



Effect of binder amount on the development of coal-binder interface and its relationship with the strength of the carbonized coal-binder composite

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ABSTRACT

Production of high-strength carbonized coal composites from non-caking coals only with possible application as coke is presented. A binder and a non-caking coal were mixed in different ratios and carbonized at 1000 °C to produce coal-binder composites. Two binders, one from coal origin and other from oil origin were used. Effect of coal-binder mixing ratio and base coal particle size on the fracture strength of composites was investigated. Bonding of binder with the coal particles at coal-binder interface and development of connected carbon matrix were primarily responsible for the strength of the carbonized coal composites. The trend of change in fracture strength as a function of coal-binder fraction was similar for both the binders. However, for same coal-binder mixing ratio, binder type strongly affected the maximum strength achieved. Fracture strength was found to be primarily dependent on the coal-binder mixing ratio and base coal particle size. The main finding of this study is that the irrespective of binder type, for a given base coal particle size there was only one coal-binder mixing ratio at which the maximum strength was obtained. The binder fraction at which the highest strength observed was correlated to the carbon matrix connectivity index.

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1. Introduction

In a blast furnace for steel making process, coke acts as a reducing agent, a spacer for smooth flow of gases and also provides process heat. However, among all other properties, mechanical strength of cokes is the most important desired property [1–16]. For coke making purpose, coals are widely classified as coking coal, caking coal and non-caking coals. Typically, all coking coals are caking coals but not all caking coals are coking coals. Coking coals are primarily used as a feed/base coals for coke production as these coals show excellent thermoplastic or melting property and become very hard on re-solidification. Caking coals also show thermoplastic properties but do not form a hard coke like structure on re-solidification. On the other hand, non-caking coals do not show thermoplastic properties and thus no solid coke like structure can be formed.

Coking coals are expensive in comparison to caking and non-caking coals. Cokes used in a blast furnace are produced by

blending coking coals and caking coals and/or non-caking coals. The mixing ratio and the identities are usually an industrial secret. Producing high strength coke from non-caking coals has been a topic of intense research because of its economic impact [1]. Coke producing industries are continuously carrying out R&D to produce high strength coke from caking and non-caking coals [1–8]. Typically, a part of a coking coal, 10–40% is substituted with a slightly caking coal and non-caking coal. However, this led to decrease in the coke strength (measured as Drum Index (DI)) [3–6]. Some studies added 5–10% of a coal or oil derived binder together with a caking and/or non-caking coal to regain the coke strength [3]. Takanohashi et al. [3,5,6] investigated the effect of increasing fraction of non-caking coal in a coke blend on the coke strength. They reported that DI of the produced coke decreased as non-caking coal fraction was increased, however when 5–10% of Hypercoal, a solvent extracted coal fraction, was added as a binder, the coke strength was recovered. Although, this approach reduced the amount of the coking coal by 10–30%, it could not avoid the use of coking coal completely to produce cokes with the desired strength. Hence, the use of coking coal is unavoidable with the present coke making process. Some efforts were also made to produce

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the desired strength coke from lignite by briquetting method which used a very high pressure compressing machine [14,15].

Recently, we concentrated our efforts to produce coke like carbonized coal composites with strength as high as an industrial coke from non-caking coals only. We added coal and oil derived binders as additives [12]. However, the fracture strength of the carbonized coal-binder composites (CCB) was not high [12]. It was attributed to weak coal-binder bonding and no attempts were made to understand the effect of coal-binder mixing ratio and base coal particle size on the fracture strength. The aim of this study is to investigate the effect of coal-binder mixing ratio and the base coal particle size on the fracture strength. By changing the coal-binder mixing ratio, we successfully produced composites with fracture strength much higher than the coke. To understand the bonding mechanism, coal-binder interface and carbon matrix of the coal-binder composite was observed by a light microscope and a scanning electron microscope. The fracture strength of the CCB composites was found to be primarily dependent on the coal-binder mixing ratio and base coal particle size. The main finding of this study is that irrespective of binder type, for a given base coal particle size there was only one particular coal-binder mixing ratio at which the maximum strength was obtained. This study did not compare the effect of binder type on the fracture strength and it will be taken as a separate study.

Although, the final aim of this research is to produce high strength coke from non-caking coals only by adding a binder as an additive, conditions under which coal-binder composites were carbonized in the laboratory were different from that in a conventional industrial coke oven [13]. It would be thus unreasonable to compare the industry coke and lab coke on the same level because manufacture condition (Coal size, carbonization temperature, etc.) and sample preparation condition (boring, which causes generation and growth of fissure in coke, is necessary to obtain sample) of industrial coke is different from that of laboratory coke. For example, coal size for industry coke is about 3mm 80%. This size is bigger than that of the present experimental condition. Additionally, it is also not correct to make a direct comparison of the strength of the carbonized coal-binder composites with the industrial cokes [11]. Industrial cokes strength is expressed as Drum Index. Industrial standard method to measure Drum Index is by loading about 10–15 kg of 50 mm and higher coke particles in a drum and rotating it for 150 times. After the desired number of rotation, the coke is passed through a sieve with opening of 15 mm. The weight fraction of coke that remained on the sieve gives the Drum Index of the coke. Higher DI means higher coke strength. However, in the present laboratory scale study, it was not possible to produce 10–15 kg of cokes samples needed for Drum Index test. Therefore, we carbonized caking coals used for industrial coke production under similar conditions as CCB composites and then compared the fracture strengths.

2. Experimental

Adaro coal, a low rank non-caking coal and Mulia, a lignite from Indonesia were selected as a base coals. The elemental composition and properties of the coals is shown in Table 1. Adaro and Mulia do not show thermoplastic properties. On heating, these do not undergo softening, melting and re-solidification stages. These are non-caking coals primarily used as thermal coals.

Two binders, coal-derived solvent extracted coal fraction (MOSXF), and oil-derived Asphalt pitch (ASP), were used. MOSXF was produced at AIST laboratory by solvent extraction method described elsewhere in details [3–6]. 1-Methylnaphthlene (1-MN) was used as a solvent for solvent extraction process. Mount Owen coal was used to produce solvent extracted fraction (MOSXF). The selection of Mount Owen coal for SXF binder production was primarily due to the fact that slightly caking coals give higher solvent extraction yields. It has already been reported that the all solvent extracted fractions of coals show high thermoplastic properties irrespective of the original coal properties [3,10]. ASP was obtained from an industry source on non-identity disclosure conditions. Additionally, carbonized coal-binder composite samples were produced from Goonyella coal (GON), a coking coal having high thermoplastic properties, as a reference for comparing the fracture strength. Properties of all coals and binders are shown in Table 1. MOSXF, ASP and GON show thermal plasticity and are used either as binders or coking coals. ASP has high sulfur content which makes it a less suitable candidate as binder for blast furnace cokes. GON is a coking coal and widely used a standard caking coal for laboratory scale studies for coke research.

Samples for carbonization were prepared by mortar mixing coal and binder in a desired ratio. About 5 g of sample is prepared by mixing 60–80% coal (Adaro) and 40–20% ASP or MOSXF on dry weight percent basis. The size of base coal particles was between 0.5–1 mm and <150 μ while binder ASP, and MOSXF particles were <150 μ . Samples were carbonized using Sharma et al. [12] muffle furnace carbonization setup. First, about 5 g sample was loaded into a 20 mm steel pipe/holder and a load of 200 g was put on the top. The holder was than heat treated in 15 L/min N₂ from room temperature to 1000 m at 3 °C/min and held for 30 min at 1000 °C. The sample was cooled to room temperature in N₂. The carbonized sample, called carbonized coal-binder composite from hereon was taken out and its fracture strength was analyzed by Auto Graph instrument (AG-IS-5 kN, SHIMADZU).

Mechanical strength of industrial cokes is measured as Drum Index (DI) [11,16]. For DI measurement, about 15 kg of sample is needed for testing. In this laboratory scale study it was not possible to produce 15 kg of samples. Therefore, we used fracture strength, measured using an Auto Graph instrument, as a measure for mechanical strength of the carbonized coal-binder composite samples [12]. Fracture strength was measured by putting a cylindrical

Table 1
Properties of coals and binder.

	Elemental analysis, (wt%, daf)					Proximate (db, wt%)		Thermal plasticity			
	C	H	N	S	O (diff)	Ash	VM	ST °C	MFT °C	RT °C	MF ddpm
Adaro	73.4	5.36	1.16	–*	20.08	2.9	48.8	–	–	–	–
Mulia	57.2	5.6	0.8	–*	36.4	2.6	55.1	–	–	–	–
Coal derived solvent extracted binder (MOSXF)	84.8	6.18	1.52	0.89	6.61	0.08	43.6	244	375–441	489	>60000
Oil derived Asphalt Pitch (ASP)	86.0	5.62	1.41	5.72	1.21	0.4	39.9	174	302–445	509	>60000
Goonyella (GON)	87.8	5.2	1.79	0.56	4.65	8.6	24.1	397	456	498	977

–*: not-analyzed; –: not-applicable; VM: volatile matter; ST: softening temperature; MFT: maximum fluidity temperature; RT: re-solidification temperature; MF: maximum fluidity

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