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Aims and Scope

The *Journal of the Korean Wood Science and Technology* (*JKWST*) launched in 1973 as an official publication of the Korean Society of Wood Science and Technology has been served as a core of knowledges on wood science and technology. The Journal acts as a medium for the exchange of research in the area of science and technology related to wood, and publishes results on the biology, chemistry, physics and technology of wood and wood-based products. Research results about applied sciences of wood-based materials are also welcome. The Journal is published bimonthly, and printing six issues per year. Supplemental or special issues are published occasionally.

The abbreviated and official title of the journal is '*J. Korean Wood Sci. Technol.*'. All submitted manuscripts written in English or Korean are peer-reviewed by more than two reviewers. The title, abstract, acknowledgement, references, and captions of figures and tables should be provided in English for all submitted manuscripts. All articles are indexed in SCOPUS and Korea Citation Index (KCI).

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Original Article

Characteristics of White Charcoal Produced from the Charcoal Kiln for Thermotherapy[1]

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ABSTRACT

In this study, the characteristics of the white charcoal from charcoal kilns made for both charcoal production and thermotherapy and from the traditional charcoal kiln were compared and examined. A charcoal kiln for thermotherapy as a secondary purpose was made to minimize environmental problems such as fine dust and harmful gas generated from sealed charcoal kiln in consideration of comfort and safety. White Charcoal produced from the charcoal kiln for both charcoal production and thermotherapy had higher ash and volatile matter and lower fixed carbon than that from the traditional charcoal kiln. The density of the white charcoal produced from the charcoal kiln for both charcoal production and thermotherapy was slightly higher than that of the traditional one, but the equilibrium moisture content and pH were not significantly different. The calorific value, refinement degree, hardness and anatomical structure were not different between the two. It was concluded that the white charcoal produced from the advanced charcoal kiln for thermotherapy as a secondary purpose meets the quality certification standards of Korea Forest Research Institute.

Keywords: charcoal kiln, charcoal quality, proximate analysis, thermotherapy, white charcoal

1. INTRODUCTION

Domestic charcoal production in 2016 is 9,156 tons, accounting for 10% of domestic demand (Korea Forest Service, 2018). Although the production of charcoal is thought to have increased due in part to recent environmental problems and increased use of fuel, it is experiencing many difficulties because of the thoughtless distribution of charcoal from Southeast Asia, lack of utilization of charcoal byproducts, excessive environmental regulations, and lack of workforce.

It is time to solve the difficulties that the charcoal manufacturers are experiencing and to find new ways to revitalize the charcoal manufacturing industry. Revitalizing the charcoal thermotherapy that Korean people have traditionally enjoyed is one of solutions. Traditionally, charcoal kilns used in producing charcoal are made of loess and stone, and in recent years, loess

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bricks and red bricks have become the main materials for producing charcoal kilns. Thermotherapy is enjoyed at a temperature of around 100°C during the process of cooling the charcoal kiln of a high temperature after making charcoal (white charcoal). At this time, far-infrared rays are generated in a charcoal kiln. When it is irradiated to the human body, it causes resonance in the body and raises the temperature of the deep layers. Then it promotes metabolism and is helpful for treatment of chronic diseases such as stress and problems with the immune system by improving the ability to regenerate tissues. Thus, it has long been a widely used naturopathy (Fuse and Taki, 1987; Honda and Inoue, 1988). Recently, the authors have shown that far-infrared rays help mice to relieve their stress and improve their memory (Tran *et al*., 2016; Mai *et al*., 2018a, 2018b). Therefore, thermotherapy using residual heat from the charcoal kiln after the production of charcoal is a good way to revitalize the charcoal manufacturing industry and expected to get attention as one of the new healing methods.

The charcoal kilns for the production of charcoal, which is currently used for thermotherapy, has a structure suitable for the production of charcoal. Therefore, there is a need to solve environmental issues such as purification of air contaminated by fine dust inside charcoal kilns and inflow of harmful gas generated in the adjacent charcoal kilns for a safe and comfortable thermotherapy. Therefore, it is necessary to improve the structure of charcoal kilns suitable for thermotherapy, that is, a structure which can provide a pleasant indoor air quality without any inconvenience to thermotherapy users, and a safe structure without adversely affecting the quality of charcoal produced. In order to revitalize the traditional charcoal industry, the authors developed a charcoal kiln enabling thermotherapy, using ceramic materials that emit many far-infrared rays (Kim, 2015).

The authors (Kim *et al*., 2006; Kim and Hanna, 2006; Kwon *et al*., 2012; Kwon *et al*., 2013) have analyzed the quality and properties of charcoal that is produced at various temperature in many ways. The superior quality of charcoal made from traditional charcoal kilns (Hwang *et al*., 2002; Kwon *et al*., 2011) was also reported.

In this study, we compared the quality of white charcoal produced from a kiln developed to be suitable for both charcoal production and thermotherapy by improving traditional kilns with that of white charcoal produced from a traditional kiln.

2. MATERIALS and METHODS

2.1. Structure of Charcoal Kiln for both charcoal production and thermotherapy

The structure of the charcoal kiln for both charcoal production and thermotherapy is shown in Fig. 1 (Kim, 2015). For the stability of the whole charcoal structure, first, the floor was pierced with concrete, and then it was clayed with loess to install abrasion resistant ceramic bricks and loess bricks. The charcoal kiln used lightweight ceramic bricks and cement bricks for semi-permanent use. The walls were doubled, using ceramics and loess materials such as MnO, Mullite, SiC etc. that can secure stability and maximize the far-infrared radiation efficiency, and the ceiling of the charcoal kiln was built as a domed type for the improvement of the yield of charcoal and beautiful appearance. Unlike traditional charcoal kilns, two entrances were built, one for charcoal production and the other one for thermotherapy, and they are separately installed on the front and back side of the charcoal kiln to minimize the environmental issues such as fine dust generated by the poor charcoal working environment and to make thermotherapy easier.

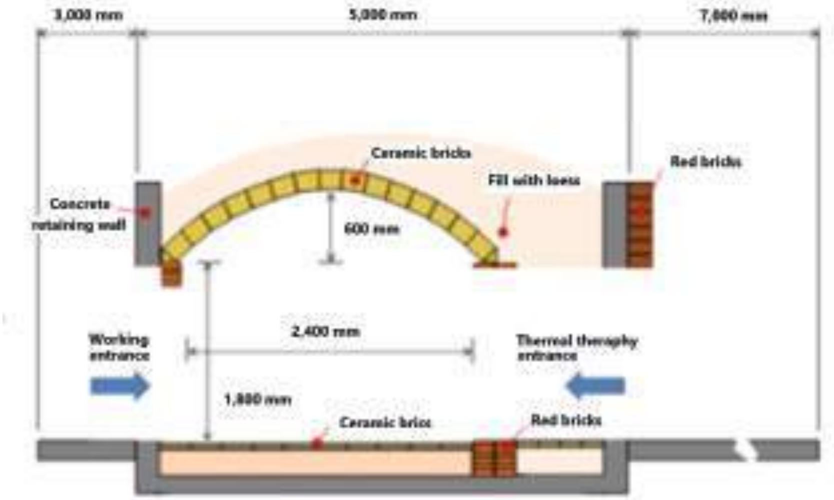

Fig. 1. Overview of a modified charcoal kiln for thermotheraphy.

2.2. Testing materials

In this study, white charcoal produced in the charcoal kiln for both charcoal production and thermotherapy which is installed in Paekgok-myeon, Jincheon-gun, Chungcheongbuk-do as shown in Fig. 1 and white charcoal produced in the charcoal kiln only for charcoal production built by the same company were used as testing materials.

2.3. Experimental method

2.3.1. Technical analysis

With Moisture (KS E ISO 589 anthracite-measurement of total moisture), ash (KS E ISO 1171 solid mineral fuel-measurement of ash content) and volatile matter (KS E ISO 562 anthracite and coke-crystals of volatile matter) and fixed carbons were calculated using the following equation.

$$\text{Fixed Carbon}(\%) = 100 - (\text{Water Content} + \text{Ash} + \text{Volatile Matter})$$

2.3.2. Density

The surface of the charcoal samples was covered with paraffin and then the volume was measured using a measuring cylinder containing water, and the density was calculated as follows.

$$Density(g/cm^3) = \frac{W}{V} \times 100$$

$W = Charcoal\ Weight(g)$, $V = Charcoal\ Volume(cm^3)$

2.3.3. Hygroscopicity

To measure the hygroscopicity of charcoal, charcoal powder pulverized to 60 mesh or less was dried in a dryer (105±2°C) for 24 hours. Then, it was allowed to stand in a desiccator maintained at a relative humidity of 80% at room temperature for 24 hours to calculate the moisture absorption amount. Then, the relative humidity was adjusted using a mixture of distilled water and KCl (distilled water: 993.6 g, KCl: 356.4 g).

$$Hygroscopicity(\%) = \frac{M_1 - M_2}{M_2} \times 100$$

$M_1 = Dried\ Charcoal\ Weight(g)$,
$M_2 = Charcoal\ Weight\ at\ a\ relative\ humidity\ of\ 80\%(g)$

2.3.4. Calorific value

The charcoal sample were pulverized to a size of 80mesh or less, and 0.5 g of the charcoal sample was placed in a calorimeter (Oxygen Bomb Calorimeter 6400, parr, USA), and then, the oxygen gas was charged to 30 kg/cm^2 or less and ignited to calculate the calorific value from the temperature change before and after the combustion.

2.3.5. pH

About 1g of the pulverized charcoal sample having a size of 60mesh or less was put into a flask, mixed with 100 ml of distilled water, heated for 10 minutes to evaporate water, cooled by adding distilled water and measured with a pH meter (Sartorius, model PB-10).

2.3.6. Refinement degree

The degree of refinement was measured using a charcoal refining system (FA 56 type, Samyang Electric Company, Japan) capable of measuring an electric resistance of 10^0 to $10^8 \Omega$/cm.

2.3.7. Hardness

The degree of scratch of the charcoal surface was analyzed by using a charcoal hardness meter (ranging from 1 to 20, Samyang Electric Company, Japan) classified into 20 categories based on the difference in hardness of metals mixed with lead, antimony, copper and zinc in a specific way. The metal piece composed of the softest lead in the hardness meter is No. 1, and the metal piece of the hardest steel is No. 20.

2.3.8. Anatomical characteristics

To observe the anatomical characteristics of charcoal, charcoal samples were observed under an accelerating voltage of 15kV with a scanning electron microscope (JEOL, JSM-5000).

3. RESULTS and DISCUSSION

3.1. Technical analysis

Generally, charcoal consists of water, volatile matter that is volatilized by heat, inorganic matter (ash) that remains after combustion, and fixed carbon that is not reduced by heat itself. Table 1 indicates the results of the technical analysis of the white charcoal produced from a traditional charcoal kiln and the one produced from a charcoal kiln for both charcoal production and thermotherapy. The moisture content of white charcoal produced from the traditional charcoal kiln was 9.60% and that of white charcoal produced from the charcoal kiln for both charcoal production and thermotherapy was 9.15%. Therefore, the difference between the two samples was not significant. However, Lee and Kim (2010a) reported the moisture content of white charcoal produced from the traditional charcoal kiln was 7.9% and Kwon *et al*. (2011) reported the water content of white charcoal produced from the charcoal kiln for both charcoal production and thermotherapy was 6~8%, and therefore charcoal used in this study showed a slightly higher moisture content. The ash was 1.14% of white charcoal produced from the traditional charcoal kiln and 1.50% of white charcoal produced from the charcoal

Table 1. Proximate analyses of the charcoal samples

(unit : %)

	Moisture content	Ash	Volatile matter	Fixed carbon
Charcoal from a modified kiln for thermotheraphy	9.15±0.01	1.50±0.12	9.10±3.75	80.19±3.80
Charcoal from a traditional kiln	9.60±0.04	1.14±0.03	7.06±1.69	82.20±1.68

Table 2. Density, pH, and EMC of the charcoal samples

	Density (g/cm^3)	pH	EMC(%)
Charcoal from a modified kiln for thermotheraphy	0.47±0.04	9.29±0.06	9.88±0.04
Charcoal from a traditional kiln	0.45±0.07	9.59±0.02	10.85±0.04

[1)] EMC : Equilibrium moisture content

kiln for both charcoal production and thermotherapy. Kwon *et al*. (2011) estimated the ash content to be 1.63 to 2.71%, and Lee and Kim (2010a) estimated the ash content to be to 2.5%, and Kwon *et al*. estimated the peripheral charcoal to be 2.67% and the central charcoal to 3.10%. Therefore, white charcoal in this study showed a somewhat low ash content. The volatile matter of white charcoal from the traditional kiln was 7.05%, and that of white charcoal from the charcoal kiln for both charcoal production and thermotherapy was 9.10%, which is a little higher. The content of volatile matter was slightly different so Lee and Kim (2010a) reported 9.9%, while Kwon *et al*. (2011) reported 3.4%. Fixed carbon was 82.20% for the charcoal kiln only for charcoal production and 80.19% for the charcoal kiln for both charcoal production and thermotherapy. Kwon *et al*. (2011) reported that the average fixed carbon of white charcoal was 87%, and Lee and Kim (2010a) reported it was 79.3%. The amount of fixed carbon of white charcoal in this study was not significantly different from that of general charcoal. The charcoal used in this study showed excellent properties that meet the quality certification standards (National Institute of Forest Science, 2017) of wood products (No. 2017-9) notified by the Korea Forest Research Institute.

3.2. Density, pH, hygroscopicity

Table 2 shows the density, pH, and hygroscopicity of the charcoal produced from the charcoal kiln only for charcoal production and the white charcoal produced from the charcoal kiln for both charcoal production and thermotherapy. The density of the white charcoal produced from the traditional charcoal kiln was 0.45 g/cm^3, and that of the white charcoal produced from the charcoal kiln for both charcoal production and thermotherapy was 0.47 g/cm^3, which is slightly higher than that of the white charcoal produced from the traditional charcoal kiln pH was 9.29 for the charcoal kiln only for charcoal production and 9.59% for the charcoal kiln for both charcoal production and thermotherapy. In general, charcoal properties are strongly influenced by carbonization temperature, and pH is inclined to be alkaline with the carbonization temperature increasing (Jo *et al*., 2008). Kwon *et al*.

Table 3. Calorific value, refining degree, and hardness of the charcoal samples

	Calorific value (kcal/kg)	Refining degree	Hardness
Charcoal from a modified kiln for thermotherapy	8,139±41	0～1	12
Charcoal from a traditional kiln	8,095±13	0～1	12

(2012, 2013) reported that using an oriental oak, the pH of charcoal increased with increasing carbonization temperature, showing strong alkalinity. Recently, Hidayat *et al*. (2017) reported an increase in pH with increasing carbonization temperature in the study of carbonization using core wood of tropical wood. Charcoal produced at such a high temperature has a high pH. This is because of the difference in the types and amounts of the acidic or alkaline functional groups generated depending on the carbonization temperature. Another reason is believed to be that the acidic functional groups in the low-temperature carbides and the basic functional groups in the high-temperature carbides become richer (Jo *et al*., 2006). After analyzing the hygroscopicity of charcoal measured at a relative humidity of 80%, it was found that the equilibrium moisture content of the white charcoal from the traditional kiln was 10.85%, and the equilibrium moisture content of the white charcoal from the charcoal kiln for both charcoal production and thermotherapy was 9.88%, so both the figures are similar. Modern houses are likely to become a sealed indoor environment due to heat insulation and sound insulation design. This sealed environment tends to be in a high humidity condition, and as a result, indoor VOCs, harmful bacteria, and fungi are problematic, so that the use of charcoal is highly recommendable because people are greatly interested in humidity control and deodorization using environmentally friendly materials (Lee and Kim, 2010a; Lee and Kim, 2010b).

3.3. Calorific value, hardness, refinement degree

Table 3 indicates the results of calorific value, hardness and refinement degree of the charcoal produced from a traditional charcoal kiln and the one produced from a charcoal kiln for both charcoal production and thermotherapy. The calorific value of white charcoal from the traditional charcoal kiln was 8,139 kcal/kg, while that of white charcoal from the charcoal kiln for both charcoal production and thermotherapy was 8,095 kcal/kg. The calorific values of the charcoal produced in the two charcoal kilns is grade A meaning an excellent product based on the quality certification standards (National Institute of Forest Science, 2017) of wood products notified by the Korea Forest Research Institute (No. 2017-9). Refining is a high-temperature treatment process that is finally performed while burning charcoal, and the quality of charcoal changes during this process. The refinement degree refers to the degree of carbonization of charcoal by measuring the electrical resistance of the surface of charcoal. It is measured in 10 steps from 0 to 9, and the closer to 0, the better the quality of charcoal. Also, the hardness of charcoal indicates that of the charcoal surface, and the higher the number, the harder it is. The refinement degree and hardness showed the same excellent characteristics for both the charcoals from the charcoal kiln only for charcoal production and from the charcoal kiln for both charcoal production and thermotherapy.

3.4. Anatomical characteristics

Fig. 2 shows photographs of three sections of charcoals produced from a traditional charcoal kiln and a charcoal kiln for both charcoal production and thermotherapy, and these photographs were observed by a scanning electron microscope. Generally, the cross-sections of the charcoals are almost the same as those of wood, but the cell walls have a homogeneous structure, and the shape of the duct is tangentially or radially deformed or distorted a little. Spinning and tangential sections are not much different from those of wood, and the wall of each cell is homogeneous and shows an amorphous form. It has been reported that the structure of charcoal varies with the manufacturing temperature (McGinnes *et al*., 1971;

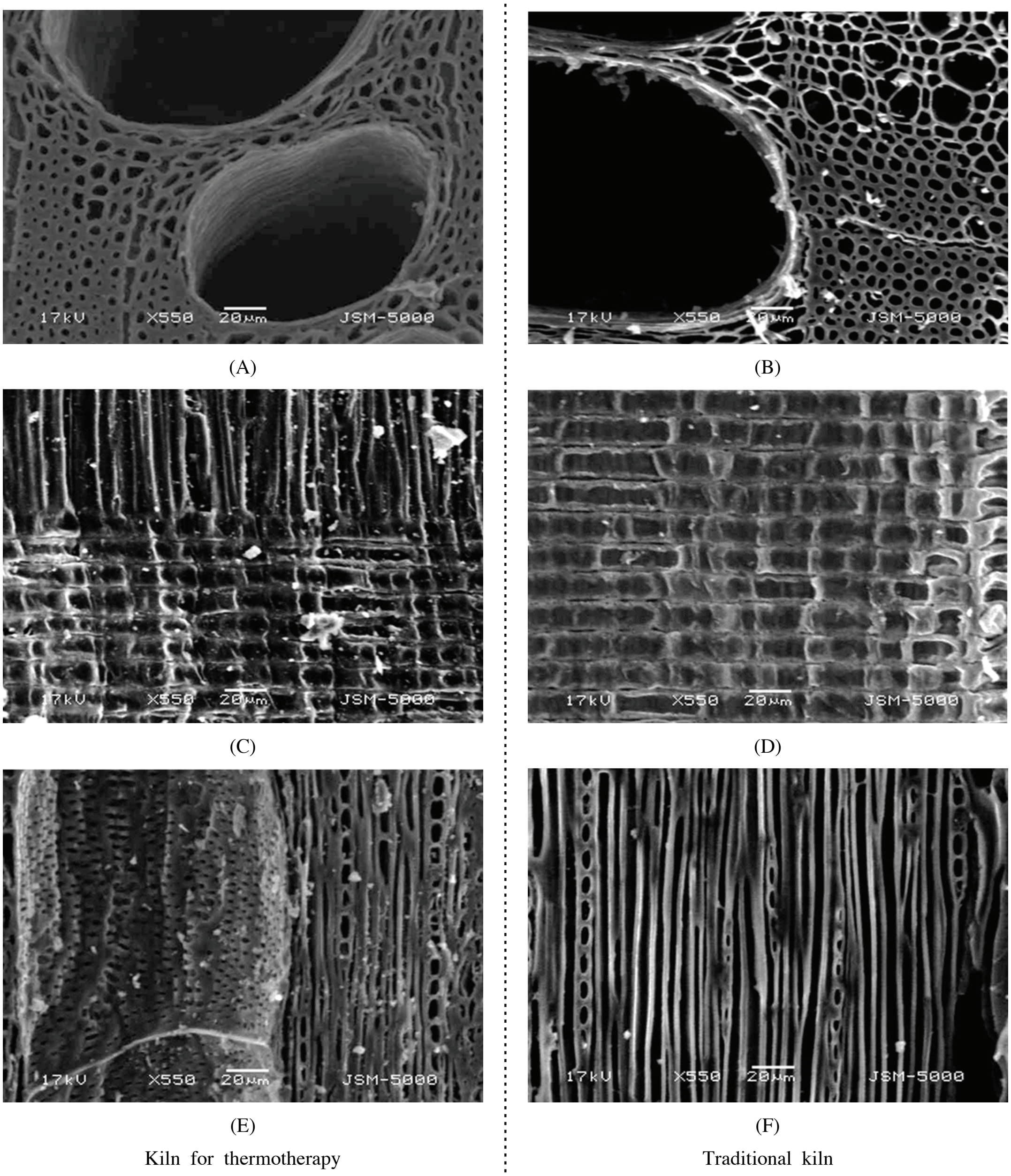

Fig. 2. SEM images on cross sections(A,B), radial sections(C,D), and tangential sections(E,F) of white charcoal from the thermotherapy and traditional kilns.

Elder *et al*., 1979; Cutter *et al*., 1980; Kim and Hanna, 2006; Kwon *et al*., 2009), and archaeological aspects have also been studied in relation to the identification of species (Prior and Alvin, 1983, 1986; Prior and Gasson, 1993; Angeles, 2001; Eom and Xu, 2010). The authors (Kim and Hanna, 2006) studied the difference in the anatomical characteristics based on the manufacturing temperature from the results of the scanning electron microscope analysis of charcoal which was produced at various temperatures. In other words, charcoal produced at 1000°C, which is almost the same temperature used for white charcoal in this study, made ducts and parenchymatous cells greatly destroyed and deformed and cell walls much thinner than charcoal produced at 400-800°C. Besides, the surface of calcium crystals in wood has a smooth appearance on charcoal which is produced at 400-600°C, but, in the case of charcoal produced at 800-1000°C, small voids appear on the surface of calcium crystals.

4. CONCLUSION

The results of the study on the characteristics of the white coal produced from a traditional kiln and the one produced from a charcoal kiln for both charcoal production and thermotherapy are as follows.

1. According to the technical analysis of the white charcoal produced from the traditional charcoal kiln and the one from the charcoal kiln for both charcoal production and thermotherapy, the moisture content was less than 10%, the ash content was less than 3%, the volatile content was less than 10%, and the fixed carbon was more than 80%, which means an excellent quality.
2. The density was 0.45 g/cm^3~0.47 g/cm^3, and the pH was 9.29 to 9.59, and the hygroscopicity was about 10% at a relative humidity of 80% so there was little difference between the white charcoals of the two kilns.
3. The calorific value was more than 8000kcal, the refinement degree was 0, and the hardness was 12 so there was little difference between the white charcoals of the two kilns, which means an excellent quality.
4. There was no difference in the structure of the three sections observed by a scanning electron microscope.

Based on the above results, it can be concluded that white charcoal produced from the charcoal kiln for both charcoal production and thermotherapy has the characteristics similar to those of white charcoal produced from the traditional charcoal kiln.

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