

# Comparison between climatic factors and climate deterioration index on strength reduction of particleboards subjected to various climatic conditions in Japan

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**Abstract** An outdoor test on particleboards subjected to various climatic conditions was conducted in Japan. The significant climatic factors that reduce the particleboard strength (bending strength and internal bond strength) were investigated using multiple regression analysis. The climatic factors that reduce strength were temperature, sunshine duration, and/or precipitation. These three factors were not always significant; the significant climatic factors were different for each exposure time. In addition, the effects of climatic factors on strength reduction were different. Thus, multiple regression analysis using each climatic factor separately was not powerful. Therefore, the three climatic factors were combined into a first principal component using principal component analysis. The principal component score is referred to as the climate deterioration index (CDI). Strength at each exposure time decreased linearly with increasing CDI. The CDI is simpler and more useful as a climate index than individual climatic factors for predicting the strength reduction. In addition, both the relationship between CDI and strength reduction at each exposure time using analysis of covariance and the effects of CDI and exposure time were significant.

## 1 Introduction

In general, particleboards are only used indoors. In order to increase the demand for particleboards, they should be able to be used outdoors. Basic data regarding outdoor use are needed. Outdoor exposure tests on particleboards have been

conducted in North America (Hann et al. 1962; Gatchell et al. 1966; Suchsland 1973; River 1994). However, in Japan, particleboards have rarely been tested until the early 2000s (Suzuki 2001). Therefore, sites were selected as representative of the Japanese climate, and an outdoor test on particleboards subjected to various climatic conditions was conducted from 2004 to 2009. The eight sites selected were Asahikawa, Noshiro, Morioka, Tsukuba, Maniwa, Okayama, Shizuoka, and Miyakonojo (Table 1). Recently results have been reported by the authors' research group (Korai et al. 2012, 2013, 2014a, b; Korai 2012; Korai and Hattori 2013; Korai and Saotome 2014; Watanabe et al. 2014; Korai and Watanabe 2015; Kojima et al. 2009, 2012; Kojima and Suzuki 2011a, b; Sekino et al. 2014).

Usually temperature, sunshine duration, and precipitation are the main climatic factors that reduce strength (bending strength and internal bond strength) (Kojima et al. 2012). In general, multiple regression analysis is effective for analyzing climatic factors that reduce strength. First, in this study climatic factors were analyzed using multiple regression analysis, and then climatic factors that reduce strength were selected using a stepwise method based on Akaike's Information Criterion (AIC). The relationship between climatic factors and strength reduction was investigated. The stepwise method based on AIC provides a simple way to select the significant explanatory variables for multiple regression analysis, so this method was adopted (Crawley 2012b).

On the other hand, due to the complex correlation between these climatic factors, a comprehensive evaluation of the climatic factors on strength reduction is complicated. Thus, in a previous study by the authors, the three climatic factors were combined into a first principal component using principal component analysis (Korai and Watanabe 2015). The score of the first principal component was closely related to

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the strength reduction. The strength of particleboards subjected to outdoor exposure in high-score areas decreased significantly. It was determined that the score was a simple and useful index for predicting strength reduction that resulted from climatic phenomenon. The score is referred to as the climate deterioration index (CDI). Secondly, in this study the effects of the CDI as a climate index on strength reduction were investigated using analysis of covariance (ANCOVA). ANCOVA is different from analysis of variance (ANOVA). The strength decreased with increasing CDI; there was high correlation between strength and CDI. In this case, the CDI is covariate, so the effects of the outdoor exposure time (exposure time) can be investigated using the CDI as a covariate. ANCOVA can analyze both the effects of exposure time and CDI, but ANOVA cannot analyze both. ANCOVA provides a more powerful analysis than ANOVA (Crawley 2012a).

## 2 Materials and methods

### 2.1 Outdoor exposure and strength tests

Commercially available phenol–formaldehyde resin-bonded particleboards were used. The density of the particleboards was  $0.75 \text{ g/cm}^3$ . The 30–40 particleboards measuring  $910 \times 1823 \times 12.2 \text{ mm}^3$  were cut into specimens measuring  $300 \times 300 \text{ mm}^2$ . The cut edges of the specimens were coated with enamel paint, which acts as a waterproofing agent. The twelve specimens that were selected randomly were subjected to outdoor exposure to the south at an angle of  $90^\circ$  at each site. The two specimens were collected from outdoor exposure stands after 1-, 2-, 3-, 4-, and 5-year exposure and conditioned in a constant temperature and humidity room (at a temperature of  $20^\circ \text{C}$  and relative humidity of 65 %) for approximately one month. After conditioning, the moisture content of the specimens was approximately 8–10 % (Korai et al. 2013). For the strength tests, modulus of rupture (MOR) as bending strength and internal bond strength (IB) tests were

conducted in compliance with JIS A 5908 (JIS 2003). The initial MOR and IB of the particleboard were 20.3 (2.29) MPa and 0.833 (0.09) MPa, respectively. The number in parentheses indicates the standard deviation. Further details can be found in a previous report by Korai et al. (2012). The eight sites listed in the introduction section were numbered site 1–8, respectively (Table 1). Small numbers indicated northern sites. The annual climatic factors of mean temperature, sunshine duration, and precipitation at these sites are listed in Table 2.

### 2.2 Variable selection from climatic factors

Many annual climatic factors were obtained from the website of the Japan Meteorological Agency (Japan Meteorological Agency 2014). Among these annual climatic factors, mean temperature, maximum temperature, minimum temperature, sunshine duration, solar radiation, precipitation, and relative humidity are likely to affect strength reduction as explanatory variables. Correlation coefficients between these climatic factors and strength were measured to investigate the relationships between them, and climatic factors that reduce the strength were revealed.

### 2.3 Statistical analysis

The criterion variable was strength, and the explanatory variables were climatic factors. Multiple regression analysis was conducted using these variables. Furthermore, significant explanatory variables were selected using a stepwise method based on AIC.

Climatic factors at eight sites listed in Table 2 were standardized, and these standardized climatic factors were analyzed using principal component analysis. The score of the first principal component (CDI) was calculated. Regression analysis was conducted using CDI as an explanatory variable at eight sites for 1–5 years of outdoor exposure. The criterion variable was strength. ANCOVA was conducted using CDI as a covariate. Factors that reduce the strength were CDI and exposure time, which had five levels (1-, 2-, 3-, 4-, and 5-year exposure).

The above statistical analyses were conducted using the computer software “R. 3.0.2 (R Development Core Team 2013)”.

## 3 Results and discussion

### 3.1 Correlation coefficient between climatic factor and strength

Table 3 lists the correlation coefficients between each climatic factor and IB. The mean temperature, precipitation,

**Table 1** Site number, sites, latitude, and longitude for outdoor exposure sites

Site no.	Sites	North latitude	East longitude
Site 1	Asahikawa	43°41'	142°22'
Site 2	Noshiro	40°11'	140°00'
Site 3	Morioka	39°37'	141°05'
Site 4	Tsukuba	36°02'	140°05'
Site 5	Maniwa	35°05'	133°41'
Site 6	Okayama	34°41'	133°46'
Site 7	Shizuoka	34°57'	138°25'
Site 8	Miyakonojo	31°43'	131°05'

**Table 2** Climatic factors and CDI for outdoor exposure sites from April 2004 to March 2009

Exposure time (year)	Site no.	Climatic factors			CDI	IB (MPa)	MOR (MPa)
		<i>T</i> (°C)	<i>S</i> (h)	<i>P</i> (mm)			
1	1	7.2	1598	984	−2.15	0.812	14.9
	2	11.6	1272	1731	−1.49	0.630	14.9
	3	10.6	1633	1535	−1.17	0.639	13.2
From April 2004 to March 2005	4	14.5	2174	1693	0.49	0.605	14.1
	5	14.5	1786	1683	−0.17	0.551	12.9
	6	16.9	2074	1509	0.61	0.556	14.0
	7	17.4	2257	3454	2.21	0.337	11.9
	8	16.9	2036	3302	1.66	0.229	7.90
2	1	7.0	1548	987	−2.20	0.626	13.7
	2	11.4	1333	1622	−1.37	0.540	14.1
From April 2004 to March 2006	3	10.3	1638	1468	−1.1	0.458	11.5
	4	14.2	2093	1409	0.39	0.573	12.5
	5	14.2	1816	1355	−0.17	0.434	9.90
	6	16.7	2084	1141	0.61	0.324	8.33
	7	17.0	2206	2624	1.99	0.212	8.90
	8	16.8	2047	2889	1.84	0.125	7.17
3	1	7.1	1572	1009	−2.18	0.666	12.8
	2	11.5	1375	1571	−1.38	0.464	9.63
	3	10.4	1646	1370	−1.13	0.521	10.6
From April 2004 to March 2007	4	14.3	1983	1455	0.37	0.318	9.85
	5	14.2	1781	1326	−0.21	0.323	7.05
	6	16.7	2038	1160	0.66	0.185	7.65
	7	17.0	2117	2432	1.97	0.152	6.67
	8	17.0	1993	2688	1.91	0.09	5.86
4	1	7.1	1606	966	−2.16	0.596	11.8
	2	11.5	1401	1475	−1.41	0.287	9.41
From April 2004 to March 2008	3	10.4	1672	1348	−1.09	0.480	8.69
	4	14.3	2004	1377	0.37	0.320	7.70
	5	14.2	1786	1315	−0.2	0.186	6.28
	6	16.7	2037	1082	0.6	0.208	4.77
	7	16.9	2122	2326	1.95	0.07	5.79
	8	17.0	2025	2569	1.96	0.06	5.14
5	1	7.2	1598	946	−2.21	0.360	6.34
	2	11.5	1444	1470	−1.38	0.377	10.3
	3	10.5	1691	1315	−1.07	0.193	4.01
From April 2004 to March 2009	4	14.3	1963	1399	0.36	0.140	9.44
	5	14.2	1781	1274	−0.23	0.119	4.69
	6	16.7	2026	1057	0.64	0.186	5.22
	7	16.9	2104	2302	1.97	0.05	5.07
	8	17.0	1989	2566	1.93	0.06	4.88

The CDI (score of first principal component) was calculated using the standardized *T*, *S*, and *P*. Due to a lack of climatic factors for Site 5 (Maniwa), climatic factors for Tsuyama were used instead. Tsuyama is located near Maniwa

*T* annual mean temperature, *S* annual sunshine duration, *P* annual precipitation, *CDI* climate deterioration index, *IB* internal bond strength, *MOR* modulus of rupture

and sunshine duration are listed in Table 2. Maximum temperature, minimum temperature, and relative humidity were obtained from the website of the Japan Meteorological

Agency, and these climatic factors are not listed. *IB* is also listed in Table 2. For example, in the fourth row and first column, the mean temperature for the 4-year exposure and

**Table 3** Correlation coefficient between each climatic factor and IB at each exposure time

Exposure time (year)	Climatic factor					
	Mean temperature	Maximum temperature	Minimum temperature	Sunshine duration	Precipitation	Relative humidity
1	−0.841**	−0.839**	−0.834*	−0.596 <sup>ns</sup>	−0.944***	0.249 <sup>ns</sup>
2	−0.804*	−0.790*	−0.814*	−0.645 <sup>ns</sup>	−0.819*	0.633 <sup>ns</sup>
3	−0.990***	−0.980***	−0.975***	−0.830*	−0.699 <sup>ns</sup>	0.613 <sup>ns</sup>
4	−0.933***	−0.917**	−0.939***	−0.634 <sup>ns</sup>	−0.744*	0.534 <sup>ns</sup>
5	−0.808*	−0.863**	−0.748*	−0.863**	−0.650 <sup>ns</sup>	0.339 <sup>ns</sup>
Mean	−0.875	−0.878	−0.862	−0.713	−0.771	0.474
SD	0.083	0.073	0.093	0.123	0.115	0.171
COV (%)	9.45	8.35	10.8	17.3	14.9	36.1

These climatic factors were measured annually. Exposure time is defined in Table 2

IB internal bond strength, SD standard deviation, COV coefficient of variation, ns no statistical significance

\* Statistical significance at 5 % level

\*\* Statistical significance at 1 % level

\*\*\* Statistical significance at 0.1 % level

**Table 4** Correlation coefficient between each climatic factor and MOR at each exposure time

Exposure time (year)	Climatic factor					
	Mean temperature	Maximum temperature	Minimum temperature	Sunshine duration	Precipitation	Relative humidity
1	−0.575 <sup>ns</sup>	−0.631 <sup>ns</sup>	−0.539 <sup>ns</sup>	−0.447 <sup>ns</sup>	−0.810*	−0.053 <sup>ns</sup>
2	−0.830*	−0.857**	−0.811*	−0.756*	−0.591 <sup>ns</sup>	0.624 <sup>ns</sup>
3	−0.925***	−0.929***	−0.922**	−0.655 <sup>ns</sup>	−0.697 <sup>ns</sup>	0.559 <sup>ns</sup>
4	−0.965***	−0.966***	−0.953***	−0.786*	−0.521 <sup>ns</sup>	0.708*
5	−0.217 <sup>ns</sup>	−0.279 <sup>ns</sup>	−0.186 <sup>ns</sup>	−0.396 <sup>ns</sup>	−0.176 <sup>ns</sup>	0.350 <sup>ns</sup>
Mean	−0.702	−0.732	−0.682	−0.608	−0.559	0.438
SD	0.311	0.285	0.322	0.178	0.240	0.304
COV	44.3	38.9	47.2	29.2	43.0	69.6

These climatic factors were measured annually. Exposure time is defined in Table 2

MOR modulus of rupture, SD standard deviation, COV coefficient of variation, ns no statistical significance

\* Statistical significance at 5 % level

\*\* Statistical significance at 1 % level

\*\*\* Statistical significance at 0.1 % level

IB of the particleboard subjected to outdoor exposure at the eight sites for the 4-year exposure were used to calculate the correlation coefficient of  $-0.933$ . The majority of correlation coefficients for relative humidity had positive values and a high COV (coefficient of variation), and thus relative humidity was not included as an explanatory variable. The correlation coefficients of mean temperature, maximum temperature, and minimum temperature were similar, and in this study mean temperature was included. Solar radiation is presumably better than sunshine duration because the former is related to energy radiated from the sun. However, solar radiation was not measured at sites 2, 5, and 8, and was therefore unavailable. Thus, the sunshine

duration was used instead. Table 4 lists correlation coefficients between each climatic factor and MOR. The MOR is listed in Table 2. Table 4 provides results similar to those of IB listed in Table 3. As discussed in the introduction, mean temperature (T), sunshine duration (S), and precipitation (P) are the main climatic factors that reduce the strength of the particleboard as explanatory variables.

### 3.2 Multicollinearity of climatic factors

Multicollinearity should be avoided when conducting multiple regression analysis. In the case of the Japanese climate, T, S and P are related to each other. For

**Table 5** Correlation coefficient and VIF at each exposure time

Exposure time (year)	Correlation coefficient			VIF		
	<i>T</i> vs. <i>S</i>	<i>T</i> vs. <i>P</i>	<i>S</i> vs. <i>P</i>	<i>T</i>	<i>S</i>	<i>P</i>
1	0.763*	0.712*	0.547 <sup>ns</sup>	3.40	2.39	2.03
2	0.825*	0.598 <sup>ns</sup>	0.448 <sup>ns</sup>	3.94	3.16	1.57
3	0.827*	0.627 <sup>ns</sup>	0.474 <sup>ns</sup>	4.08	3.19	1.67
4	0.816*	0.616 <sup>ns</sup>	0.487 <sup>ns</sup>	3.68	2.99	1.61
5	0.837**	0.617 <sup>ns</sup>	0.493 <sup>ns</sup>	4.09	3.34	1.62

Exposure time and climatic data are defined in Table 2

*T* annual mean temperature, *S* annual sunshine duration, *P* annual precipitation, *VIF* variance inflation factor, *ns* no statistical significance

\* Statistical significance at 5 % level

\*\* Statistical significance at 1 % level

**Table 6** AIC and significant climatic factor calculated using IB and climatic factors at each exposure time

Exposure time (year)	AIC							Significant climatic factor
	Step 1	Step 2			Step 3			
	<i>T, S, P</i>	<i>T, P</i>	<i>T, S</i>	<i>S, P</i>	<i>T</i>	<i>S</i>	<i>P</i>	
1	−44.9	<b>−46.0</b>	−32.2	−40.7	−34.1	−	−42.0	<i>T, P</i>
2	−34.6	<b>−36.6</b>	−31.1	−34.4	−33.0	−	−33.6	<i>T, P</i>
3	−56.8	<b>−58.0</b>	−52.5	−34.2	−54.3	−	−28.3	<i>T, P</i>
4	<b>−46.0</b>	−41.7	−41.9	−30.1	−	−	−	<i>T, S, P</i>
5	−39.9	−37.8	−40.2	<b>−41.8</b>	−34.9	−41.4	−	<i>S, P</i>

Exposure time and climatic data are defined in Table 2. Boldface values indicate the lowest AIC

*IB* internal bond strength, *AIC* Akaike’s Information Criterion, *T* annual mean temperature, *S* annual sunshine duration, *P* annual precipitation

example, high temperature is related to high sunshine duration. Climatic factors with high correlation between them are not suitable as explanatory variables due to multicollinearity. To investigate multicollinearity, Table 5 lists the correlation coefficients among *T*, *S*, and *P*. The correlation coefficients between *T* and *S* were high, and multicollinearity was doubtful. Therefore, the variance inflation factor (*VIF*) is also listed in Table 5 to investigate multicollinearity. If *VIF* of the climatic factor is more than 10, multicollinearity is suggested, and the climatic factor is excluded (Aoki 2014). The *VIF*s listed in Table 5 were less than 10, and thus, the climatic factors did not suggest multicollinearity. *T*, *S*, and *P* were used as explanatory variables.

### 3.3 Multiple regression analysis to select significant climatic factors

To investigate the effects of climatic factors on strength reduction, multiple regression analysis was conducted using *T*, *S*, and *P* as explanatory variables. Furthermore, the stepwise method based on *AIC* was also conducted to select

the significant climatic factors. A low *AIC* indicates significant explanatory variables (Crawley 2012b). Table 6 lists the *AIC*s calculated using *IB* and climatic factors at each exposure time, and boldface values represent the lowest *AIC* in each exposure time. At Step 1, multiple regression analysis was conducted using *T*, *S*, and *P*, and the *AIC* was −44.9 for 1-year exposure in the first row and first column. At Step 2, two explanatory variables (*T* vs. *P*, *T* vs. *S*, or *S* vs. *P*) were selected, and three *AIC*s were calculated. The *AIC* calculated using *T* and *S* was −46.0, which was the lowest among the three *AIC*s. At Step 3, one explanatory variable (*T* or *P*) was selected, and two *AIC*s were calculated. The *AIC* of −46.0 at Step 2 was lower than that at Step 3. The *AIC* of −46.0 was the lowest in the first row, which indicates that *T* and *P* are explanatory variables. These variables were selected as significant climatic factors that reduce strength, and this process was repeated for each exposure time. The significant climatic factors selected are *T* and *P* at 1-, 2-, and 3-year exposure. At the 4-year exposure, they are *T*, *S*, and *P*, and at the 5-year exposure, they are *S* and *P*. The significant climatic factors were different at each exposure time.

**Table 7** AIC and significant climatic factor calculated using MOR and climatic factors at each exposure time

Exposure time (year)	AIC							Significant climatic factor
	Step 1		Step 2		Step 3			
	<i>T, S, P</i>	<i>T, P</i>	<i>T, S</i>	<i>S, P</i>	<i>T</i>	<i>S</i>	<i>P</i>	
1	11.7	9.65	15.0	9.65	–	14.4	<b>7.65</b>	<i>P</i>
2	11.8	10.3	10.3	11.6	<b>8.70</b>	11.3	–	<i>T</i>
3	1.28	1.75	<b>0.68</b>	10.8	1.10	12.1	–	<i>T, S</i>
4	–1.37	–3.37	–2.29	10.8	<b>–4.29</b>	–	14.5	<i>T</i>
5 <sup>a</sup>	18.7	18.1	16.7	17.2	16.2	15.2	–	–

Exposure time and climatic data are described in Table 2. Boldface indicates the lowest AIC

*MOR* modulus of rupture, *AIC* Akaike's Information Criterion, *T* annual mean temperature, *S* annual sunshine duration, *P* annual precipitation

<sup>a</sup> 5-year exposure was not successful using multiple regression analysis owing to low correlation

**Table 8** Standardized regression coefficient and adjusted coefficient of determination of the IB multiple regression equations at each exposure time

Exposure time (year)	Standardized regression coefficient			Adjusted R <sup>2</sup>
	<i>T</i>	<i>S</i>	<i>P</i>	
1	–0.343	–	–0.700	0.928
2	–0.489	–	–0.527	0.754
3	–0.909	–	–0.129	0.986
4	–1.07	0.369	–0.262	0.934
5	–	–0.717	–0.296	0.735

Exposure time and climatic data are defined in Table 2

*IB* internal bond strength, *T* annual mean temperature, *S* annual sunshine duration, *P* annual precipitation, *Adjusted R*<sup>2</sup> adjusted coefficient of determination

Table 7 lists the AICs calculated using MOR and climatic factors at each exposure time. At 5-year exposure, the AIC could not be calculated owing to low correlation. The significant climatic factors of MOR were more different than those of IB listed in Table 6.

Table 8 lists the standardized regression coefficient calculated by multiple regression analysis using IB and climatic factors selected in Table 6 at each exposure time. The effects of significant climatic factors to reduce the IB were different. For example, for the 1-year exposure, the standardized regression coefficient of *T* was –0.343 and that of *P* was –0.700. The former was less effective than the latter. On the other hand, at the 3-year exposure, the standardized regression coefficient of *T* was –0.909, and the standardized regression coefficient of *P* was –0.129. The former was more effective than the latter. The effects of each climatic factor on the IB reduction were different. Table 9 lists the standardized regression coefficient calculated by multiple regression analysis using MOR and climatic factors selected in Table 7 at each exposure time. It was more difficult to predict the MOR using multiple regression analysis than to predict the IB.

**Table 9** Standardized regression coefficient and adjusted coefficient of determination of the MOR multiple regression equations at each exposure time

Exposure time (year)	Standardized regression coefficient			Adjusted R <sup>2</sup>
	<i>T</i>	<i>S</i>	<i>P</i>	
1	–	–	–0.810	0.599
2	–0.830	–	–	0.638
3	–1.21	0.345	–	0.851
4	–0.965	–	–	0.919
5 <sup>a</sup>	–	–	–	–

Exposure time and climatic data are defined in Table 2

*MOR* modulus of rupture, *T* annual mean temperature, *S* annual sunshine duration, *P* annual precipitation, *Adjusted R*<sup>2</sup> adjusted coefficient of determination

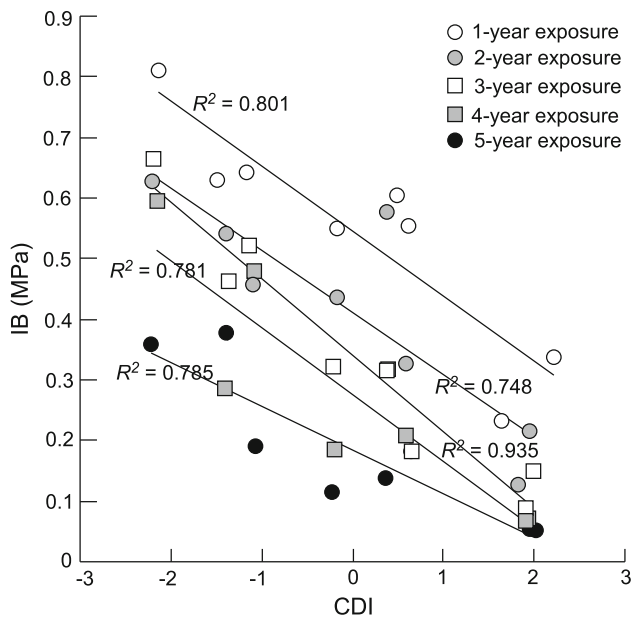
<sup>a</sup> 5-year exposure was not successful using multiple regression analysis owing to low correlation

These investigations suggest that it is very difficult to predict strength reduction using multiple regression analysis with climatic factors. At each exposure time, the significant climatic factors were different, and the effects of the factors on strength reduction were also different. Therefore, powerful multiple regression analysis cannot be conducted using climatic factors.

### 3.4 ANCOVA using CDI

Instead of separate climatic factors, the CDI was developed as a simple and useful climate index (Korai and Watanabe 2015). This section explains that the CDI is simpler and more useful than each climatic factor separately using ANCOVA.

Figure 1 shows the relationship between CDI and IB for each exposure time. The IB decreased linearly with increasing the CDI, and the high correlation was seen in Fig. 1 for each exposure time. Moreover, when the exposure time increased, each regression line decreased.



**Fig. 1** Relationship between CDI and IB for each exposure time. *CDI* climate deterioration index, *IB* internal bond strength,  $R^2$  coefficient of determination

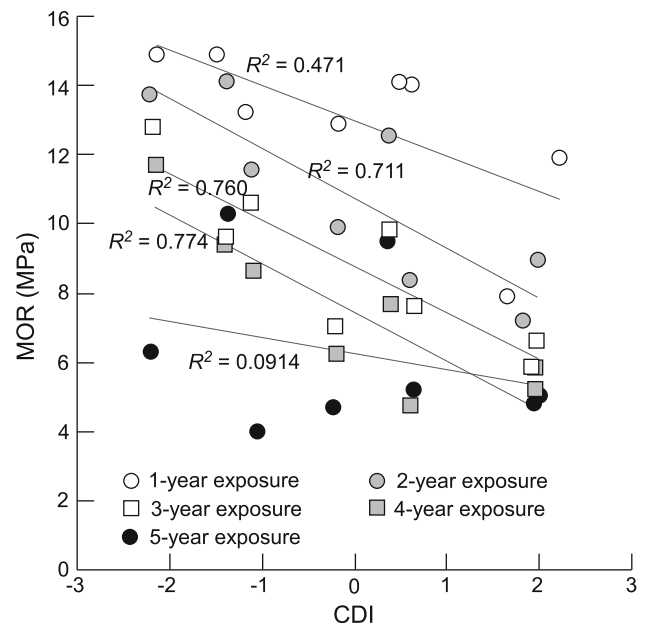
Table 10 is the ANOVA table of IB analyzed using ANCOVA. It also lists the test result of homogeneity of slopes (interaction between CDI  $\times$  exposure time) shown in Fig. 1. The probability (p value) of interaction between CDI and exposure time was 0.445, which was not statistically significant; the interaction was not recognized. Thus, the homogeneity of regression coefficients (parallel slopes) among five regression lines is suggested, and the ANCOVA can be continued. Table 10 also lists the test results of the effects (CDI and exposure time) shown in Fig. 1. The p values of CDI and exposure time were  $1.72 \times 10^{-12}$  and  $1.10 \times 10^{-8}$ , respectively. These were statistically significant at the 0.1 % level. These factors decrease the IB, and the IB reduction by the CDI is larger than that by the exposure time due to the higher adjusted proportion of the CDI. These results show that the CDI is more simple and useful as a climate index for predicting IB reduction than each climatic factor separately as discussed above due to its simplicity and high correlation.

**Table 10** ANOVA table of IB analyzed using ANCOVA

Factor	Sum of squares	Degree of freedom	Mean square	F value	p value	Adjusted proportion (%)
CDI	0.866	1	0.866	131	$1.72 \times 10^{-12}$ ***	51.1
Exposure time	0.594	4	0.149	22.6	$1.10 \times 10^{-8}$ ***	33.8
CDI $\times$ exposure time	0.0252	4	0.00631	0.958	0.445	0
Error	0.198	30	0.00658			15.2

ANOVA analysis of variance, ANCOVA analysis of covariance, *IB* internal bond strength, *CDI* climate deterioration index

\*\*\* Statistical significance at the 0.1 % level



**Fig. 2** Relationship between CDI and MOR for each exposure time. *CDI* climate deterioration index, *MOR* modulus of rupture,  $R^2$  coefficient of determination

Figure 2 shows the relationship between CDI and MOR for each exposure time. The MOR decreased linearly with increasing CDI, and the high correlation was seen in Fig. 2 except for the 5-year exposure. Similarly, Table 11 is an ANOVA table of MOR analyzed using ANCOVA. The trend is the same as the IB discussed above. The CDI is also a simple and useful climate index for predicting the MOR reduction. As for IB listed in Table 10, the effect of CDI was larger than that of exposure time, but as for MOR the latter was larger than the former due to the higher adjusted proportion of the exposure time. The MOR reduction is affected by exposure time more than by CDI; the IB reduction is affected by CDI more than by exposure time. As compared with Figs. 1 and 2, the slopes in Fig. 1 were larger than those in Fig. 2, which supports these conclusions.

The MOR reduction is due to the surface deterioration of the particleboard (Wong et al. 1998), whereas the IB reduction is due to the interior deterioration of the

**Table 11** ANOVA table of MOR analyzed using ANCOVA

Factor	Sum of squares	Degree of freedom	Mean square	F value	p value	Adjusted proportion (%)
CDI	104	1	104	36.1	$1.35 \times 10^{-6}$ ***	23.5
Exposure time	229	4	57.3	19.9	$4.25 \times 10^{-8}$ ***	50.6
CDI $\times$ exposure time	10.9	4	2.72	0.945	0.4519	0
Error	86.3	30	2.88			25.9

ANOVA analysis of variance, ANCOVA analysis of covariance, MOR modulus of rupture, CDI climate deterioration index

\*\*\* Statistical significance at 0.1 % level

particleboard (Kawai et al. 1987). The surface deterioration at high CDI sites is larger than that at low CDI sites. Similarly, the interior deterioration at high CDI sites is larger than that at low CDI sites. However, for surface deterioration, the difference between low and high CDI sites is small, whereas for interior deterioration, the difference between low and high CDI sites is large. The interior at high CDI sites is deteriorated more than that at low CDI sites and results in the large effect of CDI on IB reduction.

## 4 Conclusion

At each exposure time, the selected significant climatic factors that reduce particleboard strength were different, and the effects of these factors on strength reduction were also different. Thus, powerful analyses between climatic factors and strength cannot be conducted using multiple regression analysis. However, the correlation coefficients between CDI and strength were very high, and the strength at each exposure time decreased with increasing CDI. The CDI is a simpler and more useful climate index than each climatic factor for predicting strength reduction. Powerful analyses can be conducted using CDI.

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