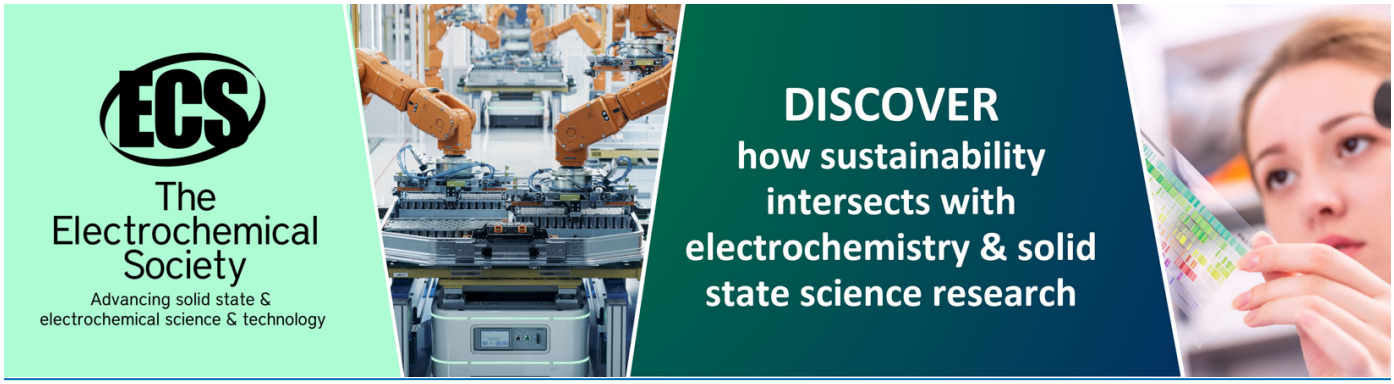
Petrographic composition of coke product from Batu Ayau Formation Coking Coal, Kutai Basin, Central Kalimantan



Petrographic composition of coke product from Batu Ayau Formation Coking Coal, Kutai Basin, Central Kalimantan

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Abstract. The Batu Ayau Formation in the Kutai Basin has coking coal deposits that have the potential to be processed into coke. Analysis using organic petrography method is an important parameter to identify the composition of the coke product to determine the coke quality. The purpose of this study was to determine the composition of the coke products made from coking coal of Batu Ayau Formation in Kutai Basin, Central Kalimantan. Petrographic analysis on 12 samples obtained in Kal-Teng seam showed that the percentage of coke products varied. Carbon in the binder phase is 85.60 - 92 vol.%, then the form of carbon in the filler phase is 7.45- 13.64 vol.% and a small part of other than carbon material (miscellaneous categories) of 0-0.73% vol. The dominance of inert organic as a filler of the coke wall was identified. The studied coke which is originally made from coking coal with moderate volatile values shows that the coke is ideal in term of its petrographic composition.

1. Introduction

Coke is one type of coal products that has the ability to melt and make coherent residue when heated. That residue gets harden, which is called cake [1]. Coke is mostly known as metallurgical coke and used in factory processing especially for iron ore processing on blast furnace. In this process, the coke acts as a fuel as well as a reducing agent assists in the load-bearing process and provides a pathway for gas passage in the furnace later. The reducing agent function means that it separates oxygen from iron, while as an energy source, it is used to melt the ore. Coke should also have certain porosity because it is needed to pass the hot gas (aeration) in the furnace.

The need of coke for the metallurgical industry in Indonesia is still dependent on the supply of imported foundry coke. Domestic coke consumption is around 192.000 tons per year [2]. One of the uses of coke is to refine iron and nickel by using blast furnace [3]. This study will focus on coke products from Batu Ayau Formation coal in Kutai Basin, Central Kalimantan coal which has high-rank coal deposits. Petrographic analysis will be conducted to know the characteristics of the coke. Knowledge on the product of coke from Indonesian coking coal will be acquired from this study.

2. Geological Background

2.1. Regional Physiography and Tectonics

Physiographically this area is located in the Kutai Basin which is adjacent to Mangkalihat High and 2 fault zones, Bengalon and Sangkulirang Fault. Kutai Basin is bordered by Kuching orogenesis complex in the west and Makassar strait in the east. This basin is divided into 2 sub basins. They are Upper and

Lower Kutai Basin. The Upper Kutai Basin is located in the northwestern part where the research area is located, while the Kutai Bawah Basin is in the eastern part (see Figure 1).

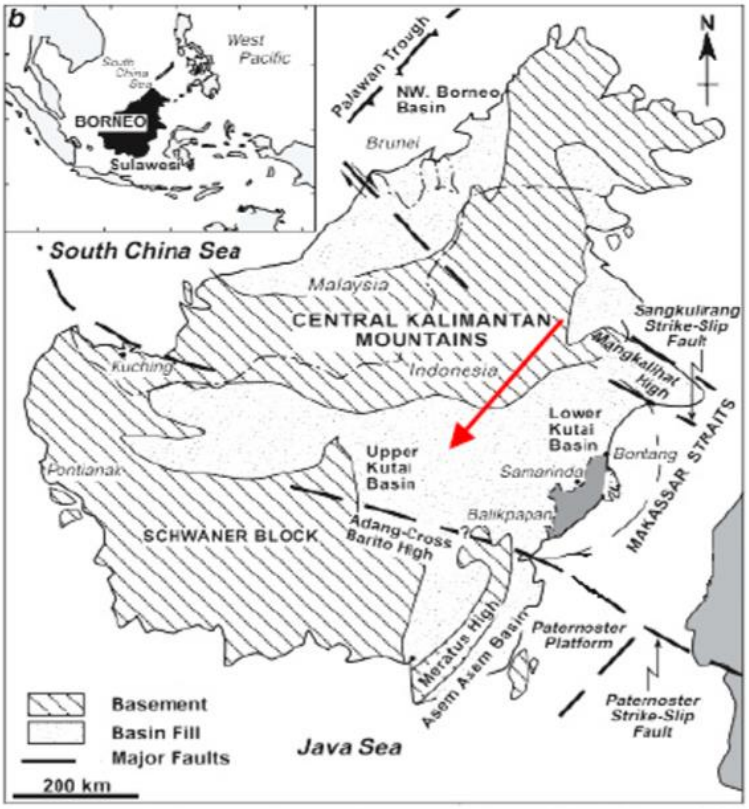

Figure 1. Physiography of Kutai Basin [4]. Studied area is shown by the (red arrow).

Kutai Basin is characterized by Tertiary structure, mainly the tectonic reversal or structure inversion. Inversion structure in Kutai Basin is formed by folding and simple fault propagation along planar fault [5].

2.2. Stratigraphy and Coal Characteristic

The stratigraphy in the study area is composed by Batu Ayau, Ujohbilang, and Karamuan Formation (see geological map in Figure 2). The Age of Batu Ayau Formation is Eocene, while Ujohbilang Formation was deposited in Oligocene. Karamuan Formation was formed in Miocene. There were also some intrusions occurred in that time, for example, Sintang Intrusion. Batu Ayau Formation in this area consists of sandstone, mudstone, carbonaceous siltstone with coal seam intercalation. The Batu Ayau Formation represents Middle-Late Eocene rift deposit which were deposited in fluvial-deltaic to outer shelf environment. Whereas Ujohbilang Formation is dominated by mudstone, some sandstone contains carbonates in some parts. This formation is the product of the sag phase in the Oligocene which caused deepening and changing to marine condition. Karamuan Formation consists of mudstone which contains carbonates in some parts, quartz sandstone, siltstone, and some fossiliferous carbonates and shale [6].

In the studied area, coal seams are found in the lower part of Batu Ayau Formation. Batu Ayau Formation coals in this area are considered as coking coal. It is characterized by volatile matter content of about 26.7 wt. % (adb). Petrographically the amount of vitrinite is more than 90 vol. % in average and Ro max of about 1 %. The carbon content is around 85 wt.%. CSN maximum is 9, the maximum fluidity value is about 1092 ddpm while HGI is 97 [7].

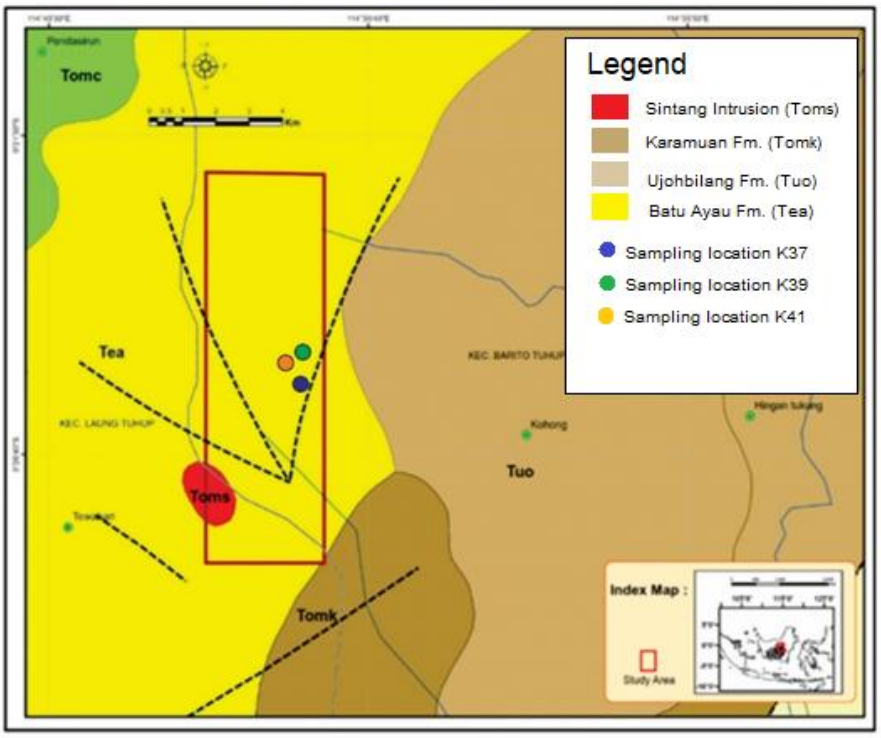

Figure 2. Geological map in the research area (red box) and surroundings [6. with modification].

3. Methodology

Field observation and coking coal sampling were conducted in the early phase of this research [see 7]. Coal lithotype identification was used to know the vertical succession of coal seam. The coal sampling was carried out based on coal lithotype by ply by ply. As many as 12 samples were taken from 3 seams which were named Kal-Teng (K) 37, 39, and 41 seams for this study. Samples were taken from Batu Ayau Formation in Murung Raya area, Central Kalimantan.

Laboratory work in form of organic (coke) petrography analysis was conducted at the Department of Geological Engineering, Universitas Gadjah Mada. The coke samples were produced by coking process at TekMIRA Laboratory in Bandung. Polished sections were used for organic petrography. Observation was conducted using a reflectance microscope with 40x magnification. The identification of coke products was based on coke microscopic methods [see 8,9].

4. Results

4.1. Field Data

The thickness of K. 37, K. 39 and K. 41 is 1.5 - 2.11 m (see Figure 3). The seams are characterized by the dominance of bright coal lithotype. Generally, the bright coal lithotype is in the form of glossy greyish black color, quite smooth surface and vitreous coal seam.

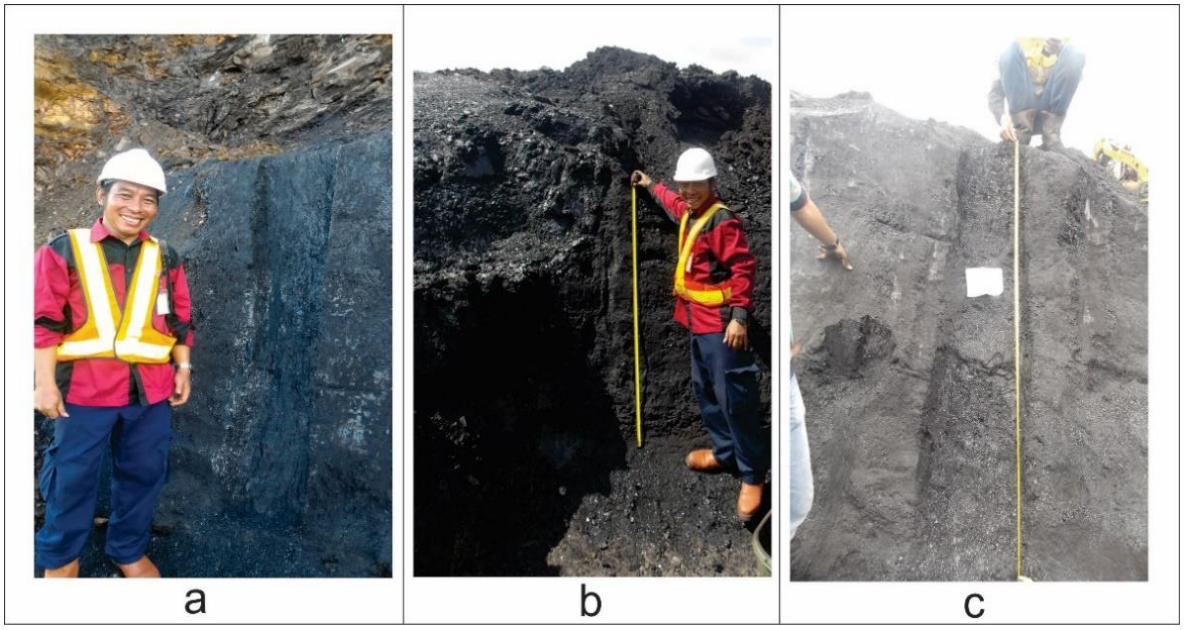

Figure 3. Appearance of the outcrop K. 37 (a), K. 39 (b), and K. 41 (c)

4.2 Petrography Data

The coke petrography which depicts the composition of coke products is shown in Table 1. The coke produced from all coking coals is dominated by binder phase carbon form as much as 85.6 – 92.00 vol.% and less dominant filler phase carbon form as much as 7.45 – 13.64 vol.% and a small portion of the miscellaneous material of about 0 – 0.73 vol. %. The average petrographic composition of the coke product for each seam is as follows, K-37 is on average composed by binder phase carbon of 88.09 vol.%, filler phase of 11.54 vol.%, and miscellaneous categories of 0.27 vol.%. K-39 is composed by binder phase carbon of 90.27 vol.%, filler phase of 9.5 vol.%, and miscellaneous categories of 0.22 vol.%. While K-41 is composed by binder phase carbon of 90.77 vol.%, filler phase of 9.13 vol.%, and miscellaneous categories of 0.09 vol.% (see graphic in Figure 4). Figures 5-7 show the microscopic appearances of coke in this study.

Table 1. Petrographic composition of studied coke.

Seam	Sample code	*Binder Phase Carbon*											**Total (%)**	*Filler Phase Carbon*							**Total (%)**	*Miscellaneous Category*								**Total (%)**
		Isotropic	*Incipient*	*Circular*			*Lenticular*			*Ribbon*				*Organic Inerts*		*Miscellaneous Inerts*			*Inorganic Inerts*			*Depositional Carbon*			*Additive Carbon*			*Miscellaneous Observations*		
				F	M	C	F	M	C	F	M	C		F	C	OC	BC	NCV	F	C		SOC	SC	PYC	CB	A	PC	GC	RC	
K. 37	K. 37B	0.91	2.73	2.18	24.91	36.91	1.82	2.00	4.18	1.45	2.73	5.82	**85.64**	4.18	4.18	0.36	0	0	1.82	3.09	**13.64**	0	0	0.73	0	0	0	0	0	**0.73**
	K. 37C	0.36	2.91	4.18	39.82	20.00	8.73	6.36	1.82	1.09	1.82	1.09	**87.82**	5.27	3.64	0.36	0	0	1.45	1.09	**11.82**	0	0	0	0	0	0	0	0	**0**
	K. 37M	0.55	2.55	15.27	26.36	20.73	9.82	7.27	2.55	1.45	1.82	0.73	**89.09**	5.45	2.91	1.09	0	0	0.73	0.73	**10.91**	0	0	0	0	0	0	0	0	**0**
	K. 37T	0.73	2.55	12.00	33.45	15.64	7.27	8.00	1.82	0.73	3.64	4.00	**89.82**	5.09	2.91	0	0	0	0.73	1.09	**9.82**	0	0	0.36	0	0	0	0	0	**0.36**
K. 39	K. 39B	0.73	0.91	32.91	20.18	4.36	20.55	8.18	1.64	0.36	1.27	0.91	**92.00**	4.36	2.00	0.55	0	0	0.73	0.36	**8.00**	0	0	0	0	0	0	0	0	**0**
	K. 39C	0.36	1.45	12.36	42.91	16.36	1.82	9.45	3.27	1.09	2.18	0.73	**92.00**	4.00	2.36	0	0	0	0.73	0.36	**7.45**	0	0	0.36	0.18	0	0	0	0	**0.55**
	K. 39M	1.09	1.09	4.36	40.36	28.00	2.18	4.73	1.82	2.18	2.55	1.09	**89.45**	5.45	2.55	0	0	0	1.09	1.45	**10.55**	0	0	0	0	0	0	0	0	**0**
	K. 39T	0.36	1.82	11.64	36.36	14.18	6.55	11.27	2.91	1.45	1.09	0	**87.64**	4	5.82	0	0	0	0.73	1.45	**12.00**	0.18	0	0	0.18	0	0	0	0	**0.36**
K. 41	K. 41B	0.36	1.82	26.18	38.36	3.27	7.82	10.36	0.73	1.82	0.36	0	**91.09**	6	1.82	0.18	0	0	0.56	0.36	**8.91**	0	0	0	0	0	0	0	0	**0**
	K. 41C	0.73	0.73	13.45	38.36	17.82	6.36	8.36	0.73	1.09	0.73	0.73	**89.09**	4.55	4	0.36	0	0	1.09	0.73	**10.73**	0	0	0.18	0	0	0	0	0	**0.18**
	K. 41M	0.36	1.82	3.64	43.27	19.27	5.82	7.27	1.09	3.27	5.45	0	**91.27**	2.36	6	0.36	0	0	0	0	**8.73**	0	0	0	0	0	0	0	0	**0**
	K. 41T	0.73	2.55	7.82	36.36	8.36	12.18	9.45	4	4.36	5.82	0	**91.64**	3.64	4.55	0	0	0	0	0	**8.18**	0	0	0.18	0	0	0	0	0	**0.18**

Note: F: fine; M: medium; C: coarse; OC: oxidized coal; BC: brecciated coal; NCV: non-coking vitrinite; SOC: sooty carbon; SC: spherulitic carbon ; PYC: pyrolytic carbon; CB: coke breeze; A: anthracite; AC: anthracite; PC: petroleum coke; GC: green coke; RC: reacted coke.

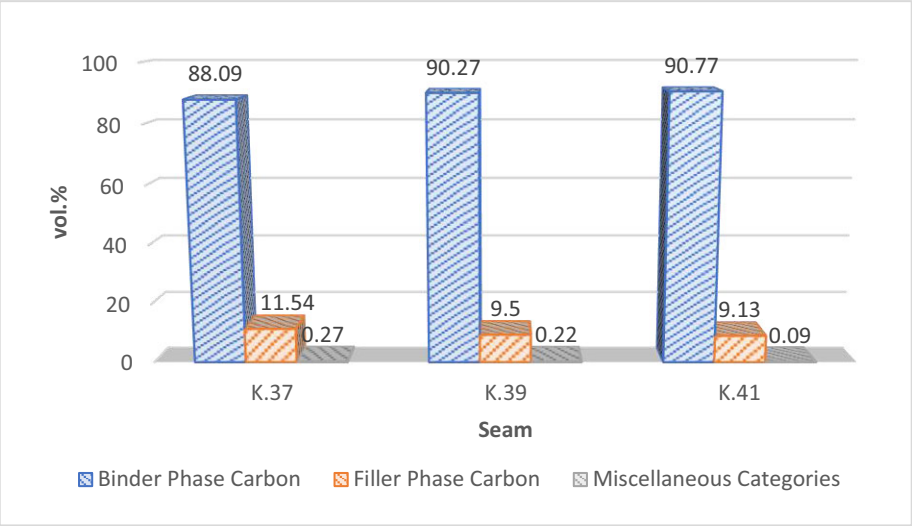

Figure 4. Average composition of coke products for each seam.

Binder phase carbon form

Binder phase product is the most dominant component in the studied coke. The binder phase is the transformation of reactive maceral in coking coal as the parent coal. The binder phases found were isotropic and anisotropic (incipient, circular, lenticular, and ribbon). The carbon isotropic form resembled a thin crack surface on a plain plate. Isotropic showed a relatively uniform shape and has no clear boundaries compared to the anisotropic form.

Anisotropic consists of various forms of carbon. Incipient is a form of carbon transition from isotropic to anisotropic. The shape of the incipient found in the sample was like an irregular slit. Circular, lenticular, and ribbon have a relatively compact shape compared to incipient. Circular was very dominant, which had a shape like a circle (oval and elongated). The form of circular carbon with medium and coarse size was more abundant than fine size. The lenticular had a flat, tapered shape that resembled a protruding lens. The ribbon had a wave-like shape.

Filler phase carbon form

The filler phase product quantity is less than the binder phase. The most common filler phases were organic inert and inorganic inert. Miscellaneous inert were found in small amounts in some samples.

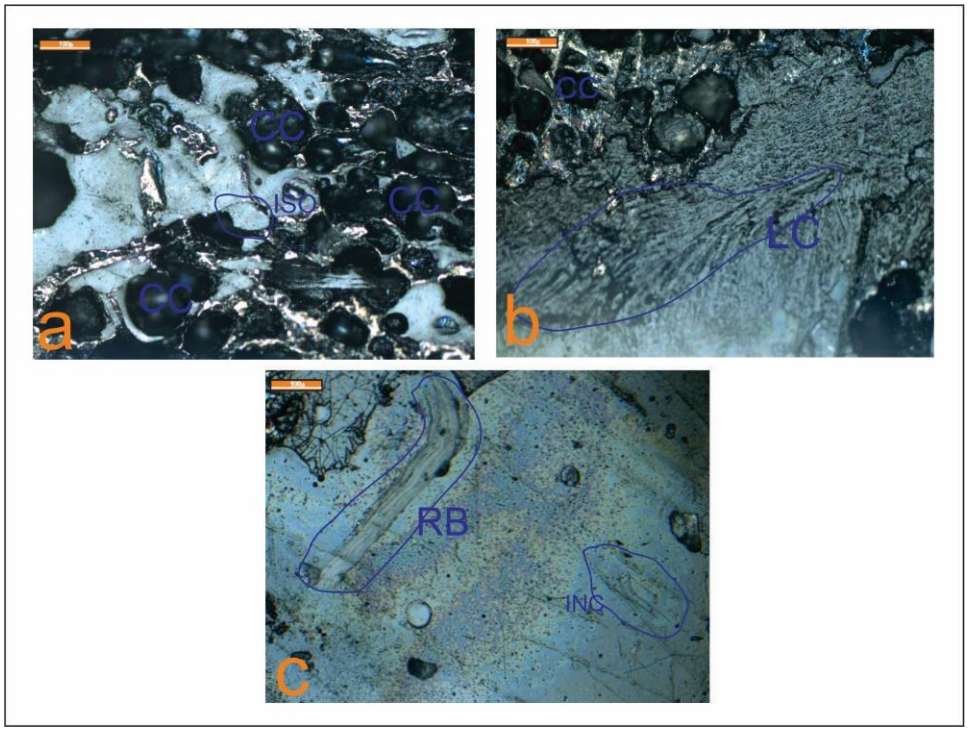

Figure 5. Microscopic appearance of coke product. (a) Circular carbon (CC) and isotropic (ISO) in K.41B sampel. (b) Lenticular carbon (LC) associated with circular carbon (CC) in K.39M sample. (c) Ribbon carbon (RB) and incipient (INC) in K.37T.

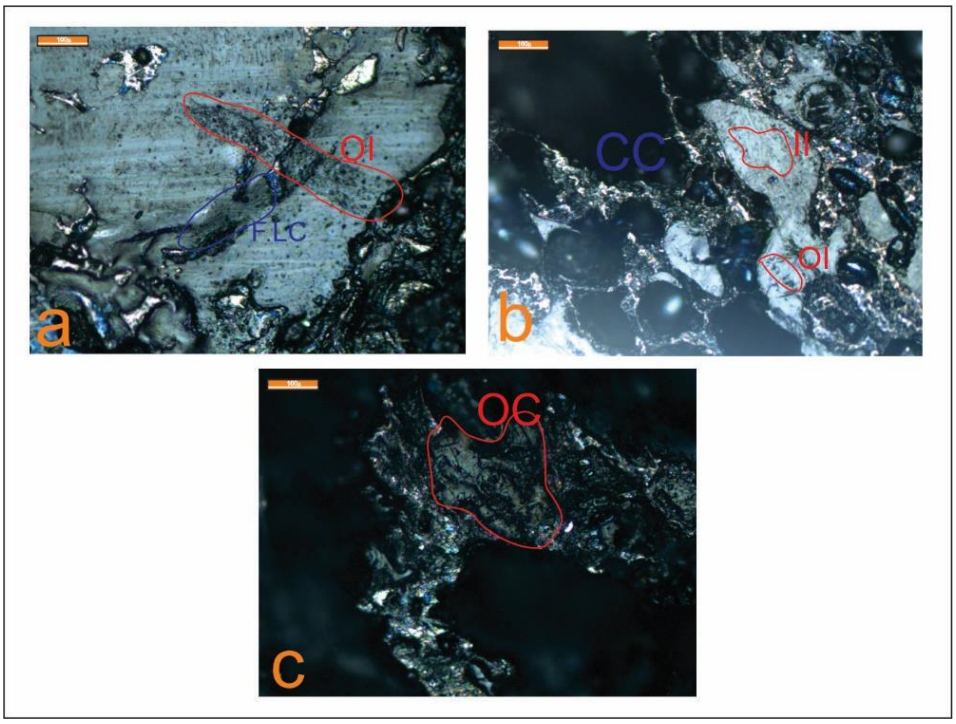

Figure 6. Microscopic appearance of coke product. (a) Organic inert (OI) associated with fine lenticular (F.LC) in K.37C. (b) Inorganic inert (II) associated with circular carbon (CC) in K.41B. (c) Oxidized carbon (OC) in K.39B.

Organic inert was like dark, smooth ribbons that fill the fractures in binder phase. They were divided into two sizes, fine and coarse. The two measures relatively had almost the same percentage in each sample. Inorganic inert was showing a form resemble black material that appears around binder phase product. Inorganic inert originated from minerals in coking coal. Oxidized coal had a rectangular shape that had cracks, low relief, and degasification pores because of the removal of dissolved gases from liquids.

Miscellaneous categories

There are miscellaneous products found in the samples, namely pyrolytic carbon (depositional carbon), coke breeze (additive carbons), and sooty carbon. Depositional carbons are a type of material that is deposited on the coke surface near the surface area in the coking process. Depositional carbons found in the study sample were pyrolytic carbon. Pyrolytic carbon had a smooth, brightly colored ribbon that filled the space between the binder phase and the filler phase.

Additive carbons are inert additives (anti fissurant) that are added during the coking process. The additive carbons found in the study sample were coke breeze. Coke breeze in the sample had a dense, fine-grained shape and bright in color. Sooty carbon is carbon particles produced by incomplete combustion of hydrocarbon. In the samples, it usually had a deformed irregular form and still showing the rest of original maceral.

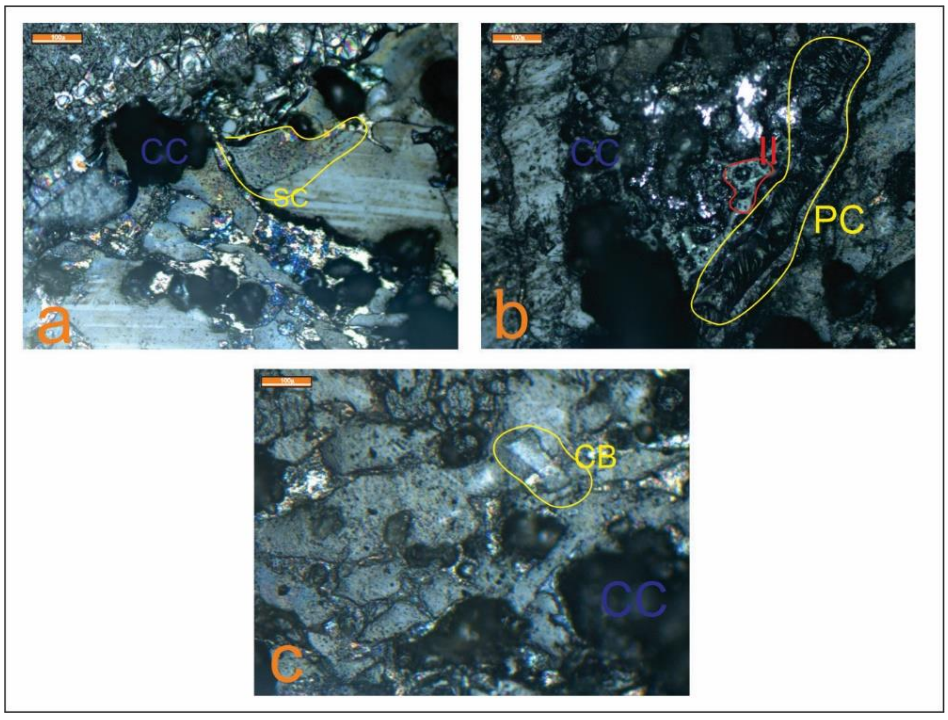

Figure 7. Microscopic appearance of coke product. (a) Sooty carbon (SC) associated with circular carbon (CC) in K.37 C. (b) Pyrolytic carbon (PC) associated with circular carbon (CC) on K.39C. (c) Coke breeze (CB) associated with circular carbon (CC) in K.39T.

5. Discussion

Coke is produced by heating coking coals in a special oven in a reducing atmosphere condition. Coking coals refer to bituminous class coals of high, medium, and low volatile rank that possess the ability to soften when heated, become plastic, and resolidify into a coherent mass. During the heating in the absence of air, it will melt vesiculate and harden into a spongelike mass of almost pure carbon. As the

temperature of the coal increases, it becomes plastic, fusing together before resolidifying into coke particles. This phenomenon is known as the caking process. This process will produce particular characteristics in the petrographic composition of coke.

The composition of the coke product is one of important parameters for determining the microstructure of coke. Among others are pore size and coke walls, the form of carbon and comparison with the maceral composition of coking coal before processed into coke. In term of coking process, maceral can be divided into two part, namely reactive maceral and inert maceral. The reactive maceral in coking coal (vitrinite, liptinite, resinite, and reactive semifusinite) are softened during the carbonization process and will be transformed into binder carbon (binder phase carbon). These macerals tend to appear in a predominantly anisotropic (non-uniform) form of carbon. This is characterized with optical properties that vary when the polished sample is rotated and viewed by polarized light during microscopic observations. Meanwhile, inert maceral (inert semifusinite, fusinite, micrite, macrinite, and inertodetrinite) does not soften during carbonization, which will be transformed into filler carbon (filler phase carbon). These macerals tend to appear as isotropic (uniform) carbon with uniform optical properties. There is also miscellaneous category which is material entity other than carbon.

In general, the coke products from studied seams are dominated by binder phase products and less dominant filler phase products, as well as a small portion of the miscellaneous categories. The binder phase carbon product is divided into isotropic and anisotropic. Petrographic composition of the binder phase is shown in Table 2. The dominance of the binder phase carbon indicates that many macerals underwent a softening process, hardened again and bound inert maceral. The carbon binder phase can be used to determine the value of the degree of anisotropism and to see the level of volatility of the coal (see Gray, 1976).

Table 2. The percentage of dominant product of binder phase carbon in studied coke.

Coke Product	Percentage (Vol.%)
Isotropic	0,36 - 1,09%
Incipient	0,91 - 2,91%
Fine Circular	2,18 - 32,91%
Medium Circular	20,18 - 43,27%
Coarse Circular	4,36 - 20,73%
Fine Lenticular	1,82 - 20,55%
Medium Lenticular	2 - 11,27%
Coarse Lenticular	0,73 - 4,18%
Fine Ribbon	0,36 - 4,36%
Medium Ribbon	0,36 - 5,82%
Coarse Ribbon	0,36 - 5,82%

Anisotropic can be divided into incipient, circular, lenticular, and ribbon. Circular carbon dominates with a percentage of >50 vol.%. This confirms that the level of volatility in coal is relatively high and the degree of anisotropism is high. Fine size lenticular carbon is found to be the most abundant. This also shows that the sample has a relatively high volatile content. The size of the fine lenticular carbon material which dominates indicates that the strength of the coke is better. Lenticular with medium-coarse size and ribbon also indicates the presence of altered coal with a high degree of anisotropis but has a low volatile value.

The filler phase carbon products found can be categorized as organic inert, inorganic inert, and oxidized coal (composition is depicted in Table 3). The existence of the filler phase carbon indicates that there are some macerals that did not soften during the carbonization process and functioned as a

filler in the binder phase carbon product. The filler phase carbon is used to determine the carbon associated with the inert maceral.

Table 3. The percentage of dominant product of filler phase carbon in studied coke.

Coke Product	Percentage (vol.%)
Organic Inert	6.36 – 9.82%
Inorganic Inert	0 – 4.91%
Oxidized Coal	0 – 1.09%

The organic inert carbon has a low level of anisotropism and still retains the original form of inert maceral. Organic inert is dominated the filler phase in the studied coke. Inert macerals such as some of the inertinite and liptinite maceral groups are thought to be the precursor of organic inert carbon. Organic inert carbon is useful for reducing the potential for cracks in the coke wall structure and increasing reactivity to CO_2. Inorganic inert carbon which is only found in small amounts indicates that the amounts of minerals in coal was also low. In contrast to organic inert carbon, this type of carbon is useful for reducing the reactivity of coke to inhibit gas diffusion. Oxidized coal is found in several samples in the study area due to weathering experienced during the coking process.

Table 4 shows the composition of miscellaneous categories found in organic petrographic observations. Those are pyrolytic carbon (depositional carbon) and coke breeze (additive carbons). Depositional carbon indicates an overheating process or heating process that happened too fast. The overheating process occurs on the wall or head of the furnace. This will increase the number of cracks and causes coking carbon to be stuck to the oven wall. However, there is also the possibility that depositional carbons were formed as a result of a condensation reaction or cracked hydrocarbon. Coke breeze is an additional inert carbon that is added during the carbonization process to protect the cathodic from corrosion. Sooty carbon is impure carbon particles produced by incomplete combustion of hydrocarbon. These miscellaneous carbons are found in very low quantities. This will not give a significant effect on the characteristic of the studied coke in general.

Table 4. The percentage of dominant product of miscellaneous categories in studied coke.

Coke Product	Percentage (vol.%)
Pyrolitic Carbon	0 – 0.73%
Coke Breeze	0 – 0.18%
Sooty Carbon	0 – 0.18%

Studied coke was produced from single coal (not blended coal). The composition is showing the characteristics of medium to high volatile coke. This indicates that the original coking coal can be used to produce coke as the primary material or blending material. The coke quality produced tends to have medium to high quality. This is also supported by the fact that the reactive maceral composition is relatively high but the coal has only a limited amount of inert maceral.

6. Conclusions

Based on this research, there are several characteristics found in the coke from Batu Ayau Formation coking coal from Central Kalimantan.

1. The coke is composed by coking products dominantly in form of carbon in the binder phase (85.6 - 92.00 vol.%), then in form of carbon in the filler phase (7.45 - 13.64 vol.%) and a small number

of miscellaneous material (0 - 0.73 vol.% vol). Coking product in miscellaneous categories are mainly pyrolytic carbon (depositional carbon) and coke breeze (additive carbons).

2. The coke quality produced tends to have medium to high quality.

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