Effect of Starting Time and Test Specimen Size on the Deterioration of Particleboard in an Outdoor Exposure Test

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Abstract

Relatively short-term (3-, 6-, and 12-mo) outdoor exposure tests using particleboard specimens of two different sizes to clarify the effect of specimen size and starting time on the deterioration of the mechanical properties (bending and internal bond strength) of the particleboard were conducted. The weathering intensity was determined from the results of the short-term exposure tests, and the effect of the specimen size on the weathering intensity was discussed. The strength retention tended to decrease exponentially with elapsed time. After a 1-year exposure in Shizuoka, Japan, the retained strength was less than 60 percent. Rectangular specimens had less strength retention than the square specimens and are thought to be a more reliable indicator of the true effect of weathering conditions on strength loss. Short- and long-term exposure tests are equally useful for determining the effect of outdoor exposure on particleboard properties.

The use of wood-based panels, especially particleboard, in construction has been increasing steadily in Japan (Food and Agriculture Organization of the United Nations [FAO] 2016). Reduction in the domestic production of veneer-based panel products in Japan has resulted in the increased use of mat-formed panel products for structural purposes. For exterior applications, durability is a very important property (McNatt and Link 1989, Kajita et al. 1991).

Short- and long-term tests are used to evaluate the durability of wood-based panels. Short-term evaluations assess the changes in mechanical properties after accelerated aging treatments, such as water immersion, boiling, steaming, freezing, or drying (American Society for Testing and Materials [ASTM] 1993, European Committee for Standardization [CEN] 1993 Standard EN321, APA 1994, Japanese Standards Association [JSA] 1994). Accelerated aging treatments are quicker to perform and more standardized than outdoor exposure tests. For example, the test specimen size and treatment cycle methods for each accelerated aging treatment are prescriptive in each standard, allowing results from different studies to be more reliably compared.

By contrast, long-term tests, such as outdoor exposure tests, evaluate long time frames by incorporating the factor of elapsed time. However, there is no standardized outdoor exposure test method for wood-based materials, and methodologies such as specimen and experiment sizes, start time, time frames, measurement intervals, and exposure conditions can vary considerably between studies. This makes it difficult to compare and contrast results across different research studies on the subject. It is important to consider the starting time for an outdoor exposure test because the deterioration in such tests is markedly affected by the weathering conditions. For example, in a 1-year exposure test, the deterioration of specimens exposed to high temperature and high humidity in the early and late phases will differ. Although this phenomenon is intuitive, no information on the effect of starting time on the deterioration of wood-based panels has been reported.

In addition, the specimen size used for outdoor exposure tests has not been standardized. Typically, research has used samples measuring 300 by 300 mm (Koch 1970, Williams et al. 2005) or 300 by 50 mm (Alexopoulos 1992, River 1994,

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Kojima et al. 2009). Although the specimen size affects the characteristics of deterioration, no reports have discussed the effect of size in outdoor exposure tests using wood-based materials. Moreover, no reports have discussed how the effects of weathering conditions are related to the deterioration of each specimen size. Previously, we conducted long-term outdoor exposure tests using 300 by 300-mm specimens from 2004 to 2011, with a fixed starting time in April (Kojima et al. 2009; Kojima and Suzuki 2011a, 2011b; Korai 2012; Korai and Hattori 2013; Korai et al. 2013). We have attempted to discuss the relationships between the deterioration of wood-based panels exposed for the long term and ''weathering intensity'' based on weather parameters (Kojima et al. 2011, 2012).

In this study, we conducted relatively short-term (3-, 6-, and 12-mo) outdoor exposure tests using particleboard of two different sizes and varied the starting time to clarify the effects of specimen size and starting time on the deterioration of the mechanical properties (bending and internal bond strength) of particleboard. The effect of specimen size on board deterioration during short-term weathering tests is discussed.

Materials and Methods

Sample panels

Commercial phenol formaldehyde (PF)-resin–bonded particleboard (density 0.78 g/cm^3, thickness 12.4 mm) was used for the outdoor exposure test. This particleboard was made from recycled wood, and categorized as type 18P in the Japanese Industrial Standards (JIS). In this study, two sizes of particleboard were used: 300 by 300 mm (termed ''square'') and 300 by 50 mm (termed ''rectangular''). The modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond strength (IB) values of the sample panels were measured before the outdoor exposure tests. Average MOR was 24.9 (1.9) MPa, MOE was 3.76 (0.19) GPa, and IB was 0.78 (0.12) MPa. Each value is the mean of 10 samples; the numbers in parentheses are the standard deviations.

Outdoor exposure test in Shizuoka, Japan

The outdoor exposure tests were carried out at Shizuoka University (Shizuoka, Japan; 34°N, 138°E, 48 m above sea level). All of the panel specimens (300 by 300 and 300 by 50 mm) were coated with a waterproof agent (SI25FC-1, Nippe Home Products Co., Ltd., Japan) along the exposed edges and placed vertically on a south-facing exposure stand. All specimens were put outdoors without any shade. Thus, specimens were directly exposed to the sunlight and rainfall. Specimens were exposed for 3, 6, or 12 months. The 3-month exposure tests were conducted in summer (June to August 2014), autumn (September to November 2014), winter (December 2014 to February 2015), and spring (March to May 2015). The 6-month exposure tests were conducted in the dry (December 2014 to May 2015) and wet (June to November 2015) seasons. For the 1-year exposure test, to determine the effect of starting time, tests were started in summer (June 2014), autumn (September 2014), winter (December 2014), and spring (March 2015). Table 1 summarizes the climate data for Shizuoka collected during the outdoor exposure test. Figure 1 shows the monthly average temperature, precipitation, and sunlight hours for all outdoor exposure periods in Shizuoka. All

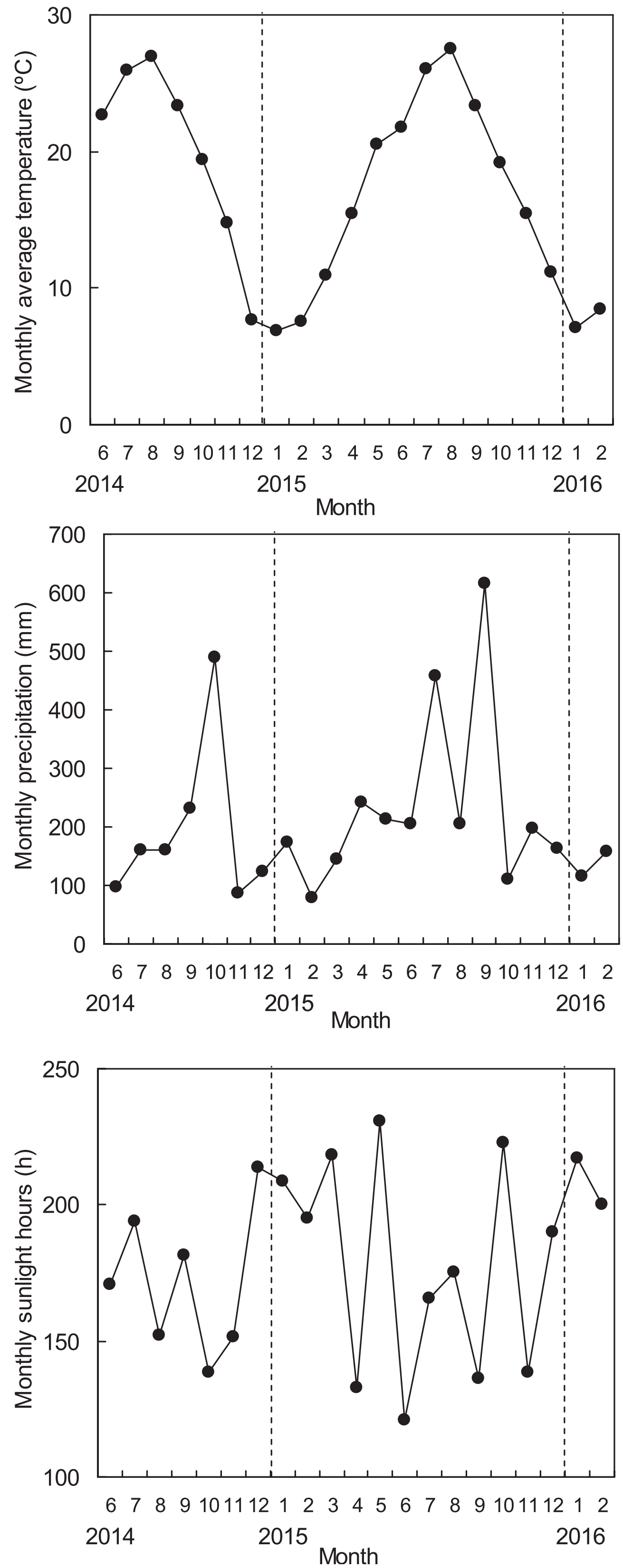

Figure 1.—Climate conditions for Shizuoka, Japan. (Upper) Monthly average temperature, (middle) monthly precipitation, and (lower) monthly sunlight hours.

Table 1.—Summary of the outdoor exposure tests and climate conditions during the outdoor exposure tests in Shizuoka, Japan.

Term	Season	Period	Average temperature (°C)	Total precipitation (mm)	Total sunlight hours (h)
3 mo	Summer	Jun 2014–Aug 2014	25.5	410.5	510.0
	Autumn	Sep 2014–Nov 2014	16.1	835.0	508.0
	Winter	Dec 2014–Feb 2015	8.0	443.0	679.0
	Spring	Mar 2015–May 2015	18.5	619.5	540.0
6 mo	Wet	Jun 2015–Nov 2015	20.7	1,748.5	1,006.8
	Dry	Nov 2014–May 2015	13.1	1,062.5	1,207.5
1 yr	—	Jun 2014–May 2015	17.0	2,308.0	2,181.7
	—	Sep 2014–Aug 2015	16.9	3,087.5	2,124.4
	—	Dec 2014–Nov 2015	16.9	2,849.5	2,227.1
	—	Mar 2015–Feb 2016	17.2	3,055.5	2,212.4

climate data in Table 1 and Figure 1 were obtained from the Japan Meteorological Agency (2016). Five rectangular and two square specimens were prepared for each outdoor exposure condition. After exposure for 3, 6, or 12 months, the boards were removed, dried at 60°C for 24 hours, and then reconditioned at 20°C and 65 percent relative humidity for 2 weeks. The square specimens were cut into four 260 by 50-mm pieces for the bending tests, while the rectangular specimens were not cut after reconditioning. The bending tests were performed in accordance with JIS A 5908 (JSA 1994). After this test, one 50 by 50-mm specimen was removed from the unbroken part of each rectangular test specimen for the IB test. Before the IB test, all rough surfaces (ca. 1 to 2 mm in depth) resulting from the outdoor exposure were smoothed using a sander. The IB tests were performed in accordance with JIS A 5908 (JSA 1994). All mechanical tests were performed after reconditioning, accomplished in a moisture content of about 10 percent.

Results and Discussion

Change in the bending properties and internal bond strength in the outdoor exposure test

Here, the bending properties (MOR and MOE) and IB retention are defined as follows:

- MOR retention (%) = (MOR after exposure test/MOR of original samples) × 100
- MOE retention (%) = (MOE after exposure test/MOE of original samples) × 100
- IB retention (%) = (IB after exposure test/IB of original samples) × 100

Figure 2 shows the changes in strength retention after the 3-, 6-, and 12-month outdoor exposure tests in Shizuoka. In this figure, the upper, middle, and lower graphs show the MOR, MOE, and IB retention, respectively. The results for square and rectangular specimens are shown on the left and right, respectively. Retention of all three properties tended to decrease exponentially with time, and retention was less than 60 percent for all three after the 1-year exposure. In our previous studies, the strength retention tended to decrease rapidly in the first year of long-term outdoor exposure tests and then decreased gradually (Kojima and Suzuki 2011a, 2011b). Even with short-term exposure, it is clear that the strength retention decreased exponentially. For the same length of exposure (3 and 6 mo), there was a difference in strength retention depending upon the exposure season. The effect of exposure season was particularly apparent for IB retention. The results of the outdoor exposure tests clearly reflected the weather conditions.

Effect of starting time on the deterioration of particleboard subjected to outdoor exposure for 1 year

Figure 3 shows the strength retention of square and rectangular specimens after the 1-year exposure. In this figure, the upper, middle, and lower graphs show the MOR, MOE, and IB retention, respectively. The results for square and rectangular specimens are on the left and right, respectively. It is clear that the degree of deterioration differed according to the starting time for outdoor exposure. For the square specimens, the difference was significant at the 5 percent level only for the IB retention. For the rectangular specimens, all of the differences in retention were significant. This suggests that results from rectangular specimens may provide a more reliable indication of the effects of weathering on exposed particleboard.

Effect of specimen size on the deterioration of particleboard subjected to outdoor exposure

Figure 4 compares the strength retention of square and rectangular specimens. The upper, middle, and lower graphs show the MOR, MOE, and IB retention, respectively. In this figure, the broken lines are the diagonals of the graphs. Most data points were above the diagonal, which means that the property retention of rectangular specimens was lower than that of square specimens. The MOR and MOE retention for rectangular specimens was about 3 percent lower than for square specimens, and the IB retention for rectangular specimens was about 7 percent lower than for square specimens. Regarding the MOR and MOE retention, the specimen size effect was small after the 3-month exposure time and increased with increasing exposure time.

As mentioned above, the board deterioration resulting from weathering conditions clearly differed with the specimen size. Generally, the mechanical properties of mat-formed panels such as particleboard decrease because of panel swelling. With outdoor exposure, it was hypothesized that temperature and precipitation affect the cycle of swelling and drying, while sunlight affects the surface deterioration of the panels. However, the results suggest that weather conditions have more complex effects on the rate of panel deterioration. In the authors' previous work (Kojima et al. 2012), the weathering intensity for exposed particleboard was calculated based on temperature (T), precipitation (P), and sunlight hours (S) during the period of outdoor

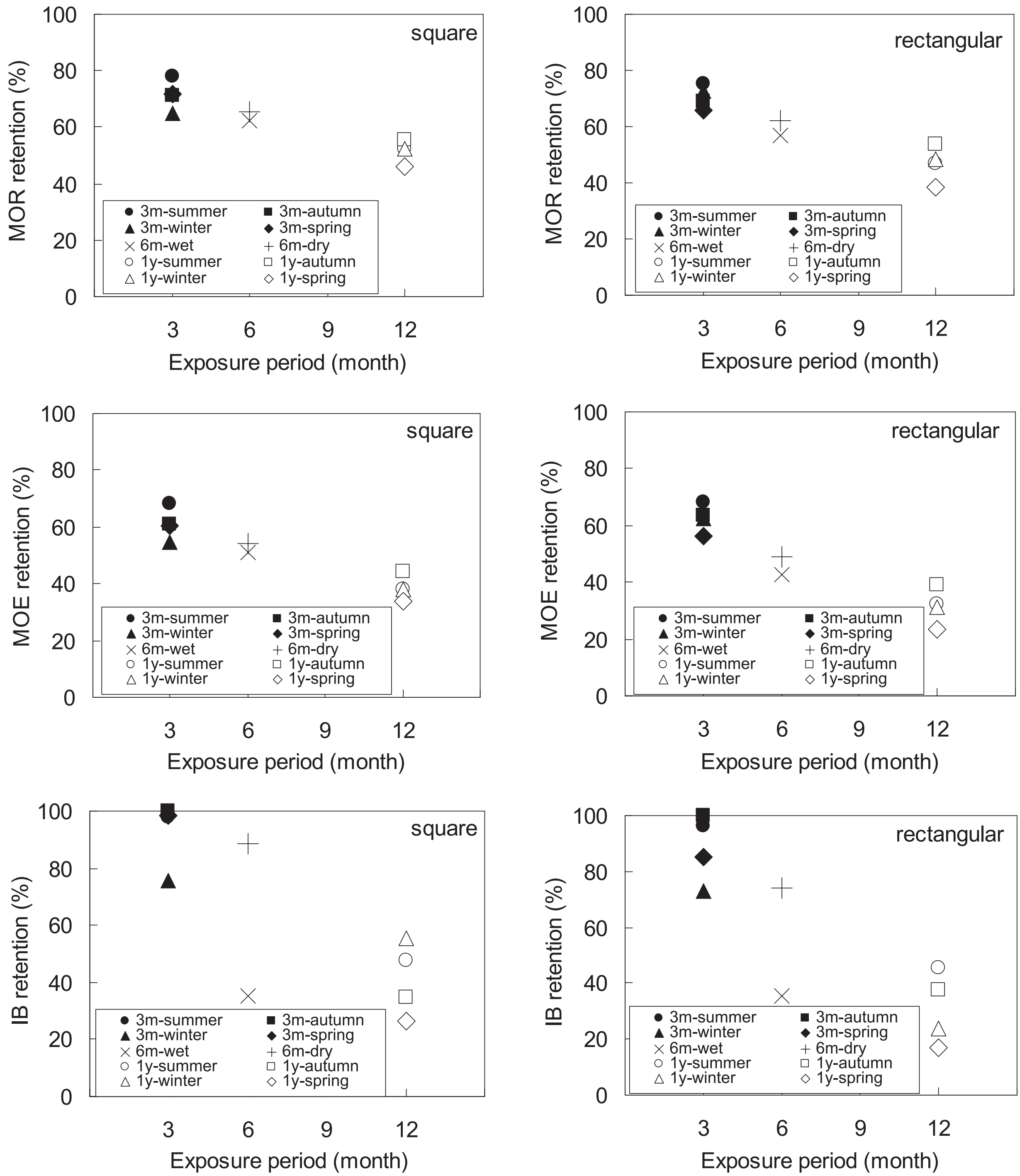

Figure 2.—Changes in strength retention of square specimens (left panels) and rectangular specimens (right panels) during the 3-, 6-, and 12-month outdoor exposure tests in Shizuoka, Japan. (Upper) Modulus of rupture (MOR), (middle) modulus of elasticity (MOE), and (lower) internal bond strength (IB). 3m = 3 months, 6m = 6 months, 1y = 1 year.

exposure. Weathering intensity is expressed as the sum of each weather factor (i.e., ΣT, ΣP, ΣS) or the sum of combinations of weather parameters [i.e., $\Sigma(T \times S)$, $\Sigma(T \times P)$, $\Sigma(P \times S)$, and $\Sigma(T \times P \times S)$]. Daily weather data from the Japan Meteorological Agency (2016) were used as the inputs. The weathering intensity tool was used to estimate the contribution of each weather factor on board deterioration and to explore correlations between weathering intensity and measured board deterioration in the long-term outdoor exposure tests. The highest correlation coefficient was obtained when $\Sigma(T \times P)$ was used as the weathering intensity index. In the current study, we have attempted to apply the same method to the deterioration measured during short-term outdoor exposure tests and clarify the effects of weathering parameters on specimens of different sizes in the outdoor exposure test.

To study weathering intensity, the MOR, MOE, and IB retentions were measured after exposure for 3, 6, and 12

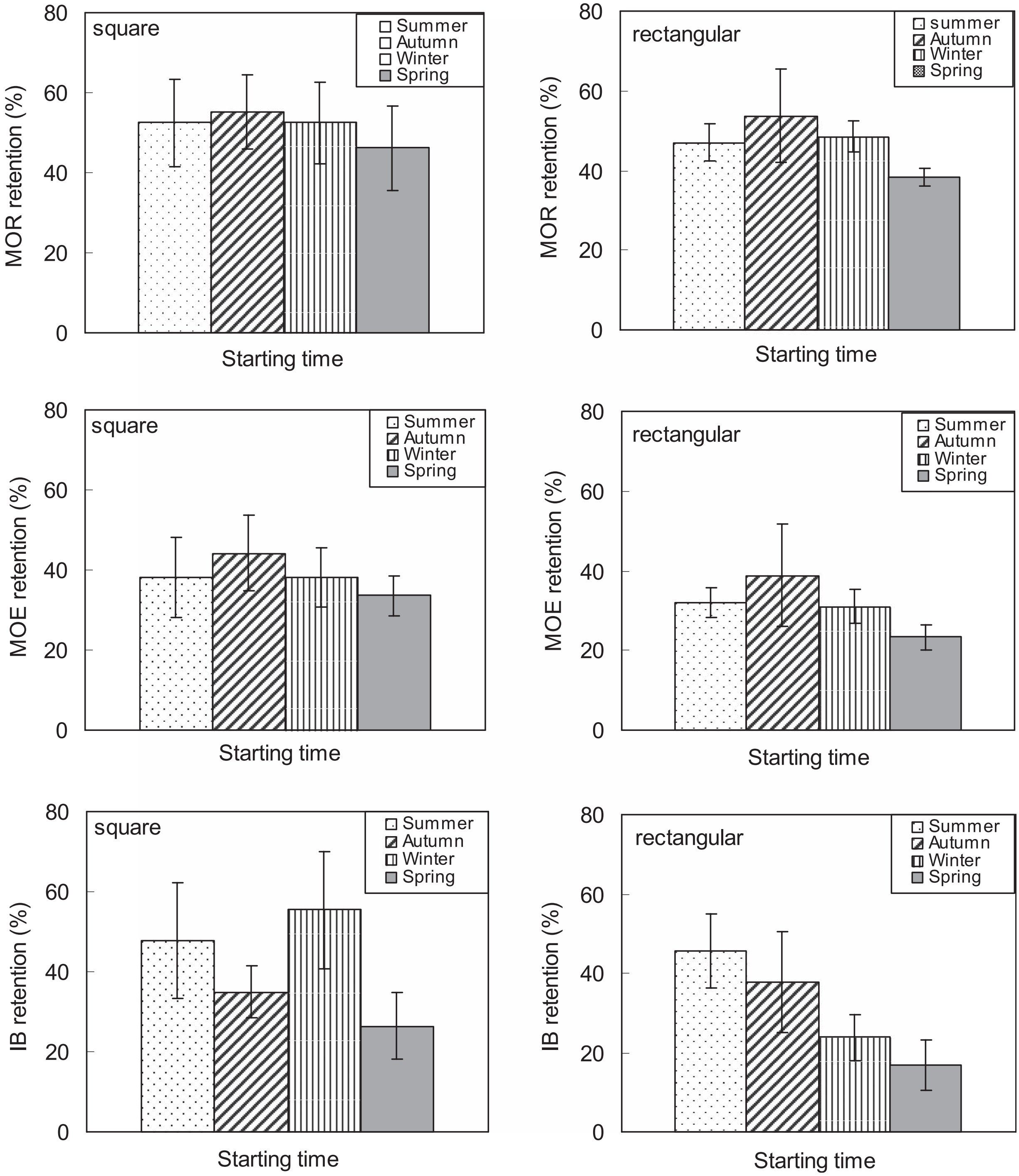

Figure 3.—Strength retention after 1-year exposure using square specimens (left panels) and rectangular specimens (right panels). (Upper) Modulus of rupture (MOR), (middle) modulus of elasticity (MOE), and (lower) internal bond strength (IB). Error bars denote the standard deviations.

months. The logarithm of the weathering intensity was determined from the coefficient of correlation from a linear regression analysis.

As an example, Figure 5 shows the relationship between MOR retention and the logarithm of the weathering intensity (log ΣP) for both specimen sizes. In this figure, the line is the linear regression line. We calculated the correlation coefficient between the strength retention and weathering intensity for each combination of weather parameters. Table 2 shows the correlation coefficients between the seven measures of weathering intensity and the retention of three strength properties (MOR, MOE, and IB). The correlation coefficients for the rectangular specimens were higher than those for the square specimens when a single weather parameter (e.g., ΣT, ΣP) was used as the weathering intensity and when the weathering parameters were combined [e.g., $\Sigma(T \times S)$, $\Sigma(T \times P)$]. The higher correlation between strength loss and weather parameters in

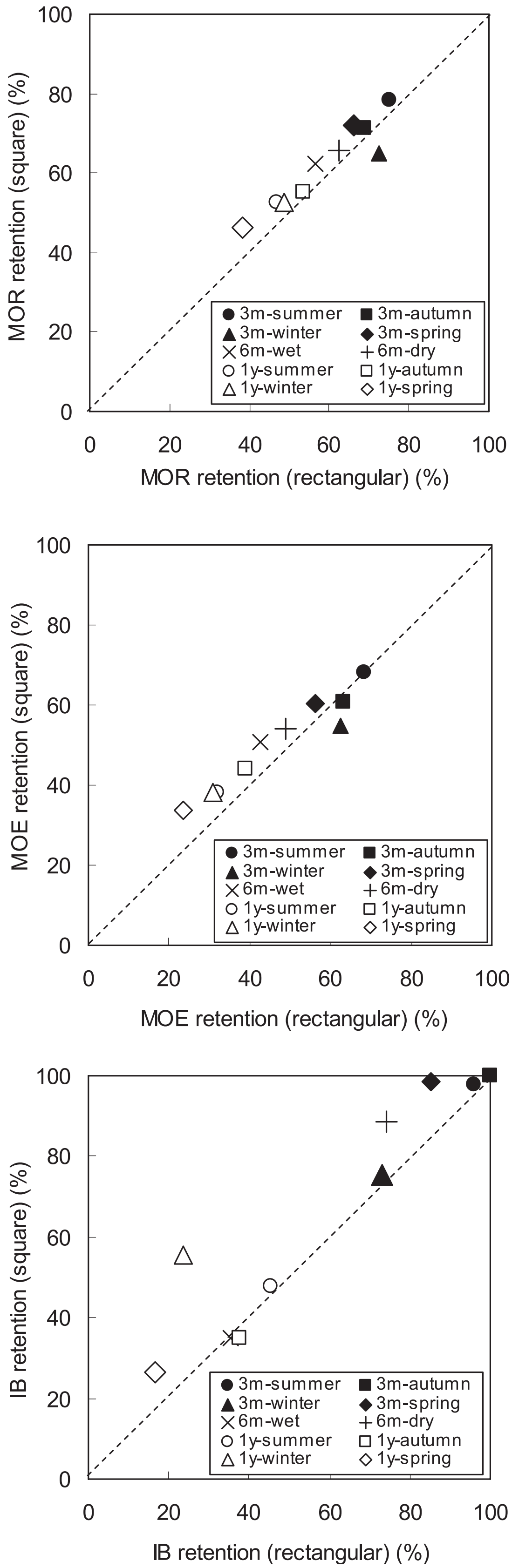

Figure 4.—Relationships between retention of strength properties of square and rectangular specimens. (Upper) Modulus of rupture (MOR), (middle) modulus of elasticity (MOE), and (lower) internal bond strength (IB). 3m = 3 months, 6m = 6 months, 1y = 1 year. The broken lines are the diagonals.

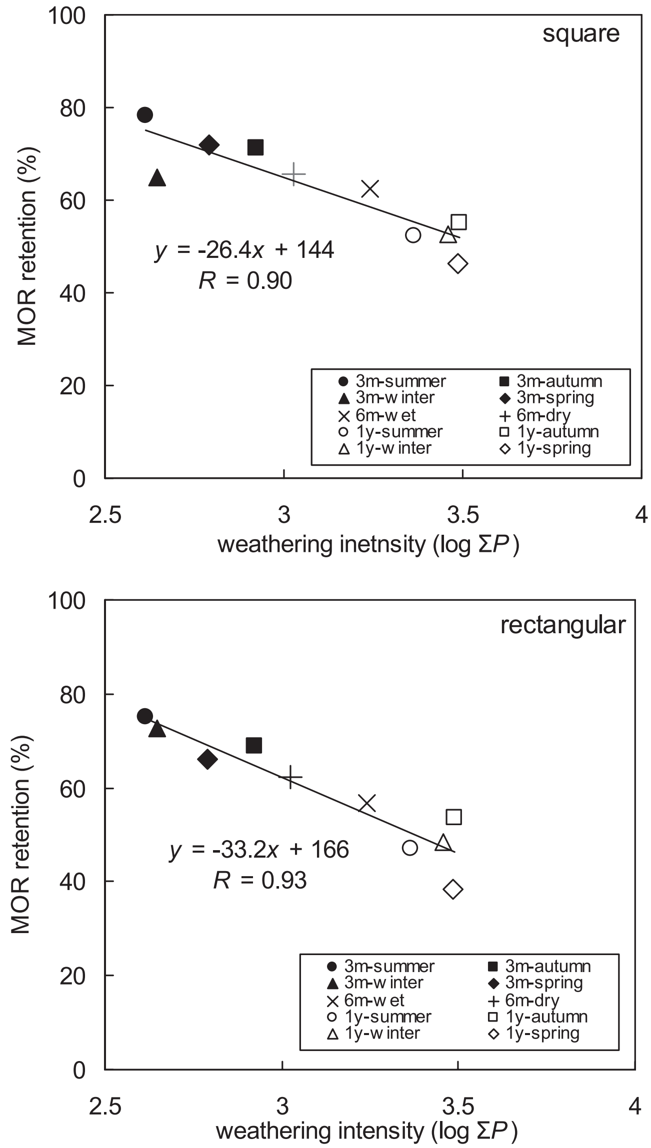

Figure 5.—Relationship between the modulus of rupture (MOR) retention and the weathering intensity [log(ΣP)]. (Upper) Square specimens and (lower) rectangular specimens. 3m = 3 months, 6m = 6 months, 1y = 1 year. The lines are the linear regression lines.

the small specimens also reflects the greater susceptibility of these to exposure-induced deterioration. In contrast to the findings of our previous study of long-term outdoor exposure (Kojima et al. 2012), here the board strength loss indices were more closely correlated with single weather parameters rather than combined parameters over the long-term weathering study. This means that a single weathering condition may have a greater effect on board deterioration than combined weathering parameters with short-term exposure, while multiple weathering parameters can affect the board deterioration in long-term exposure tests. Because the correlation coefficients in this short-term exposure study are similar to the long-term exposure test results (Kojima et al. 2012), it is clear that short-term exposure tests also reflect the weathering intensity.

Table 2.—Correlation coefficients of the seven measures of weathering intensity and three types of strength retention of square and rectangular specimens.[a]

Weathering intensity	MOR retention		MOE retention		IB retention	
	Square	Rectangular	Square	Rectangular	Square	Rectangular
log ΣT	0.76	0.87	0.77	0.88	0.75	0.80
log ΣP	0.90	0.93	0.90	0.94	0.83	0.88
log ΣS	0.94	0.91	0.94	0.94	0.83	0.89
log $\Sigma(P \times T)$	0.78	0.89	0.79	0.88	0.77	0.81
log $\Sigma(T \times S)$	0.78	0.88	0.80	0.89	0.78	0.83
log $\Sigma(P \times S)$	0.79	0.73	0.77	0.72	0.70	0.69
log $\Sigma(T \times P \times S)$	0.71	0.70	0.70	0.68	0.67	0.65

[a] MOR = modulus of rupture; MOE = modulus of elasticity; IB = internal bond strength.

Conclusions

In residential construction, durability (resistance to weathering-induced strength loss over time) is one of the most important properties of particleboard. In this study, durability of commercially available structural grade particleboard was assessed using short-term outdoor exposure tests in Shizuoka, Japan. The ability of boards to retain their strength properties (MOR, MOE, and IB) decreased exponentially with exposure time, with the effect most pronounced in the small (300 by 50 mm) rectangular specimens. Less than 60 percent of all strength properties were retained after 1-year of exposure in Shizuoka. The strength retention was higher in the case of the much larger (300 by 300 mm) square specimens owing to their larger size buffering effect. Comparing these results with those of the authors' previous work on long-term exposure of particleboard to weathering indices, it was concluded that results from shorter term weathering experiments could still provide a good framework for predicting the effects of changing various weathering parameters such as temperature, precipitation, and sunlight hours over the exposure period.

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