Microscopic evaluation of coal and coke for metallurgical usage

Nandita Choudhury, Debadutta Mohanty*, Prabal Boral, Saroj Kumar and Sushanta K. Hazra

Central Institute of Mining and Fuel Research, Dhanbad 828 108, India

The growing demands of the steel industry to import coking coals necessitates their optimal use by proper blending with indigenous coals. Petrographic assessment depicts the heterogeneity of the coals. Maceral composition and vitrinite reflectance per cent as a rank parameter are the basic outcomes of coal petrographic studies that are in frequent use for categorizing coals. The present study also gives an idea about the potentialities of petrographic techniques to decide the optimum blend proportion from coal type, rank and V-step distribution pattern. Apart from this, coke microtextural studies can be used as an efficient tool not only to cross-check the predicted quality of the coke, but also to predict its behaviour during metallurgical operations. Attempts have been made here to predict coke quality from the microtextural study. Three indigenous coals and four imported coals with reflectance ranging from 0.81 to 1.23% have been used in the present study to illustrate the potentialities of microscopic techniques for the assessment of coal and coke for metallurgical usage.

Keywords: Anisotropy, carbonization parameter, reactive macerals, reflectance, V-step distribution.

AMONG its various end uses, coal finds importance in the steel industry for coke making. Coke quality in terms of its ability to produce heat for melting the ore, to reduce the ore to metal, to impart permeability to facilitate the reactions and to bear the load of the charge in the blast furnace, is dependent on[1]: (a) nature of individual coals and their blend proportion and (b) operational parameters.

Coke quality is 70–80% dependent on coal rank, coal type and blend composition, the rest 20–30% is dependent on coal preparation and operational conditions like heating rate, coal pulverization level and charge bulk density[2,3]. Amongst all the uses, perhaps the art of coke making demands critical assessment of the petrographic parameters as it strikes to the heterogeneity of coal in terms of the physical mixture of microscopic entities, i.e. macerals[4]. The situation is more compelling in the Indian context because of the scarcity of coking coals, which are mostly imported. The imported coals have to be blended properly with the indigenous coals for optimal use and, hence deciding upon the blend property is the main objective of the present study. The second aspect dealt with here is to evaluate the metallurgical performance of coke from the coke microtexture.

Different workers from all over the globe have tried to interrelate the petrographic property of coal, coke microfabric and coke quality[5–13]. The importance of proper blending for better coke quality has been realized for a long time and researchers have developed different models based on petrographic parameters, especially reflectance value as well as other parameters[14,15] to decide the blend proportion and its composition.

Extensive work on coal petrography in relation to carbonization of Indian coking/caking coals has been carried out in our laboratory. Mukherjee et al.[16] described the Indian coal resources and their utilization pattern. Chaudhuri and Ghose[17] used coal petrography as a tool for deciding the blend proportion for coke making. They have provided an excellent account on the correlation of petrographic parameters with their carbonization properties[18]. Chaudhuri et al.[19] have elaborated the role of pressure and hydrothermal treatment on coke microtexture. Choudhury et al.[20] emphasized the role of maceral and rank of Indian caking/coking coals on the micro fabric characteristics of coke. Amongst other pioneering works in this line are those by Pareek[21] and Ghosh[22] that emphasized coal petrographic studies for assessment of coking behaviour of Indian coals. Ghosh[23] has shown the importance of coke microtextural study for its technological appraisal, while Chatterjee et al.[24] stressed upon use of maceral composition for calculation of chemical composition of composite coal samples.

Nature of coal

The chemico-physical behaviour and thermo-chemical transformation of coal during any industrial use, particularly in the process of carbonization is largely governed by its petrographic make-up and its rank as it strikes to the heterogeneity of coal. Micro-petrographic techniques are popular now for characterization of coal for industrial purposes. Indian coals show far greater variability in maceral composition than coals from Western countries.

The major share of our coking coal reserves are locked up in the Jharia, Raniganj and Bokaro coalfields. Our deficiency of coking coal reserves is compensated by imported coals from USA, Australia, China, Indonesia, Argentina, etc. For the present study, three indigenous coals from Jharia Coalfield and four imported coals, two each from Australia and Argentina, have been chosen. The coals were initially assumed to be single or individual coals before detailed petrographic studies were carried out.

Experimental

From the three indigenous (numbered Ind-1, 2 and 3) and four imported (numbered Imp-1, 2, 3 and 4) washed coals, the blends (numbered B-1, 2, 3, 4, 5 and 6) were prepared with the pattern and proportion as mentioned in Table 1. The blend proportions have been randomly chosen to study the variation in coke property with change in proportion. The qualities of the individual coals as well as their blends were assessed through the petrographic study (rank and maceral composition) (IS 9127 and ISO 7404 [Part I–III, V]) and proximate analysis (IS 1350 [Part I]). Polarized light microscope [Leica (erstwhile Leitz) MPV system and DMRXP HC] have been used for measuring the reflectance per cent and maceral analyses were done using both panchromatic light and fluorescence mode. The rheological parameters like CSN (Crucible Swelling Number) and GKLT coke type (Gray-King Low Temperature) of the coals were also determined to judge their suitability for carbonization and coke making following IS methods (IS 1353: 1993, reaffirmed April 2005).

Totally eleven cokes (numbered with k as superscript to the corresponding coal or blend number) were prepared from the individual coals and their blends in the carbolite coke oven pilot plant in our institute, maintaining the operational wall temperature at $1050 \pm 25°C$ for about 18 h. For assessment of cokes, the coke quality indices like CSR (Coke Strength after Reaction) and CRI (Coke Reactivity Index) were determined using IS methods (IS 4023: 1991).

Polished moulds were prepared from –2 mm size of the coke samples for coke microtexural studies. These were studied using 50X oil immersion objective with reflected light and γ-plate under a microscope. Point counting techniques were used to quantify various carbon forms by their domain shapes and sizes along with the pores and fissures, as observed in the coke under the microscope. The methodology and nomenclature followed here for coke microtextural studies were from Chaudhuri et al.[19] and Choudhury et al.[20], modified after Gray and Devanney[2], Moreland et al.[3] and Coin[25]; in context of Indian coals. The different recognizable features were divided into two major groups of carbon forms: (a) 'reacted' or 'binder phase', those suffered through the plastic phase

and (b) 'inert' or 'filler phase', those remain inert during thermo chemical transformations. The binder phase is further classified into isotropic, weakly anisotropic, mosaic, flow and lamellar-type anisotropy of various domain sizes and filler phase carbon forms into organic and inorganic inert materials, deposited carbon, etc.

Results and discussion

The mean (maximum) reflectance percentage (MMR%) of the coals and their blends varied from 0.81 to 1.23, indicating that these are moderately to good coking coals (Table 1). The reflectance values of Imp-3 and Imp-4 were comparatively high and that of Ind-1 was the lowest one.

The V-step distribution of the selected coals ranged from V_6 to V_{18}. The assumption of all the selected coals being of a single rank, does not hold good for a few coals from their wide V-step distributions, especially in the case of the Imp-1 and Imp-2. The peak V-step distribution of all the coals, excepting Ind-1 and Ind-2 lies around V_{11} and V_{12}, indicating their good caking behaviour and can be used for blending (Table 1) as well as used as single coals for coke making.

Considering the behaviour during carbonization processes, macerals can be divided into two broad groups – reactives/fusible and inerts/infusible. Owing to the nature of the Indian Gondwana coals due to their characteristic mode of origin, a four-fold classification of macerals was realized by Chaudhuri et al.[26], instead of the three-fold classification recommended by ICCP and International Standard Organization (ISO), which is generally being used for Carboniferous coals of Europe and America. Chandhuri et al.[26] added semivitrinite to the maceral classification of vitrinite, liptinite and inertinite. According to them[26] semivitrinites with mean random reflectance percentage <1.80 are fusible in the carbonization process and become completely incorporated into the coke matrix. Similar work has also been reported from other parts of the globe[4,27]. Vitrinite is the principal contributor to the fusible components along with the semivitrtinite and liptinite that form a reactive group of macerals that fuse during carbonization to act as a binder phase carbon form. During carbonization, fusible macerals bond together with the non-fusible or partially fusible inertinite macerals that forms the filler phase carbon form of the coke. The reactive maceral content of Indian coals usually remains much below the proportion required to yield good coke. The range of total reactive macerals per cent (including mineral matter basis) of selected coals was 49.3–68.4, except for Ind-1, having the highest total reactive maceral content of 71.7 (Table 2). The semivitrinite content of these coals though signficant in quantity, varied between narrow ranges from 1.2 to 4.0% and hence its effect on the variation of coke microtexture is not recognizable. Some of the macerals and their association found in the

Table 1. V-step distribution, mean (maximum) reflectance percentage (MMR%) and blend proportion of coals

Type	Sample no.	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}	V_{16}	V_{17}	V_{18}	MMR%	B-1	B-2	B-3	B-4	B-5	B-6
Indigenous coal	Ind-1	2	43	47	8										0.81						
	Ind-2			25	48	23	4								0.96		45	45	45	45	45
	Ind-3					11	50	36	3						1.18		35	20	35	35	20
Imported coal	Imp-1		4	20	18	17	19	8	3	2	3	3			1.09	80	20				
	Imp-2			2	3	13	42	32	6	2		2			1.18			35			
	Imp-3				1	3	42	47	7	1			1		1.21				20		
	Imp-4					3	24	58	13	1				3	1.23	20				20	35
Blended coal	B-1		1	4	3	3	29	51	7	2					1.21						
	B-2		1	15	25	17	23	13	2	1	1	1			1.07						
	B-3			12	23	17	26	18	3	1			1		1.08						
	B-4			10	22	16	28	22	2						1.09						
	B-5			9	23	15	25	23	5						1.10						
	B-6			11	20	12	22	29	6						1.11						

Table 2. Petrographic analysis, proximate analysis and rheological properties of coals

Type	Sample no.	Petrographic analysis — Maceral % — Vt	Sv	Lp	R_t	In	MM	MMR%	Proximate analysis (wt%) — M	Ash	VM (dmf)	FC (dmf)	CSN — CSN_E	CSN_P	GKLT coke type — $GKLT_E$	$GKLT_P$
Indigenous coal	Ind-1	63.5	1.2	7.0	71.7	18.1	10.2	0.81	1.7	17.5	37.5	62.5	2½	3	G3	>G2
	Ind-2	51.6	2.0	1.6	55.2	33.8	11.0	0.96	1.4	17.4	33.8	66.2	3	2	>G1	>G1
	Ind-3	45.5	2.2	1.6	49.3	40.7	10.0	1.18	1.8	18.3	24.0	76.0	4	3½	G	G2
Imported coal	Imp-1	65.6	2.0	0.8	68.4	27.2	4.4	1.09	1.1	10.2	26.9	73.1	5½	6	>G4	>G5
	Imp-2	57.0	3.2	0.5	60.7	36.4	2.9	1.18	1.1	8.5	23.6	76.4	4½	4	>G3	>G5
	Imp-3	59.8	3.8	0.2	63.8	31.6	4.6	1.21	1.0	9.7	23.0	77.0	7	7½	G5	>G5
	Imp-4	52.9	3.7	0.7	57.3	39.0	3.7	1.23	0.9	6.2	23.1	76.9	6	4	>G4	G5
Blended coal	B-1	54.6	4.0	0.6	59.2	37.6	3.2	1.21	1.0	11.5	23.8	76.2	4½	4½	G5	>G5
	B-2	51.8	2.8	1.2	55.8	34.4	9.8	1.07	1.3	17.3	28.3	71.7	4½	3	G3	>G3
	B-3	53.1	2.7	1.0	56.8	34.8	8.4	1.08	1.4	13.3	25.6	74.4	4	3½	>G2	>G3
	B-4	52.1	1.8	1.4	55.3	34.6	10.1	1.09	1.3	17.1	28.4	71.6	4	3	>G2	>G3
	B-5	50.1	2.1	1.5	53.7	36.6	9.7	1.10	1.3	16.1	27.6	72.4	3½	3	>G2	>G2
	B-6	51.7	2.3	1.3	55.3	36.0	8.7	1.11	1.2	14.3	28.5	71.5	4	3	G3	>G3

Vt, vitrinite; Sv, Semivitrinite; Lp, Liptinite; R_t, Total reactivite macerals; In, Inertinite; MM, Mineral matter; MM, Mineral matter; FC, Fixed carbon; E, experimental value; P, predicted value.
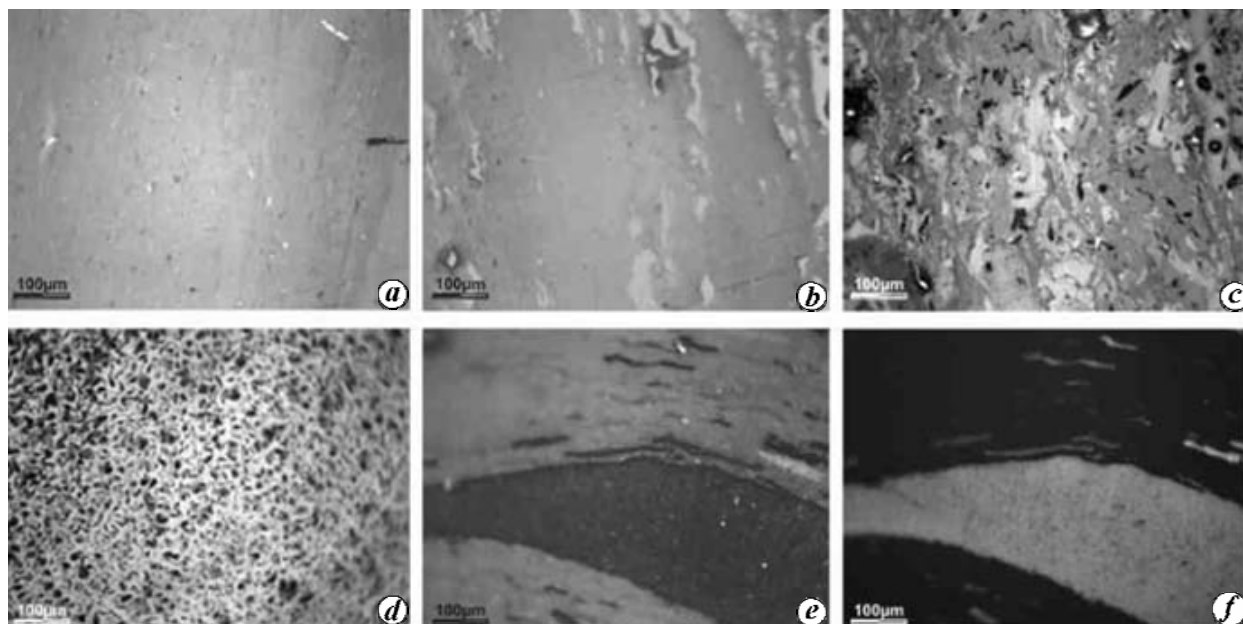
Figure 1. Photomicrographs of some of the macerals from the studied coals. *a*, Telovitrinite with fine pores; *b*, Vitrinertite; *c*, Trimacerite; *d*, Inertinite (semifusinite); *e*, Megaspore and tenuispore within vitrinite ground mass. *f*, (*e*) under fluorescent mode. × 50 oil immersion (*a–e* under reflected white light).

coals are shown in Figure 1. The ash content of the indigenous coals varied between 17.4 and 18.3%, whereas the ash content of most of the imported coals was around 10% (Table 2). For blending, the coals and their proportions (Table 1) were so chosen that the reflectance range was maintained around 1.0–1.1% and the total reactive content between 55.0 and 60.0% with V-step distribution from V_7 to V_{17}, mostly within V_8 to V_{14} with a peak around V_{11} and V_{12}.

Both experimental (with subscript 'E') as well as predicted values (with subscript 'P') from standard curves[18] for CSN and GKLT (Table 2) showed that the rheological properties of the coals and their blends were good enough for coke preparation and, the experimental values varied from 2½ to 7 and G to G5, respectively.

The main parameters of coke for metallurgical performance assessment like CSR and CRI were found to be optimum for the prepared cokes. The experimental values of CSR ranged from 52.0 to 62.0 for all the cokes (excluding B-1), being 54.0–58.0 for the blended ones. Likewise, the experimental values of CRI ranged from 23.0 to 35.0 (excluding B-1), whereas it varied from 26.0 to 33.0 for the blended coals (Table 3). A point to be noted is that the high reactive content but low reflectance value is well depicted by higher CRI_E and lower CSR_E values for Ind-1 coal. The indication of Ind-3 being a good coking coal form, its V-step distribution and reflectance value is confirmed from its CRI_E (23.0) and CSR_E (62.0) values. The coal B-1 needs special mention as it

(total reactive macerals, 59.2%; MMR%, 1.21) is prepared from two imported coals, i.e. Imp-3 (blend proportion, 80%; total reactive macerals, 63.8%; MMR%, 1.21) and Imp-4 (blend proportion, 20%; total reactive macerals, 57.3%; MMR%, 1.23) and hence produced good quality coke ($CSR_E = 64.0$, $CRI_E = 26.0$) owing to its good petrographic make-up. Cokes prepared from the imported coals (Imp-1 and Imp-2) showed good coke quality.

In general, the coke microtexture is indicative of its quality and is dependent on coal rank and type, and is influenced by heating rate, coal pulverization level and charge bulk density[2]. Coke microtextural studies thus help in judging the quality of the coke with regard to its petrographic make-up and reflectance values if the operational conditions are constrained. In the present study, the operational conditions of the coke oven were kept the same for all the coals and their blends.

The total reactive macerals of coal are contributors to the binder phase carbon forms of the cokes and exhibit one-to-one correlation, with a few exceptions because of the limitation of microscopic studies. Though there is a relationship between binder phase (reacted) carbon form and different V-types of the original coal, there exists some overlap between the textural varieties produced from different coal types. The binder phase carbon forms in coke vary from 22.8 to 34.4% and 24.6 to 32.2% for single and blended coals respectively (Table 3). The binder phases show a general decrease in coke reactivity from the isotropic to lamellar type of carbon forms[28]. Low rank

Table 3. Coke microfabric nomenclature (modified after Gray and Devanney[2], Coin[25] and Moreland et al.[3]), coke microstructural composition and coke quality indices

				Cokes from single (assumed) coals						Cokes from blended coals				
				Indigenous			Imported							
Carbon forms	Coal type	Appearance	Coke texture (domain size) / Sample no.→ / Mean (max.) Ro%→	Ind-1[K] 0.81	Ind-2[K] 0.96	Ind-3[K] 1.18	Imp-1[K] 1.09	Imp-2[K] 1.18	Imp-B1[K] 1.20	B-2[K] 1.07	B-3[K] 1.08	B-4[K] 1.09	B-5[K] 1.10	B-6[K] 1.11
				Microstructural composition (volume %)										
	High volatile Ro%: 0.65–0.79	Isotropic / Dark under crossed nicols, often porous	a.	24.5	5.5	0	1.1	0	0.6	0.4	3.3	1.4	3.7	2.6
	Ro%: 0.80–0.94	Weakly anisotropic / Beginning of recognizable anisotropism, domain size	b. (<0.5 μm)	7.7	20.8	0	4.2	0.5	2.9	2.4	2.0	2.1	3.4	3.9
Reacted (binder phase)	High volatile to medium volatile Ro%: 0.95–1.19	Mosaic / Composed of small, rounded, isochromatic areas	c. Fine (0.5–1 μm)	0.3	6.9	1.0	4.0	1.9	6.9	5.8	13.1	8.7	4.5	3.7
			d. Medium (1–2.5 μm)	0	0.7	2.6	9.3	11.3	7.2	6.6	5.4	5.4	6.0	3.7
			e. Coarse (2.5 to 3 μm)	0	0.3	9.5	6.0	9.3	1.8	10.9	2.7	5.7	2.4	2.6
	Medium volatile to low volatile Ro%: 1.20–1.45	Flow / Composed of elongated isochromatic areas, often curved around pores	f. Fine (2.5–5 μm, L > 2B)	0	0.2	3.1	2.0	2.5	4.2	0.9	1.1	0.9	2.7	1.2
			g. Medium (5–8 μm, L > 2B < 4B)	0	0	1.6	2.0	0.4	4.6	0.8	0.6	1.5	1.2	4.1
			h. Coarse (2.5–25 μm, L > 5B)	0	0	2.4	2.0	0.2	2.7	0.6	1.1	1.1	0.4	4.9
Reacted (binder phase)	Low volatile Ro%: 1.46–1.79	Lamellar / Large, elongated isochromatic areas	i. (2.5–25 μm, L > 5B)	0	0	2.6	0.2	0.1	1.3	0	0.1	0.1	0.2	1.4
		Pyrolitic carbon	j.	0.5	0	0	1.2	0	0	1.0	1.0	0.4	0.1	0
		Total binder phase carbon form		33.0	34.4	22.8	32.0	26.2	32.2	29.4	30.4	27.3	24.6	28.1
Inert (filler phase)		l. Inertinite / Organic		4.5	6.9	13.0	6.9	18.1	6.4	5.0	6.3	6.1	4.4	6.6
		m. Mineral matter / Inorganic		3.0	1.6	10.1	7.3	2.4	6.1	8.7	5.5	8.7	7.1	8.6
		Total filler phase carbon form		7.5	8.5	23.1	14.2	20.5	12.5	13.7	11.8	14.8	11.5	15.2
		n. All pores and fissures		59.5	57.1	54.1	53.8	53.3	55.3	56.9	57.8	57.3	63.9	56.7
	Grand total			100	100	100	100	100	100	100	100	100	100	100
		CAQ		1.4	2.1	5.8	4.5	4.5	4.8	4.4	3.7	4.1	3.7	4.9
		CSR$_E$		52.0	55.0	62.0	60.0	60.0	64.0	54.0	56.0	57.0	57.2	58.0
		CSR$_P$		28.3	39.7	68.4	63.6	63.7	65.3	62.9	57.6	60.7	57.5	65.5
		CRI$_E$		35.0	28.0	23.0	26.0	27.0	26.0	33.0	31.5	30.0	30.0	28.0
		CRI$_P$		48.1	41.4	21.8	26.1	26.1	24.8	26.7	30.3	28.2	30.4	24.7

E, Experimental value; P, predicted value from CAQ.
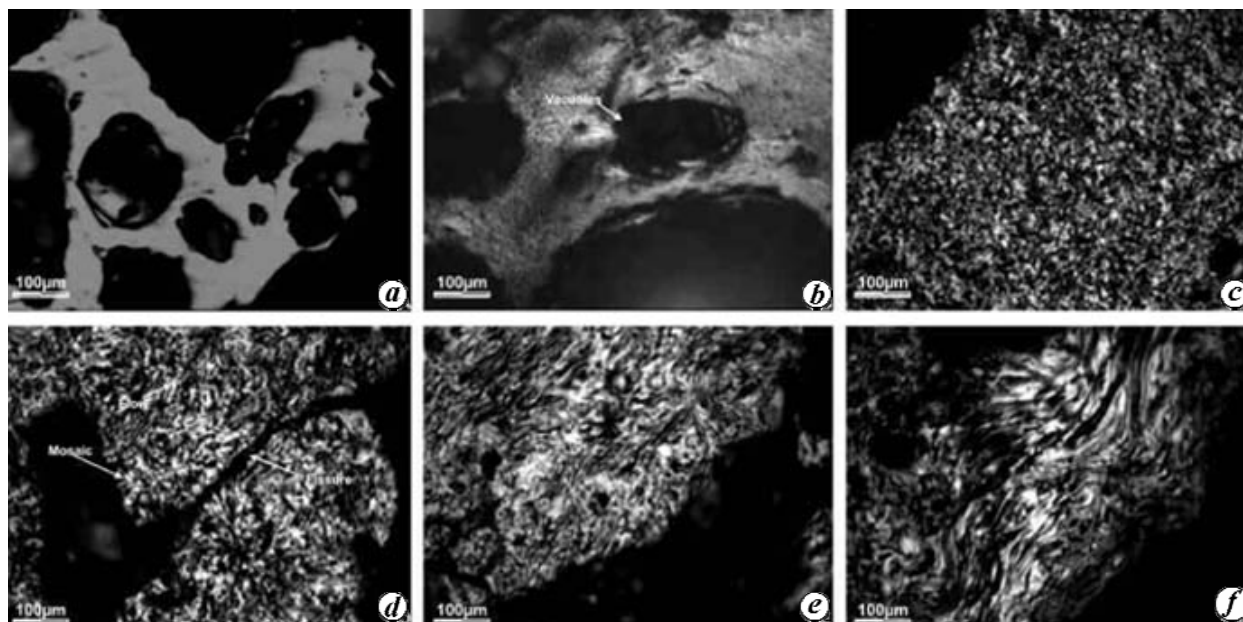
Figure 2. Photomicrographs of some of the coke microtextures. *a*, Isotropic texture with vacuoles (in Ind-1[k]); *b*, Weakly anisotropic (in Ind-2[k]); *c*, Fine (dominated) to medium mosaic (in Imp-2[k]); *d*, Flow (dominated) and mosaic (Imp-B1[k]); *e*, Lamellar and flow (Ind-3[k]). *f*, Lamellar (Imp-1[k]). × 50 oil immersion Xpl.

(and high VM) coals yield higher proportion of high reactive carbon forms. Such dominance of high reactive carbon forms increases its CRI value with corresponding increase in the rate of coke consumption and decrease in the coke strength after reaction (low CSR), making it unsuitable for metallurgical usage. The rank effect is well demonstrated from the poor-quality coke prepared from Ind-1 and Ind-2 coals, even though these had high total reactive content, as is obvious from the dominance of isotropic and weakly anisotropic carbon forms in the cokes. The microtextural components in other coals were mostly distributed in the mosaic or higher anisotropic region. The presence of distribution pattern of the microtextural components and large proportion of mosaic and flow textures of binder phase carbon form in the cokes produced from blended coals clearly indicate better coke quality. Figure 2 illustrates the different coke microtextures observed in the prepared cokes. The isotropic and weakly anisotropic types of carbon forms produced from high volatile coals, Ind-1 and Ind-2 are shown in Figure 2 *a* and *b* respectively, and are indicative of poor coke quality. Mosaic texture shown by Imp-2[k] (Figure 2 *c*) indicates better coke quality, while the predominance of flow texture along with mosaic texture in Imp-B1[k] (Figure 2 *d*) are indicative of even better coke quality. The lamellar texture as shown in Ind-3[k] (Figure 2 *e*) and Imp-1[k] (Figure 2 *f*) is usually produced from the low volatile coals.

Pores and fissures have an impact on coke property, as increase in porosity not only enhances the reaction rate (represented by CRI), but also significantly reduces its strength (represented by CSR), resulting in a large volume of fines. Hence optimum porosity is required for proper reaction of the coke for specific end uses. Usually isotropic and weakly anisotropic type of texture show higher and bigger size pores/vaculoes. Volatile, rich, micro-lithotypes (function of rank and maceral make-up) such as vitrite, clarite and liptite on devolatilization impart pore structure to the coke. The range of pores and fissures varied between 53.3 and 63.9% subjected to the fact that sub-micron size pores are beyond the limits of microscopic observation and measurement.

The presence of microtextural components from isotropic to lamellar region in the coke (Imp-1[K]) prepared from 'Imp-1' suggests its blended nature and also indicates that one of the blended components was high volatile coal. Low volatile coal was also present in fair amount, indicated by its V-step distribution (V_{13} to V_{18}) as well as from the presence of coarse flow and lamellar carbon forms.

Anisotropy of carbon form thus is a measure of coke quality. The anisotropy index can be expressed as a function of the textural domain size and bi-reflectance. Different workers have defined the index variously and tried to predict the coke quality parameters such as CRI and CSR[29–32]. The following equation proposed by Diessel and Wolff-Fischer[32] has been used to calculate the coke anisotropy index, CAQ.

$$CAQ = [a + 2b + 3c + \cdots + nj]/[a + b + c + \cdots + j],$$

(1)

where a, b, c, . . . , j represent textural variety (Table 3, column 4) of the carbon forms and the numerical values

indicate the level of anisotropy of the corresponding carbon form.

CAQ is related to CSR and CRI by the following set of equations[32]:

$$CRI_P = 63.11 - 11.98CAQ + 0.84CAQ^2 \quad (r = 0.91)$$

$$CSR_P = 1.86 + 21.44\,CAQ - 1.72CAQ^2 \quad (r = 0.88). \quad (2)$$

Considerable mismatch exists between the predicted[32] (from eq. (2)) and the experimental values of CSR and CRI for Ind-1[k] and Ind-2[k], whereas these match well for Imp-1[k] and Imp-2[k] and their blends. The prediction holds fairly well for all the cokes from the blend, except B-2 and B-6. The equation matches well for the cokes prepared from imported coals (Imp-1 and Imp-2) and their blends (Imp-B1). A good prediction for CSR and CRI had also been obtained from the same equation for the blended coals (except B-2 and B-6).

Deviations of experimental values of CSR and CRI from those predicted using the eq. (2), may be attributed to nature of Indian coals and factors like basicity index, etc. The experimental values of CSR and CRI from the present study are plotted (Figure 3) with the corresponding calculated values of CAQ (from eq. (1)). Within the experimental limits, the parameters are found to be related by a similar set of equations from the plotted data:

$$CSR_P = 51.30 + 0.70CAQ + 0.21CAQ^2 \quad (r = 0.78)$$

$$CRI_P = 31.06 + 1.66CAQ - 0.51CAQ^2 \quad (r = 0.72). \quad (3)$$

Conclusion

The strength of coal petrographic tools lies in the fact that it reflects to the heterogeneity of the coals. The petrographic parameters, i.e. maceral composition and reflectance values are excellent ones for categorizing the coals into coking and non-coking. These are also useful while deciding the optimum blend proportion of the individual coals in a blend and to discriminate the blended coals from the individual ones on the basis of their V-step distribution.

Coke microtextural analysis is an important tool for assessment and comparison of the nature of cokes, as it is dependent on the type of coal used. Thus different microscopic carbon forms are indicative of the constituent macerals of the parent coal and its rank. As the degree of anisotropism of carbon form is directly related to its reactivity, it is demonstrated that this can be used for estimating the different coke quality indices.

Deviations of the experimental values of CSR and CRI from the values predicted by Diessel and Wolff-Fischer[32] indicate that the equation (eq. (2)) needs modification for Indian coals and their blends for better predictability using a large number of datasets on microtexture and carbonization parameters. These deviations are mainly due to the nature of the Indian coals that differ markedly from the imported ones. Usually, Indian coals have a low vitrinite content and are highly intermixed in nature, enriched with organic as well as inorganic inert materials. Particularly, inert materials appear to physically hinder proper growth of the flow and lamellar domains when in close association in the microlithotypes. The large-sized organic as well as inorganic inert materials not only hinder the growth of the domain size, but also form fissures in the cell walls of the coke. Sometimes the vitrinites are highly oxidized and behave almost like inerts[33], but are considered as reactive ones. This may give rise to misleading predictions.

In essence, petrographic studies of the micro-constituents and micro-fabric of coal and coke are indispensable for any metallurgical operation to get first-hand information about the performance of coke during metal extraction.
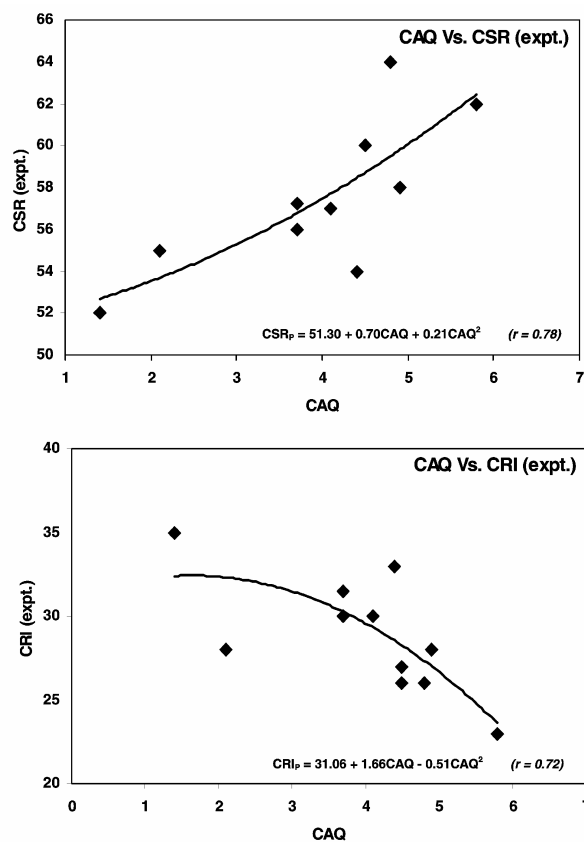

Figure 3. Plot of CSR_E and CRI_E against CAQ.

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