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Swelling and shrinkage behavior of raw and processed coals during pyrolysis

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Abstract

Direct observation of transient swelling and shrinkage behavior of raw coals and processed coals was conducted by using a digital camera with a long focus lens, and quantitative description of swelling and shrinkage was resulted from subsequent image processing. The results showed that the raw and processed coals in pyrolysis behaved differently. The shrinkage of the processed coals was quite different, the maximum volumetric shrinkage ratio at 1000 °C as in the range of 32–38% with swelling ratios less than 5%, and the volumetric swelling ratio increased and the shrinkage ratio decreased with the increase of coal sample density. The maximum volumetric swelling ratio of the raw coals was more prominent than those of the processed coals. The raw coal A_2 showed a maximum swelling ratio of 20–85% and the raw coal B_2 showed a maximum swelling ratio of 25–45%. The volumetric swelling ratios decreased and the shrinkage increased with the decrease of the sample size. It is considered that the different pyrolysis behaviors were mainly due to the variation in their macroscopic structures. However, the similar swelling and shrinkage curves of coal samples were observed for the same raw or processed coals. In addition, the effect of volatile matter on the volumetric shrinkage ratios would be weakened if the raw coal was crushed into powder and then pressed into processed coal samples. Scanning electron microscope analysis showed that the structure of coke after pyrolysis was also different.

Keywords: Coal pyrolysis; Swelling; Shrinkage

1. Introduction

The swelling and shrinkage phenomenon occurring during pyrolysis is of considerable interest for coke and steel producers, as it may result in built-up of oven wall pressure or coking pressure. Large coking pressure can lead to a dangerous situation and to difficulties in discharging coke cakes in a coke oven. Besides, it may also result in different char structures, which in turn significantly influence the char combustion, gasification kinetics, and ash formation [1]. The relationship between coking pressure and lateral shrinkage, vertical shrinkage during pyrolysis was investigated in the coke oven [2,3]. Alvarez et al. [4,5] examined the interrelation between thermoplastic properties of coals and volumetric contraction observed for semi-coke layers, and investigated the relationship between dangerous/safe coals and the devolatilisation that took place during the coking process. Several studies related to the coking pressure accumulation during pyrolysis were carried out, focused either on the generation mechanism of coking pressure [6–10], or on the methods for identifying dangerous coking coals [11,12]. It is clear from the above works that the type of coal has a profound influence on coking pressure. These works took into account the effects of heating rate, coal type, macromolecular structure in the plastic

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stage, temperature and pressure on the different products obtained from the pyrolysis, such as tar, char, etc.

In most of previous studies, actual process of coal pyrolysis could not be directly observed as the interior of experimental system of pyrolysis is not visually observable. In addition, the location of measurement could not be specified as necessary in experiment. Strezov et al. [1,13–15] provided useful information of coal swelling and char morphology changes by observing the transient pyrolysis behavior of individual coal particles during heating by laser heating technology, and the swelling behavior of single particles was observed using a CCD video camera equipped with a long distance microscopic lens. To date, no report on the bulk coal in pyrolysis has appeared.

Coal is a complex substance with many physical changes and chemical reactions taking place during pyrolysis. Development and optimization of coal utilization processes are relied on the knowledge of the effects of operating conditions on the thermoplastic properties of coal, e.g., swelling, fluidity and viscosity. So far no unified understanding on coal pyrolysis has been obtained. Therefore, it is quite necessary to further study the swelling and shrinkage behavior of coals during pyrolysis.

It is well known that the swelling and shrinkage behavior of coals depends on coal type, heating rate, pressure and particle size, and it occurs as a result of the complex combination of numerous factors. Most of previous studies take coals under single condition as one of experimental materials, such as the single raw coal particle. The effects of diverse conditions on coal pyrolysis behavior have not well understood. The present work aims at studying the transient swelling and shrinkage behavior of several raw and processed coals during low temperature pyrolysis. The present research results, therefore, may be of importance in extending understanding of primary nature of coal pyrolysis behavior during low temperature pyrolysis.

2. Experimental

2.1. Coal samples

Two types of coking coals (denoted as samples A and B) from Shanxi Province, China, were chosen as parent coals in this study. Both of them were subjected to two kinds of coal samples. One was crushed to the particle size of 90% <50 μm, then the coal powder was pressed into coal cakes with different densities. These samples were named as processed coals A_1 and B_1, respectively. The other set of coal samples was ground to coal cakes and then carved into the desired size by a knife, and the different size samples could be obtained. Obviously, these coal cakes have the same internal structure and character as the raw coal cakes. In order to distinguish them from the processed coals, they were named as raw coals and signed as A_2 and B_2, respectively. To avoid the effect of coal rank and the variability of coal samples on experimental results, the parent coal of each sample was chosen from the same coal cake with a fixed constant rank. The properties of the coal samples are listed in Table 1. It is apparent that the volatile matter (VM) content of coal sample A is greater than that of coal sample B. The geometrical sizes of samples are given in Table 2.

Table 1
Properties of the coal samples

	Proximate analysis (ad) (%)				Ultimate analysis (daf) (%)				
	H_2O	VM	FC	Ash	C	H	N	O	S
A	1.09	25.87	60.93	12.11	80.46	4.62	1.74	12.58	0.60
B	1.27	13.39	65.24	20.10	84.33	4.65	1.84	8.70	0.48

	Dilatometry Audibert-Arnu					Plastometry Gieseler			
	t_1 (°C)	t_2 (°C)	t_3 (°C)	a (%)	b (%)	t_1 (°C)	t_2 (°C)	t_3 (°C)	F_{max} (log MF/ddpm)
A	368	407	467	31	244	376	446	478	3.86
B	380	426	470	20	63	388	463	482	1.48

Table 2
Initial geometrical sizes of the coal cakes

	Processed coals		Raw coals	
	A_1	B_1	A_2	B_2
Diameter × height (mm × mm)	20.5 × 14.3	20.5 × 14.2	20.0 × 10.8	19.0 × 10.3
	20.5 × 13.2	20.5 × 13.1	10.3 × 10.2	10.4 × 10.0
	20.5 × 12.3	20.5 × 12.0	6.0 × 5.3	6.0 × 6.0
	–	–	2.0 × 1.9	2.2 × 2.2

2.2. Experimental apparatus

The experimental apparatus is shown in Fig. 1. Two glass windows are installed on both ends of the reactor, which allow clear view for a digital camera equipped with a long distance lens to monitor the transient image change of coal samples at one end of the reactor. In order to improve the image quality, the light source is used at the other end of the reactor. When the light source is turned on, the inside of the chamber is bright enough for the digital camera to take vivid images. A coal cake is placed on a graphite substrate inside the corundum tube under an argon atmosphere. A thermocouple is installed close to the sample to measure the temperature during heating. The swelling and shrinkage images of coal samples are recorded by the camera, and later transferred into a computer for image processing with the ACDSee software. The reactor is operated under atmospheric pressure and the heating rate is controlled by a programming temperature controller. The heating is from room temperature up to 1000 °C. The average heating rate is 1.5 °C/min from room temperature to 500 °C, and ≈3 °C/min in the remaining temperature range. As the samples are small, they are considered to be heated uniformly with this heating rate. The images are taken at specified time instants until the maximum temperature is reached. The sample dimensions are measured on the screen of the monitor based on the