Title Page

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Evaluating the durability of wood-based panels using internal bond strength results from accelerated aging treatments

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Abstract

In this study, the durability of wood-based panels was evaluated by comparing the internal bond strength (IB) retention after five laboratory-accelerated aging tests with the IB retention arising from 5 years of outdoor exposure in Shizuoka City. In each accelerated aging test, the IB retention of MDI-bonded panels showed high retention as compared to other panels. Outdoor exposure in Shizuoka City resulted in the IB retention for PB (PF) and OSB (aspen) being less than 10% during the 5-year exposure period. MDFs kept initial internal bond strength over the same period. Calculation of mean IB retention allowed comparison of the severity of aging between the accelerated test methods and outdoor exposure. The ASTM six-cycle test method was the most severe among the standard treatment cycles applied.

Text

Introduction

Mat-formed wood-based panels, such as particleboard (PB) and medium-density fibreboard (MDF), have become widely used in residential construction in recent years. For such use, long-term durability of the wood-based panels is important. Estimating how long panels maintain required performance under actual environmental conditions has been a goal of studies evaluating the durability of wood-based materials. To achieve this, the deterioration mechanism(s) must be clarified in relation to various conditions. Many researchers have conducted outdoor exposure tests using veneer-based materials in Japan.[1–4] Sekino and Suzuki reported 10-year test results for wood-based panels, including plywood (PW), oriented strand board (OSB), PB, MDF, hardboard, and cement-bonded PB.[5] Several other studies on the durability of MDF, OSB, and PB have also been published.[6–8] However, many problems exist in applying test results obtained in North America and Europe[9–13] to Japan, which has different weather conditions. For this reason, accumulating and evaluating test data in Japan is needed. To evaluate the durability performance of wood-based panels, mechanical tests using actual building materials should be conducted,[14] but this is very difficult to realize.

Methods for evaluating the durability of wood-based panels include long-term and short-term tests. Long-term evaluation, such as outdoor exposure tests, is a method to evaluate long time frames by incorporating the factor of elapsed time. However, outdoor exposure tests have many disadvantages, such as being time-consuming and difficult to carry out on; moreover, these tests influence from differences caused by the test location.[14] 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 tests are superior to short-term outdoor exposure tests, and they are essential in determining the durability of wood-based panels. Such accelerated aging tests may seem artificial, but in recent decades, many attempts have been made to correlate degradation caused by outdoor aging with that by laboratory-accelerated aging,[15,16] including the use of ASTM D1037,[17] APA D-1 and D-4,[18] and V313[19] tests, because the results of outdoor aging tests are sometimes used as basic indicators when determining standardized test methods.[12,20] In a previous paper, we focused on thickness swelling (TS) during some accelerated aging tests and outdoor exposure using eight commercial wood-based panels and determined the TS characteristics of each aging test. Furthermore, we clarified how laboratory-accelerated aging test results corresponded to a given outdoor exposure test result.[21] However, to understand the durability of wood-based panels, the internal bond strength is one of the most important factors. Moreover, clarifying how laboratory-accelerated aging test results correspond to a given outdoor exposure test result is important.

The objectives of this study were to evaluate the effects of aging treatments on internal bond strength of some structural panels, assess 5-year degradation caused by an outdoor exposure test conducted in Shizuoka, and establish a correlation in aging effects between accelerated aging treatments and outdoor exposure tests using the internal bond (IB) strength.

Experimental

Sample panels

The four groups of commercial wood-based panels used in this study, Particleboard (PB), MDF, OSB, and Plywood (PW), are widely used for construction purposes in Japan (Table 1). Each panel group included two panel types of differing specifications for eight panels in total. The PB panels were made from recycled wood with different binders. The MDF panels differed in thickness, binder type, and end-use application. The OSB panels used 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 are 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 PB and MDF with high durability performance. 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. 22 original panels (100cm×200cm) were prepared for each panel type. These were cut to sample panels (30cm×30cm), and then we selected randomly 24panels for accelerated aging tests and outdoor exposure test. The mechanical properties of the panels before aging treatments are summarized in our previous paper.[22]

Accelerated aging test methods

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

(1) 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 IB testing was conducted after reconditioning.

(2) Cyclic APA D-1 treatment is specified in APA.[18] 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 IB testing was conducted after reconditioning.

(3) V313 is the specified European Standard[19] method for cyclic testing of moisture resistance. The procedure has also been adopted as the JANS (Japanese Australian New Zealand Standard) by the joint committee for Australia, New Zealand, and Japan. The test specimens are 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 IB testing was conducted after reconditioning.

(4) The ASTM six-cycle method is a common test method and is specified in ASTM D1037 for mat-formed panel products.[17] It consists of six repetitions of combined treatments consisting of 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 IB

testing was conducted after reconditioning.

(5) VPSD consists of a vacuum pressure soaking and drying procedure. 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 IB testing 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. Eight test pieces measuring 50 × 50 mm were taken from each panel for the IB test. After each treatment, the IB testing was performed in accordance with JIS A-5908.[23] The loading rate was controlled at 2mm/min.

Outdoor exposure test

For each panel type, 12 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 till 2013. In this report, the results of 5 years of exposure are discussed. Two test sample boards of each panel type were removed after 1, 2, 3, 4, and 5 years of exposure, and the IB was measured after reconditioning that consisted of drying at 60°C for 24 h and conditioning at 20°C and 65% RH for 2 weeks. Thirteen pieces measuring 50 × 50 mm were taken from each panel for the IB test.

Results and discussion

Characteristics of IB deterioration on each accelerated aging treatment

The values of IB for control samples (non-treatment) are shown in Table 1. In this paper, the IB retention was defined as follows:

$$\text{IB retention (\%)} = (\text{IB after treatment} / \text{IB for control samples}) \times 100. \quad (1)$$

Figure 1 shows the changes in IB retention found for each of the five accelerated aging test methods. The IB retention for the Cyclic JIS-B treatment, Cyclic APA D-1 treatment, V313 method, and ASTM six-cycle method are those of six repeated cycles. The IB retention of VPSD was determined after 10 repeated cycles. In this paper, when IB retention became over 100%, we defined it as "100% retention. As shown in Fig. 1, for all aging treatments, the IB retention except for plywood decreased exponentially with cycle increasing. This is because the structure of plywood was different from those of the other panels. For PB (PF) and OSB (aspen), the IB retentions were less than 10% in all treatments. In contrast, the IB retention of PB(MDI) was over 40%. Moreover, MDF (MDI) was about 80% for all aging treatments. To compare element size, the IB retention for MDF was higher than those of PB or OSB. This is the why element size was highly affected to internal bond strength. Of all the standard methods, the ASTM six-cycle procedure provides the most severe treatment. This observation agreed with our previous paper focusing on the TS results from accelerated aging treatments.[21]

To compare the deterioration rates for each treatment, the IB retention of boards versus the number of aging cycles (t) is given by

$$\text{IB retention} = A + (100 - A) \times \exp(-t/B) \qquad (2)$$

where A and B are empirical constants.[24] Coefficient A is the saturation value, and B indicates a decreasing rate. These coefficients were determined by nonlinear least-squares regression. Table 3 shows the values of A and B for the five accelerated aging treatments using six mat-formed panels, except for plywood. Comparing A and B values among panels under the same treatment, the A and B values for MDF (MDI) were the highest of the treatments used. The value of A was lowest for PB (PF).

Next, we examined the relationship between the TS and IB retention, as shown in Fig. 2. The IB retention tended to decrease exponentially with increasing TS. This tendency of IB retention was consistent with previous experimental reports.[25–27] Saito et al.[25–27] suggested that the IB strength tended to decrease exponentially with increasing TS, regardless of the kind of resin in particleboards. In this paper, the TS of boards (T) versus IB retention (R) is given by $R = \exp(4.590 - 0.084T)$. This result is shown as a curve in Fig. 2.

IB retention 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. Table 4 shows the IB retention values following 5 years of outdoor exposure in Shizuoka City. The annual average temperature during these 5 years was 16.9°C as compared to the 30-year average of 16.3°C. Annual precipitation (2304 mm) was the same as normal (2322 mm).[28]

The tabulated results show that the IB retention of PB (PF) and OSB (aspen) were less than 10% during the 5-year exposure period, with a value of 15% for OSB (pine).

In contrast, MDFs maintained their initial internal bond strength over the same period. These results are consistent with those obtained from laboratory-accelerated aging in that MDI-bonded panels showed higher IB retention values than PF-bonded panels under both sets of test conditions. Definitive conclusions cannot yet be drawn because the outdoor exposure test will continue for another 5 years.

Severity of the aging treatments

A period of at least 5 years of outdoor exposure is necessary to obtain reliable results.[29] Thus, in this study, we attempted to compare the results of the five accelerated aging laboratory procedures and those of 1-, 2-, 3-, 4-, and 5-year outdoor exposure tests in Shizuoka City. In Fig. 3, the amount of IB retention resulting from each aging treatment has been used to construct an aging spectrum. The results obtained from a single standard treatment cycle were used for JIS-B and APA D-1, along with IB retention values from three and six standard treatment cycles of V313 and the ASTM six-cycle test, respectively. VPSD results were from one, three, five, and ten cycles. The spectrum indicates that the ASTM six-cycle method for PB (PF), PB (MDI), MDF (MDI), and OSB (pine), 10 VPSD cycles for MDF (MUF), and 5-year outdoor exposure for OSB (aspen) were the most severe treatment conditions. The aging effects resulting from JIS-B, V313, and five VPSD cycles were comparable and of medium severity. One or three VPSD cycles and APA showed only nominal aging effects. The least severe changes arose from 1- or 2-year outdoor exposures, except for plywood (9).

Connection between accelerated aging treatments and outdoor exposure tests

An important goal of this study was to determine the relationship between the accelerated aging methods and outdoor exposure tests. To this end, the mean IB retention was calculated for eight types of panels to relate the severity of accelerated aging treatments to the IB retention arising from outdoor exposure. The mean IB retention was given by

Mean IB retention = [IBr-PB (PF) + IBr-PB (MDI) + IBr-MDF (MUF)…….+ IBr-PW (9)]/8 (3)

Figure 4 shows how the mean IB retention provides a bridge between accelerated aging treatment and outdoor exposure tests. In this figure, the type of aging treatment is given along the *y*-axis. The arrangement of treatments was determined in order of the size of the mean IB retention for six-cycle (ten-cycle for VPSD) or 5-year outdoor exposure; asterisks indicate treatment cycles using the standard method. Based on this figure, the severity of each treatment can be appreciated. For example, the severity of 2-year outdoor exposure is about the same as a single VPSD cycle. Similarly, six APA D-1 cycles are of about the same severity as three JIS-B cycles and ten VPSD cycles. Additionally, 5-year outdoor exposure shows almost the same severity as five VPSD cycles. Of all the standard methods, the ASTM six-cycle procedure provides the most severe treatment, with six JIS-B cycles being the most severe.

Conclusions

The relationship between five laboratory-based accelerated aging tests and outdoor exposure in Shizuoka was assessed using IB strength retention criteria. The results were as follows:

(1) For IB retention using five accelerated aging tests, the retention for PB (PF) and OSB (aspen) panels was smaller than the other panels on every treatment. MDI-bonded panels maintained higher retention, and except for PWs, the retention decreased exponentially. The ASTM six-cycle method was the most severe treatment.

(2) For outdoor exposure results in Shizuoka, the IB retention of PB (PF) and OSB (aspen) were less than 10% during the 5-year exposure period, with values of 15% for OSB (pine). MDFs, however, kept their initial internal bond strength over the same period.

(3) Calculation of mean IB retention allowed the severity of accelerated aging test procedures to be compared to the results of outdoor exposure. The ASTM six-cycle test method showed the greatest severity among the standard treatment cycles, with six repetitions of the JIS-B cycle being the most severe treatment.

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References

1. Yoshida H (1986) Bond durability of water-based polymer-isocyanate adhesives (API resin) for Wood I (in Japanese). Mokuzai Gakkaishi 32(6):432–438
2. Inoue A (1992) A new method for predicting bond durability I (in Japanese). Mokuzai Gakkaishi 38(10):923–930
3. Ishihara S (1994) Durability of fire-retardant lauan plywood after 1-, 2-, 3-, 7- and 15-year outdoor exposures (in Japanese). J Soc Mater Sci Jpn 43:297–303
4. Hayashi T, Miyatake A, Harada M (2002) Outdoor exposure tests of structural laminated veneer lumber. J Wood Sci 48:69–74
5. Sekino N, Suzuki S (2003) Durability of wood-based panels subjected to ten-year outdoor exposure in Japan. Bull Iwate Univ For 34:23–36
6. Ikeda M, Eumi Y, Kimura H, Takase H (1992) Durability of MDF against outdoor exposure (in Japanese). Mokuzai Kogyo 47(12):598–602
7. Suzuki S, Ikeda M, Inoue H, Shibusawa T, Kawai S (1999) Durability performance of laboratory-made OSB and some wood-based panels subjected to outdoor exposure (in Japanese). Wood Preserv 25(6):263–270
8. Hayashi T, Miyatake A, Kawai S (2000) Effects of outdoor exposure on the strength distribution of oriented strand board (OSB) and particleboard (in Japanese). J Soc Mater Sci Jpn 49:384–389
9. Hann RA, Black JM, Blomquist RF (1962) How durable is particleboard? For Prod J 12:577–584
10. Northcott PL, Colbeck HGM (1966) Prediction of plywood bond durability. For Prod J 18:403–408

11. Gressel P (1980) Testing and judging the durability of particleboard adhesives: a proposal for the establishment of generally valid testing guidelines (in German). Holz als Roh- und Werkstoff 38:17–35

12. River BH (1994) Outdoor aging of wood-based panels and correlation with laboratory aging. For Prod J 44(11/12):55–65

13. Okkonen EA, River BH (1996) Outdoor aging of wood-based panels and correlation with laboratory aging. Part 2. For Prod J 46(3):68–74

14. Suzuki S, Watai J (2000) Literature review for durability performance of wood and wood-based material (in Japanese). Bull Shizuoka Univ For 24:63–70

15. Lehmann WF (1977) Durability of composition board products. Proceedings of the WSU Symposium on Particleboard 11:351–368

16. Lehmann WF (1978) Cyclic moisture conditions and their effect on strength and stability of structural flakeboards. For Prod J 28(6):23–31

17. American Society for Testing and Materials (ASTM) (1993) Standard test method for properties of wood-based fiber and particle panel materials. ASTM-D 1037

18. APA-The Engineered Wood Association (1994): APA PRP 108

19. European Standard (1993) Fiberboards, cyclic tests in humid conditions, EN321

20. Dinwoodie JM (1981) Characterizing the performance of chipboard in the United Kingdom. Proceedings of the WSU Symposium on Particleboard 15:59–78

21. Kojima Y, Norita H, Suzuki S (2009) Evaluating the durability of wood-based panels using thickness swelling results from accelerated aging treatments. For Prod J 59(5):35–41

22. Norita H, Kojima Y, Suzuki S (2008) The aging effects of water immersion treatments in wet-bending for standardized testing of wood panels. J Wood Sci

54(2):121–127

23. Japanese Industrial Standards (1994) JIS Standard specification for particleboard, JIS A-5908. Japanese Standards Association, Tokyo

24. Suzuki S, Saito F (1988) Fatigue properties of particleboards. I. Effects of aging treatment on tensile properties parallel to the surface. Mokuzai Gakkaishi 34(7):590–596

25. Saito F, Endang S, Miyata Y (1981) Effect of swelling under mechanical restraint on the internal bond particleboards (in Japanese). Mokuzai Gakkaishi 27(11):782–787

26. Saito F, Endang S, Makino K (1982) Behavior of particleboards subjected to cyclic exposure under restraint (in Japanese). Mokuzai Gakkaishi 28(10):596–602

27. Saito F, Taniguchi T (1984) Particle-bond durability of isocyanate bonded particleboards (in Japanese) Mokuzai Gakkaishi 30(11):921–926

28. National Astronomical Observatory (2008) Chronological Scientific Tables. National Astronomical Observatory, pp 189

29. Deppe HJ (1981) Long-term comparative tests between natural and accelerated weathering exposures of coated and uncoated wood-based material. Proceedings of the WSU Symposium on Particleboard 15:79–100

Figure legends

Table 1. Specifications of the commercial panels tested and internal bond strength under control conditions

Note: a. Data are given as the mean ± standard deviation (n = 10).

Table 2. Detailed steps used in each cycle of the five accelerated aging tests

Note: Conditioning refers to settling at room temperature.

Table 3. Coefficients A and B for the five accelerated aging treatments using eight boards[a]

Notes:

a. The coefficients A and B were determined by nonlinear least-squares regression.

b. Regression analysis could not be performed for MDF (MDI) subject to the V313 method.

Table 4. IB retention resulting from the 5-year outdoor exposure test in Shizuoka City

Note: The standard deviation is given in parentheses (n = 13).

Fig. 1. IB retention in five kinds of accelerated aging tests

Fig. 2. Relationship between thickness swelling and internal bond retention

Note: The solid line is the regression curve.

Fig. 3. The spectrum of aging intensity shown by the various treatments

Note: Mean values of 8 (accelerated aging treatments) and 13 (outdoor exposure) test samples. The error bars represent standard deviations.

Fig. 4. Connection between accelerated aging treatments and outdoor exposure tests

Note: Asterisks indicate treatment procedures using standard methods.

Tables

Table1

Symbols	Panel types	Adhesives	Thickness (mm)	Density (g/cm^3)	Construction	IB[a] (MPa)
PB(PF)	Particleboard	PF	12.2	0.76	Three layer	0.66±0.08
PB(MDI)		MDI	12.1	0.80		1.97±0.17
MDF(MUF)	MDF	MUF	12.2	0.76		0.57±0.07
MDF(MDI)		MDI	9.1	0.72		1.03±0.11
OSB(aspen)	OSB	PF	12.4	0.64	Three layer cross oriented	0.38±0.12
OSB(pine)			11.8	0.68		0.63±0.20
PW(12)	Plywood		12.0	0.64	Five-ply	1.11±0.38
PW(9)			8.8	0.61	Three-ply	1.42±0.37

Table 2

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

Table 3

	Cyclic JIS-B		Cyclic APA D-1		V313		ASTM 6-cycle		VPSD	
	A	B	A	B	A	B	A	B	A	B
PB(PF)	4.7	0.50	5.6	0.69	11.5	0.99	4.3	0.56	13.9	0.85
PB(MDI)	41.2	1.26	40.2	2.33	49.9	1.42	38.4	1.97	62.4	1.78
MDF(MUF)	28.0	1.49	46.7	1.21	68.7	0.63	66.1	1.23	67.8	1.29
MDF(MDI)[b]	80.3	0.99	76.3	3.71	---	---	60.9	3.76	45.4	8.89
OSB(aspen)	9.5	0.49	10.2	0.56	12.4	0.48	8.5	0.62	17.7	0.55
OSB(pine)	18.6	0.59	23.4	0.71	34.2	0.76	15.5	0.76	23.5	1.85

Table 4

	1-year (%)	2-year (%)	3-year (%)	4-year (%)	5-year (%)
PB(PF)	41(18)	26(13)	18(7)	8(4)	7(2)
PB(MDI)	100(9)	88(12)	83(9)	57(7)	42(6)
MDF(MUF)	100(7)	96(9)	100(15)	100(15)	95(12)
MDF(MDI)	100(9)	100(7)	97(7)	100(14)	97(7)
OSB(aspen)	34(16)	51(14)	43(12)	7(2)	6(3)
OSB(pine)	79(20)	60(17)	36(10)	31(14)	15(7)
PW(12)	100(19)	61(37)	49(17)	84(21)	75(24)
PW(9)	100(25)	91(37)	83(23)	92(23)	97(15)

Figures

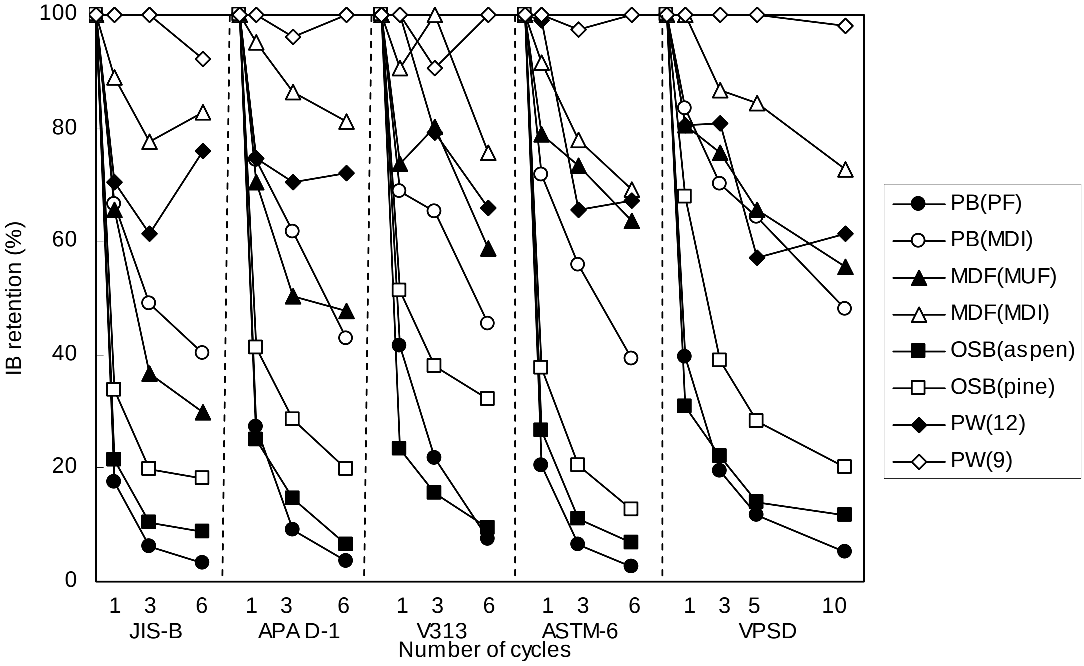
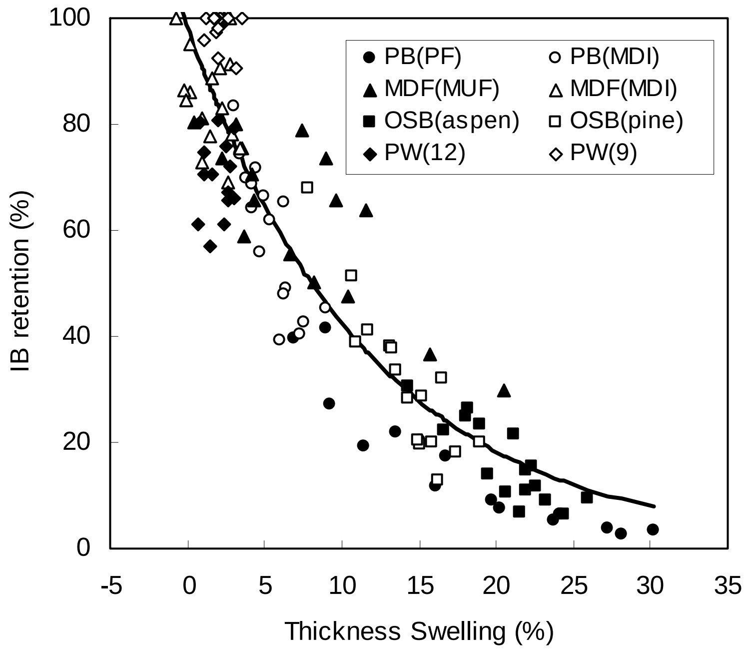
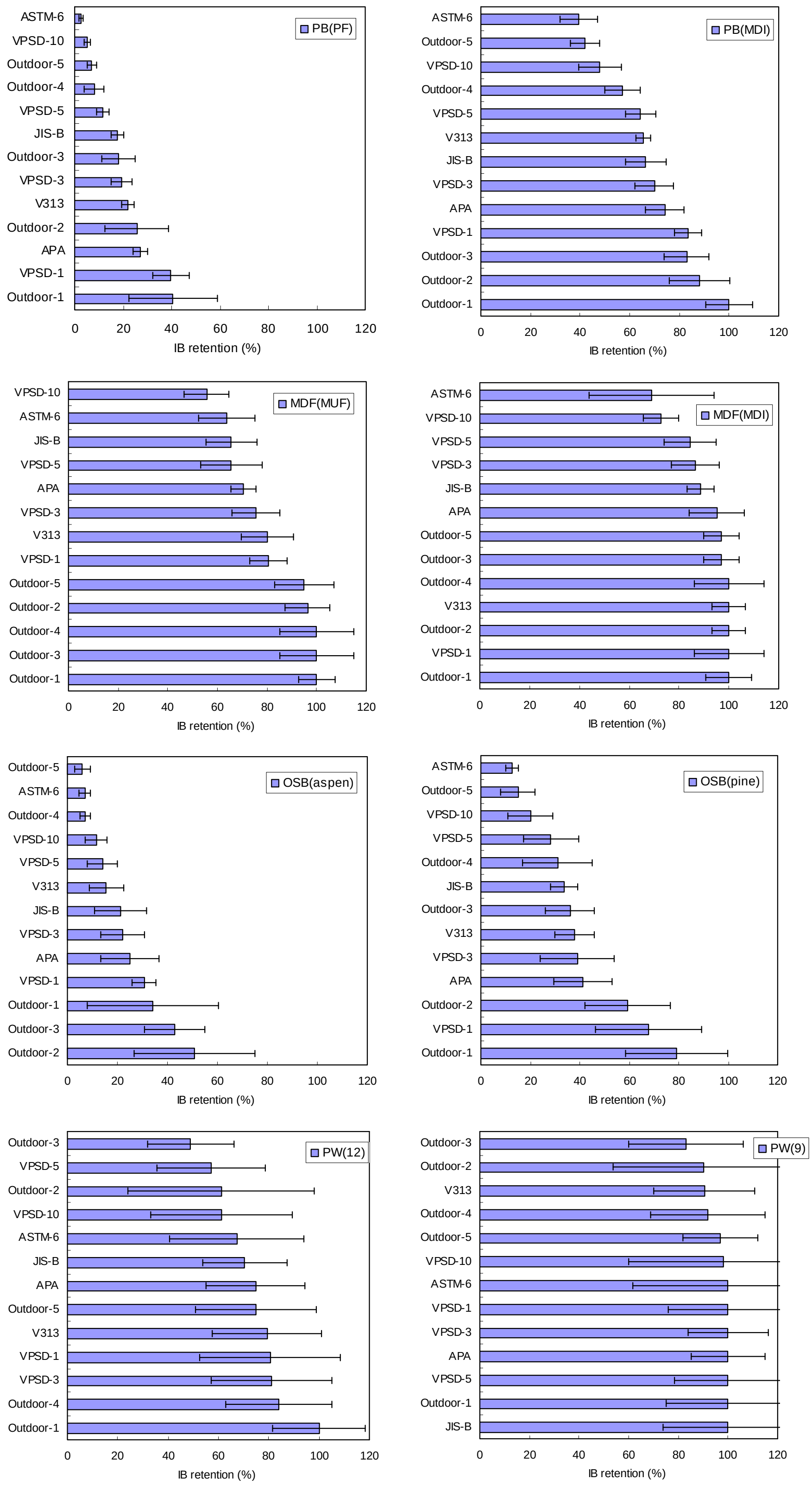


Figure 1



100
80
60
40
20
0
-5
0
5
10
15
20
25
30
35
IB retention (%)
Thickness Swelling (%)
PB(PF)
PB(MDI)
MDF(MUF)
MDF(MDI)
OSB(aspen)
OSB(pine)
PW(12)
PW(9)

Figure 2


PB(PF)
ASTM-6
VPSD-10
Outdoor-5
Outdoor-4
VPSD-5
JIS-B
Outdoor-3
VPSD-3
V313
Outdoor-2
APA
VPSD-1
Outdoor-1
0 20 40 60 80 100 120
IB retention (%)
PB(MDI)
ASTM-6
Outdoor-5
VPSD-10
Outdoor-4
VPSD-5
V313
JIS-B
VPSD-3
APA
VPSD-1
Outdoor-3
Outdoor-2
Outdoor-1
0 20 40 60 80 100 120
IB retention (%)
MDF(MUF)
VPSD-10
ASTM-6
JIS-B
VPSD-5
APA
VPSD-3
V313
VPSD-1
Outdoor-5
Outdoor-2
Outdoor-4
Outdoor-3
Outdoor-1
0 20 40 60 80 100 120
IB retention (%)
MDF(MDI)
ASTM-6
VPSD-10
VPSD-5
VPSD-3
JIS-B
APA
Outdoor-5
Outdoor-3
Outdoor-4
V313
Outdoor-2
VPSD-1
Outdoor-1
0 20 40 60 80 100 120
IB retention (%)
OSB(aspen)
Outdoor-5
ASTM-6
Outdoor-4
VPSD-10
VPSD-5
V313
JIS-B
VPSD-3
APA
VPSD-1
Outdoor-1
Outdoor-3
Outdoor-2
0 20 40 60 80 100 120
IB retention (%)
OSB(pine)
ASTM-6
Outdoor-5
VPSD-10
VPSD-5
Outdoor-4
JIS-B
Outdoor-3
V313
VPSD-3
APA
Outdoor-2
VPSD-1
Outdoor-1
0 20 40 60 80 100 120
IB retention (%)
PW(12)
Outdoor-3
VPSD-5
Outdoor-2
VPSD-10
ASTM-6
JIS-B
APA
Outdoor-5
V313
VPSD-1
VPSD-3
Outdoor-4
Outdoor-1
0 20 40 60 80 100 120
IB retention (%)
PW(9)
Outdoor-3
Outdoor-2
V313
Outdoor-4
Outdoor-5
VPSD-10
ASTM-6
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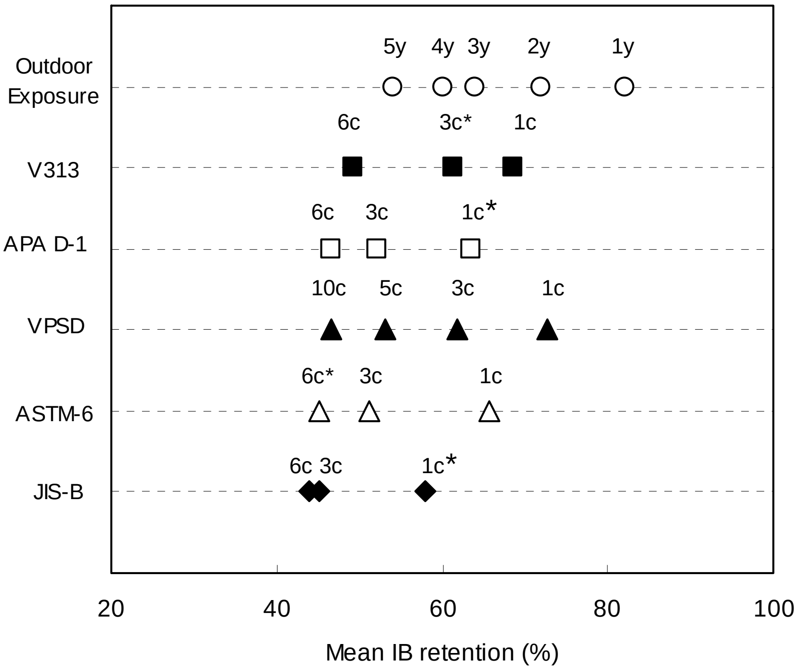
VPSD-5
Outdoor-1
JIS-B
0 20 40 60 80 100 120
IB retention (%)

Figure 3



5y
4y
3y
2y
1y
Outdoor Exposure
6c
3c*
1c
V313
6c
3c
1c*
APA D-1
10c
5c
3c
1c
VPSD
6c*
3c
1c
ASTM-6
6c 3c
1c*
JIS-B
20
40
60
80
100
Mean IB retention (%)

Figure 4