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Mechanical Properties of Woodceramics According to Carbonizing Temperature*1

- Bending, Compression and Hardness -

Hee-Seop Byeon*2, Sang-Yeol Ahn*2, Seung-Won Oh*3†, and Jin-Ji Piao*3

ABSTRACT

This paper reports the mechanical properties of bending, compression and hardness of woodceramics manufactured at different carbonizing temperatures (600℃, 800℃, 1000°C, 1200℃ and 1500℃) in a vacuum sintering furnace using sawdust boards of *Pinus densiflora, Pinus koraiensis* and *Larix kaemferi.*

The highest values of bending MOR (MOR_b) were 104 kgf/cm^2 (1200℃), 91 kgf/cm^2 (1500℃) and 86 kgf/cm^2 (1500℃), the highest values of compression strength were 152 kgf/cm^2 (1200℃), 160 kgf/cm^2 (1000℃) and 189 kgf/cm^2 (1000℃), the highest values of hardness were 2.00 kgf/mm^2 (800℃), 2.01 kgf/mm^2 (1200℃) and 2.28 kgf/mm^2 (1000℃) in *P. densifora, L. kaemferi* and *P. koraiensis*, respectively. The carbonizing temperature of 600℃ was not proper to the mechanical properties for three kinds of sawdust boards and the highest values of mechanical properties were different from the kinds of mechanical properties and species of sawdust boards.

Therefore, it is necessary to manufacture woodceramics at a proper temperature for particular species of sawdust boards to obtain good mechanical properties.

Keywords : mechanical property, carbonizing temperature, woodceramics, sawdust board

1. INTRODUCTION

Woodceramics is a new porous carbon material which is obtained by thermoforming wood and/or woody materials impregnated with phenolic resin at high temperature in a vacuum furnace. As they have the characteristics of electromagnetic shielding effect and far-infrared irradiation, they are expected to be used as industrial materials widely (Okabe *et al.*, 1996a, 1996b). Since Okabe & Saito (1995a) had developed woodceramics, the researches of basic properties in manufacturing method, the analysis of structural change and electrical characteristics in carbonized products etc. have been accomplished (Hokkirigawa *et al.*, 1995, 1996a, 1996b;

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*2 Faculty of Forest Science, Institute of Agriculture & Life Science, Gyeongsang Nat'l Univ., Jinju, Korea.
*3 Division of Forest Science, College of Agriculture and Life Science, Research Institute of Bioindustry, Chonbuk Nat'l Univ., Chonju, Korea.
† Corresponding author : Seung-Won Oh (ohsw@chonbuk.ac.kr)

Kano *et al.*, 1996; Kasai *et al.*, 1996; Okabe & Saito, 1995b; Okabe *et al.*, 1995a, 1995b, 1996; Shibata *et al.*, 1997). It is necessary to investigate the manufacturing method of woodceramics using waste wood-based materials, thinned small log and wastepaper.

Woodceramics could be also used for *ondol* : Korean traditional heating system for the basement in a room and/or floor. It is important to investigate the mechanical properties of woodceramics for the utilization of *ondol*. This paper reports the mechanical properties of woodceramics manufactured at different carbonizing temperatures using a sawdust board.

2. MATERIALS & METHODS

2.1. Woodceramics specimen preparation

Woodceramics manufactured at different carbonizing temperatures using a sawdust board (sawdust's moisture content: 6%, resin: 10%, temperature: 190℃, pressure: 40→20→10 kgf/cm^2, press time: 6→5→4 min, density: 0.6 g/cm^3, moisture content: 8.5%) were used in order to evaluate the mechanical properties of bending, compression and hardness. The carbonizing temperatures were set at 600°C, 800°C, 1000°C, 1200°C and 1500℃ with the phenolic resin impregnation rate of 70% by a vacuum sintering furnace KOVAC KSF-200V(Korea vacuum(Ltd.)), for three kinds of species, *Pinus densiflora* S. et Z., *Pinus koraiensis* S. et Z, and *Larix kaemferi* C., respectively. The rising rate of temperature of 5℃/min was used for two hours at each carbonizing temperature. The cooling rate of temperature was also set at 5℃/min. The sizes of specimen were 10×10×90 mm, 10×10×10 mm and 10×10×30 mm for the bending, compression and hardness tests, respectively. The hardness of woodceramics was measured at three positions for one specimen.

2.2. Mechanical property measurement

The bending test for the woodceramics was first performed by three point loading method (concentrated load at midspan and supported at its ends) in a universal testing machine (UTM, Taeshin accuracy machine, TSU-2). The span was 70 mm, and the cross-head speed was set at 0.6 mm/min. The static bending modulus of elasticity (MOE_b) and modulus of rupture (MOR_b) were calculated from the following equations:

$$MOE_b = \frac{\Delta p l^3}{4bh^3 \Delta y} \quad (1)$$

where, Δp: the different load below the proportional limit, l: the span, b: width of the specimen, h: height of the specimen, Δy: deflection resulting from Δp.

$$MOR_b = \frac{1.5pl}{bh^2} \quad (2)$$

where, p: maximum load, l: the span, b: width of the specimen, h: height of the specimen.

After the bending test, the compression and hardness tests were performed with the rest parts of the same specimens. The loading rate was 0.5mm/min for compression and hardness tests. The hardness value was the load when 10mm diameter ball was embedded at 0.32mm. The compression modulus of elasticity(MOE_c) and maximum crushing strength(CS) were calculated from the following equations:

$$MOE_c = \frac{\Delta p \cdot l}{\Delta l \cdot A} \quad (3)$$

where, MOE_c: compression modulus of elasticity, Δp: the different load below the pro-

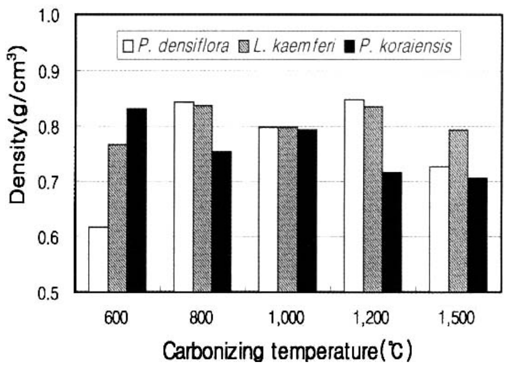

Fig. 1. The averaged values of density according to carbonizing temperature and species of woodceramics material.

portional limit, l: measuring distance, Δl: deflection resulting from Δp, A: area of cross section.

$$CS = \frac{P}{A} \qquad (4)$$

where, CS: compression strength, P: maximum load, A: area of cross section.

3. RESULTS & DISCUSSION

3.1. Bending strength properties

Table 1 shows the physical and mechanical properties of woodceramics manufactured at different carbonizing temperatures.

Fig. 1 shows the average values of density according to carbonizing temperature and the species of woodceramics material. The mean values for 5 replications of density were ranged

Table 1. The physical and mechanical properties of woodceramics manufactured at different carbonizing temperatures

Species	CT[a]	Density[b] (g/cm^3)	Deflection[c] (mm)	MOE$_b$[d] (kgf/cm^2)	MOR$_b$[e] (kgf/cm^2)	Hardness (kgf/mm^2)	MOE$_c$[f] (kgf/cm^2)	CS[g] (kgf/cm^2)
P. densiflora	600℃	0.62[h](0.03)[j]	0.29[h](0.05)	15,420[h](4,823)	53[h] (7)	1.59[i](0.57)	990[h] (72)	33[h] (6)
	800℃	0.84 (0.04)	0.25 (0.04)	23,180 (7,255)	74 (18)	2.00 (0.52)	1,570 (298)	115 (27)
	1000℃	0.80 (0.01)	0.33 (0.08)	14,150 (5,094)	79 (12)	1.69 (0.18)	1,800 (117)	137 (16)
	1200℃	0.85 (0.01)	0.37 (0.06)	19,020 (2,182)	104 (15)	1.54 (0.31)	2,000 (274)	152 (33)
	1500℃	0.73 (0.03)	0.37 (0.04)	20,620 (3,278)	91 (16)	1.90 (0.48)	1,720 (262)	91 (41)
L. kaemferi	600℃	0.77 (0.00)	0.35 (0.07)	13,320 (2,185)	64 (10)	1.21 (0.16)	820 (217)	42 (7)
	800℃	0.84 (0.01)	0.38 (0.10)	16,740 (2,031)	72 (10)	1.97 (0.18)	1,520 (241)	99 (17)
	1000℃	0.80 (0.02)	0.29 (0.02)	17,220 (3,702)	83 (13)	1.51 (0.33)	2,070 (64)	160 (14)
	1200℃	0.84 (0.00)	0.37 (0.05)	17,420 (4,317)	82 (14)	2.01 (0.32)	2,030 (234)	102 (20)
	1500℃	0.79 (0.00)	0.42 (0.08)	16,930 (2,459)	91 (5)	1.91 (0.24)	1,410 (137)	93 (25)
P. koraiensis	600℃	0.83 (0.03)	0.36 (0.06)	15,070 (1,414)	57 (18)	1.71 (0.21)	1,420 (168)	73 (17)
	800℃	0.75 (0.01)	0.40 (0.28)	18,800 (5,573)	72 (26)	2.02 (0.35)	2,300 (145)	124 (11)
	1000℃	0.79 (0.02)	0.49 (0.14)	12,390 (5,558)	66 (42)	2.28 (0.62)	2,520 (603)	189 (26)
	1200℃	0.72 (0.03)	0.55 (0.10)	12,430 (3,437)	75 (4)	1.85 (0.20)	1,490 (397)	89 (17)
	1500℃	0.71 (0.02)	0.37 (0.06)	20,370 (2,763)	86 (6)	1.42 (0.11)	1,810 (297)	101 (11)

[a] Carbonizing temperature, [b] Based on air-dry (20±1℃, 65±2%) weight and volume, [c] Deflection at maximum load, [d] Modulus of elasticity as determined from a bending test, [e] Modulus of rupture as determined from a bending test, [f] Modulus of elasticity as determined from a compressive test, [g] Compressive maximum crushing strength, [h] Each mean value from 15 replications, [i] Each mean value from 5 replications, [j] Parenthesis is standard deviation value from 5 replications.

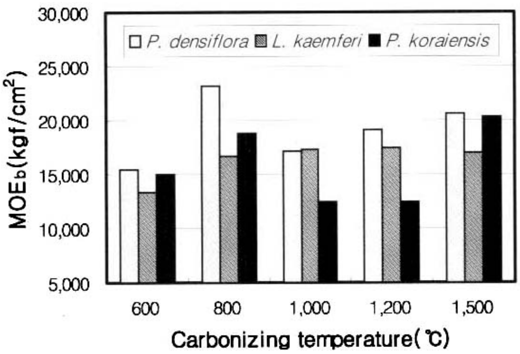

Fig. 2. The averaged values of static MOE_b according to carbonizing temperature and species of woodceramics material.

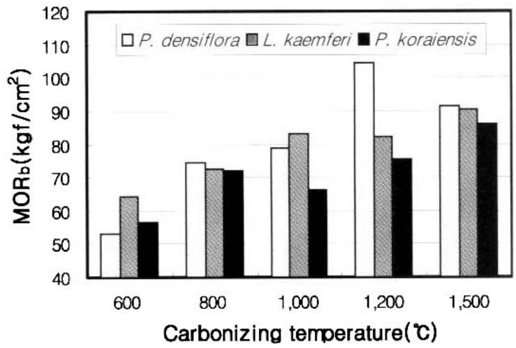

Fig. 3. The averaged values of MOR_b(modulus of rupture) according to carbonizing temperature and species of woodceramics material.

from 0.62 to 0.85 g/cm^3 and no relationships were found between density and the increase of carbonizing temperature and the species of woodceramics material. Oh & Byeon (2002) reported that the density of woodceramics carbonized with MDF at different temperatures increased with increasing carbonizing temperature below the temperature of 800℃, but the density was slightly decreased beyond 1000℃. Okabe (1996) also reported the density of woodceramics carbonized with MDF (impregnating rate of 68.9%) increased with increasing carbonizing temperature below 1000℃, but it decreased beyond 1000℃ and then it increased again.

Fig. 2 shows the averaged values of static bending MOE_b according to carbonizing temperature and the species of woodceramics material. The mean values from 5 groups of MOE_b were distributed in a narrow range of 13,320-17,420 kgf/cm^2 in *L. kaemferi.* However, they were distributed in a wide range of 15,420-23,180 kgf/cm^2 and 12,390-20,370 kgf/cm^2 in *P. densiflora* and *P. koraiensis*, respectively. No relationships were found either between MOE_b and carbonizing temperature, and species of woodceramics as in the case of density. This result was different from previous report (Okabe, 1996) that the MOE_b of woodceramics increased with increasing carbonizing temperature below 2000℃.

Fig. 3 shows the averaged values of MOR_b according to carbonizing temperature and the species of woodceramics material. The values of MOR_b increased with increasing carbonizing temperature in the woodceramics of all species. The highest MOR_b occurred at the carbonizing temperature of 1500℃ except *P. densiflora*, which had the highest MOR_b at 1200℃ of carbonizing temperature. This is the similar trend to a previous report (Oh & Byeon, 2002). Even though the difference among the species of woodceramics material was small, the MOR_b of *P. koraiensis* was the lowest and the value of MOR_b in *P. densilflora* was very similar to that in *L. kaemferi.* The highest values of MOR_b for carbonizing temperature from 600℃ to 1500℃ were 104 kgf/cm^2, 91 kgf/cm^2 and 86 kgf/cm^2 for *P. densifora*, *L. kaemferi* and *P. koraiensis*, respectively. The highest values of MOR_b were at the temperature of 1200℃, 1500℃ and 1500℃ for *P. densiflora*, *L. kaemferi* and *P. koraiensis*, respectively. These values of MOR_b are almost the half values of the previous report (Oh & Byeon, 2002). More research would be needed to discover the cause of lower bending MOR_b.

The correlation of bending MOE_b and MOR_b was shown in Fig. 4. Generally, there was a close correlation between MOE and MOR for static bending test of solid wood. However, poor

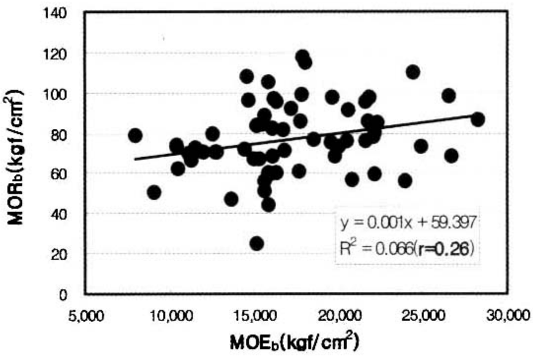

Fig. 4. The relationship between MOE_b and MOR_b for woodceramics according to carbonizing temperature and species of woodceramics material.

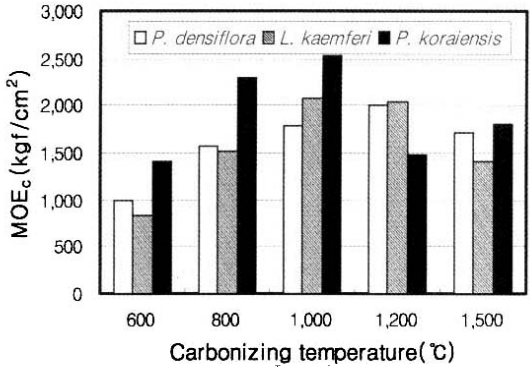

Fig. 6. The averaged values of compression MOE_c according to carbonizing temperature and species of woodceramics material.

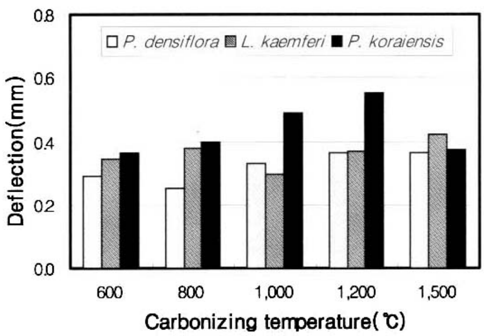

Fig. 5. The averaged values of deflection according to carbonizing temperature and species of woodceramics material.

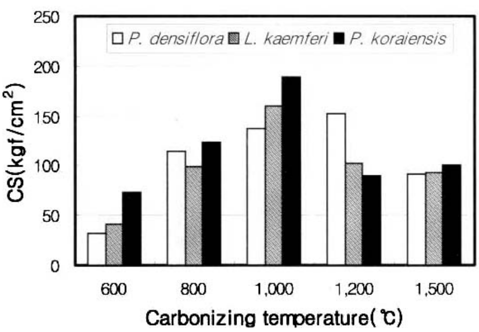

Fig. 7. The averaged values of maximum crushing strength according to carbonizing temperature and species of woodceramics material. Note; CS - Compressive strength.

correlation (regression coefficient of 0.257) was found in MOE and MOR for woodceramics produced at different carbonizing temperatures.

Fig. 5 shows the averaged values of deflection to maximum load according to carbonizing temperatures and the species of woodceramics material. The values of deflection in *P. koraiensis* were the highest among three species in contrast to the lowest in MOR_b. The value of deflection to maximum load in *P. densiflora* was also very similar to that of *L. kaemferi* as in the case of MOR_b.

3.2. Compressive strength properties

Fig. 6 shows the averaged values of MOE_c according to carbonizing temperature and the species of woodceramics material. The values of MOE_c increased below the carbonizing temperature of 1000℃ or 1200℃ and then decreased. The highest values of MOE_c of *L. kaemferi* and *P. koraiensis* were 2,070 kgf/cm^2, 2,520 kgf/cm^2 at temperature of 1000℃, respectively. The highest value of MOE_c in *P. densiflora* was 2,000 kgf/cm^2 at 1200℃.

Fig. 7 shows the averaged values of compressive strength according to carbonizing temperature and the species of woodceramics material. The values of compressive strength were almost the same trend to MOE_c. The highest values of com-

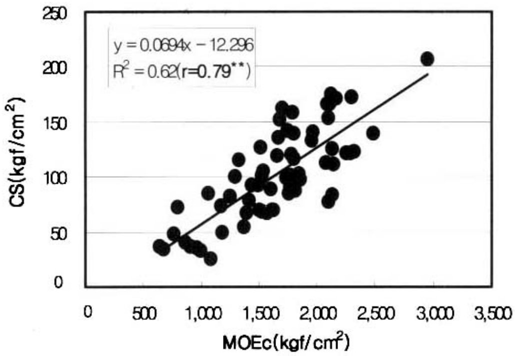

Fig. 8. The relationship between MOEc and CS for woodceramics according to carbonizing temperature and species of woodceramics material. Notes; CS: Compressive strength, MOE_c: Modulus of elasticity as determined from a compression test.

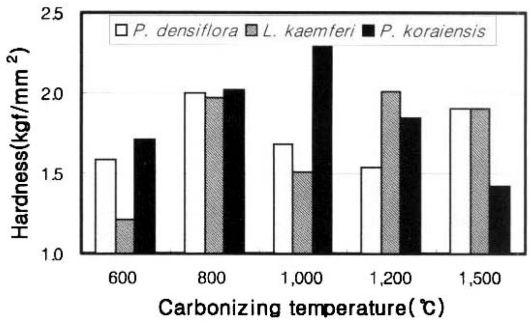

Fig. 9. The averaged values of hardness according to carbonizing temperature and species of woodceramics material.

pression strength were 152 kgf/cm^2, 160 kgf/cm^2, 189 kgf/cm^2 for *P. densiflora*, *L. kaemferi* and *P. koraiensis*, respectively.

Fig. 8 shows the correlation between compressive MOE_c and maximum crushing strength. The correlation coefficient of 0.79 between compression MOE_c and compressive strength was much higher than that between bending MOE_b and MOR_b and it was significant at 1% level.

3.3. Hardness property

Fig. 9 shows the averaged values of hardness according to carbonizing temperature and the species of woodceramics material. The values of hardness increased below carbonizing temperature of 1000℃ for *P. koraiensis* and then decreased. There were no correlations between the other species. The values of hardness ranged in 0.89-2.69 kgf/mm^2, 1.04-2.47 kgf/mm^2 and 1.29-2.35 kgf/mm^2 for *P. densiflora*, *L. kaemferi* and *P. koraiensis*, respectively.

4. CONCLUSIONS

The study was accomplished in order to evaluate several mechanical properties of woodceramics manufactured at different carbonizing temperatures (600℃, 800℃, 1000℃, 1200℃ and 1500℃) using a sawdust board of *P. densiflora, L. kaemferi* and *P. koraiensis.* The following results were obtained:

1) No relationships were found between MOE_b and the increasing of carbonizing temperature and the species of woodceramics material. However, the specimens manufactured at higher carbonizing temperature had the higher compression MOE_c below 1000℃.

2) It was found that the higher carbonizing temperature, the higher value of MOR_b except for that *P. densiflora* which had the highest value at the temperature of 1200℃. The compressive maximum crushing strength showed the highest value at 1000℃ except for that *P. densiflora* had the highest value at 1200℃.

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