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Multi-Purpose Utilization of Woody Resources by Compressive Molding with High-Pressure Steam

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"The compressive molding process of wood with the high-pressure steam technique" has been developed in our laboratory. By using this processing technique, a high-performance and ecological material can be fabricated from wasted woody resources without using chemicals. We are studying about the effective utilization of woody resources by this eco-process under the following areas; (1) Adding value to wood, (2) Improvement of the physical properties of low quality wood, (3) Effectively using industrial lumbering residues and construction residues as wood biomass-boards, and (4) Development of non-wood biomass-boards fabricated from agricultural residues and weeds. In addition, essential oil in wood can be extracted by a new apparatus developed in our laboratory "Steam extraction method with high-pressure steam". Biomass is viewed as a potential resource and may be a future alternative for oil. In effect, the process can contribute positively towards the ecological production of woody resources and the fixation of carbon.
Keywords: Woody resource, Compressive molding, High-pressure steam.

1. INTRODUCTION

Recently, environmental destruction and exhaustion of materials and energy have become serious problem. Biomass resources especially woody resources in the forest are watched as a potential resource. These are sustainable and renewable, ecological and biodegradable materials. The resources are expected as an alternative of oil. Thus we developed "The compressive molding process of wood with the high-pressure steam technique"[1,2] and we are suggesting the effective utilization of wasted woody resources by employing the developed process. The compressive molding process can produce a high-performance and ecological material from woody resources by using high-pressure steam without chemicals.

1. Development of high performance wood. New functions (fire resistance, self-cleaning, etc) are added to wood with keeping the characters by the process with and without inorganic modification.
2. Improvement of physical properties of softer wood. The mechanical properties of softer wood are improved by the process. In addition, we are investigating how a developed process, assembling techniques, may be effectively utilized for thinnings [3].
3. Effective use of industrial lumbering and construction residues. Large volumes of disposed sawdust, chips, etc. are wasted. These are effectively utilized by fabricating of wood–biomass board from the residues by the process [4-6].
4. Development of non-wood biomass-board from weed along roads or riverbanks and agricultural residues such as cornstalk, corncob, etc. Mulching material is fabricated from the residues by the process.

In addition, we developed a new apparatus to extract useful essential oil in woody resources. Moreover, after extraction, boards are produced from the residues by the compressive molding with high-pressure steam treatment [7,8].

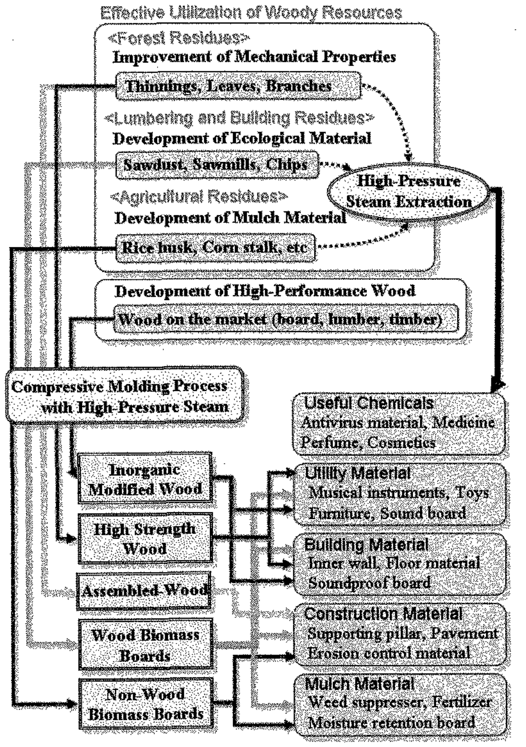


Fig.1. Summarized diagram of this study

2. MATERIAL AND METHODS

2.1 Compressive molding with high-pressure steam

The developed apparatus has an airtight autoclave with a pressing component. High-pressure steam is injected into the autoclave. The processes in this technique are briefly introduced in the following stages:

(1) Softening stage

High-pressure steam at 120-150℃ is injected into the autoclave. The temperature and the moisture contents of the material are increased so that the material becomes softer.

(2) Compressing stage

Softened material is compressed by the pressing component (Capacity of max-press, 1.5MPa) with molding blocks. The compressing stroke is controlled.

(3) Fixing stage

Deformed shape of compressed material is fixed by high-pressure steam at 160-200℃. The fixation is caused by the structural change of cellulose crystals and partial chemical degradation.

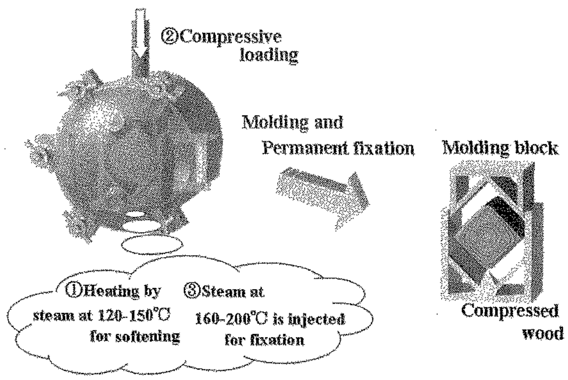
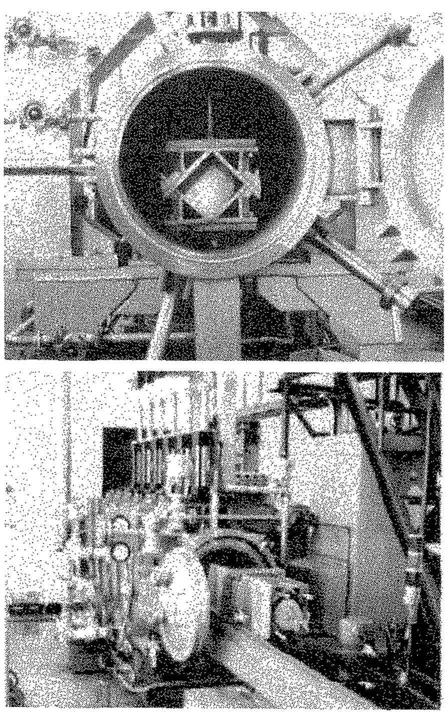


Fig.2. Schematic diagram of compressive molding with high-pressure steam



Pic.1. Developed apparatus (upper: compact type, bottom: 6 press-component equipped type)

2.2 Material and Experiment

2.2.1 Produce of inorganic modified wood

It has been discussed that the nature of metal component affects the wood surface during the compressing stage. Then, physical properties of wood surface were investigated by inserting metal plates between wood (Japanese cedar; *Cryptomeria japonica*) and the molding blocks then compressed by 50%. The condition of wood surfaces including fire resistance, surface hardness, and color changes were investigated.

2.2.2 Preparation of a highly densified wood

Many species of softwood and hardwood were compressed to a target density of 1.5 g/cm^3 by the compressive molding process. The physical properties of compressed woods including density, modulus of rupture (MOR) and modulus of elasticity (MOE), surface hardness, the specific dynamic modulus, loss tangent, and color changes were investigated.

2.2.3 Development of assembling technique and production of assembled-wood

In the first step, grooves were cut on logs as shown in the left of Fig.3. The cut logs (right of Fig.3) were coupled and softened in the first stage of the compressive molding process. In addition, a new method for large cross section laminated lumber obtained from logs and timber without adhesives were investigated.

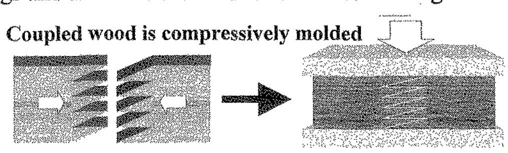


Fig.3. Example of developed assembling technique

2.2.4 Prodution of wood biomass-boards

The materials of board fabrication were 600g of air-dried sawdust shown in Table I. These were processed to a target density of about 1.0 and a size of 300×200×10 mm. Fabricated boards were evaluated on the basis of their physical characteristics such as density, MOE, MOR, surface hardness and C/N.

Table I Raw materials of wood biomass-boards

	Species	Density(g/cm^3)
Soft wood	Sugi	0.38
	Hinoki	0.41
	Karamashu	0.53
Hard wood	Rubber	0.56
	Shirakaba	0.60
	Keyaki	0.62

2.2.5 Production of non-wood biomass-boards

Non-wood biomass-boards were fabricated from the agricultural residues shown in Table II. The fabricated boards were investigated using the same tests as the wood biomass boards.

Table II Raw materials of non-wood biomass-board

	Part
Rice	Straw
	Husk
Corn	Stalk
	Cab

2.3 Treatment condition

Treatment conditions of three stages for each experiment in this paper were set...

(1) 120℃ (Saturated steam pressure, 0.2MPa), 10min or 20min (for assemble-wood fabrication)
(2) Compressing stroke was controlled for compressing to a target density in each experiment
(3) 180℃ (Saturated steam pressure, 1.0MPa), 10min or 20min (for assemble-wood fabrication)

3. RESULTS AND DISCUSSION

3.1 Characteristics of inorganic modified wood

The value of surface hardness for Fe transcribed wood increased by 1.2 times compared with normally compressed wood. The fire resistance properties shown in Fig.4, indicate that the properties of Al transcribed wood was improved. The values of L* for wood surface decreased as a result of the modification. Particularly, the Fe transcribed wood was 31.07 (Raw material; 76.73, Compressed wood with no-modification; 51.92) and the surface color became darker. In addition, the value of a* for Cu transcribed wood was 11.82 (Raw material; 5.31, Compressed wood with no-modification; 9.36) and the surface color changed to a red-like color.

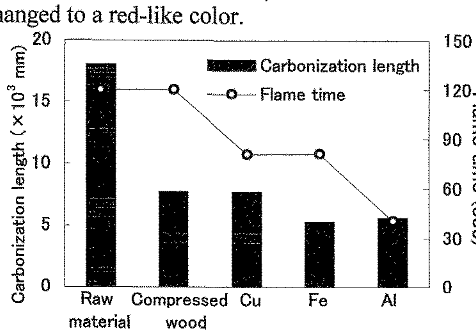


Fig.4. Results of fire resistance test

3.2 Characteristics of highly densified wood

The mechanical properties of each highly densified wood were improved. The maximum density of compressed wood was obtained as 1.46 for Japanese cedar (the initial value was 0.32). Generally, strength of wood depends on its density (density dependence). The value of MOR for compressed wood increased with a rise in density proportionally. However, the values of surface hardness shapely increased with density (Fig.5). Surface hardness of the highly densified wood was nearly equal to metals.

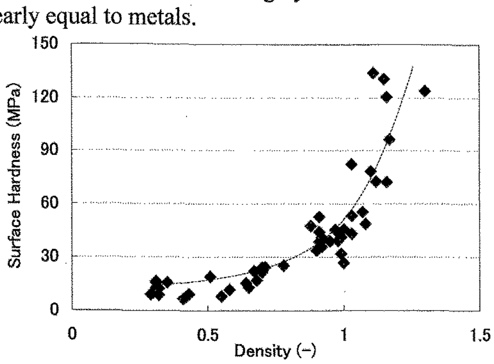


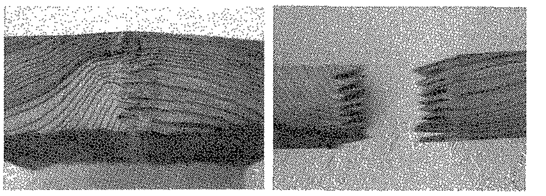
Fig.5. Relationship between surface hardness and density of compressed wood

The color of both surface and inside became darker. Because hemicelluloses were converted to furfurals, the ratio of cell wall increased with compressing. Additionally, the specific dynamic modulus and the loss tangent increased with compressing.

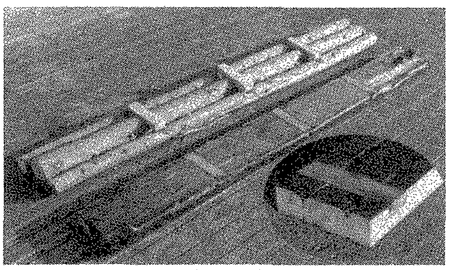
3.3 Physical properties of assembled-wood

Left side of Pic.2 shows fabricated assembled-wood by the compressive molding process with side finger method. The tensile strength perpendicular to grain was lower than the raw material (tested sample is shown on right side of Pic.2). However, geometrical investigations are necessary. The finger shape, compressing condition and treatment condition should be investigated.

Next, a large size assembled-wood was fabricated. Pic.3 shows the example fabricated from logs with bark digging ditch and bars by the compressive molding process without adhesive. By using this assembling technique, a large volume material could be manufactured from thinnings without gluing. The final production may be used as construction materials such as bridge support pillars.



Pic.2 Assembled-wood (type; side finger joint)



Pic.3 Assembled-wood from logs with bark digging ditch and bars

3.4 Physical properties of wood biomass-boards

The sawdust particles of fabricated boards were combined by physical adhesives. Each board had a peculiar smell and all had different colors from their original materials. Table III shows physical properties of the fabricated boards. Results of strength test for the boards fabricated from Keyaki had the highest and satisfied the JIS MDF type 20. Each board had different values of internal bond strength.

Table III Physical properties of wood biomass-boards

	Density (g/cm^3)	Surface hardness (MPa)	Internal bond strength (GPa)	Thickness swelling (%)
Sugi	0.95	8.86	0.87	12.2
Hinoki	0.93	6.68	1.06	10.3
Karamashu	0.97	7.37	0.48	7.4
Rubber	0.80	7.78	1.23	12.7
Shirakaba	0.88	9.70	0.28	19.9
Keyaki	0.83	19.9	1.82	9.7

Fig.8 shows dimensional stability of the boards. Karamatsu had the best stability. No clear difference was seen between softwoods and hardwoods. It seems that constituent (oil and resins contained in each raw material) functioned as adhesives and water resistant.

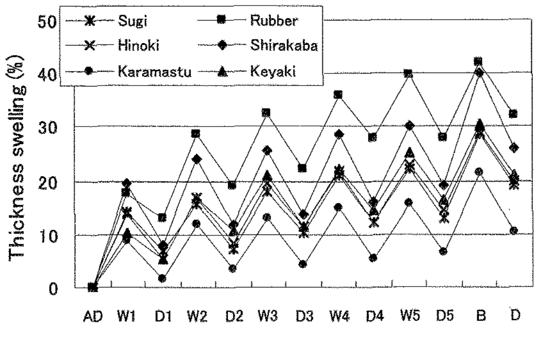


Fig.8. Changes in the thickness swelling (AD = Air dry; W1-W5 = 24h immersion in water; D1-D5 and D = Oven dry at 105C; B = Boiling)

3.5 Characteristics of Non-wood biomass-boards

Mechanical properties of non-wood boards fabricated from weeds and agricultural residues were not sufficiently enough compared with wood boards (Table IV). However, the boards fabricated from agricultural residues contained useful constituents (K_2O, Na_2O, MgO, CaO, etc) and ions (K and N, P, etc). Table V shows the values of C/N for the boards fabricated from rice and corn residues, the values were lower than the wooden boards. It seems that the characteristics of the boards fabricated from weeds were similar to the agricultural residue boards. Therefore, non-wood biomass-boards can be used as mulching materials combines abilities to organic fertilizer and weed suppress. Resilience properties against impact were good, so the boards can be used as shock absorbing pads, and may be useful in situations where cushioning materials are needed.

Table IV Physical properties of non-wood boards

	Part	Density (-)	Surface hardness (MPa)	Internal bond strength (KPa)	Thickness swelling (%)
Rice	Straw	0.83	1.34	27.95	12.17
	Husk	0.87	1.62	14.16	5.56
Corn	Stalk	0.83	2.26	299.1	1.40
	Cab	0.9	1.61	157.2	5.54

Table V Total nitrogen and carbon contents of fabricated boards (and the raw material of before fabricating)

	Part	Board (raw material) Total N	Total C	C/N
Rice	Straw	0.47 (0.53)	34.94 (39.26)	73.89 (74.72)
	Husk	0.35 (0.40)	36.12 (43.64)	104.81 (110.62)
Corn	Stalk	0.86 (0.98)	42.08 (46.14)	49.72 (47.17)
	Cab	0.30 (0.38)	36.28 (41.65)	120.28 (110.49)

Note: Sugi sawdust-board C/N = 781.48 (936.90)
Karamatsu sawdust-board C/N = 969.20 (3179.96)

4. CONCLUSION

We developed a system to compressively mold woody resources with high-pressure steam. By using this processing technique, ecological and high performance material could be produced from wasted woody resources without using chemicals. In addition, useful essential oil was successfully extracted by the developed method with high-pressure steam. The physical properties of wood were greatly improved by compressing. Biomass boards fabricated from woody resources had sufficient strength to be used for practical purposes. The boards will be utilized multi-purposely. On the other hand, the mechanism and complete manufacturing setting of the molding process have not been fully understood scientifically [9].

Biomass is viewed as a potential resource and may be a future alternative for oil. The process can positively contribute towards the ecological production of woody resources and the fixation of carbon. We expect the compressive molding process to contribute to one of the solutions for the earth's crisis in next generation.

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