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ORIGINAL ARTICLE

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Bond durability of kenaf core binderless boards II: outdoor exposure test

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Abstract An outdoor exposure test was conducted on kenaf core binderless boards (pressing temperatures 200°, 180°, and 160°C; pressing pressure 3.0 MPa, time 10 min, target board thickness 5 mm, target board density 0.8 g/cm^3) to estimate their bond durability. Modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding strength (IB), thickness change, weight loss, Fourier transform infrared (FTIR) spectra, and color difference (ΔE^*) by the CIE $L^*a^*b^*$ system were measured at various outdoor exposure periods up to 19 months. These values were then compared with those of a commercial medium-density fiberboard (MDF; melamine–urea–formaldehyde resin; thickness 9.0 mm, density 0.75 g/cm^3). Generally, dimensional stability and the retention ratios of MOR, MOE, and IB after the outdoor exposure test increased with increased pressing temperature of binderless boards. The MOR retention ratio of the kenaf core binderless boards with a pressing temperature of 200°C was 59.5% after 12 months of outdoor exposure, which was slightly lower than that of the MDF (75.6% after 11 months of outdoor exposure). Despite this, the bond durability of the kenaf core binderless boards should be viewed as favorable, especially when considering the fact that the retention ratio of 59.5% was achieved without binder and without obvious element loss.

Key words Kenaf core · Self-bonding · Binderless board · Durability · Outdoor exposure test

Introduction

Recently there has been considerable interest in issues regarding the negative side effects of synthetic glues on the environment.[1,2] One way to minimize the problem is to use glues from natural sources su ch as tannin,[3] and another is to eliminate the use of glue itself. In this regard, many researchers have investigated the production of binderless boards from various origins.[4–9] We have also studied the production and properties of binderless boards from kenaf core.[10–13] So far, most studies have dealt with the initial board properties after manufacture,[4–10] however; no studies, to our knowledge, have reported on the long-term behavior of binderless boards. Chow[14] conducted a 2-h boiling test on bark binderless boards to evaluate their water-resistance properties; the aging conditions were not severe enough to permit evaluation of their long-term behavior and eventually it was not considered. We assessed the bond durability of kenaf core binderless boards and reported results from a two-cycle accelerated aging boil test.[15] Although use of an accelerated aging test is an effective method for durability estimation,[16,17] accelerated aging cycles are different from actual aging conditions and the resulting material degradations may not be identical.[18] Other studies investigated the relationship between outdoor aging and laboratory aging,[19,20] however; considering the peculiar structure and degradation mechanism of mat-formed panels with its compressed elements, it is necessary to conduct an outdoor exposure test to more accurately evaluate the durability.[18–25] In particular, kenaf core binderless boards manufactured at a pressing temperature of 200°C were highly water resistant and the boiling cycles might not be enough for their degradation.[13,15] Therefore, in this article, we report on an estimation of the durability of kenaf core binderless boards based on an outdoor exposure test.

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Materials and methods

Preparation of binderless boards

Binderless boards were manufactured from kenaf core powder by hot pressing. The kenaf core powder and the manufacturing method were the same as those in our previous study.[13,15] Three manufacturing conditions were used with a different pressing temperature (PT) of 160°, 180°, and 200°C, and the other conditions were as follows: pressing pressure, 3.0 MPa; time, 10 min; target board thickness, 5 mm; board size, 300 × 300 mm; target board density, 0.8 g/cm^3; and press closing time, 5 s. More than 20 boards were manufactured for each PT condition.

Specimens

Binderless board specimens with a size of 50 × 200 mm, three provided from each board, were subjected to the outdoor exposure test described below. No protective coating was applied to the specimens. For reference, a nonstructural medium-density fiberboard (MDF), bonded with melamine–urea–formaldehyde (MUF) resin with a thickness of 9.0 mm and a density of 0.75 g/cm^3, was also used for the test. The surface exposed to sunlight was defined as the "top" surface, and the reverse side surface was defined as the "bottom" surface.

Outdoor exposure test

The specimens were mounted on a rack at 45° facing south, by tying them with wire to plastic mesh (mesh size of 2.0 cm) that was tightly stretched over the plywood frame of the rack, as shown in Figs. 1 and 2. The use of the plastic mesh and wire for specimen support was to ensure free movement of air and water around the specimens. The outdoor exposure test began on 29 May 2004 on the rooftop (urethane membrane waterproofed) of the fifth building in the Graduate School of Agricultural and Life Sciences, the University of Tokyo, Bunkyo-ku, Tokyo, Japan (35° 42′ 59.0″N, 139° 45′ 40.6″E), in full sunshine. Specimens were actually held on the rack in two rows (Fig. 1) at 40–70 cm height from the rooftop. The actual history of the temperature and relative humidity at the exposure site, as shown in Fig. 3, was recorded every hour using a thermo recorder (TR-72S,

Fig. 1. The outdoor exposure test

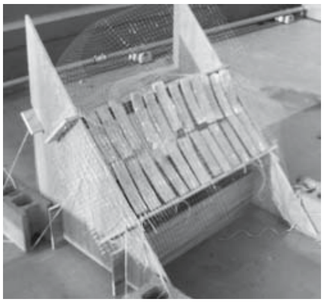
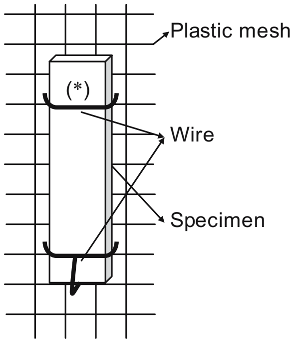


Fig. 2. Specimen support. *Asterisk*, the measuring point for the color analysis, 25 mm from both edges



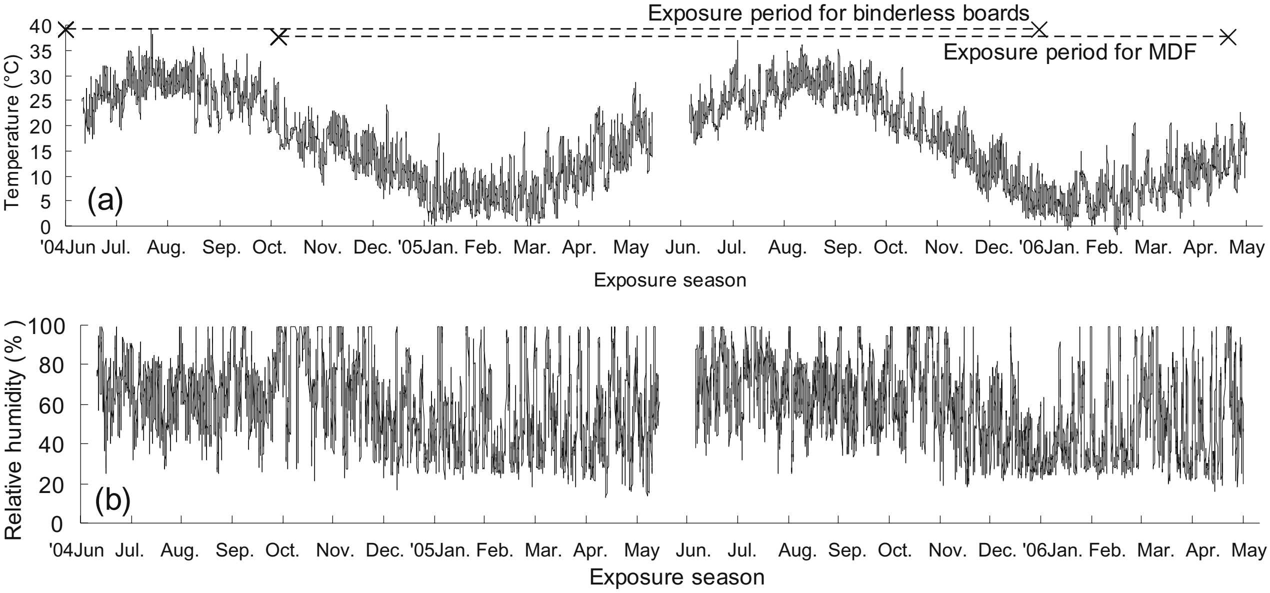


Fig. 3a, b. The history of **a** temperature and **b** relative humidity during the outdoor exposure test. *MDF*, Medium-density fiberboard

Table 1. Monthly average temperature, relative humidity, precipitation and sunshine during the exposure period in Tokyo

Year	Month	Average temperature (°C)	Average relative humidity (%)	Average precipitation (mm)	Sunshine (h)
2004	May	19.6	67	149.0	139.9
	June	23.7	66	112.5	170.6
	July	28.5	62	23.5	232.2
	August	27.2	65	79.5	177.8
	September	25.1	68	195.0	140.0
	October	17.5	69	780.0	116.8
	November	15.6	60	108.5	160.9
	December	9.9	49	79.5	166.3
2005	January	6.1	47	77.0	200.0
	February	6.2	45	48.0	148.9
	March	9.0	49	71.0	175.1
	April	15.1	54	81.0	216.1
	May	17.7	58	180.5	172.3
	June	23.2	70	170.5	119.3
	July	25.6	71	247.5	103.9
	August	28.1	68	189.5	159.9
	September	24.7	67	177.5	154.2
	October	19.2	69	201.5	108.3
	November	13.3	52	34.5	194.6
	December	6.4	39	3.5	212.4
2006	January	5.1	44	67.0	169.9
	February	6.7	53	113.0	128.5
	March	9.8	48	79.5	176.2
	April	13.6	57	123.0	147.0

Data from Amedas Information, 2004–2006, Tokyo, 35° 41.4′N, 139° 45.6′E

Shiro, Japan) installed in a ventilated case for meteorological instruments. The monthly average temperature, relative humidity, precipitation, and sunshine (Amedas Information, 2004–2006, Tokyo, 35° 41.4′N, 139° 45.6′E) during the exposure period in Tokyo are shown in Table 1. For reference, indoor control specimens were kept in a testing room that was conditioned at 20°C and 65% relative humidity.

Evaluation

Specimens were tested as initial controls and after various exposure periods: 1, 3, 6, 9, 12, 15, 17, and 19 months for binderless board specimens with a PT of 200°C (BL200); 1, 3, 6, 9, and 12 months for those with a PT of 180°C (BL180); 1, 3, 4, 5, and 6 months for those with a PT of 160°C (BL160); and 6, 8, 11, 15, 17, and 19 months for MDF specimens. The tests were conducted according to JIS A 5905–1994 (fiberboards), and percent retained strength was determined for each specimen. The parameters assessed were modulus of rupture (MOR), modulus of elasticity (MOE), and internal bonding strength (IB), based on the specimen dimension before exposure. As for BL200, the IB test was conducted twice on the same specimen. The second IB values, with the specimen surface removed by the first IB measurement, were regarded as IB without the influence of surface degradation. Thickness change and weight retention were also evaluated. All specimens were conditioned at 20°C and 65% relative humidity for 7 days (curing process) before testing after they were removed from the rack. Their moisture content (MC) after the curing process was regarded as the equilibrium value according to a preliminary experiment, and the actual specimen MC was determined using fractured specimens immediately after the testing.

Color difference of the specimens for both top and bottom surfaces were determined by a color analyzer (TC-1800, Tokyo Denshoku, Japan) to evaluate their appearance. The color measuring point is shown in Fig. 2. The CIE (Commission International del'Eelarirange) L^* (lightness), a^* (from red to green), b^* (from yellow to blue) color parameters were measured and the color difference (ΔE^*) was calculated according to the following formula:

$$\Delta L^* = L^* - L_0^*;\ \Delta a^* = a^* - a_0^*;\ \Delta b^* = b^* - b_0^*;$$
$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2},$$

where L_0^*, a_0^*, and b_0^* are the initial control values of the specimens before the outdoor exposure.[26]

To investigate the chemical changes during the outdoor exposure, Fourier transform infrared (FTIR) spectra of the binderless board specimens were recorded (FT/IR-615, Jasco, Japan) as KBr tablets.[11] Samples (1.0mg) were scratched from the top and bottom surfaces of the specimens with outdoor exposure periods of 0, 3, and 6 months. They were dried in a vacuum drying oven over P_2O_5 at a temperature of 40°C for 24h before making KBr tablets (KBr 200mg) for the FTIR analysis.

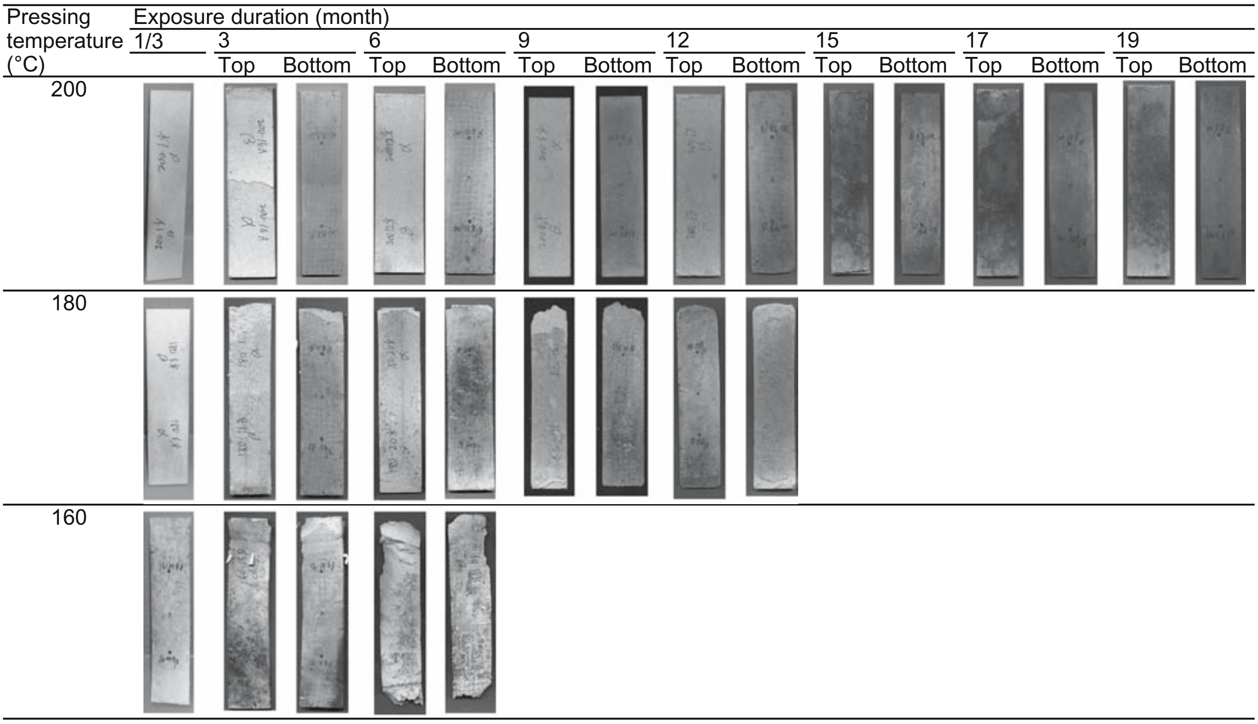


Fig. 4. Appearances of binderless board specimens after different outdoor exposure periods

Results and discussion

Appearance and color change

Figure 4 shows the appearance of binderless board specimens after different exposure periods. Generally, BL200 showed high dimensional stability, while BL180 and BL160 showed element loss from 3 months of exposure.

For all binderless board specimens, slight cracks developed along their section after 1 week of exposure, which was one of the reasons for the great reduction in IB retention ratio as discussed below. The slight cracks showed no further development in BL200, while they developed further in BL180 and BL160. In contrast, for MDF, cracks were not observed until after 12 months of exposure. In the case of structural laminated veneer lumber (LVL),[26] it was reported that cracks were observed in the surface veneer on top after 2–3 months of exposure, suggesting a different deterioration mechanism for wood-based materials made with different element shapes.

As for BL180 and BL160, mold was observed on their top and bottom surfaces, while no mold was observed on BL200 and MDF. The durability observed in BL200 was due to chemical changes during hot pressing,[11,12] and the dimension stability that resulted in constant dryness of the specimens (as shown in Figs. 5–7 below).[15]

Table 2 shows the L^*, a^*, b^*, and ΔE^* values. Generally, after 1 month of exposure (rain season), the top of the specimens changed obviously to a grayish color. As for both top and bottom surfaces, the color difference among binderless boards and MDF after each specific exposure period decreased with increasing exposure duration, regardless of the different initial L^*, a^*, and b^* values. Hayashi et al.[26] reported the color change of structural LVL after an outdoor exposure test. In their study, for example, it was reported that the L^*, a^*, and b^* values of LVL from western hemlock after a 1-year outdoor exposure were 46.1, 0.27, and 7.14, which was found to be quite similar to those of BL200 and BL180, as shown in Table 2. This might indicate that the color of the top surface of wood-based material converges after outdoor exposure, regardless of the raw material, due to the effect of ultraviolet light.

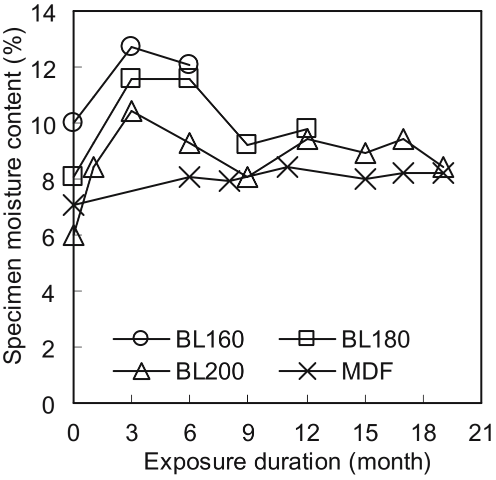


Fig. 5. Specimen moisture content after the curing process. *BL160*, *BL180*, and *BL200* indicate binderless boards with a pressing temperature of 160°, 180°, and 200°C, respectively

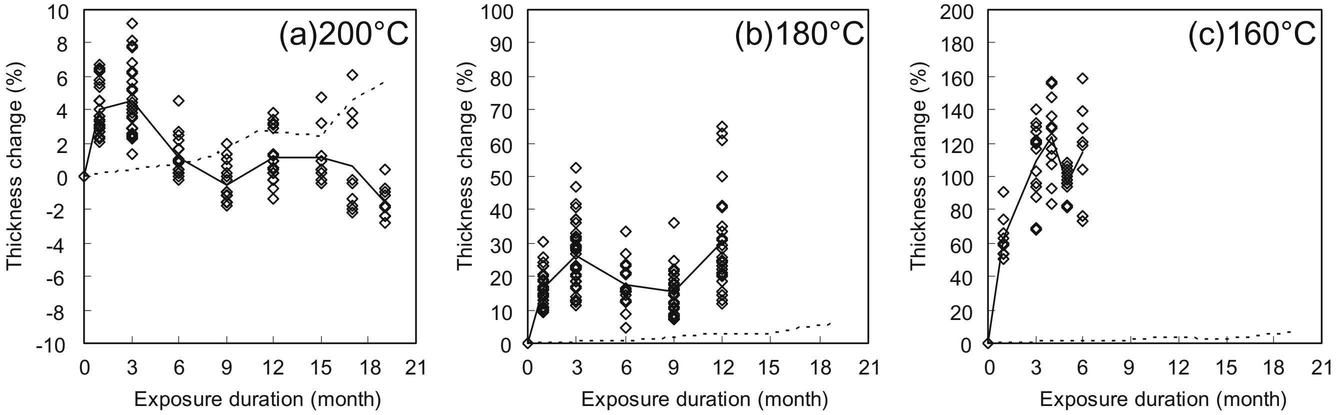


Fig. 6a–c. Relationships between thickness change and exposure duration for binderless boards with a pressing temperature of **a** 200°, **b** 180°, and **c** 160°C. *Solid line*, average values at each exposure period; *broken line*, average values of MDF [melamine–urea–formaldehyde (MUF) type] with thickness 9.0 mm and density 0.75 g/cm^3

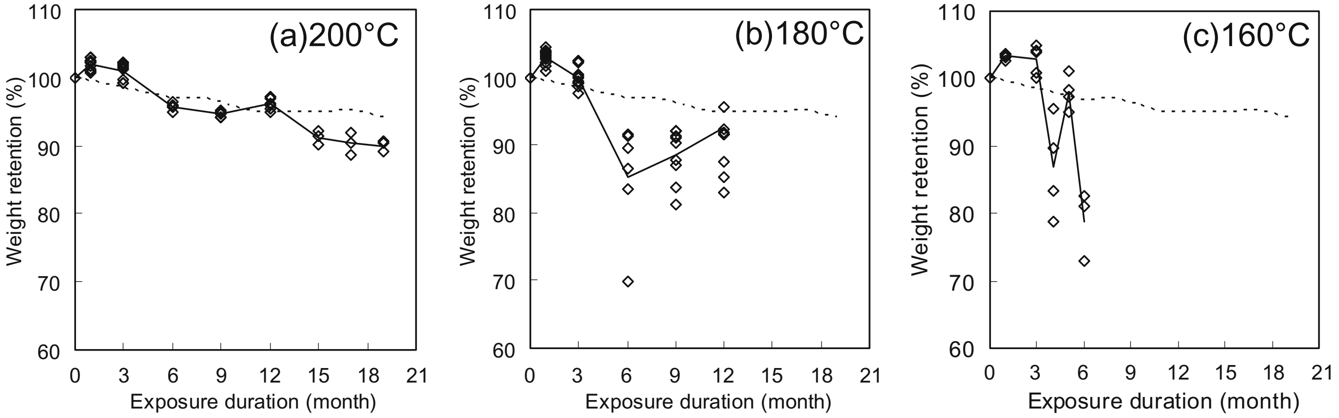


Fig. 7a–c. Relationships between weight retention and exposure duration for binderless boards with a pressing temperature of **a** 200°, **b** 180°, and **c** 160°C. *Solid line*, average value at each exposure period; *broken line*, average value of MDF (MUF type) with thickness 9.0 mm and density 0.75 g/cm^3

In the case of BL200, the IB retention ratio after a 1-month outdoor exposure was lower than that after a two-cycle accelerated aging boil test, and the number of IB specimens that fractured at the surface layer actually increased as outdoor exposure proceeded, suggesting that surface degradation had a great influence on the IB reduction. The surface degradation was mainly due to the combined effects of ultraviolet light and rainwater, and it was reported that part of lignin would be decomposed and extracted out of the boards.[27] Particularly in the case of binderless boards, it should be noted that lignin is suggested to be one of the important factors of self-bonding.[6,11,12] Assuming lignin involvement, surface color change might indicate surface degradation to some extent.

Specimen moisture content

Figure 5 shows the MC of the test specimens after the curing process. The following points were observed: (1) MC of the exposed binderless board specimens increased from their initial state; (2) changes in MC of binderless boards were greater than those of MDF; and (3) MC of binderless boards decreased with increasing PT for a specific exposure period. These changes in MC could have an influence on thickness and weight change which is discussed in the following sections.

Thickness change

Figure 6 shows the thickness change of the binderless boards and MDF for different outdoor exposure durations. For BL200 (Fig. 6a), thickness increased by less than 10% in the first 3 months, which included the rainy season (Table 1). This could be attributed to the following two factors: (1) element swelling that occurred as a result of the increase in MC (Fig. 4); and (2) a decrease in IB (discussed below). The thickness swelling in the first 3 months was recovered from that time forth, but a slight thickness increase was observed from 9 to 12 months including the beginning of the rainy season (Table 1). After 6 months, thickness decrease was sometimes observed even though the MC was increased from the initial state (Fig. 5).

Table 2. Changes in specimen color during the outdoor exposure test

Boards	Exposure duration (months)	Top				Bottom			
		L^*	a^*	b^*	ΔE^*	L^*	a^*	b^*	ΔE^*
BL200	0	33.6	5.3	9.86	0	33.6	5.3	9.86	0
	1	56.0	2.77	13.19	22.8	34.9	5.47	12.17	2.7
	3	60.8	−0.02	5.04	28.2	34.7	6.4	12.36	2.9
	6	57.2	0.19	4.04	24.9	34.5	6.14	12.17	2.6
	9	49.6	0.18	2.77	18.3	40.6	6.04	14.42	8.4
	12	44.5	0.14	2.88	14	29.3	4.57	9.33	4.4
	15	48.5	0.26	2.62	17.3	42.7	4.49	12.4	9.5
	17	38.8	0.12	1.78	10.9	30.6	4.41	9.49	3.1
	19	25.6	0.89	3.64	11.1	31.8	6.16	11.68	2.7
BL180	0	60.0	5.69	18.53	0	60.0	5.69	18.53	0
	3	55.4	0.58	7.15	13.3	39.1	5.75	14.04	21.4
	6	54.7	0.86	6.27	14.2	44.9	4.15	14.6	15.7
	9	53.1	0.16	3.94	17.1	40.1	6.38	15.21	20.3
	12	44.7	0.15	2.66	22.7	51.3	4.42	15.6	9.3
BL160	0	76.1	1.21	16.83	0	76.1	1.21	16.83	0
	1	46.8	2.43	13.64	29.5	45.8	5.48	17.31	30.6
	3	46.4	1.1	6.55	31.4	49.4	4.2	16.21	26.9
	6	43.5	1.02	5.15	34.6	45.4	3.38	14.18	30.9
MDF	0	44.8	4.36	15.26	0	44.8	4.36	15.26	0
	6	48.5	3.55	10.56	6	47.6	5.3	17.33	3.5
	8	41.3	1.55	8.8	7.9	44.4	4.67	15.43	0.6
	11	45.1	0.71	6.86	9.2	31.9	2.61	9.78	14.2
	15	39.2	1.18	6.43	10.9	40.8	3.85	12.33	5
	17	42.7	1.03	5.8	10.3	35.4	3.12	9.87	10.9
	19	43.5	0.75	5.86	10.2	34.4	1.53	8.53	12.7

BL200, BL180, and BL160, binderless boards with a pressing temperature of 200°, 180°, and 160°C, respectively; MDF, medium-density fiberboard bonded with melamine–urea–formaldehyde resin with a thickness of 9 mm and a density of 0.75 g/cm^3; L^*, lightness; a^*, parameter along the x-axis from red to green; b^*, parameter along the y-axis from yellow to blue; ΔE^*, color difference

However, as shown in Fig. 4, element loss was minor and thus the thickness decrease was due to shrinkage of elements as a result of extraction of water-soluble chemical components (discussed below). Generally, BL200 showed high dimensional stability as MDF did, which was consistent with our previous results.[15]

For BL180 (Fig. 6b), a thickness increase was observed at the exposure duration of 1 month, which was in the rainy season. This was because of the combined effects of IB reduction (as discussed below) and element swelling as a result of MC increase (Fig. 5). More than half of the specimen showed delamination at the edge after 3 months of exposure, which was the reason for the relatively wide data variation. The delamination sometimes caused element loss (which can also be observed in Fig. 7b as "weight loss," as discussed below) and the thickness was rather decreased from 3 to 6 months. The thickness increase observed at the exposure duration of 9–12 months might also be due to the rainy season, which was similar to the case of BL200.

For BL160 (Fig. 6c), a marked thickness increase was observed after 1 week and collapse almost occurred at 3 months of exposure. This is partly because the outdoor exposure test was started in the rainy season and the first week included several rainy days.

Weight change

Figure 7 shows the weight retention of the binderless boards and MDF for different outdoor exposure durations. Generally, a weight increase was observed in the binderless board specimens during the first 3 months, which was due to the increase in MC (Fig. 5), while after 6 months weight loss was observed. BL200 showed almost the same weight retention behavior as MDF up until 12 months.

The cases of weight loss in BL200 and MDF were mainly caused by the extraction of water-soluble chemical components (as discussed in the following section), because element loss or biological degradation was not observed (Fig. 4). In contrast, the cases of weight loss observed in BL180 and BL160 were mainly due to element loss (Fig. 4) in addition to extraction of water-soluble components, and it is suggested that the influence of biological degradation was probably small.

Chemical change

Figure 8 shows the FTIR spectra of the binderless boards for different outdoor exposure durations. Generally, it was found that the differences among the FTIR spectra of the

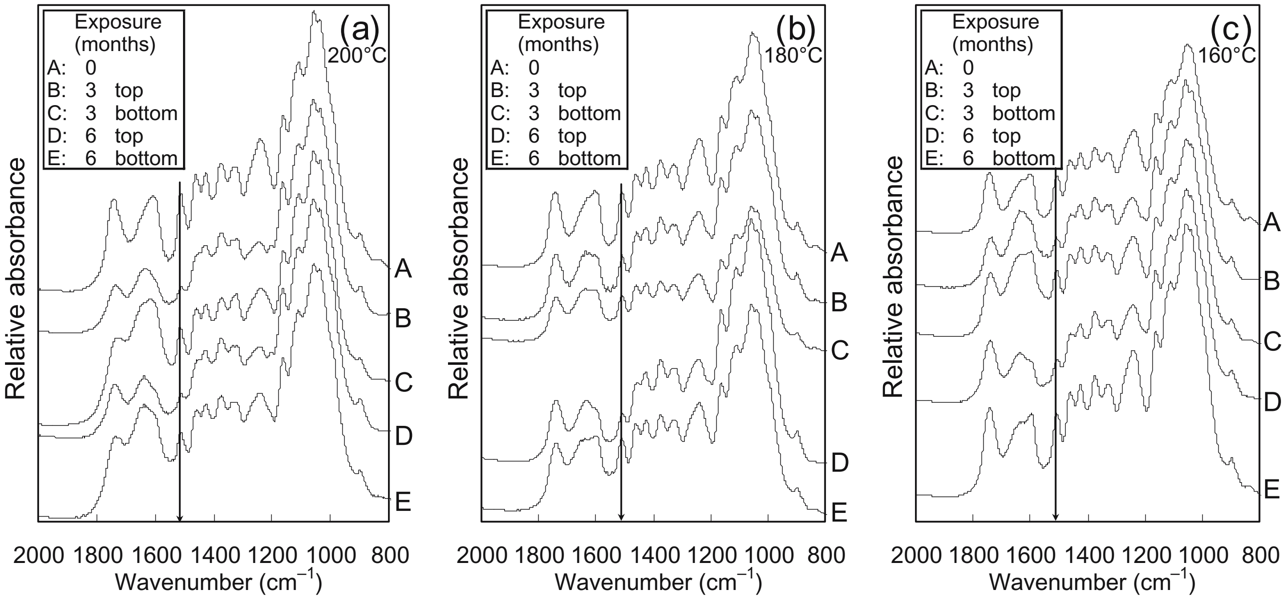


Fig. 8a–c. Fourier transform infrared spectra of the binderless board specimens with a pressing temperature of **a** 200°, **b** 180°, and **c** 160°C for different exposure durations

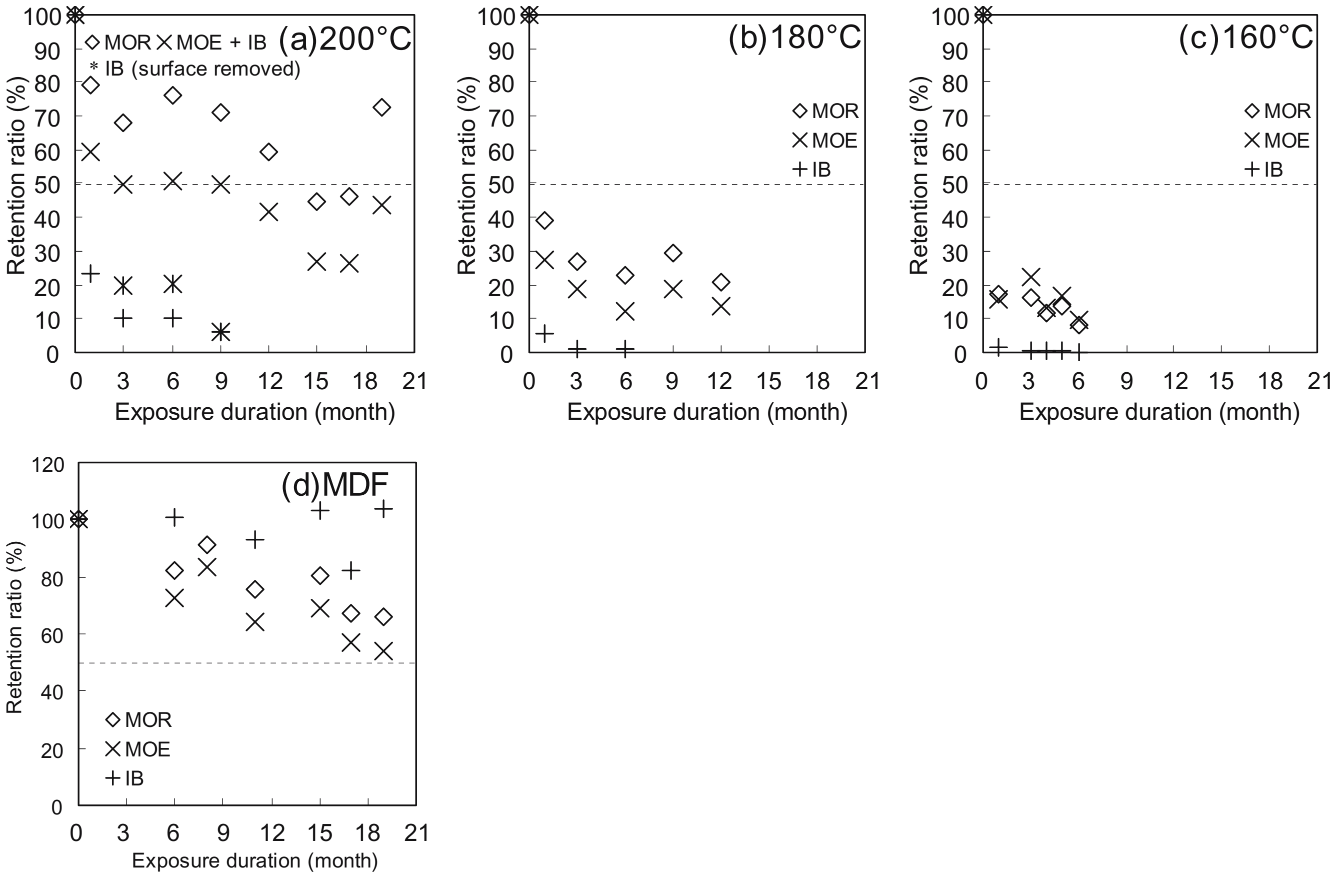


Fig. 9a–d. Relationships between exposure duration and the retention ratios of mechanical properties after outdoor exposure for binderless boards with a pressing temperature of **a** 200°, **b** 180°, and **c** 160°C, and **d** MDF (MUF type) with thickness 9.0mm and density 0.75g/cm^3. *MOR*, Modulus of rupture; *MOE*, modulus of elasticity; *IB*, internal bonding strength

Table 3. Mechanical properties of binderless boards and MDF after outdoor exposure test and those of indoor controls

Boards	Outdoor exposure								Indoor controls				
	Exposure duration (months)	MOR (MPa)	MOE (GPa)	*n*	IB (MPa)	*n*	IB[a] (MPa)	*n*	MOR (MPa)	MOE (GPa)	*n*	IB (MPa)	*n*
BL200	0	14.1 ± 1.77	3.19 ± 0.33	14	1.44 ± 0.40	20	–		14.5 ± 1.72	2.81 ± 0.50	14	1.44 ± 0.40	20
	1	11.2 ± 2.04	1.90 ± 0.37	8	0.34 ± 0.15	16	–		–	–		–	
	3	9.6 ± 2.11	1.59 ± 0.38	6	0.14 ± 0.07	12	0.29 ± 0.09	6	–	–		–	
	6	10.7 ± 3.20	1.63 ± 0.48	6	0.14 ± 0.09	8	0.30 ± 0.05	4	–	–		–	
	9	10.0 ± 2.10	1.59 ± 0.39	6	0.09 ± 0.05	8	0.10 ± 0.04	8	–	–		–	
	12	8.4 ± 1.48	1.34 ± 0.32	6	–		–		14.1 ± 0.30	3.59 ± 0.18	6	1.63 ± 0.21	5
	15	6.3 ± 1.62	0.86 ± 0.24	6	–		–		–	–		–	
	17	6.5 ± 1.99	0.84 ± 0.35	3	–		–		–	–		–	
	19	10.2 ± 1.40	1.39 ± 0.30	3	–		–		–	–		–	
	23	–	–		–		–		14.0 ± 0.86	3.74 ± 0.06	6	1.95 ± 0.34	8
BL180	0	16.4 ± 2.64	3.66 ± 0.41	8	1.49 ± 0.30	16	–		16.4 ± 2.64	3.66 ± 0.41	8	1.49 ± 0.30	16
	1	6.4 ± 2.37	1.01 ± 0.35	8	0.09 ± 0.05	16	–		–	–		–	
	3	4.4 ± 1.26	0.68 ± 0.19	8	0.01 ± 0.01	16	–		–	–		–	
	6	3.7 ± 1.57	0.45 ± 0.22	6	0.02 ± 0.01	8	–		–	–		–	
	9	4.9 ± 0.97	0.68 ± 0.19	9	–		–		–	–		–	
	12	3.4 ± 0.95	0.51 ± 1.34	9	–		–		10.2 ± 1.29	2.41 ± 0.20	6	0.77 ± 0.12	5
	23	–	–		–		–		11.9 ± 1.36	3.06 ± 0.30	6	1.39 ± 0.17	8
BL160	0	14.1 ± 2.82	2.93 ± 0.40	8	1.21 ± 0.32	16	–		14.1 ± 2.82	2.93 ± 0.40	8	1.21 ± 0.32	16
	1	2.5 ± 0.69	0.46 ± 0.10	5	0.02 ± 0.01	10	–		–	–		–	
	3	2.3 ± 0.43	0.65 ± 0.20	5	0.01 ± 0.01	10	–		–	–		–	
	4	1.6 ± 0.12	0.38 ± 0.10	5	0.00 ± 0.01	7	–		–	–		–	
	5	1.9 ± 0.54	0.50 ± 0.10	5	0.01 ± 0.01	8	–		–	–		–	
	6	1.2 ± 0.64	0.28 ± 0.10	3	0.00 ± 0.00	5	–		–	–		–	
	12	–	–		–		–		12.3 ± 3.93	2.74 ± 0.66	5	0.78 ± 0.41	5
	23	–	–		–		–		11.8 ± 1.11	2.85 ± 0.24	5	0.84 ± 0.21	6
MDF	0	35.1 ± 1.57	3.34 ± 0.08	10	0.44 ± 0.10	20							
	6	28.9 ± 3.97	2.43 ± 0.31	6	0.44 ± 0.08	10							
	8	32.1 ± 1.75	2.78 ± 0.10	6	0.56 ± 0.08	8							
	11	26.6 ± 0.92	2.14 ± 0.04	7	0.41 ± 0.10	8							
	15	28.2 ± 1.69	2.31 ± 0.10	9	0.45 ± 0.08	8							
	17	23.5 ± 1.88	1.90 ± 0.09	8	0.36 ± 0.11	8							
	19	23.1 ± 2.34	1.80 ± 0.15	8	0.46 ± 0.10	8							

Data given as average values with standard deviations

MOR, Modulus of rupture; MOE, modulus of elasticity; IB, internal bond strength; *n*, number of specimens

[a] For sample with surface removed

binderless boards with different PT and exposure duration were small. However, a difference was observed in the peak at 1507 cm^{-1} derived from the aromatic units in lignin.[11] It was found that the peak intensity at 1507 cm^{-1} for the top surface of the boards decreased more than that for the bottom surface, as the outdoor exposure progressed. Therefore, it is reasonable to suppose that lignin degradation occurred in the top surface of the boards under the influence of ultraviolet light and that the lignin degradation products were extracted with rainwater.[27] This phenomenon might partly be responsible for the weight loss shown in Fig. 7.

Mechanical properties

Table 3 shows the mechanical properties of binderless boards and MDF after outdoor exposure tests and the mechanical properties of the indoor controls. Although the MOR values of BL180 and BL160 were reduced after indoor exposure, that of BL200 was almost stable. It is suggested that BL200 might have a high durability against indoor exposure condition.

Figure 9 shows the retention ratios of the mechanical properties of binderless boards and MDF after the outdoor exposure. Generally, retention ratios decreased abruptly after 1 month of exposure in the case of binderless boards, which was consistent with other studies where it was reported that a sudden property reduction could often occur at an early stage of outdoor exposure in the case of mat-formed panels.[19,22,24] In contrast, other studies reported that structural LVL showed a rather gradual MOE retention ratio.[26,28] It was also found that the retention ratios increased with increasing PT of binderless boards, indicating an increase in water-resistance properties, as shown in our previous study.[15] In spite of the high water-resistance properties of BL200,[15] its MOR retention ratio was 59.5% after 12 months of outdoor exposure (Fig. 9a). The value was lower than that of MDF, which was 75.6% after 11 months of outdoor exposure (Fig. 9d). In another study, a MOR retention ratio of around 70% after 12 months was reported for particleboard (MUF).[22] However, the bond durability of BL200 could still be viewed favorably considering the fact that the MOR retention ratio was achieved without binder and without obvious element loss (Fig. 4).

The IB retention ratio was found to be improved by specimen surface removal (Fig. 9a), indicating the weakness at its top surface layer. However, the values were still only 19.9% and 20.5% at 3 and 6 months, respectively, after the surface removal. It should also be pointed out that the retention ratios decreased in the order of MOR, MOE, and IB, at for the same PT and exposure duration, the reason for which was described in our previous report[15] and elsewhere.[23] Previously, we showed that the retention ratios of BL200, BL180, and BL160 after a two-cycle accelerated aging boil test were 106.4%, 76.5%, and 47.4% for MOR; 69.1%, 53.3%, and 12.8% for MOE; and 3.4%, 3.3%, and 0% for IB, respectively.[15] Thus, it could be presumed that the condition of 1 month of outdoor exposure (rainy season) was more severe than that of the two-cycle accelerated aging boil test conducted in our previous study.[15]

Conclusions

An outdoor exposure test was conducted on kenaf core binderless boards and their bond durability was then estimated. Generally, dimensional stability and retention ratios of MOR, MOE, and IB of kenaf core binderless board increased with increased pressing temperature. The dimensional stability of BL200 compared favorably with that of MDF (MUF type) for up to 12 months of outdoor exposure. Although they showed sufficiently high water-resistance properties to pass the two-cycle accelerated aging boil test, the MOR retention ratio was 59.5% after 12 months of outdoor exposure, which was slightly lower than that of MDF. However, bond durability was still favorable when considering the fact that the MOR retention ratio of 59.5% was achieved without binder and without obvious element loss.

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