J Wood Sci (2011) 57:126–133
DOI 10.1007/s10086-010-1146-x

ORIGINAL ARTICLE

Yoichi Kojima · Shigehiko Suzuki

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

Received: June 2, 2010 / Accepted: July 21, 2010 / Published online: October 29, 2010

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 5 years of outdoor exposure in Shizuoka City, Japan. In each accelerated aging treatment, methylene diphenyl diisocyanate-bonded panels showed higher bending retention than phenol formaldehyde (PF)-bonded panels. The bending retentions after six repeated cycles of the JIS-B, APA D-1, and ASTM treatments showed a correspondence of nearly one-to-one in the data for the three different treatments. The Shizuoka City 5-year outdoor exposure test data showed that 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% of the original values, respectively, after the 5-year exposure period. The deterioration of the bending properties after the 5-year outdoor exposure in Shizuoka City was the same as that for six repetitions of the ASTM treatment.

Key words Wood-based panel · Bending properties · Durability performance · Accelerated aging treatments · Outdoor exposure

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 quicker to perform and more standardized than 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 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 articles, 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 is very limited, although this information is important for discussing the structural performance of the specimen. Bending properties are difficult to evaluate directly by TS or IB measurement because they are affected not only by the internal bond strength but also by the configuration of the wood elements. Thus, we focused

Y. Kojima (✉) · S. Suzuki
Faculty of Agriculture, Shizuoka University, 836 Ohya, Suruga-ku, Shizuoka 422-8529, Japan
Tel. +81-54-238-4856; Fax +81-54-238-4856
e-mail: ykojima@agr.shizuoka.ac.jp

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 5-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 from different wood species. The plywood panels also differed in thickness. Because the OSB samples used in this project were 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 methylene diphenyl diisocyanate (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 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 carried out one, three, or six times, and a bending test was conducted after reconditioning.
2. The cyclic APA D-1 treatment is specified by 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 carried out 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 carried out 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 cycle of six treatment steps, i.e., 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 carried out one, three, or six times, and a bending test was conducted after reconditioning.
5. The VPSD treatment involves 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 carried out 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 1. Specifications of the tested commercial panels and bending properties for control (untreated) samples

Abbreviation	Panel type	Adhesive	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	37.7 ± 8.9	4.90 ± 0.69
OSB(pine)			11.8	0.68	cross oriented	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

[a] Data are given as mean ± standard deviation
MOR, modulus of rupture; MOE, modulus of elasticity; PB, particleboard; PF, phenol formaldehyde; MDI, methylene diphenyl diisocyanate; MDF, medium-density fiberboard; MUF, melamine-urea-formaldehyde; OSB, oriented strandboard; PW, plywood

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] For OSB, the bending tests were conducted only after the JIS-B, APA D-1, and ASTM treatments had been carried out six times; the V313 treatment had been carried out three times; and the VPSD treatment had been carried out ten times.

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 a 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 started in March 2004 and will run until 2013. In this report, the results of 5 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.

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

Method	Exposure	Temperature (°C)	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 six-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

Conditioning refers to settling at room temperature
VPSD, vacuum pressure soaking and drying

Results and discussion

Deterioration of bending properties for each accelerated aging treatment

The bending properties (MOR and MOE) for the control samples (untreated) are shown in Table 1. In this article, the bending retentions are defined as follows:

$$\text{MOR retention (\%)} = (\text{MOR after treatment}/\text{MOR for control samples}) \times 100$$

$$\text{MOE retention (\%)} = (\text{MOE after treatment}/\text{MOE for control samples}) \times 100$$

Figures 1 and 2 show the changes in bending retentions found for each of the five accelerated aging test treatments. The bending retentions for the cyclic JIS-B, cyclic APA D-1, V313, and ASTM six-cycle treatments are shown for one, three, and six repeated cycles; the bending retentions for the VPSD treatment are shown after one, three, five, and ten cycles. In this article, if 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. The bending retentions decreased

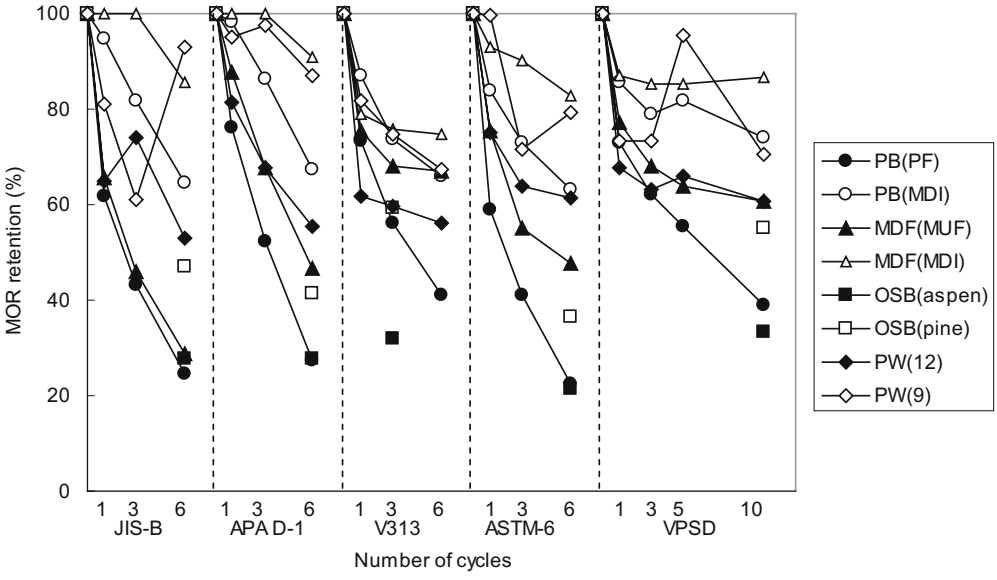

Fig. 1. Modulus of rupture (*MOR*) retentions for the five accelerated aging treatments. *PB*, particleboard; *PF*, phenol formaldehyde; *MDI*, methylene diphenyl diisocyanate; *MDF*, medium-density fiberboard; *MUF*, melamine-urea-formaldehyde; *OSB*, oriented strandboard; *PW*, plywood; *VPSD*, vacuum pressure soaking and drying

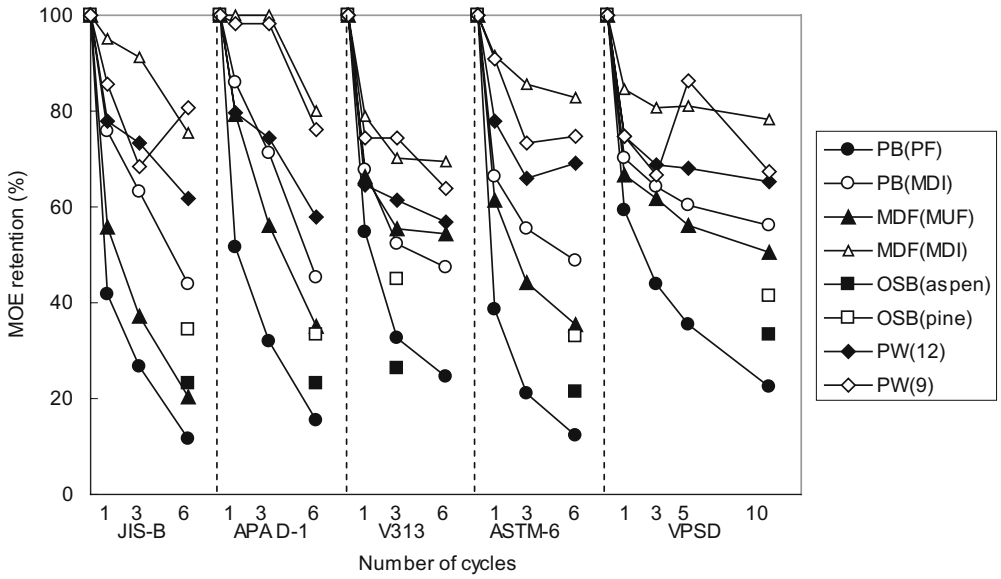

Fig. 2. Modulus of elasticity (*MOE*) retentions for the five accelerated aging treatments

Table 3. Correlation coefficients for bending properties among the five accelerated aging treatments

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

The number of repeated cycles is given in parentheses
The coefficients *a* and *b* were determined by linear least-squares regression ($Y = aX + b$)
R is the coefficient of correlation

exponentially with increasing cycles. Comparison of the binder types showed that MDI-bonded panels had higher bending retentions than phenol formaldehyde (PF)-bonded panels. The MOE retentions (Fig. 2) showed the same tendency as that for 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 [with the number of repetitions shown in parentheses: JIS-B(6), APA D-1(6), V313(3), ASTM(6), and VPSD(10)], we conducted 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 clearly observed. In particular, the *R* values between the following pairs of treatments were greater than 0.9: the JIS-B(6) and APA D-1(6), the JIS-B(6) and ASTM(6), the APA D-1(6) and ASTM(6), the APA D-1(6) and VPSD(10), the V313(3) and VPSD(10), and the ASTM(6) and VPSD(10). 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(6) and APA D-1(6), the JIS-B(6) and ASTM(6), the APA D-1(6) and ASTM(6), and the V313(3) and VPSD(10). The results of the linear regression analysis for these four combinations of accelerated aging treatments, shown in Fig. 3, were as follows:

$$\text{BendingRet (APA D-1(6))} = 1.01 \times \text{BendingRet (JIS-B(6))}\ (R = 0.96)$$
$$\text{BendingRet (ASTM(6))} = 0.99 \times \text{BendingRet (JIS-B(6))}\ (R = 0.93)$$
$$\text{BendingRet (ASTM(6))} = 0.98 \times \text{BendingRet (APA D-1(6))}\ (R = 0.98)$$
$$\text{BendingRet (VPSD(10))} = 0.98 \times \text{BendingRet (V313(3))}\ (R = 0.91).$$

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. A possible reason for this close correlation is that these three accelerated aging treatments utilized the aging effects of heat and water (moisture), with each including a hot water soaking or a steaming step. Moreover, a one-to-one correspondence was observed between V313(3) and VPSD(10), and this close correlation could be because these two accelerated aging treatments utilized the aging effects of water absorption and desorption without heating treatment.

Figure 4 shows the relationships for the bending retentions after one cycle and three cycles of JIS-B, APA D-1, and ASTM treatments. These combinations showed a nearly

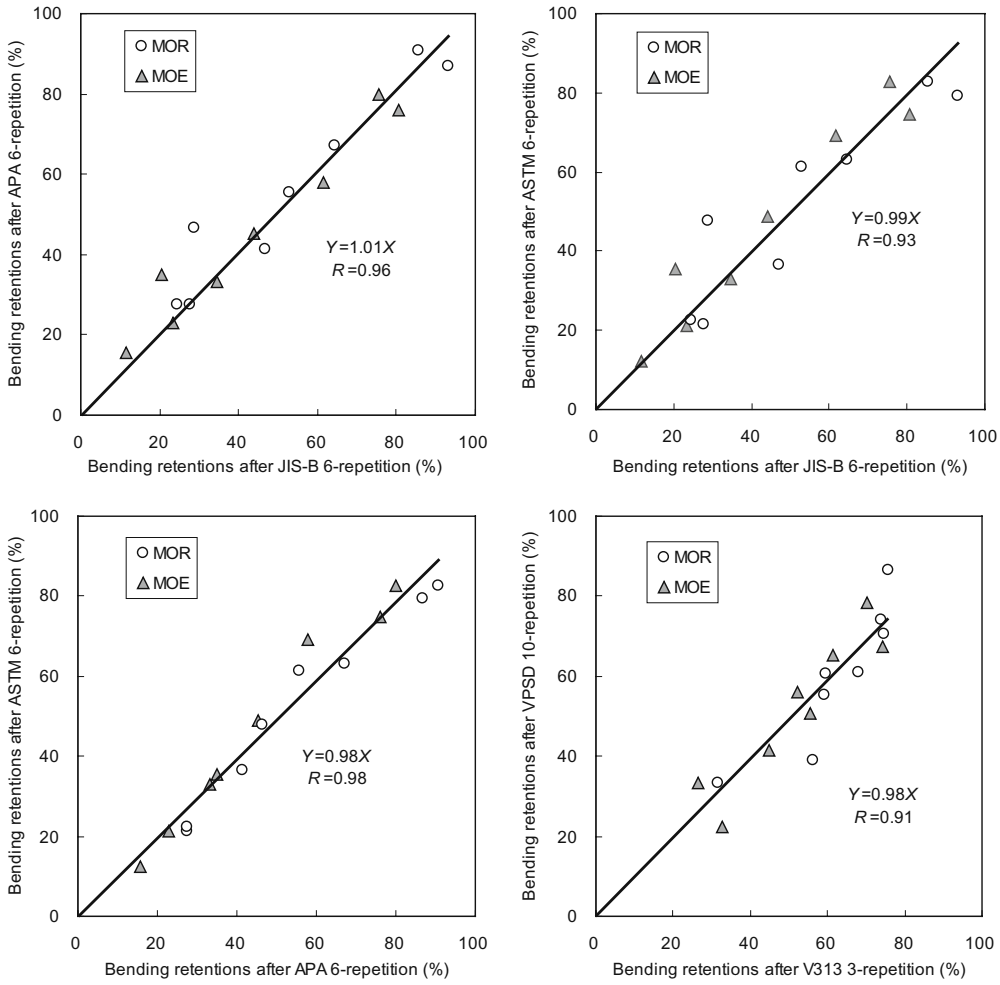

Fig. 3. Linear regressions of bending retentions for four combinations of accelerated aging treatments. The *solid line* represents the line $Y = X$

one-to-one correspondence after six treatments cycles. Because the bending test for OSB was conducted for six treatment cycles only in this study, the bending retention results for six panels, i.e., all except OSBs, are shown in Fig. 4. The bending retentions after one cycle and three cycles of the APA D-1 treatment were higher than those of the JIS-B and ASTM treatments. Despite the one-to-one correspondence among the bending retentions after six treatment cycles (Fig. 3), the APA D-1 treatment showed only a 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 cycles of the JIS-B and ASTM treatments showed a nearly one-to-one correspondence. This result indicated that the aging effects of one cycle of the JIS-B treatment and one cycle of the ASTM treatment 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 of wood-based panels are temperature, precipitation, sunshine duration, and wind, among others. Table 4 shows the bending retention values following 5 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% after the 5-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 other than plywoods, the bending retentions tended to decrease exponentially.

Accelerated aging treatments and outdoor exposure test correlations

The main objective in this report was to assess the correlations between accelerated aging treatments and outdoor exposure tests using bending properties. Ikeda and Suzuki

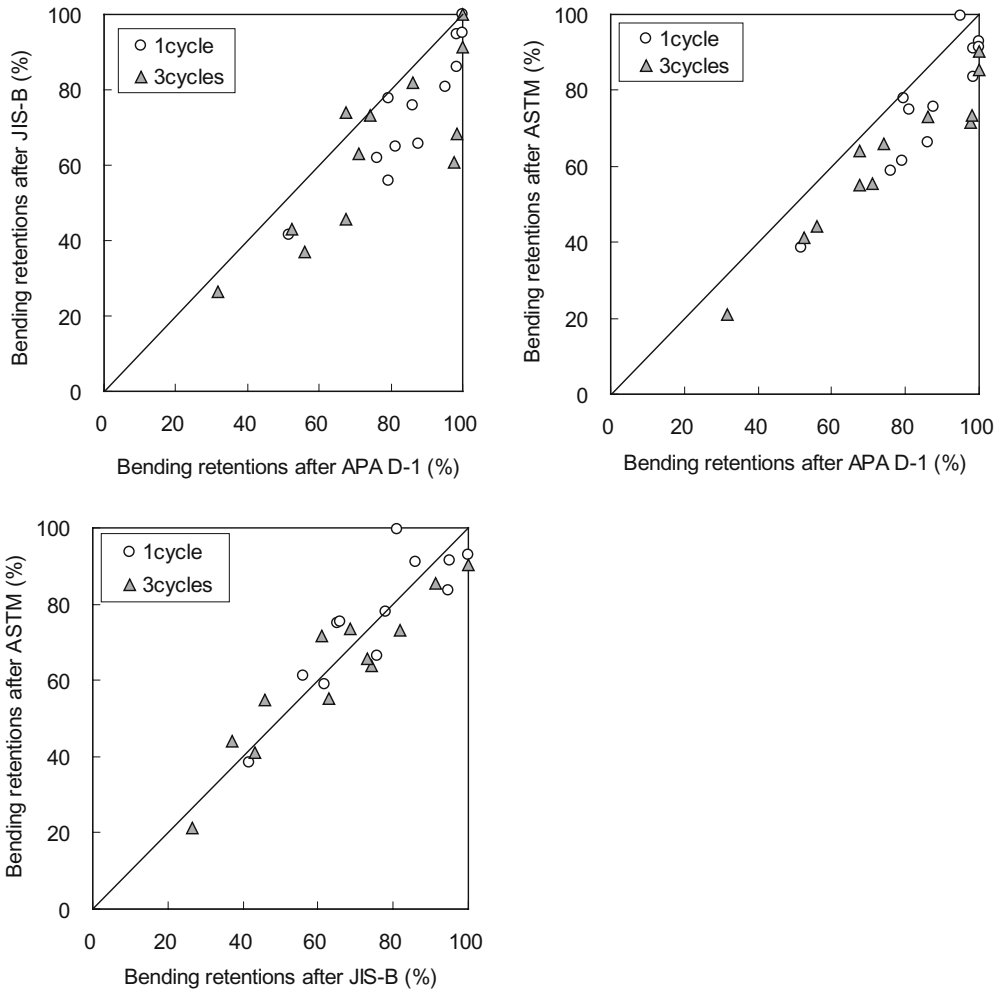

Fig. 4. Linear regression of bending retentions (MOE and MOR values for all boards except the OSBs) after one cycle and three cycles of accelerated aging treatments

Table 4. Bending retentions resulting from the 5-year outdoor exposure test in Shizuoka City

	1 year		2 years		3 years		4 years		5 years	
	MOR ret(%)	MOE ret(%)	MOR ret(%)	MOE ret(%)	MOR ret(%)	MOE ret(%)	MOR ret(%)	MOE ret(%)	MOR ret(%)	MOE ret(%)
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

reported that there was a linear relationship between the IB of the boards after five cycles of VPSD and after 5 years of outdoor exposure.[10]

Linear regression analysis ($Y = aX + b$) of the bending retentions of the five accelerated aging treatments and the 5-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 = 0.82–0.95) with the 5-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 5-year outdoor exposure test. A possible reason for this close correlation is that the aging effects of the ASTM treatment are similar to the aging effects of the outdoor exposure test based on natural weathering. The results of the linear regression analysis for this combination, shown in Fig. 5, were as follows:

Table 5. Correlation coefficients for bending properties between accelerated aging treatments and the outdoor exposure test in Shizuoka City

X-axis	Coefficient	*Y*-axis				
		JIS-B(6)	APA(6)	V313(3)	ASTM(6)	VPSD(10)
Five-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

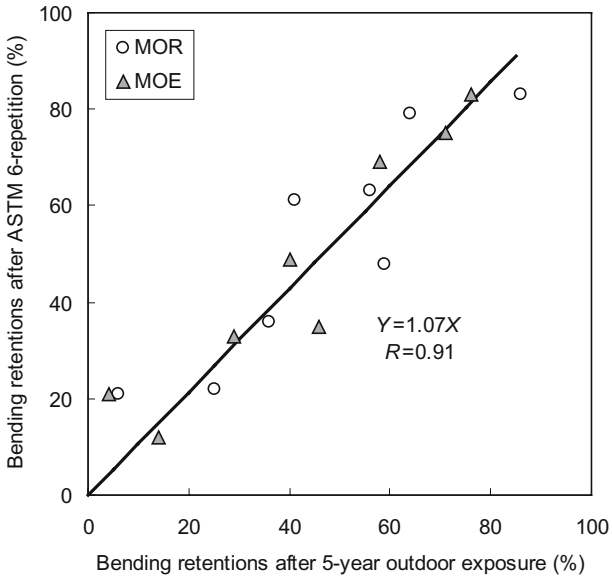

Fig. 5. Linear regression of bending retentions between the 5-year outdoor exposure test and six repetitions of the ASTM treatment

$$\text{BendingRet}\,(\text{ASTM}(6)) = 1.07 \times \text{BendingRet}\,(\text{5-year outdoor})\,(R = 0.91)$$

The deterioration of the bending properties after 5 years of outdoor exposure was the same as that for six repetitions of the ASTM treatment.

Conclusions

In this article, 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 5-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. 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 cycles of the JIS-B, APA D-1, and ASTM treatments showed a nearly one-to-one correspondence.

The Shizuoka City 5-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 5-year exposure period. The deterioration of the bending properties after 5 years of outdoor exposure was the same as that after six repetitions of the ASTM treatment.

Acknowledgments The outdoor exposure test in Shizuoka City was conducted as part of a project organized by the Research Working Group on Wood-based Panels from the Japan Wood Research Society. The authors express their thanks to all participants in this project.

References

1. McNatt JD, Link CL (1989) Analysis of ASTM D1037 accelerated-aging test. For Prod J 39:51–57
2. Kajita H, Mukudai J, Yano H (1991) Durability evaluation of particleboards by accelerated aging tests. Wood Sci Technol 25:239–249
3. Yoshida H (1986) Bond durability of water-based polymer-isocyanate adhesives (API resin) for wood I (in Japanese). Mokuzai Gakkaishi 32:432–438
4. Inoue A (1992) A new method for predicting bond durability I (in Japanese). Mokuzai Gakkaishi 38:923–930
5. 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
6. Hayashi T, Miyatake A, Harada M (2002) Outdoor exposure tests of structural laminated veneer lumber. J Wood Sci 48:69–74
7. Sekino N, Suzuki S (2003) Durability of wood-based panels subjected to 10-year outdoor exposure in Japan. Bull Iwate Univ For 34:23–36
8. Ikeda M, Eumi Y, Kimura H, Takase H (1992) Durability of MDF against outdoor exposure (in Japanese). Mokuzai Kogyo 47: 598–602
9. 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 25:263–270
10. Ikeda M, Suzuki S (1999) Evaluation of the durability performance of wood-based panels subjected to outdoor exposure (in Japanese). Bull Shizuoka Univ For 23:25–36
11. Hayashi T, Miyatake A, Kawai S (2000) Effects of outdoor exposure on the strength distribution of oriented strandboard (OSB) and particleboard (in Japanese). J Soc Mater Sci Jpn 49:384–389
12. Hann RA, Black JM, Blomquist RF (1962) How durable is particleboard? For Prod J 12:577–584
13. Northcott PL, Colbeck HGM (1966) Prediction of plywood bond durability. For Prod J 18:403–408
14. Gressel P (1980) Testing and judging the durability of particleboard adhesives: a proposal for the establishment of generally valid testing guidelines (in German). Holz Roh Werkst 38:17–35
15. River BH (1994) Outdoor aging of wood-based panels and correlation with laboratory aging. For Prod J 44:55–65

16. Okkonen EA, River BH (1996) Outdoor aging of wood-based panels and correlation with laboratory aging. Part 2. For Prod J 46:68–74
17. Lehmann WF (1977) Durability of composition board products. In: Proceedings of the WSU Symposium on Particleboard, vol 11, pp 351–368
18. Lehmann WF (1978) Cyclic moisture conditions and their effect on strength and stability of structural flakeboards. For Prod J 28:23–31
19. American Society for Testing and Materials (ASTM) (1993) Standard test method for properties of wood-based fiber and particle panel materials. ASTM-D 1037, ASTM, West Conshohocken
20. APA – The Engineered Wood Association (1994) Performance standards and qualification policy for structural-use panels. APA PRP 108. APA, Tacoma
21. European Standard (1993) Fiberboards, cyclic tests in humid conditions. EN321
22. Dinwoodie JM (1981) Characterizing the performance of chipboard in the United Kingdom. In: Proceedings of the WSU Symposium on Particleboard vol 15, pp 59–78
23. 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 54:121–127
24. 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 59:35–41
25. Kojima Y, Suzuki S (2010) Evaluating the durability of wood-based panels using internal bond strength results from accelerated aging treatments. J Wood Sci. doi: 10.1007/s10086-010-1131-4
26. Japanese Industrial Standards (1994) JIS standard specification for particleboard, JIS A-5908. Japanese Standards Association, Tokyo
27. National Astronomical Observatory (2008) Chronological scientific tables. National Astronomical Observatory, pp 189
28. Deppe HJ (1977) Technical progress in using isocyanate as an adhesive in particleboard manufacture. In: Proceedings of the 11th Washington State University Symposium on Particleboard. Washington State University, Pullman, pp 13–31
29. Johns WE, Maloney TM, Huffaker EM, Saunders JB, Lentz MT (1981) Isocyanate binders for particleboard manufacture. In: Proceedings of the 15th Washington State University Symposium on Particleboard. Washington State University, Pullman, pp 213–239
30. Loew GH, Sachs I (1981) Isocyanate as a binder for particleboard. In: Proceedings of the 15th Washington State University Symposium on Particleboard. Washington State University, Pullman, pp 473–492