Effects of density profile of MDF on stiffness and strength of nailed joints

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Abstract

Nail-head pull-through, lateral nail resistance and single shear nailed joints tests were conducted on medium density fiberboard (MDF) with different density profiles, and the relations between the results of these tests and the density profiles of MDF were investigated. The maximum load of nail-head pull-thorough and the maximum load of nailed joints were little affected by the density profile. However, the ultimate strength of lateral nail resistance, the stiffness and the yield strength of nailed joints were affected by the density profile of MDF and showed high values when the surface layer of MDF had high density.

It is known that bending performance is also influenced by density profile. Therefore, the stiffness and the yield strength of nailed joints were compared with the bending performance of MDF. The stiffness of nailed joints was positively correlated with the modulus of elasticity (MOE); in the case of CN65 nails, the initial stiffness of joints changed little in response to changes in MOE. The yield strength of nailed joints had a high positive correlation with the modulus of rupture (MOR). The stiffness and the yield strength of nailed joints showed linear relationships with MOE and MOR, respectively.

Keywords

Press closing speed, nail-head pull-through, lateral nail resistance, single shear joint, density profile

Introduction

Recently, there have been numerous examples of the use of wood-based panels for important structural parts like bearing walls, floors and roof sheathings. While there are many kinds of wood-based panels, it is expected that more attention will focus on mat-formed materials such as MDF and particleboards, because they have wide raw material selectivity which can utilize demolition residuals, factory waste, small diameter logs and low-quality wood.

The mechanical properties of MDF and particleboard depend on how they are manufactured. Therefore, research has been conducted on the influence of manufacturing methods on bending performance, internal bond strength, thickness swelling and the linear expansion of MDF[1,2] and particleboard[3-5].

Since these mechanical properties provide valuable information for evaluating the characteristics of wood-based materials, the authors had previously investigated the influence of density profile of MDF on the bending performance[2]. In order to utilize these mat-formed materials as structural members of wooden structures, it is important to evaluate the nailed joint performance.

Several researches for nailed joint performance have been conducted on the commercial mat-formed materials[6,7]. However, these studies were mainly described about maximum load of nailed joint, did not deal with the general shear performance of nailed joint, e.g., initial stiffness and yield strength. Furthermore, there is little research that has examined the relation between the manufacturing methods of the mat-formed materials and the performance of nailed joints, and there is only one example for particleboard[8].

In this study, nail-head pull through, lateral nail resistance and nail joint shear tests were conducted on four types of MDF having different density profiles to examine the influence of density profile on nailed joint performance and to consider the suitability of a method for estimating nailed joint performance from the bending performance.

Materials and methods

Preparation of the MDF test pieces [2]

The raw material, consisting of wood fiber produced from sawmill waste of sugi (*Cryptomeria japonica* D. Don), was dried until moisture content reached 6.8%. A melamine urea co-condensated resin (Honen Corporation, MB-240: solid content= 60%) was used as a binder. A 20% ammonium chloride solution equivalent to 10% of the weight of adhesive was added to the adhesive as a curing agent. Distilled water was added to the adhesive to give the fiber mat a moisture content of 16% (including the ammonium chloride solution) after adhesive spraying.

The adhesive was sprayed until a fiber mat with 12% resin content and fiber mat was formed by hand. The fiber mat was hot pressed in a one- or two-step method with a positional control-type hot press (YAMAMOTO ENG.WORKS Co., LTD, TA-200-1W) at 180℃. Two-step method was especially adapted to form a high-density inner layer. Press closing speeds of the one-step method were set at 10.0mm/second, 2.0mm/second and 0.5mm/second, and press time was set at 9 minutes after mat thickness reached the target board thickness of 12mm.

For the two-step method, press closing speed was set at 10.0mm/second until mat thickness reached 50% (= 540mm) of its initial value. After maintaining this condition for 6.5 minutes, the press closing speed was changed to 2.0mm/second and maintained for 2 minutes after mat thickness reached the target board thickness of 12mm. Table 1 shows the hot press schedule and the names of sample panels.

The sample panel dimensions were 500mm long×500mm wide ×12mm thick, and the target panel density was 0.7g/cm^3. The average density of the sample panels PCS10, PCS2, PCS0.5 and PCS10-2 were 0.72, 0.72, 0.71 and 0.70g/cm^3, and the standard deviations were 0.02, 0.01, 0.03, and 0.02g/cm^3, respectively.

Figure 1 shows the density profile of sample panels measured by density profiler (GreCon DA-X). The dimensions of the test pieces were 50mm long ×50mm wide ×12mm thick, and 6 pieces were cut from center and edge of the sample panel. PCS10 and PCS2 have a high-density layer in the surface area. On the other hand, PCS0.5 and PCS10-2 have a low-density layer in the surface area while the density of the inner layer is high. The shape of the density profile of PCS10 and PCS2 were close to the density profile of the commercial MDF[9)].

Figure 2 shows the average density of the layer from the surface of the panel to each position along the thickness direction (hereafter called the *average layer density*). The average layer density of sample panels PCS10 and PCS2 approaches the target panel density from a state of high density as the distance from the surface increases. In contrast, the average layer density of sample panels PCS0.5 and PCS10-2 approaches the target panel density from a state of low density as the distance from the surface increases. The average layer density of PCS0.5 becomes about 0.7g/cm^3 when the distance from the surface is about 3mm or more, while the average layer density of PCS10-2 becomes about 0.7g/cm^3 when the distance from the surface is about 6mm.

The test pieces of nailed joint were obtained from these sample panels. All test pieces were seasoned under conditions of 20℃, 65%RH until they reached a constant mass in the environment.

Nail-head pull-through test

Figure 3 shows the configuration of the nailed joint tests. The dimensions of the nail-head pull-through test pieces were 50mm long ×50mm wide ×12mm thick, and the average moisture content of the test pieces was PCS10: 7.3%, PCS2: 7.5%, PCS0.5: 7.8% and PCS10-2: 9.3%. The nails used were CN50 or CN65. Penetrated tip holes having a diameter of 2.5mm for CN50 (about 87% of the nail diameter) and 3.0mm for CN65 (about 90% of the nail diameter) were installed before nailing because the nail could be driven a right angle with the test piece surface. The nails were driven by hand hammering. Three or four test pieces were measured according to ASTM D1037[10)]. The slit width of the specimen holding fixture was 25mm.

A monotonic load was applied to the test pieces at average deformation speed of 2.0mm/minute. The measurements were ended when the load had decreased to 80% of the maximum load.

Lateral nail resistance test

The dimensions of the lateral nail resistance test pieces were 80-100mm long ×50mm wide ×12mm thick, and their average moisture content was PCS10: 7.4%,

PCS2: 7.6%, PCS0.5: 7.9% and PCS10-2: 9.3%. Measurements were taken according to ASTM D1037[10]. The clearance between the test piece and the jig was 0.75mm on one side. The nails used were CN50 or CN65. The edge distance of MDF was determined based on wood-framed houses and Japanese conventional post and beam houses. When MDF is jointed to the studs of 204 dimension lumber and to the posts of 105mm square lumber, the edge distance of MDF are 9.5mm and 26.25mm, respectively. Therefore, the edge distance was set at 9mm or 26mm. Penetrated tip holes were installed in MDF similar to the nail-head pull-through test. Seven test pieces were examined.
A monotonic load was applied to the test pieces at average deformation speed of 2.0mm/minute. When the load had decreased to 80% of the maximum load or deformation became twice the nail diameter, the measurements were ended.

Single shear test of nailed joints

Using the other end of the lateral nail resistance test pieces, a single shear test of nailed joints was carried out. Spruce (*Picea abies*) glulam samples 250mm long ×50mm wide ×50-70mm thick, having an average air-dry density of 0.47g/cm^3 and average moisture content of 12.5%, were used for the frame members. The grade of the glulam was E105-F345, according to Japanese Agricultural Standard. The glulam was grouped with the mean value of the air-dry density so that standard deviations were uniform among the test pieces. The nails used were CN50 or CN65. In this study, nail-heads were slightly floated to avoid a significant frictional force between the MDF and the glulam. The nails were arranged perpendicular to the interface of the lamina. The edge distance of MDF was assumed to be two kinds (9mm and 26mm). Penetrated tip holes were installed in MDF similar to the nail-head pull-through test.
A monotonic load was applied to the test pieces at average deformation speed of 2.0mm/minute. The relative displacement between the glulam and the tensile jig was measured with a displacement transducer. When the load had decreased to 80% of the maximum load or relative displacement reached 30mm, the measurements were ended.

Results and discussion

Nail-head pull-through maximum load

The nail-head pull-through test pieces showed three types of failure. PCS10 and PCS2 showed caving of nail-heads, PCS0.5 showed both caving of nail-heads and bending between nailed joint parts and tensile jigs, and PCS10-2 showed bending.
The nail-head pull-through load was evaluated by maximum load (*Pmax,p*)[10]. Figure 4 shows the relation between the bearing force of CN50 joints and the average board density. There was a positive correlation between *Pmax,p* and the average board density. The experimental value was corrected based on the standard density, 0.7g/cm^3, to examine the influence of the density profile on the experimental value.
Figure 4 also shows the ultimate lateral nail resistance load (*Pu,l*) and maximum single shear load (*Pmax,s*) of the 9mm edge distance with CN50. A similar density

correction of the bearing force was done for the initial stiffness and the bearing force that had been obtained from the lateral nail resistance test and single shear test of nailed joints. Table 2 shows all test results.

Figure 5 shows Pmax,p of the 4 types of MDF. Although PCS0.5 had a much different density profile from PCS10 and PCS2 (Figure 1), the Pmax,p of those were almost the same. PCS10-2 showed the lowest value among the 4 types of MDF. This tendency was the same regardless of the kind of nail.

Because the bending strength[2)] of PCS10-2 (MOR = 8.4MPa) was extremely low (about 0.3 times that of PCS10 (26.9MPa) and PCS2 (28.3MPa) and about 0.4 times that of PCS0.5 (19.8MPa)), it is thought that PCS10-2 failed in bending mode rather than from caving of the nail-head, and the Pmax,p value of PCS10-2 became lower than the other MDF values as a result. This indicates that the Pmax,p would not be greatly influenced by the density profile, if the bending strength of MDF is not extremely low. One-way analysis of variance revealed that the differences among 4 types of MDF were significant at 99% confidence level regard less of the kind of nail (Table 2).

Lateral nail resistance yield load

All lateral nail resistance test pieces showed caving of nail-trunks bent by applied load regardless of the specifications. The load-displacement curve obtained in the lateral nail resistance test was substituted in the perfect elasto-plastic model as shown in Figure 6. This model is enclosed the line that passes through the points on the curves corresponding to 0.1 and 0.4 times maximum load until 0.5 times deformation of the nail diameter, the line parallel to the *x*-axis, 0.5 times deformation of the nail diameter and the *x*-axis. The area of this model becomes equivalent to absorbed energy until 0.5 times deformation of the nail diameter is reached. Ultimate load (*Pu,l*) is defined as the line parallel to the *x*-axis[11)]. Ultimate strength (*Fe,l*) was obtained by dividing the ultimate load by the nail diameter and thickness of MDF.

Figure 7 shows the *Fe,l* values of the 4 types of MDF. The influence of the density profile was observed, the value of PCS10 and PCS2 was the highest in *Fe,l*, and decreased in the order of PCS0.5 and PCS10-2. In the lateral nail resistance test, the surface area of MDF received most of the partial compressive stress when the nail was deformed by bending, PCS10 and PCS2 with the high density layer in the surface area seemed to have the largest *Fe,l*. One-way analysis of variance revealed that the differences among 4 types of MDF were significant at 99% confidence level regard less of the kind of nail and edge distance (Table 2).

Single shear performance of nailed joints

The 9mm edge distance test pieces showed failure in which the edge of the MDF could be pulled out by the caving of the trunk of the nail in MDF, regardless of the type of MDF. The 26mm edge distance with CN50 test pieces showed three types of failure: nail withdrawal (PCS2, PCS0.5), a combination of nail withdrawal and layer peeling (PCS10) and a combination of nail withdrawal and bending (PCS10-2). The 26mm edge distance with CN65 test pieces showed two types of failure: nail withdrawal (PCS2) and a combination of nail withdrawal and bending (PCS10, PCS0.5, PCS10-2).

Figure 8 shows examples of load-displacement curves obtained from the examination (PCS2 and PCS10-2). Yielding part load for the same kind of nail was almost a constant value, regardless of the edge distance, but there was significant influence of the edge distance in the shape of the load-displacement curve after yielding.

The obtained load-displacement curve was substituted in the perfect elasto-plastic model (Figure 6) to calculate the following values: initial stiffness (*Ks,s*), yield load (*Py,s*), maximum load (*Pmax,s*)[11]. Though 0.1 times and 0.4 times the point of maximum load are generally connected as a straight line in this evaluation method, the authors assumed the first straight line as follows: 0.1 times and 0.4 times the point of maximum load for the edge distance of 9mm, and 0.05 times and 0.2 times the point of maximum load for the edge distance 26mm. The second straight line has same slope as the line passes through the points on the curves corresponding to *p*2 (Figure 6) and 0.9 times maximum load and is the tangent to the curve. The load corresponding to the intersection of first straight line and second straight line is defined as yield load, and the displacement on the curve corresponding to yield load is defined as yield displacement. The line passes through the origin and the coordinate yield load and yield displacement is defined as initial stiffness.

Figure 9 shows *Ks,s*, *Py,s*, and *Pmax,s* of the 4 types of MDF. As for *Ks,s*, PCS10 and PCS2 having a high surface density, were the highest, followed by PCS0.5 and PCS10-2, usually in that order. *Py,s* values of PCS10, PCS2, and PCS0.5 were approximately the same, and only PCS10-2 was low.

When shear force was applied to a nailed joint, it appears that the bearing stress on the panel material and lumber (caving stress on the members by nail-trunk) was concentrated on the boundary surface between the panel material and lumber during initial deformation as shown in Figure 10. After that, as deformation of the member progressed, the area from the boundary surface toward the member section may have increased until a yielding condition was reached[12]. Therefore, there were differences in *Ks,s* which expresses initial deformation behavior among the 4 types of MDF, due to the influence of the density profile.

Py,s values of PCS10, PCS2, and PCS0.5 did not differ because the average layer density eventually stabilized at $0.7 g/cm^3$ after a certain threshold of surface distance was reached (Figure 2). However, it appears that PCS10-2 with a wide low density layer from the surface to the core layer showed lower *Py,s* than the other 3 types of MDF. One-way analysis of variance for *Ks,s* and *Py,s* revealed that the differences among 4 types of MDF were significant at 99% confidence level for nailed joint type except for *Ks,s* of the 9mm edge distance with CN65(Table 2).

Pmax,s values of the 4 types of MDF were very close. It seems that the density profile had little effect on *Pmax,s* if the average board density, the board thickness, etc., were equal, because the 4 types MDF of the 9mm edge distance showed caving of overall nail to MDF and pulling out from the edge of the MDF. As for the edge distance of 26mm, three failure modes were observed, but all modes involved the withdrawal of the nail. It is thus thought that the decrease of the nail holding resistance of the lumber influenced *Pmax,s*. One-way analysis of variance for *Pmax,s* revealed that the differences among 4 types of MDF were not significant at 95% confidence level for the nailed joint except for the type of 9mm edge distance with CN65. In the case of the joint of 9mm edge distance with CN65, that difference was significant at 95% confidence level.

The nailed joint with CN65 showed 0-20% higher *Pmax,s* than the nailed joint with CN50(Figures 8 and 9). However, it must be investigated in future about the influence of performance of nailed joint upon structural performance of wooden construction.

Yanaga et. al.[13] reported that it is suitable to set the edge and end distances at six times or more of the nail diameter to prevent the nail holding resistance from decreasing in the nailed joints. In this research, only the edge distance of 26mm satisfied this condition. Thus, $K_{s,s}$, $P_{y,s}$, and $P_{max,s}$ for the edge distance of 9mm were divided by the respective shear performance values for the edge distance 26mm to examine the decreasing rate of initial stiffness, yield load and maximum load for the 9mm edge distance.

Figure 11 shows the ratio of each shear performance value. In the initial stiffness ratio, no clear trend was seen with decreasing edge distance because of the wide fluctuation in $K_{s,s}$. The yield load and maximum load ratio of the 4 types of MDF were almost the same value, with an average yield load ratio of 0.97-1.11 regardless of the kind of the nail, and the average maximum load ratio was 0.62-0.71 for CN50 and 0.55-0.62 for CN65.

Since the edge distance of 9mm is assuming nail joints on 204 dimension lumber, it should be noted that $P_{max,s}$ with CN50 was about 35% lower, and $P_{max,s}$ with CN65 was about 45% lower than the value of nailed joint with sufficient edge distance.

Single shear performance, lateral nail resistance and bending performance

Since $P_{y,s}$ in the nailed joint can be estimated from $F_{e,l}$ of the panel material and the yield bending moment of the nail[11], $P_{y,s}$ is dominated by $F_{e,l}$. Thus, the relation between $P_{y,s}$ and $F_{e,l}$ of MDF in Figure 12 is shown by the mean value of each type of MDF. Here, each performance value was compared without correcting based on the density, including the effect of the average board density and the density profile. The edge distance/nail diameter ratio of the lateral nail resistance specimen differs depending on the test conditions, and $F_{e,l}$ depends on the nail diameter even if the edge distance is sufficient[14]. Therefore, $F_{e,l}$ between each test condition cannot be compared directly.

There was a close positive relation between $P_{y,s}$ and $F_{e,l}$, but this relation differed depending on the test condition. The reason for this was that $P_{y,s}$ for each condition was almost the same (Figure 9) while $F_{e,l}$ differed depending on the test condition (Figure 7). From this result, even if the lateral nail resistance test was conducted according to the actual edge distance of the nailed joint and $P_{y,s}$ were estimated using $F_{e,l}$ obtained from that test, there is a possibility that $P_{y,s}$ might not be expressed in an actual nailed joint.

The nail-head pull-thorough performance was not related to the shear performance of nailed joints. Failure of the nail head penetration generally occurs when the thickness of the panel material is insufficient[15]. In this study, failure of the nail head penetration was not observed in any type of MDF.

It was found that $K_{s,s}$ and $P_{y,s}$ reached a high value if a high density layer was formed in the surface area. Previously, the authors had revealed that a high bending performance could be obtained when a high density layer was formed in the surface area of MDF[2]. Consequently, the single shear performance of nailed joint was compared with the bending performance.

The relations between *Ks,s* and MOE are shown in Figure 13 by the mean value of each type of MDF. *Ks,s* with CN50 and CN65 showed almost the same value for the edge distance 26mm. As for the edge distance 9mm, *Ks,s* with CN50 was higher than that with CN65 for the same MOE. Also in the case of the 9mm edge distance, the edge distance/nail diameter ratio with CN50 was about 3.14 and that with CN65 was about 2.70. *Ks,s* for large diameter nails was generally higher[16)], suggesting that the results of this study were affected by a decrease in the edge distance/nail diameter ratio.
The decision coefficient of the relation between *Ks,s* and MOE with CN50 was higher than the case with CN65. This is because there was relatively little change in *Ks,s* with CN65. The correlated straight line in Figure 13 provides a good illustration of the relation between *Ks,s* and MOE.
Figure 14 shows the relations between *Py,s* and MOR. Since there was little influence of the edge distance on *Py,s*, there was a straight regression line bringing the data of the edge distance 9mm and 26mm together, depending on the kind of nail. *Py,s* and MOR showed a close positive relation, *Py,s* with CN65 reached a value about 1.1 times higher than in the case with CN50 for the same MOR. When nailed joint reaches a yielding condition, moment on member subject to bearing stress is balanced to bending yield moment of nail. Since the yield moments calculated from nominal yield strength of CN50 and CN65[11)] are 2.75kNmm and 3.63kNmm, respectively, it is considered that the difference between the *Py,s* of nailed joint with CN50 and CN65 was occurred by the yield moments of these nails.
Single shear performance of nailed joint is significant parameter that has influence on structural performance of construction. However, obtaining shear performance of nailed joint is not simple as compared with the case of bending performance. Using the regression lines in Figures 13 and 14, *Ks,s* and *Py,s* of various MDF with 12mm thick could be easily estimated from MOE and MOR, respectively.

Conclusion

Tests on nail-head pull-through, lateral nail resistance and single shear of nailed joints were conducted using MDF having different density profiles to examine the influence of density profile on nailed joint performance. The following results were obtained:
1) The effect of density profile on nail-head pull-through maximum load was small but there was a significant effect of average board density.
2) The effect of density profile on the ultimate lateral nail resistance strength was strong and ultimate strength increased with increasing density layer in the board surface area.
3) The influence of the density profile was most remarkable in first-stage rigidity though initial stiffness and the yield load in the nail joint shear test showed a high value when there was a high-density layer in the board surface area. The density profile did not influence the maximum load.
4) The initial stiffness showed a positive correlation with MOE, and there was little change in the initial stiffness with CN65 compared with the amount of change in MOE. The yield load of nailed joints showed a strong positive correlation with MOR. Because a straight line relation was seen, the nail joint shear performance of an MDF of 12mm in thickness can be estimated from bending performance.

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Figure Legend

Fig. 1. Density profile along the board thickness direction.

Fig. 2. Average layer density of the layer from the surface to various positions.

Fig. 3. Configuration of nailed joint tests.

Fig. 4. Relations between strengths of nailed joint with CN50 obtained from 3 type tests and board density.

Fig. 5. Maximum load obtained from nail-head pull-through tests. *Bars* indicate standard deviations

Fig. 6. Definition of stiffness and strengths of nailed joints. P_{max}: maximum load; P_u: ultimate load; P_y: yield load; K_s: initial stiffness; d: nail diameter; $p1$: 5% or 10% of P_{max}; $p2$: 20% or 40% of P_{max}

Fig. 7. Ultimate strength obtained from lateral nail resistance tests. $e1$: end distance of MDF. *Bars* indicate standard deviations

Fig. 8. Load-displacement diagrams for single shear joints.

Fig. 9. Single shear performance of nailed joints. $e1$; end distance of MDF. *Bars* indicate standard deviations

Fig. 10. Notional deformation of single shear joint.

Fig. 11. Ratio of single shear performance of nailed joints with end distance of 9mm to that with end distance of 26mm.

Fig. 12. Relations between the yield load of single shear joints and ultimate strength obtained from lateral nail resistance tests.

Fig. 13. Relations between the initial stiffness of single shear joints and the modulus of elasticity.

Fig. 14. Relations between the yield load of single shear joints and the modulus of rupture.

Table Title

Table 1. Symbols of specimens and press schedules of MDF.

Table 2. Results of nail-head pull-through tests, lateral nail resistance tests and single shear tests of nailed joints. $e1$: end distance of MDF; $F_{e,l}$: ultimate strength obtained from lateral nail resistance tests; $P_{max,p}$, $K_{s,s}$, $P_{y,s}$ and $P_{max,s}$ are the same as in Fig. 6; Number with parentheses show standard deviations; (*): significant at 95% confidence level; (**); significant at 99% confidence level; (NS): not significant at 95% confidence level

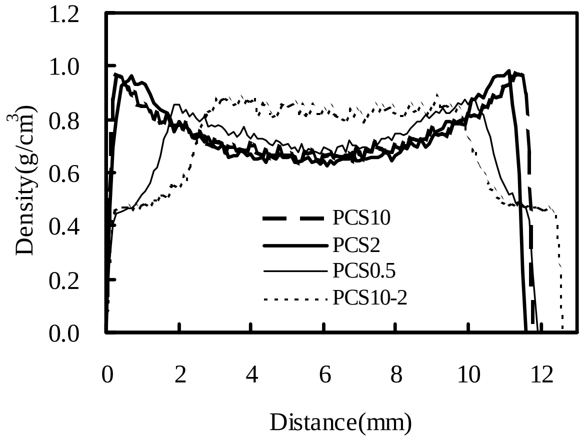

Fig. 1. Density profile along the board thickness direction.

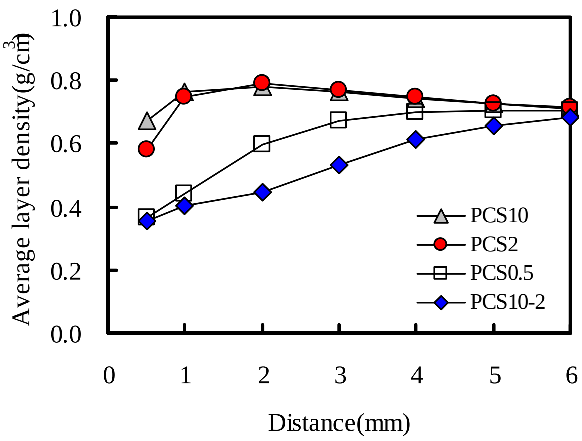

Fig. 2. Average layer density of the layer from the surface to various positions.

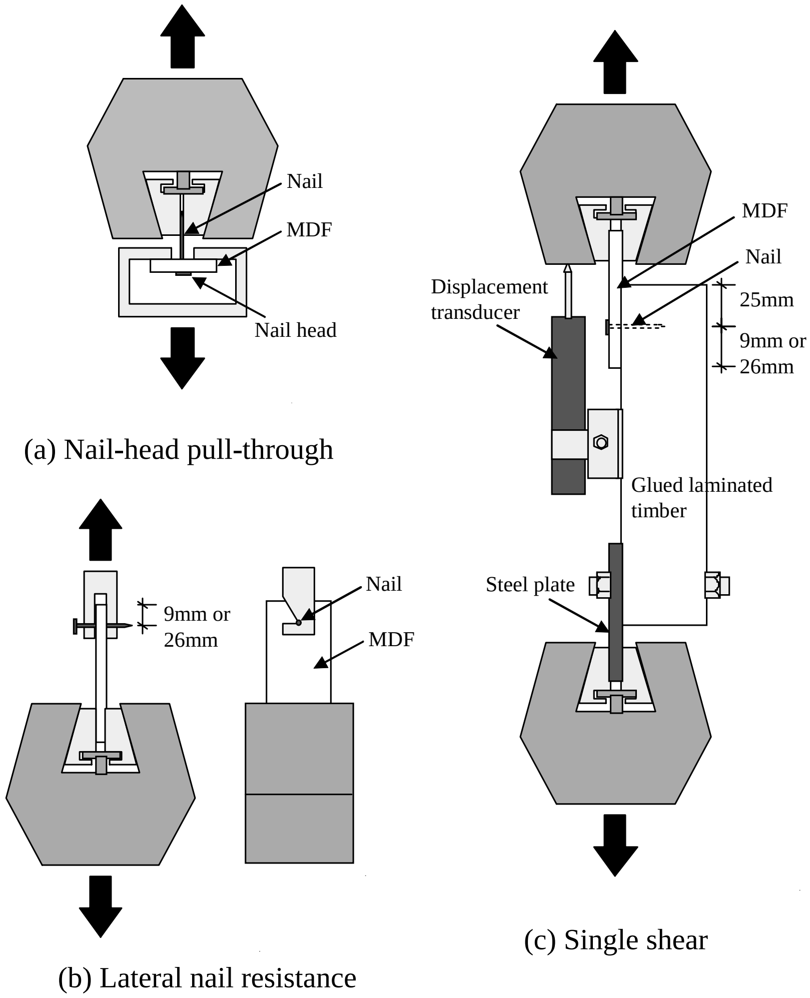

Fig. 3. Configuration of nailed joint tests.

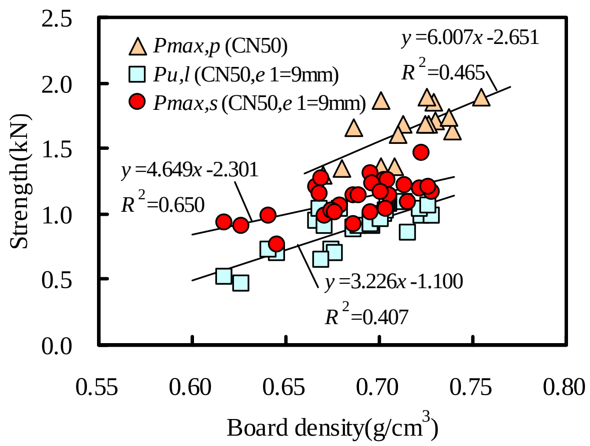

Fig. 4. Relations between strengths of nailed joint with CN50 obtained from 3 type tests and board density.

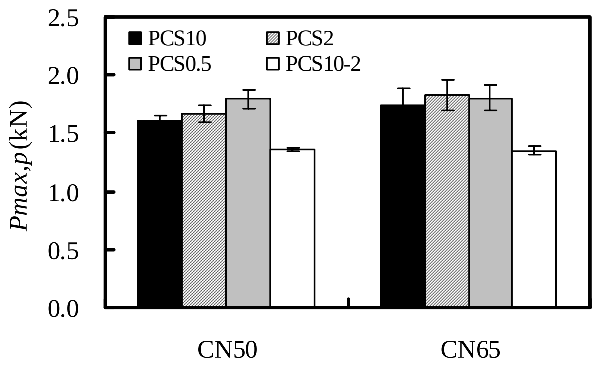

Fig. 5. Maximum load obtained from nail-head pull-through tests.
Bars indicate standard deviations

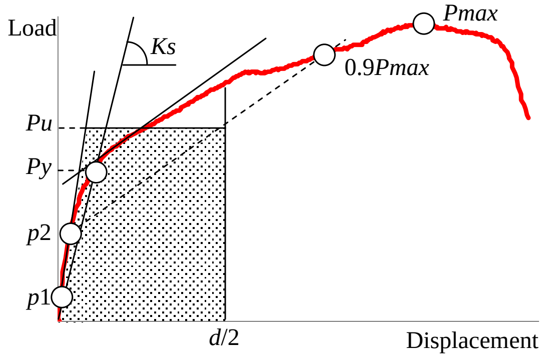

Fig. 6. Definition of stiffness and strengths of nailed joints.

Pmax: maximum load; *Pu*: ultimate load; *Py*: yield load; *Ks*: initial stiffness; *d*: nail diameter, *p*1; 5% or 10% of *Pmax*, *p*2; 20% or 40% of *Pmax*

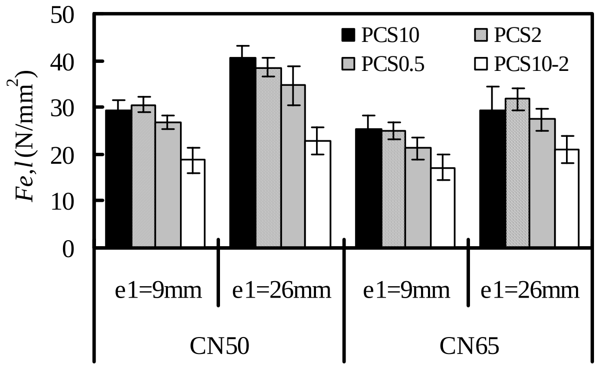

Fig. 7. Ultimate strength obtained from lateral nail resistance tests.
*e*1: end distance of MDF. *Bars* indicate standard deviations

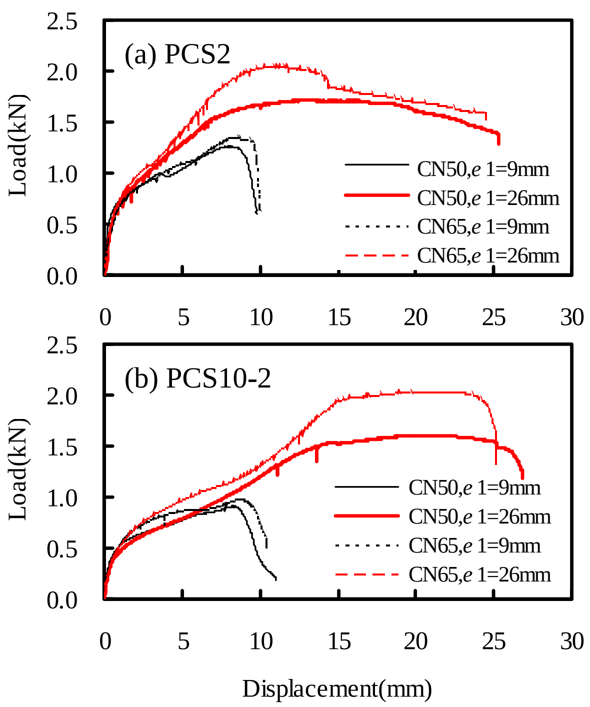

Fig. 8. Load-displacement diagrams for single shear joints.
*e*1; end distance of MDF

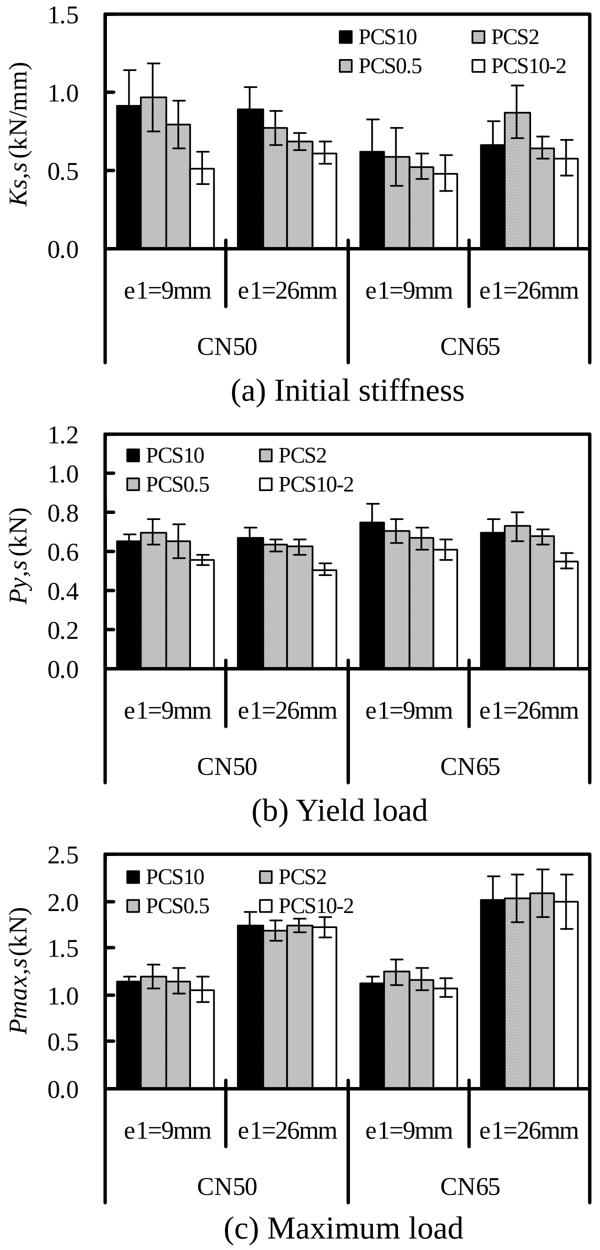

Fig. 9. Single shear performance of nailed joints.
*e*1; end distance of MDF. *Bars* indicate standard deviations

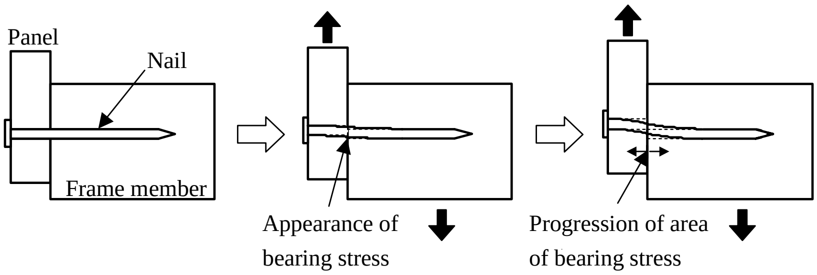

Fig. 10. Notional deformation of single shear joint

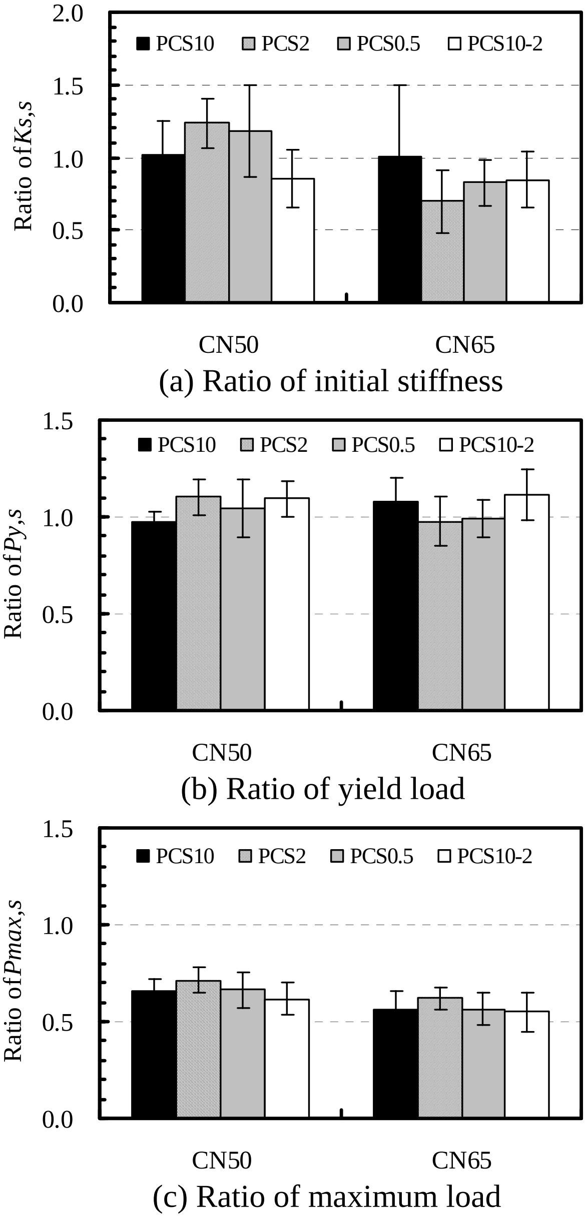

Fig. 11. Ratio of single shear performance of nailed joints with end distance of 9mm to that with end distance of 26mm.

Bars indicate standard deviation

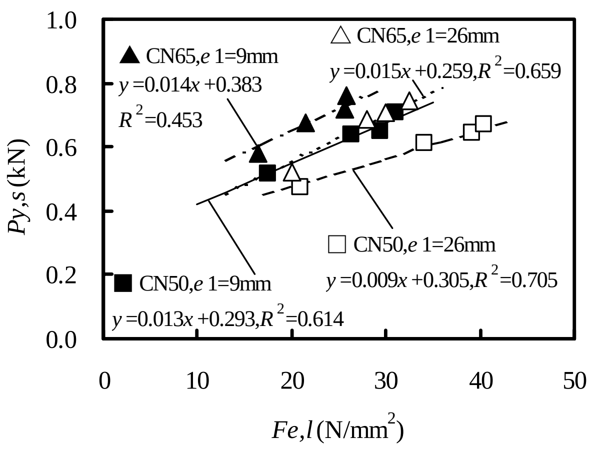

Fig. 12. Relations between the yield load of single shear joints and ultimate strength obtained from lateral nail resistance tests.

*e*1; end distance of MDF

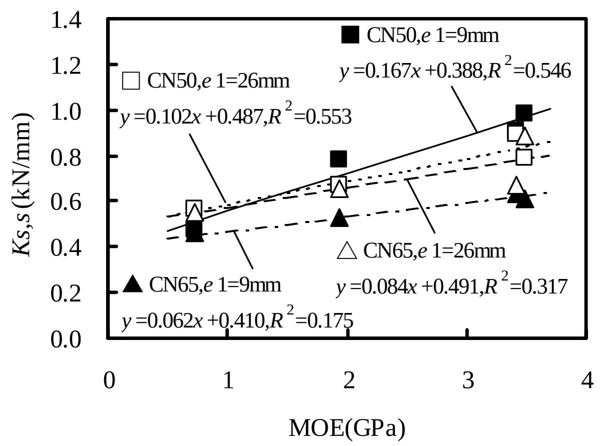

Fig. 13. Relations between the initial stiffness of single shear joints and the modulus of elasticity.

*e*1; end distance of MDF

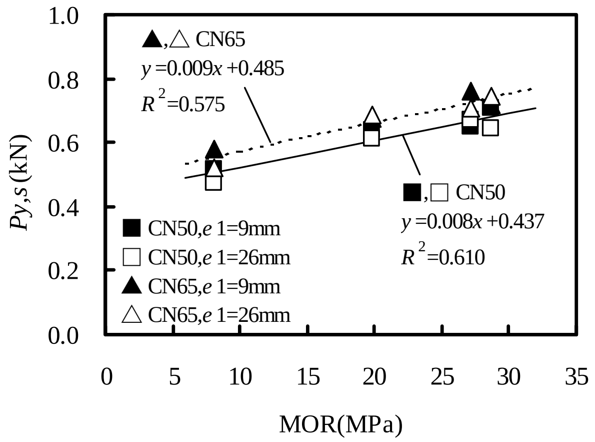

Fig. 14. Relations between the yield load of single shear joints and the modulus of rupture.

*e*1; end distance of MDF

Table 1. Symbols of specimens and press schedules of MDF

Symbol	Pressing method	Press closing speed (mm/sec.)	Press time (min.)	Target thickness (mm)
PCS10	One-step	10.0	9.0	12
PCS2	One-step	2.0	9.0	12
PCS0.5	One-step	0.5	9.0	12
PCS10-2	Two-step	10.0→2.0	6.5→2.0	540→12

Table 2. Results of nail-head pull-through tests, lateral nail resistance tests and single shear tests of nailed joints

Test type		Board type	CN50				CN65			
			e 1=9mm		*e* 1=26mm		*e* 1=9mm		*e* 1=26mm	
Nail-head pull-through	*Pmax,p* (kN)	PCS10	1.61(0.04)				1.74(0.14)			
		PCS2	1.66(0.07)	(**)			1.83(0.13)	(**)		
		PCS0.5	1.79(0.08)				1.80(0.11)			
		PCS10-2	1.61(0.02)				1.35(0.04)			
Lateral nail resistance	*Fe,l* (N/mm^2)	PCS10	29.51(1.88)		40.50(2.45)		25.39(2.83)		29.48(5.00)	
		PCS2	30.58(1.63)	(**)	38.57(1.99)	(**)	25.02(1.66)	(**)	31.79(2.31)	(**)
		PCS0.5	26.83(1.32)		34.65(4.28)		21.23(2.46)		27.47(2.42)	
		PCS10-2	18.73(2.75)		22.67(2.88)		17.16(2.61)		21.03(2.88)	
Single shear of nailed joint	*Ks,s* (kN/mm)	PCS10	0.91(0.24)		0.89(0.14)		0.62(0.21)		0.67(0.15)	
		PCS2	0.96(0.22)	(**)	0.78(0.11)	(**)	0.59(0.19)	(NS)	0.87(0.17)	(**)
		PCS0.5	0.79(0.15)		0.68(0.05)		0.53(0.08)		0.64(0.07)	
		PCS10-2	0.52(0.10)		0.61(0.07)		0.48(0.11)		0.58(0.11)	
	Py,s (kN)	PCS10	0.65(0.04)		0.67(0.05)		0.75(0.09)		0.70(0.07)	
		PCS2	0.70(0.07)	(**)	0.63(0.03)	(**)	0.71(0.06)	(**)	0.73(0.07)	(**)
		PCS0.5	0.65(0.09)		0.62(0.04)		0.67(0.06)		0.68(0.04)	
		PCS10-2	0.55(0.03)		0.51(0.03)		0.61(0.05)		0.55(0.04)	
	Pmax,s (kN)	PCS10	1.14(0.07)		1.75(0.13)		1.12(0.08)		2.01(0.25)	
		PCS2	1.20(0.12)	(NS)	1.69(0.10)	(NS)	1.25(0.14)	(*)	2.02(0.25)	(NS)
		PCS0.5	1.15(0.14)		1.74(0.08)		1.16(0.11)		2.08(0.25)	
		PCS10-2	1.06(0.14)		1.72(0.11)		1.07(0.10)		1.99(0.28)	

*e*1: end distance of MDF; *Fe,l*: ultimate strength obtained from lateral nail resistance tests; *Pmax,p*, *Ks,s*, *Py,s* and *Pmax,s* are the same as in Fig. 6; Number with parentheses show standard deviations; (*): significant at 95% confidence level; (**); significant at 99% confidence level; (NS): not significant at 95% confidence level