

A Novel Recycling Technology of Bamboo Using NaOH

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Abstract: The bamboo industry in Japan is declined, and disordered bamboo forests are increasing. Although maintenance of bamboo forest is needed, a large amount of bamboo wastes after logging is generated and left untreated. Therefore, new utilization of bamboo wastes after logging are desired. In this research, we aimed to develop a new recycling technology for bamboo using alkali hydroxide. By pyrolyzing bamboo using hydroxide under an inert atmosphere, thermal decomposition of organic contents and alkali fusion of silica component inside the bamboo were carried out simultaneously to recover combustible gas, charcoal and silica component. The thermal decomposition behavior of bamboo, the properties of the obtained charcoal and extraction of silica in the presence of alkali hydroxide were investigated, and the optimum condition of bamboo recycling treatment was examined. As a result, it was found that when 1 g of bamboo was pyrolyzed at higher than 500 °C with 3 g NaOH, the almost silica was extracted, a large amount of gas generated, and a carbonized material with specific surface area of about more than 1100 m²/g was obtained.

Key words: *Bamboo, NaOH, Alkali fusion, Pyrolysis, Silica*

INTRODUCTION

The bamboo industry has declined due to the decrease in demand and an increase in imported products. Approximately 350,000 ha is disordered in approximately 400,000 ha of the whole bamboo forest area in Japan. Bamboo growth is much faster than other trees, and it cause destruction of existing forests, induction of sediment collapse, damage of houses, etc. On the other hand, bamboo can be used as an effective natural resource by controlling the growth.

Bamboo is a gramineae plant that absorbs a lot of silica (SiO₂) from the ground when growing. Silica is widely used for many industry and is important resources for Japan. In previous study, silica is extracted from rice husk ash using alkali fusion method [1]. In addition, it is possible to recover charcoal, liquid and gases by pyrolysis of bamboo, and the addition of hydroxide promotes thermal decomposition of bamboo to produce the charcoal with high surface area and the high amount of gases [2], [3].

In this research, we aimed to develop a new recycling technology for bamboo using sodium hydroxide. Bamboo was heated in an inert atmosphere together with

hydroxide, and thermal decomposition treatment of bamboo body and alkali fusion treatment of silica component inside the bamboo were carried out simultaneously to recover combustible gas, charcoal and silica component. The thermal decomposition behavior of bamboo, the properties of the carbonized residue and the extraction of silica in the presence of alkali hydroxide was investigated, and the optimum condition of bamboo recycling treatment was examined.

EXPERIMENT

Bamboo sample

Bamboo powder, which was collected from Chiba prefecture, Japan, was pulverized to powder with diameter of less than 3 mm and air-dried to be used in this study.

The silica content in the bamboo sample was measured by the following procedure. First, bamboo powder was placed in a muffle furnace and burned at 800 °C for 1 hour to be the ash, then the ash was mixed with sodium hydroxide, and ground into a nickel crucible at a mixing weight ratio of 1: 3. The crucible was again placed in a muffle furnace, heated at 500 °C for 1 hour, and then

cooled to room temperature. After that, the crucible was taken out and soaked in 150 mL of 1 M hydrochloric acid solution to completely dissolve silica component, and the silicon concentration in the extracted solution was measured with an atomic absorption photometer (PerkinElmer, AAnalyst 200), and the silicon content per 1 g of bamboo was calculated. Table 1 shows the bamboo powder composition used in this experiment. The moisture content was measured using a moisture meter. In addition, the bamboo powder was burned at 700 °C. in the air atmosphere, and the residual amount was defined as the ash content. Fixed carbon and Volatile matter amount were entrusted to Center for Analytical Instrumentation of Chiba University for measurement. It was found that the silica content per 1 g of bamboo sample was about 2 mg/g, which was almost same at the silicon content of bamboo in Chiba reported previously about 1.1 to 2.4 mg/g [4].

Table 1 Composition of the bamboo powder.

Moisture	Ash	Fixed carbon and Volatile matter			Si
		C	H	N	
11 %	2 %	44.9 %	5.4 %	0.2 %	2 mg/g

Pyrolysis with NaOH

Experimental procedure for pyrolysis with NaOH was shown in Fig. 1. Bamboo powder (1 g) was placed in a reactor together with sodium hydroxide (1 - 3 g) and heated to 300 - 700 °C in an electric tube furnace under a nitrogen atmosphere for 0 - 2 h. After heating, the reactor was cooled to room temperature, then distilled water was added into the reactor, stirred with magnetic stirrer and filtered to recover an insoluble solid and a solution with soluble components in water. The concentration of silicon in the filtrate was measured with an atomic absorption spectrophotometer, and the extracted amount of silica component was calculated. In addition, the gas generated during thermal decomposition was collected in a gas pack, and the amount of generated gas was measured using gas chromatograph (GC-8A, SHIMAZU). The solid residue was dried, and the weight of the residue was measured. The surface shape of the residue was observed with a scanning electron microscope (SEM) (JEOL, JSM-6510A) and specific surface areas of the residue were measured by a BET specific surface area measuring equipment (MacsorbModel-12, manufactured by MOUNTECH).

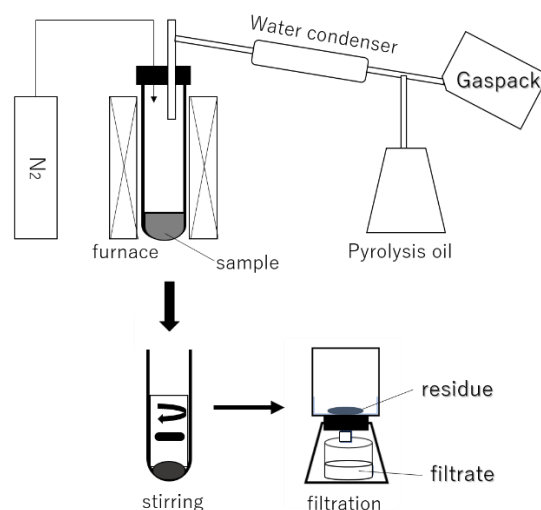


Fig. 1 Schematic diagram of an experimental.

Silica powder preparation

Preparation of silica powder from the solution extracted from bamboo was carried out by the following procedure. 5 g of bamboo was pyrolyzed at 500 °C for 2 h with addition of 10 g sodium hydroxide, then cooled to room temperature, and the solid in the reactor was dissolved in 1 M HCl solution. The obtained extracted silica solution was neutralized by adding a sulfuric acid solution and heated to reduce the amount of water to precipitate the dissolved silica from the solution. After heating, the solution was shaken for 10 minutes, the liquid and the solid were separated by a centrifugation, and the solid was recovered by decantation. The solid was dried, and observation of surface shape and component analysis were carried out with SEM and energy dispersive X-ray spectrometry(EDS).

RESULTS AND DISCUSSION

Residual weights under each condition are shown in Fig. 2. The heating time is 1 h. As the temperature rises, the residual weight decreases (Fig. 1). When the thermal decomposition temperature is 300 °C, the residual weight is large, and the residue weight tends to be constant when heated above 400 °C. In addition, the residual weight decreases with increasing sodium hydroxide addition. This suggests that an increase in the amount of sodium hydroxide and the thermal decomposition temperature promotes thermal decomposition of bamboo to reduce the weight of the residues.

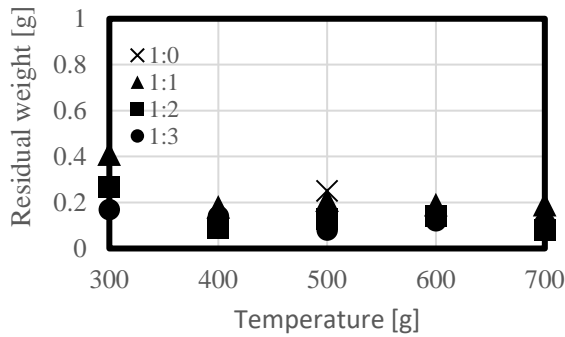


Fig. 2 Residual weights after pyrolysis.

Fig. 3 shows the specific surface area of the residue obtained under each condition. The heating time is 1 h. When the addition amount of sodium hydroxide was 1 g, specific surface areas of the residue is very low, regardless of thermal decomposition temperature. On the other hand, when the addition amount of sodium hydroxide was 2 g or 3 g, the specific surface areas of the residue increases with increasing temperature, and the residue with about 1500 m²/g of specific surface area can be obtained at 600 °C and 700 °C.

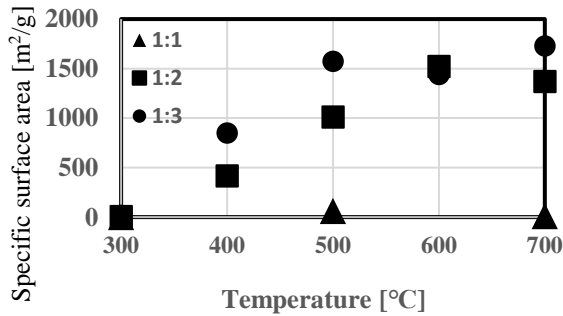


Fig. 3 Specific surface area of the residue after pyrolysis.

Fig. 4 shows SEM photographs of the residue obtained under each condition. The heating time is 1 h. At a thermal decomposition temperature of 500°C, there is no difference between the residues without NaOH addition and with 1 g NaOH addition (Fig. 4 (a), (b)), whereas a porous shape can be confirmed in the residue with 3 g NaOH addition (Fig. 4(c)). On the other hand, with 3 g NaOH addition at 300°C, porous shape was not observed (Fig. 4 (d)).

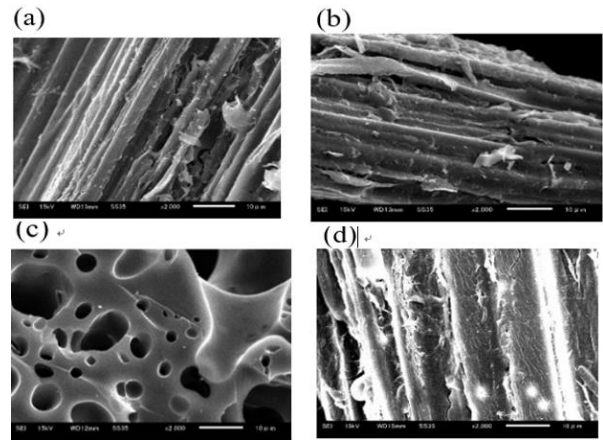


Fig. 4 SEM photograph of the residue (a) without NaOH not added at 500 °C, (b) with NaOH 1 g addition at 500 °C, (c) with NaOH 3 g addition at 500 °C, and (d) with NaOH 3 g addition at 300 °C.

The extracted amount of silicon under each condition is shown in Fig. 5. The heating time is 1 h. When the addition amount of sodium hydroxide was 1 g, silica extraction could not be confirmed, while when sodium hydroxide addition amount is 2 g or 3 g, regardless of the thermal decomposition temperature, almost silica content in bamboo is extracted.

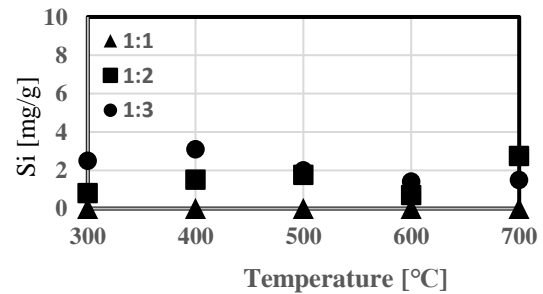


Fig. 5 Extracted amount of silicon under each condition.

SEM photo of the silica powder obtained from bamboo is shown in Fig. 6. It was observed that the powder was gel-like agglomerate. By quantitative analysis using EDS, it was confirmed that the main components of this powder are mainly composed of silicon (39.5 %) and oxygen (53.5 %), and the minor contents, sodium and sulfur, derived from sodium hydroxide and sulfuric acid. These are suggested that bamboo-derived silica can be recovered using this process.

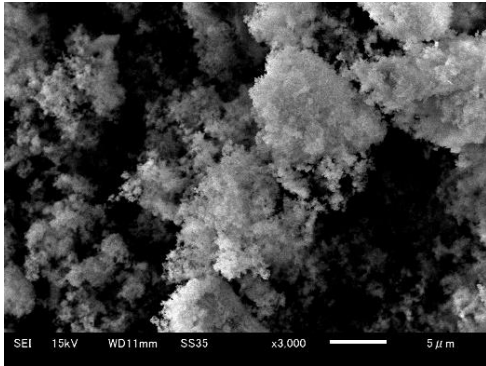


Fig. 6 SEM photograph of the silica powder from bamboo

Generated gas amounts under each condition are shown in Fig. 7. The heating time is 1 h. As the temperature rises and the amount of sodium hydroxide added increased, the amount of generated gas was increased. These results indicate that sodium hydroxide can promote the gasification of bamboo and the promotion is more effective at higher temperature.

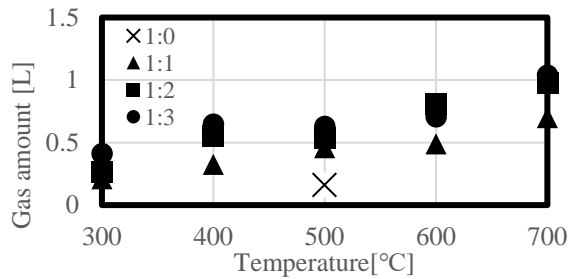


Fig. 7 Gas amounts generated during the pyrolysis.

Fig. 8 shows the amounts of H₂, CH₄, CO and CO₂ generated by pyrolysis with NaOH. Heating time is 1 h. When sodium hydroxide is added, the percent of H₂ in the generated gas is about 90 to 95%, regardless of the NaOH addition and thermal decomposition temperature. CH₄ accounted for about 5 to 10% and the amounts of CO and CO₂ are minor (< 0.5 %), which generated decreased with increasing sodium hydroxide addition. On the other hand, when sodium hydroxide was not added and heated at 500 °C, H₂ and CH₄ accounted for about 25% of the total, CO and CO₂ accounted for about 75%. These results indicate that the addition of sodium hydroxide promotes the generation of gas containing H₂ and CH₄.

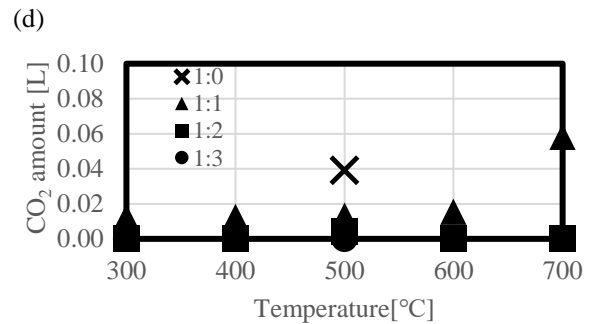
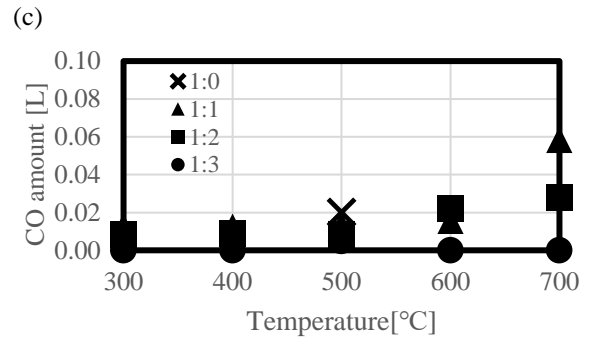
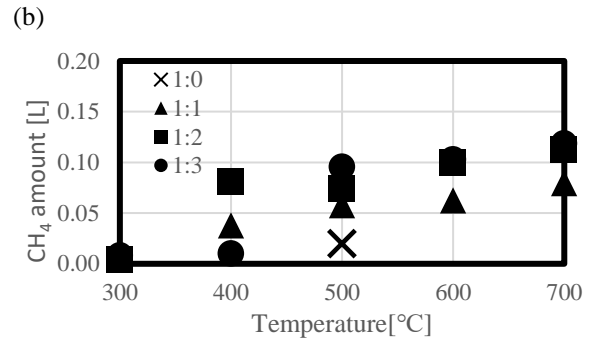
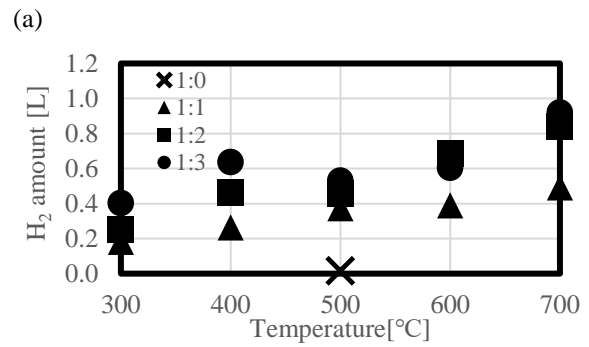


Fig. 8 The amounts of (a) H₂, (b) CH₄, (c) CO and (d) CO₂ generated during the pyrolysis.

Residual weights during the pyrolysis are shown in Fig. 9. The addition amount of sodium hydroxide was 3 g. When the thermal decomposition temperature was 300 °C, the residue weight was about 0.2 g with increasing the temperature, the weight was 0.15g when it was 400 °C, and the weight was 0.1 g when it was at higher than 500 °C or higher.

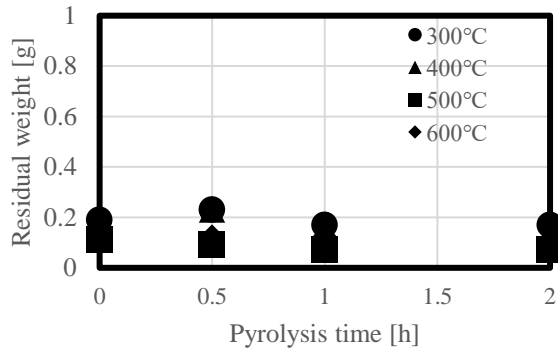


Fig. 9 Residual weights after pyrolysis.

Fig. 10 shows the specific surface area of the residue during pyrolysis. The amount of sodium hydroxide was 3 g. When the thermal decomposition temperature was 300 °C, an increase in the specific surface area could be confirmed after 2 h pyrolysis. When the thermal decomposition temperature was 400 °C, the specific surface area increased, and became constant after 1 h pyrolysis. When the thermal decomposition temperatures were 500 °C and 600 °C, the products with the specific surface area of 1000 - 1500 m²/g could be obtained at the pyrolysis time from 0 h to 2 h.

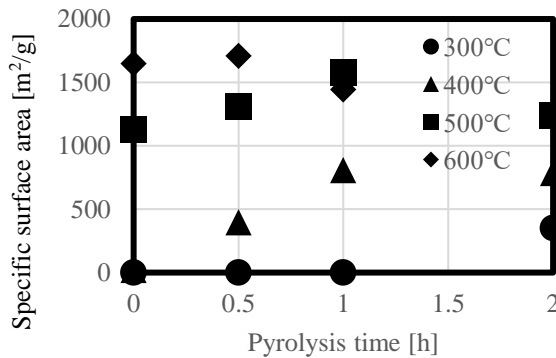


Fig. 10 Specific surface area of the residue after pyrolysis.

The extracted amount of silicon under each condition is shown in Fig. 11. The amount of sodium hydroxide was 3 g. Regardless of the thermal decomposition time, almost silica content in bamboo is extracted. The extraction amount of Si cannot be measured for 2 hours of pyrolysis time due to equipment trouble.

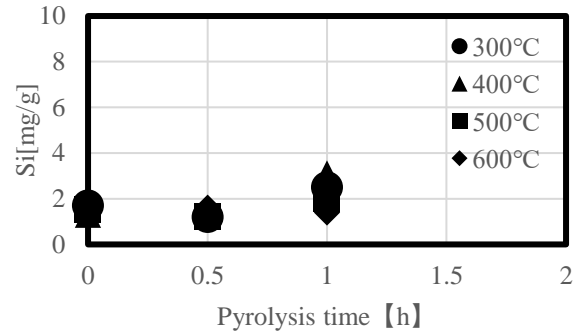


Fig. 11 Extracted amount of silicon under each condition.

Generated gas amounts during pyrolysis are shown in Fig. 12. The amount of sodium hydroxide was 3 g. As the thermal decomposition time increases, the amount of generated gas increases. In the case of the thermal decomposition temperature of 300 °C, the amount of generated gas gradually increased and becomes constant after 1 h during the pyrolysis. When the thermal decomposition temperature is 400 °C - 600 °C, the amount of generated gas increases and becomes constant after 0.5 h pyrolysis. These results indicate that the thermal decomposition temperature promotes the gasification speed of bamboo.

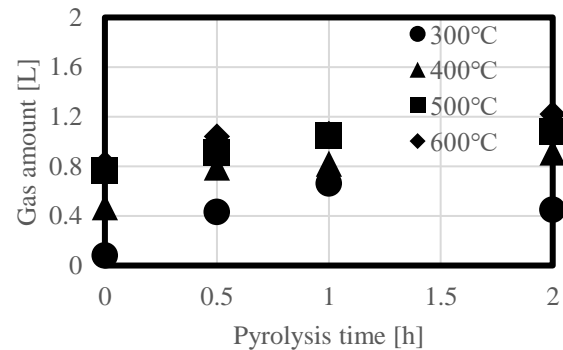


Fig. 12 Gas amounts generated during the pyrolysis.

Fig. 13 shows the amounts of H₂, CH₄, CO and CO₂ generated by during pyrolysis with NaOH. The amount of sodium hydroxide was 3 g. The percent of H₂ in the generated gas is about 90 to 95%, regardless of the heating time and thermal decomposition temperature. H₂ and CH₄ show the same behaviour as in Fig. 13, while CO and CO₂ are minor (< 0.5 %) on all pyrolysis conditions.

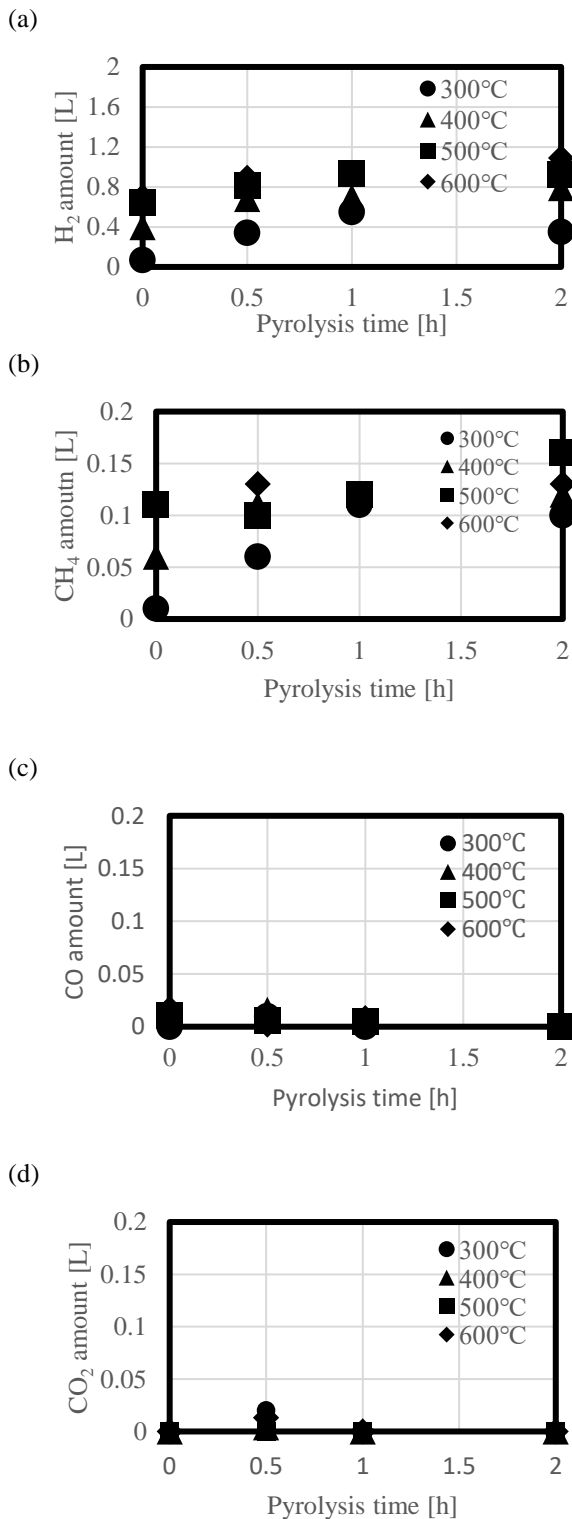


Fig. 13 The amounts of (a) H₂, (b) CH₄, (c) CO and (d) CO₂ generated during the pyrolysis.

CONCLUSION

We aimed to develop a new recycling technology for bamboo using alkali hydroxide. By pyrolyzing bamboo using hydroxide under an inert atmosphere, thermal decomposition of organic contents and alkali fusion of silica component inside the bamboo were carried out simultaneously to recover combustible gas, charcoal and silica component.

As a result, it was found that when 1 g of bamboo was pyrolyzed at higher than 500 °C with 3 g NaOH, the almost silica was extracted, a large amount of gas generated, and a carbonized material with specific surface area of about more than 1100 m²/g was obtained. And it is considered that thermal decomposition is completed in 0.5 hour under this condition.

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