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特　　集

Fundamental Experiments for Developing Underground Coal Gasification (UCG) System

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For Underground Coal Gasification (UCG), it is necessary to evaluate the combustion area in the coal seam precisely. We are planning to use acoustic emission/microseismicity (AE/MS) monitoring for estimation of the underground combustion area. Analyzing the AE/MS waveforms from underground rocks, fracture extension around the combustion reactor can be grasped. For this objective, laboratory experiments are conducted for the UCG model. During burning coal block molded cylindrically by mortar, temperatures inside coal and AE activity were monitored. From the experimental results, it was found that many AE events were generated during combustion of coal, and the AE activity was close related to the change of temperature inside coal block. These AE generations seems to be caused by the crack initiation and extension around coal combustion area in the influence of thermal stress. Therefore, AE/MS monitoring is expected to be a useful tool to evaluate the UCG combustion reactor.

Keywords : Underground Coal Gasification, UCG, Acoustic Emission, AE, Coal Combustion

1 INTRODUCTION

Underground Coal Gasification (UCG) is a technology for creating a combustion reactor in an underground coal seam to collect heat energy and gases (hydrogen, methane, etc.). Although UCG technology was developed originally in Europe and the USSR in the 1940s, many countries have recently shown interest in this method because modern sensing and control techniques reduce UCGs' impact on the earth environment, i.e., emitting no noxious gases to the air and producing no ash on the surface.

However, for constructing a secure and environmentally friendly UCG system, it is necessary to evaluate the combustion area in the coal seam precisely and to monitor groundwater pollution. Especially, evaluation and control of the underground combustion area are important not only for efficient gas production but also for estimation of subsidence and gas leakage to the surface.

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Modern UCG systems use acoustic emission/microseismicity (AE/MS) monitoring for estimation of the underground combustion area, as shown in Fig. 1. By analyzing the AE/MS waveforms from underground rocks, fracture extension around the combustion reactor can be grasped and prevented from developing excess fracture by changing the injection gas. For this objective, laboratory experiments were

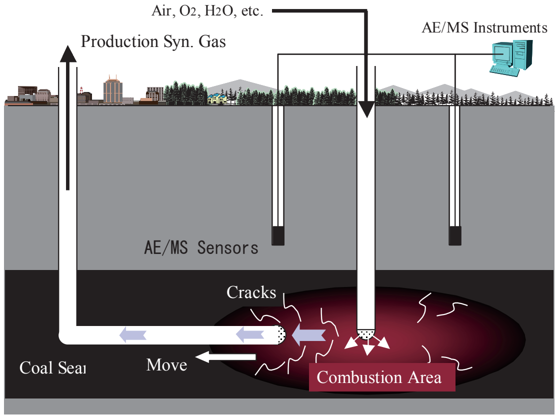

Fig. 1. UCG system and AE/MS monitoring system

conducted for the UCG model. While burning coal blocks that had been molded cylindrically with mortar, temperatures inside the coal and the associated AE activity were monitored.

2 FUNDAMENTAL EXPERIMENTS USING COAL BLOCKS

2.1 Point Heating Experiments and Coal Specimens

Point heating experiments using CO_2 lasers have been done to certify the generation of AE with heating processes of coal and coal-measures rocks[(1)(2)]. Coal and coal-measures rock specimens produced at Kushiro Coal Mine Co. Ltd., Japan were used for the experiments. The results obtained from the series of experiments showed that coal generated AE with special AE activity patterns in heating processes. However, rocks, sandstone, and shale never emitted AE in the same process. These experimental results confirmed that AE/MS monitoring is applicable for evaluation of combustion volume and its migration in the coal seam.

In laboratory experiments using coal blocks, the same coal produced at Kushiro Coal Mine Co. Ltd. was also used. The coal block (approximately 100 × 100 × 600 mm) was covered cylindrically with concrete mortar to 300 mm diameter and 600 mm height. After casting the coal block specimen, a 10 mm diameter drill hole was bored through the coal block as a linking channel for the air supply.

2.2 Experimental setup

Figure 2 presents the experimental setup. Four thermocouples were inserted into the mortar to monitor the temperature inside the coal block. In addition, six AE transducers were attached on the surface of the specimen to detect AE waveforms. Output signals from AE transducers were amplified to 32 dB using amplifiers (Physical Acoustics Corp., AE2A) and recorded on a data logger (Graphtec Corp., DM3000) with sampling time of 100 ns. The frequency response of this AE measurement system is 100–400 kHz. Furthermore, the number of events and the ring-down count pulse from an AE transducer are recorded on the other data recorder (Graphtec Corp., GL900-8) through a signal conditioner and envelope processor (Dunegan/Endevco Corp., 3000 series) to observe AE activity.

In this experiment, the injection air flow was controlled through adjustment of an electric blower observing the flowmeter. After igniting the coal at the bottom of specimen with burning charcoal, the flow rates were controlled stepwise as 300, 350, 550, and 0 L/min. During coal combustion, production gas sampling was conducted periodically using a gas sample bag. The gas components and contents were analyzed using gas chromatography.

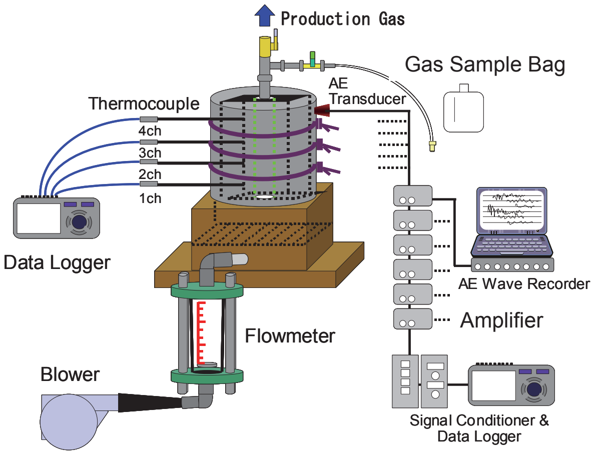

Fig. 2. Experimental setup for coal block specimen

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Variation of temperature around the coal block

Figure 3 presents temperature changes occurring with elapsed time at four positions inside the specimen. Thermocouple Ch1 was on the bottom side of the specimen; Ch4 was on the upper side. From this graph, results show that the temperature inside the specimen increased from lower to upper, i.e., the combustion area increased upward. Furthermore, the temperature gradients were dependent on the flow rate.

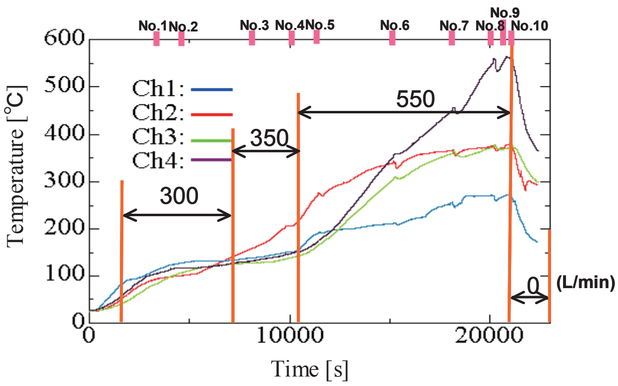

Fig. 3. Variation of temperature with time and the flow rate

3.2 Variation of gas contents

In Fig. 3, the times of No. 1 – No. 10 represent production gas sampling times. Table 1 presents typical gas components and composition percentages for each sampling gas. To see sampling for No. 5, most gas compositions were drastically increases; also in No. 10, the gases aside from methane decreased. Results show that the composition of production gas was dependent on the injection-air flow rate. When the air flow rate was changed to 350–550 L/min, the production gas compositions increased with high temperature gradients. For No. 10, it was estimated that complete

Table 1. Production gas composition

	Composition(%)									
	No1	No2	No3	No4	No5	No6	No7	No8	No9	No10
CO	0.236	0.690	0.365	0.291	8.339	9.343	1.605	1.196	0.430	0.000
CO_2	9.633	16.438	13.508	12.898	18.594	17.075	16.771	15.451	14.452	9.088
CH_4	1.753	3.753	2.905	3.078	20.735	14.002	7.002	5.260	3.440	3.225
1,3-C_4H_6	0.010	0.015	0.024	0.026	0.222	0.080	0.039	0.019	0.012	0.000

combustion took place. These results suggest that production and composition are controllable by adjusting the injection-air flow rate.

3.3 AE activity with coal combustion

Figure 4 presents AE activity during combustion of the specimen. Because many AE events were detected, fractures apparently corresponded to the number of events that could be generated inside the specimen. Furthermore, the accumulated events curve shows a similar tendency to that of the temperature of coal. This result demonstrates that the AE activity is dependent on the injection-air flow rate: the degree of fracture development inside the combustion volume is controllable by adjusting the injection air.

Figure 5 depicts the typical AE waveforms detected during combustion of the specimen. It is difficult to calculate the AE source location from AE waveforms. At this moment, only nine events have been determined: all were located around the specimen center as shown in Fig. 6. In this figure, the specimen and AE source locations (small circles) are described three-dimensionally by VRML (Virtual Reality Modeling Language).

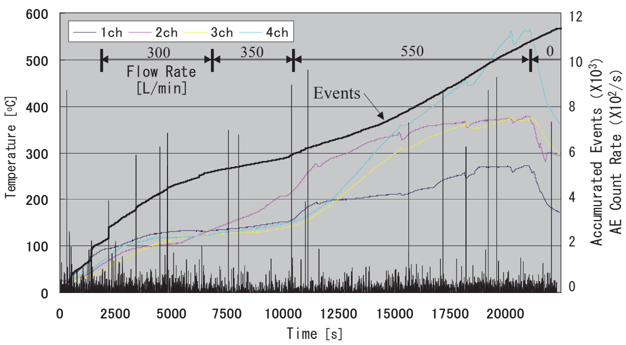

Fig. 4. Temperature and AE activity

3.4 Combustion Cavity and Fracture Zone

After the combustion finished, the specimen was cut perpendicular to the linking channel at four sections to observe the combustion cavity, as portrayed in Fig. 7. White areas in each section show the combustion cavity. The combustion cavity diameter decreased from bottom to top. Furthermore, the fracture zone was detected around the cavity. These fracture zones were inferred to have been formed by crack initiation with AE under compressive thermal stress.

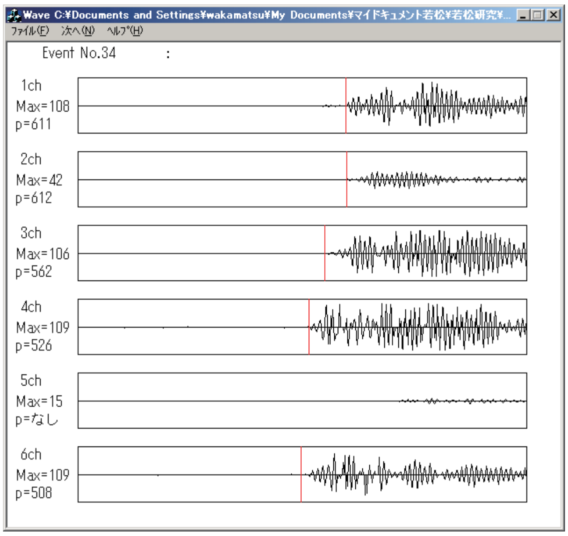

Fig. 5. Typical AE waveforms for source locations

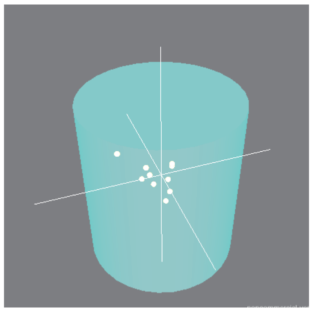

Fig. 6. AE source locations

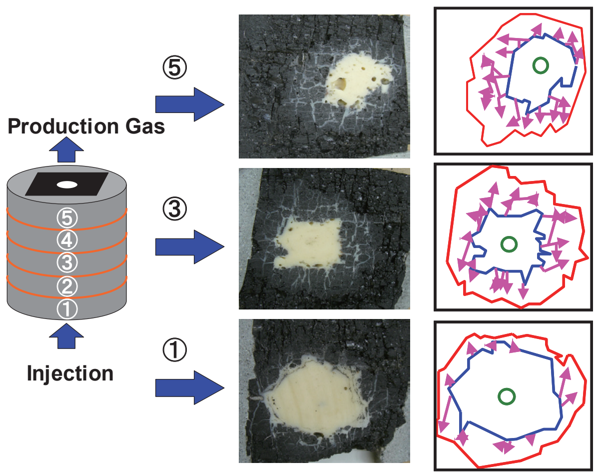

Fig. 7. Cross section images of the coal block specimen

4 CONCLUSIONS

Experimental results obtained using the coal block showed that the combustion propagated from the bottom to the top of the specimen, temperature gradients inside the coal and the composition of production gas depended on the injection-air flow rate. Moreover, many AE events were generated during coal combustion; the AE activity was closely related to the change of temperature inside the coal block. These AE generations apparently result from crack initiation and extension around the coal combustion area under the influence of thermal compressive stress. Therefore, AE/MS monitoring is expected to be a useful tool to evaluate UCG combustion reactors.

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石炭の地下ガス化（UCG）システム開発に関する基礎実験

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概要
石炭の地下ガス化（UCG）においては，炭層内の燃焼領域を正確に把握する必要がある。この燃焼領域の評価のためにAE/MS（破壊音）計測を計画している。AE/MS波形を解析することにより，燃焼領域周辺の破壊進展を把握することが可能になる。このために，モルタルで円柱形に固めた石炭塊の燃焼実験を行い，燃焼中の内部温度，AE活動を計測した。その結果，燃焼中に多くのAEが発生し，そのAE活動は内部温度の変化と関連していた。これらのAEの発生は,燃焼領域の周辺で熱応力によりき裂が発生,拡張したためと考えられる。このため,AE/MS計測はUCGの燃焼領域の評価に有効な手段になりえることが確認された。

キーワード: 石炭の地下ガス化，UCG，アコースティック・エミッション，AE，
石炭の燃焼

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