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Manufacture of Wood Veneer-Bamboo Zephyr Composite Board*1
- I. Properties of Bamboo Zephyr and Composite Board Made from Moso, Giant Timber and Hachiku Bamboo -

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ABSTRACT

Wood veneer-bamboo zephyr composite board (WBCB) was manufactured to evaluate the properties of bamboo as alternative raw materials for the manufacture of composite panels. Bamboo zephyr was prepared using Moso bamboo (*Phyllostachys pubesens* Mazel. et Z), Giant timber bamboo (*Phyllostachys bambusoides* Sieb. et Zucc), and Hachiku bamboo (*Phyllostachys nigra* var. *henosos* Stapf). The effect of age and species of bamboo on zephyr production was investigated in terms of the pass number of bamboo split through the rollers, and the width increasing rate of bamboo split. Five-ply WBCBs were produced with Keruing veneers as face and back layers, leading to three layers of bamboo zephyr sheets as core layer. Each layer was placed so that its grain direction was at right angles to that of the adjacent layer and the layers were bonded together with phenol-formaldehyde (PF) resin.

The pass number of bamboo split was increased with an increase of the thickness of culm wall. At the same thickness, Moso bamboo showed no effect of the age of bamboo on the pass number. The pass number of split of Giant timber bamboo was lower than that of Moso bamboo. No significant effect of bamboo species and age on the width of zephyr produced was observed. The width of zephyr obtained could be expressed as a function of diameter multiplied by thickness of culm wall. The physical and mechanical properties of WBCB manufactured in all given conditions did not show any significant differences, and they were above the requirement of Korean Standard (KS).

Keywords : wood veneer-bamboo zephyr composite board, bamboo zephyr, Giant timber bamboo, Hachiku bamboo, Moso bamboo, age of bamboo, strength properties

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1. INTRODUCTION

Currently, decreasing supply and quality of wood resources have prompted the search for nontraditional materials as alternative raw materials for the manufacture of composite panels. One of the most promising alternative raw materials is bamboo because it is a fast-growing, economical, and renewable material with good physical and mechanical properties compared to some wood species. Several studies have been tried to manufacture structural composite board such as plywood (Zhang, 1992) and strandboard (Lee *et al.*, 1996 : Lee *et al.*, 2000) using bamboo, showing the potential for the practical use of bamboo as alternative materials for composite panel. However, considering its favorable stiffness and strength properties of bamboo as well as productivity, one of the most promising way to use bamboo is to manufacture the composite panel using bamboo zephyr, which is a sheet material of fibrous net-like structure obtained by crushing bamboo or low quality lumber using several sets of twin rollers which have series of "V" shape grooves on the surface (Kim *et al.*, 1994).

According to Nugroho's reports (2000, 2001), bamboo zephyr boards exhibited superior strength properties compared to those of commercial products. But composite products composed of these zephyr-type elements only and processed by hot pressing have a large amount of thickness swelling caused by water absorbtion. And there is a large degree of unevenness of the surface of the board, and many voids among the elements causes a weakening of the bonding strength between them as well as a poor appearance of the products. Although they examined the pre-hot-pressed treatment method to solve these problems, no satisfactory solution have not been found yet.

In this research, wood veneer-bamboo zephyr composite board (WBCB) were manufactured with Keruing veneers as face and back layers and with three layers of bamboo zephyr sheet as core layer to solve the problems caused by large degree of unevenness of the surface of bamboo zephyr. The characteristics of bamboo zephyr production and the physical and mechanical properties of the manufactured WBCB were investigated in terms of the ages and species of bamboo.

2. MATERIALS and METHODS

2.1. Materials

Moso bamboo (*Phyllostachys pubesens* Mazel. et Z), Giant timber bamboo (*Phyllostachys bambusoides* Sieb. et Zucc), and Hachiku bamboo (*Phyllostachys nigra* var. *henosos* Stapf) were obtained from Jinju, Hadong, and Chilgok, in Korea, respectively. The diameters of the obtained bamboo poles were in the range between 6 cm and 10 cm. Moso and Giant timber bamboo from one to four years old and Hachiku bamboo from one to two years old were used for this research. Keruing (*Dipterocarpus spp.*) veneers with 1.6 mm thickness and 5.7% moisture content (MC) were used as face and back layers to manufacture WBCB.

2.2. Preparation of Bamboo Zephyr

Bamboo poles were cross-cut to 1 m long and placed in plastic bags to make bamboo zephyr without any loss of moisture. The ranges of MC of bamboo zephyr were between 80 and 100%. The bamboo culms were split parallel to the grain into six equal parts, and each part was passed through a roller until final roller space was 1.5 mm (Fig. 1). The properties of the produced bamboo zephyr according to bamboo age and species were compared in terms of weight,

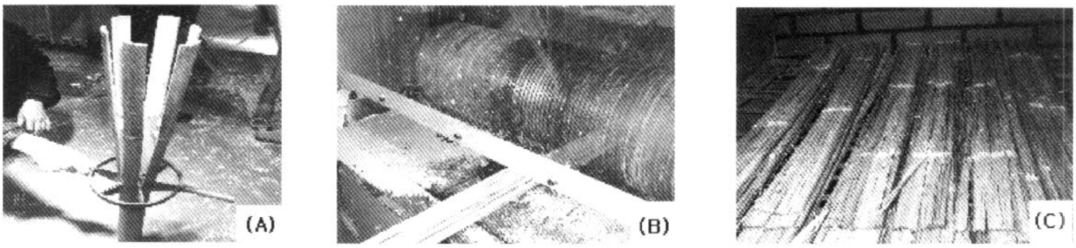


Fig. 1. Production process of bamboo zephyr. (A): Bamboo splits, (B): Cutting method of bamboo split into bamboo zephyr, (C): Dried bamboo zephyr

diameter, thickness of culm wall, and number of bamboo passes through the roller. The produced zephyr was dried to 7.8% MC and then stored until it was used to manufacture WBCB.

2.3. Production of WBCB

According to the previous report (Roh *et al.*, 2001), five-ply WBCB were manufactured with 1.6 mm-thickness Keruing veneers as face and back layers and with three layers of bamboo zephyr as core layer. Each layer was placed so that its grain direction is at right angles to that of the adjacent layer and the layers were bonded together by phenol-formaldehyde (PF) resin (Fig. 2). Each layer had 1,520 g (oven dry basis) of bamboo zephyr. The properties of PF resin and the manufacturing conditions of WBCB were shown in Table 1.

2.4. Measurement of WBCB Properties

The composite panels were tested for bending properties (MOR and MOE), internal bond (IB) strength and thickness swelling (TS) according to the Korean Standards for particleboard (KS F 3104, 1997) and structural plywood (KS F 3113, 1999). The static bending tests were conducted at 0 and 90 degrees which against to direction angle of the span to the main grain direction of face veneer of the board. The tests for measuring IB strength were conducted to measure the adhesion strength of veneer layer, bamboo zephyr layer, and interface layer between outer and inner part of bamboo zephyr layers, outer part of bamboo zephyr and veneer layer, and inner part of bamboo zephyr and veneer layer.

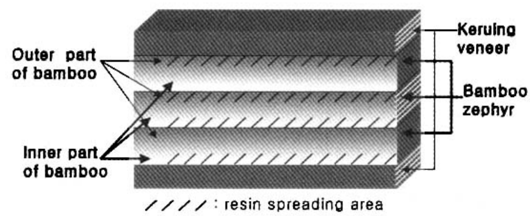


Table 1. Adhesive properties and manufacturing conditions of WBCB

Adhesive properties		Manufacture conditions of panel	
Resin	Phenol-formaldhyde	Amount of resin spread	320 g/m^2
pH	12.4	Cold press	12 kgf/cm^2, 12 min.
Solid content (%)	45.7	Hot press	140°C, 12 kgf/cm^2, 60 sec/mm
Viscosity(cP)	80.4		

3. RESULTS and DISCUSSION

3.1. Characteristics of Bamboo Zephyr Production

3.1.1. Number of bamboo passes through the rollers

The average thickness of bamboo zephyr passed through the roller (1.5 mm of final roller space) was 2.77±0.4 mm. Regardless of bamboo's age and species, the most important factor on zephyr production was thickness of culm wall. The pass number of bamboo split through the roller increased with an increase in thickness. Fig. 3. showed the relationships between the thickness of culm wall and the pass number of bamboo split according to bamboo's age. The pass number of the culm wall with 6, 8, and 10 mm thickness were 10, 22, and 32, respectively. However, Moso bamboo did not show any relationships between its age and the pass number at the same thickness. Therefore, it was possible to predict the pass number by the thickness of culm wall (y=5.23x-20.23 (R^2=0.86)). Similar trends were observed in Giant timber bamboo and Hachiku bamboo. Fig. 4. showed the relationship between the thickness of culm wall and the pass number of bamboo split of three different bamboo species in all their ages. Above 7 mm of thickness, the highest pass number was observed in Moso bamboo, followed by Hachiku and Giant timber bamboo. Considering the pass number, it could be concluded that Giant timber bamboo and Hachiku bamboo was more efficient to produce bamboo zephyr than Moso bamboo.

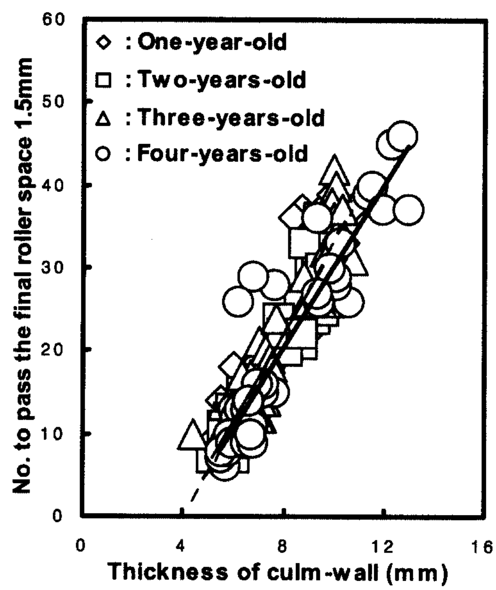


Fig. 3. Relationships between the thickness of culm wall and the pass number of bamboo split through the rollers according to Moso bamboo age.
One-year-old: Y = 5.67X-22.69 (R^2 = 0.83)
Two-years-old: Y = 5.22X-19.94 (R^2 = 0.90)
Three-years-old: Y = 5.53X-22.46 (R^2 = 0.87)
Four-years-old: Y = 4.87X-18.65 (R^2 = 0.87)

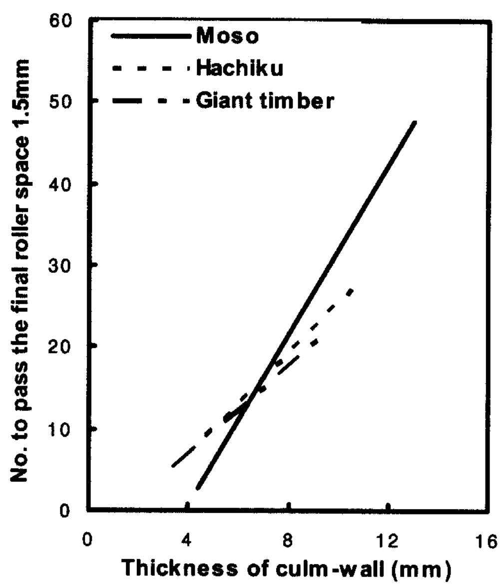


Fig. 4. Pass number of three different bamboo split at various thickness of culm wall until the final rollers space is 1.5 mm.
Moso bamboo: Y = 5.23X-20.23 (R^2 = 0.86)
Giant timber : Y = 2.72X-4.16 (R^2 = 0.74)
Hachiku bam-boo: Y = 3.12X-5.89 (R^2 = 0.86)

3.1.2. The width increasing rates of bamboo split

Regardless of bamboo species, the width increasing rates of bamboo split was increased with the increase in thickness of the culm wall. At the 5 mm thickness of culm wall, the width of zephyr was two times larger than that of bamboo split before zephyr production, and three times at 10 mm thickness. No effect of bamboo species on the width increasing rates was observed. To predict the width of bamboo zephyr obtainable from bamboo, the relationships between the bamboo diameter multiplied by bamboo culm-wall and the width of bamboo zephyr were examined (Fig. 5). The equations showed coefficients of correlation (R^2) above 0.8. The widths of bamboo zephyr obtained from three- or four-years-old bamboo showed a little larger than those from one- or two-years-old bamboo.

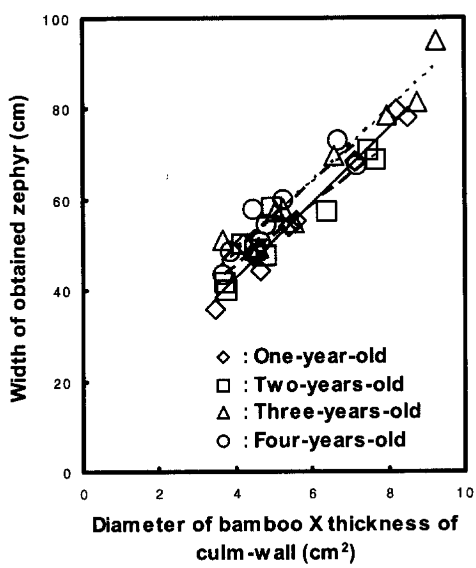


Fig. 5. Comparison of the width of zephyr obtained from Moso bamboo with various ages.
One-year-old : Y = 8.25X + 9.66 (R^2 = 0.97)
Two-years-old : Y = 6.70X + 18.48 (R^2 = 0.89)
Three-years-old : Y = 7.84X + 16.63 (R^2 = 0.94)
Four-years-old : Y = 7.28X + 20.05(R^2 = 0.87)

Although the width of zephyr obtainable from one-year-old bamboo at the same thickness, the diameter was larger in Moso bamboo than in Giant timber bamboo with small differences. Fig. 6 showed the relationship between the width of obtained zephyr and the diameter of bamboo multiplied by thickness of clum-wall. The fitted equation (y=7.55x + 16.60) showed a coefficient of correlation above 0.90. In conclusion, although zephyr could be easily produced from three species of bamboos, the Giant timber bamboo was the most efficient to produce large area of zephyr compared to Moso and Hachiku bamboo.

3.2. Properties of WBCB

3.2.1. Effect of species on properties of WBCB

The densities of the manufactured WBCBs were in the range between 0.77 and 0.83 g/cm^3. The MOR and MOE of the WBCB manufactured using one-year-old bamboo zephyr are

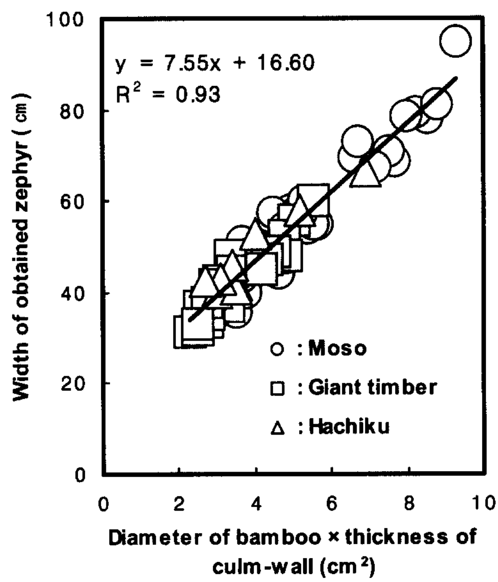


Fig. 6. Relationship between width of bamboo zephyr and the diameter of bamboo multiplied by thickness of culm wall.

shown in Fig. 7 and 8. The values of MOR parallel to the main grain direction of face veneer of WBCB manufactured using Moso, Giant timber, and Hachiku bamboos were 756, 678, and 724 kgf/cm^2, and the values of MOR perpendicular to the main grain were 468.6, 338, and 561 kgf/cm^2, respectively. The values of MOR of WBCB manufactured by Moso and Hachiku bamboos were similar, but those of WBCB manufactured by Giant timber bamboo showed slightly lower values. The values of MORs manufactured with three bamboo species were slightly lower than those of laminated bamboo lumber (density 0.94 g/cm^3, 4-layers) manufactured by Nugroho (2001). But in all bamboo species, the measured MOR of WBCB satisfied the criteria of Korean Standard for structural plywood.

There were no significant differences among the values of MOE according to three different bamboo species. The values of MOE parallel to the grain were in the range between 105 and 115×10^3 kgf/cm^2, and those perpendicular to the grain was between 41 and 44×10^3 kgf/cm^2. The values of MOE parallel and perpendicular to the grain based on KS are 66.5 and 25.5×10^3 kgf/cm^2, respectively.

Fig. 9 showed the values of TS and IB of WBCB manufactured using zephyr of three different one-year old bamboo species. In all three species, the values of TS were below 12%, which is the requirement of KS for particleboard. The TS of WBCB was a little higher compared to that of particleboard, which had resulted from the movement of moisture into layer of zephyr with no resin. Hachiku bamboo showed higher TS than Moso and Giant timber. No significant difference of IB strength was found between WBCB manufactured by Giant timber and WBCB by Hachiku bamboo, but WBCB by Moso bamboo showed a little lower values of IB strength. However, all

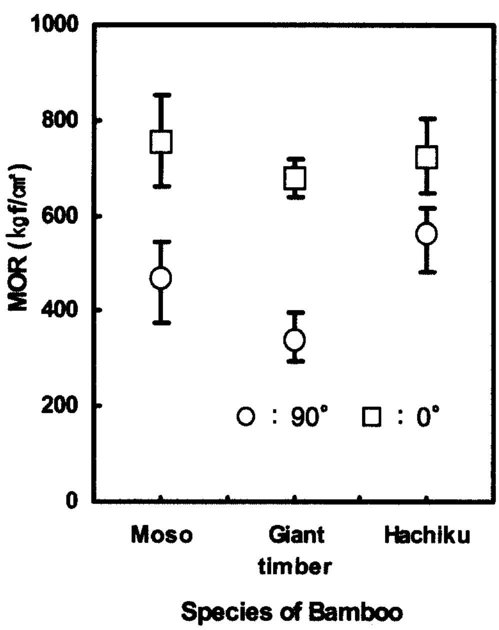


Fig. 7. Comparison of dry MOR of WBCB manufactured using three different species of one-year-old bamboo.

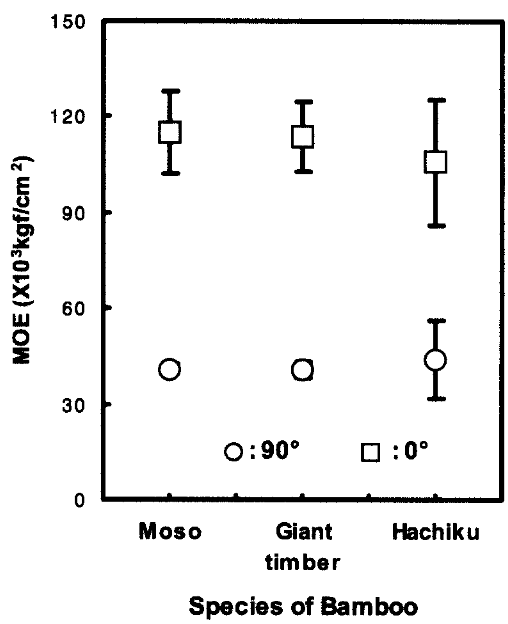


Fig. 8. Comparison of dry MOE of WBCB manufactured using three different species of one-year-old bamboo.

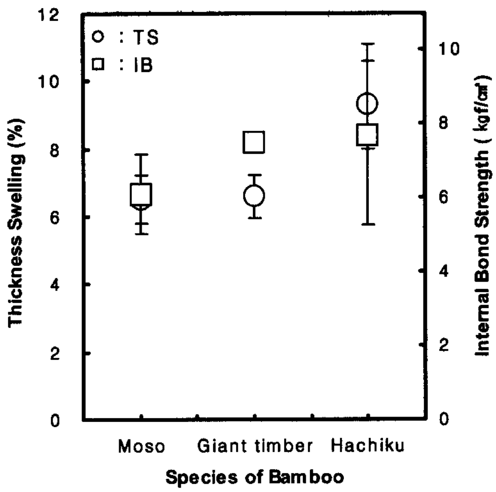


Fig. 9. Relationship between TS and IB strength of WBCB and species of bamboo at one-year-old.

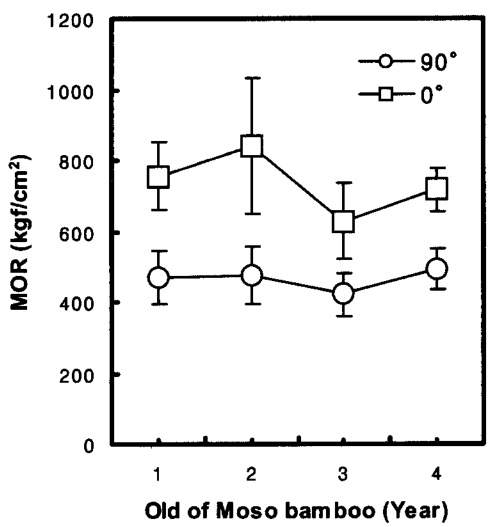


Fig. 10. Change of MOR of WBCB manufactured using Moso bamboo with various ages.

the IB strengths were above the criteria of KS in the given conditions.

3.2.2. Effect of bamboo age on properties of WBCB

Fig. 10 and Fig. 11 showed the values of MOR and MOE of five-ply WBCB manufactured

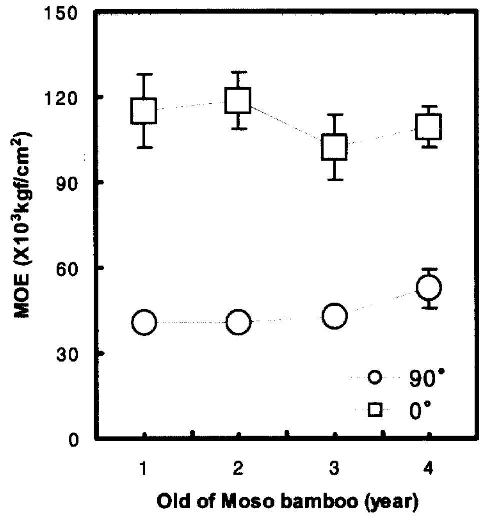


Fig. 11. Change of dry MOE of WBCB manufactured using Moso bamboo with various ages.

using zephyr of Moso bamboo from one to four year olds, respectively. Regardless of age, the values of MOR parallel to grain were in the range between 628 and 838 kgf/cm^2, and that of MOR perpendicular to grain were in the range between 422.1 and 493.7 kgf/cm^2.

The values of MOR of WBCB manufactured using one- or two-year-old bamboo zephyr were higher than those of MOR of WBCB manufactured using three- or four-years-old bamboo zephyr. However, no significant differences were observed in the MOR perpendicular to the grain. The values were above KS, and similar trends were found in MOE. The values of MOE were above KS, regardless of bamboo age.

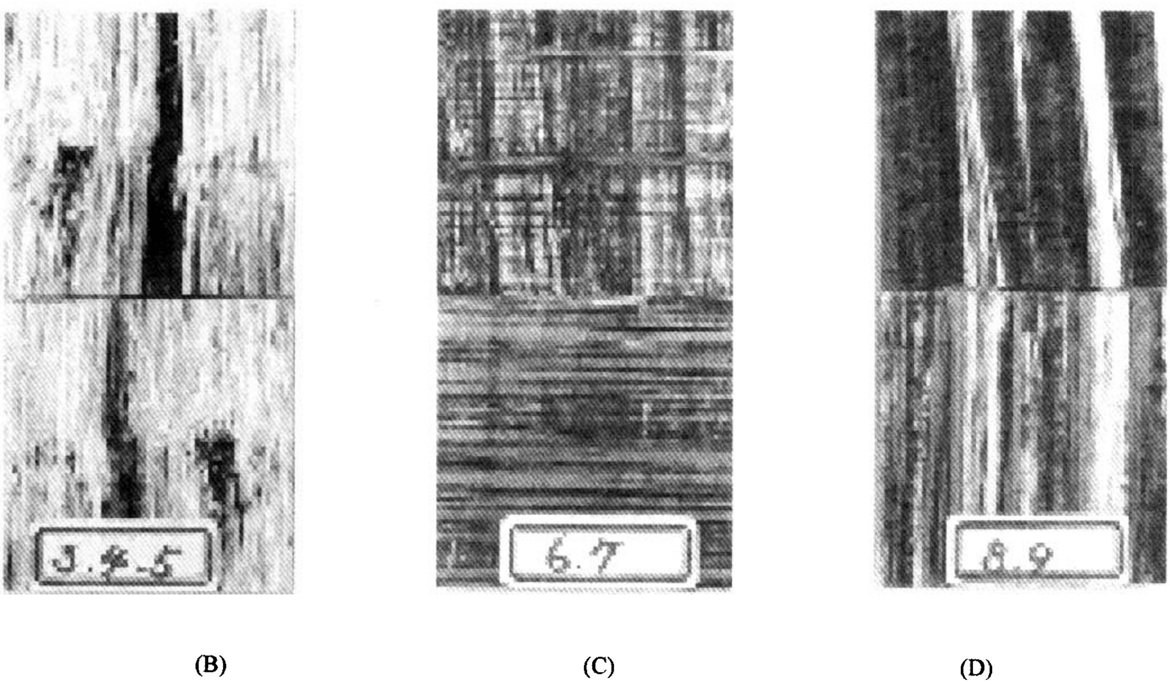
Fig. 12 showed the values of TS and IB strength according to bamboo age. The values of TS and IB strength satisfied the criteria of KS in all ages. There was no significant difference in TS in terms of bamboo age. The values of IB strength tended to increase with increasing the bamboo ages.

Five-ply WBCB has five boundary interfaces, which were located in two veneer layers (A)

Table 2. Fractured areas of WBCB made from different species and ages of bamboo on determining IB strength

Species of bamboo	Age (year)	Internal bond strength (kgf/cm^2)	Percentage of fracture area				
			A	B	C	D	E
Moso	1	6.1	0	77	13	3	7
	2	8.2	0	13	80	0	7
	3	7.4	0	7	90	3	0
	4	8.9	0	0	100	0	0
Giant timber	1	7.5	0	36	36	27	0
	2	8.0	0	10	70	20	0
	3	8.9	0	7	87	6	0
	4	11.0	0	23	60	0	17
Hachiku	1	7.7	0	60	23	10	7
	2 or more	10.0	0	2	98	0	0

A : Veneer layers, B : Bamboo zephyr layers
C : Interface layers of outer part and inner part of bamboo zephyr
D : Interface layer of outer part of bamboo zephyr and veneer
E : Interface layers of inner part of bamboo zephyr and veneer



(B) (C) (D)

Fig. 13. Fractured areas of WBCB used for determining IB strength. B: Bamboo zephyr layers, C: Interface layers of outer part and inner part of bamboo zephyr, D: Interface layer of outer part of bamboo zephyr and veneer

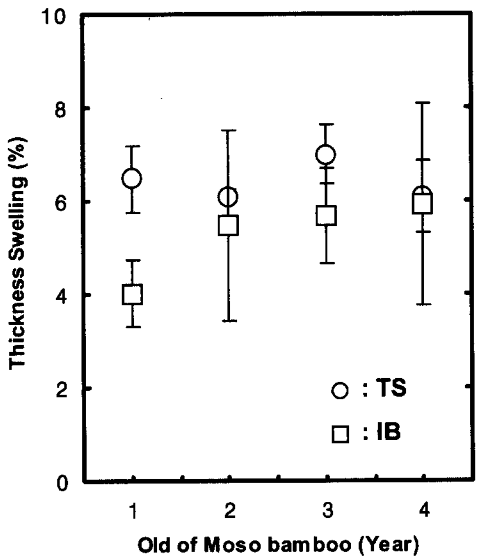


Fig. 12. The effect of age of Moso bamboo on TS and IB strength of WBCB.

and bamboo zephyr layers (B), and between two interface layers of outer part and inner part of bamboo zephyr (C), one interface layer of outer part of bamboo zephyr and veneer (D), and one interface layer of inner part of bamboo zephyr and veneer (E) (Fig. 13). The bonding property of these interface were shown in Table 2.

The failure patterns were similar to all bamboo species. Except one-year-old bamboo, most of failure occurred at two interface layers of outer part and inner part of bamboo zephyr, followed by three bamboo zephyr layers, one interface layer of outer part of bamboo zephyr and veneer. But no failure occurred between two veneer layers. In the case of one-year-old bamboo, more failure occurred between bamboo zephyr layers, which might be explained by a weak strength of one-year-old bamboo compared to two- to four-years-old bamboo.

WBCB manufactured using two- to four-years-old bamboo zephyr showed failures occurring at the three bamboo zephyr layers. It might be resulted from the poor penetration of resin due to wax or silica on the outer face of bamboo. Thus, further research is required to minimize the effect of wax or silica on the bonding property.

4. CONCLUSION

Wood veneer-bamboo zephyr composite board (WBCB) was manufactured to evaluate the possibility of bamboo as alternative raw materials for the manufacture of composite panels. Moso, Giant timber and Hachiku bamboo were chosen to manufacture bamboo zephyr. The physical and mechanical characteristics of bamboo zephyr were evaluated based on Korean Standard (KS F 3104 and 3113) and the results of the research were as follows.

The pass number of bamboo split through roller to reach final roller space up to 1.5 mm was increased with an increase of the thickness of culm wall. At the same thickness, Moso bamboo showed no effect of the age on the pass number. Giant timber bamboo showed the number of bamboo passes through the roller lesser than Moso and Hachiku bamboo. There was no effect of bamboo age on the width of bamboo zephyr production, and Moso bamboo was more efficient to produce large area of bamboo zephyr than Giant timber bamboo. The width of zephyr can be predicted by the function of the diameter multiplied by the thickness of culm-wall (y=7.55x+16.60 (R^2=0.93)).

Although WBCB manufactured by Moso bamboo showed higher values of MOR and MOE than those of Giant timber and Hachiku bamboo, the difference among species was small. WBCB by Giant timber bamboo showed higher values in IB strength and lower values in TS compared to WBCB by Moso and Hachiku bamboos. No effect of bamboo age on bending properties was observed, and the increase of bamboo age showed high dimensional stability and better bonding property. From the results of failure patterns of WBCB, most of failure occurred at the interface among the layers of bamboo zephyr, especially in the case of one-year-old bamboo zephyr. The physical and mechanical properties of WBCB manufactured did not show any differences in all species and ages of bamboo. They were above the requirement of KS.

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