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Fabricaiton of binderless boards from wood shavings by compressively molding with high-pressure steam

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Large volumes of industrial lumbering and construction residues are wasted now. We are studying about effective utilization of the woody resources by compressive molding with high-pressure steam treatment. By using this technique, high performance binderless boards can be fabricated from the resources without chemical adhesives. In this study, we investigated the relationship between the mechanical properties of the fabricated boards and the density as well as steaming conditions. The binderless boards were fabricated from shavings of Japanese cedar. The boards were evaluated on the basis of their physical characteristics such as density and bending properties, surface hardness, dimensional stability and etc. By fixing treatment time for 5 min, the molded shape was not completely fixed. On the other hand, the strength of boards fabricated with excessive steaming deteriorated. It was caused by the degradation of chemical components in the material under high-pressure steam atmosphere. However, it is possible to use the ecological board as a building material by fabricating with better steaming conditions.

Key words: Woody resources, Binderless boards, High-pressure steam

1. INTRODUCTION

Processing companies waste a large volume of sawdust, chips, bark, etc by lumbering, sawmilling and other processes. Many problems occur by incinerating the wastes (air pollution, global warming). Then, the ecological and sustainable utilization of these resources is required. The compressive molding process with high-pressure steam treatment [1-2] is seen as one of methods of effective utilizing woody resources. By using this technique, ecological boards can be fabricated from the woody residues and agricultural residues, weeds and etc without adhesives [3-6]. The process needs only high-pressure steam (temperature region is about 100-200 degrees Celsius) without chemicals. Therefore, the fabricated materials are biodegradable and user-friendly. The purpose of our present study is to analyze the fixation mechanism, to verify the validity of this method and to generate the fundamental data needed for industrialization.

In this paper, binderless boards were fabricated from wood shavings by the processing technique. We investigated the relationship between the mechanical properties of the boards and steaming conditions as well as the board density.

2. MATERIAL AND METHODS

2.1 Board fabrication

The material used for the experiment was air-dried Japanese cedar (*Cryptomeria japonica* D.don) shavings. Apparatus (Hisaka works, ltd. made HT 50-250) for board fabrication consists of an airtight autoclave with pressing components.

The shaving was put inside metallic frames and a plate put over the material. The processes in binderless board fabrication are briefly introduced in the following stages:

(1) Vacuuming stage
Air in the apparatus and material is vacuumed out before injecting steam for 10 min. Effective softening is done by pumping air out of wood shavings.
(2) Softening stage
High-pressure steam at 100 degrees Celsius is injected into the autoclave and softens the material for 10min.
(3) Compressing stage
The softened material is compressed to various target densities by the pressing component (Capacity of max-pressure, 65MPa).
(4) Fixing stage
Deformed shape of compressed material is fixed by high-pressure steaming at 180 degrees Celsius for 5-60 min. The fixation is caused by the structural change in cellulose crystals and partial chemical degradation.
(5) Curing stage
By curing treatment, heat and residual stress in the material is gradually decreased. The curing was done for 30 min in this study.

2.2 Sample preparation and testing

The fabricated binderless boards were of dimensions 200 x 200 mm and 10mm thick and it was cut for the determination of mechanical properties. Prepared samples were tested for the modulus of elasticity (MOE), modulus of rupture (MOR), surface hardness (SH), internal bond strength (IB), thickness swelling (TS) and dimensional stability (DS) in accordance with JIS A

5908-2003. A single point static test, the span for the bending was 150 mm with loading speed of 10 mm/min. Surface hardness (Brinell method) and internal bond strength were measured with loading speed 10 mm/min and 2 mm/min respectively.

In the dimensional stability test, samples were subjected to cyclic conditions of oven drying for 24h and wetting in water for 24h at 105 and 20 degrees Celsius atmosphere respectively.

In addition, thermal property, color changes and Formalin level were investigated. Thermal conductivity was measured by the hot-wire method (Kyoto Electronics QTM-500). L* a* b* values of the top and the bottom surface were measured by the spectra photo meter (Minolta CM-2600d). Diffusion of Formalin from boards were checked by the desiccator method (JIS A 1460-2001) using boards were of dimensions 50×50 mm and 10 mm thick.

3.RESURTS AND DISCUSSION

3.1 Bending properties

To investigate the effect of fixing time on mechanical properties, specific MOE and specific MOR for the board (density range, 0.5–0.6 g/cm^3) were measured. Table I shows the values for the board fabricated with different steaming times. By excluding the 5 min treated specimen, both quantities decreased with an increase in steaming times. Both values for the 5min specimen showed the least results. As described later (3.3 Dimensional stability, shown in Figure 3), the compressed shape for this board was not sufficiently fixed. However, the bending energy in fracture for 5min specimen was higher than 20 and 40, 60min specimens. In the load-deformation curve, the fracture displacement became shorter with an increase in fixing time. The boards with over 10 min steaming were embritlled by steaming treatment at 180 degrees Celsius. These were caused by deterioration of chemical components in wood under excessive steaming. It was reported that hemi-cellulose was decomposed and eluted by steaming treatment at 180 degrees Celsius.

Table I Changes in specific MOE, specific MOR and bending energy in fracture (board density 0.5-0.6 g/cm^3)

	Steaming time (min)				
	5	10	20	40	60
MOE/ ρ (GPa/-)	0.38	0.73	0.68	0.64	0.45
MOR/ ρ (MPa/-)	2.75	4.80	3.62	3.40	3.07
Bending energy in fracture (mJ)	80.2	126.4	70.6	61.0	58.9

Figure 1 shows the relationship between MOE and MOR of the boards with various densities that were fabricated by 10 min fixing treatment. The MOE and MOR values were found to be dependent on the board density (density range, 0.49-1.20 g/cm^3). The correlation of the between MOE and MOR values was strong. In comparison with the relationships of the fabricated boards with several fixing times, it was observed that the inclinations in MOE-MOR were slightly decreased with an increase in steaming time.

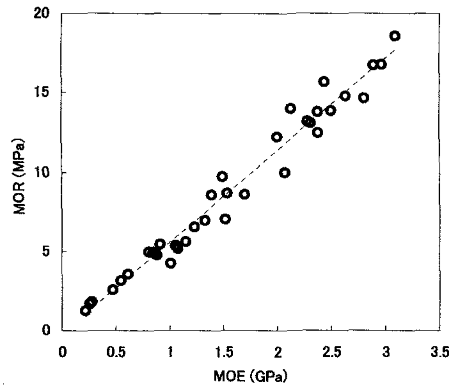

Fig.1 Relationship between MOE and MOR of the boards fixed by 180C 10min steaming (sample density, 0.49-1.20 g/c m^3)

3.2 Surface hardness and Internal bond strength

In determination of the effect of steaming time on surface hardness, no clear trends were observed (density range, 0.5-0.6 g/cm^3). The values of surface hardness for all samples indicated approximately 2.0 MPa. In our previous reports [3-4], no significant difference was observed in SH values for boards fabricated from *Western Red Cedar* sawdust by steaming at 140-200 / 20 degrees Celsius. (The densities were about 1.0 g/cm^3) The SH values had a relation with particle size more than steaming conditions [3]. In addition, the differences between the top and bottom surfaces were unclear. In the case of the board fabricated from Sugi sawdust, bottom SH indicated higher values than the corresponding top values [7]. This was caused by many finer particles escaping to the bottom during the compressing phase.

The effects of a steaming time on internal bond strength indicated a similar trend as the results of bending tests. The values for 10 min steamed specimen showed the highest results (approximately 40 kPa, the board density about 0.5-0.6g/cm^3).

The relationship between the density of specimens and the surface hardness as well as internal bond strength are shown in Figure 2. Both quantities correlated with the board density and each value for highly densified board varied widely. It seems that these variations were caused by the partial differences in the degree of shavings overlapping. The variations were remarkable with a rise in the density.

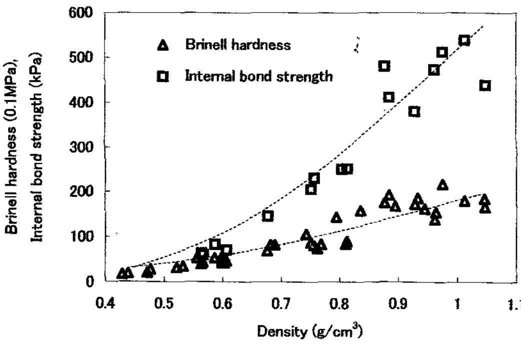

Fig. 2 Relationship between Brinell hardness and the board density (top surface hardness)

It was reported that the internal bond strength increased as the particle became finer. The IB value for Sugi sawdust board was 875.5 kPa with particle size below 0.25 mm (density, 0.95 g/cm^3) [7]. Therefore, the raw material shapes are fundamental to the physical bond strength of binderless boards.

3.3 Swelling test and Dimensional stability

There was a clean trend in the dimensional stability of the boards fabricated (density range, 0.5-0.6 g/cm^3) with different steaming times as shown in Figure 3. It must be noted that the changes in thickness and weight were the largest for the condition of 5min steaming. In fact, the compressed shapes of the 5min boards were not sufficiently fixed. On the other hand, the fluctuations for over 10 min specimens decreased with an increase in steaming time. The dimensional stability correlated with the degree of fixation of deformed shapes of fibers and amounts of dissolved sugars originating from hemi-cellulose in the material.

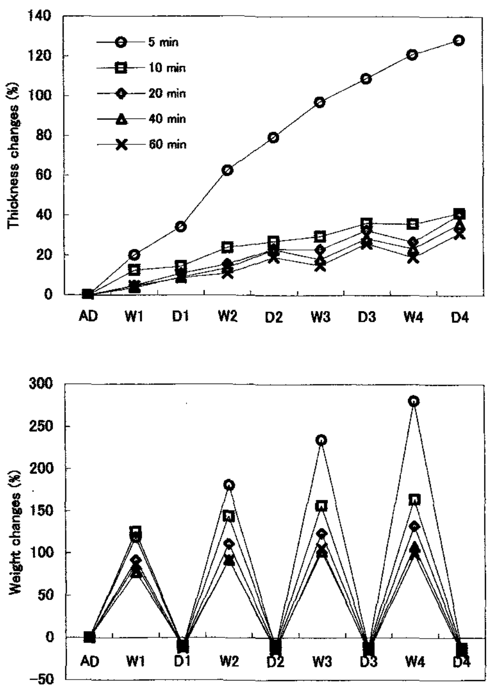

Fig. 3 Changes in the thickness and the weight of the samples as a result of repeated wetting and drying (AD=air dry; W=immersion; D=Ovendry)

Figure 4 shows the results of the percentage increases in thickness and weight for the variously densified boards when (a) samples were immersed in cold water for 24 hours and (b) the samples were dried at 105 degrees Celsius for 24 hours after immersing. Thickness changes by immersing were about 10 %, the values are acceptable according to JIS for particle boards (specified value, below 12%). Thickness of the lower density specimens (density, below 0.7 g/cm^3) increased after drying. Compressed shapes of the boards were sufficiently fixed by 10min fixing (shown in Fig.4). However, the physical bonds of low densified boards were not strong, therefore the combination become loose by drying after wetting.

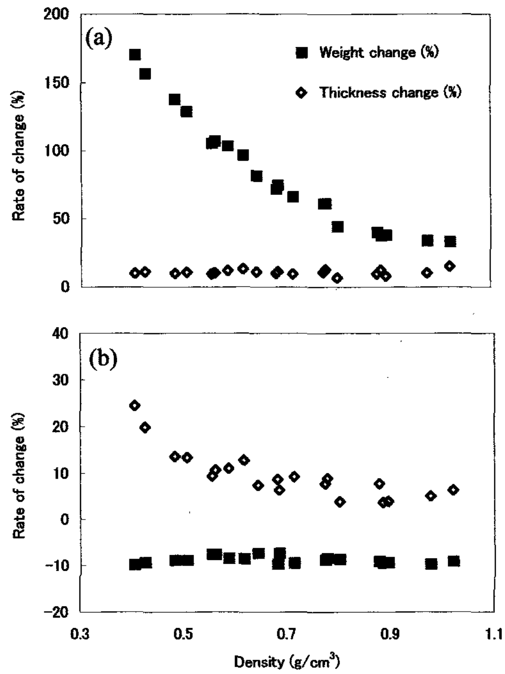

Fig. 4 Changes of weight and thickness welling test

(a) 24 hour immersion in cold water

(b) 24 hour oven dry at 105 C after (a)

3.4 Color changes

To investigate the effect of steaming time on board color, L*a*b* values of the top and bottom surface were checked. Figure 5 shows the changes in L* values of the boards (range of the board density, 0.5-0.6 g/cm^3). The values gradually reduced with an increase in steaming time. However, the changes in a* and b* values by steaming were slight. It is noteworthy that a difference existed between the top and the bottom surfaces. The L* values of the bottom were lower than the top surface.

It seems that the darkening was caused by following factors (1) the bottom was heated more than top by thermal conduction from jigs, (2) partially hydrolyzed hemi-cellulose and degradation or polymerization of lignin. During the fixing phase, dissolved chemicals accumulate and condense at the bottom by gravitation, thus the bottom color became deeper than top.

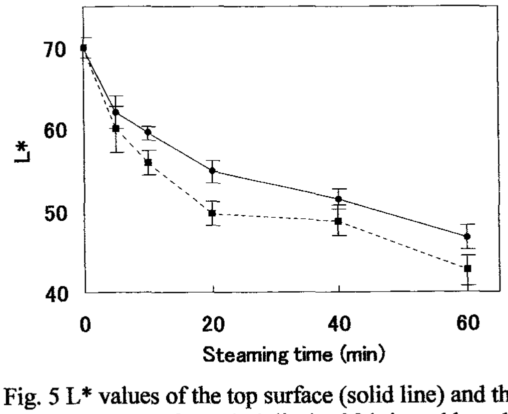

Fig. 5 L* values of the top surface (solid line) and the bottom surface (dash line) of fabricated boards

3.5 Thermal conductivity

Figure 6 shows the relationship between thermal conductivity of fabricated boards and the density. T thermal conductivity increased with a rise in the board density, proportionately (dashed line shown the approximate line). To compare with the quality of normal wood, the relationships for fiber and radial directions [8] are illustrated in Fig.6. In addition, the relationship for tangential direction of wood shows almost a similar trend as the radial direction.

The boards consisted of randomly overlapped wood shavings, it seems that the anisotropy of thermal quality of wood was averaged. It was found that the fabricated boards had enough insulation efficiency at the same level as wood. Additionally, no clear differences were observed in the changes in thermal conductivities of the fabricated boards by steaming conditions.

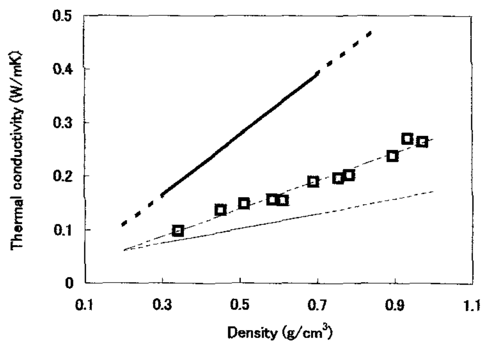

Fig.6 Thermal conductivity of the fabricated boards with various densities and normal wood

Note: Thick line: Fiber direction, Thin line: radial direction (H. Urakami et al., 1981)

3.6 Formalin tests

The formaldehyde emission amounts in fabricated boards are shown in Table II. The values drastically decreased from 0.13 to 0.01 mg/L with the increase of time from 5 to 10 min. Over 10 min, the changes in value were slightly. It seems that the formaldehyde in material were extracted by steaming treatment at 180 degrees Celsius for over 10 min, thus resulting the drastic decrease of the value was observed.

According to the stipulations of JIS A5908-2003, the amount of formaldehyde emission in the plywood is measured by using 10 pieces of the materials of dimensions 150 x 50 mm. In the case of the amounts is under 0.3mg/L, the plywood is ranked top grade. Incidentally the value for the binderless board fabricated by 10 min fixing with stipulated dimensions was about 0.02 mg/L. The measured values for the boards with over 10 min steaming were acceptable according to the top grade. It will be investigated that the mechanism of formaldehyde decreasing in material.

Table II The formaldehyde emission amount

Steaming time (min)	Formaldehyde emission amount (mg/L)
5	0.13
10	0.01
20	0.00
40	0.02
60	0.02

4 CONCLUSIONS

This paper described about the fundamental properties of the binderless boards that were fabricated from Sugi shavings by the compressive molding process with high-pressure steaming. In the effects of steaming conditions on mechanical properties, the better fixing time at 180 degree Celsius was 10 min according to the results of bending tests. It was observed that the strength decreased with an increase in steaming time. In addition, the darkening of the board surfaces by steaming was measured. These were caused by the accumulation of hydrolysis or modification of chemical components in wood. On the other hand, the steaming treatment for 5min could not sufficiently fixed its compressed shapes. Additionally, the amount of formaldehyde emission drastically decreased by over 10min steaming treatment.

Next, the relationships between the mechanical properties and the board density were investigated. The values of the properties increased with a rise in the density. The boards with the density more than 0.7 g/cm^3 had enough strength and dimensional stability. By using these fundamental data, we would like to examine possible practical applications.

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