Title Page

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Evaluation of wood-based panel durability using bending properties from accelerated aging treatments

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Abstract

The durability of wood-based panels was evaluated by comparing the bending properties of panels subjected to five accelerated aging treatments with the bending properties of panels that had experienced five years of outdoor exposure in Shizuoka City, Japan. In each accelerated aging treatment, MDI-bonded panels showed higher bending retentions than PF-bonded panels. The bending retentions after six repetitions of the JIS-B, APA D-1, and ASTM treatments showed a correspondence of nearly one-to-one. The Shizuoka City five-year outdoor exposure test showed the bending retentions of all panels decreased with time. In particular, the bending retentions of PF resin-bonded particleboard and oriented strandboard made from aspen were less than 30% and 10% during the five-year exposure period, respectively. The deterioration of the bending properties after the five-year outdoor exposure in Shizuoka City was equal to the ASTM six-cycle treatment.

Text

Introduction

The durability of wood-based panels is one of the most important properties considered in housing construction[1,2], because mat-formed panels, such as particleboard (PB) and medium-density fiberboard (MDF), have become widely used in recent years. For such use, basic information on long-term durability of the wood-based panels is needed. An estimation of how long the panels maintain their required performance under actual environmental conditions has been a goal of many studies.

Methods for evaluating the durability of wood-based panels include long-term and short-term tests. Long-term tests, such as the outdoor exposure test, are methods that evaluate long timeframes by incorporating the factor of elapsed time. Many researchers have conducted outdoor exposure tests using veneer-based samples in Japan[3–6]. Ten-year test results for wood-based panels were reported by Sekino and Suzuki[7]. Several other studies on the durability of mat-formed panels have also been published[8–11]. However, many problems exist in applying test results obtained in North America and Europe[12–16] to Japan, which has different weather conditions. For this reason, accumulating and evaluating test data in Japan is necessary.

In contrast, short-term evaluations assess changes in mechanical properties after accelerated aging treatments, such as water immersion, boiling, steaming, freezing, or drying. Accelerated aging treatments are superior to outdoor exposure tests, and they are essential in determining the durability of wood-based panels. Such accelerated aging treatments may seem artificial, but in recent decades, many attempts have been made to correlate degradation caused by outdoor aging with that of accelerated aging[17,18], including the use of the ASTM D1037[19], APA D-1 and D-4[20], and V313[21] treatments. The results of outdoor aging tests are sometimes used as basic indicators when determining standardized test methods [14,22].

In our previous papers, we focused on thickness swelling (TS) and internal bond strength (IB) during accelerated aging and outdoor exposure tests using eight commercial wood-based panels. We also clarified how accelerated aging treatment results corresponded to given outdoor exposure test results[23-25]. Information from aging treatments using a bending test specimen was very limited, although this information is important for discussing the structural performance of the specimen. Bending properties were difficult to evaluate directly by TS or IB because they were affected not only by the internal bond strength but also by configuration of wood elements. Thus, we focused on evaluating the bending properties to assess the durability performance of wood-based panels.

The objectives of this study were 1) to clarify the effects of accelerated aging treatments on the bending properties of structural panels, 2) to establish correlations between accelerated aging treatments, 3) to assess five-year degradation caused by an outdoor exposure test conducted in Shizuoka City, and 4) to establish correlations between accelerated aging treatments and outdoor exposure tests based on the bending properties.

Experimental

Sample panels

The four groups of commercial wood-based panels used in this research, PB, MDF, oriented strandboard (OSB), and plywood (PW), are widely used for construction purposes in Japan (Table 1). Each panel group included two types of differing specifications for a total of eight panels. The PB panels were made from recycled wood with different binders. The MDF panels differed in thickness, binder, and end-use application. The OSB panels were imported products with different wood species. The Plywood panels also differed in thickness. Because the OSB used in this project was obtained from North America and Europe, these panels were not necessarily representative of the OSB typically used in Japan. Although North America has very little MDI-bonded particleboard or MDF, MDI-bonded PB and MDF were selected because fabricators in Japan show a strong preference for these materials due to their high durability. The parallel direction on each panel surface was defined by the machine direction for PB and MDF, the surface strand alignment for OSB, and the surface veneer grain direction for Plywood. The mechanical properties (modulus of rupture, MOR, and modulus of elasticity, MOE) of the panels before aging treatments are summarized in Table 1.

Accelerated aging test treatments

To determine the bending properties of the eight wood-based panels, five accelerated aging treatments were conducted: cyclic JIS-B, cyclic APA D-1, V313, ASTM six-cycle, and vacuum pressure soaking and drying (VPSD), as described below. With the exception of the VPSD procedure, all of the treatments followed standard methods or modifications of these methods.

(1) The cyclic JIS-B treatment consisted of immersion in boiling water for 2 h, followed by immersion in water at 20°C for 1 h, and then drying at 60°C for 21 h. The treatment was repeated one, three, or six times, and a bending test was conducted after reconditioning.

(2) The cyclic APA D-1 treatment is specified in APA[20]. It consists of immersion in water at 66°C for 8 h, drying at 82°C for 14.5 h, and settling at room temperature for 1.5 h. The treatment was repeated one, three, or six times, and a bending test was conducted after reconditioning.

(3) The V313 treatment is the specified European Standard[21] method for cyclic testing of moisture resistance. The procedure has also been adopted as the Japanese Australian New Zealand Standard (JANS) by the joint committee for Australia, New Zealand, and Japan. The test specimens were exposed to immersion in water at 20°C for 72 h, freezing at –12°C for 24 h, drying at 70°C for 72 h, and settling at room temperature for 4 h. The treatment was repeated one, three, or six times, and a bending test was conducted after reconditioning.

(4) The ASTM six-cycle treatment is a common test method, and is specified in ASTM

D1037 for mat-formed panel products.[19] It consists of six repetitions of combined treatments, including immersion in water at 49°C for 1 h, steaming at 93°C for 3 h, freezing at –12°C for 20 h, drying at 99°C for 3 h, steaming at 93°C for 3 h, and drying at 99°C for 18 h. The treatment was repeated one, three, or six times, and a bending test was conducted after reconditioning.

(5) The VPSD treatment consists of a vacuum pressure soaking and drying. It consists of soaking under vacuum for 0.5 h, soaking under pressure (290 kPa) for 1 h, and drying at 60°C for 22 h. The treatment was repeated one, three, five, or ten times, and a bending test was conducted after reconditioning.

Reconditioning involved oven drying for 24 h at 60°C, followed by 2 weeks of conditioning at 20°C and 65% relative humidity (RH). These five treatments are summarized in Table 2. Ten test pieces measuring 250 mm in the parallel direction × 50 mm were taken from each panel for the bending test. After each treatment, the bending test was performed in accordance with JIS A-5908.[26] In the case of OSB, the bending tests were conducted using only six repetitions for the JIS-B, APA D-1, and ASTM six-cycle treatments, three repetitions for the V313 treatment, and ten repetitions for the VPSD treatment.

Outdoor exposure test in Shizuoka City

For each type of panel, twelve test sample boards, each 300 × 300 mm, were subjected to the outdoor exposure test on the campus of Shizuoka University (Shizuoka City, Japan; 34°N, 138°E). All four edges of each sample were coated with protective agent to prevent excessive edge swelling from water adsorption during test exposure. The boards were set vertically on a test frame facing south. The outdoor test was started in March, 2004, and will run until 2013. In this report, the results of five years of exposure are discussed. Two test sample boards of each type of panel were removed after 1, 2, 3, 4, and 5 years of exposure, and their bending properties were measured after reconditioning. Eight pieces measuring 250 mm in the parallel direction × 50 mm were taken from each panel for the bending test.

Results and discussion

Deterioration of bending properties for each accelerated aging treatment

The bending properties (MOR and MOE) for the control samples (non-treatment) are shown in Table 1. In this paper, the bending retentions were defined as follows:

MOR retention (%) = (MOR after treatment / MOR for control samples) × 100

MOE retention (%) = (MOE after treatment / MOE for control samples) × 100

Figures 1 and 2 show the change in bending retentions found for each of the five accelerated aging test treatments (Fig. 1: MOR retention, Fig. 2: MOE retention). The bending retentions for the cyclic JIS-B, cyclic APA D-1, V313, and ASTM six-cycle treatments represent six repeated cycles. The bending retention for the VPSD treatment was determined after ten repeated cycles. In this paper, when the bending retention was greater than 100%, we defined it as “100% retention”. As shown in Fig. 1, for all aging treatments, the MOR retention of MDF(MDI) was about 80%. The MOR retentions of plywoods varied widely. This is the reason why the initial values for plywoods varied widely. The bending retentions decreased exponentially with increasing cycles. Comparison of binder types showed MDI-bonded panels had higher bending retentions than PF-bonded panels. The MOE retentions (Fig. 2) showed the same tendency as the MOR retentions, but the MOE retentions were lower overall.

Relationships among the five accelerated aging treatments

To determine the relationships among the five accelerated aging treatments (JIS-B six-repetition, APA D-1 six-repetition, V313 three-repetition, ASTM three-repetition, and VPSD ten-repetition), we conducted a linear regression analysis (Y = aX + b) on the aging effects. The coefficients a and b and the coefficient of correlation R are summarized in Table

3. For all combinations of accelerated aging treatments, linear relationships were observed clearly. In particular, each value of R between the JIS-B six-repetition and APA D-1 six-repetition, the JIS-B six-repetition and ASTM six-repetition, the APA D-1 six-repetition and ASTM six-repetition, the APA D-1 six-repetition and VPSD ten-repetition, the V313 three-repetition and VPSD ten-repetition, and the ASTM six-repetition and VPSD ten-repetition treatments, were more than 0.9. Moreover, among these combinations of accelerated aging treatments, there were four combinations that satisfied $R \geq 0.9$ and $-10 \leq b \leq 10$: the JIS-B six-repetition and APA D-1 six-repetition, the JIS-B six-repetition and ASTM six-repetition, the APA D-1 six-repetition and ASTM six-repetition, and the V313 three-repetition and VPSD ten-repetition. The results of the linear regression analysis for these four combinations of accelerated aging treatments, shown in Fig. 3, were as follows:

$$\text{BendingRet (APA D-1(6))} = 1.01 \times \text{BendingRet (JIS-B(6))} \quad (R = 0.96)$$

$$\text{BendingRet (ASTM(6))} = 0.99 \times \text{BendingRet (JIS-B(6))} \quad (R = 0.93)$$

$$\text{BendingRet (ASTM(6))} = 0.98 \times \text{BendingRet (APA D-1(6))} \quad (R = 0.98)$$

$$\text{BendingRet (VPSD(10))} = 0.98 \times \text{BendingRet (V313(3))} \quad (R = 0.91).$$

In these equations, BendingRet is the MOR and MOE retentions after the accelerated aging treatment shown in parentheses. The bending retentions after the JIS-B(6), APA D-1(6), and ASTM(6) treatments showed a nearly one-to-one correspondence. This is why these three accelerated aging treatments were attributed to aging effects of heat and water (moisture) mainly composed of hot water soaking or a steaming step. Moreover, a one-to-one correspondence was observed between V313(3) and VPSD(10). This is why these two accelerated aging treatments were attributed to aging effects of water absorbing or desorption without heating treatment.

Figure 4 shows the relationships for the bending retentions after one-cycle and three-cycle treatments for JIS-B, APA D-1, and ASTM treatments. These combinations showed a nearly one-to-one correspondence after six-cycle treatment. Because the bending test for OSB was conducted only for six-cycle repetitions in this study, the bending retention results for six panels, except for OSB, are shown in Fig. 4. The bending retentions after one-cycle and three-cycle repetitions of the APA D-1 treatment were higher than those of the JIS-B and ASTM six-cycle treatements. Considering the one-to-one correspondence among the bending retentions after six-cycle repetitions of these treatments (Fig. 3), the APA D-1 treatment showed small deterioration of bending properties in the early cycles, which increased with treatment repetitions. On the other hand, the bending retentions after one-cycle and three-cycle repetitions of the JIS-B and ASTM six-cycle treatments showed a nearly one-to-one correspondence. This result indicated that the aging effects of one-cycle of the JIS-B and ASTM six-cycle treatments were similar.

Bending retentions in the outdoor exposure test in Shizuoka City

The outdoor exposure test is a natural weathering method and provides the basis for applying laboratory-based accelerated aging test methods as practical standards. The weather conditions affecting the deterioration for wood-based panels are temperature, precipitation, sunshine duration, wind, and so on. Table 4 shows the bending retention values following five years of outdoor exposure in Shizuoka City. The annual average temperature during these five years was 16.9°C, as compared to the 30-year average of 16.3°C. The annual precipitation (2304 mm) was normal (2322 mm)[27].

The tabulated results show that the bending retentions of all panels decreased with time. In particular, the bending retentions of OSB(pine), PB(PF) and OSB(aspen) were less than 40%, 30% and 10% during the five-year exposure period, respectively. In contrast, MDI-bonded boards maintained high retentions over the same period, because the bending strength of MDI-bonded board is generally equal to or better than that of PF-bonded board[28-30]. For mat-formed panels, except for plywoods, the bending retentions tended to decrease exponentially.

Accelerated aging treatments and outdoor exposure test correlations

The main objective in this report is to discuss the correlations between accelerated aging treatments and outdoor exposure tests using bending properties. Ikeda and Suzuki reported that there was a linear relationship between the IB of the boards after five-cycle repetitions of VPSD and after five years outdoor exposure.[10]

A linear regression analysis ($Y = aX + b$) of the bending retentions of the five accelerated aging treatments and the five-year outdoor exposure test was conducted. The coefficients a and b and the coefficient of correlation R are summarized in Table 5. All accelerated aging treatments showed good correlation ($R = 0.82$ to 0.95) with the five-year outdoor exposure test. Among the five combinations, the combination that satisfied $R \geq 0.9$ and $-10 \leq b \leq 10$ was the combination between the ASTM six-cycle treatment and the five-year outdoor exposure test. This is the reason that the aging effect like ASTM six-cycle consisted of many treatment steps was similar to the aging effect of outdoor exposure test based on the natural weathering. The results of the linear regression analysis for this combination, shown in Fig. 5, were as follows:

$$\text{BendingRet (ASTM(6))} = 1.07 \times \text{BendingRet (five-year outdoor)} \quad (R = 0.91)$$

The deterioration of the bending properties after five years of outdoor exposure was the same as those of the ASTM six-cycle treatment.

Conclusions

In this paper, the relationship between accelerated aging treatments and an outdoor exposure test in Shizuoka City was assessed using bending properties. Five accelerated aging treatments and a five-year outdoor exposure test were performed on eight types of commercial wood-based panels. For each accelerated aging treatment, the bending retentions decreased exponentially with increasing cycles. The MDI-bonded panels showed higher bending retentions than the PF-bonded panels. The bending retentions for some combinations of the five accelerated aging treatments showed high correlations. In particular, the bending retentions after six repetitions of the JIS-B, APA D-1 and ASTM treatments showed a nearly one-to-one correspondence.

The Shizuoka City five-year outdoor exposure test showed that the bending retentions of all panels decreased with time. In particular, the bending retentions of PF resin-bonded particleboard (PB(PF)) and oriented strandboard (OSB) made from aspen were less than 30% and 10%, respectively, after the five-year exposure period.

The deterioration of the bending properties after five years of outdoor exposure was the same as those of the ASTM six-cycle treatment.

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Figure legends

Table 1.

Specifications of the tested commercial panels and bending properties for control samples

Note: a) Data given as mean ± standard deviation

MOR: Modulus of rupture, MOE: Modulus of elasticity

Table 2.

Detailed steps used in each cycle of the five accelerated aging treatments

Note: Conditioning refers to settling at room temperature.

Table 3.

Correlation coefficients for bending properties among the five accelerated aging treatments

Note: The coefficients a and b were determined by linear least-squares regression (Y = aX + b). R is the coefficient of correlation.

Table 4.

Bending retentions resulting from the five-year outdoor exposure test in Shizuoka City

Table 5.

Correlation coefficients for bending properties between accelerated aging treatments and the outdoor exposure test in Shizuoka City

Note: The coefficients a and b were determined by linear least-squares regression (Y = aX + b). R is the coefficient of correlation.

Figure 1.

MOR retentions in the five accelerated aging treatments

Figure 2.

MOE retentions in the five accelerated aging treatments

Figure 3.

Linear regressions of bending retentions for four combinations of accelerated aging treatments

Figure 4.

Linear regression of bending retentions after one-cycle and three-cycle repetitions of accelerated aging treatments

Note: The solid line represents the line Y = X.

Figure 5.

Linear regression of bending retentions between the five-year outdoor exposure test and the ASTM six-cycle treatment

Tables and Figures

Table1

Symbols	Panel types	Adhesives	Thickness (mm)	Density (g/cm^3)	Construction	MOR[a] (MPa)	MOE[a] (GPa)
PB(PF)	Particleboard	PF	12.2	0.76	Three layer	21.6±3.5	3.44±0.46
PB(MDI)		MDI	12.1	0.80		29.7±2.4	3.97±0.19
MDF(MUF)	MDF	MUF	12.2	0.76	homogeneous	44.9±3.0	4.07±0.22
MDF(MDI)		MDI	9.1	0.72		33.8±1.4	3.10±0.15
OSB(aspen)	OSB	PF	12.4	0.64	Three layer cross oriented	37.7±8.9	4.90±0.69
OSB(pine)			11.8	0.68		36.0±6.9	4.68±0.62
PW(12)	Plywood		12.0	0.64	Five-ply	49.3±13.4	6.55±0.84
PW(9)			8.8	0.61	Three-ply	71.8±13.1	8.78±1.16

Table2

Method	Exposure	Temperature (ºC)	Pressure (kPa)	Time (h)
Cyclic JIS-B				
	water soak	100		2
	water soak	20		1
	Dry air heat	60		21
Cyclic APA D-1				
	water soak	66		8
	Dry air heat	82		14.5
	conditioning			1.5
V313				
	water soak	20		72
	Freezing	-12		24
	Dry air heat	70		72
	conditioning			4
ASTM 6-cycle				
	water soak	49		1
	Steam	93		3
	Freezing	-12		20
	Dry air heat	99		3
	Steam	93		3
	Dry air heat	99		18
VPSD				
	Vacuum			0.5
	Pressure soak		290	1
	Dry air heat	60		22

Table3

X-axis	coefficient	Y-axis			
		APA(6)	V313(3)	ASTM(6)	VPSD(10)
JIS-B(6)	a	0.90	0.50	0.88	0.61
	b	7.2	33.2	6.7	26.2
	R	0.97	0.79	0.94	0.88
APA(6)	a		0.59	0.99	0.72
	b		27.4	-0.7	19.6
	R		0.87	0.98	0.95
V313(3)	a			1.29	1.03
	b			-24.5	-2.8
	R			0.86	0.91
ASTM(6)	a				0.71
	b				20.7
	R				0.95

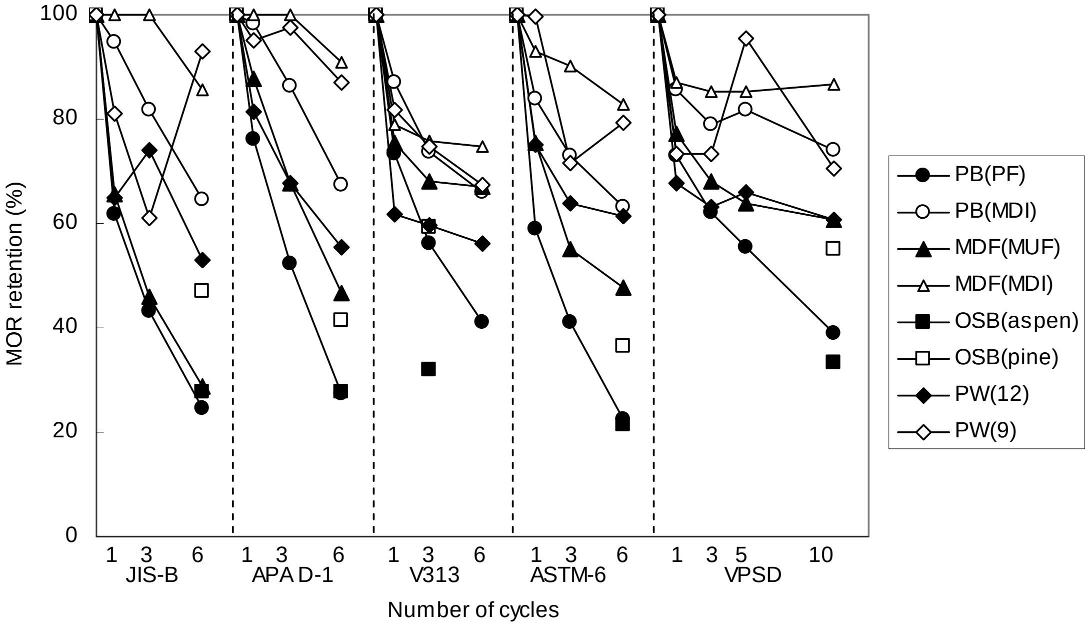
Table4

	1-year		2-year		3-year		4-year		5-year	
	MORret(%)	MOEret(%)	MORret(%)	MOEret(%)	MORret(%)	MOEret(%)	MORret(%)	MOEret(%)	MORret(%)	MOEret(%)
PB(PF)	59	47	44	30	33	22	29	19	25	14
PB(MDI)	96	76	86	70	67	42	63	49	56	40
MDF(MUF)	100	90	90	80	70	51	81	65	59	46
MDF(MDI)	100	100	96	90	72	59	92	76	86	76
OSB(aspen)	35	37	61	52	35	30	11	11	6	4
OSB(pine)	77	73	62	60	41	33	46	36	36	29
PW(12)	73	78	67	66	51	53	78	78	41	58
PW(9)	72	77	59	62	70	47	82	84	64	71

Table5

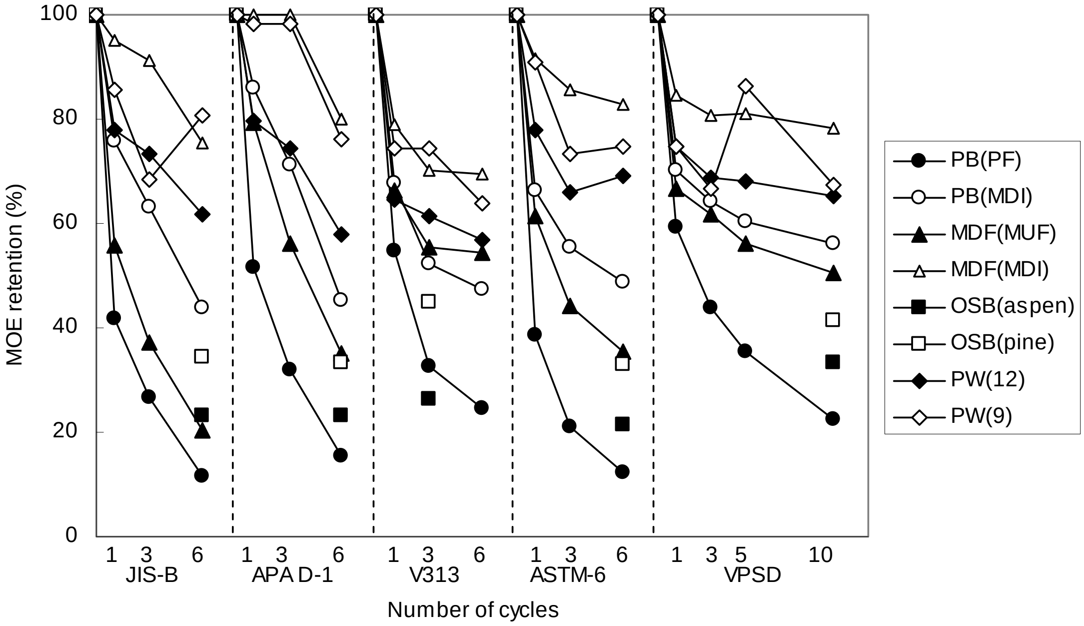
X-axis	coefficient	Y-axis				
		JIS-B(6)	APA(6)	V313(3)	ASTM(6)	VPSD(10)
5-year Outdoor Exposure	a	0.86	0.88	0.61	0.92	0.69
	b	10.4	11.4	30.2	8.7	25.3
	R	0.82	0.92	0.93	0.93	0.95

Figure 1



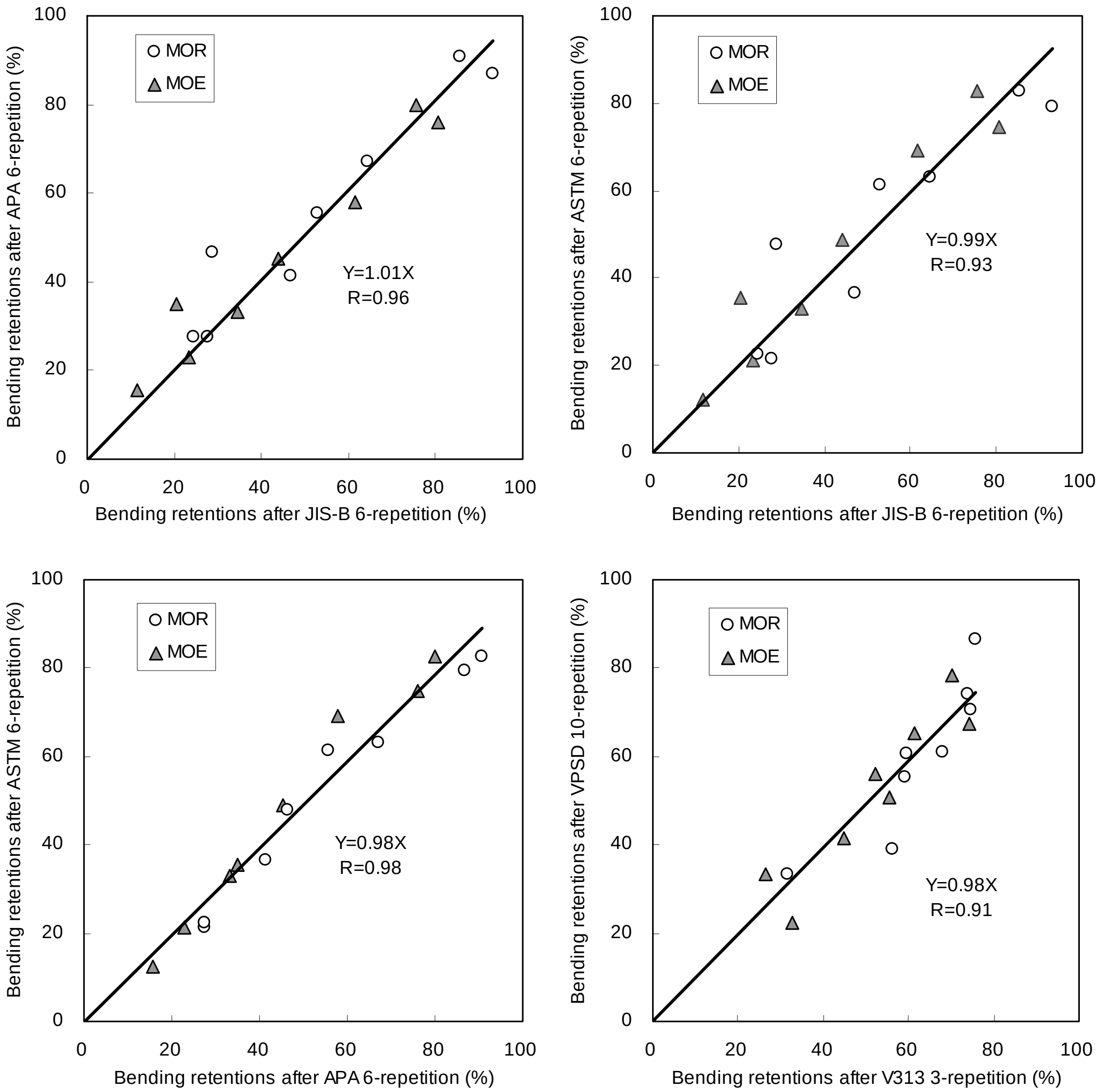
100
80
60
40
20
0
MOR retention (%)
1 3 6
JIS-B
1 3 6
APA D-1
1 3 6
V313
1 3 6
ASTM-6
1 3 5 10
VPSD
Number of cycles
PB(PF)
PB(MDI)
MDF(MUF)
MDF(MDI)
OSB(aspen)
OSB(pine)
PW(12)
PW(9)

Figure 2



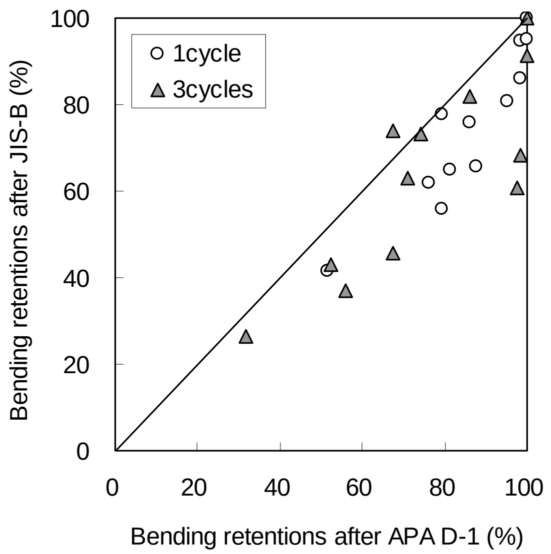
100
80
60
40
20
0
MOE retention (%)
1 3 6
JIS-B
1 3 6
APA D-1
1 3 6
V313
1 3 6
ASTM-6
1 3 5 10
VPSD
Number of cycles
PB(PF)
PB(MDI)
MDF(MUF)
MDF(MDI)
OSB(aspen)
OSB(pine)
PW(12)
PW(9)

Figure 3

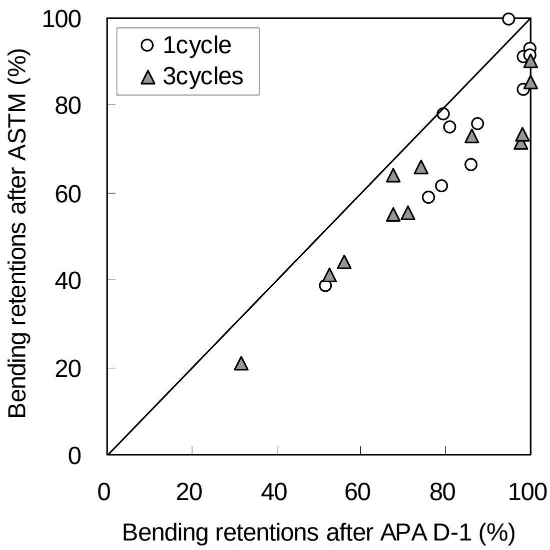


MOR
MOE
Y=1.01X
R=0.96
Bending retentions after APA 6-repetition (%)
Bending retentions after JIS-B 6-repetition (%)
MOR
MOE
Y=0.99X
R=0.93
Bending retentions after ASTM 6-repetition (%)
Bending retentions after JIS-B 6-repetition (%)
MOR
MOE
Y=0.98X
R=0.98
Bending retentions after ASTM 6-repetition (%)
Bending retentions after APA 6-repetition (%)
MOR
MOE
Y=0.98X
R=0.91
Bending retentions after VPSD 10-repetition (%)
Bending retentions after V313 3-repetition (%)

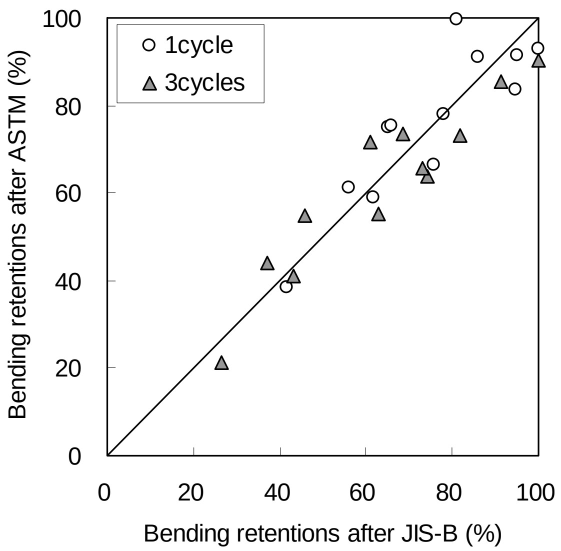
Figure 4



1cycle
3cycles
Bending retentions after JIS-B (%)
Bending retentions after APA D-1 (%)
0
20
40
60
80
100

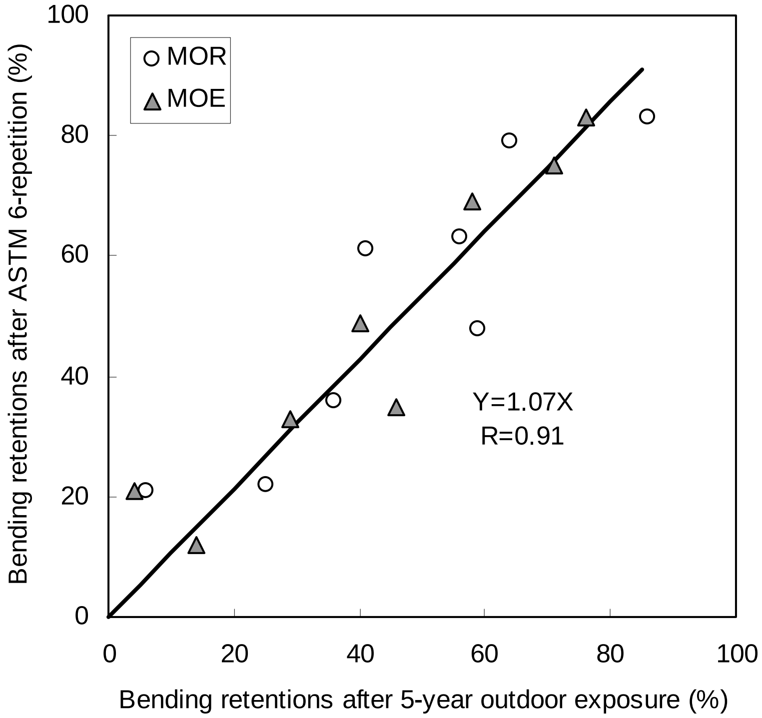


1cycle
3cycles
Bending retentions after ASTM (%)
Bending retentions after APA D-1 (%)
0
20
40
60
80
100



1cycle
3cycles
Bending retentions after ASTM (%)
Bending retentions after JIS-B (%)
0
20
40
60
80
100

Figure 5



100
80
60
40
20
0
0
20
40
60
80
100
MOR
MOE
Y=1.07X
R=0.91
Bending retentions after ASTM 6-repetition (%)
Bending retentions after 5-year outdoor exposure (%)