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Development of binderless fiberboard from kenaf core

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Abstract Binderless fiberboards with densities of 0.3 and 0.5 g/cm^3 were developed from kenaf core material using the conventional dry-manufacturing process. The effects of steam pressure (0.4–0.8 MPa) and cooking time (10–30 min) in the refining process, fiber moisture content (MC) (10%, 30%), and hot-pressing time (3–10 min) on the board properties were investigated. The results showed that kenaf core binderless fiberboards manufactured with high steam pressure and long cooking time during the refining process had high internal bond (IB) strength, low thickness swelling (TS), but low bending strength values. The binderless fiberboards made from 30% MC fibers showed better mechanical and dimensional properties than those from air-dried fibers. Hot-pressing time was found to have little effect on the IB value of the binderless board at the refining conditions of 0.8 MPa/20 min, but longer pressing time resulted in lower TS. At a density of 0.5 g/cm^3, binderless fiberboard with the refining conditions of 0.8 MPa/20 min recorded a modulus of rupture (MOR) of 12 MPa, modulus of elasticity (MOE) of 1.7 GPa, IB of 0.43 MPa, and 12% TS under the optimum board manufacturing conditions.

Key words Binderless fiberboard · Kenaf core · Processing variables · Chemical composition

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Introduction

Not all lignocellulosic materials are suitable for making binderless board that shows good performance. Okamoto et al.[1] reported that steam-injection pressed binderless medium density fiberboard made from mixed softwood and hardwood fibers has low internal bonding strength (IB). Binderless board produced from oil palm frond was also reported to have an extremely low IB value of less than 0.1 MPa at board density less than 0.7 g/cm^3.[2,3]

Kenaf core is light in weight and rich in hemicelluloses, which makes it a good raw material for binderless board manufacturing. Using the steam-injection pressing method, kenaf core binderless particleboards were successfully developed in our previous studies.[4,5] Significant degradation of chemical components was found to occur under steam-treatment pressures of 0.6–1.0 MPa and self-bonding was achieved among the kenaf core particles.[6] In conventional fiberboard production, lignocellulosic materials are reduced to fibers in a refining process, where the steam pressure of the cooking treatment usually ranges from 0.55 to 1.05 MPa.[7] This suggests the possibility of making binderless fiberboard from kenaf core using conventional dry-process fiberboard manufacturing without any other special treatment.

In this study, binderless fiberboards were manufactured from kenaf core, and the effects of refining conditions (steam pressure and cooking time) and pressing conditions (fiber mat moisture content and pressing time) on the board properties were investigated.

Materials and methods

Fiber preparation

Kenaf (*Hibiscus cannabinus* L.) core from China was used as the raw material. Its air-dried density was about 0.14 g/cm^3. The kenaf core was first cut into chips of about 3 cm long, followed by defibration using a pressurized refiner

with a refiner plate diameter of 305 mm (BRP45-300SS; Kumagai Riki Kogyo). The chips (440 g air-dry basis per batch) were fed into a pressure vessel where they were steamed and then defibrated between the refiner plates (plate gap 0.3 mm) for 2 min. The pressure in the system was maintained by a constant supply of steam. In this study, seven refining conditions were used, with steam pressure of 0.4–0.8 MPa and cooking times of 10–30 min as shown in Table 1. The refined fibers were then air-dried to a moisture content (MC) of around 10%. The dimensions of the fibers are shown in Table 2. The lengths and diameters of 100 randomly chosen fiber samples (dust passed through 30 mesh screen was excluded) in each condition were measured using a USB microscope (DS-3USV) (Micro Square)

Table 1. Experimental variables of steam cooking conditions in refining process

Code	Steam pressure (MPa)	Cooking time (min)
0.4/10	0.4	10
0.6/10	0.6	10
0.6/20	0.6	20
0.6/30	0.6	30
0.8/10	0.8	10
0.8/20	0.8	20
0.8/30	0.8	30

Table 2. Dimensions of fibers under various refining conditions

Fiber code	Length (mm)	Diameter (μm)	L/D
0.4/10	4.65 (2.14)	304 (149)	19.38 (12.83)
0.6/10	5.50 (2.49)	284 (136)	21.86 (10.69)
0.6/20	4.73 (2.21)	305 (151)	18.29 (10.04)
0.6/30	4.09 (2.31)	298 (148)	16.34 (11.35)
0.8/10	5.28 (2.92)	299 (136)	20.51 (12.95)
0.8/20	4.14 (2.76)	296 (120)	16.10 (12.16)
0.8/30	3.55 (2.05)	280 (145)	15.68 (10.84)

The results are given as averages and standard deviations (in parentheses) from the mean values of 100 randomly chosen fiber samples
L/D, length/diameter ratio of each fiber sample

The lengths and diameters of the fibers were measured at 20× and 200× magnifications, respectively, and the length/diameter ratio of each sample was calculated. The bulk density of the fibers was also calculated based on the weight of the fibers loosely filled into a container measuring 12 × 13 × 9 cm.

Fiberboard manufacture

The dimensions of the fiberboards were 230 × 230 × 6 mm. The target board densities were set at 0.3 and 0.5 g/cm^3. Fibers of 10% and 30% MC were used for board fabrication. The fiber MC of 30% was obtained by spraying water onto the air-dried fibers. The fibers were then hand-formed into a fiber mat by using a forming box, followed by hot pressing into fiberboard. The maximum pressing pressure was 3.0 MPa, and the boards were pressed at a temperature of 190°C for 3–10 min. Two boards in each condition were manufactured except for the board with the refining condition of 0.8 MPa/20 min, 10% MC (one board).

As a reference, binderless fiberboards with refining conditions of 0.6 MPa/10 min and 0.8 MPa/20 min were also manufactured by using steam-injection pressing (SIP), where steam of 1.0 MPa (183°C) was injected for 10 min during pressing. Because the platens were sealed with a 12-mm-thick stainless steel frame, the boards produced measured 230 × 230 × 12 mm. Only one steam-pressed board in each condition was made as a reference in this study. Table 3 summarizes the manufacturing conditions of binderless fiberboard. The target densities were 0.3 and 0.5 g/cm^3 for each condition.

Property evaluation of binderless fiberboard

Prior to the evaluation of the mechanical and physical properties, the boards were conditioned at ambient conditions for about 2 weeks, reaching a MC of 5%–7%. The properties of the binderless fiberboards were then evaluated basically according to the Japanese Industrial Standard for

Table 3. Manufacturing conditions of kenaf binderless fiberboard

Refining condition code	Board thickness (mm)	MC (%)	Pressing condition	
			Method	Time (min)
0.4/10	6	30	HP	10
0.6/10	6	30	HP	10
	6	10	HP	10
	12	10	SIP	10
0.6/20	6	30	HP	10
0.6/30	6	30	HP	10
0.8/10	6	30	HP	10
0.8/20	6	30	HP	10
	6	10	HP	10
	6	30	HP	5
	6	30	HP	3
	12	10	SIP	10
0.8/30	6	30	HP	10

MC, moisture content; HP, hot pressing; SIP, steam-injection pressing

Fiberboards (JIS A 5905, 2003)[8] with a modification of sample width for the bending test.

Two specimens measuring 6 × 25 × 200 mm (or 12 × 25 × 220 mm) were prepared from each board for each of the dry and wet static bending tests. The three-point static bending test was conducted over an effective span of 150 mm for 6-mm-thick samples, and 180 mm for 12-mm-thick samples, at a loading speed of 10 mm/min. Because the wet bending property of the low-density boards was expected to be relatively low, the specimens were immersed in 20°C water for only 3 h prior to testing. The linear expansion (LE) after 3 h of water immersion was also calculated.

Four test specimens measuring 50 × 50 mm were prepared from each sample board for the IB test, with four specimens of the same size for thickness swelling (TS) tests (24 h immersion in 20°C water). The density profiles of the binderless fiberboards with special manufacturing conditions were determined using a density profiler, by means of gamma radiation transmitted through a 50 × 50-mm sample along the thickness at intervals of 0.02 mm.

Chemical analysis of fibers and binderless fiberboards

In binderless fiberboard production, a series of chemical changes in kenaf core are expected to occur during fiber refining and hot pressing/steam-injection pressing processes. The alcohol–benzene extractives, hot water extractives, α-cellulose, hemicelluloses, and lignin content of the raw kenaf core, fibers, and fiberboards under selected conditions were analyzed, as shown in Table 4.

The ground particles of the above materials that passed through a 30 mesh screen and were retained on 60 mesh were used for chemical analysis. The samples were suspended in a mixture of ethanol and benzene (1:2, v/v) and refluxed for 24 h, then with distilled water at 60°C for 3 h. The analyses of extractives were carried out in duplicate. The lignin content was determined by the Klason method, whereas the holocellulose content was measured by using the Wise method. The α-cellulose content was determined by extracting the holocellulose with 17.5% NaOH solution. These chemical analysis tests were carried out in triplicate.

Results and discussion

Effects of refining condition on the weight loss and fiber quality

The amount of weight loss was calculated by measuring the air-dry weight of kenaf core before and after the defibration process. Figure 1a shows the weight loss of kenaf core under various refining conditions. It can be seen that the weight loss increased with increasing steam pressure and cooking time. At the refining conditions of 0.6 MPa/30 min,

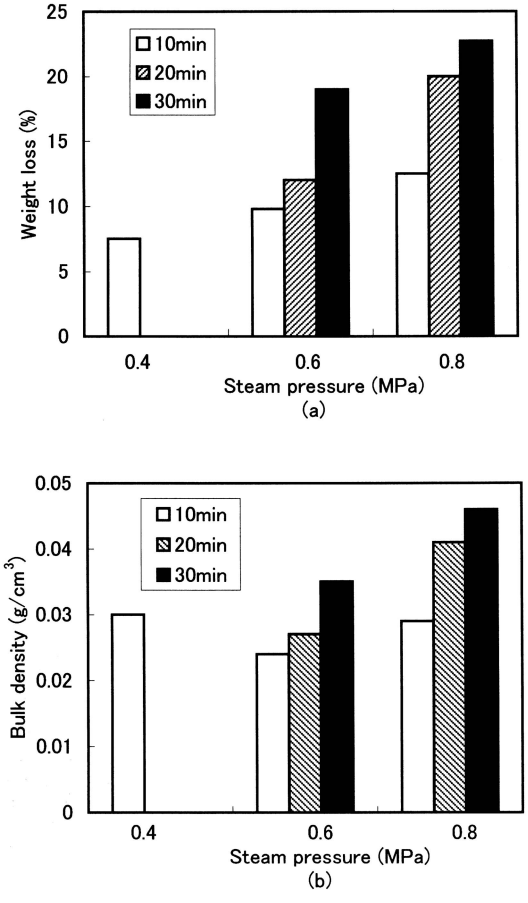

Fig. 1. Weight loss (**a**) and bulk density (**b**) of kenaf core fiber obtained under various steam pressures and cooking times during refining

Table 4. Chemical composition of various samples

Code	Sample type	Refining condition	Mat MC (%)	Pressing method	Chemical composition (%)				
					AB extractives	HW extractives	Lignin	Hemicelluloses	α-Cellulose
Control	Kenaf core				1.87	1.25	23.29	34.31	37.16
F0.6/10	Fiber	0.6/10			4.71	4.43	21.73	26.71	37.34
F0.8/20	Fiber	0.8/20			9.17	8.31	20.47	16.32	42.16
B0.6/10-A	Fiberboard	0.6/10	10	HP	4.55	4.45	21.73	25.61	36.40
B0.6/10	Fiberboard	0.6/10	30	HP	4.91	4.26	21.55	25.45	36.47
B0.8/20	Fiberboard	0.8/20	30	HP	9.13	8.30	20.85	16.32	42.18
SB0.6/10	Fiberboard	0.6/10	10	SIP	9.34	8.18	20.03	20.20	36.38
SB0.8/20	Fiberboard	0.8/20	10	SIP	11.91	7.63	20.26	16.81	41.16

AB, alcohol benzene; HW, hot water

0.8 MPa/20 min, and 0.8 MPa/30 min, weight loss was particularly high.

Fiber geometry is known to be one of the important factors that affect the board properties. In this study, different refining conditions were found to produce fibers with different geometries (Table 2). The length and length/diameter ratio of fibers increased when the refining condition changed from 0.4 MPa/10 min to 0.6 MPa/10 min, but they decreased with further increased steam pressure and cooking time. Furthermore, fibers produced under mild refining conditions were fluffy, straight, and light in color, whereas those produced under severe refining conditions were curly, lumpy, and dark in color. The degree of degradation of kenaf core was indicated by the appearance of the fibers.

Figure 1b shows the bulk densities of the fibers at different refining conditions. With a 10-min cooking time, the bulk density of the fiber decreased when the refining condition changed from 0.4 MPa/10 min to 0.6 MPa/10 min, but increased with further increase in steam pressure and cooking time. The bulk densities of fibers from the refining conditions of 0.6 MPa/10 min and 0.8 MPa/20 min were 0.024 and 0.041 g/cm^3, respectively.

Chemical composition of the fibers and binderless fiberboards

The chemical compositions of various fibers and binderless fiberboards are shown in Table 4. These data are based on the initial dry weight of the materials used. The alcohol–benzene and hot-water extractives of all the fiber and binderless fiberboard samples were found to be more plentiful than those obtained from untreated kenaf core. Fibers with more severe refining conditions showed higher contents of alcohol–benzene and hot-water extractives. The hot-water extractive content was 1.25% for untreated kenaf core, and it increased to 4.43% and 8.31% for the fibers obtained under the refining conditions of 0.6 MPa/10 min and 0.8 MPa/20 min, respectively. Meanwhile, the hemicelluloses content was found to decrease significantly with increasing steam pressure and cooking time. The changes of hot-water extractive and hemicelluloses contents indicate the occurrence of significant degradation under the severe refining conditions. Hemicelluloses are hydrolyzed and increase their solubility in water during steam/heat treatment. Water-soluble components are mainly derived from the hemicelluloses degradation products.[9] In this study, lignin also showed a certain degree of degradation. Fibers refined under the conditions of 0.8 MPa/20 min and fiberboards made from such fibers showed higher α-cellulose content than other samples, which could be due to the effect of high weight loss of the material during refining process. Velasquez et al.[10] also reported the amount of cellulose and lignin in the remaining material to increase with the severity of pretreatment when making binderless fiberboard from steam-exploded *Miscanthus sinensis*.

The chemical composition of binderless board is affected by the pressing method. Conventional hot pressing did not result in further significant change in the chemical composition; the content of chemical components remained almost the same after hot pressing. However, steam-injection pressing gave rise to substantial changes with the fiber refining condition of 0.6 MPa/10 min. After steam-injection treatment, the hot-water extractives increased from 4.43% to 8.18%. The chemical changes that occur in board manufacture are further discussed in the later part of this article.

Effects of refining conditions on the properties of kenaf binderless fiberboard

The actual densities of the test specimens used were in the range of 0.27–0.33 g/cm^3 and 0.44–0.57 g/cm^3 for board target densities of 0.3 and 0.5 g/cm^3, respectively. Because density has a significant effect on the board performance, all of the experimental values obtained were corrected to the target board densities of 0.3 and 0.5 g/cm^3 based on the linear regression between board density and properties. The linear regression lines on the relationships between board density and properties under each refining condition were taken first. Each plot was then shifted to the targeted densities of 0.3 and 0.5 g/cm^3 according to the slope of the linear regression line, and the average values were calculated.

Internal bonding strength

Figure 2 shows the effects of cooking conditions during the refining process and board densities on the IB value of kenaf binderless fiberboard. The IB increased with increasing board density. The fiberboard from severe refining conditions showed higher IB values at 0.5 g/cm^3 than at 0.3 g/cm^3. The board with the refining condition of 0.8 MPa/30 min recorded an IB value of 0.51 MPa.

During refining, the kenaf core is subjected to steam treatment which might cause thermodecomposition and hydrolyzation of the hemicelluloses component. The steam then converts and transforms the hydrolyzed hemicelluloses into low molecular weight water-soluble carbohydrates and other decomposition products, which can act as resin adhe-

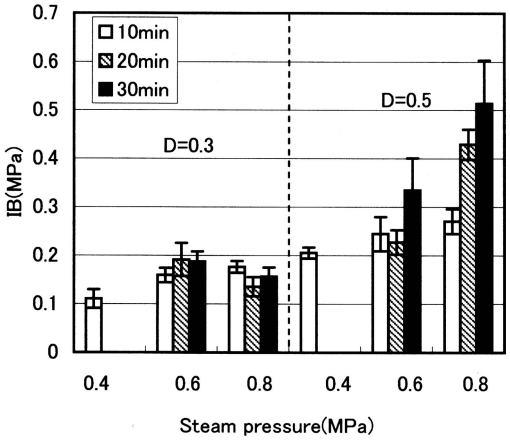

Fig. 2. Effect of steam pressure and cooking time during refining on the internal bond strength (*IB*) of kenaf core binderless fiberboard. *Vertical lines* through the bars represent the standard deviation from the mean. Fiber moisture content (MC) was 30%. *D*, density (g/cm^3)

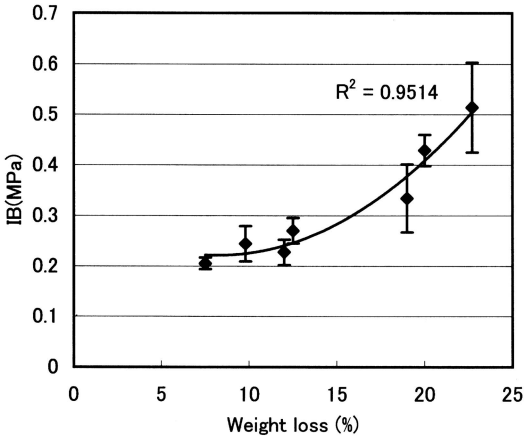

Fig. 3. Relationship between IB of binderless fiberboard and weight loss of kenaf core during fiber refining. *Vertical lines* represent the standard deviation from the mean. R^2 is the correlation coefficient. The board density was 0.5 g/cm^3

sive for bonding.[11] Higher steam pressure and longer cooking time result in more significant degradation of chemical components, giving rise to a higher IB value. Table 4 shows an increase in alcohol–benzene and hot-water extractives, and decreases in hemicelluloses and lignin contents of the fibers when the refining condition was changed from 0.6 MPa/10 min to 0.8 MPa/20 min.

As observed previously, weight loss of kenaf core during the refining process increased with increasing steam pressure and cooking time. The IB values also showed a close relationship with weight loss. Figure 3 shows the relationship between IB and weight loss of kenaf in the refining process. In addition to chemical changes, severe refining conditions resulted in finer fibers than those found under mild conditions. This caused an increase in the bonding area that, in turn, contributed to improved IB. Velasquez et al.[12] reported that binderless fiberboard from steam-exploded *Miscanthus sinensis* with a grinding process improved the IB value, and this was attributed to the increase of bonding area which can be observed in scanning electron micrographs. Suchsland et al.[13] also reported an increase in IB values when the pretreatment steam pressure increased, as more fines were produced under more severe pretreatment.

At low board density, however, increasing the severity of refining conditions did not result in a higher board IB. This could be attributed to the generally higher bulk density of the fiber from severe refining conditions, which contributed to poor contact of fibers and consequently inferior interfiber bonding.

At a density of 0.5 g/cm^3, the IB of the fiberboard with the refining conditions of 0.6 MPa/30 min, 0.8 MPa/20 min, and 0.8 MPa/30 min met the requirements of Type 15 board. Considering that no binder was used and the board densities were low, the IB values of the binderless fiberboard were relatively high. At a similar density level, kenaf core hot-pressed particleboards using melamine urea resin as an adhesive at a resin content of 10% had IB values of less than 0.3 MPa.[14] Binderless boards made from steam-exploded

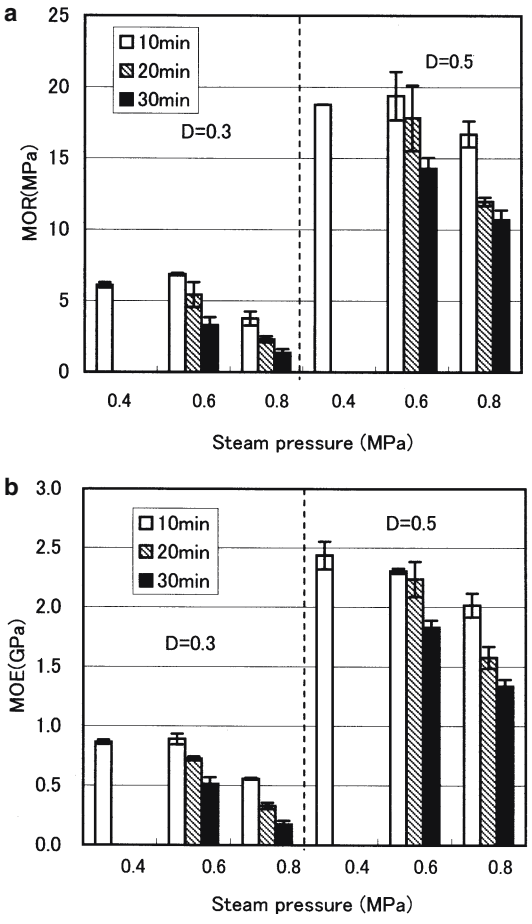

Fig. 4. Effect of steam pressure and cooking time during refining on **a** the modulus of rupture (*MOR*) and **b** modulus of elasticity (*MOE*) of kenaf core binderless fiberboard. *Vertical lines* through the bars represent the standard deviation from the mean. Fiber MC was 30%

fibers of oil palm frond, however, had an extremely low IB value of less than 0.1 MPa at densities below 0.70 g/cm^3.[2]

Bending strength

The effects of board density and fiber refining condition on the modulus of rupture (MOR) and modulus of elasticity (MOE) of kenaf core binderless fiberboard are shown in Fig. 4. The MOR value increased significantly when the board density increased from 0.3 to 0.5 g/cm^3. At a refining condition of 0.6 MPa/10 min, the MOR was 6.9 MPa at 0.3 g/cm^3 board density, and 19.4 MPa for 0.5 g/cm^3 board density. In contrast to IB, the MOR decreased with increasing steam pressure and cooking time in the refining process. With the refining condition of 0.8 MPa/30 min, the MOR was only 10.7 MPa for 0.5 g/cm^3 board. This is because the value of MOR not only depends on the bonding strength among fibers, but also the individual fiber strength and fiber geometry. Severe steam treatment conditions might result in a high degree of hydrolysis or modification of the chemical components, causing a reduction in the fiber strength. Short length and low length/diameter ratio for fibers from

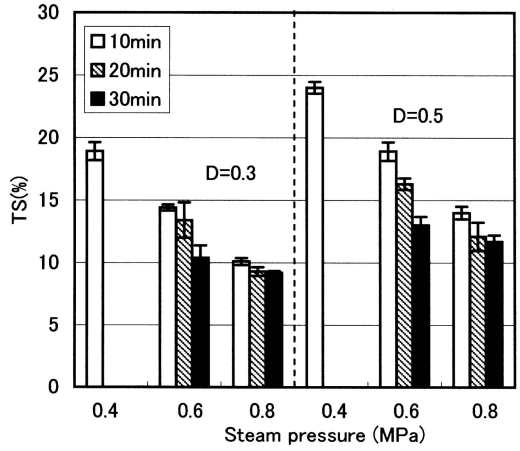

Fig. 5. Effect of steam pressure and cooking time during refining on the thickness swelling (*TS*) of kenaf core binderless fiberboard. *Vertical lines* through the bars represent the standard deviation from the mean. Fiber MC was 30%

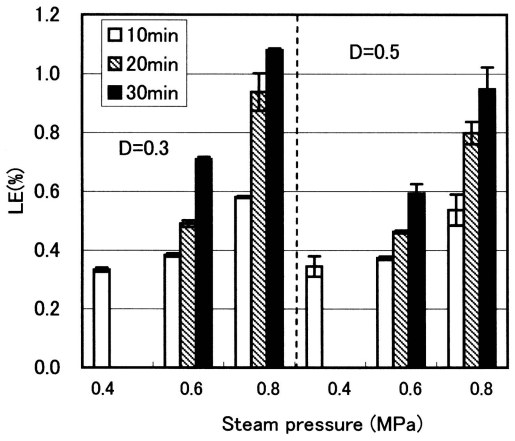

Fig. 6. Effect of steam pressure and cooking time during refining on the linear expansion (*LE*) of kenaf core binderless fiberboard. *Vertical lines* through the bars represent the standard deviation from the mean. Fiber MC was 30%

severe refining conditions could also contribute to a low MOR. Similar results were also reported in earlier studies in which oil palm binderless fiberboard produced under severe explosion treatments gave boards with high IB but low MOR value.[2]

Except for the board fabricated from fibers with 0.8 MPa/30 min refining condition, the MOR of all low-density binderless fiberboard (0.3 g/cm^3) exceeded the requirement for Grade A insulation board. The MOE values showed trends similar to those of MOR. At a density of 0.5 g/cm^3, the highest MOE value recorded was 2.4 GPa.

Similar to the trend for dry MOR, the wet MOR decreased with increasing steam pressure and cooking time in the refining process. Compared with the requirement of the JIS A 5905[8] for fiberboard, the kenaf binderless fiberboard showed low performance for wet MOR, with a residual strength of about 20%–35%.

Dimensional stability

Binderless fiberboard from severe refining conditions showed low thickness swelling (TS). Figure 5 shows the TS values of binderless fiberboard after 24 h of immersion in water at 20°C. The fiberboard from 0.8 MPa/30 min refining condition recorded a TS value of only 11.7% at 0.5 g/cm^3 board density. Sekino et al.[15] made dimensionally stable particleboard by using steam-pretreated particles, and indicated that the reduction in hygroscopicity, due to the changes in hemicelluloses in steam pretreatment, is one factor for the improved dimensional stability. The improved dimensional stability also contributed to reductions of elasticity. Laemsak and Okuma[2] reported that severe steam-explosion conditions resulted in high dimensional stability as the fibers lost elasticity through destruction of the aromatic nuclei of lignin.

Except for the boards from the 0.4 MPa/10 min and 0.6 MPa/10 min refining conditions, which showed slightly higher TS values, boards made with other refining conditions showed TS of below 17%, meeting the requirements of JIS A 5905[8] for fiberboard. The TS values also increased with increasing board density, owing to higher degree of springback.

In contrast to TS, LE increased with increasing steam pressure and cooking time in refining conditions (Fig. 6) This can be explained as an effect similar to the Poisson effect, where increase in thickness restrains movement in the lateral direction, as reported in the previous studies.[16,17] Boards of higher density generally showed lower LE values when compared with low density boards.

Effects of fiber moisture content and hot-pressing time on the board properties of kenaf binderless fiberboard

Fiberboard made from 30% MC fibers showed higher MOR, MOE, and IB, and lower TS values than those of air-dried fibers (Fig. 7). The moisture content of a mat entering the hot press is of great importance in pressing composition board. High moisture content aids in plasticizing the wood fibers, enables faster heat transfer to the mat core, decreases the melting point of lignin, and creates better contacts among fibers. Because no binder was added during board manufacturing, relatively high mat moisture content is required to promote the formation of hydrogen bonding and lignin bonding among the fibers. However, in the preliminary experiment, the board was found to be delaminated when using high mat moisture content (30% MC) to make high-density (0.7 g/cm^3) board. The binderless fiberboard produced from fibers of 10% and 30% MC did not result in significantly different chemical composition and density profile.

Fiberboard with refining condition of 0.8 MPa/20 min showed almost the same IB value for pressing times ranging from 3 to 10 min. These boards also had similar bending properties, although longer pressing time resulted in lower TS. The TS values of binderless fiberboard with a 10-min pressing time were 35% and 25% lower than that with a 3-

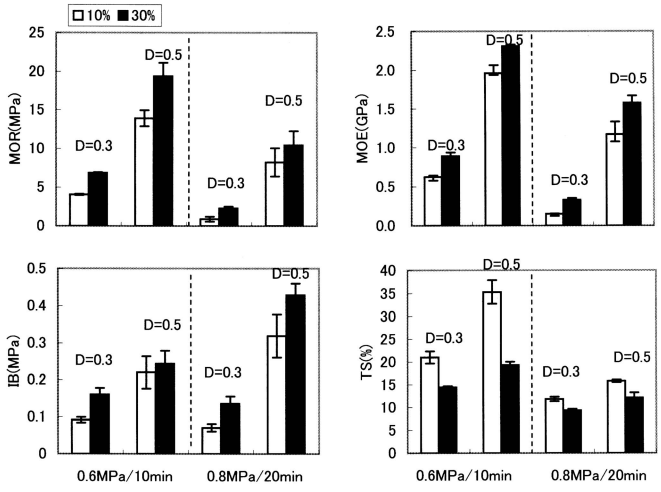

Fig. 7. Effect of fiber mat moisture content on the properties of kenaf core binderless fiberboard. *Vertical lines* through the bars represent the standard deviation from the mean. The fiber refining conditions were 0.6 MPa/10 min and 0.8 MPa/20 min

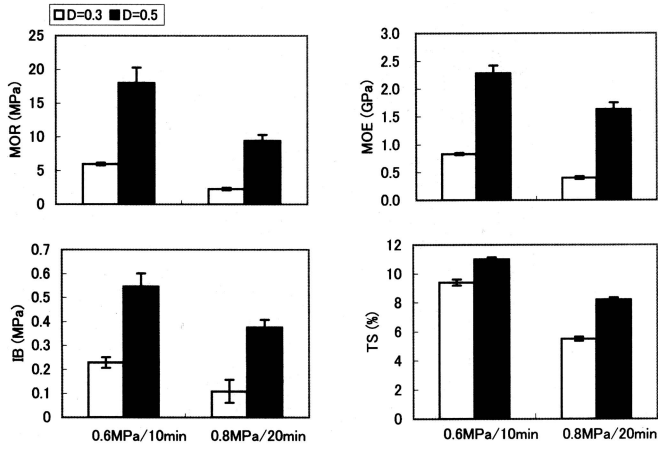

Fig. 8. Properties of kenaf core binderless fiberboard made by steam-injection pressing. *Vertical lines* through the bars represent the standard deviation from the mean. The fiber refining conditions were 0.6 MPa/10 min and 0.8 MPa/20 min

min pressing time at board densities of 0.3 and 0.5 g/cm^3, respectively.

Binderless fiberboard manufactured using steam-injection pressing

Figure 8 shows the properties of binderless fiberboard made by steam-injection pressing with the fiber refining conditions of 0.6 MPa/10 min and 0.8 MPa/20 min. Like hot-pressed board, the bending strength of steam-pressed board made from severe refining conditions showed lower values. The MOR and MOE values of steam-pressed board with the refining condition of 0.6 MPa/10 min were 18 MPa and 2.3 GPa, respectively, at a board density of 0.5 g/cm^3. The TS of the steam-pressed board showed low values (<12%); they can meet the requirement of the JIS standard. The IB value of steam-pressed board showed a trend different from that of hot-pressed board. The fiberboard with the refining condition of 0.6 MPa/10 min showed higher IB values than that of the fiberboard with the refining condition of 0.8 MPa/20 min. This is most probably due to a further degradation of fibers obtained under the refining condition of 0.6 MPa/10 min during steam-injection pressing, as revealed by the chemical changes. As shown in Table 4, the fiber hot-water extractives of 4.4% remained almost the same after hot pressing, but increased to 8.2% after steam pressing. Meanwhile, steam-injection pressing resulted in a reduction of hemicellulose content. The hemicellulose content for the refined fiber, hot-pressed fiberboard, and steam-pressed fiberboard were 26.7%, 25.5%, and 20.2%, respectively. The increase in hot-water extractives and decrease in hemicellulose content explain the significant increase in IB value after steam pressing. Fibers from refining condition of 0.8 MPa/20 min appeared to experience insignificant further chemical degradation during steam-injection pressing, but an extended steam treatment duration could cause a decrease in IB value. It is worth mentioning that at the refining condition of 0.6 MPa/10 min, steam-pressed boards showed an increase in IB value without significant decrease in MOR. This may be due to the fact that the fiber geometry was not altered much during the steam-injection pressing; hence, a relatively high bending strength was maintained.

In this study, the density profiles of the steam-pressed boards were not found to be significantly different from those of hot-pressed boards. This may be due to the low density of the raw material and the consequently high compression ratio of the board, as well as to the high initial pressure (6 MPa) when making steam-pressed boards.

Although steam-injection pressing can also be applied to binderless fiberboard production, as well as to that of binderless particleboard,[4,5] the use of the conventional dry process for fiberboard to make binderless fiberboard is much simpler without the requirement for special equipment.

Conclusions

Kenaf core binderless fiberboard can be manufactured by using the conventional dry process for fiberboard. The fiber refining condition apparently affects the board properties of binderless fiberboard. Higher steam pressure and longer steaming time produced boards with higher IB, and dimensional stability, but lower bending strength. An appropriate choice of refining conditions is important to achieve a balance between the bending property and bonding strength. The binderless fiberboards made from 30% MC fibers showed better mechanical and dimensional properties than those made from air-dried fibers.

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