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Converting Sawdust into Boards by the High-Pressure Steam Method

Siaw Onwona-Agyeman, Ken-ichi Kyomori*, Mikiji Shigematsu*
and Mitsuhiko Tanahashi*
Dept. of Bio-processing, Faculty of Agriculture, Gifu University, Gifu 501-1193, Japan
Fax: 81-58-293-2843, e-mail: oagyeman@cc.gifu-u.ac.jp
* Dept. of Bio-processing, Faculty of Agriculture, Gifu University, Gifu 501-1193, Japan
Fax: 81-58-293-2917, e-mail: tanah@cc.gifu-u.ac.jp

Abstract

The high-pressure steam apparatus was used to successfully fabricate sawdust boards from six different wood species. The satisfactory physical properties obtained indicate that the apparatus could be used in effectively utilizing sawdust or waste generated from wood in general. By varying the species, boards with different physical properties could be fabricated. While particle size had an effect on certain physical characteristics, our investigations with western red cedar showed that the chemical composition also played a major role in the strength properties of the sawdust boards. The absence of synthetic adhesives in the fabrication process signifies that the products are less likely to pose any serious threat to the environment.
Key words: Sawdust boards, highly pressure steam, softwood species, hardwood species and physical characteristics

1. INTRODUCTION

Sawdust constitutes a significant proportion of waste at most wood processing sites. The utilization of wood residues for energy production is not a new concept yet in many countries, burning or landfill still remains the most common disposal options. With a dwindling supply of wood fibers and emerging environmental laws that prohibits fiber extraction from certain forests, the wood industry is seriously looking into an effective means of utilizing milling waste. The main purpose of our research is to focus on an environmentally acceptable means of converting sawdust into boards. This paper briefly introduces the fabrication process for sawdust boards, a process that is entirely based on the high-pressure steam treatment without the use of chemical adhesives [1,2,3]. Another objective of the research was to investigate the effect of particle size and species type on strength properties. Three softwood species (Sugi, *Cryptomeria japonica* D. Don; Hinoki, *Chamaecyparis obtuse* Sieb. Et Zucc.; Karamatsu, *Larix leptolepis* Gordon) and three hardwood species (Rubber, *Hevea brasilensis*; Keyaki, *Zelkova serrata*; Shirakaba, *Betula platyphylla*) were used for the investigation. An attempt was also made by way of the steam extraction method [1] to find out whether the presence of chemical components in western red cedar (*Thuja plicata*) affects the strength characteristics of sawdust boards.

2. MATERIALS AND METHODS

2.1 Sample preparation

Sawdust for the experiment was selected from three softwood species (Sugi, *Cryptomeria japonica* D. Don; Hinoki, *Chamaecyparis obtuse* Sieb. Et Zucc.; Karamatsu, *Larix leptolepis* Gordon) and three hardwood species (Rubber, *Hevea brasilensis*; Keyaki, *Zelkova serrata*; Shirakaba, *Betula platyphylla*). The sawdust particles for each species were separated into various particle size classes after screening them through sieves (Table I). With the exception of Sugi and Rubber wood that had five particle size classes, the rest of the species were sorted into three particle class sizes.

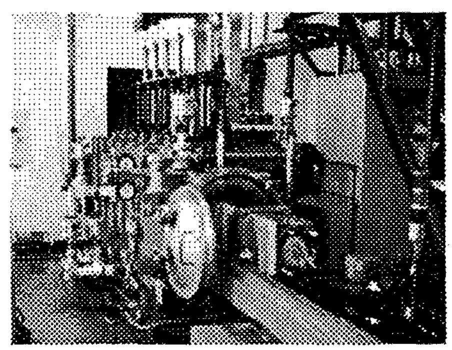

Fig.1. Diagram of the high-pressure steam apparatus

2.2 Board fabrication and testing

After oven drying at 105℃ for about 3 hours, 600g of the samples prepared above were put inside metallic frames lined with Teflon sheets for fabrication. The high-pressure steam apparatus (Fig. 1) consists of an airtight pressure chamber (Hisaka made HTP-60/250) with an internal diameter of 60 cm and a depth of 250 cm, a compressor, an intake valve and an exhaust valve. The fabrication processes involved are briefly introduced in the following stages:

(a) Softening stage: steam is initially injected into the chamber to drive away air for 5 minutes. More steam is injected while the temperature gradually rises to 120℃ in 5 minutes. The temperature is then held constant for 10 more minutes. (b) Compressing stage: The softened mats are compressed to a target density of about 1 g/cm^3.

(c) Fixation stage: In this compressed stage, more steam is injected while the temperature gradually rises to 180℃ within a 10-minute duration and maintained for a further 10 minutes.

The single-layer homogeneous boards were of dimensions 200×300 mm and 10 mm thick.

All boards were trimmed and cut to various specifications for testing (in accordance with JIS A 5908-1994).

3. RESULTS AND DISCUSSION

3.1 Mean density and thickness swelling (TS)

Mean densities for all the various board species and particle class sizes are shown in Table I. None of the board densities was exactly equivalent to the target density of 1 g/cm^3. Nevertheless, the mean densities all exceeded the air-dry density of the original materials before fabrication. Generally, the boards with finer particle sizes tended to have the highest densities. Results of the percentage increases in thickness (thickness swelling) when samples were immersed in cold water for 24 hours are also shown in Table I. Generally, boards with finer particles had lower values of thickness swelling and most of the selected conifer boards had TS values within the JIS specification of below 12%.

Table I. Particle size classes and board physical properties for the various species

Type of Sawdust Board (Particle size,mm)	Mean density (g/cm^3)	TS (%)	IB, (KPa)	SH (MPa)
Sugi 1 (2.00-4.70)	0.83	11.2	64.1	5.46
Sugi 2 (0.84-2.00)	0.79	11.1	109.8	4.42
Sugi 3 (0.42-0.84)	0.78	18.5	170.3	4.50
Sugi 4 (0.25-0.42)	0.81	14.3	332.0	6.07
Sugi 5 (< 0.25)	0.95	12.2	875.5	8.86
Hinoki1 (0.84-2.00)	0.70	16.5	73.4	4.73
Hinoki2(0.355-0.84)	0.85	14.7	189.4	5.43
Hinoki3 (< 0.355)	0.93	10.3	1061.0	6.68
Karamatsu1(0.84-2.00	0.87	9.4	162.3	6.08
Karamatsu2(0.35-0.84)	0.86	9.0	237.2	4.94
Karamatsu3(<0.35)	0.97	7.4	476.4	7.37
Rubber1 (2.00-4.70)	0.74	23.2	30.1	6.45
Rubber2 (0.84-2.00)	0.75	20.8	32.4	5.87
Rubber3 (0.42-0.84)	0.80	16.8	34.3	5.44
Rubber4 (0.25-0.42)	0.81	20.4	14.7	5.75
Rubber5 (< 0.25)	0.80	12.7	235.5	7.78
Keyaki1 (0.84-2.00)	0.65	19.2	1479.4	4.85
Keyaki2 (0.355-0.84)	0.70	19.7	869.3	5.76
Keyaki3 (< 0.355)	0.83	19.9	1824.4	7.26
Shirakaba1(0.84-2.00)	0.87	10.8	166.4	4.94
Shirakaba2(0.35-0.84)	0.78	10.4	144.6	4.19
Shirakaba3(< .355)	0.88	9.7	282.6	5.41

Note: Particle class size 2.00-4.70 refers to particles that passed through the 4.70 mm sieve but could not pass through the 2.00 mm sieve.

Boards were also produced from sawdust (without sorting into particle sizes) generated from the six species and results of their physical characteristics are shown in Table II. As far as density is concerned, no significant differences existed between the species. The lowest value for thickness swelling was registered for karamatsu species, an indication that boards produced from this specie will be suited for exterior use.

Table II. Physical properties of sawdust boards fabricated from unscreened sawdust

	Density (g/cm^3)	SH (MPa)	IB (KPa)	TS (%)
Sugi	0.79	4.46	140.05	12.2
Hinoki	0.78	5.08	131.40	10.3
Karamashu	0.87	5.51	199.75	7.4
Rubber	0.78	5.66	33.35	12.7
Keyaki	0.68	5.31	1174.35	19.9
Shirakaba	0.83	4.57	155.50	9.7

3.2 Surface hardness (SH) and internal bond strength (IB)

For all the species, the SH values increased as particle size became smaller, though the

In the determination of internal bond strength, failure occurred in the core of most of the samples, indicating that the particles were more loosely packed in the core than areas near the surface. It was observed for all the species that internal board strength (IB) increased as the particle became finer (Table I). Boards fabricated from Keyaki had the highest IB values while Rubber wood boards had the lowest values with the exception of the finest class size board. Generally, most of the finer board types and all the Rubber wood boards satisfied the JIS MDF standards. The extremely low IB values for Rubber board could be due to the absence of latex, which had previously been extracted. Results of the surface hardness tests indicates that the SH values generally increased with particle size though the trends varied among the species. Tests were performed on both surfaces (top and bottom) of all the samples. During the compression phase of the fabrication process, many finer particles escaped to the bottom, thus resulting in a higher concentration of finer particles and hence a higher top SH values than the corresponding bottom values. This was quite visible when longitudinal sections were made through the samples. In general, no significant differences in SH values existed between the softwood and hard wood species. The SH values for all the species ranged from 4.42 MPa to 8.86 MPa. No significant differences existed among the SH values for the unscreened sawdust boards (Table II) but the IB value for keyaki specie was exceptionally high (1174.35 Kpa), exceeding the JIS standards for all MDF type boards. The IB value for karamatsu was also within the JIS specification for MDF type 5 boards (196 KPa).

3.3 Dimensional stability

This experiment was carried out on samples from the unscreened sawdust boards. In order to determine their dimensional stability, board samples were subjected to cyclic conditions of oven-drying/wetting, after which a permanent increase in thickness was attained. Dimensionally stable samples are those with low values of percentage changes in thickness after being subjected repeated drying and wetting. After the fifth oven drying treatment D5, the samples were boiled and finally oven-dried. The total thickness swelling of a board sample after immersion in water is attributed to the release of the compressive stresses, hygroscopic swelling of the fibres, and the deterioration of the inter-particle bonding [4]). As shown in Figure II, the

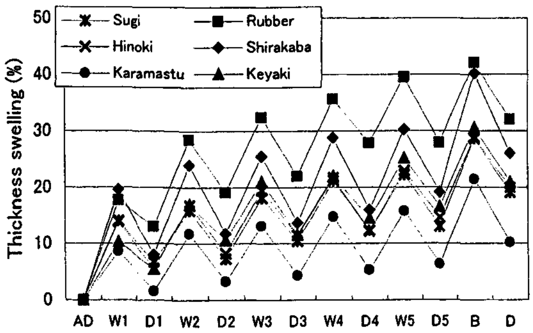

Fig.II. Changes in the thickness swelling
(AD = Air dry; W1-W5 = 24h immersion in water; D1-D5 and D = Oven dry at 105C; B = Boiling)

softwood boards exhibited more stability than the selected hardwood species. Even after boiling and finally drying, very low changes were seen in karamatsu (*Larix leptolepis*) boards (at most 10%), a very strong indication that structures made of such materials would be able to withstand external conditions subject to repeated wetting and drying.

3.4 Total carbon total nitrogen

The purpose of conducting this test was to verify if any changes had occurred in the total carbon and nitrogen components of the original material after fabrication (Table III). The total nitrogen contents were so low and hardly showed any differences. With the exception of Karamatsu, the total carbon contents for all the species did not vary significantly between the sawdust and boards.

Table III. Total nitrogen and total carbon

Board Type	Total Nitrogen (%)	Total Carbon (%)	C/N
Rubber wood (sawdust)	0.14	44.06	308.97
Rubber wood (board)	0.14	43.31	300.82
Shirakaba (sawdust)	0.06	43.33	769.68
Shirakaba (board)	0.09	46.53	499.10
Keyaki (sawdust)	0.12	44.51	391.47
Keyaki (board)	0.16	43.35	273.53
Sugi (sawdust)	0.06	46.15	936.90
Sugi (board)	0.06	46.37	781.48
Hinoki (sawdust)	0.09	49.40	551.52
Hinoki (board)	0.09	49.87	548.46
Karamatsu (sawdust)	0.01	41.24	3179.96
Karamatsu (board)	0.05	52.16	969.20

3.5 Effect of extracting chemical constituents on physical properties

To investigate the effect of chemical constituents, the steam extraction processed was used to extract essential oil from western red cedar. Wood from this tree species contains many extractives, especially methyl thujate, thujic acid and α–, β–, γ–thujaplicin [5]. One big advantage of this method is that the extraction process goes on at the same time as the board fabrication. Boards were fabricated from red cedar sawdust (without extraction) and the physical properties such as MOE, MOR and IB were compared. Results from Fig III indicate that all the three strength characteristics reduced as a result of the extraction. MOR and MOE dropped by 11.27%, and 13.65% respectively. The most significant reduction of 63.57 was observed for internal bond strength (IB).

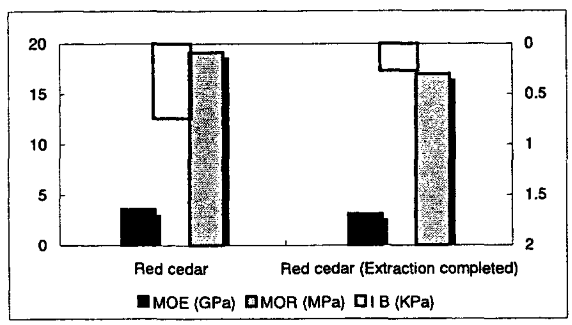

Fig. III. Effect of extracting chemical constituents on MOR, MOE and IB for red cedar

4. CONCLUSION

All the boards were produced from sawdust, which is usually considered as milling waste in many countries and thus burnt to produce greenhouse gases.

In effect, the fabrication process can contribute positively towards the fixation of carbon. Without using any adhesives, very satisfactory physical and mechanical properties of the sawdust boards were obtained with the selected softwood and hardwood species. The mean densities of the boards were all higher than the air-dry densities of the parent wooden material (Fig IV). Improvements in these density values were generally higher for the softwoods, with sugi registering the highest. By varying particle size and wood species, particleboards of various physical properties can be fabricated by this method for different end uses. As mentioned in our previous work [6,7] boards that do not meet JIS MDF requirements and may not be suitable as

Table IV. Improvements in board densities compared with original wooden material

	Air-dry Density (g/cm^3)	Board Density (g/cm^3)	Percentage Increase (%)
Sugi	0.38	0.79	51.9
Hinoki	0.41	0.78	47.4
Karamashu	0.53	0.87	39.1
Rubber	0.56	0.78	28.2
Shirakaba	0.60	0.68	8.8
Keyaki	0.62	0.83	27.7

construction materials may be used for other purposes such as weed suppressers or erosion control structures. The boards are biodegradable so with time its constituent would return into the soil without posing any environmental threat. Further studies are required to determine other chemical constituents of the boards and to further explore the possibility of enhancing their characteristics. The fabrication process is an environmentally clean one as it utilizes only steam and a compression apparatus. Continuation of the studies can go a long way to contribute significantly towards the reduction of agricultural and forestry waste in particular and biomass waste in general.

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