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ORIGINAL ARTICLE

Nail-head pull-through strength and lateral nail resistance strength of wood-based boards subjected to various climatic conditions in Japan

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Abstract Particleboard (PB), oriented strand board (OSB), and medium-density fiberboard (MDF) were subjected to various climatic conditions at four sites (Morioka, Tsukuba, Okayama, and Miyakonojo; sites 1, 2, 3, and 4, respectively) in Japan. The reduction in the nail-head pull-through strength and lateral nail resistance strength (both strengths combined are hereafter referred to as nailed board strength) of PB and OSB at sites 3 and 4, which are high-temperature sites, was larger than that at the other sites. Temperature played a significant role in decreasing the nailed board strength. However, the nailed board strength of MDF did not significantly decrease for any site. Biodeterioration, rather than the extraction of wood components and the removal of materials on the board surface, was the main cause of mass loss. In particular, OSB exhibited noticeable biodeterioration. In contrast, there was hardly any biodeterioration in MDF. The correlation between density and nailed board strength was observed to be strong after the outdoor exposure test of PB and OSB.

Keywords Wood-based board · Outdoor exposure · Nail-head pull-through strength · Biodeterioration · Density

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Introduction

Wood-based boards (boards) are generally used only indoors. To create an increase in the demand for these boards, potential outdoor uses are being investigated. For outdoor use of boards, the boards must be subjected to outdoor exposure to various climatic conditions. In North America, outdoor exposure tests on boards have been conducted [1–5], whereas in Japan, boards were rarely tested until the early 2000s [6]. Outdoor exposure tests started in 2004 as part of a project organized by the Research Working Group on Wood-based Panels from the Japan Wood Research Society, and our research group [6–10], Kojima et al. [11–15], and Sekino et al. [16] recently reported the results.

Furthermore, the bending strength and internal bond strength (IB) of the boards were investigated in most of the outdoor exposure studies. Understanding the effect of outdoor exposure tests on the nail-head pull-through strength (NHPT) and lateral nail resistance strength (LNR) (both strengths combined are hereafter referred to as nailed board strength) is also important; however, very few studies have investigated this effect [7]. In our previous study, the nailed board strength subjected to outdoor exposure at Tsukuba in Japan was investigated [7].

In this study, particleboard (PB), oriented strand board (OSB), and medium-density fiberboard (MDF) were subjected to various climatic conditions at four sites in Japan from 2004 to 2011. The nailed board strength subjected to outdoor exposure at a low-temperature site [Morioka (site 1)], a medium-temperature site [Tsukuba (site 2)], and high-temperature sites [Okayama (site 3) and Miyakonojo (site 4)] was investigated. Table 1 lists the climate conditions at the four sites from 2004 to 2011. The annual mean temperatures at sites 3 and 4 are roughly equal, and the

Table 1 Site no., site, north latitude, east longitude, climate conditions for outdoor exposure sites from 2004 to 2011, and temperature grouping

Site no.	Site	North latitude	East longitude	Climate conditions			Temperature grouping
				Annual mean temperature (°C)	Annual precipitation (mm)	Annual sunshine duration (h)	
1	Morioka	39°37′	141°05′	10.6	1338	1672	Low
2	Tsukuba	36°02′	140°05′	14.4	1171	1974	Middle
3	Okayama	34°41′	133°46′	16.7	1069	2048	High
4	Miyakonojo	31°43′	131°05′	16.9	2515	1963	High

annual precipitation at site 3 is lower than that at site 4. Therefore, the reduction in the nailed board strength at both sites was predicted to be different. Site 3 was added as a high-temperature site, and differences between climate conditions at site 3 and 4 were observed.

The mass loss of the boards subjected to outdoor exposure increased with increasing exposure time [6]. Furthermore, the mass loss of OSB was much higher than that of the other boards [6]. In general, the biodeterioration of a board results in mass loss [6, 17–19]. However, for an outdoor exposure test, in addition to biodeterioration, mass loss is assumed to be caused by the leaching of wood extractives by rainwater and the removal of materials on the board surface due to weathering. Therefore, the major cause of mass loss was investigated for outdoor exposure tests in this study. Furthermore, this study investigated the strength reduction in the boards. The major indices of strength reduction are thickness change, mass loss, and density of the boards; in particular, the effects of thickness change, mass loss, and density on strength reduction are elucidated. The results of this study clarify the origins of strength reduction in the boards and provide valuable information to improve the durability of boards for outdoor use.

Experimental

Outdoor exposure test

The PB was bonded with phenol–formaldehyde resin, the OSB was manufactured from aspen (*Populus tremula*), and the MDF was bonded with methylene diphenyl diisocyanate resin. Table 2 summarizes the initial mean NHPT, LNR, IB, and board thickness before the outdoor exposure tests. Initial density before the outdoor exposure tests is listed in Table 3. The boards used in this study were commercial products. Further details about these boards are available in the references [6, 7].

30-40 boards measuring 910 × 1823 mm were cut into specimens measuring 300 × 300 mm. Stainless steel nails (SUS304, 50 mm in length, 6.3 mm in head diameter, 2.8 mm in shank diameter) were driven into specimens, as shown in Fig. 1. Then, the twelve specimens that were selected randomly were placed on an exposure stand that faced south at an angle of 90° to the ground at each site, and the nail head faced south. Two specimens were collected for testing every year. The outdoor exposure time was six or seven years (2004–2010 or 2004–2011), whereas the outdoor exposure time at site 2 was 5 years (2004–2009). Further details about the nailed board strength are available in the Ref. [7].

Property tests

The nailed specimens collected from the exposure stands were conditioned in constant temperature and humidity room (at temperature of 20 °C and relative humidity of 65 %) for approximately 1 month. The moisture content of the nailed specimens was approximately 8–10 % [7]. In our previous studies, specimens measuring 300 × 300 mm were used for bending strength and IB tests, and these specimens were also conditioned [6, 7]. After conditioning, the mass and thickness of these specimens were measured to calculate their mass loss, thickness change, and density after the outdoor exposure test. Figure 1 shows four measuring points of the thickness.

The mass loss was calculated as follows:

$$\text{Mass loss }(\%) = \frac{m_0 - m_1}{m_0} \times 100$$

where m_0: air-dried mass before outdoor exposure test and m_1: air-dried mass after outdoor exposure test.

The thickness change was calculated as follows:

$$\text{Thickness change }(\%) = \frac{t_1 - t_0}{t_0} \times 100$$

where t_0: air-dried thickness before outdoor exposure test and t_1: air-dried thickness after outdoor exposure test.

NHPT and LNR tests (12 mm from the edge) were conducted in compliance with ASTM D 1037 [20]. For the NHPT and LNR tests, specimens measuring 50 × 50 mm and 90 × 50 mm, respectively, were removed from the specimens measuring 300 × 300 mm (Fig. 1) [7]. The LNR of the OSB was measured parallel to its grain. An IB

Table 2 Initial mean nail-head pull-through strength (NHPT), lateral nail resistance strength (LNR), internal bond strength (IB), and board thickness before outdoor exposure

Abbreviation	NHPT (kN)	LNR (kN)	IB (MPa)	Board thickness (mm)
PB	1.70 (0.15)	1.74 (0.24)	0.833 (0.09)	12.2
OSB	1.58 (0.44)	1.81 (0.50)	0.556 (0.13)	12.4
MDF	1.53 (0.10)	1.34 (0.11)	1.22 (0.19)	9.0

The numbers in the parentheses indicate the standard deviations

PB phenol–formaldehyde resin-bonded particleboard, *OSB* oriented strand board manufactured from aspen, *MDF* methylene diphenyl diisocyanate resin-bonded medium-density fiberboard

Table 3 Board density before and after outdoor exposure at site 4 after 5-year outdoor exposure

	Board density (g/cm^3)		
	PB	OSB	MDF
Before exposure	0.75	0.63	0.71
After 5-year exposure	0.58	0.33	0.69

The site no. is described in Table 1

PB phenol–formaldehyde resin-bonded particleboard, *OSB* oriented strand board manufactured of aspen, *MDF* methylene diphenyl diisocyanate resin-bonded medium-density fiberboard

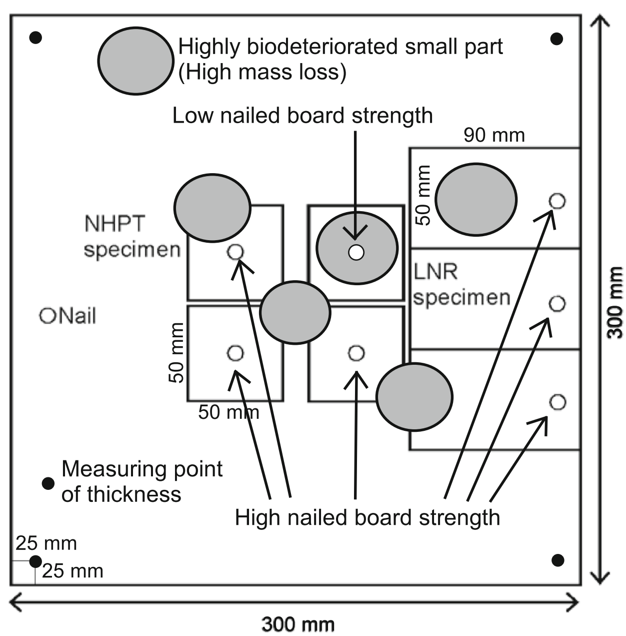

Fig. 1 Trimming of NHPT specimens measuring 50 × 50 mm and LNR specimens measuring 90 × 50 mm and locally biodeteriorated specimen measuring 300 × 300 mm subjected to outdoor exposure. *NHPT* nail-head pull-through strength, *LNR* lateral nail resistance strength

test was conducted in compliance with JIS [21, 22] compared with NHPT and LNR. For the IB test, specimens measuring 50 × 50 mm were removed from the 300 × 300 mm specimens [6]. The number of specimens used for the NHPT, LNR, and IB tests was eight, six and thirteen, respectively. Furthermore, thirty specimens were used for the initial NHPT, LNR, and IB values listed in Table 2.

Leaching test

For the leaching test, specimens measuring 90 × 30 mm that were not subjected to outdoor exposure were immersed in water at 70 °C for 6 h, followed by drying at 105 °C for 16 h (one cycle). This process was repeated for seven cycles. Three specimens were used in the leaching test. The mass loss in the leaching test was calculated as follows:

$$\text{Mass loss }(\%) = \frac{m_0 - m_1}{m_0} \times 100$$

where m_0: oven-dried mass before immersion and m_1: oven-dried mass after immersion.

Measurement of density profile

The density profiles of specimens measuring 50 × 50 mm that were not subjected to outdoor exposure were measured using a density profile measuring system (GreCon, DA-X). Two specimens were used in each measurement test. In addition, the density profiles of the specimens at site 4 after the 5-year outdoor exposure were measured. Furthermore, the surface of these specimens was observed to confirm that weathering eroded the board surface.

Results and discussion

Nailed board strength

Figure 2a–c shows the relationships between exposure time and mean NHPT of PB, OSB, and MDF at the four sites. The NHPT of PB at site 1 did not significantly decrease and was 1.3 kN after 6 years. However, the value decreased at sites 2, 3, and 4 when the exposure time increased,

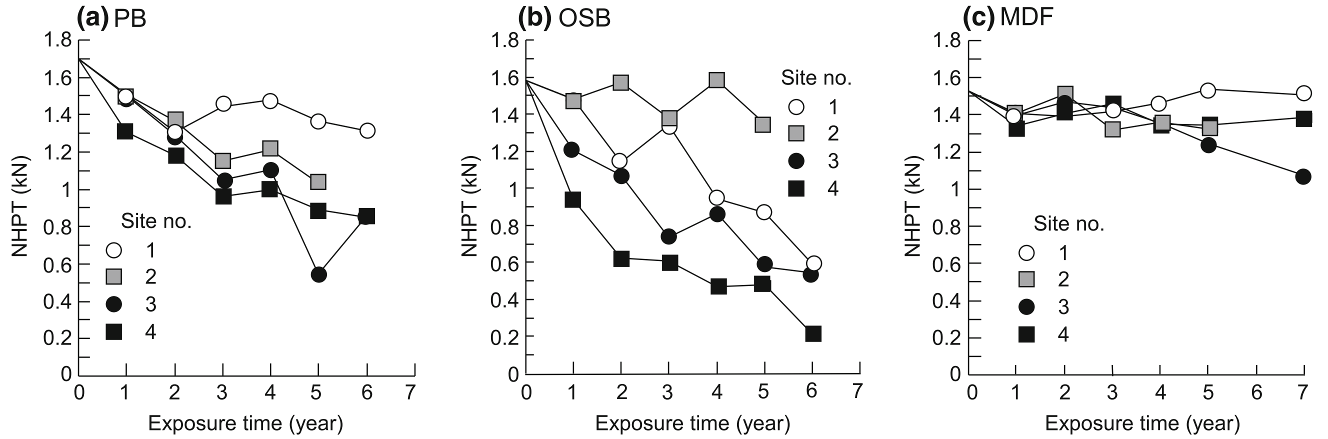

Fig. 2 Relationships between exposure time and mean nail-head pull-through strength (NHPT) at the four sites for **a** phenol–formaldehyde resin-bonded particleboard (PB), **b** oriented strand board (OSB) manufactured from aspen, and **c** methylene diphenyl diisocyanate resin-bonded medium-density fiberboard (MDF). The site no. is described in Table 1. The *white*, *gray*, and *black colors* indicate low-, middle-, and high-temperature sites, respectively, as indicated in Table 1

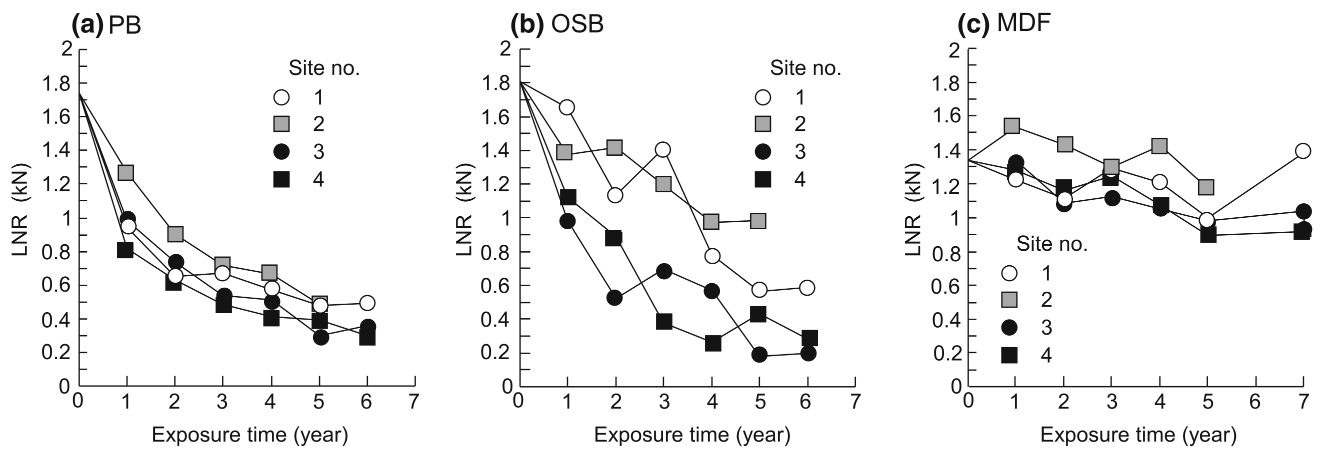

Fig. 3 Relationships between exposure time and mean lateral nail resistance strength (LNR) at the four sites for **a** phenol–formaldehyde resin-bonded particleboard (PB), **b** oriented strand board (OSB) manufactured from aspen, and **c** methylene diphenyl diisocyanate resin-bonded medium-density fiberboard (MDF). The site no. is described in Table 1. The *white*, *gray*, and *black colors* indicate low-, middle-, and high-temperature sites, respectively, as indicated in Table 1

reaching approximately 0.8 kN at sites 3 and 4 after 6 years. Furthermore, the NHPT of OSB decreased with an increase in the exposure time, except at site 2. Finally, the NHPT of MDF at site 3 decreased to 1.1 kN after 7 years but hardly decreased at the other sites.

Figure 3a–c shows the relationships between exposure time and mean LNR of PB, OSB, and MDF at the four sites. The LNR of PB and OSB decreased with an increase in the exposure time at all four sites. Furthermore, with increasing exposure time, MDF exhibited better LNR than PB and OSB.

Major causes of mass loss

Table 4 lists the mass loss of the boards subjected to outdoor exposure. The mass loss increased with increasing exposure time. Furthermore, the mass loss of OSB was much higher than that of the other boards. In particular, the mass loss of OSB at site 4 was very high.

As described in the introduction, the major cause of mass loss must be investigated for outdoor exposure tests. First, to investigate the leaching of wood extractives, boards that were not subjected to outdoor exposure were immersed in water at 70 °C, and the mass loss of these boards was measured. Figure 4 shows the mean mass loss of each leached board. The mass loss of PB, OSB, and MDF was 4, 2, and 0.8 %, respectively, at five cycles and was retained at six and seven cycles. If the number of cycles of the leaching test increased, the mass loss would not increase. The mass loss of the boards subjected to the leaching test was lower than that of the boards subjected to

Table 4 Mass loss of wood-based boards subjected to outdoor exposure

Site no.	Exposure time (year)	Mass loss (%)		
		PB	OSB	MDF
1	1	0	0	0.52
	2	0	0	0.38
	3	1.58	1.96	2.18
	4	2.58	5.80	2.75
	5	6.25	7.57	3.22
	6	4.04	20.8	
	7			9.60
2	1	0	0	0
	2	0	0	0.60
	3	1.59	1.62	0.95
	4	2.72	2.66	1.47
	5	4.34	6.65	2.43
3	1	0.38	0.54	0.69
	2	1.49	5.31	1.44
	3	4.10	15.9	2.26
	4	3.86	3.93	2.42
	5	5.58	12.9	2.70
	6	11.7	29.7	
	7			3.73
4	1	1.44	7.84	0.39
	2	4.65	16.8	1.41
	3	7.50	21.8	2.25
	4	10.3	34.0	3.80
	5	10.1	39.9	4.39
	6	15.9	46.4	
	7			5.87

The site no. is described in Table 1

PB phenol–formaldehyde resin-bonded particleboard, *OSB* oriented strand board manufactured from aspen, *MDF* methylene diphenyl diisocyanate resin-bonded medium-density fiberboard

outdoor exposure test. Thus, it was concluded that the leaching of wood extractives is not a major cause of mass loss.

Next, to investigate the removal of materials on the surface, the surfaces of boards subjected to the 5-year outdoor exposure at site 4 were examined, as shown in Figs. 5, 6, 7. Site 4 is characterized by the most severe climate conditions for an outdoor exposure test [10, 15], and therefore it is selected. The materials on the surface of PB, OSB, and MDF were hardly removed. Table 3 lists the density of each board before and after the 5-year outdoor exposure at site 4. The density of PB and OSB remarkably decreased after the 5-year outdoor exposure. This density reduction did not result from the removal of materials on the board surface as discussed later. In contrast, the density of MDF hardly decreased. Moreover,

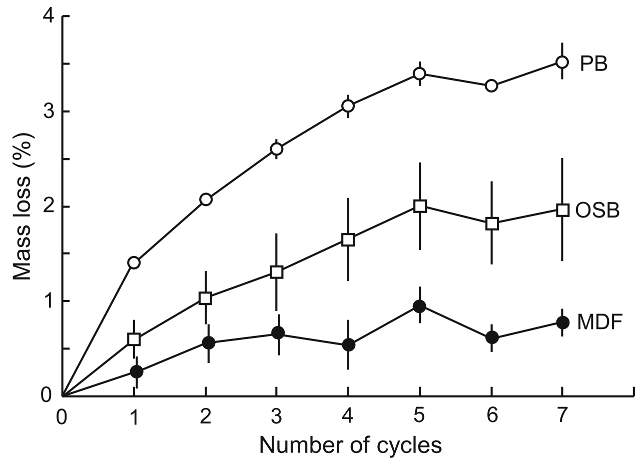

Fig. 4 Relationships between cycle and mean mass loss for phenol–formaldehyde resin-bonded particleboard (PB), oriented strand board (OSB) manufactured from aspen, and methylene diphenyl diisocyanate resin-bonded medium-density fiberboard (MDF). *Error bars* standard deviations. The specimens were immersed in water at 70 °C for 6 h followed by drying at 105 °C for 16 h (one cycle) and repeating the process for seven cycles

the density profiles of these boards were measured, as shown in Fig. 8. The shape of the density profile of MDF after outdoor exposure was almost identical to that before outdoor exposure. Therefore, it can be concluded that the surface materials in MDF were hardly removed. For PB and OSB, the density profiles for the surface layers contained lower peaks after the 5-year outdoor exposure. This transformation was not caused by the removal of materials (Figs. 5, 6) but by the swelling of the surface layers. Furthermore, it can be observed that any surface materials hardly were removed in these boards as described above.

On the basis of these results, it can be concluded that biodeterioration, rather than the extraction of wood components and the removal of materials on the board surface, is the main cause of mass loss. In particular, OSB exhibited noticeable biodeterioration. In contrast, there was hardly any biodeterioration in MDF.

Mechanism of reduction in nailed board strength subjected to outdoor exposure

When a board absorbs water, it swells. This swelling collapses bonding points, thereby decreasing the strength. The mechanism for this reduction is the same for both indoor [23] and outdoor uses of a board [6]. In general, when a board is used indoors, it does not absorb much water; therefore, the swelling is low, and the strength hardly decreases. However, when a board is used outdoors, it is subjected to rainwater. Therefore, the board swells significantly, and the bonding points of the board collapse.

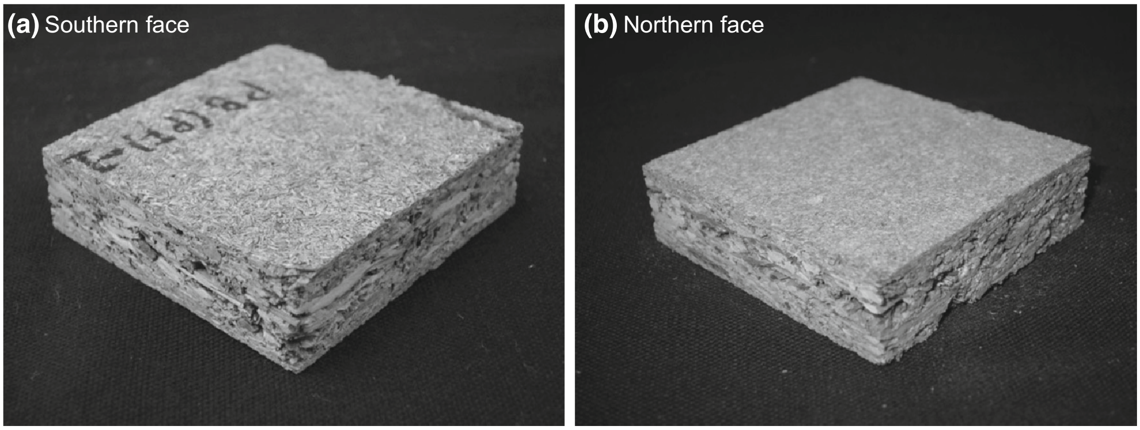

Fig. 5 The surface of phenol–formaldehyde resin-bonded particleboard (PB) subjected to outdoor exposure after 5 years at site 4. The site no. is described in Table 1

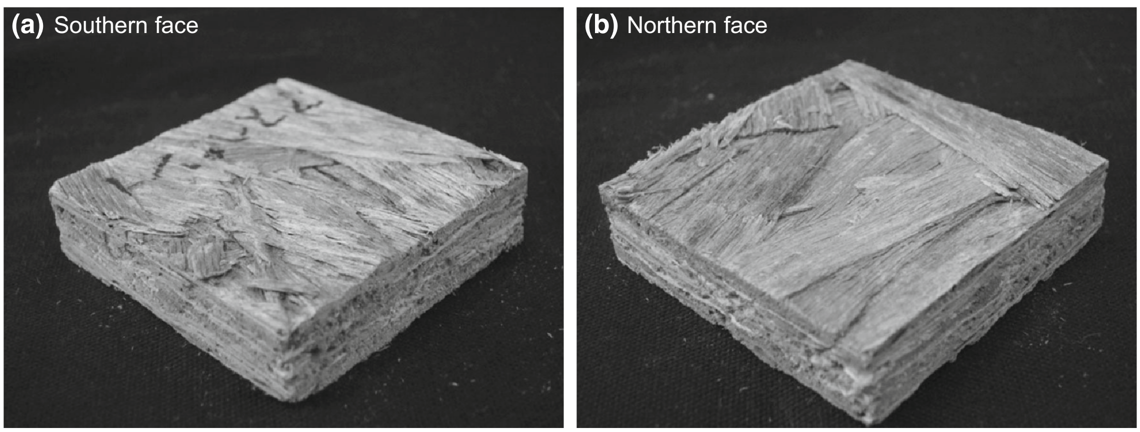

Fig. 6 The surface of oriented strand board (OSB) manufactured from aspen subjected to outdoor exposure after 5 years at site 4. The site no. is described in Table 1

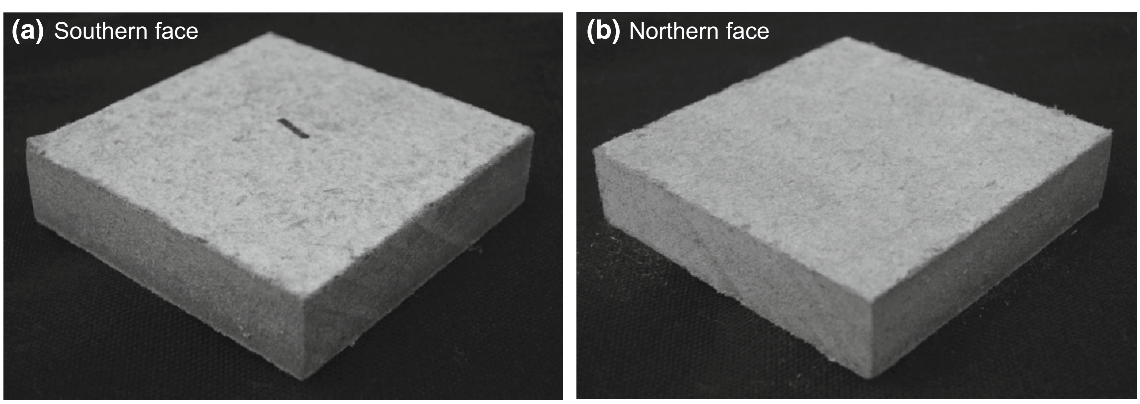

Fig. 7 The surface of methylene diphenyl diisocyanate resin-bonded medium-density fiberboard (MDF) subjected to outdoor exposure after 5 years at site 4. The site no. is described in Table 1

Furthermore, large voids are formed inside the board because of significant swelling, resulting in biodeterioration inside the board [6]. This biodeterioration results in further reduction in the strength. When a board is used indoors, biodeterioration is not a significant issue; however, for outdoor use, biodeterioration becomes significant.

As described in the introduction, the reduction in the nailed board strength at sites 3 and 4 was predicted to be

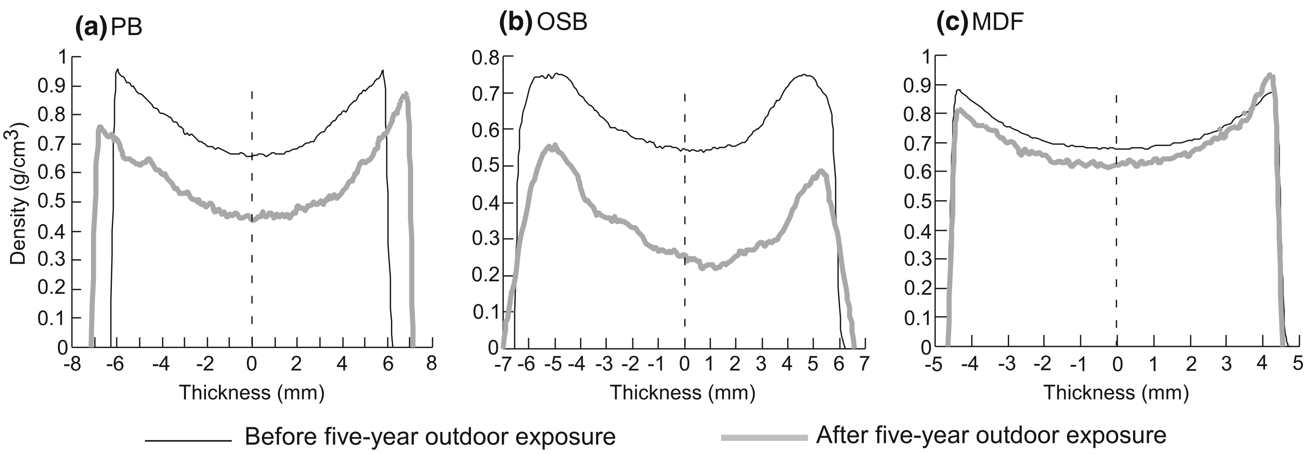

Fig. 8 Density profiles of phenol–formaldehyde resin-bonded particleboard (PB), oriented strand board (OSB) manufactured from aspen, and methylene diphenyl diisocyanate resin-bonded medium-density fiberboard (MDF) before outdoor exposure and after 5-year outdoor exposure at site 4. The site no. is described in Table 1

different. However, the differences were subtle, as observed in Figs. 2 and 3. Temperature plays a more significant role than precipitation in the reduction of the nailed board strength.

According to Table 4, the mass loss at site 4 was higher than that at site 3, whereas the nailed board strength at site 4 was almost the same as that at site 3. As described in the experimental section, the mass loss was measured using specimens measuring 300 × 300 mm. When the specimens were subjected to outdoor exposure, they were presumed to be biodeteriorated locally (Fig. 1). This part was small; however, the mass significantly decreased. Thus, the mass loss increased significantly because of this highly biodeteriorated small part. The nailed board strength at this highly biodeteriorated small part decreased significantly but this part was rare. Most parts were not significantly biodeteriorated, and the nailed board strength did not significantly decrease at these parts. Therefore, the mass loss at site 4 decreased more than that at site 3, whereas the nailed board strength at site 4 was almost the same as that at site 3.

Correlation among thickness change, mass loss, density, and board strength

The major indexes of reduction in the strength of a board subjected to outdoor exposure, which are used in several studies, are its thickness change [12, 16, 23, 24] and mass loss [17–19]. Note that here, the density is related to both thickness change and mass loss. However, these studies did not analyze the relationship between density and strength. In addition, the relationship between density and nailed board strength has hardly been investigated thus far. Therefore, the relationship must be elucidated. Figure 9 shows the relationships among the thickness change, mass loss, density, and mean board strength (IB, NHPT, and LNR) for PB. IB is compared with NHPT and LNR, as described in the experimental section. The board strength decreased with increasing thickness change and increasing mass loss. In addition, the correlation between mass loss and board strength was stronger than that between thickness change and board strength; for the outdoor exposure test, the mass loss was more effective than the thickness change as an index of board strength reduction. Furthermore, the correlation between density and board strength was stronger than that between mass loss and board strength; the density was more effective than the mass loss as an index of board strength reduction.

Figure 10 shows the relationships among the thickness change, mass loss, density, and mean board strength for OSB. The strength of the correlation followed the order density >mass loss >thickness change, except for NHPT. As compared with Figs. 9 and 10, the order for OSB was the same as that for PB. The correlation between thickness change and board strength for OSB was much weaker than that for PB. In addition, the mass loss of OSB was much higher than that of PB with an increase in the outdoor exposure time. These findings are due to the more extensive biodeterioration in OSB than in PB. The thickness change generally increases with increasing outdoor exposure time. However, the more extensive biodeterioration significantly decreases the raw wood material of board, decreasing the board thickness and consequently the thickness change. The board strength at the low- and middle-temperature sites decreased with increasing thickness change, as observed in Fig. 10 because of low biodeterioration. The board strength at the high-temperature sites was very low despite the low thickness change because of extensive biodeterioration. This finding

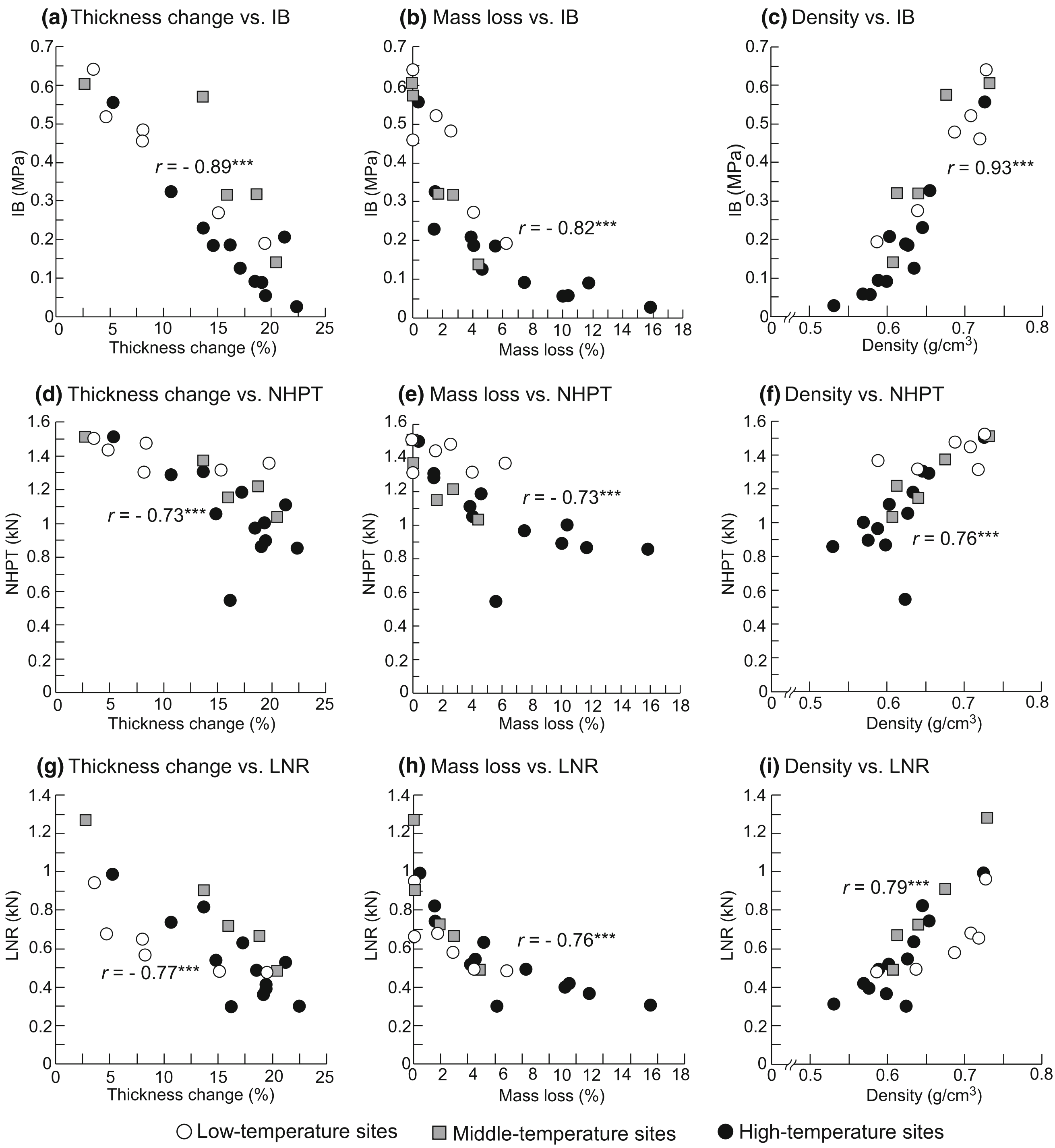

Fig. 9 Relationships among the thickness change, mass loss, density, and mean board strength (internal bond strength (IB), nail-head pull-through strength (NHPT), and lateral nail resistance (LNR)) of phenol–formaldehyde resin-bonded particleboard (PB) subjected to outdoor exposure. Low-temperature site: site 1. Middle-temperature site: site 2. High-temperature sites: sites 3 and 4. The site no. is described in Table 1. *r* correlation coefficient. *Triple asterisk* statistical significance at 0.1 % level

is due to the weak correlation between thickness change and board strength. However, the correlation between density and board strength was strong despite the low thickness change at the high-temperature sites. The density is related to both the thickness change and mass loss, as described previously, resulting in strong correlation.

These investigations demonstrate that density is a more effective index than thickness change and mass loss when

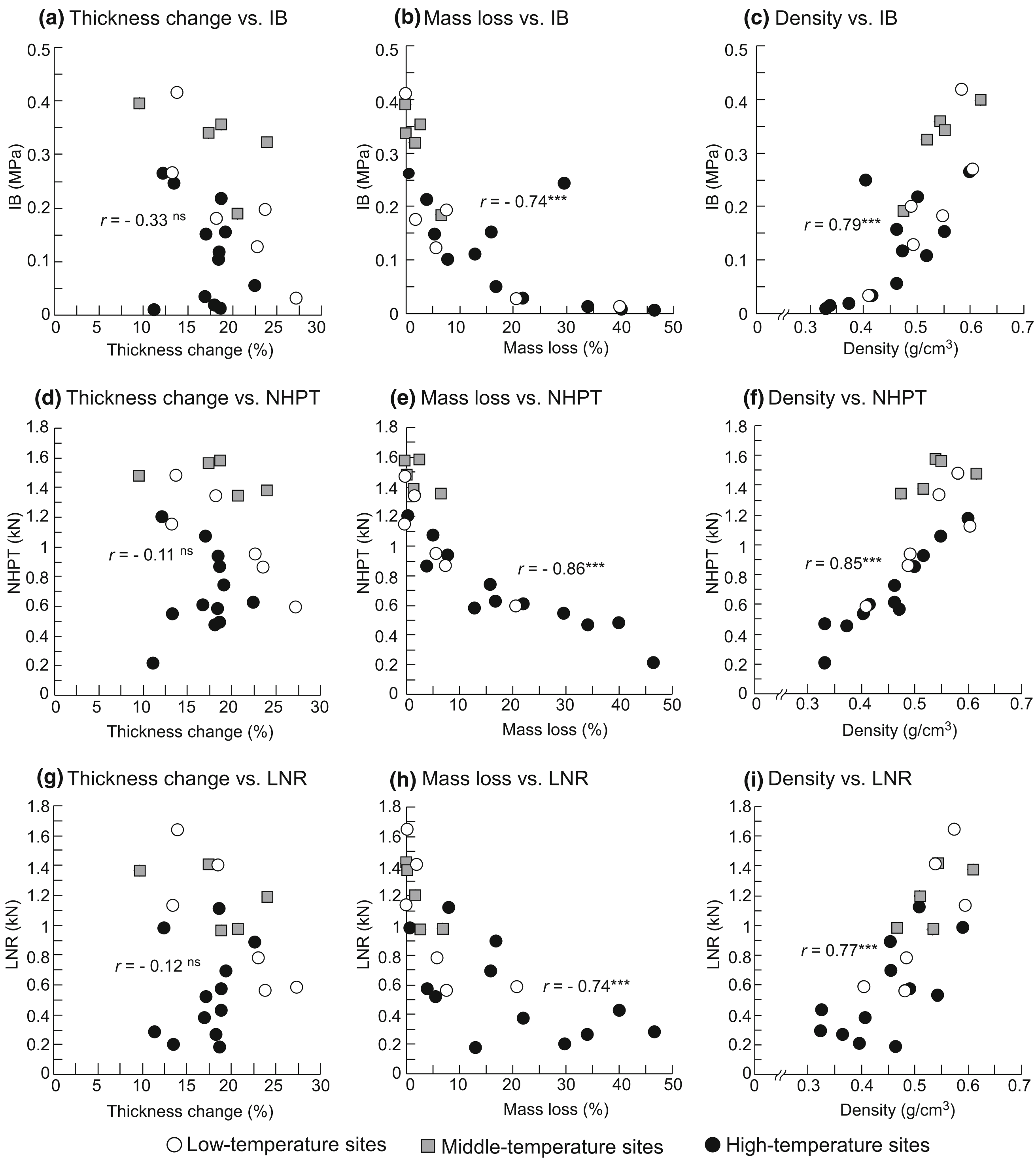

Fig. 10 Relationships among the thickness change, mass loss, density, and mean board strength [internal bond strength (IB), nail-head pull-through strength (NHPT), and lateral nail resistance (LNR)] of oriented strand board (OSB) manufactured from aspen subjected to outdoor exposure. Low-temperature site: site 1. Middle-temperature site: site 2. High-temperature sites: sites 3 and 4. The site no. is described in Table 1. *r* correlation coefficient. *Triple asterisk* statistical significance at 0.1 % level. *ns* no statistical significance

the nailed board strength is investigated after an outdoor exposure test.

Figure 11 shows the relationships among the thickness change, mass loss, density, and board strength for MDF. As observed in Figs. 2 and 3, the nailed board strength for MDF did not decrease with an increase in the exposure time. In addition, in our previous study, the IB for MDF did not decrease [8]. Hence, the relationships among the

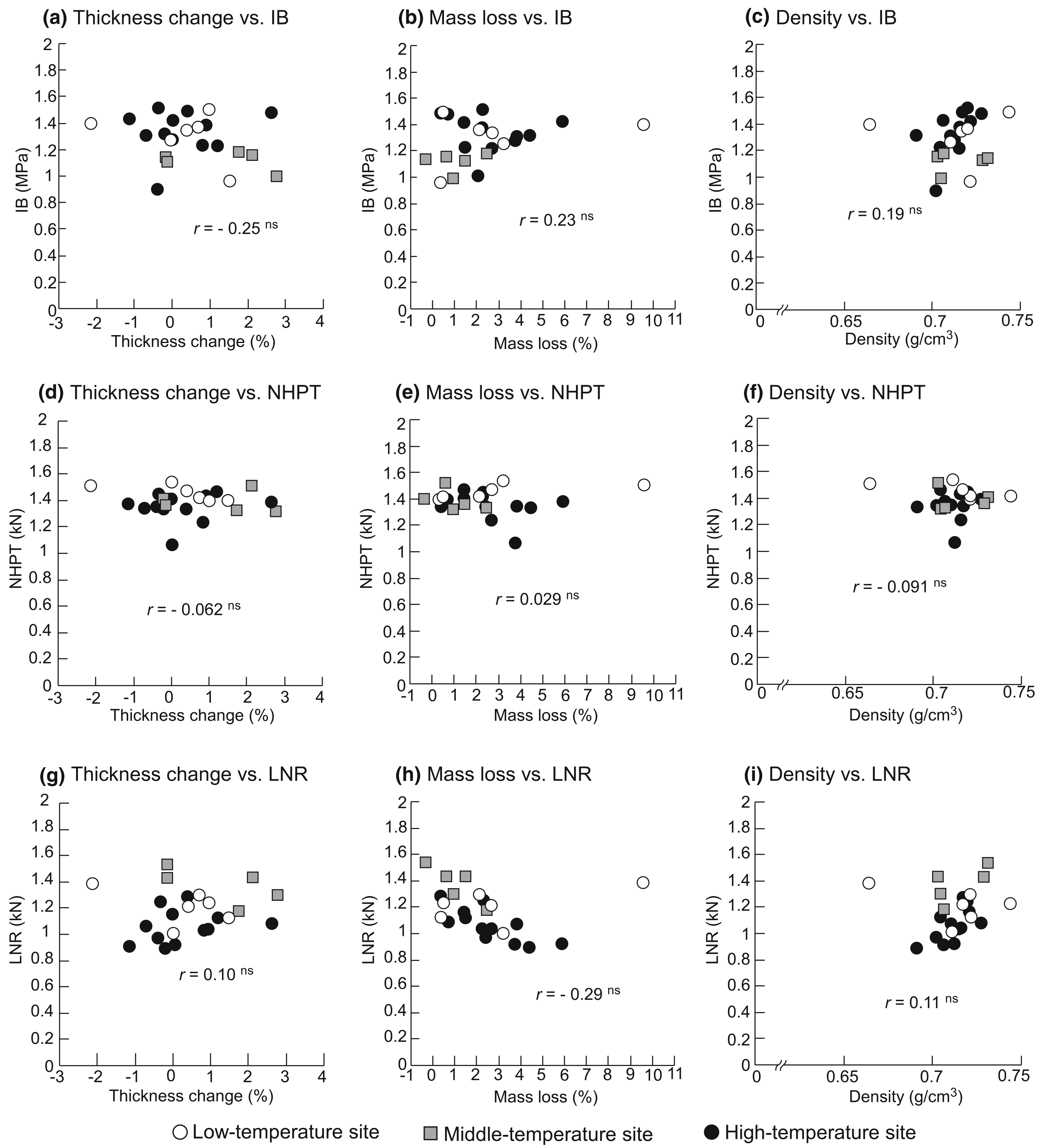

Fig. 11 Relationships among the thickness change, mass loss, density, and mean board strength [internal bond strength (IB), nail-head pull-through strength (NHPT), and lateral nail resistance (LNR)] of methylene diphenyl diisocyanate resin-bonded medium-density fiberboard (MDF) subjected to outdoor exposure. Low-temperature site: site 1. Middle-temperature site: site 2. High-temperature sites: sites 3 and 4. The site no. is described in Table 1. *r* correlation coefficient. *ns* no statistical significance

thickness change, mass loss, density, and board strength for MDF were not highly correlated.

Conclusions

The nailed board strength of PB and OSB at sites 3 and 4, where the temperature is high, was lower than that at sites 1 and 2. However, the nailed board strength of MDF did not decrease significantly. The main cause of mass loss was biodeterioration. In particular, OSB exhibited noticeable biodeterioration. In contrast, there was hardly any biodeterioration in MDF. When the boards deteriorated significantly as a result of the outdoor exposure test, the thickness change and mass loss increased. The board density is dependent on both the thickness change and mass loss. Therefore, strong correlation was observed between density and nailed board strength. The density is more effective than thickness change and the mass loss as an index when the nailed board strength is investigated.

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References

1. Hann RA, Black JM, Blomquist RF (1962) How durable is particleboard? Forest Prod J 12:577–584
2. Gatchell CJ, Heebink BG, Hefty FV (1966) Influence of component variables on properties of particleboard for exterior use. Forest Prod J 16(4):46–59
3. Carll CG, Feist WC (1989) Long-term weathering of finished aspen waferboard. Forest Prod J 39(10):25–30
4. River BH (1994) Outdoor aging of wood-based panels and correlation with laboratory aging. Forest Prod J 44(11/12):55–65
5. Okkonen EA, River BH (1996) Outdoor aging of wood-based panels and correlation with laboratory aging: part 2. Forest Prod J 46(3):68–74
6. Korai H, Sekino N, Saotome H (2012) Effects of outdoor exposure angle on the deterioration of wood-based board properties. Forest Prod J 62:184–190
7. Korai H, Adachi K, Saotome H (2013) Deterioration of wood-based boards subjected to outdoor exposure in Tsukuba. J Wood Sci 59:24–34
8. Korai H (2012) Durability of medium density fiberboard subjected to outdoor exposure (in Japanese). Mokuzai Gakkaishi 58:347–356
9. Korai H, Watanabe K, Nogami H, Fukino M, Fujimoto Y (2014) Simple and useful index for analyzing particleboard subjected to outdoor exposure. J Adhesive Soc Jpn 50:260–267
10. Korai H, Watanabe K (2015) Effectiveness of principal component analysis for analyzing particleboard subjected to outdoor exposure. J Wood Sci 61:35–39
11. Suzuki S (2001) Evaluation of wood-based panel durability (in Japanese). Wood Indus 56:7–12
12. Kojima Y, Norita H, Suzuki S (2009) Evaluating the durability of wood-based panels using thickness swelling results from accelerated aging treatments. Forest Prod J 59(5):35–41
13. Kojima Y, Suzuki S (2011) Evaluating the durability of wood-based panels using internal bonding strength results from accelerated aging treatments. J Wood Sci 57:7–13
14. Kojima Y, Suzuki S (2011) Evaluating the durability of wood-based panels using bending properties after accelerated aging treatments. J Wood Sci 57:126–133
15. Kojima Y, Shimoda T, Suzuki S (2012) Modified method for evaluating weathering intensity using outdoor exposure tests on wood-based panels. J Wood Sci 58:525–531
16. Sekino N, Sato H, Adachi K (2014) Evaluation of particleboard deterioration under outdoor exposure using several different types of weathering intensity. J Wood Sci 60:141–151
17. Imamura Y, Nishimoto K (1984) Bending performance of particleboards exposed to fungal attack (in Japanese). Mokuzai Gakkaishi 30:1027–1034
18. Toole ER, Barnes HM (1974) Biodeterioration of particleboard. Forest. Prod J 24(10):55–57
19. Schmidt EL, Hermann J, French DW, Hall H, Gertjejansen RO (1978) Strength reduction of particleboard caused by fungi. Forest Prod J 28(2):26–31
20. ASTM D1037-96a (1996) Standard methods of evaluating the properties of wood-base fiber and particle panel materials. 20. American Society for Testing and Materials, West Conshohocken, USA
21. JIS A 5908 (2003) Particleboards. Japanese Standard Association, Tokyo, Japan
22. JIS A 5905 (2003) Fiberboards. Japanese Standard Association, Tokyo, Japan
23. Sekino N, Okuma M (1986) Performance of construction particleboard II. Bending in service as underlayment of floors (in Japanese). Mokuzai Gakkaishi 32:163–169
24. Sekino N, Suzuki S (2003) Durability of wood-based panels subjected to ten-year outdoor exposure in Japan. Bull Iwate Univ Forests No 34:23–36