COKE PETROGRAPHY – JELLINBAH EAST

A brief commentary applicable to low ash coal from Jellinbah East, Queensland and descriptions of given photomicrographs of coke microtextures

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INTRODUCTION

The organic components of coal are classified by microscopy into three maceral groups, **Vitrinite, Liptinite** and **Inertinite**. In addition, coal contains minerals - syngenetic minerals that were deposited along with the original plant material, and epigenetic minerals that were deposited into the accumulated peat /coal infilling voids in cells, cracks and fissures and replacing other minerals.

On carbonisation, the liptinite macerals volatilise and act as softeners with their decomposition products enhancing fluidity, and as they normally account for a very minor proportion of the coal (<5%) make little contribution to the yield of coke whereas the major coke forming macerals are vitrinite and inertinite. Vitrinite is the principal contributor to the fusible components along with some of the semi-inertinite (e.g. relatively low reflecting semifusinite) that display fluidity and bond together with the diluent non fusible or partially fusible inertinite macerals to form a coherent solid mass – coke.

Note: Some inertinites are fusible in the carbonisation process and become completely incorporated into the coke matrix. The amount of fusible inertinite present in a given sample of coal is dependent on both rank, maceral composition and beneficiation processes (if any) and is therefore unique to that coal. In unoxidised Australian coals up to 38 percent of the total inertinite may be fusible (Reifenstein, 1995).

Coke properties such as mechanical strength and reactivity are major considerations for metallurgical coke manufacture for blast furnaces in iron making. Whilst some coals alone may produce an acceptable coke product it has become normal practice that blends of a variety of coals are used to meet both technical and economic objectives; e.g. it is desirable to incorporate low volatile coals into the coke oven feed to enhance the coke yield. Furthermore it may be possible to incorporate some cheaper, weakly coking coals to reduce coal supply costs.

The coke maker adjusts the coking coal blend to meet the requirements of the day according to the required coke quality needed for the blast furnace at the time, the coke plant capacity and demand for coke product, cost of feed coals and prices for byproducts. In times of lower iron production from the blast furnace it may be more appropriate to increase the amount of cheaper, higher volatile coal in the coke oven feed as overall coke requirements would be reduced. In this way the overall coal supply cost would be reduced, but offset by a lower coke yield, though a greater volume of saleable byproducts would be recovered from the coke ovens.

Coke quality control tests traditionally evolved from various drum strength indices but in recent years the **Coke Strength after Reaction** (CSR) test and **Coke Reactivity Index** (CRI) have become more important, particularly for blast furnaces with pulverised coal injection systems. Microscopical examination of the coke also provides useful microstructural and microtextural data that can be related back to the parent coal(s) in the coke oven feed. Microtextural analysis of coke enables determination of the proportions of fusible coal macerals on carbonisation and also groups of parent coal types in the coke.

When the incident light metallurgical microscope is configured with a certain illumination system and appropriate adjustments of the polariser and analyser are made, these microtextures become readily apparent (500x magnification). Some users induce interference colours by use of a quartz wedge or gypsum plate to enhance display of the anisotropy. Coin (1983) explained the methodology used at BHP Central Research Laboratories, Newcastle and reported the classification system used to describe the various coke microtextures, shown in Table 1.

Category	**Characteristics**	**Probable Derivation**
Inert Maceral Derived Components		
Isotropic		"Inert" macerals (fusinite, macrinite etc)
Basic Anisotropic	Uniform or undulose anisotropism	"Semi-inert" macerals, vitrinites of high rank
Reactive Maceral Derived Components		
Very fine grain anisotropic	<0.5 micron mosaic grain size	Vitrinite with Ro max of less than 0.90%
Fine grain anisotropic	0.5 to <2.5 micron mosaic grain size	Vitrinite with Ro max of 0.90 – 1.10%
Medium grain anisotropic	2.5 to <5.0 micron grain size	Vitrinite with Ro max of 1.10 – 1.30%
Coarse grain anisotropic	>5.0 micron mosaic grain size (fibres)	Vitrinite with Ro max of 1.30 – 1.50%
Foliate anisotropic	Strong anisotropism	Vitrinite with Ro max of >1.50%
Graphite		Either pyrolytic origin (deposits on outer surfaces of coke charge or, as flakes associated with iron or "reacted material".)
Carbonaceous-Indeterminate		
Reacted material	Very low reflectance and relief	Product of degradation in tuyere cokes etc.
Non-Carbonaceous		
Primary (e.g. quartz, feldspar etc.)	Often obvious as overgrowths within the porosity	Produced during coke reaction
Secondary (e.g. silicon carbide, mullite etc.)	High reflectance	
Iron spherules		

Table1. Classification Used for Coke Microtextural Point Count Analysis (modified after Coin, 1983)

The size of the mosaic in the coke correlates with the rank of the parent coal. As most of this material is derived from the maceral group - vitrinite, its maximum reflectance in oil (Rv,max) is a very useful parameter for analysis of the coal.

Coin (1983) reported that a coke mosaic size index (CMSI) calculated from the percentages of the various mosaic types present in the coke can be correlated with parameters such as Coke Strength after Reaction (CSR) values and Coke Reactivity Indices (CRI), having a better correlation than Rv,max. The index can vary from 1 to 5 and is calculated as follows:

$$\text{CMSI} = (a + 2b + 3c + 4d + 5e) / (a + b + c + d + e)$$

where: a = percent very fine grain mosaic
b = percent fine grain mosaic
c = percent medium grain mosaic
d = percent coarse grain mosaic
e = percent foliate mosaic

CSR is the percentage +10 mm sized coke remaining after a selected sample of sized coke is reacted with CO_2 at a specified high temperature and subjected to an I type drum tumble test. The method was developed by Nippon Steel Corporation. CRI is calculated from the loss of mass when the coke sample is reacted with CO_2 as in the CSR test.

USA METHODOLOGY

Gray & Devanney (1986) explained the classification of carbon forms in metallurgical cokes used by US Steel Corporation. The reflected microscope is used with an antiflex 40x oil immersion objective to produce a total magnification of 500x. A quartz or gypsum tint plate is used to add colour to the carbon-form textures.

The binder phase classes describe the degree of development of the carbon microtextures from mainly vitrinite macerals with parent coal rank increasing down the column. The Ribbon (coarse) class equating with the Foliate anisotropic class described by Coin, these categories formed principally from vitrinites of **Rv,max >1.50%.** (Refer to the paper for detailed explanations of the various microtextures; for Jellinbah East coal the major ones are: ***binders*** - ribbon, and perhaps a minor amount of lenticular coarse, and ***fillers*** – organic inerts). The combined binder, filler and miscellaneous coke carbon forms analysis (% volume) determines the following:

Classes	Microtextures	% Volume
Binder phase	Isotropic **Anisotropic:** Incipient Circular (fine) Circular (medium) Circular (coarse) Lenticular (fine) Lenticular (medium) Lenticular (coarse) Ribbon (fine) [Length >4x Width] Ribbon (medium) Ribbon (coarse) **Total binder phase**	
Filler phase	Organic inerts (fine) Organic inerts (coarse) Miscellaneous inerts Inorganic inerts (fine) Inorganic inerts (coarse) **Total filler phase**	
Miscellaneous	Depositional carbon Additive carbons Miscellaneous **Total Miscellaneous materials**	
	Total Carbon Forms Analysis	100.0

COMMENTS

Vitrinites from Jellinbah East coal exhibit an $R_{v,}$max (mean maximum reflectance in oil at 546 nm and 23^{o}C) of about 1.7 percent and so will produce mainly fibre /ribbon or foliate microtextures (shown in photomicrographs 2, & 9to 14 as F - Flow-type).

There is a definite place for Jellinbah East coal in coking blends where an **overall surplus of reactive macerals exists with other components, particularly the medium and higher volatile prime coking coals.** A Jellinbah East coking coal product with higher vitrinite content (70 –75 percent reactive macerals) would be more desirable in other circumstances but nevertheless with about ?50 percent fusible components it is a very useful low volatile coking blend constituent to increase net carbon yield from carbonisation of the blend and in addition provide elongate ribbon microtextures that enhance coke strength and reactivity parameters.

REFERENCES

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GRAY, R.J. & DEVANNEY, K.F., (1986): Coke carbon forms: microscopic classification and industrial applications. International Journal of Coal Geology, 6, 277-297. Elsevier, Netherlands.

REIFENSTEIN, A.P., (1995) : Processes associated with coal to coke transformation. Thesis submitted for the degree of Master of Science at the University of New South Wales (unpublished).

PHOTOMICROGRAPHS OF COKE MICROTEXTURES

MICROTEXTURES OF COKED JELLINBAH:

(vitrinites produce flow type, elongate ribbon, fibre microtextures)

1. II - The bright (white) material is described as an Inorganic Inclusion (it may be pyrrhotite – $FeS_{(1-x)}$ or possibly metallic iron, produced by the reduction of pyrite - FeS_2 in the parent coal).

2. AI – In the upper part of the field we see Anisotropic Inert derived from very weakly fusible semifusinite, note the slight purple and yellowish colored sections – the material would display differing colors on rotation of the microscope stage.

   F – In the lower part of the field we see Flow type i.e. Fibre or Ribbon (coarse) as described by Coin and also by Gray respectively. Note the vesicle and the elongate cracks that are subparallel to the observed length; the cross cutting cracks would be zones of weakness on coke breakage.

3. AI – Anisotropic Inert derived from weakly fusible semifusinite, note the slight purple and yellowish colored sections – the material would display differing colors on rotation of the microscope stage. The black blobs appear to be mainly holes (porosity) and minerals.

4. AI – Anisotropic Inert derived from partially fusible semifusinite, note the slight granularity of the yellowish colored sections with a tendency to display purple hues– the material would display differing colors on rotation of the microscope stage. The black blobs appear to be mainly holes (porosity) and mineral derived inorganic inerts.

5. BA – Basic Anisotropic derived from high rank (low volatile) poorly fusible very high rank vitrinite (Rv,max ?+1.9%) or weakly fusible semi-inertinite - ?semi-macrinite, note the lack of porosity; the material would display differing colors on rotation of the microscope stage.

   AI – Anisotropic Inert derived from poorly fusible semifusinite, note the strong purple coloured sections and relics semifusinite appearance– the material would display differing colors on rotation of the microscope stage. The black blobs appear to be mainly holes (porosity).

6. AI – Anisotropic Inert derived from partially fusible semifusinite and ?inertodetrinite, note the strong purple coloured sections and relics semifusinite appearance– the material would display differing colors on rotation of the microscope stage. The black blobs appear to be mainly holes (porosity), some may contain inorganics from minerals.

   I – Isotropic Inert (Organic Inert) derived from nonfusible semifusinite, note the relatively even coloration – the material would display the same color on rotation of the microscope stage. The black blobs appear to be mainly holes (porosity) and inorganics from minerals.

7. I – Isotropic Inert (Organic Inert) derived from nonfusible telo-inertinite; note the even coloration (no change on rotation of the microscope stage) and relic bogen structure from the parent maceral fusinite. The dark cavities are mainly voids conferring porosity.

8. BA – Basic Anisotropic particle showing “uniform or undulose anisotropism” probably derived from (low volatile) poorly fusible very high rank vitrinite (Rv,max ?+1.9%) or weakly fusible semi-inertinite - ?semi-macrinite, note the absence of vesicules; the color would change on rotation of the microscope stage.

9. F – Flow type (Ribbon, Fibre) derived from low volatile fusible vitrinite. Note the large pore in the top left field with the thick pore wall comprised of flow type (ribbon, fibre) that is well bonded to the adjoining anistropic inert

   AI – Anisotropic Inert derived from poorly fusible semifusinite well bonded to the flow type or fibre, the dark blobs appear to be mainly holes (porosity) with some containing inorganics from minerals.

10. F – Flow type (Ribbon, Fibre) derived from vitrinite, note the high ratio of length to width so the fibre confers microstrength. The fibre is well bonded with the adjacent isotropic inert. Note the elongate cracks that are subparallel to the long dimension of the fibre. Althouugh some weakness may be indicated cracks that are perpendicular to the fibre length would be of much greater concern.

    I - Isotropic inert derived from nonfusible inertinite, acting as an aggregate in concrete confering strength through its intimate bonding with the adjoining Flow type (Ribbon, Fibre) and forming part of the thick walls to the large pores (black areas at the margins of the photomicrograph).

11. F - Flow type (Ribbon, Fibre) derived from the low volatile bituminous vitrinite of Jellinbah East coal forming thick, strong walls to large pores although some fractures that may weaken the coke are evident.

12. F - Flow type (Ribbon, Fibre) derived from the low volatile bituminous vitrinite of Jellinbah East coal forming thick, very strong walls around the pore.

    AI – derived from fusible inertinite, the interference colors would vary with rotation of the microscope stage.

13 & 14. F – Flow type (Ribbon, Fibre) typically derived from the fusible low volatile bituminous vitrinite such as that from Jellinbah East coal, forming very thick, very strong walls around the large pores. Note the absence of any large cracks

BLEND I COKE – *contains high, medium, and low volatile coking coals.*
(The only Low Volatile coal in the blend being from USA)

Repeating part of Table 1 - Cokes from the reactives (fusible) components show the following microtextures:

Note the increasing anisotropic domain size with coal rank, very fine grain for high volatile coals to coarse for medium to lower volatile coals and elongate ribbon or fibres for low volatile bituminous coals with Rv, max> 1.5%). The USAsystem describes these gradations of anisotropic material as incipient, circular, lenticular, and ribbon forms that are produced with increasing rank of the parent coal.

Reactive Maceral Derived Components		
Very fine grain anisotropic	<0.5 micron mosaic grain size	Vitrinite with Ro max of less than 0.90%
Fine grain anisotropic	0.5 to <2.5 micron mosaic grain size	Vitrinite with Ro max of 0.90 – 1.10%
Medium grain anisotropic	2.5 to <5.0 micron grain size	Vitrinite with Ro max of 1.10 – 1.30%
Coarse grain anisotropic	>5.0 micron mosaic grain size (fibres)	Vitrinite with Ro max of 1.30 – 1.50%
Foliate anisotropic	Strong anisotropism	Vitrinite with Ro max of >1.50%
Graphite		Either pyrolytic origin (deposits on outer surfaces of coke charge or, as flakes associated with iron or “reacted material”.)

15. The field shows an Istropic Inert on the left bonded to a Fine Mosaic from a high volatile coking in the centre with an anisotropic inert on the right. Note the flow of Fine Mosaic into cavities of both inerts.

16. The centre of the field shows an elongately fractured Flow type (Ribbon, Fibre) well bonded into Fine Mosaic from a high volatile coking coal with Medium Mosaic from a medium volatile coal on the lower right side.

17. Note the Coarse Mosaic in the upper left, forming a relatively thick wall to adjacent pores and bonding to an Anisotropic Inert (from poorly fusible inertinite). Compare the mosaic size with the Medium grained Mosaic in the next picture - photomicrograph 18.

18. Thick wall to pore in Medium Mosaic coke derived from medium volatile coking coal. A small section of Coarse Mosaic indicates some medium to lower volatile components and an elongate Flow type (Ribbon, Fibre) from the low volatile coal component (on the right of the field) appears to be well bonded but containing some microcraccks that are subparallel to the length.

19. Flow type (Ribbon, Fibre) microtexture on the left side of the field is derived from the low volatile coal component, note the fractures between the pores above and below. These may weaken the pore wall although it appears well bonded to the Fine Mosaic which grades to Medium Mosaic towards the upper right field.

20. A large Anisotropic Inert (centre) is well bonded intp the coke by a Fine Mosaic on the left adjoined by Flow type (Ribbon, Fibre) microtexture on the far upper left side. Coarse Mosaic adjoins the anisotropic inert on the right of the field, and again with Fine Mosaic on the far lower right.

BLEND III COKE - *contains high, medium, and low volatile coking coals.*

(The only Low Volatile coal in the blend being from Jellinbah East)

21. Large Isotropic Inert derived from fusinite and well bonded into the coke by Medium grained Mosaic on the right of the field and fine mosaic on the upper left. The absence of microfractures reinforces the interpretation of strong bonding.

22. Anisotropic Inert in the centre of the field (confirmed by rotation of the microscope stage) with Coarse Mosaic developed to the left side and Fine Mosaic on the right. The Inert is well bonded with the mosaic and forms part of two pore walls (black areas in the centre of the field).

23. Strongly anisotropic coke with Medium Mosaic in the upper left field bonded to Inerts on the far left and across to to Flow type (Ribbon, Fibre) on the right side. Note the ?shrinkage cracks, perpendicular to the length, in the fibre and particularly the crack at the boundary at the top of the fibre where a the bond with the finer mosaic is interrupted. The bonding along the length of the fibre appears to be quite good.

24. On the left of the field we see a long Flow type (Ribbon, Fibre) well bonded to Fine Mosaic in the lower left field with an Inert incorporated towards the centre field. This in turn is strongly bonded to mosaic grading from fine to medium in size and incorporating an Anisotropic Inert on the far right side of the field. The elongate fractures (?shrinkage cracks) in the ribbon appear not to greatly affect the bonding of the fibre with the Fine Mosaic. Note the few pores so that the pore wall thickness is generally relatively large conferring strength.

25. Anisotropic Inert well bonded to Fine Mosaic on the upper left side. Note the micro pores and development of some Fine Mosaic within the structure.

26. Strongly anisotropic Flow type (Ribbon, Fibre) well bonded to Fine Mosaic on the right side of the field. Although the pores appear large on thefar left side and top left of the field the thickness of the pore walls is considerable and consists of the relatively low reactivity fibre material.

27. Medium Mosaic on the left side of the field strongly bonded to a Flow type (Ribbon, Fibre) that shows several cracks anda pores on the lower right side of the field. Some small inerts are well bonded into the mosaic.

28. Flow type (Ribbon, Fibre) comprise most of the field and is well bonded as it grades into a Medium Mosaic on the far right. Note the Anisotropic Inerts on the far left side of the field are very strongly bonded into the mosaic on the far left of the field and Flow type (Ribbon, Fibre) near the centre. The mass forms a very thick, strong wall to surrounding pores.

29. A large pore in Flow type (Ribbon, Fibre) which comprises most of the thick low reactivity wall with Fine Mosaic (from a medium to higher volatile coal) on the far left and top right.

The field shows a large area of Fine Mosaic on the left side with a very well bonded Flow type (Ribbon, Fibre) at the top left. In the top right of the field we see a completely bonded Basic Anisotropic grain (probably formed from a high rank vitrinoid (Vstage 19+) of negligible fluidity showing some shrinkage (devolatilisation cracks). On the lower right is an Anisotropic Inert also well bonded into the matrix of Fine Mosaic almost abutting a large pore that is partly visible on the far right.