to travel to escape from the carbonisation zone. The fissure pattern for the cokes showed that those made from the high volatile, high fluidity coals were much more extensively fissured. The fissures formed a network spanning the entire coke block, whereas those from the low volatile cokes were straight fissures running in the wall-to-center direction, and, more often than not, only extending part of the way to the center. The extent of fissuring was found to be inversely proportional to the coking pressure generated in the MWO. Fissuring has been shown in earlier work by other researchers to occur very soon after resolidification, and fissures were found to extend into barely formed coke. The possibility that their presence could affect the generation or prevention of coking pressure should therefore not be dismissed. For fissures to be effective they would have to interface with the area of low permeability causing the build-up of gas. As for the coals considered here, this possibility has been shown to exist. Supporting, indirect evidence is the fact that in the small experiment where fissuring was not possible, high pressures build up for the high volatile coals. It is well possible that their fissure pattern prevents such a build-up at a larger scale. Furthermore, interrupted fissuring experiments on two of the coals gave the impression that for the high volatile coal the fissures formed earlier and extended further into the coke.

The work presented here has shown that the conditions required for fissures to be relevant for coking pressure prevention exist for the set of coals examined. This information could be useful in completing the picture of coking pressure generation mechanisms, accounting for some coals that have been predicted to generate pressure, but do not do so when put to the test.



B – 377 °C

D – 265 °C

B - 435°C

D - 347°C

B - 641°C

D 505°C

Figure 3 Interrupted Fissuring Experiments for Coals B and D with the Final Charge CenterLime Temperature indicated

Acknowledgement

The authors would like to thank the European Coal and Steel Community (ECSC) for financing the project under which the results presented here were obtained. We would also like to thank INCAR, Oviedo, Spain, for supplying the coals and the Gieseler fluidity data.

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