J Wood Sci (2004) 50:62–67
DOI 10.1007/s10086-003-0522-1

ORIGINAL ARTICLE

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Manufacture and properties of low-density binderless particleboard from kenaf core

Received: October 15, 2002 / Accepted: February 10, 2003

Abstract Low-density binderless particleboards from kenaf core were successfully developed using steam injection pressing. The target board density ranged from 0.10 to 0.30 g/cm^3, the steam pressure used was 1.0 MPa, and the steam treatment times were 7 and 10 min. The mechanical properties, dimensional stability, and thermal and sound insulation performances of the boards were investigated. The results showed that the low-density kenaf binderless particleboards had good mechanical properties and dimensional stability relative to their low board densities. The board of 0.20 g/cm^3 density with a 10-min treatment time produced the following values: modulus of rupture 1.1 MPa, modulus of elasticity 0.3 GPa, internal bond strength 0.10 MPa, thickness swelling in 24 h water immersion 6.6%, and water absorption 355%. The thermal conductivity of the low-density kenaf binderless particleboards showed values similar to those of insulation material (i.e., rock wool), and the sound absorption coefficient was high. In addition, the boards are free from formaldehyde emission. Kenaf core appears to be a potential raw material for low-density binderless panels suitable for sound absorption and thermally resistant interior products.

Key words Low density · Binderless particleboard · Kenaf core · Thermal conductivity · Sound absorption coefficient

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Part of this report was presented at the 52th Annual Meeting of the Japan Wood Research Society, Gifu, Japan, April 2002

Introduction

The density of raw material has a significant influence on the properties of particleboard. A wood species of low density produces a particleboard with higher strength compared to that of higher density.[1] The reason lies in the fact that the low-density wood has a relatively high compaction ratio when hot-pressed into a board, resulting in better contact among the particles. To obtain a high strength value, a certain compaction ratio is needed. For ordinary amino resin-bonded particleboard manufacturing, the compaction ratio is usually higher than 1.2, so it is difficult to make low-density particleboard using relatively high-density raw materials.

Many studies have been done on the development of low-density particleboard.[2–8] Among these studies, isocyanate compound adhesive was usually used as the binder, which can improve the bondability of low-density board in a low compaction ratio. Kawai and Sasaki.[2] developed a low-density board with a density of 0.4 g/cm^3 that had the same density as that of raw material, so its compaction ratio was only 1.0. Sellers et al.[9] used kenaf core for manufacturing low-density phenol-formaldehyde (PF)-bonded particleboard with a board density of 0.256 g/cm^3. Studies on low-density binderless particleboard have not been reported.

Kenaf is an annual plant. The stalk consists of an outer bast layer and an inner core. The core is light in weight with a density of only about 0.15 g/cm^3. It is a potential raw material for low-density particleboard manufacturing.

Our previous paper[10] reported that the binderless particleboards from kenaf core with a target density of 0.40–0.65 g/cm^3 were successfully developed using the steam-injection press. The performance of the boards was high when the board density was relatively low. The results of this experiment may be partly attributed to the light weight characteristics of the kenaf core. This suggests that the kenaf core appears to be a potential raw material for low-density binderless panels suitable for sound absorption and thermal insulation products. In addition, resin adhesive is not added during board manufacturing, and the products are free from formaldehyde emission, which is especially suitable for interior use. Even lower-density (0.10–0.30 g/cm^3) binderless particleboards from kenaf core were developed in this study, and the mechanical properties, dimensional stability, thermal and sound insulation performances of the boards were investigated.

Materials and methods

Raw material preparation

Kenaf (*Hibiscus cannabinus L.*) core about 1.2 m long and 10–20 mm in diameter with an air-dried density of 0.14 g/cm^3 was used as raw material. First, the kenaf core was cut into chips about 5 cm in length and adjusted to a moisture content of about 60%. The kenaf chips were further processed into particles with a target thickness of 0.5 mm using a knife-ring flaker; the particles were then air-dried to about 12% moisture content. According to the mesh analysis, about 75% of the particles used passed through 8-mesh screen and were retained on 60-mesh screen.

Board manufacture

The dimensions of the boards were 300 × 300 × 12 mm. The weights of the kenaf core particles were measured according to their target board densities, after which particles were hand-formed (using a forming box) into homogeneous single-layered mats. After forming, the mats were pre-pressed and then pressed with a sealed steam-injection press. The press was sealed with a 12 mm thick stainless steel frame. Steam was introduced into the press after it closed, and the pressing pressure reached the desired level set at 6 MPa. The mats were pressed with steam gauge pressure of 1.0 MPa (183°C) and treatment times of 7–10 min. The steam was then released. It took about 30 s to release the steam from the press and to open the press. During pressing, the temperature of both the upper and lower platens was kept at 190°C, which was a little higher than the steam temperature to avoid steam condensation.

The target densities of boards were set at five levels: 0.10, 0.15, 0.20, 0.25, and 0.30 g/cm^3. The steam treatment times were set at 7 and 10 min for each target board density level.

Board evaluation

Prior to property evaluation of the mechanical properties, dimensional stability, thermal insulation, and sound absorption properties, the binderless boards were conditioned at room temperature for about 2 weeks. They reached a moisture content of 5%–7%.

The mechanical properties and dimensional stability of the binderless boards were then evaluated in accordance with the Japanese Industrial Standard for Particleboards[11] (JIS A 5908, 1994). The static bending test was conducted on two 12 × 25 × 230 mm specimens from each board using a three-point bending test over an effective span of 180 mm at a loading speed of 10 mm/min. Five to seven 50 × 50 mm test specimens were prepared from each sample board for internal bond (IB) tests. Four specimens of the same size from each sample board were prepared for thickness swelling (TS) and water absorption (WA) tests for 24 h water immersion.

The thermal conductivity and sound absorption coefficient of the particleboards were tested on the boards within the density range 0.10–0.25 g/cm^3. The thermal conductivities of the particleboards were tested on two 50 × 50 × 12 mm specimens from each board in accordance with the American Society for Testing Materials[12] (ASTM C518-76). In addition, the thermal conductivity of rock wool was tested by the same method for comparison.

Normal incident sound absorption coefficients of particleboards were tested on an 84 mm diameter 12 mm thick specimen for each board in accordance with the test for sound absorption of materials by the tube method[13] (JIS A 1405). The standard sound frequency range (100–2000 Hz) was used for the test.

Results and discussion

All the particleboards were successfully manufactured. Except the boards with 0.10 g/cm^3 target density, all the boards had smooth surfaces.

Mechanical properties

It was difficult to test the mechanical properties of the kenaf binderless particleboards at 0.10 g/cm^3 target density for their poor strength. The compaction ratio for 0.10 g/cm^3 density board is only 0.7, resulting in poor contact among particles. The mechanical properties were evaluated only in boards in the target density range of 0.15–0.30 g/cm^3. In this study, the real densities of the specimens were usually 0.01–0.03 g/cm^3 lower than the target densities.

Figure 1 shows the modulus of rupture (MOR) and modulus of elasticity (MOE) of binderless particleboards in relation to board density. The broken lines are the regression lines based on the results of a previous study.[10] The MOR and MOE values obtained in this study matched well with previous results. As the board density increased, the MOR and MOE increased almost linearly. The mean MOR and MOE were 1.1 MPa and 0.3 GPa, respectively, for the board with a density of 0.20 g/cm^3. These values were quite good relative to their low board density. At a board density of 0.256 g/cm^3, kenaf core hot-pressed particleboards using 4% PF as the binder recorded a MOR value of 1.07 MPa,[9] whereas the value for steam-injection-pressed binderless particleboard was 1.85 MPa in this study, which was 1.7 times the former value. Compared with the density, the steam treatment time in the range of this study has little effect on the MOR and MOE.

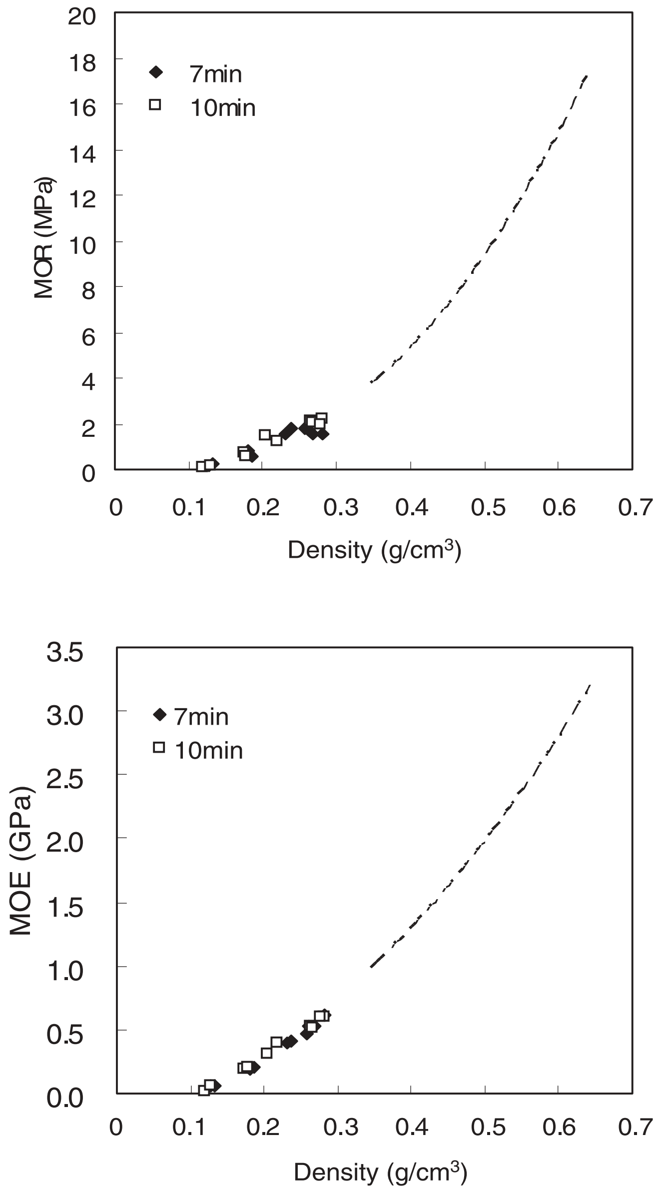

Fig. 1. Effect of board density and steam treatment time on the modulus of rupture (*MOR*) and modulus of elasticity (*MOE*) of kenaf binderless particleboard. The broken lines are the regression lines based on the results of a previous paper[10]

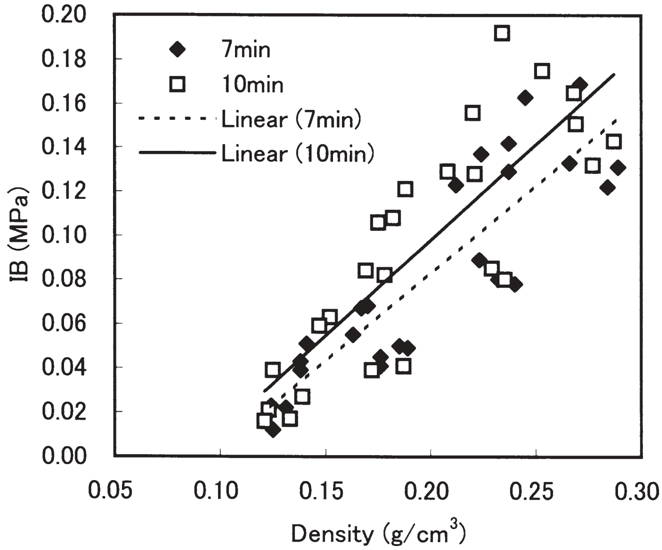

Fig. 2. Effect of board density and steam treatment time on the internal bond strength (*IB*) of low-density kenaf binderless particleboard

For IB strength, as shown in Fig. 2 good results were obtained relative to their low board density; even boards of 0.26 g/cm^3 density can satisfy the requirement of 8-type particleboard (0.15 MPa). The low-density kenaf binderless particleboards showed relatively high IB performance, matching that of other low-density wood-based panels using resin adhesive during board manufacturing: The IB value of steam-injection pressed fiberboards bonded with 10% isocyanate resin adhesive at densities of 0.10–0.30 g/cm^3 was almost the same as that of the kenaf binderless boards in this study.[14] Kenaf core hot-pressed particleboards using 4% PF as the binder had IB values of 0.11–0.21 MPa at a density of 0.256 g/cm^3,[9] which is also similar to the value obtained in this study.

Binderless board with such low density has not been reported before. With a density of 0.50 g/cm^3, the binderless board from kenaf core using conventional hot pressing showed an IB value of 0.09 MPa.[10] The binderless medium-density fiberboard (MDF) from wood fiber using steam-injection pressing recorded an IB value of 0.1 MPa at 0.65 g/cm^3 board density.[15] In this study, the IB value was 0.15 ± 0.06 MPa (average value ± 95% confidence intervals) according to the regression line of 10 min steam treatment time at a density of only 0.26 g/cm^3. The high bondability of steam-pressed kenaf binderless low-density boards may be attributed to the relatively high compaction ratios compared to other low-density boards made from relatively high-density raw materials, as well as to the change of the chemical composition of kenaf core during steam treatment, which was explained in a previous paper.[10]

The steam treatment time also affected the IB value, as shown in Fig. 2, the IB values increased with increasing treatment time. At 0.20 g/cm^3 board density, the IB value for a 10-min treatment time was 18% higher than that at 7 min.

Dimensional stability

The thickness swelling (TS) of the boards are quite good especially for the lower-density board (Fig. 3). The low TS may be attributed to the following factors. One is the low compaction ratio of the boards, causing the springback to be low. The other is application of the steam-injection pressing method, which has proved to increase the dimensional stability of wood-based materials. The steam treatment time affects the TS value, as shown in Fig. 3: the longer the treatment time, the lower the TS. Okamoto et al.[15] reported that the dimensional stability of the MDF improved with increasing treatment time and steam pressure. Thoman and Pearson[16] concluded that the decrease in TS of

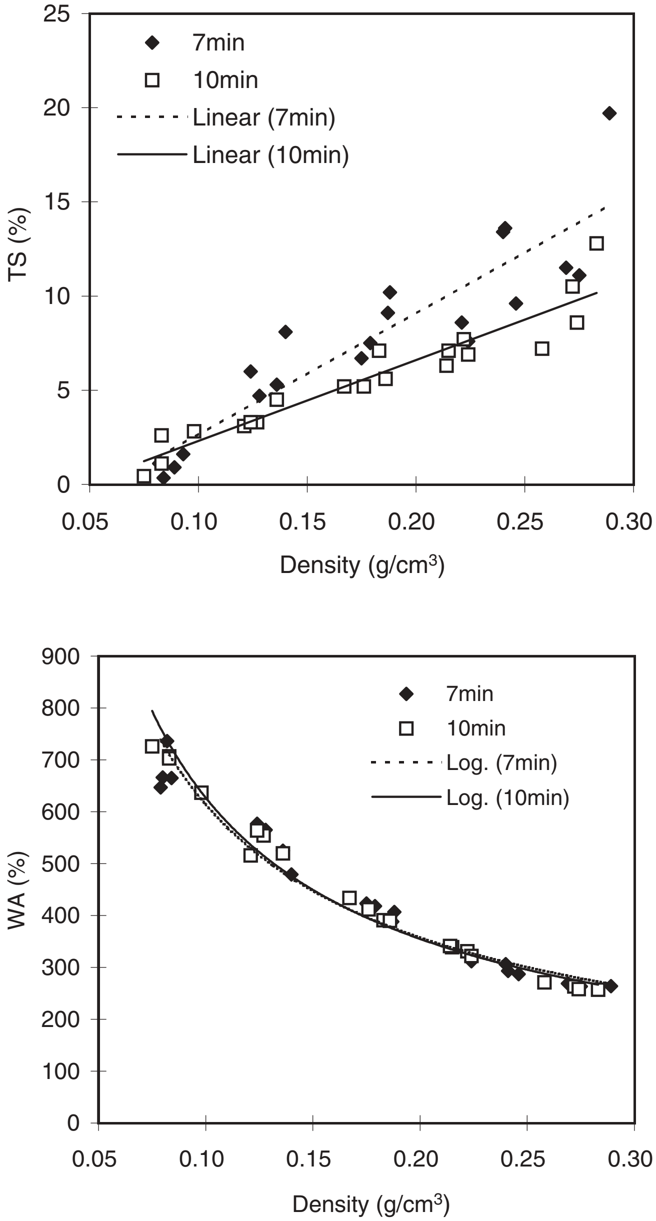

Fig. 3. Effect of board density and steam treatment time on thickness swelling (*TS*) and water absorption (*WA*) after 24 h of water immersion of low-density kenaf binderless particleboard

the steam-pressed boards was 50%–64% that of the controls. The mechanism for improving the dimensional stability may include the following factors: degradation of the hygroscopic hemicelluloses to form free sugars, which may undergo reversion reactions to form less hygroscopic polysaccharides; degradation of the hemicelluloses to form soluble sugars, which in turn form an adhesive during pressing; the relief of internal stresses under the plasticizing action of the steam.

The results of the WA tests are shown in Fig. 3. The WA values in this study were relatively high owing to the porous character of the low-density board, which absorbs more water than the compressed high-density board. The WA values decreased significantly with increasing board density. The WA was 355% at a board density of 0.20 g/cm^3.

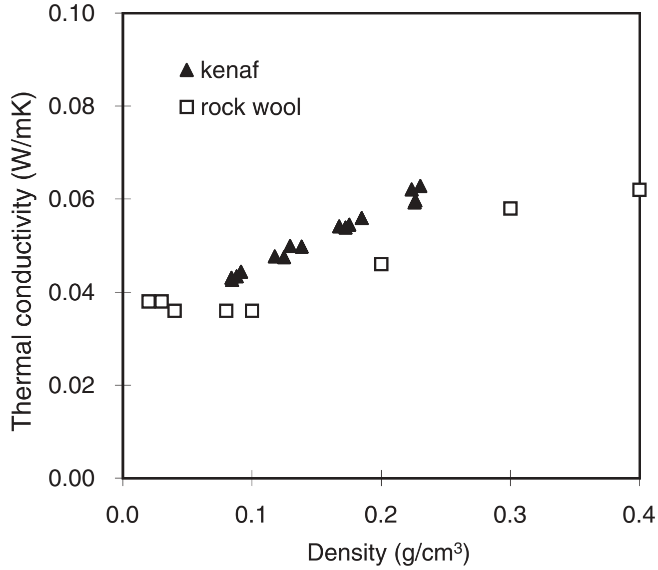

Fig. 4. Thermal conductivity of low-density kenaf binderless particleboard and rock wool

Table 1. Thermal properties of various materials

Material	Density (g/cm^3)	Thermal conductivity (Kcal/mh°C)	Ref.
Kenaf binderless board	0.15	0.043 (0.051)[a]	
Kenaf binderless board	0.20	0.050 (0.058)	
Wood (pine, lauan)	0.45–0.63	0.13 (0.151)	17
Plywood	0.49	0.071 (0.083)	18
Particleboard	0.69	0.083 (0.097)	18
Hardboard	0.89	0.108 (0.126)	18
Insulation board	0.26	0.044 (0.051)	19
Concrete	2.00	1.2 (1.396)	19
Bricks	1.70	0.53 (0.616)	8

[a] Numbers in parentheses are expressed in W/mK

Compared with the results reported by Sellers et al.,[9] kenaf binderless particleboards had excellent dimensional stability. At the same density of 0.256 g/cm^3, the TS was 9.0%, and WA was 290% in this study, whereas those reported in a previous paper[9] were 23% and 246%–325%, respectively.

Thermal insulation properties

Thermal conductivity, λ, is an indicator of the value of a material as a heat insulator. It is directly related to the density of the board, the heaviest boards having the least insulating effect. This is due to the fact that the lighter board contains a large number of voids filled with air, which is one of the poorest conductors. Thus the lighter porous particleboards conduct less heat than the heavier particleboards. As shown in Fig. 4, at a density range of 0.10–0.25 g/cm^3, the λ of the kenaf binderless particleboard is 0.040–0.065 W/mK, almost the same as that of rock wool.

Thermal properties of various materials are shown in Table 1. It can be seen that the λ of the kenaf binderless

Table 2. Sound absorption coefficient of wood-based materials

Material	Density (g/cm^3)	Thickness (mm)	Sound frequency (Hz)					Ref.
			125	250	500	1K	2K	
Kenaf binderless particleboard	0.15	12	0.02	0.05	0.17	0.43	0.64	
Wood board (pine)	0.52	19	0.09	0.1	0.12	0.08	0.08	17
Plywood	0.55	12	0.25	0.14	0.07	0.04	0.10	17
Commercial particleboard	–	20	0.26	0.08	0.08	0.06	0.08	8
Low-density particleboard	0.3	30	0.06	0.15	0.37	0.65	0.52	8
Insulation fiberboard	0.22	12.7	0.04	0.06	0.14	0.38	0.69	17
Low-density fiberboard	0.2	12	0.006	0.02	0.08	0.35	0.71	14

particleboard at a density of $0.15\,g/cm^3$ was 28 times lower than that for concrete, 3 times lower than that for pine solid wood, and 1.9 times lower than that for commercial particleboard. It can be concluded that low-density kenaf binderless particleboards are excellent materials for thermal insulators.

Sound absorption properties

The sound absorption coefficient of a material, α, is defined as the ratio of the sound energy absorbed to the total energy impact. Sound absorption properties were highly dependent on the sound frequency, board density, and board thickness (12 mm in this study). As shown in Fig. 5, at high sound frequency α was relatively high, and it increased with decreasing board density. This is due to the porosity of the low-density board, which provides functional drag, thereby reducing sound energy to heat. The α at lower sound frequencies were relatively low but could be increased by increasing the board thickness. The sound absorption coefficients of various wood-based materials are shown in Table 2. The sound absorption property of kenaf binderless particleboard at a density of $0.15\,g/cm^3$ was almost equal to that of the insulation board. It can be concluded that low-density kenaf binderless particleboards are suitable for sound absorption boards. The board density and board thickness can be adjusted to suit the intended application.

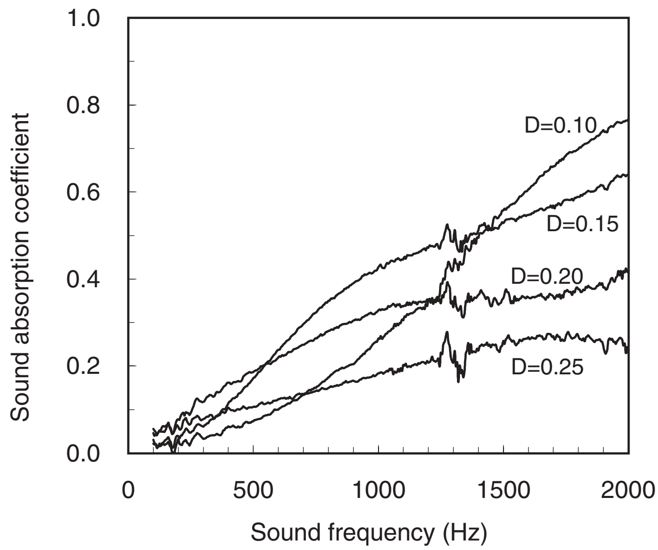

Fig. 5. Sound absorption coefficients of low-density kenaf binderless particleboard. *D*, target board density (g/cm^3)

Conclusions

Low-density binderless particleboards (0.10–$0.30\,g/cm^3$) from kenaf core can be manufactured using steam-injection pressing technology. The mechanical properties and dimension stability of the boards were quite good relative to their low board density. The thermal conductivity of the boards was almost the same as the insulation material (rock wool), and the sound absorption property of the binderless particleboards at $0.15\,g/cm^3$ density was nearly as efficient as that of the insulation board. For overall consideration of the mechanical properties, dimensional stability, and thermal and sound absorption properties of the kenaf binderless particleboard, the boards with densities of 0.15–$0.20\,g/cm^3$ are promising building materials for thermal insulation and sound absorption applications. Moreover, resin adhesive is not added when manufacturing these boards, and the products are free from formaldehyde emission, making them especially suitable for interior use. The low-density kenaf binderless particleboards can be used as ceiling tiles and decorative panel substrates, among offer uses. The board may also be used as the core material for composite panels.

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