Research paper

Effects of Carbonization Temperatures in an Earthen Kiln on the Properties of Bamboo Charcoal

Gwo-Shyong Hwang[1,2)]

【Summary】

Moso bamboo (Phyllostachys pubescens), Makino bamboo (*Phyllostachys makinoi*), and Ma bamboo (*Dendrocalamus latiflorus*) were used for charcoal making in an earthen kiln. Bamboo specimens were cut to 4~6 cm in width and 20 cm in length and then put in a with stainless steel cylinder. Five cylinders were piled up to 1 m in height. The carbonization temperature in each cylinder was respectively measured using a K-type thermocouple. In order to investigate the properties of bamboo charcoal affected by differences in the carbonization temperature in the earthen kiln, the pH value, true density, electrical resistivity, and specific surface area were determined for specimens sampled from different cylinders. From the results of the processes of carbonization temperatures of each cylinder in the earthen kiln, curves of different temperatures were obtained. The highest carbonization temperatures in different cylinders at the end of carbonizing were 774, 745, 695, 609, and 537℃, respectively, from top to bottom. pH values of bamboo charcoal were at the range of 8.96~10.26 and were not obviously affected by the species or carbonization temperature. The true density of bamboo charcoal increased with an increase in the carbonization temperature. The electrical resistivity of the 3 kinds of bamboo charcoal significantly decreased with an increase in the carbonization temperature. For all 3 kinds of bamboo charcoal, the specific surface area increased with an increase in the carbonization temperature.

Key words: earthen kiln, carbonization temperature, bamboo charcoal.

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研究報告

土窯炭化溫度對竹炭性質之影響

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摘　要

本研究以國產之桂竹、孟宗竹與麻竹為材料，利用土窯研製竹炭。將上述三種材料鋸製成寬度4~6 cm、長度20 cm之試片後，放入五個直徑與高度均為20 cm之不銹鋼衝孔圓筒並堆疊成高度1 m，每一圓筒內中央分別插入直徑3.2 mm之K type測溫棒。為了瞭解土窯炭化溫度對竹炭性質之影響，取出土窯內各圓筒內不同炭化溫度之竹炭試材進行pH、真密度、電阻與比表面積等試驗，各圓筒內最終之炭化溫度由上而下分別為774、745、695、609與537℃。竹炭pH介於8.96~10.26受竹種與炭化溫度之影響不明顯，竹炭之真密度隨炭化溫度增高而增大，三種竹炭之電阻隨炭化溫度之增高而明顯降低，三種竹炭之比表面積隨炭化溫度之增高而增大。

關鍵詞：土窯、炭化溫度，竹炭。

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INTRODUCTION

Bamboo charcoal has a wide variety of applications, such as humidity control (Fujihara et al. 2003), deoderization (Hung et al. 2004), maintaining freshness (Hosokawa et al. 1991), water purification (Zhou and Lu 2010, Hiroya and Emi 2012), soil improvement (Lin et al. 2011, Ho et al. 2013), etc. Bamboo charcoal offers a good environment for life, such as environmental improvement materials, also raw materials to industries for developing new products.

In order to solve downcast problems of bamboo processing industries, investigating the products of bamboo charcoal by local industries and the manufacture of high-quality charcoal using local bamboo species are very essential.

The Taiwan Forestry Research Institute (TFRI) began developing bamboo charcoal making in 2002 to use domestic bamboo effectively. The earthen kiln-building technology and charcoal-making technology reached maturity after half a year. The TFRI built 16 seat charcoal kilns in Taiwan to 2008 and taught charcoal-making technology to farmer groups to promote the domestic bamboo charcoal industry. Recently, we published some research papers in Taiwan (Lin et al. 2004, Hwang et al. 2004, Hwang et al. 2006).

MATERIALS AND METHODS

Materials

In this study, Moso bamboo, Makino bamboo, and Ma bamboo were from Nantou, Miaoli, and Chiayi, respectively. These bamboo were cut to 4~6 cm in width and 20 cm in length after being heat-treated with smoke and air-drying for about 2 mouths. They were then used to make charcoal with different temperatures in an earthen kiln. In order to reduce the effect of the bamboo height on the properties of bamboo charcoal, 3 kinds of bamboo with heights of 1~3 m were used for charcoal sample making. The moisture content, specific gravity, and thickness of the

culm wall were measured in 10 specimens for each kind of bamboo.

Bamboo charcoal making

The kiln was 2.8 m wide, 2.8 m long, and 1.4 m high with an arch-type ceiling is shown in Fig. 1. Three kinds of bamboo specimens were put into a stainless steel cylinder that was 20 cm in diameter and 20 cm in height with numerous 5 mm holes (Fig. 2). Five cylinders piled up to 1 m in height were installed 30 cm away from the side of the chimney flue in the rear part of the kiln. The carbonization temperature in each cylinder was respectively measured using a K-type thermocouple.

Bamboo charcoal test

In order to investigate the properties of bamboo charcoal affected by the carbonization temperature distribution in the earthen kiln, the pH value, true density, electrical resistivity, and specific surface area were determinated for specimens sampled from different cylinders. The pH value was measured after boiling for 5 min by adding 100 mL water to a bamboo charcoal sample. The true density of the bamboo charcoal was measured by Quantachrome ultrapycnometer 1000 (QUANTACHROME INSTRUMENTS) after drying at 105℃ using a powder mesh size of 36~60. The specific surface area of the bamboo charcoal was measured by PMI Automated BET Sorptometer BET-202A (Porous Material Inc.) using the same samples as for true density. The electrical resistance of the bamboo charcoal was measured by AVO DLRO-10 and AVO BMM-2580 (AVO INTERNATIONAL LTD.) from both ends of

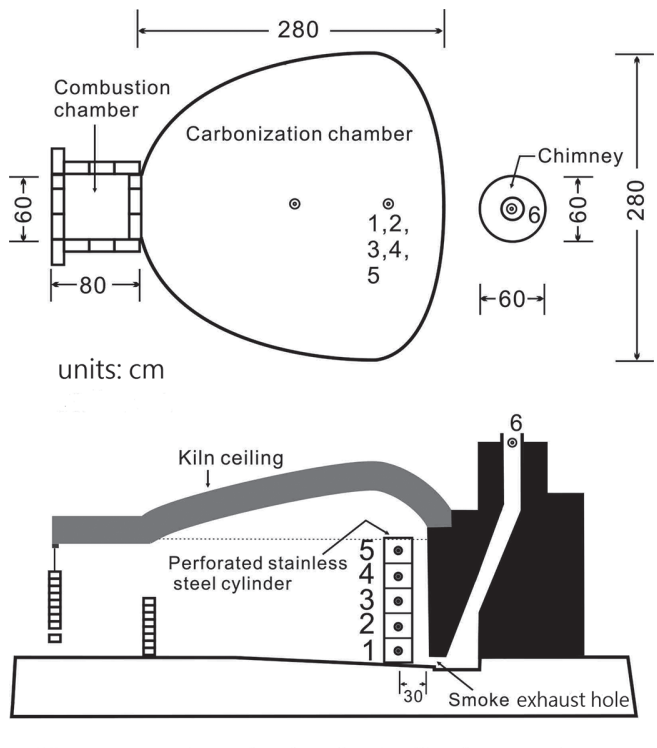

Fig. 1. Dimensions of the earthen kiln and measurement points (nos.1~6) of the carbonization temperature.

Fig. 2. Three kinds of bamboo specimens in stainless steel cylinders for charcoal making.

a specimen. The electrical resistivity, ρ, was calculated as:

$\rho = (R \times A) / L$;

where R is the electrical resistance of the specimen (Ω), A is the cross-section area of the specimen (cm^2), and L is the length of the specimen (cm).

RESULTS AND DISCUSSION

Properties of bamboo

The properties of the test material are shown in Table 1. The specific gravities of Makino bamboo, Moso bamboo, and Ma bamboo were 0.91, 0.87, and 0.78, respectively. However, the thicknesses of the culm wall were respectively 6.86, 10.01, and 11.38 mm in the reverse order of specific gravity.

Carbonization temperature

Figure 3 shows the carbonization temperature curves for each cylinder in the earthen kiln. In order to increase the bamboo charcoal yield, the kiln and bamboo must be preheated to shorten the ignition time of the bamboo as much as possible. The initial temperature in Fig. 3 was after preheating for 4d. The earthen kiln used in this study can achieve the complete spontaneous carbonization of woody materials. In order to enhance the quality of bamboo charcoal, a large amount of air was injected into the kiln when the secondary carbonization was carried out after the end of the primary carbonization. Because external heat cannot be applied to an earthen kiln during bamboo charcoal making, the temperature in the kiln tends to become uneven. The highest temperatures in the cylinders at the end of carbonization were 774, 745, 695, 609, and 537℃, respectively, from top to bottom.

Properties of bamboo charcoal

pH values of bamboo charcoals shown in Table 2 were in the range of 8.96~10.26 and

Table 1. Properties of bamboo specimens

Species	Moisture content (%)	Specific gravity	Thickness of the culm wall (mm)
Moso bamboo	9.43±0.18	0.87±0.03	10.01±0.72
Makino bamboo	10.77±0.35	0.91±0.04	6.86±0.86
Ma bamboo	10.93±0.38	0.78±0.04	11.38±1.71

were not obviously affected by the bamboo species or carbonization temperatures. The pH value of wood charcoal from acidic to alkaline with a rising carbonization temperature, but the bamboo charcoal maintains its alkalinity regardless of the carbonization temperature (Fujihara et al. 2003). The true density of bamboo charcoal shown in Table 3 increased with an increase in the carbonization temperature. At the same carbonization temperature, the true density of Ma bamboo charcoal was the highest, followed by Makino bamboo charcoal , and Moso bamboo charcoal. Lan et al. (2008) studied the properties of Moso bamboo charcoal and indicated that the true density of bamboo charcoal increased with an increasing charcoalization temperature. The increases in density of charcoal are attributed to coalescing of cell walls or shrinkage of intercellular interstices (Elder et al. 1979). The electrical resistivity of the 3 kinds of bamboo charcoal shown in Table 4 significantly decreased with an increase in the carbonization temperature, but the electrical resistivity of Makino bamboo charcoal was lower than those of Moso bamboo charcoal and Ma bamboo charcoal at the same carbonization temperature. This is considered to be due to the thin culm walls of

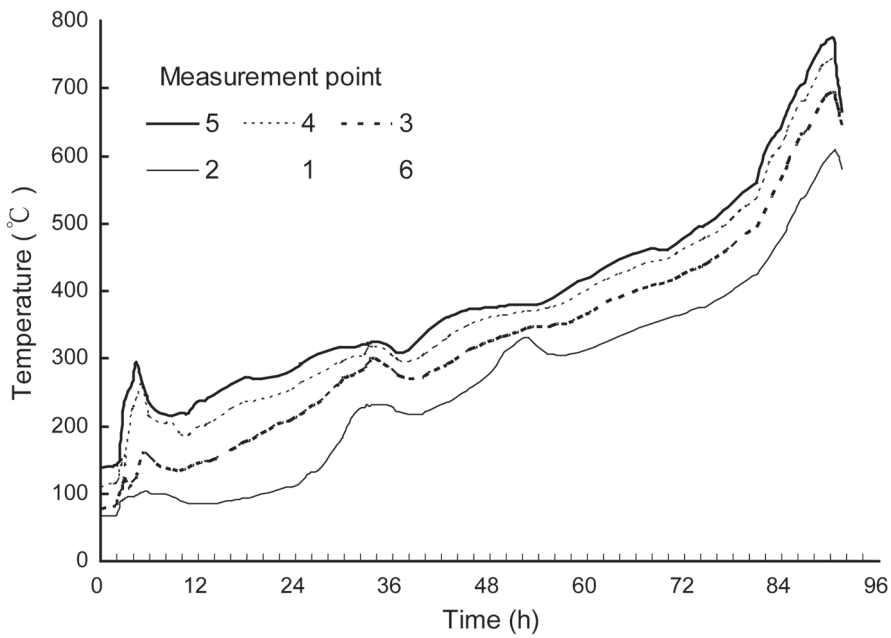

Fig. 3. Temperature curves of the carbonization processes (measurement points 1~6 are shown in Fig. 1).

Table 2. pH values of bamboo charcoal at different carbonization temperatures

Carbonization temperature (℃)	pH value		
	Moso bamboo	Makino bamboo	Ma bamboo
774	9.88±0.04	9.94±0.08	10.26±0.10
745	9.12±0.09	9.46±0.11	9.96±0.12
695	8.96±0.02	9.18±0.03	9.46±0.03
609	9.37±0.11	9.10±0.02	9.66±0.04
537	9.54±0.06	9.61±0.06	9.66±0.11

Table 3. The true density of bamboo charcoal at different carbonization temperatures

Carbonization temperature (℃)	True density (g cm^{-3})		
	Moso bamboo	Makino bamboo	Ma bamboo
774	1.95	1.96	2.04
745	1.87	1.90	1.91
695	1.76	1.77	1.79
609	1.58	1.61	1.62
537	1.51	1.52	1.52

Table 4. Electrical resistivity of bamboo charcoal at different carbonization temperatures

Carbonization temperature (℃)	Electrical resistivity (Ω · cm)		
	Moso bamboo	Makino bamboo	Ma bamboo
774	1.20±0.39	0.84±0.25	1.64±0.46
745	1.26±0.04	1.06±0.15	2.15±0.37
695	31.76±0.67	19.71±10.59	37.09±11.06
609	$8.96\pm2.81\times10^{4}$	$0.83\pm0.37\times10^{4}$	$1.11\pm0.87\times10^{4}$
537	$1.37\pm0.55\times10^{6}$	$0.89\pm0.35\times10^{6}$	$1.03\pm0.51\times10^{6}$

Table 5. The true density of bamboo charcoal at different carbonization temperatures

Carbonization temperature (℃)	Specific surface area (m^2 g^{-1})		
	Moso bamboo	Makino bamboo	Ma bamboo
774	369.71	358.01	408.83
745	294.45	273.42	304.66
695	215.27	226.91	197.42
609	183.36	92.91	144.37
537	67.13	23.85	42.94

Makino bamboo. Fukuda et al. (2001) studied the utilization of bamboo charcoal and indicated that the higher carbonization temperature, the lower was the electrical resistance of the charcoal. Lan et al. (2008) also reported that the resistivity decreased with an increasing charcoalization temperature. Results for the specific surface area of the 3 kinds of bamboo charcoal with different carbonization temperatures are shown in Table 5. It indicates that the specific surface area increased with an increase in the carbonization temperature for all 3 kinds of bamboo charcoal. Abe (2004) reported that the physical adsorption ability of the adsorbent increases with an increase in the specific surface area.

CONCLUSIONS

From the results of temperature changes in each cylinder in the earthen kiln, the temperature rise in the upper part was earlier and more rapid than those in the lower part. The highest temperature exceeded 770℃, whereas, the lowest temperature was about 530℃. The test results of bamboo charcoal indicates that the pH of the different bamboo charcoal was not obviously affected by the carbonization temperature, the electrical resistivity of bamboo charcoal significantly decreased with an increasing carbonization temperature, and the true density and specific surface area of bamboo charcoal increased with an increasing

carbonization temperature.

LITERATURE CITED

Abe I. 2004. Carbonization and acitivation techniques for prodution of carbonaceous adsorbent. TANSO 211:21-9. [in Japanese with English summary].

Elder TJ, Murphey WK, Blankenhom PR. 1979. A note on the thermally induced changes of intervessel pits in black cherry (*Prunus serotina* EHRH). Wood and Fiber 11(3):179-83.

Fujihara S, Shima K, Chiba K. 2003. Fundamental characteristics and humidity control capacity of bamboo charcoal. Mokuzai Gakkaishi 49(5):333-41.[in Japanese with English summary].

Fukuda Y, Kainuma Y, Mizuguchi T. 2001. Utilization of bamboo charcoal to processing and cookery (Part I Effects of bamboo charcoal on oxidative stability of frying oil). Nippon Shokuhinn Kagaku Kaishi 48(2):105-11. [in Japanese with English summary].

Hiroya H, Emi Y. 2012. Water treatment by charcoal. Kobe Coll Stud 59(2):35-46. [in Japanese with English summary].

Ho HM, Kuo WR, Peng CW, Hwang GS, Lin HC. 2013. Investigation of yield and seedling growth of cabbage from cultural media with Moso bamboo charcoal. J Agric For (NCYU) 10(1):43-60. [in Chinese with English summary].

Hosokawa K, Minamide T, Kanai H, 1991. The application of bamboo shoots freshness. Bamboo J 9:27-32. [in Japanese with English summary].

Hung CP, Ko CH, Hsu DJ, Wang SY, Shiau IL, 2004. Effect of carbonization conditions on purification of bamboo charcoal. For Prod Ind 29(3):183-98. [in Chinese with English summary].

Hwang GS, Ho CL, Yu HY, Su YC. 2006. Bamboo vinegar collected during charcoal making with an earthen kiln and its basic properties. Taiwan J For Sci 21(4):547-57. [in Chinese with English summary].

Hwang GS, Yu HY, Toba A. 2004. Effects of carbonization temperatures in an earthen kiln on the true density and electric resistivity of Makino bamboo charcoal. Taiwan J For Sci 19(3):237-45. [in Chinese with English summary].

Lan FL, Lay HL, Teng WF. 2008. Study on Moso bamboo charcoal property. Crop Environ Bioinform 5:180-6. [in Chinese with English summary].

Lin HC, Wu YD, Peng CH, Hwang GS, Kuo WR. 2011. Application of Moso bamboo charcoal cultural media to vegetable plug seedlings. For Prod Ind 29(3):159-71. [in Chinese with English summary].

Lin YJ, Hwang GS, Yu HY. 2004. Cost analysis for the building of bamboo charcoal kiln. Qua J Chinese For 37(2):195-204. [in Chinese with English summary].

Zhou KC, Lu KT. 2010. Improvement of drinking water qualities by using Moso bamboo activated carbon made from different activation temperatures. Q J For Res 32(4):35-44. [in Chinese with English summary].