Effects of Outdoor Exposure Angle on the Deterioration of Wood-Based Board Properties

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Abstract

Wood-based boards were exposed to an outdoor environment at angles of 90° and 45° to the ground surface in order to investigate the effect of exposure angle on board properties. In a study on 5-year outdoor exposure, the effects of the exposure angle varied depending on the type of board. Particleboard (PB) and oriented strand board (OSB) deteriorated faster when exposed at 45° compared with 90°, and the difference was more apparent with longer exposure. Five years of exposure at 45° lowered the retention of the modulus of rupture and internal bond of phenolic resin–bonded PB to 15 and 4 percent, respectively. In contrast, medium-density fiberboard (MDF) showed no difference in deterioration between both exposure angles. After 5 years of exposure, the retention of the modulus of rupture was 70 to 80 percent in MDF, while that of internal bond was 81 to 97 percent, thereby showing that the internal bond was better retained than the modulus of rupture. The high durability of MDF was attributable partly to its smoother surface compared with the other boards, which prevented residual rainwater on the surface from infiltrating into the board. Conversely, PB and OSB were prone to surface weathering, which led to the ingress of rainwater. The resultant swelling resulted in the collapse of bonding points, followed by the formation of voids inside the boards. Residual moisture in the voids then caused decay as well as a further reduction in strength (biodegradation).

The outdoor exposure test is used to assess the durability of wood-based boards and plywood (Kojima et al. 2009b; Kojima and Suzuki 2011a, 2011b). Japan and other countries have reportedly conducted outdoor exposure tests on boards and plywood (Hann et al. 1962, River 1994, Okkonen and River 1996), although Japan tests mainly plywood and rarely board (Suzuki 2001). Therefore, the outdoor exposure testing of boards must be conducted in Japan in order to assess board durability.

Although various methods of outdoor exposure testing have been reported, there are few detailed reports on the differences between exposure at angles of 90° and 45° to the ground surface. The deteriorating effects of solar radiation and rainwater are likely to depend on the exposure angle. In general, 45° exposure causes faster deterioration than 90° exposure (Carll and Feist 1989, Williams et al. 2001). In the present study, however, only oriented strand board (OSB) and flakeboard were subjected to outdoor exposure. Particleboard (PB) and fiberboard—both important as wood-based materials—were not exposed outdoors. In terms of exposure angle, these boards, as well as OSB and flakeboard, must also be subject to outdoor exposure.

At the same time, the direction and angle used for the outdoor exposure testing of the properties of polymers are prescribed in Japanese Industrial Standards (JIS) Z 2381 (JIS 2001; 45° or 30° exposure angle), JIS K 7081 (JIS 1993; 30° exposure angle in Japan, latitude − 10° in middle latitude area), JIS K 7219 (JIS 1998; 30° exposure angle), and JIS K 5600-7-6 (JIS 2002; 45° exposure angle). In principle, the specimens should face south at an angle of either 30° or 45°, depending on the material being tested. As for board and plywood, the exposure angle has yet to be decided because of insufficient exposure angle data. In this study, we investigated the basic data on outdoor exposure and the effects of exposure angle on the deterioration of board and plywood.

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This study also analyzed data as part of the results obtained from the wood-based panel outdoor exposure project conducted in eight areas of Japan: Asahikawa, Morioka, Noshiro, Tsukuba, Shizuoka, Okayama, Maniwa (northern region of Okayama Prefecture), and Miyakonojo (Sekino and Korai 2005). Testing at the two exposure angles (90° and 45°) was conducted only in Tsukuba.

Experimental

Outdoor exposure

The boards and plywood tested were PB, OSB, medium-density fiberboard (MDF), and softwood plywood (PW). PB consisted of two types that differed in terms of binder: one using phenol-formaldehyde resin, PB(PF), and the other using methylene diphenyl diisocyanate, PB(MDI). OSB came from two different tree species: aspen (*Populus tremula*), OSB(aspen), and Scotch pine (*Pinus sylvestris*), OSB(pine). The two types of MDF differed in terms of binder and usage: one was 9-mm-thick structural MDF that uses MDI, MDF(MDI); the other was 12-mm-thick MDF that uses melamine-urea-formaldehyde resins, MDF(MUF). Two types of PW having different thicknesses (number of layers) were tested: 12-mm-thick PW (consisting of five layers), PW(12), and 9-mm-thick PW (consisting of three layers), PW(9). Table 1 summarizes the abbreviations and basic properties of the boards and plywood before exposure. All boards and plywood used in this study were manufactured at factories for structural applications except for MDF(MUF).

The boards and plywood measuring 900 by 1,800 mm were cut into specimens measuring 300 by 300 mm. The cut edges were coated with enamel paint as a waterproofing agent. The specimens were exposed south at an angle of 90° or 45°, as shown in Figure 1. Testing was conducted in Tsukuba (36°N, 140°E), Ibaraki Prefecture, Japan. The annual mean temperature was 14.3°C, and the annual mean precipitation in Tsukuba was 1,368 mm from 2004 to 2010 (from the database of the Japan Meteorological Agency).

The duration of outdoor exposure was 7 years (2004 to 2011) in the project, but the present study analyzed data on only up to 5 years of exposure. After every year of exposure, two specimens measuring 300 by 300 mm were collected for each type of board and plywood and then tested for their postexposure properties.

Property tests

The 300 by 300-mm specimens collected from the exposure stands were initially conditioned for about 1 month at constant room temperature of 20°C and relative humidity of 65 percent. Modulus of rupture (MOR) and internal bond (IB) tests were conducted in accordance with JIS A 5905 (JIS 2003a) and JIS A 5908 (JIS 2003b). The MOR of the plywood and OSB, which showed in-plane anisotropy, was measured parallel to the surface fibers (Fig. 2). The dimensions of specimens used for the MOR test measured 280 by 50 mm (Fig. 2), with a span length of 180 mm. The MOR was calculated by using the thickness after conditioning. Water absorption (WA) was measured by weighing each specimen before and after the 24-hour water soaking test prescribed in the thickness swelling test of JIS A 5905 and JIS A 5908. The dimensions of specimens used for the IB and WA tests measured 50 by 50 mm (Fig. 2). Eight specimens were used for the MOR test. Thirteen specimens were used for the IB and WA tests. Prior to the IB test, the thickness and weight of the specimens were measured in order to calculate thickness change and mass loss due to outdoor exposure. As the initial thickness and weight of these 50 by 50-mm specimens for the IB test were not measured before outdoor exposure, the initial thickness and weight were estimated from the mean thickness and mean weight of the 300 by 300-mm specimens prior to outdoor exposure. The specimens for the IB and WA tests were sampled from both edge sections of the specimens for the MOR test and from the center of the 300 by 300-mm specimens (Fig. 2). Prior to the IB test, all harsh surfaces (about 3 mm in depth) of the specimens resulting from outdoor exposure were eliminated in order to measure bonding strength in the board core part.

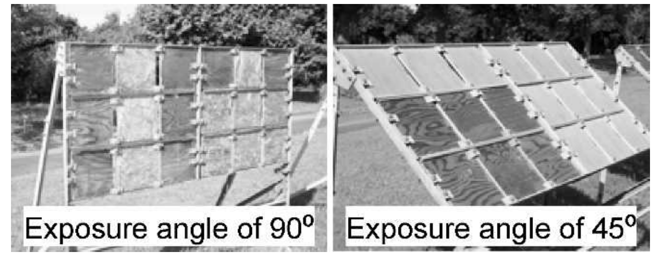

Figure 1.—Outdoor exposure test on boards and plywood at 90° (left) and 45° (right).

Results and Discussion

Thickness change

The manufacturing method of plywood differs from that of boards (PB, OSB, and MDF). Thin veneers are laminated together to make plywood, resulting in the veneers hardly being compressed at all (Sekino and Inoue 1996).

Table 1.—Abbreviations and basic property of boards and plywood exposed outdoor before exposure.[a]

Abbreviation	Panel type	Binder	Density (g/cm^3)	Thickness (mm)	MOR, mean (SD) (MPa)	IB, mean (SD) (MPa)
PB(PF)	Particleboard	PF	0.75	12.2	20.3 (2.29)	0.83 (0.09)
PB(MDI)	Particleboard	MDI	0.80	12.1	28.8 (2.10)	2.19 (0.18)
OSB(aspen)	OSB	PF	0.63	12.4	39.1 (6.77)	0.56 (0.13)
OSB(pine)	OSB	MDI	0.67	11.8	36.8 (7.75)	0.64 (0.19)
MDF(MDI)	MDF	MDI	0.71	12.2	36.1 (2.44)	1.22 (0.19)
MDF(MUF)	MDF	MUF	0.76	9.00	45.4 (2.94)	0.62 (0.11)
PW(12)	Plywood	PF	0.64	12.0	68.6 (9.69)	1.15 (0.31)
PW(9)	Plywood	PF	0.61	8.72	76.7 (19.1)	1.36 (0.37)

[a] MOR = modulus of rupture; IB = internal bond; PB = particleboard; PF = phenol formaldehyde resin; MDI = methylene diphenyl diisocyanate; SB = oriented strand board; MDF = medium-density fiberboard; MUF = melamine urea formaldehyde resin; PW = plywood.

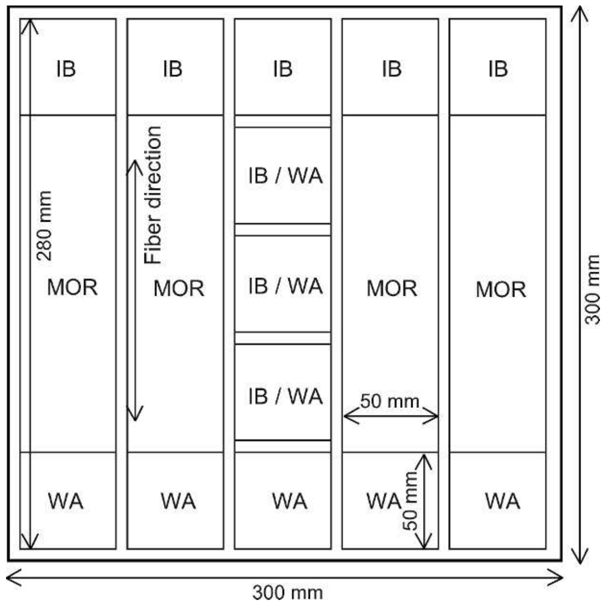

Figure 2.—Trimming of specimens for modulus of rupture (MOR; 280 by 50 mm), internal bond (IB; 50 by 50 mm), and water absorption (WA; 50 by 50 mm) from 300 by 300-mm specimens.

Conversely, boards are manufactured through the high-density compression of elements (particle, strand, and fiber). Therefore, the three types of board have a higher density than plywood (Table 1). The structural differences between board and plywood result in differences in the deterioration mechanism of mechanical properties (Sekino 2006). Because of the compression of elements, the large local swelling stress generated within a board is controlled by the bonding strength of the binder at the bonding points among the elements (Sekino 2006). As the three types of board have lower bonding strength than plywood (Sekino 2006), each board will swell significantly once the bonding points collapse (Sekino and Okuma 1986). Moreover, bonding points of low bonding strength tend to collapse easily, resulting in excessive swelling under very harsh conditions (Korai 2001). Table 2 lists the thickness changes during exposure, which were used to analyze the causes of board deterioration. The largest thickness change during the 5 years of exposure at 90° was observed in OSB(aspen) at 16.0 percent, followed in order by PB(PF), OSB(pine), and PB(MDI). A similar trend was also observed during exposure at 45°, but PB(PF), PB(MDI), and OSB(pine) swelled to an even greater extent than during exposure at 90°, thereby demonstrating the harsh conditions under exposure at 45°. OSB(aspen) deteriorated so severely that after 4 and 5 years of exposure at 45°, its thickness could not even be measured (Fig. 3). In contrast, MDF and plywood showed very low thickness change after exposure at both 90° and 45°. The large increases of thickness in PB and OSB are likely attributable to rainwater infiltrating into the board. Rainwater would have caused the board to swell, thus destroying the bonding points within the board and resulting in lower bonding strength (Sekino and Inoue 1996). The swelling also forms many voids inside the board, allowing the growth of wood-decay fungi (biodegradation; Sekino 1998, Ikeda and Suzuki 1999). Board deterioration due to rainwater likely entails lower bonding strength, biodegradation, and the combined effects of both. In particular, biodegradation must have a larger effect.

Mass loss

The mass loss of specimens during exposure is caused by the extraction and elution of components by rainwater, surface elements detached by weathering, and biodegradation. The mass loss due to biodegradation is likely to be much higher than that due to extraction and elution. Moreover, no large detachment of elements was observed. Thus, high mass loss must be caused by biodegradation, thereby making mass loss an important index of biodegradation. In fact, based on mass loss, biodegradation is mainly evaluated (JIS A 9201; JIS 1991). Table 3 lists the mass loss during exposure from which rotting was conjectured. In PB and OSB, exposure at 45° apparently caused a larger reduction in mass loss compared with exposure at 90°, although this trend was not observed in plywood and MDF. In particular, PB(PF) showed the largest reduction in mass during 90° exposure. The large mass loss of PB and OSB was likely attributable to biodegradation. The mass loss of MDF was very low for exposure at both 45° and 90°, suggesting that biodegradation did not occur in MDF. Several plywood specimens showed a large mass loss, even though their thickness remained virtually unchanged (Table

Table 2.—Thickness change of boards and plywood exposed outdoors.[a]

	Thickness change (%)							
Years of exposure	PB(PF)	PB(MDI)	OSB(aspen)	OSB(pine)	MDF(MDI)	MDF(MUF)	PW(12)	PW(9)
Exposure at 90°								
1	3.16	2.51	10.5	6.37	0.40	1.02	1.70	2.64
2	6.19	3.40	10.9	6.75	0.64	1.31	0.96	2.09
3	6.02	4.08	12.6	8.82	0.75	2.32	1.78	0.92
4	10.4	3.61	13.5	10.1	0.58	2.26	0.58	1.85
5	15.2	4.01	16.0	10.7	−0.13	2.01	0.39	0.08
Exposure at 45°								
1	2.52	3.27	11.9	4.62	0.69	1.50	2.55	1.33
2	4.63	3.63	20.3	6.87	0.97	1.67	1.37	−1.23
3	16.5	6.12	15.4	8.91	−0.12	2.23	−0.23	0.27
4	26.6	5.58	—	12.9	0.73	1.84	−1.00	0.10
5	24.8	6.80	—	14.1	−0.41	1.38	−1.52	−1.42

[a] Abbreviations are explained in Table 1 and in the text.

Figure 3.—Oriented strand board from aspen after 5 years of exposure at 45°.

2). Boards lost more mass when exposed for a longer time, but plywood did not show this trend. Plywood is composed of veneers that mutually vary in terms of physical properties; therefore, each type of plywood has its own unique properties. This is the likely reason why the trend of mass loss in plywood differed from that in boards. This study does not discuss plywood in detail but does provide reference data.

Infiltration of rainwater

The amount of rainwater infiltrating into a board exposed outdoors can be estimated up to a certain extent from the results of a 24-hour WA test. Table 4 lists the changes in WA before (initial value) and after every year of exposure. The order of initial WA was OSB(aspen) > PB(PF) > OSB(pine) ≅ PB(MDI) > MDF(MDI) > MDF(MUF) when excluding plywood. A higher board density generally means a high compaction ratio (mean board density/element density) and less WA (Kawasaki et al. 1999). MDF did not swell, and it maintained high board density, resulting in low WA. Conversely, OSB and PB swelled significantly because of outdoor exposure and showed decreased board density, resulting in high WA.

After 5 years of exposure at 90°, WA doubled from the initial values in OSB(aspen), PB, and MDF. The value increased 4.7 times in OSB(pine). After exposure at 45°, WA tripled or increased even more in PB(PF), PB (MDI), and OSB(pine) but only doubled at most in MDF. The exposure at 45° caused a larger increase in WA compared with that at 90° in PB and OSB(pine), probably because of increased thickness and thus larger voids being formed inside the board. Conversely, the angle of exposure hardly affected the WA of MDF.

Board surface properties

MDF absorbed little water, possibly because the surface layers were dense and prevented water from infiltrating into the boards. For confirmation, the density profiles were measured (Fig. 4). The profiles shown are those before exposure. The maximum densities at the surface for OSB(aspen) and OSB(pine) were 0.75 and 0.82 g/cm^3, respectively. The surface densities for PB and MDF were higher than those for OSB, at 0.95 g/cm^3 for both PB(PF) and PB(MDI), 0.88 g/cm^3 for MDF(MDI), and 0.93 g/cm^3 for MDF(MUF). Moreover, the maximum density was recorded at 1 mm or deeper from the surface in OSB but at 0.3 mm from the surface in PB and MDF. Therefore, OSB had a surface structure that allowed water to easily infiltrate the board. Both PB and MDF had a similar density profile, with PB having a slightly higher surface density than MDF. The density values suggest that water infiltrated more easily into MDF than into PB. However, the initial WA values listed in Table 4 indicate a relation of PB > MDF. Factors other than surface density should be considered when investigating the infiltration of water into the boards.

The main difference between PB and MDF is the shape of the elements. PB consists of particles. In contrast, MDF consists of fibers. The contact among elements would be higher among fibers than among particles (Sahin and Arslan 2011). Fibers are also intertwined together (Ikeda and Suzuki 1999), thereby further enhancing contact. The high contact among fibers is thus likely to prevent water from infiltrating into MDF. The high contact also produces the smooth surface of MDF, making it easier for rainwater to flow down and off the board rather than infiltrating into the board. Conversely, the surface elements of PB are less mutually adhered than those of MDF, and the less smooth surface of PB becomes rough and fluffy when wet with rainwater (Hayashi et al. 2000). This permits residual rainwater on the PB surface to infiltrate inside.

Table 3.—Mass loss of boards and plywood exposed outdoors.[a]

	Mass loss (%)							
Years of exposure	PB(PF)	PB(MDI)	OSB(aspen)	OSB(pine)	MDF(MDI)	MDF(MUF)	PW(12)	PW(9)
Exposure at 90°								
1	0	0	0	0	0	0	0	2.80
2	0	0	0.491	0	1.54	0	3.60	0
3	3.18	0	2.18	0	2.88	0	4.49	2.74
4	4.79^{BD}	2.32	0	0	1.42	0	1.20	3.15
5	8.98^{BD}	2.43	7.52^{BD}	1.50	3.42	2.81	2.49	4.33
Exposure at 45°								
1	0	0	0	0	0	0	0	1.92
2	0.360	2.03	19.2^{BD}	1.25	0	0	4.06	3.89
3	5.82^{BD}	3.17	22.0^{BD}	1.79	1.16	0	4.12	7.52
4	14.7^{BD}	4.90^{BD}	—^{BD}	4.10	2.61	2.83	5.95	10.2
5	14.8^{BD}	6.02^{BD}	—^{BD}	7.81^{BD}	2.63	3.68	8.70	8.58

[a] BD = biodegradation. For explanation of other abbreviations, see Table 1 and the text.

Table 4.—Results of a 24-hour water absorption test for boards and plywood exposed outdoors.[a]

	Water absorption (%)							
Years of exposure	PB(PF)	PB(MDI)	OSB(aspen)	OSB(pine)	MDF(MDI)	MDF(MUF)	PW(12)	PW(9)
Initial value	23.4	12.6	31.1	14.0	10.1	8.2	42.9	40.1
Exposure at 90°								
1	31.2	16.5	42.3	28.7	12.6	8.8	52.8	30.5
2	31.4	18.5	43.6	29.1	17.7	11.4	28.3	53.6
3	66.3	29.7	61.4	75.8	22.1	22.5	40.8	75.5
4	66.9	28.4	57.5	79.2	23.9	23.5	49.9	43.0
5	42.0	25.3	65.0	65.5	21.4	20.0	59.8	48.4
Exposure at 45°								
1	27.0	21.5	48.6	32.8	19.3	16.2	53.0	60.9
2	26.8	22.4	68.2	24.9	19.6	10.7	54.9	72.1
3	68.3	33.2	94.1	51.0	22.5	19.9	50.9	61.2
4	94.2	49.1	99.8	77.1	22.0	20.8	35.9	49.3
5	93.3	39.9	95.3	83.6	15.4	16.2	38.6	48.5

[a] Abbreviations are explained in Table 1 and in the text.

Modulus of rupture

Figure 5a shows the retention of MOR in PB after exposure. Neither type of PB showed any difference between at 90° and at 45° for the first 2 years of exposure. At 3 years of exposure, MOR was reduced more sharply at 45° than at 90° (which is significant at the 0.1% level according to the *t* test). After 5 years of exposure, the retention of MOR in PB(PF) and PB(MDI) was 15 and 47 percent, respectively, revealing a more conspicuous reduction at 45° than at 90°.

Figure 5b shows the retention of MOR in OSB. The exposure at 45° resulted in lower retention than exposure at 90° in OSB(aspen), with only 10 percent retention after 3 years of exposure at 45°. The retention of MOR in OSB(pine) after 5 years of exposure at 90° and 45° was 49 and 25 percent, respectively.

Figure 5c shows the retention of MOR in MDF. The exposure angle caused little difference in deterioration in both types of MDF (having different binders). After 5 years of exposure at both angles, the mean retention of MOR in MDF(MDI) and MDF(MUF) was about 77 and 65 percent, respectively. Both satisfied the waterproof category of Type M under JIS A 5905. MDF(MDI), which is intended for structural use, was actually more waterproof than MDF(MUF) and corresponded to Type P waterproofness (Sekino and Korai 2005). Although both Type P and Type M are waterproof boards, Type P indicates a more waterproof board than Type M according to JIS A 5905 and JIS A 5908. Type P board is generally manufactured by using phenol-formaldehyde resin, and Type M board is generally manufactured by using melamine-formaldehyde resin. The high waterproofness of Type P is likely reflected in the high retention of MOR in MDF(MDI) after 5 years of exposure. Figure 5d shows the retention of MOR in plywood after exposure. The properties and thus the retention varied by the type of plywood, as described above.

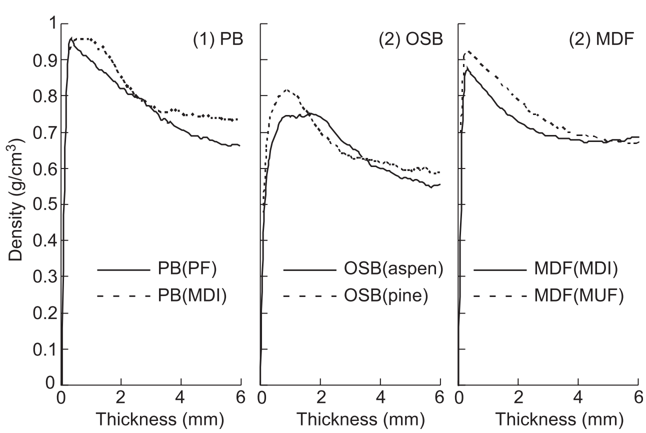

Figure 4.—Density profile of (1) PB, (2) OSB, and (3) MDF boards before outdoor exposure. Abbreviations are explained in Table 1 and in the text.

Internal bond

Figure 6a shows the retention of IB in PB. The retention in PB(MDI) was 68 percent even after 5 years of exposure at 90° but was sharply reduced by exposure at 45°. PB(PF) showed very poor retention: 17 and 3.8 percent after 5 years of exposure at 90° and 45°, respectively. Kojima et al. (2009a) reported that the retention of IB in MDI-bonded particleboard was high after some accelerated aging tests, thus reflecting high durability. In this study, PB(MDI) also showed high durability after outdoor exposure.

Figure 6b shows the retention of IB in OSB. The retention values that exceeded 100 percent were assumed to be 100 percent. When exposed at 45°, the retention of IB in OSB(aspen) was reduced sharply after only 1 year and dropped to 17 percent within 3 years. When exposed at 90°, the retention of IB in OSB(aspen) was 60 percent up to 4 years but dropped sharply to 33 percent at 5 years. The retention of IB showed a sharp reduction in OSB(pine) after 5 years of exposure at 90° and after 4 years of exposure at 45°.

Figure 6c shows the retention of IB in MDF. The retention of IB in MDF was higher compared with that in PB and OSB. In particular, the retention of IB in MDF(MDI) was 97 and 93 percent after 5 years of exposure at 90° and 45°, respectively. MDF maintained high IB even at 45° exposure, which was likely attributable to its smooth surface (Sekino 1998, Ikeda and Suzuki 1999, Hayashi et al. 2000) as described above, and its high binder durability (Sekino 1998, Ikeda and Suzuki 1999). The retention of

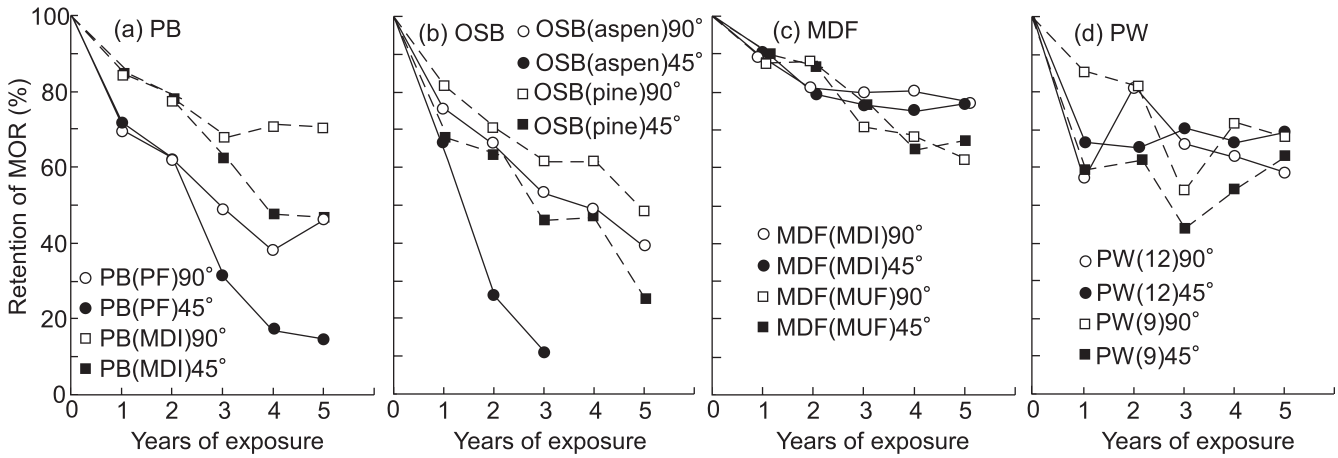

Figure 5.—Relationships between years of exposure term and retention of modulus of rupture (MOR) in (a) PB, (b) OSB, (c) MDF, and (d) PW. Abbreviations are explained in Table 1 and in the text.

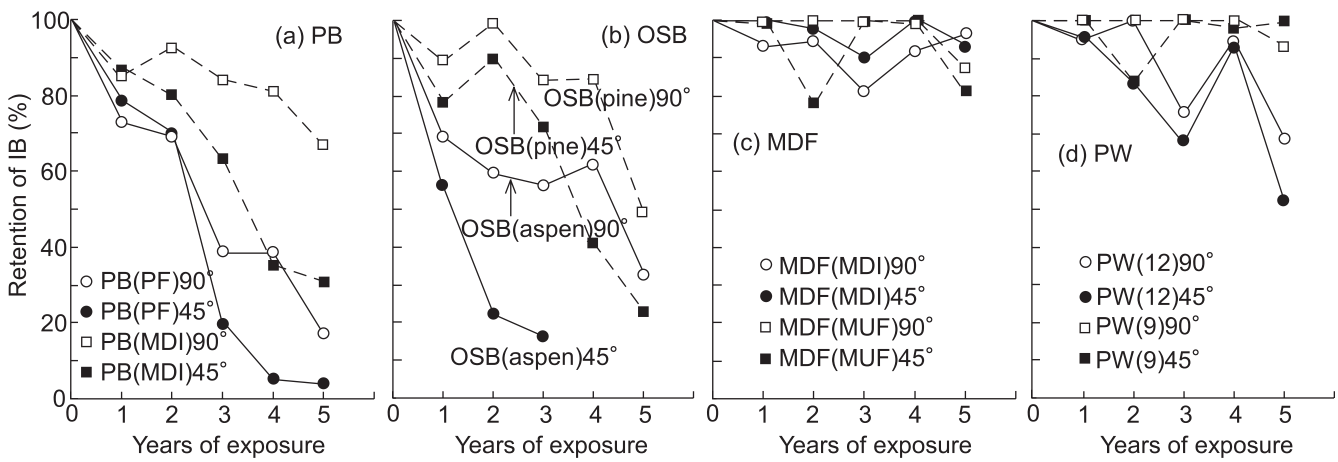

Figure 6.—Relationships between years of exposure term and retention of internal bond (IB) in (a) PB, (b) OSB, (c) MDF, and (d) PW. Abbreviations are explained in Table 1 and in the text.

MOR in MDF was low after long-term exposure (Fig. 5), but the retention of IB remained high. MOR generally depends on the surface and thus decreases because of surface deterioration caused by solar radiation and other causes. The smooth surface of MDF could prevent deterioration by rainwater but not by solar radiation. The deterioration caused by solar radiation did not affect IB, however, because IB depends on the bonding strength of the board core and not the strength of the board surface. As further exposure might reduce IB, we will continue to monitor the changes. Figure 6d shows the changes in the internal bond of plywood. As described above, the values varied depending on the type of plywood.

Biodegradation

As mentioned earlier, the surfaces of PB and OSB are less smooth than those of MDF. In particular, OSB(aspen) had a very rough surface (Hayashi et al. 2000). Therefore, rainwater tended to infiltrate into PB and OSB, thereby reducing bonding strength and causing biodegradation (Sekino 1998, Ikeda and Suzuki 1999) as well as reducing MOR and IB. There is insufficient board data regarding the extent to which MOR and IB decrease because of biodegradation. The biodegradation of Sugi (*Cryptomeria japonica* D. Don) solid wood reportedly causes a 5 percent reduction in mass and a 40 percent reduction in MOR (Fujihira et al. 1997). Imamura and Nishimoto's study (1984) found that the retention of MOR in urea-melamine-formaldehyde–bonded particleboard decreased significantly to about 20 percent in the case of mass loss as low as about 5 percent. In the case of mass loss exceeding 5 percent, the retention of MOR did not decrease but maintained a virtually constant value (Imamura and Nishimoto 1984). Comprehensive analysis of the data on actual mass loss exceeding 5 percent, the large thickness change and the high reduction in MOR and IB suggest that some biodegradation occurred in the boards marked ''BD'' in Table 3. In particular, mass loss had a large effect on biodegradation. PB(PF) and OSB(aspen) particularly showed significant biodegradation after exposure at 45°.

Conclusions

Different types of board and plywood were exposed outdoors at two different angles (90° and 45°) for 5 years, and the deterioration of their properties was analyzed. The following results were obtained:

1. The effects of exposure angle on the deterioration of board properties depended on the type of board.
2. PB and OSB were severely deteriorated by long-term exposure. Exposure at 45° caused greater deterioration than at 90°.
3. MDF did not deteriorate much even after long-term exposure and did not show much difference in deterioration at both angles.
4. Surfaces of PB and OSB were less smooth than those of MDF and were prone to the infiltration of rainwater. The outdoor exposure of PB and OSB at 45° accelerated the surface deterioration and infiltration of rainwater, resulting in the collapse of bonding points within the boards and subsequent biodegradation.
5. The high durability of MDF is attributable mainly to its smooth surface that prevents the infiltration of rainwater. The very smooth surface is attributable to a high surface density and high contact among fibers.
6. The deterioration resulting mainly from the infiltration of rainwater caused large thickness changes. Harsh deterioration was also caused by biodegradation. In particular, both PB and OSB were prone to biodegradation.

Acknowledgments

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