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Research article

Influence of binder (coal tar and pitch) addition on coal caking property and coke strength

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ABSTRACT

In order to increase the usage of semi-soft coking coal, various technologies have been developed and commercialized. Among these, an additive for improving coal caking property (hereinafter referred to as a binder) is promising. Here the mechanism of binders for improving coal caking property and the influence of binder addition to coal with different particle size on caking property and coke strength were investigated. The thermogravimetric analysis and dilatometry tests have suggested that as for coal-derived binder, the gas generating from the binder interacts with coal before coal starts to soften and that coal is reformed in-situ during heating by the interaction, which leads to enhancement of caking property. On the other hand, as for petroleum-derived binder, the experiments have implied that the reason why the petroleum-derived binder enhances coal caking properties is that the gas generating as a result of pyrolysis of the petroleum-derived binder "in" the plastic coal helps the plastic coal to swell and become more fluid. Moreover, dilatation differs greatly with coal types and particle size fractions. When the specific dilatation volume of fine coal is equal to that of coarse coal, the coke structure becomes more homogeneous, which leads to high strength coke structure. There is a possibility that under the binder addition ratio being constant, coke with maximum DI can be obtained by adding binders to fine coal and coarse coal separately so that the specific dilatation volume of fine coal becomes equal to that of coarse coal.

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1. Introduction

One of the most significant subjects for cokemaking industry today is the future depletion of hard coking coal that forms high-strength coke. Therefore, it is of great importance to develop a technology to increase the use of semi-soft coking coal that produces coke of lesser quality as coal blend for metallurgical coke production.

To cope with this problem, various technologies for increasing the use of semi-soft coking coal such as 1) measures to increase bulk density, 2) optimum coal crushing, 3) additives for improving coal caking property and so on, have been developed and commercialized. Semi-soft coking coal is inferior in caking property such as dilatation to hard coking coal, however, increasing bulk density can make up for the lack of dilatation and contribute to the production of high strength coke [1]. For example, dry coal charging processes such as CMC (Coal Moisture Control) [2] and DAPS (Dry-cleaned and Agglomerated Precompaction System) [3,4], BBCP (briquette blending carbonization process) [5] and stamp charging process [6,7] have been developed and commercialized as measures to increase bulk density. Bulk density can be increased by drying coal before charging in CMC and DAPS, blending high density coal briquette in BBCP, preparing high density coal cake outside the coke oven chamber in stamp charging process. Furthermore, it is well known that coke strength can be improved by optimum coal crushing [8–10]. Under the condition that the coke strength is the same, semi-soft coking coal can be used more by optimum coal crushing. The Burstlein-Longwy process, sometimes referred to as SOVACO process or petrographic crushing process is well known as one of optimum coal crushing methods [8]. In this process, coarse coal particle which contains relatively larger amount of inert is selectively crushed in a closed circuit, which leads to a decrease in defects in coke and an increase in coke strength. Miura et al. has improved the above method by setting the upper limit of the size of the reactive-rich particle and has shown that coke strength can be improved more [9].

As for an additive for improving coal caking property (hereinafter referred to as a binder), many laboratory tests and some industrial operations have been made with additions of the order of 2–6% of coal tar pitch and other additives and it has been shown that the caking property and coke strength can be increased [8,11–14]. There have been many studies on the development of liquid-crystal (mesophase) and optical anisotropic texture during co-carbonization of coal and binder [15–17] and interactions between them [18]. Moreover, various binders such as solvent refined coal (SRC) [19,20] produced by thermally reacting coal with hydrogen solvent, Hyper Coal [21] and thermal extracts from coal [2–24] have been reported.

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Table 1
Characteristics of the coals used in the experiment.

Coal	Proximate analysis (mass% db)		Dilatometry	Gieseler plastometry				Petrographic analysis	
	VM	Ash	Total dilation (vol.%)	Maximum fluidity (log MF/ddpm)	Softening temp. (°C)	Max. fluidity temp. (°C)	Resolidification temp. (°C)	Reflectance (%)	Total inerts (%)
HC1	24.1	8.9	95	2.95	408	454	493	1.22	36.9
HC2	21.1	9.7	105	2.61	418	465	499	1.44	32.8
HC3	20.6	9.7	24	1.20	436	473	495	1.43	42.3
HC4	20.6	8.8	26	2.22	424	467	496	1.37	38.0
SC1	35.4	9.1	34	2.05	394	435	459	0.78	26.6
SC2	31.5	8.9	8	1.60	401	438	463	0.84	29.4

However, the mechanism of binder for improving coal caking property is still unclear. Especially, there are many things to be studied on the interactions between coal and binder during heat treatment and how the interactions change with the type of the binders and affect the coal caking property. Furthermore, in most of the previous studies, binders were homogeneously mixed with coal which has a wide range of particle size distribution. It is well known that maceral composition and caking property differ with coal particle size. There have been few studies on the effect of binders on caking property of coal with different particle size. Considering that a process to treat fine coals and coarse coals separately such as DAPS has been commercialized, it is of great importance to study the effect of binders on caking property of coal with different particle size.

Therefore, in this report, first the interactions between coal and binders during heat treatment were investigated by studying the pyrolysis of the mixture of coal and binders by using thermogravimetric analysis, and were compared with the dilatation behavior. Next, a binder was added to coal with different particle size and its effect on caking property and coke strength was investigated.

2. Experiment

2.1. Samples

The characteristics of the samples used in the experiment are shown in Tables 1 and 2. Four hard coking coals (HC1, HC2, HC3 and HC4) and two semi-soft coking coals (SC1 and SC2) were used. Both CP1 and CP2 are derived from coal. CP1 is produced from tar by removing low boiling temperature components by means of distillation. CP2 is known as soft pitch. PP is petroleum pitch. CP1 and CP2 are hereinafter referred to as coal-derived binders and PP is referred to as petroleum-derived binder.

Table 2
Characteristics of the binders used in the experiment.

Binder	Softening point (°C)	Quinoline insoluble (%)	Toluene insoluble (%)
CP1	–	5	9
CP2	110	14	34
PP	240	20	45

2.2. Thermogravimetric analysis

In addition to coals (HC1 and SC1) and binders (CP1, CP2 and PP), some mixtures of coal and binder (HC1 + CP1, HC1 + CP2, HC1 + PP, SC1 + CP1, SC1 + CP2 and SC1 + PP) were used. Coal and binder were mixed by the mass ratio of 1:1. 20 mg of the sample was set in the thermogravimetric balance (SHIMADZU TG-51H) and heated up to 900 °C at the heating rate of 3 °C/min in nitrogen atmosphere. During the experiment, the changes in the weight were recorded.

2.3. Dilatation

Two types of dilatometer experiment were conducted to evaluate the influence of binder addition on coal caking property. Firstly, coal and binder were charged homogeneously or separately in a dilatometer retort in order to investigate the interaction between coal and the gas generating from binder. Secondly, coals with different particle size were charged in the retort. The results presented in all of the graphs are from a single dilatation test.

1) Homogenous and separate charge of coal and binder

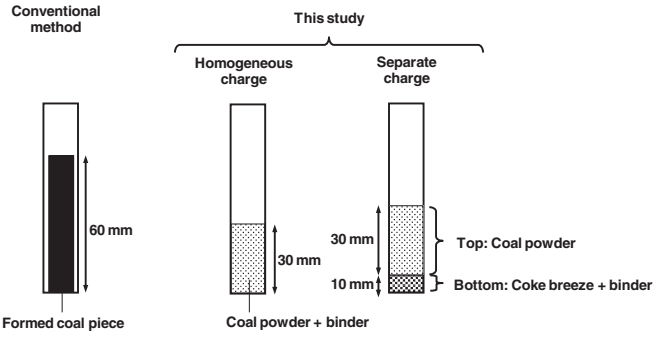

Fig. 1. Dilatometry measurement method.

In a conventional method [25], −0.15 mm coal powder is formed into a 60 mm long piece as shown in Fig. 1, but in this study, −0.3 mm coal powder was used as it was. This experimental condition was chosen in order to investigate the interaction between coal and the gas generating from binder by simulating the inter-particle gas flow in an actual coke oven. It is preferable to use coal samples having the size of −3 mm 75 to 85%, which are charged in an actual coke oven, however, considering the diameter of dilatometer tube (8 mm) and homogeneity of the sample, −0.3 mm coal powder was chosen. The powder sample was charged into the reaction tube of the dilatometer, heated, and the changes in the height by dilatation were measured.

First, coal and binder were mixed homogeneously. Each binder (CP1, CP2 and PP) was mixed with coal HC1 by the addition ratio of 5%. The mixture was charged into the reaction tube of the dilatometer to the height of 30 mm at the bulk density of 0.80 g/cm^3. Then the sample was heated from 300 °C to 550 °C at the heating rate of 3 °C/min and the changes in the height by dilatation were measured.

Next, coal and binder were charged separately and the interaction between coal and the gas generating from binder was investigated. As shown in Fig. 1, the mixture of coke breeze and binder was charged at the bottom of the reaction tube to the height of 10 mm. The mixture was prepared by mixing each binder (CP1 and PP) with coke breeze

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