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Bond durability of kenaf core binderless boards I: two-cycle accelerated aging boil test

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Abstract A two-cycle accelerated aging boil test was conducted on kenaf core binderless boards to estimate their bond durability. This is one of the methods to estimate the bond quality of kenaf core binderless boards, as stipulated by Notification 1539 of the Ministry of Land, Infrastructure, and Transport, October 15, 2001, for the Building Standard Law of Japan. Generally, retention ratios of modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB) strength after the boil test increased with increased pressing temperature. In particular, the MOR retention ratio of boards with a pressing temperature of 200°C (average 106.4%) was higher than that of a commercial medium-density fiberboard (MDF) (melamine–urea–formaldehyde resin) (average 72.7%), and the value sometimes exceeded 100%. The durability of kenaf core binderless boards with a pressing temperature of 200°C compared favorably with that of the commercial MDF (melamine–urea–formaldehyde resin), having almost the same retained strength values after the boil test.

Key words Self-bonding · Binderless board · Water resistance property · Durability · Kenaf core

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 such as tannin,[3] while 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] However, most studies have dealt with the initial board properties after manufacture,[4–10] and no studies, to our knowledge, have reported on the long-term behavior of binderless boards. Although 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. Bond quality of binderless boards should carefully be evaluated because no glue is used in their production. For this purpose we have conducted experiments that used accelerated aging tests and outdoor exposure tests to estimate the bond durability of kenaf core binderless boards. In this article, we report on an estimation of the durability of binderless boards based on the results of a two-cycle accelerated aging boil test.

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Materials and methods

Materials

Kenaf core, from kenaf (*Hibiscus cannabinus* L.) grown in Indonesia, was reduced to powder by using a flour mill (model ACM-10; Hosokawa micron, Japan). The obtained powder was almost the same as "Powder-2" used in a previous study.[13] A screen analysis was conducted on 100 g of the powder to determine its particle size distribution, as shown in Table 1. This powder was used for board manufacture without particle size classification, and the moisture content was 8%–9%.

Binderless board manufacture

Binderless boards were manufactured from the kenaf core powder by hot pressing. The method for board manufacture was the same as described in our previous study.[13] The manufacturing conditions were as follows: pressing temperature 160°, 180°, and 200°C; 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. Under 3.0 MPa, binderless boards could be obtained without steam blisters, even at a temperature of 200°C, whereas in our previous study a three-step pressing schedule was necessary for the board manufacture at 200°C.[13] This new pressure condition permitted more accurate comparison between the different pressing temperature treatments.

Evaluation

Three 50 × 200-mm specimens were cut from each binderless board. The outer two specimens of the three were used as controls to determine their average modulus of rupture (MOR) and modulus of elasticity (MOE), as stipulated for the bending test in JIS A 5905-1994 (fiberboards). The same parameters were measured in the center specimen, cut from each binderless board, after the two-cycle accelerated aging boil test (described below) and the percent retained MOR and MOE were determined. The number of sets of the three side-matching specimens used for this test was dependent on the board pressing temperature conditions for more accurate comparison with boards pressed at 200°C: seven sets for boards pressed at 200°C, and four sets each for those pressed at 180° and 160°C.

The fractured specimens from the bending test were cut to provide 50 × 50-mm specimens to conduct internal bonding (IB) testing according to JIS A 5905-1994 (fiberboards). Percent retained IB was determined from the set of three side-matching specimens. The number of specimens for IB test was twice that used for the MOR and MOE tests mentioned above.

The two-cycle accelerated aging boil test was conducted according to Notification 1539 of the Ministry of Land, Infrastructure, and Transport, October 15, 2001, for the Building Standard Law of Japan. Test specimens were boiled in water for 4 h, cooled in water at 20°C for 1 h, and then dried at 70° ± 3°C with sufficient air circulation to lower the specimen moisture content until the weight was lower than the initial weight. These treatments were then repeated and thickness swelling (TS) was determined before the MOR, MOE, and IB measurements.

For reference, the test was also applied to two types of commercial medium-density fiberboard (MDF): MDF-1, urea-formaldehyde resin (UF type), thickness 5.5 mm, density 0.8 g/cm^3; MDF-2, melamine-urea-formaldehyde resin (MUF type), thickness 9.0 mm, density 0.75 g/cm^3.

Table 1. Particle size distribution of kenaf core powder

Aperture size[a] (mm)						
+1.00	+0.500	+0.355	+0.250	+0.180	+0.150	–0.150
2.0	19.3	20.6	24.6	13.4	4.8	15.4

Data given as weight percent
[a] Plus sign, retained on the sieve; minus sign, passed through the sieve

Results and discussion

Table 2 shows the initial mechanical properties, their retained values, and thickness swelling after the accelerated aging cycles. A favorable effect of pressing temperature was observed up to 180°C, but not up to 200°C, in the dry control binderless board specimens, which was consistent with our previous studies.[10,13] Takasu et al.[15] and Takahashi et al.[16] also reported the same tendency. It is reasonable to suppose that this phenomenon could have something in common with that observed in steam-exploded binderless boards (overly severe steam explosion conditions result in reduction of board properties due to fiber damage).[7,17] In contrast, properties shown in Table 2 after accelerated aging cycles generally increased with pressing temperature, and the highest water resistance properties were observed in boards with a pressing temperature of 200°C. This was due to the effect of pressing temperature and the resulting chemical changes during hot pressing, as reported in our previous work.[11–13] It should also be pointed out that the MDF-1 (UF type) collapsed after one cycle and it was impossible to conduct further aging cycles and tests.

Figure 1 shows the relationships between pressing temperature of the binderless boards and their retention ratios for MOR, MOE, and IB after the boil test. Generally, the

Table 2. Properties of dry controls and those following two-cycle accelerated aging

Board type	Control			Two-cycle boil			
	MOR (MPa)	MOE (GPa)	IB (MPa)	MOR (MPa)	MOE (GPa)	IB (MPa)	TS (%)
Binderless (160°C)	14.1	2.9	1.21	0.5	0.1	0.00	195.6
Binderless (180°C)	16.4	3.7	1.49	11.5	1.9	0.19	14.4
Binderless (200°C)	14.1	3.2	1.44	14.8	2.4	0.65	3.6
MDF-1	60.6	5.2	1.40	–	–	–	782.6[a]
MDF-2	35.1	3.3	0.44	25.5	2.3	0.19	5.7

Data given as average values
MOR, modulus of rupture; MOE, modulus of elasticity; IB, internal bond; TS, thickness swelling; MDF-1, commercial medium density fiberboard (urea–formaldehyde resin) (0.8 g/cm^3, board thickness 5.5 mm); MDF-2, commercial medium density fiberboard (melamine–urea–formaldehyde resin) (0.75 g/cm^3, board thickness 9.0 mm)
[a] Value after one cycle. Test was discontinued due to specimen collapse after one cycle

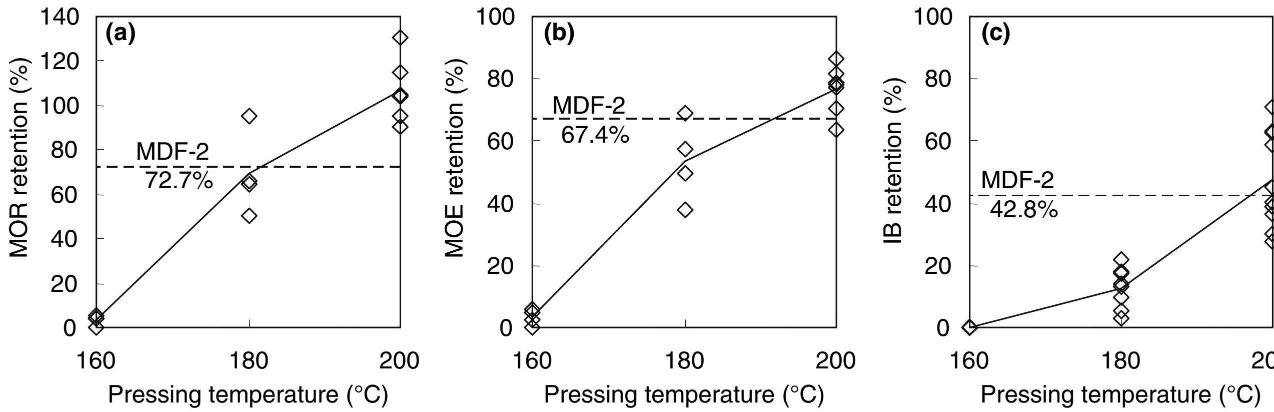

Fig. 1. Relationships between pressing temperature of binderless boards and retention ratios of their mechanical properties **a** modulus of rupture (*MOR*), **b** modulus of elasticity (*MOE*), and **c** internal bonding (*IB*). *Broken lines* show the average values of MDF-2, a commercial medium-density fiberboard (melamine–urea–formaldehyde type) with thickness 9.0 mm and density 0.75 g/cm^3

retention ratios increased with increasing pressing temperature, indicating an increase in water resistance properties. These tendencies could still be inferred even though the data variation was rather wide. The data variation might have originated from the randomness in the three-dimensional distribution of the bond points affected during the aging cycles, because boards were formed quite uniformly.[13] The MOR retention ratios of boards with pressing temperatures of 180° and 200°C were more than 50%, and in particular the values of all specimens pressed at 200°C exceeded those of MDF-2 (MUF type). This was attributed to the effect of pressing temperature[13] and the resulting chemical changes during hot pressing,[11] considering the fact that the water resistance properties of kenaf core binderless boards pressed at 200°C were higher than those of kenaf core particleboards bonded with urea–melamine–formaldehyde resin.[13] In addition, MOR retention ratios of more than 100% were observed in four out of the seven 200°C specimens. With a pressing temperature of 200°C, the MOR in the dry control specimens was rather decreased, whereas the highest water resistance properties were observed, as discussed above. Chow[14] also reported an MOR retention ratio of 98% after a 2-h boil test in the case of Douglas fir bark binderless boards with a pressing temperature of 300°C and pressing time of 5 min. As a result, the bond durability of binderless boards could favorably be inferred because the criterion for the bond durability estimation, stipulated in Notification 1539 for the Building Standard Law of Japan, is to exceed 50% retained strength after an aging treatment.

The degradation process could be estimated by considering the fact that the retention ratios decreased in the order of MOR, MOE, and IB, at the same pressing temperature.[18–20] First, MOE is influenced by the geometrical moment of inertia and MOR is determined based on section modulus, indicating that the two-cycle accelerated aging treatment reduced the effective thickness against the testing load.[18] This means that a decrease in TS (Table 2) could be interpreted as a decrease in loss of effective thickness. Second, during the aging cycles, part of the bond might have broken, and this could have resulted in the low IB retention ratio because IB is considered to be influenced by the strength of the weakest bond point.

Conclusions

An accelerated aging test was conducted on kenaf core binderless boards and their bond durability was then estimated. Generally, percent retained MOR, MOE, and IB of kenaf core binderless board increased with increased pressing temperature. In particular, the MOR retention ratio of boards with a pressing temperature of 200°C was higher than that of the commercial MDF (MUF type), and the value sometimes exceeded 100%. The durability of kenaf core binderless boards with a pressing temperature of 200°C compared favorably with that of the MDF (MUF type), having almost the same retained strength values after the two-cycle accelerated aging boil test.

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