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# THE EVALUATION OF TUYERE COKE PROBING DATA AT BLUESCOPE STEEL PORT KEMBLA WORKS

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## ABSTRACT

Tuyere coke probings have been conducted at Port Kembla over the past decade. This period of operation spans significant change in coking coal preparation, as well as the introduction of pulverised coal injection. The Port Kembla coking coal blend is very simple, being based on just two local seams. The dominant coal contains high proportions of relatively hard inert maceral coal material and particles derived from it have been identified as posing a risk to hearth and deadman cleanliness unless finely ground. This identification has relied heavily on optical microscopy techniques with particular emphasis placed on determination of the origin of fine particles found in the deadman. X-Ray diffraction (XRD) has also been used to clarify the degree of graphitisation and inferred thermal history of the fines.

## 1. INTRODUCTION

### 1.1 Previous work and sampling method

Previous probe investigations<sup>1)</sup> found that the medium-grained anisotropic binding material (RMDC) in Port Kembla coke was preferentially degraded relative to the inert particles (IMDC). Similar behaviour was found in a hot laboratory raceway simulator, where fines accumulation was in proportion to time on blast and was considerably greater than for other cokes having lesser CSR and other physical attributes<sup>2)</sup>.

The current tuyere probing campaign commenced in 1997. A 200mm diameter tube is pneumatically driven into the furnace 8-12 hours after shutdown and typically extracts a sample over a depth of 2.0 to 2.5 m from the tuyere nose. The sample is cooled under nitrogen. A matching temperature probe and bosh sample raking occur after coke probe extraction.

### 1.2 Characterisation of Port Kembla coke

The base Port Kembla coking coal blend combines coal from the Bulli and Wongawilli seams in about a 3:1 ratio. These seams share the same narrow rank range (1.15 to 1.35) but the former contains a high proportion of relatively hard inert maceral. The blend specification is for a minimum of 53% vitrinite. The coke ash contains little basic oxide mineral matter and resultant coke has very high CSR (~73%). A full description can be found elsewhere.<sup>3)</sup>

The carbon sub-saturation method,  $\Delta C$  (and DCI)<sup>4)</sup> was first developed at Port Kembla and has been

instrumental in coke quality improvement and furnace performance interpretation over the past decade. High  $\Delta C$  values correlate with high productivity, low fuel rate, low %Si and low stove heat loads through high permeability of the furnace lower zones. The method is particularly suited to the study of coke influence in the deadman because carbonaceous fines (including raceway debris and unburnt PCI) can only be consumed by dissolution in the dripping hot metal or reaction with residual slag FeO. These capacities are finite.

## 2. LABORATORY METHODS

### 2.1 Sample preparation and characterisation

Cooled probes were carefully transported to the laboratory and opened by oxy-cutting. The whole probes were then photographed. Generally, the structures described in Japanese quenched furnaces were confirmed<sup>5)</sup>, with raceway (infill) coke separated from the deadman coke by a 'bird's nest' zone where the fractions of fine coke and slag increase rapidly. These were identified, and marked before sub-division into sections of about 100-200mm in length. Typically, between 15 and 20 increments are generated per probe. Where necessary, metal and slag were manually liberated from the coke and then collected separately. On removal of each increment, the minus 8mm fraction was separated and processed as 'primary fines'. Any fines generated in the further handling of the larger material was not included in the overall fines assessment. For each increment, coarse material was screened at 90, 63, 31, 16 and 8mm.

The primary fines were considered to constitute the products of breakage and so were subjected to greater study. They were screened at 4, 2, 1 and 0.5mm. The plus 0.5mm fines were separated from metal and slag by magnetic and fluidising tube methods. Differentiation of the minus 0.5mm fractions was made by microscopic assessment and they were divided at 250, 125, 64 and 32 $\mu$ m.

For the purpose of characterising coke from raceway and deadman zones, measured and microscopic data for a sufficient number of the appropriate increments were combined.

### 2.2 Microtextural classification

For the examination of minus 4mm deadman materials, a quantitative method of characterisation was established. For each of the size fractions 4x2mm, 2x1mm and 1x0.5mm, particles were designated according to the following system:

- Id** comprised almost wholly (>90%) of discrete inert derived component (IMDC)
- Im** dominated by a single inert (>60%) but with significant associated reactive maceral derived component (RMDC)
- T1** both IMDC and RMDC are present, the IMDC as several smaller parts and predominates.
- T2** IMDC and RMDC are present in proportions and form typical of normal coke texture.

The system also recognises discrete graphite and petroleum coke particles that are present in very small

and consistent amounts. No classification for particles composed mainly or entirely of RMDC has been needed. Micrographs exemplifying this classification system are presented in Fig. 1(a-d).

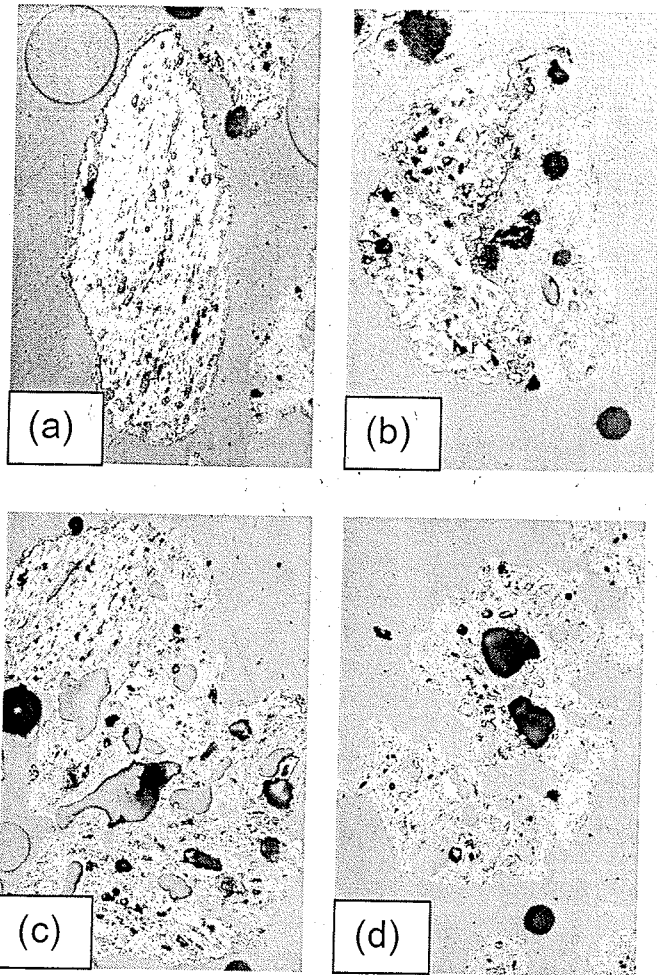


Fig. 1 (a) Id particle (b) Im particle (c) T1 particle (d) T2 particle (Scale: height of micrograph = 1.3mm).

For the minus 0.5mm deadman fraction, an additional discrimination was required.

**Type A** IMDC portions are generally bright and RMDC reflectivity is reduced relative to feed coke.

**Type B** RMDC is extensively degraded and graphitised, some IMDC is seen.

**Type C** a higher proportion of the particles are Id and Im. The RMDC is like Type A but the IMDC is mainly less bright but may contain a brighter core.

Small amounts of graphite and char were also observed. Fig. 1a also serves to illustrate Type A while Types B and C are illustrated in Fig. 2.

### 2.3 Lc determination

The use of XRD to estimate the temperature attained by coke sampled from blast furnaces is now well established and is based on the application of Sherrer's equation<sup>6</sup>. Graphitisation progresses as coke is heated and the increased ordering of the carbon layers allows calibration and quantification of the maximum temperature of samples extracted.

Here, the method has been applied to coke lumps from raceway and deadman locations, and to minus 4mm deadman fines.

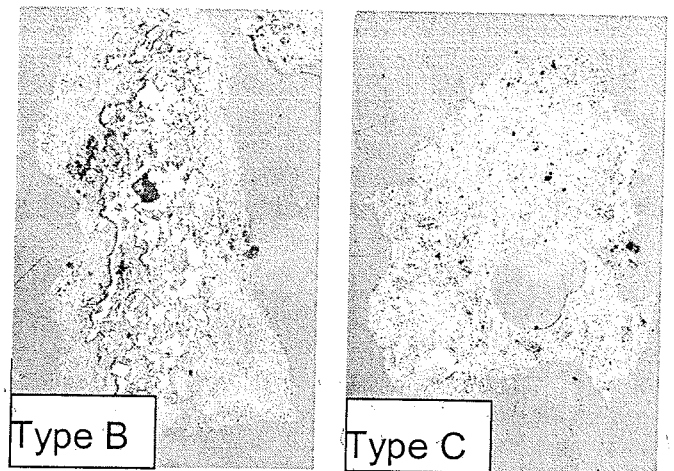


Fig. 2 Type B and Type C particles (Scale: height of micrograph = 1.3mm)

## 3. SUPPORTING WORK

### 3.1 Mechanical properties of RMDC and IMDC

The mechanical properties of Port Kembla coke RMDC and IMDC particles were characterised by ultra micro-indentation using a UMIS 2000 system<sup>7</sup>). Fig. 3 shows results for cokes sourced in 2000 and tested in the as charged feed condition, after exposure to N<sub>2</sub> for two hours at 1600°C, after CSR testing, after a simulated BF temperature/gas mixture regime to 1600°C and after raking from the furnace bosh. Hardness of IMDC is not changed under any condition but that of RMDC reduces greatly under all high temperature conditions.

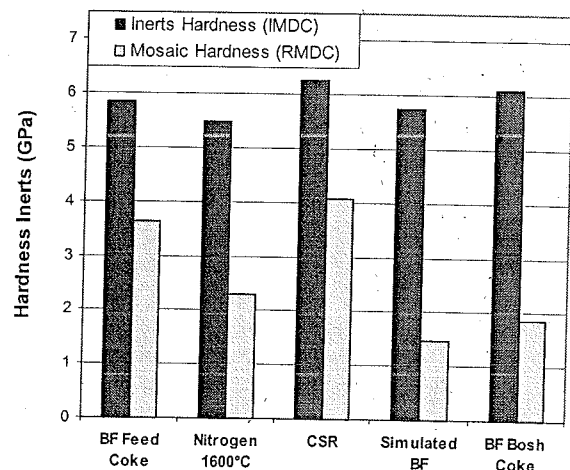


Fig. 3 UMIS Microhardness results for IMDC and RMDC after various treatments

### 3.2 High temperature testing

Tuyere velocities of 250ms<sup>-1</sup> dictate that raceway coke particle collisions involve high energies. These were not felt to be adequately represented by conventional drum test methods and so a new method was devised. Samples comprising 21 closely sized coke pieces (19x21mm) were heated to 1600°C at

3°C/min and then held for two hours. An atmosphere of 60% N<sub>2</sub> and 40% CO was imposed from 900°C to 1600°C and until cool down. The samples were then subjected to impact from a 3kg mass dropped from 1.5m. After each succession of 5 impacts, the sample was screened before being returned for further impacts. Samples received a total of 25 impacts with minus 5mm fines being removed at each screening. Fig. 4 shows the % plus 5mm after 25 drops as a function of the sample mass – a defacto density.

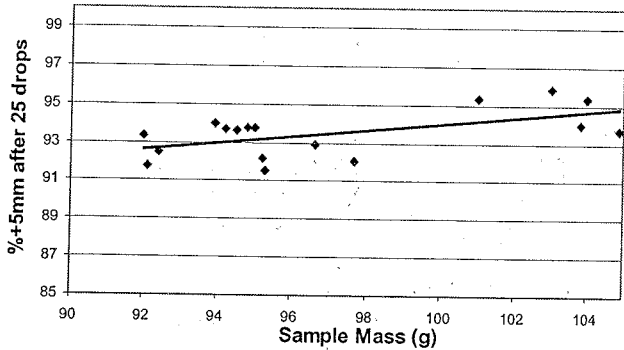


Fig. 4 Effect of sample mass (density) on fines generation under impact testing

Plant CSR particle count data demonstrates that this density variation is derived from the density of the RMDC matrix. Therefore, the achievement of increased matrix density is expected to improve coke performance by limiting breakage at high temperature.

#### 4. OBSERVATIONS AND DISCUSSION

##### 4.1 Particle sizings

Many other investigators have reported increased amounts of fines in the deadman with PCI use<sup>8</sup>. Such a generalisation cannot be made here. This is perhaps because of the dominant role of IMDC particles and the fact that the data spans a period where coke strength has been deliberately improved by finer grinding of the coking coal to reduce IMDC size.

However, data for coke lumps (ie excluding minus 4mm material considered to be breakage product) showed different size reductions between furnace top and tuyere level for raceway and deadman zones. In the raceway, the mean lump size reduction was 20 to 30 mm with indication of increase with increasing PCI rate. In the deadman, the mean lump size reduction was about 20 mm without apparent link to PCI rate.

The injection of coal increases the residence time of coke in the active coke zone. These results are consistent with this fact and with the harsher environment of the active coke zone/raceway. Further, they suggest that the use of PCI may not increase deadman coke residence time greatly.

##### 4.2 Liquids distribution

A typical liquids distribution pattern clearly exists and is exemplified in Fig. 5. No significant change has been observed with PCI introduction. While considerable metal is found in the raceway region, there is almost no slag. This suggests the less dense

slag has been displaced by the gasses ascending from the raceway. The slag presence decreased from about 3% to 1% when sinter basicity (C/S) was reduced from 2.2 to 1.9 in 2000. This reduction also led to a significant improvement in lower furnace permeability and the role of slag mobility seems to be confirmed.

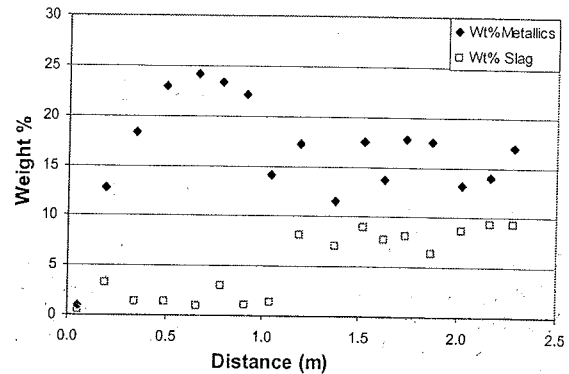


Fig. 5 Tuyere probe liquids distribution (10/12/02)

##### 4.3 Minus 4mm fines in the deadman

The 4x0.5mm characterisation was completed for each of eleven probes. The microtextural variation between size fractions is highly repeatable and Fig. 6 presents averaged data.

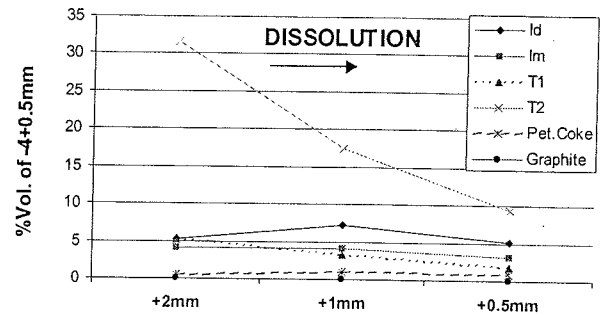


Fig. 6 Volume fractions of material types in deadman fines fractions

As indicated, size reduction accompanying the necessary elimination of fines by carbon dissolution in metal results in early consumption of RMDC and relative accumulation of IMDC materials.

Clearly the more finely crushed these particles are before coking, the easier is the task of consuming any that are released. This is due to increased surface area.

##### 4.4 Minus 0.5mm fines in the deadman

Nine probes were evaluated. The carbonaceous content of this fraction represents only 1.5 to 2.5% of the deadman material. All but one returned similar results, having 67(+/-13)% Type A, 18(+/-10)% Type B and 8(+/-3)% Type C material.

Type B material is mainly derived from RMDC and its low presence indicates that the greatest threat arising from RMDC occurs when that material weakens excessively or prematurely to liberate IMDC particles.

One probe was exceptional and contained large proportions of PCI char (19%) and Type C (34%) material. These clearly seem to be the products of

coarsely ground (>2%+200 $\mu$ m) and high inert bearing injectant coal used shortly after the start of injection and before optimal PCI grinding practice was achieved. The possibility for large injected coal particles to leave the raceway without burning or charring had not previously been recognised.

#### 4.5 Lc results

For selected probes, coke lumps from two raceway and two deadman locations were tested. Fines from the same deadman locations were also tested.

Samples were carefully prepared to avoid inclusion of material that could contain graphite produced from surface catalysis by or precipitation from iron droplets. Lumps of 19x31mm were tumbled to remove surface adhesions, then crushed with intermediate removal of minus 0.5mm fines and ultrasonic washing until a 2x1 mm sample was obtained. This was then crushed to minus 0.5mm and then ground to a minus 74 $\mu$ m powder. Samples of deadman fines were prepared from 4x1mm materials. These were crushed to minus 1mm. After ultrasonic washing, the minus 0.5 material was removed and the remaining 1x0.5mm fraction was crushed and ground to the same minus 74 $\mu$ m size.

The XRD analyses were performed on a Philips 1730 machine using standard techniques<sup>9)</sup>. Fig. 7 represents the general form of the results. The data are presented in Lc units rather than temperature because full calibration to the highest obtained Lc values has not yet been possible.

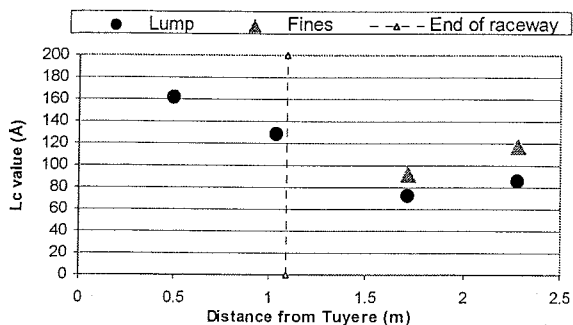


Fig. 7 Lc from tuyere coke samples (10/12/02)

As expected the Lc values for raceway lumps always exceed those of deadman lumps. Deadman fines return Lc values greater than the matching lumps. Calibration work has established that the differences shown are significant. The deadman fines are expected to be a mixture of materials formed in the deadman itself and in other parts of the furnace including the raceway. Only the fines generated from in or near the raceway can be expected to experience temperatures greater than in the deadman and therefore such results clearly indicate that significant quantities of raceway generated fines have been deposited in the deadman. In some cases, deadman fines Lc values exceed raceway lump values.

These results contradict those of Yoshida et al.<sup>10)</sup> who reported that at all tuyere level locations, lumps and associated fines had the same Lc. However, the result does seem consistent with the findings of Shimizu et al.<sup>11)</sup> who reported bosh coke fines having higher Lc than for lump. If fines can be transported to

the bosh, it also seems reasonable for them then to reach and to accumulate in the deadman.

## 5. CONCLUSIONS

Optical microscopy can play a valuable role in studying the behaviour of coke in the lower zones of the blast furnace.

The use of XRD is also of great value in the study of coke samples from the largely inaccessible lower zones.

The IMDC and RMDC materials in Port Kembla behave very differently and this is fundamental to the performance of coke and of the furnace.

Coke performance can be enhanced when coal inerts are crushed finely to increase IMDC surface area. Performance can also be improved when the RMDC coke matrix density is increased so that IMDC particles are not so easily released. This will increase their proportion dissolved into the raceway gasses and decrease the load that must be dissolved into dripping metal after discharge into the deadman as debris.

When injectant coal contains overly coarse and unreactive particles, it is possible for those particles to exit the raceway without reaction and to be coked within the furnace.

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