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**Min Zhang · Ee-ding Wong · Shuichi Kawai
Jin-heon Kwon**

Manufacture and properties of high-performance oriented strand board composite using thin strands*

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Abstract Three-layered composite oriented strand boards were manufactured using very thin hinoki (Japanese cypress, *Chamaecyparis obtusa* Endl.) strands oriented in the faces and mixtures of sugi (Japanese cedar, *Cryptomeria japonica* D. Don.) and hinoki particles in the core. The boards were composed of two density levels, with 1:8:1, 0.5:9:0.5, and 0:10:0 face:core:face ratios. Polymeric and emulsion type isocyanate resins were used. The resin contents for the strands in the face and particles in the core were 10% and 5%, respectively. The steam-injection press was applied at 0.62 MPa (160°C), and the steam-injection time was 2 min. The mechanical and physical properties of the boards were evaluated based on the Japanese Industrial Standard. The parallel moduli of rupture and elasticity along the strand orientation direction and the wood screw retaining force increased with increasing face/core ratios. Incorporation of 10%–20% of thin strands in the face of the boards improved the parallel moduli of rupture and elasticity by 47%–124% and 30%–65%, respectively. In addition, the thickness swelling after water-soaking at 20°C for 24 h, and the parallel linear expansion after boiling for 2 h and water-soaking at 20°C for 1 h, of the three-layered composite boards were below 8% and 0.15%, respectively, despite a short steam-injection press time. The thickness swelling of the boards decreased with increasing face/core ratios. In contrast, the presence of face strands seems to have a minimal effect on the moduli of rupture and elasticity along the perpendicular direction of the three-layered composite boards. A similar trend was observed for the internal bond strength, hardness, and linear expansion along the perpendicular direction.

Key words Thin strand · Particle · Oriented strand board · Three-layered composite · Steam-injection press

M. Zhang (✉) · E. Wong · S. Kawai
Wood Research Institute, Kyoto University, Uji 611-0011, Japan
Tel. +81-774-38-3676; Fax +81-774-38-3678
e-mail: zhangmin@kuwri.kyoto-u.ac.jp

J. Kwon
College of Forestry, Kangweon National University, Chuncheon 200-701, Korea

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Introduction

In recent years, following the reduction in timber resources and degradation of the global environment, effective utilization of thinnings and fast-growing forest resources have gained increasing importance.[1,2] Currently, the annual thinnings from the plantations of hinoki and sugi are available in large quantities in Japan. Therefore, much research has focused on the utilization of these materials. It is possible to process hinoki and sugi thinnings into an engineered wood product such as glulam, but there are many problems of production efficiency and low recovery. It may be more feasible to convert hinoki or sugi thinnings into laminated veneer lumber.[3,4] Thinnings of hinoki or sugi also have a great potential to be used as the raw material for the particleboard or fiber-based board industry. Development of a growing and utilization system of hinoki and sugi would represent a significant contribution to the conservation of natural forest resources and preservation of the environment.

Previous studies reported the effect of particle configuration on particleboard properties.[5–8] It is clear that the bending strength of particleboard is highly dependent on the length/thickness ratio of the particle; that is, the moduli of rupture (MOR) and elasticity (MOE) increase with increasing particle length (L) or decreasing particle width (W) and thickness (T). The mechanical properties of the particleboard can thus be marked improved by using longer and thinner particles or strands. Early studies on the manufacture and properties of strand board or oriented strand board (OSB)[9–12] reported great improvement in the MOR and MOE of the board due to the orientation of strands but with little improvement in the dimensional stabilities. The high dimensional stability of OSB may be achieved through application of new processing technologies, such as three-layered structural design, isocyanate resins, and steam-injection pressing method.

This paper reports the use of oriented hinoki strands with 0.1 mm thickness, almost equivalent to its fiber bundle diameter for producing fiberboards, in the face of three-layered OSB composite, with mixtures of hinoki and sugi particles in the core. The application of steam-injection press and the effects of the face/core ratio on board properties are discussed.

Materials and methods

Materials

The raw materials used in this experiment were thin strands from hinoki (*Chamaecyparis obtusa* Endl.) thinnings produced by a slicer and mixtures of sugi (*Cryptomeria japonica* D. Don.) and hinoki particles from sawmill wastes produced by a ring flaker. The mixing ratio of sugi and hinoki particles was about 1:1. The hinoki strands were very thin, with a mean dimension of 100 (L) × 20 (W) × 0.1 (T) mm. The average thickness of sugi and hinoki particles was 0.5 mm. The moisture content of strands and particles was 10%. The adhesives used were polymeric and emulsion-type isocyanate resins (P-MDI, E-MDI) formulated by Gunei Chemistry Industry and Nippon Polyurethane Industry, respectively.

Manufacture of three-layer OSB composite

The composite produced consisted of three layers, where the faces and core were composed of oriented hinoki strands and a mixture of sugi and hinoki particles, respectively. The board was 385 × 365 × 12 mm, with target densities of 0.60 and 0.70 g/cm^3. The weight ratios of face strands/core particles/face strands were 0:10:0, 0.5:9:0.5, and 1:8:1, expressed hereafter as face/core ratios of 0:10, 1:9, and 2:8, respectively. In view of the great specific surface area of the very thin hinoki strands, the thickness of which is similar to that of the fiber bundle, the 10% resin content of P-MDI and E-MDI were applied in the faces and 5% in the core, based on the oven-dry weight of strands and particles. Acetone (20%) was added based on the resin content for better resin consistency and distribution. The face strands were hand-formed using a forming box with a frame consisting of slots about 25 mm wide divided by thin aluminum plates, which were located about 30–50 mm above the top of the mat. On the whole, the angle of deviation between the longitudinal axes of the board and the oriented strands was about 20°. The OSB composites were produced by applying steam-injection press at 160°C (0.62 MPa), with a steam-injection time of 2 min followed by 15 s of breathing time.

Board property evaluations

The properties of the three-layered OSB composites were evaluated in accordance with the Japanese Industrial Standard (JIS) A 5908 and Z 2117. The properties evaluated include the parallel and perpendicular moduli of rupture (MOR) and elasticity (MOE), bending strength after boiling (wet-MOR and wet-MOE), internal bond (IB) strength, wood screw retaining force, and Brinell hardness. The bending test specimens were 220 × 40 × 12 mm, and the effective span/board thickness ratio was 17:1. The loading speed of the bending test was 1 mm/min. For the wet bending test, the specimens were boiled for 2 h followed by 1 h of water soaking at 20°C prior to testing. In addition, the degree of parallel and perpendicular linear expansion (LE) after the above-mentioned conditioning was measured using a dial gauge. The IB, wood screw retaining force, and Brinell hardness test specimens were 50 × 50 mm, 50 × 40 mm, and 40 × 40 mm, respectively. The loading speed of the Brinell hardness test was 0.5 mm/min.

Thickness swelling (TS) and water absorption (WA) were measured under dry–wet conditioning cycles: air-drying followed by water-soaking at 20°C for 24 h, then oven-drying at 105°C for 24 h, water-soaking at 70°C for 24 h, oven-drying at 105°C for 24 h; boiling for 4 h, and oven-drying at 105°C for 24 h. The TS and WA test specimens were 50 × 50 mm.

Five test specimens were used for each property evaluation. The values of MOR, MOE, wet-MOR, wet-MOE, IB, wood screw retaining force, and Brinell hardness of the boards were adjusted to equal target density based on the regression correlations of these properties with the density. The average values of five test specimens were used for TS and WA.

Results and discussion

Mechanical properties

MOR and MOE

Figure 1 shows the relations between the face/core ratios and the MOR and MOE of the three-layered OSB composite bonded with E-MDI. The MOR and MOE along the strand orientation direction of the board increased greatly with increasing face/core ratios. The specific MOR and MOE (i.e., ratio of MOR and MOE to board density) of the three-layered OSB composite reached 100 MPa and 8.6 GPa, respectively, at the maximum face/core ratio of 2:8. These values were comparable to those of commercial plywoods.[13] This improvement is attributed to the orientation effect of the hinoki strands in the board faces and the increase in overall board resin content arising from the increased face/core ratio as the resin content of the face strands was higher than that of the core particles.

The density profiles along the thickness of E-MDI bonded board of 0.70 g/cm^3 density with various face/core

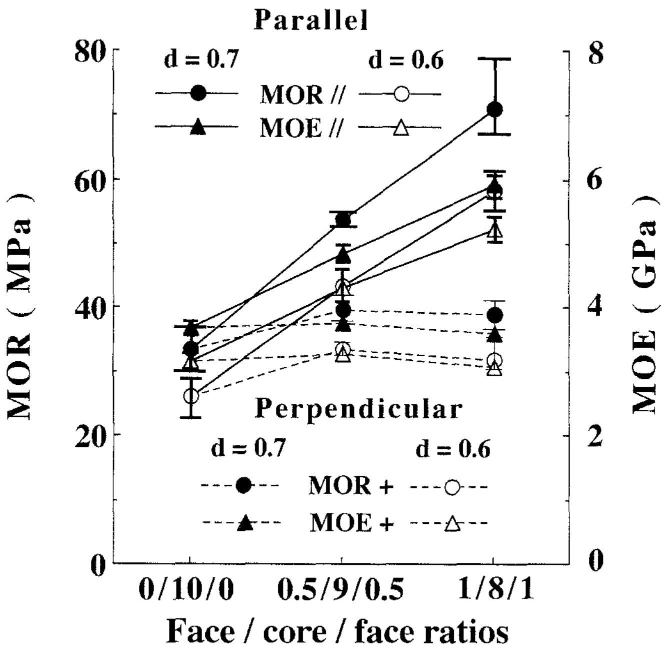

Fig. 1. Relations between face/core/face ratios and moduli of rupture (MOR, *circles*) and elasticity (MOE, *triangles*) of E-MDI bonded boards. *Solid lines*, parallel direction; *broken lines*, perpendicular direction; *solid symbols*, board density (d) = 0.7 g/cm^3; *open symbols*, *d* = 0.6 g/cm^3. Each plot shows the regression value and its range of variation

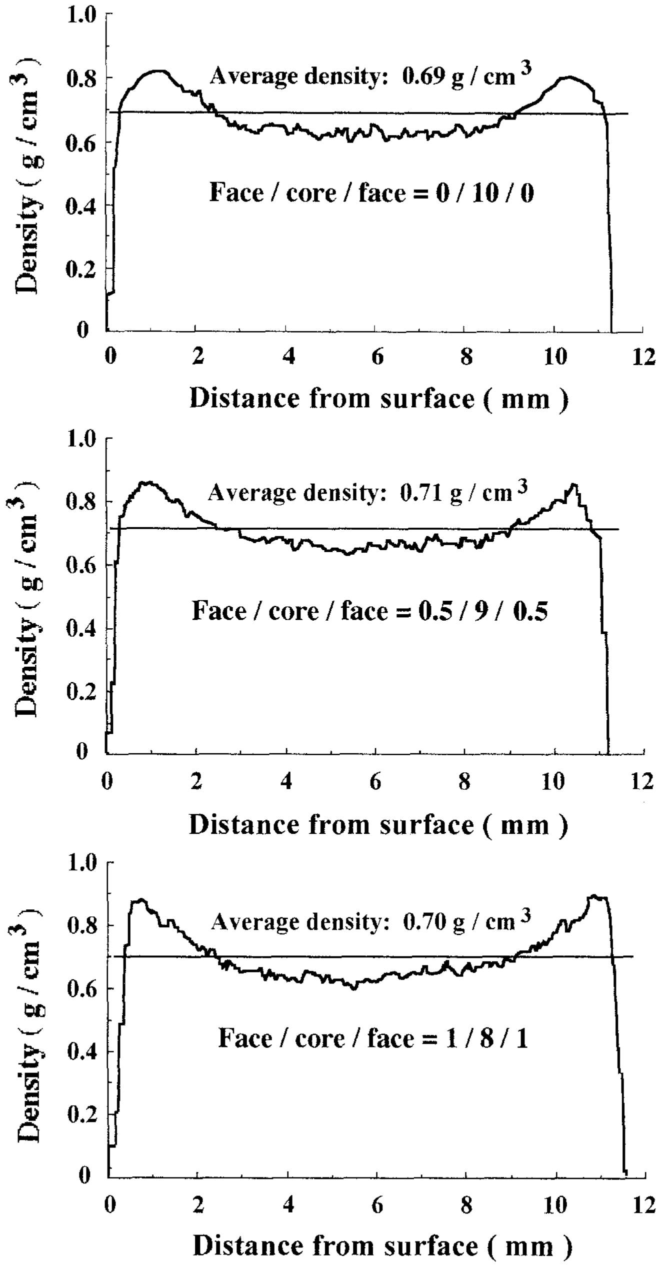

Fig. 2. Density profiles along the thickness of the boards with different face/core/face ratios. Average densities: 0.69 g/cm^3 (*top*): 0.71 g/cm^3 (*middle*); 0.70 g/cm^3 (*bottom*)

constituent ratios are shown in Fig. 2. Generally, the density profile of all types of board has a U-shape (i.e., high face density and low core density). The peak density was found to shift nearer to the board surface as the face/core ratio increased. The higher bending strength and Young's modulus of the hinoki strand have contributed to the increase in the parallel MOR and MOE, as they made up the tension-compression zones of the sandwich structure, which took up most of the bending load.

In addition, the MOR and MOE perpendicular to the strand orientation direction of the three-layered composite boards did not show great variation with changes in the face/core ratio. For face/core ratios of 1:9 or 2:8, the perpendicular MOEs of the boards were similar to those of the homogeneous particleboards (i.e., at a face/core ratio of 0:10). It was also reported in previous studies that the perpendicular MOR and MOE of the boards were not affected greatly with increasing face/core ratios.[13–16]

Similar trends and values for MOR and MOE were recorded for three-layered OSB composite bonded with P-MDI.

Figure 3 shows the relations between the face/core ratios and the rate of increase in parallel MOR and MOE of the boards. The rate of increase in MOR and MOE could be represented by a straight line with increasing face/core ratios. Incorporation of 10%–20% (weight basis) of thin oriented hinoki strands in the faces could improve the parallel MOR and MOE by 47%–124% and 30%–65%, respectively. It can be seen in Fig. 3 that the rate of increment in MOR and MOE with an increasing face/core ratio was more marked at a lower board density.

The wet-MOR and wet-MOE of the boards bonded with E-MDI are shown in Fig. 4. The bending strength was measured after boiling for 2 h and water-soaking at 20°C for 1 h. In the dry condition, the parallel wet-MOR and wet-MOE increased with increasing face/core ratios. The retention of MOR and MOE in these steam-injection pressed E-MDI and P-MDI bonded boards ranged from 50% to 70%.

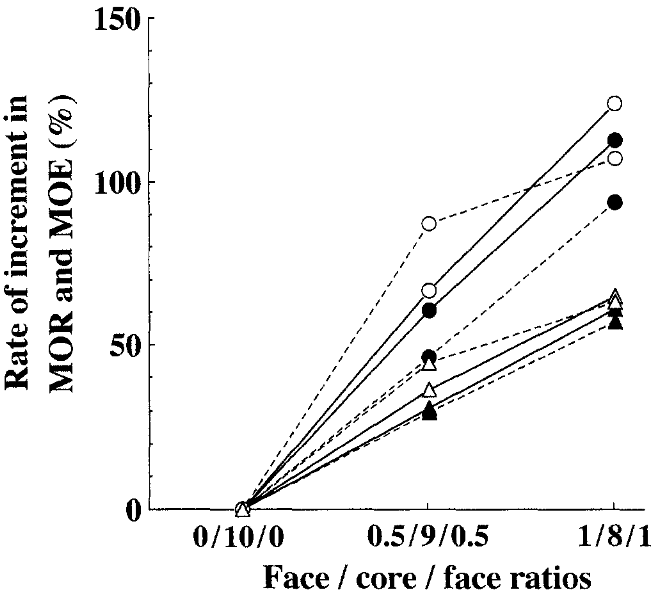

Fig. 3. Relations between face/core/face ratios and rate of increment (*Ri*) in MOR and MOE of the boards. *E-MDI*, emulsion-type isocyanate; *P-MDI*, polymeric-type isocyanate; *d*, board density (g/cm^3); *filled symbols*, *d* = 0.7; *open symbols*, *d* = 0.6; *solid lines*, E-MDI; *broken lines*, P-MDI; *circles*, Ri in MOR; *triangles*, Ri in MOE

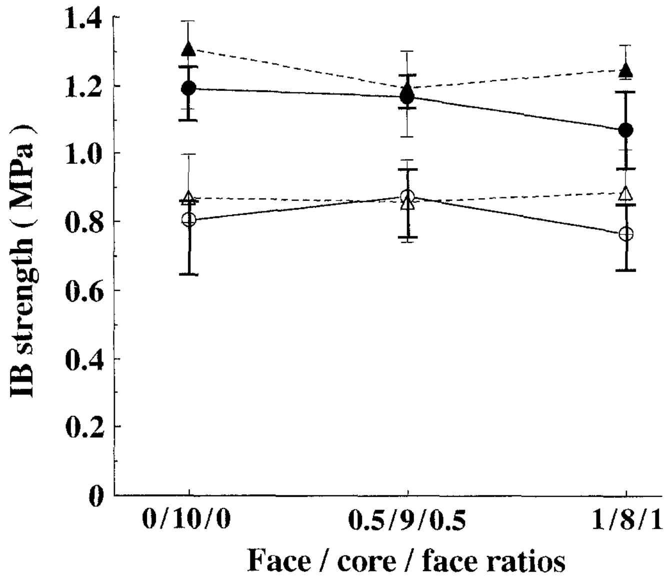

Fig. 5. Relations between face/core/face ratios and internal bond (IB) strengths of the boards. *Filled symbols*, *d* = 0.7 g/cm^3; *open symbols*, *d* = 0.6 g/cm^3; *circles*, E-MDI; *triangles*, P-MDI. Each plot shows the regression value and its range of variation

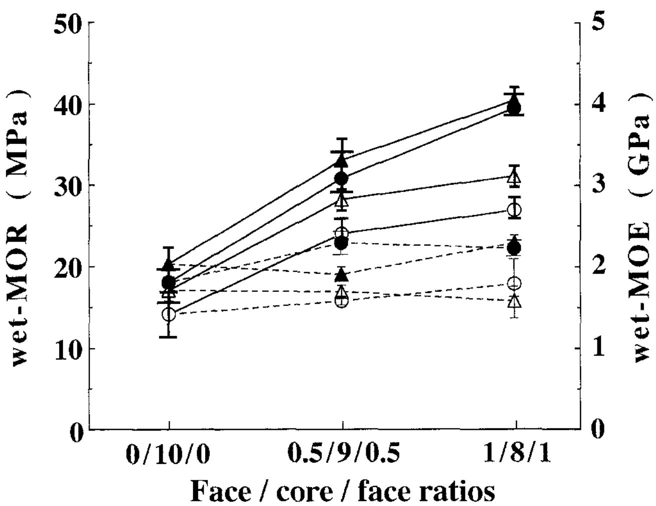

Fig. 4. Relations between face/core/face ratios and moduli of rupture (MOR) and elasticity (MOE) of the E-MDI bonded boards after boiling. See Fig. 1 for explanation of symbols

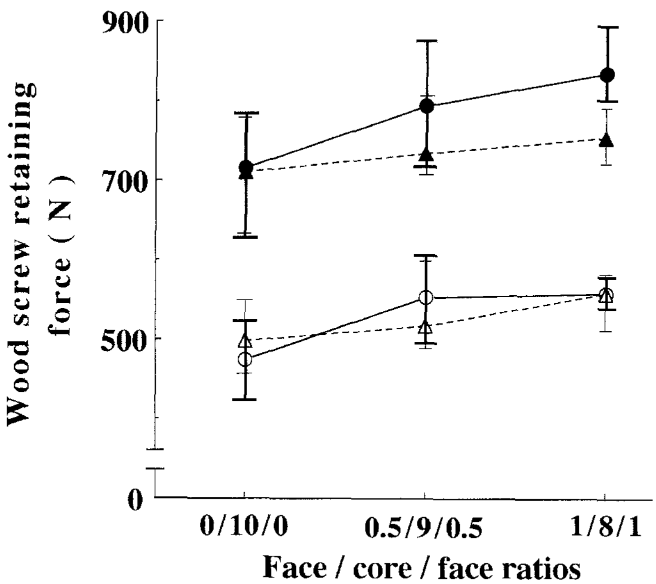

Fig. 6. Relations between face/core/face ratios and wood screw retaining forces of the boards. See Fig. 5 for explanation of symbols

Internal bond strength and wood screw retaining force

Figure 5 shows the relations between the face/core ratios and the IB strength of the boards. The IB strength of the three-layered OSB composite is not affected by adding hinoki strands in the face of the boards at either 0.60 or 0.70 g/cm^3 density. Statistical analysis also showed that the face/core ratio has no significant effect on the board IB strength at the 95% signifance level. A similar result was reported in an earlier study.[17] This is because both homogeneous or heterogeneous boards have similar core density values, as revealed in the density profiles analyses. Boards of 0.60 and 0.70 g/cm^3 density had IB strengths of 0.85 and 1.20 MPa, respectively. These values were found to be higher than those for commercial particleboards and OSB, which is due to the improved conformity and inter-particle bonding when isocyanate adhesive resin is used.

Figure 6 shows the relations between the face/core ratios and the wood screw retaining force of the boards. The three-layered OSB composite with a face/core ratio of 2:8 recorded the best properties; the effect of incorporating oriented strands in the faces on the wood screw retaining

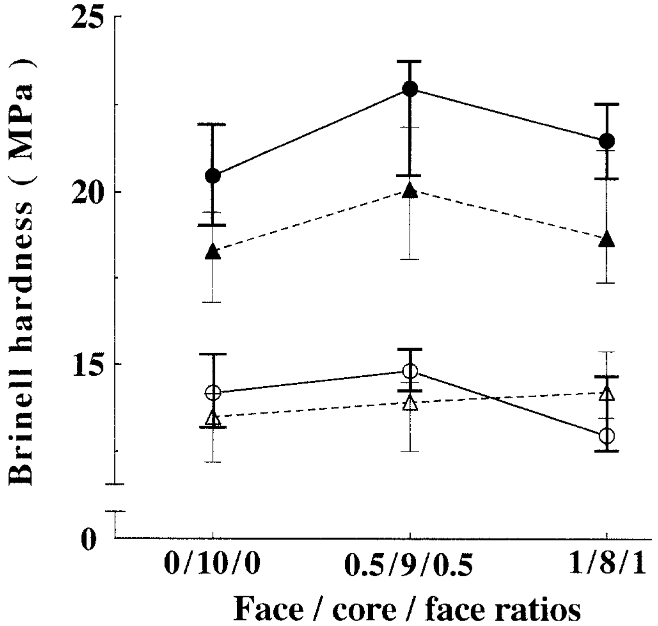

Fig. 7. Relations between face/core/face ratios and Brinell hardness of the boards. See Fig. 5 for explanation of symbols

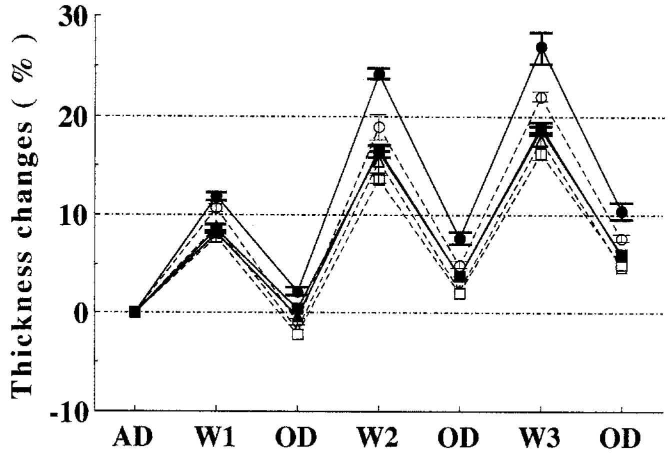

Fig. 8. Thickness changes of the E-MDI bonded boards under dry/wet cycles. *AD*, air-dried condition; *OD*, oven-dried condition at 105°C for 24 h; *W1*, water-soaking at 20°C for 24 h; *W2*, water-soaking at 70°C for 24 h; *W3*: boiling for 4 h. *Filled symbols*, *d* = 0.7 g/cm^3; *open symbols*, *d* = 0.6 g/cm^3. For face/core/face ratios: *circles*, 0/10/0; *triangles* 0.5/9/0.5; *squares*, 1/8/1. Each plot shows average value and standard deviation

force was less prominent compared to parallel MOR and MOE. The type of isocyanate resin seems to have little effect on the IB and wood screw retaining force of the boards.

Hardness

Figure 7 shows the relations between the face/core ratio and the Brinell hardness of the boards. Although the board bonded with the E-MDI was harder than the other boards, board hardness seems not to be affected significantly by variation in the face/core ratio as revealed by statistical analysis. The hardness of the three-layer composite board is considered to be influenced greatly by the density and compaction ratio of the board but not the hardness of the face material itself, as reported previously.[18] In this experiment, the face and core materials have a similar density, where the density of sugi and hinoki were about 0.40 and 0.45,[19] respectively. Despite the variation in face/core ratio, the compaction ratios of 0.60 g/cm^3 boards varied only slightly, from 1.46 to 1.50, and those of 0.70 g/cm^3 boards ranged from 1.71 to 1.75.

Dimensional stabilities

Thickness swelling

The thickness changes of the boards bonded with E-MDI at different face/core ratios after the dry/wet cycles are shown in Fig. 8. The TS of the boards exhibited a tendency to decrease with an increasing face/core ratio. The TS of the three-layered OSB composite after water-soaking at 20°C for 24 h and boiling for 4 h was less than 8% and 20%, respectively. The TS of the homogeneous particleboards could be improved by 20%–30% by incorporating 10%–20% of very thin hinoki strands in the faces.

The dimensional changes in the homogeneous particleboards during water soaking resulted mainly from the swelling of the fiber cell walls due to water absorption, disintegration of particles due to bonding strength reduction, and spring-back of the compression set imposed during the hot-pressing operation. In conventional homogeneous particleboard, a major portion of TS originates from the spring-back in the higher density face layer. In the three-layered OSB composite, the thin hinoki strands were oriented like veneer in the faces of the board, with good interstrand contact and high bonding strength contributed by the isocyanate resin. Consequently, the swelling of the hinoki strand layer in the faces was marked suppressed. In addition, the increase in the overall board resin content with an increasing face/core ratio due to the higher resin content of face strands could also contribute to the improved TS.

These three-layered OSB composites recorded lower spring-back of about 5% at the end of the dry–wet cyclic conditioning. The TS value was found to decrease with decreasing board density. A similar trend was observed in the TS of P-MDI bonded boards.

Figure 9 shows the thickness swelling/water absorption (TS/WA) ratio of the boards bonded with E-MDI after each water-soaking treatment. The TS/WA ratio indicates the degree of board thickness swelling with respect to the degree of water absorption under a similar wet condition. A board with better dimensional stability is indicated by its lower TS/WA ratio. In this experiment, the TS/WA ratio of the boards tends to decrease markedly with an increasing face/core ratio, irrespective of board density levels. The TS/WA ratio for the three-layer OSB composite with a face/core ratio of 2:8 was 30%–45% lower than those of the homogeneous particleboards. The TS/WA value of the 0.6 g/cm^3 boards with three-layer structure were below 0.15 after each soaking or boiling treatment. It can thus be

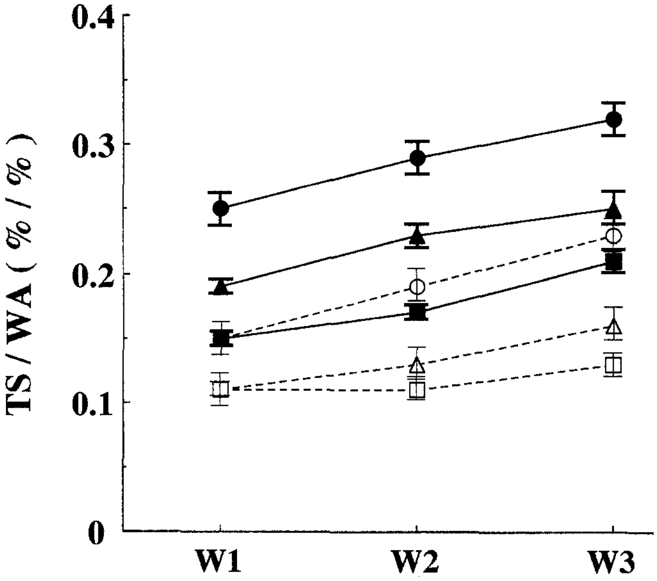

Fig. 9. Thickness swelling/water absorption ratios (*TS/WA*) of the E-MDI-bonded boards under various wet conditioning treatments. See Fig. 8 for explanation of symbols

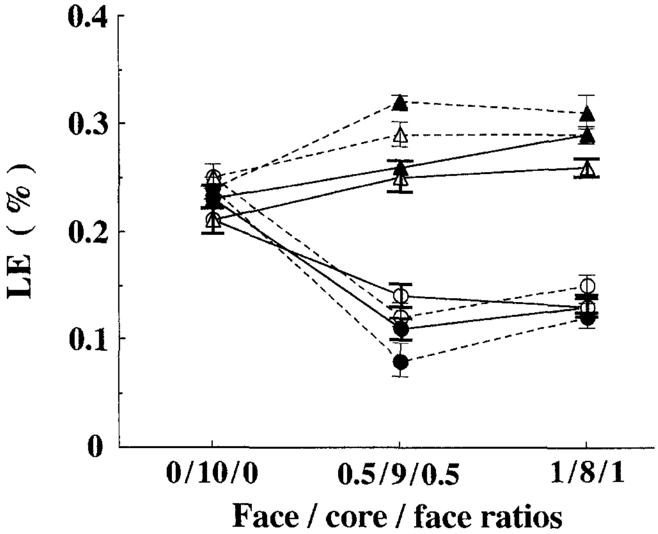

Fig. 10. Relations between face/core/face ratios and linear expansions (*LE*) of the boards after boiling for 2h and water soaking at 20°C for 1h. *Circles*, parallel direction; *triangles*, perpendicular direction; *solid symbols*, $d = 0.7\,g/cm^3$; *open symbols*, $d = 0.6\,g/cm^3$; *solid lines*, E-MDI; *broken lines*, P-MDI. Each plot shows average value and standard deviation

concluded that the three-layer OSB composite has better water resistance property and dimensional stability than the homogeneous particleboards or conventional OSB.

The TS/WA ratio of $0.7\,g/cm^3$ boards was higher than that for the $0.6\,g/cm^3$ boards owing to the fact that the relatively small variation in the values of TS for both the 0.6 and $0.7\,g/cm^3$ boards produced using a steam injection press. In contrast, the WA of higher density board is much smaller than that of lower density board. A similar trend was observed for the P-MDI bonded boards.

Linear expansion

Figure 10 illustrates the LE of the boards after 2h submersion in boiling water followed by 1h water soaking at 20°C. The LE values along the strand orientation direction for both 0.6 and $0.7\,g/cm^3$ three-layer OSB composite boards were less than 0.15%. When the face/core ratio is 1:9, the parallel LE is about half that of the homogeneous particleboards. Incorporation of the oriented long and thin strands of hinoki in the faces of the boards greatly improved the board dimensional stability along the orientation direction. The improvement is due to the fact that the degree of expansion in the longitudinal direction of wood fiber is much smaller than that in the lateral direction.[20,21] In addition, the LE perpendicular to the strand orientation direction of the three-layer composite boards increased slightly with increasing face/core ratios.

Conclusions

Incorporation of oriented hinoki strands in the faces of particleboard at low face/core ratios could improve the board parallel mechanical properties. The MOR and MOE of the three-layer OSB composite along the strand orientation direction increased greatly with increasing face/core ratios. The specific MOR and MOE values for these boards were higher than those for commercial plywoods. In addition, all of the boards exhibited 50%–70% MOR and MOE retention after boiling. In contrast, the MOR and MOE perpendicular to the strand orientation direction, internal bond strength, and hardness of the three-layer composite boards did not vary much with the variation in face/core ratio.

The water resistance and dimensional stability of the boards increased with an increasing face/core ratio. The three-layer OSB composite at a face/core ratio of 2:8 exhibited the lowest thickness swelling (7%–8%), despite a short steam-injection press time (2min), with 30%–45% reduction in the TS/WA ratio compared to homogeneous particleboards. The parallel LE along the strand orientation direction for all the three-layer OSB composites was less than one-half that for normal wood-based particleboards.

The three-layer OSB composite is regarded as new bio-based material with lighter weight, higher strength, and better dimensional stability.

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References

1. Zhang M, Kawai S, Sasaki H, Yoshida Y, Yamawaki T, Kashihara M (1994) Production and properties of composite fiberboard.

In: Zhao C, Sasaki H, Hua Y (eds) Properties and utilization of fast-growing trees. China Forestry Publishing House, Beijing, pp 270–278
2. Zhang M, Kawai S, Wong E, Kwon J (1996) Manufacture and properties of high performance composite boards. In: Proceedings of the third Pacific Rim bio-based composites symposium, Kyoto, pp 346–352
3. Sasaki H, Kato S, Tanouchi T (1983) Lathe design for manufacturing LVL from thinning materials (in Japanese). Wood Ind 38(10):23–28
4. Kato S, Sasaki H (1985) LVL plant using domestic timber as raw material (in Japanese). Wood Ind 40(6):38–43
5. Suda H, Kawai S, Sasaki H (1987) Production technology for low-density particleboard: III. (in Japanese). Mokuzai Gakkaishi 33:376–384
6. Kawai S, Sasaki H, Nakaji M, Makiyama S, Morita S (1986) Physical properties of low-density particleboard. Wood Res 72:27–36
7. Kawai S, Sasaki H (1986) Production technology for low-density particleboard: I. Mokuzai Gakkaishi 32:324–330
8. Brumbaugh J (1960) Properties of particleboards. For Prod J 10:243–246
9. Suzuki M, Sekino N (1982) Anisotropic elasticity of oriented flakeboard. Mokuzai Gakkaishi 28:91–96
10. Sekino N, Suzuki M (1984) Swelling and creep of isocyanate-bonded oriented-particleboard. Mokuzai Gakkaishi 30:17–22
11. Kim Y-J, Okuma M (1994) A study on sheet material from zephyr strands: II. (in Japanese). Mokuzai Gakkaishi 40: 1067–1072
12. Terry SJ, Jairo HL, Okuma M (1994) Organosolv-lignin-modified phenolics as strandboard binder: II. Mokuzai Gakkaishi 40:1079–1084
13. Zhang M, Kawasaki T, Yang P, Honda T, Kawai S (1996) Manfacture and properties of composite fiberboard: III. (in Japanese). Mokuzai Gakkaishi 42:854–861
14. Murakami K, Ueda H, Mathuda E, Zhang M, Kawasaki T, Kawai S (1997) Manufacture and properties of three-layered OSB (in Japanese). In: Abstracts of the 47th annual meeting of the JWRS, Kochi, Japan, p 276
15. Tanioka K, Takeda K, Zhang M, Kawai, S (1997) Manufacture and properties of three-layered composite boards: II. (in Japanese). In: Abstracts of the 47th annual meeting of the JWRS, Kochi, Japan, p 280
16. Takeda K, Takahashi S, Zhang M, Kawai S, Tanioka K (1997) Manufacture and properties of three-layered composite boards: I. (in Japanese). In: Abstracts of the 47th annual meeting of the JWRS, Kochi, Japan, p 281
17. Zhang M, Kawai S, Yang P, Honda T (1997) Manufacture of wood composites using lignocellulosic materials and their properties: II. (in Japanese). Mokuzai Gakkaishi 43:310–317
18. Zhang M, Kawai S, Yusuf S, Imamura Y, Sasaki H (1997) Manufacture of wood composites using lignocellulosic materials and their properties: III. (in Japanese). Mokuzai Gakkaishi 43:318–326
19. Wood Material Committee of Japan Material Research Society (1981) Wood engineering dictionary. Industry Publications, Tokyo, p 752
20. Zhang M, Kawai S, Sasaki H, Yamawaki T, Yoshida Y, Kashihara M (1995) Manufacture and properties of composite fiberboard: II. Mokuzai Gakkaishi 41:903–910
21. Faherty KF, Williamson TG (1995) Wood engineering and construction handbook. Donnelley, McGraw-Hill, Inc, New York, p 4