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# Changes in Surface Temperature of Woodceramics Manufactured by Pine Thinning Logs ( I ) – Effects of Resin Impregnation Rate and Burning Temperature –

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**Abstract**

Using woodceramics made from sawdust board of pine thinning logs, changes in surface temperature were investigated, by the impregnation percentage and burning temperature. As the surface temperature of a silicon rubber heater was going up, that of woodceramics also increased rapidly. In this process, the woodceramics, made under the condition of the impregnation of 80% and burning temperature at 1,000℃, were the highest in surface temperature. Also, it was found that woodcermics maintained heat for a long time because the descending velocity of their surface temperature was slower than that of the heater. The woodceramics's characteristics showed that it is suitable as raw material with Ondol-the traditional Korean heating system.

Key words: sawdust board, woodceramics, surface temperature

## 1. INTRODUCTION

It is known that woodceramics, as porous carbon materials made by burning at high temperature after impregnating thermosetting resin into wood or woody materials, are new materials, which are light and hard and have good effects of far-infrared radiation and electromagnetic wave shielding, and whose corrosion resistance and thermal conductivity are very good [11-15]. Since Okabe and Saito [11] developed and named it, various studies of them for industrial uses are now in progress [1-2, 6-9, 11-16]. Systematic studies and developments for many uses may be necessary, because woodceramics have various characteristics attributed to the properties of raw materials and the method of manufacture, such as the density of raw materials, the impregnation percentage and burning temperature. Thus, using small diameter logs of pine thinning occupying much of domestic production, the study is undertaken to examine whether woodceramics can be used, in the future, as materials on the lower part of floor boards with *Ondol* system–the traditional Korean heating system. By investigating the surface temperature of woodceramics made of sawdust according to the impregnation percentage and burning temperature.

## 2. MATERIALS AND METHODS

### 2.1 Materials

This experiment used thinning logs of *Pinus densiflora S. et Z.* for making sawdust board. The adhesive used in this work, while boards were making, was powder phenol-formaldehyde resin (Kolon Chemical Co., Ltd. KNB-100PL), with melting point of 80~95℃, and solid content was 99%.

### 2.2 Making boards

After making sawdust using a circular saw, it was sorted by not more than 1㎜ in grain size, and moisture content was regulated at 6 % or less. Each board sized 26×26×1.4㎝ was made, for which PF resin and sawdust were put into a zinc box and mixed well, and put into a square stainless mold on the hot plate of a thermal compressor, and molded in thermal compression was regulated under a certain condition. The condition of making a board was as follows: resin content: 10%, temperature: 190℃, pressure: 40→20→10 kgf/㎠, press time: 6→5→4 minutes. After thermal compression under these conditions, 10 boards of 0.6g/㎤ in density were made.

### 2.3 Impregnation and forming woodceramics

Sawdust board cut into 12×12×1.4㎝ in size were put into a decompression impregnator, which contained liquid phenol-formaldehyde resin (KPD-L777, Kolon Chemical Co., Ltd.) and impregnated at atmospheric pressure, adjusting the impregnation rate in 40~80%. The properties of resin used in impregnation were as follows: solid 51~53%; specific gravity 1.06; viscosity 45~65cps; gelation time 80~95sec. After impregnating, specimens were put into a dryer for 10 hours at 60℃, for 8 hours at 100℃, 135℃ respectively, for drying and hardening. And then, it was burned at 800℃ according to the impregnation percentage and burned at 600, 800, 1,000, 1,200, 1,500℃ in sample of impregnation 70% by using vacuum sintering furnace (KOVAC KSF-200V, Ko-Ryeo vacuum Corp., Ltd.).

### 2.4 Measuring surface temperature

To measure variations in surface temperature of woodceramics, the surface temperature of rubber heater was fixed, using the temperature sensor whose objective temperature was set up in the state of 20V after connecting a silicon rubber heater to a electric voltage regulator. Woodceramics, different in the impregnation percentage and burning temperature, were put on the silicon rubber heater which was heated in objective temperature, and their changes in surface temperature were measured by the passage of time and variations in floor temperature of the heater through another temperature sensor attached to their surface, using the thermo recorder (T and D Co., Ltd. TR-71S) in the room temperature of 20±2℃. Then, the data were stored and linked in a computer to identify the variations of temperature.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Variations in surface temperature by the passage of time

The surface temperature of the silicon rubber heater, on which woodceramics made by each impregnation percentage and burning temperature of sawdust were put, was set up at 60℃, and then variations in surface temperature of the woodceramics were measured for 30 minutes at 3-minute intervals. As the results shown in Figs. 1~2, the surface temperature was increase with the impregnation percentage as time passed. Moreover, it was found that the heat conductivity was fast in its first stages, showing rapid rise until 15 minutes and afterward slow tendency, while in 30 minutes of the time elapsed the sample of the impregnation rate of 80% indicating 49.2℃ was the highest, followed by 60% at 44.8℃ and 40% at 43.7℃. It seems that these results were attributed to the difference in density by carbonizing resin, after burning each impregnation board which is different in the rate of impregnation [15]. The surface temperature, by the passage of time of woodceramics made by burning impregnation boards with the impregnation of 70%, rose as time elapsed, having a tendency to rise rapidly until 15 minutes like the temperature variations according to the impregnation percentage, while, in 30 minutes, it showed the following: 48.3℃ in the sample of burning temperature at 600℃; 57.9℃ at 1,000℃ ;

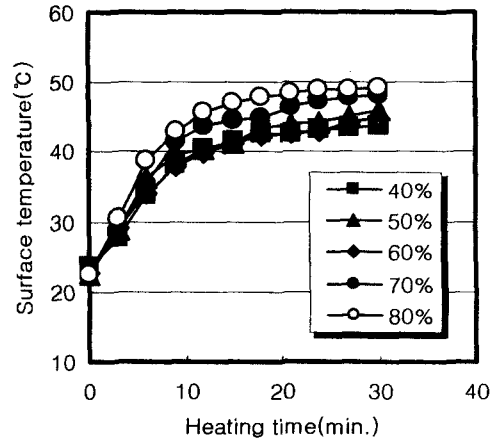


Fig.1. Relationship between heating time and surface temperature of woodceramics.

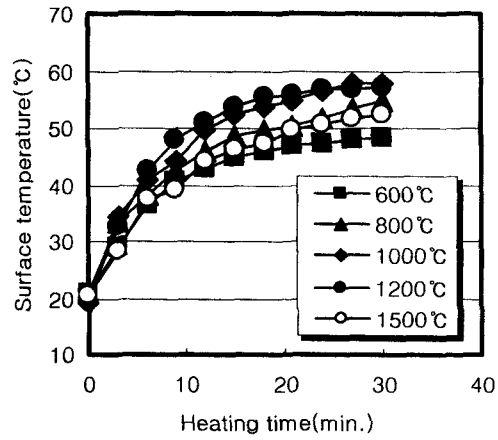


Fig.2. Relationship between heating time and surface temperature of woodceramics.

52.3℃ at 1,500℃. That is, the sample of burning temperature at 1,000℃ was the highest in surface temperature, and the sample at 600℃ was low relatively. Judging from it, it was because density, from 1,200℃ in burning temperature, reduced slightly, having an effect on heat propagation, with which density was connected closely. Okabe [10] found through his experiment, in MDFs with the impregnation rate of 68.9%, that the density was tending upward until 800℃ and then

downward until 1,500℃, followed by increasing again. Also, Oh and Byeon [7] reported that the surface temperature of woodceramics, which were made from MDFs, was the highest in burning temperature at 1,200℃.

### 3.2 Variations in surface temperature of woodceramics by the changes of the surface temperature of heater

On woodceramics, manufactured by each impregnation percentage and burning temperature and put on the silicon rubber heater, changes in surface temperature were measured, as the surface temperature of the heater rose from 25℃ to 70℃. The results are shown in Figs 3~4. In the surface temperature of woodceramics by the impregnation percentage, the heat conductibility of woodceramics became fast as the surface temperature of the silicon rubber heater grew higher: in case of the sample of the impregnation of 40%, the surface temperature of woodceramics was from 21℃ to 47.2℃ when the heater's surface temperature was at 25℃, 70℃ respectively; in the sample of 60%, from 20.5℃ in 25℃ to53.5℃ in 70℃; in the sample of 80%, from 20.1℃ in 25℃ to 53.9℃ in 70℃. Thus, it was the highest in the impregnation of 80%, while the lowest in 40%. It may mean that the impregnation percentage had an effect on the density of woodceramics after burning, and there was in close connection between heat conductivity and the density of woodceramics. As the result from investigating the surface temperature of impregnation boards with the same rate of impregnation (70%), burned by temperature, the more the surface temperature of the silicon rubber heater increased, the more that of woodceramics increased: in case of the sample of burning temperature at 600℃, it was from 20.2℃ to 52.6℃ in 25℃, 70℃ respectively in surface temperature; in the sample at 1,000℃, from 20.8℃ in 25℃ to 54.2℃ in 70℃; in the sample at 1,500℃, from 20.8℃ in 25℃ to 50.3℃ in 70℃. Also, the sample burned at 1,000℃ was the highest in surface temperature of woodceramics by burning temperature, and it appeared that what the density reduced slightly in burning temperature after 1,200℃ had an effect on variations in surface temperature. Nonaka *et al.* [5] reported on the relation between the heat conductivity of woodceramics and density that the heat conduction rose in a straight line as the temperature grew higher and a sample was burned in high temperature.

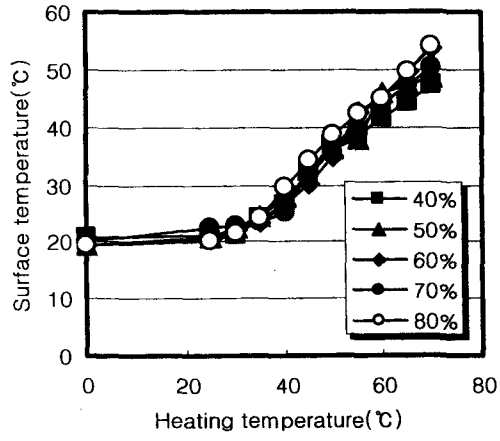


Fig.3. Relationship between heating temperature and surface temperature of woodceramics.

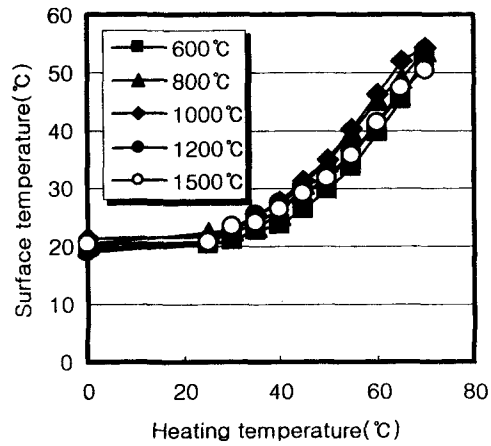


Fig.4. Relationship between heating temperature and surface temperature of woodceramics.

### 3.3 The descent of the surface temperature of woodceramics with time

To investigate the falling variations in surface temperature of woodceramics manufactured by each impregnation percentage and burning temperature, the temperature of woodceramics, which were put on the silicon rubber heater adjusted at 60℃ in surface temperature was measured during 30 minutes. Then, the surface temperature of woodceramics and heater was measured for 30 minutes at 3-minute intervals to look into the descending variations of temperature, as making the surface temperature of the heater fall down gradually by switching if off. In the fall of the surface temperature according to the impregnation percentage, as shown in Fig. 5, as the heater surface temperature was going down from 60℃ to 28.8℃ for 30 minutes, the surface temperature of woodceramics reduced slowly by the passage of time: from 45.4℃ to 31.2℃ in the impregnation percentage of the sample of 40%; from 45.5℃ to 33.4℃ in 60%; from 49.2℃ to 33.8℃ in 80%. Meanwhile, there was a big difference in temperature changes, indicating 15.4℃, between the early and after 30-minute temperature in the sample of 80% in the impregnation percentage, while the sample

with the rate of 60% was small relatively as 12.1℃. Also, the descending speed of the surface temperature of woodceramics was slower than that of the heater as a whole, which meant that woodceramics could maintain heat for a long time.

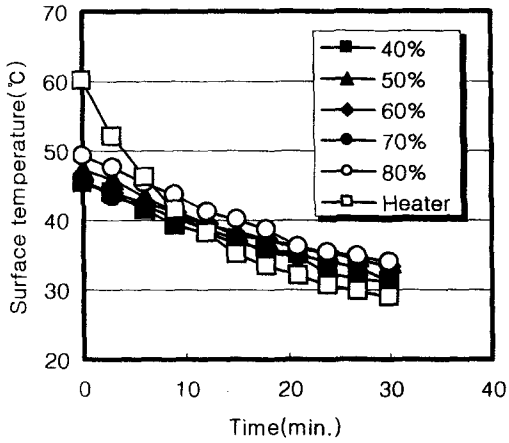


Fig.5. Relationship between time and descent of surface temperature of woodceramics.

The results from measuring the descent of the surface temperature of woodceramics burned by each temperature, as shown in Fig. 6, showed that woodceramics's surface temperature was slowly fell down as time passed: as the surface temperature of the heater was getting to lower from 60℃ to 28℃ for 30minutes, the sample at 600℃ was from 48.2 to 29.5℃; the sample at 1,000℃ was from 58.9℃ to 32.8℃; the sample at 1,500℃ was from 52.3℃ to 29.4℃. On the other hand, the sample in burning temperature at 1,000℃ was the fastest in temperature variations, showing the difference of temperatures between in the beginning and in 30 minutes was 26.1℃, while it was small relatively at 600℃, indicating 18.7℃. These results can be judged that the descent of temperature was likely to be affected by density because the density of 1,000℃ sample was the biggest as 0.83g/cm$^3$, under the same condition of the rate of impregnation. As the results, to use woodceramics for the materials of the lower part of floor boards with *Ondol* system, woodceramics manufactured under the condition of the impregnation of 80% and burning temperature at about 1,000℃ may be suitable in the aspect of variations in surface temperature and the propagation velocity of heat. Yet, it seems that changes in surface temperature were closely related to density, so further studies on manufacture methods, such as the increase of the rate of resin impregnation and burning temperature changes, and a variety of characteristics, such as thermal conductivity and strength, may be needed.

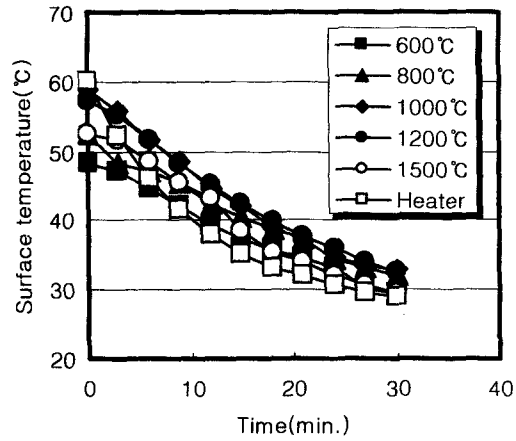


Fig.6. Relationship between time and descent of surface temperature of woodceramics.

## 4. CONCLUSIONS

Measurement on the variations in surface temperature of woodceramics, which were made from pine thinning logs, according to the impregnation percentage and burning temperature are as the following:

As the result of measuring the surface temperature of woodceramics, which were put on the silicon rubber heater adjusted at 60℃ in surface temperature, by the passage of time, it increased as time elapsed, and the sample with the impregnation of 80% and burning temperature at 1,000℃ was the highest. On the woodceramics measured as making the surface temperature of the heater rise from 25℃ to 70℃, the higher the heater's surface temperature, the higher the woodceramics's: in case of the heater's surface temperature at 70℃, the surface temperature of woodceramics was at 53.9℃ when a sample was at the impregnation of 80%, while it was at 54.2℃ when a sample was at 1,000℃ in burning temperature, showing the highest. Also, as the result of the descent of surface temperature by the passage of time, the samples with the impregnation of 80% and burning temperature at 1,000℃ showed the difference in temperature between in the beginning and in 30minutes, indicating 15.4℃ and 26.1℃ respectively, which was the fastest in the descending speed of temperature.

Moreover, it was found from the result that woodceramics could maintain heat for a long time, for the descending speed of woodceramics's surface temperature was slower than that of rubber heater.

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