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Sandwich panel of veneer-overlaid low-density fiberboard

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Abstract Low-density sandwich panels of veneer-overlaid fiberboards of 12 mm thickness for structural use were manufactured at densities of 0.3–0.5 g/cm^3 using an isocyanate compound resin adhesive and steam injection pressing method. The effects of board density, veneer thickness, and resin content on the fundamental properties of sandwich panels were examined, with the following results: (1) The dry moduli of rupture and elasticity in the parallel direction of sandwich panels with thicker veneers were superior. The dry moduli of rupture and elasticity in the parallel direction of sandwich panels with 2.0 mm thick veneer at densities of 0.4–0.5 g/cm^3 were 40–60 MPa, and 5–8 GPa, which were two and four times as much as those of homogeneous fiberboards, respectively. (2) The higher-density panels exhibited tensile failure at the bottom veneer surface during static dry bending in a parallel direction, whereas lower-density panels experienced horizontal shear failure in the core. (3) The dimensional stability of sandwich panels had good dimensional stability, with negligible springback after accelerated weathering conditions. (4) The thermal insulation properties of sandwich panels were found to be much superior to other commercial structural wood composite panels.

Key words Sandwich panel · Low-density structural panel · Fiberboard · Physical property · Thermal insulation

Introduction

Plywood is currently facing stiff competition from other structural reconstituted composite boards such as particleboard, waferboard (WB), and oriented strandboard (OSB) due to the reduction in the supply of large-diameter peeling logs. These reconstituted composite boards are environmental friendly, economical, productive-stable, and quality-reliable, but they have relatively high density (0.63–0.72 g/cm^3)[1] as they are compressed to improve their mechanical strength for structural use. Hence they are inferior to plywood in terms of their specific mechanical strength.

Laminated structures are applied to wood resource materials and boards to improve their strength or decorativeness. For example, veneer-overlaid and hardboard-overlaid particleboard are seen commercially,[2,3] although these composite panels must be of relatively high density to satisfy strength requirements. The average density of veneer-overlaid particleboard (0.66 g/cm^3)[1] is higher than that of plywood (0.50 g/cm^3).[1] Lightweight overlaid constructions from wood-based materials are also marketed, but they are usually designed for decorative and nonstructural use.[4]

Structural components made up of a lightweight core overlaid with two stiff, strong faces are known as sandwich panels.[5,6] This study aimed to develop low-density, high-strength sandwich panels for structural use using fibers for the core and veneers for the faces. This type of panel (i.e., veneer-overlaid low-density fiberboard) is also expected to have good thermal and sound insulation properties because of the low-thermal conductivity of low-density fiberboard and sandwich construction, respectively.

This paper discusses the effects of board density, veneer thickness, and resin content on the fundamental board properties, such as mechanical, dimensional, thermal, and sound insulation performances, compared to the low-density fiberboard manufactured in a previous study.[7]

Experiment

Manufacture of low-density sandwich panels

Veneer-overlaid low-density fiberboard (i.e., sandwich panels) of 370 × 360 × 12 mm with densities ranging from 0.30

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to 0.50 g/cm^3 were manufactured. The fibers commercially produced from yellow cedar (*Chamaecyparis nootkatensis* Spach.) using a pressurized single-disk refiner (PSDR) were used as raw material. The average length and width of fibers were 14.0 and 0.253 mm, respectively.[7] The moisture content of fibers in the air-dried condition was 11%. The density of the fiber[8] was estimated to be 0.50 g/cm^3.

The fibers were loosened with a sample-carding machine and then sprayed with a corresponding amount of adhesive using a newly designed laboratory scale air-cyclic pipeline blender.[9] Polymeric methylene diphenyldiisocyanate (MDI) resin adhesive (UL-4811) was formulated by Gun-ei Kagaku Kogyo Co. The resin contents of the core were 10% and 30% resin solids of isocyanate based on the oven-dried fiber weight. Though 30% resin content may be considered rather high, the improved effect of a higher resin content on the property of low-density fiberboard with a lower compaction ratio was investigated. Acetone equal to 60% and 20% of resin weight was added to the resin in the case of 10% and 30% resin contents, respectively, to obtain a suitable quantity and viscosity for efficient spraying.

The glue-furnished fibers were formed into mats using a newly designed laboratory scale fibermat former.[9] The same type of resin was spread using a roller on the loose side of the veneer face at 75 g/m^2 solid basis. Acetone, 30% of resin weight, was added to obtain suitable viscosity and quantity. The veneers were overlaid in a parallel direction on the top and bottom faces of the fibermat. Three types of rotary veneer from red meranti (*Shorea* spp.) were used with thicknesses of 0.55, 1.0, and 2.0 mm; their density was 0.47 g/cm^3.

The veneer-overlaid fiber mats were pressed into boards during one-shot steam injection pressing with a steam pressure of 0.63 MPa at 160°C. Total pressing time was 3 min including a 2.5-min steam injection for all boards. The top and bottom surfaces of the veneer-overlaid fiber mats were covered with glass fiber-reinforced Teflon net sheets, which prevent sticking to press platens while allowing free flow of steam. The sides were sealed with a 12 mm thick stainless steel frame. All of the 18 boards produced were stabilized to equilibrium conditions at ordinary room temperature and humidity.

Property testing

The mechanical properties of veneer-overlaid low-density fiberboard (i.e., sandwich panels) were tested basically according to Japanese Industrial Standards (JIS A 5908) with a modification of sample width for the bending test. The static bending test under dry and wet conditions (test B: boiling for 2 h and further soaking in water of ordinary temperature for 1 h) was conducted on 220 × 25 × 12 mm test pieces in parallel and perpendicular directions to the grain of veneer at a test span of 180 mm. There were four test pieces, three for parallel and perpendicular bending in the dry condition, respectively, and two for the wet condition from each board. The moduli of rupture (MOR) and elasticity (MOE) were calculated. Internal bond (IB) tests were conducted on four 50 × 50 × 12 mm test specimens from each board.

The compressive MOE in the thickness direction of the sandwich panels was tested on an 84 mm diameter 12 mm thick specimen for each board by the vibration method[10] in accordance with JIS K 6394. Specimens were fixed with the double-side adhesive sheets to the vibrating plate propped on a vibration exciter. An iron disk (76 mm diameter, 3 mm thick) was fixed on top of the specimen in the same manner. The accelerometer was attached with wax at the center of the iron disk. The compressive MOEs were determined from the resonance frequency using a fast Fourier transform (FFT) analyzer.

The change in the thickness of sandwich panels under the accelerated weathering condition was tested on four 50 × 50 × 12 mm specimens. The test order was as follows: air drying at 20°C and 60% relative humidity (RH) (AD), cold water soaking at 20°C for 24 h (W1), oven drying at 60°C for 24 h (OD), hot water soaking at 70°C for 24 h (W2), OD, AD, boiling for 2 h and cold water soaking at 20°C for 1 h (W3), OD, and AD. The thickness of the boards after each stage was measured and the thickness changes were calculated based on the board thickness at the initial air-dried condition.

The linear expansion (LE) parallel to the grain of the overlaid veneer, thickness swelling (TS), and equilibrium moisture content (EMC) of two 220 × 25 × 12 mm specimens from each board were measured after the moisture absorption and desorption processes. For the moisture absorption process, oven-dried specimens were put in a desiccator at 20°C and exposed to circulating air at constant RH until the boards attained EMC. The RH in the desiccator was kept constant at 33%, 67%, and 98% successively by saturated solutions of $MgCl_2$, $CoCl_2$, and $CaSO_4$, respectively. The moisture desorption process was conducted using the same solutions with the corresponding RH, but in reverse order and then were oven-dried.

The thermal conductivity of sandwich panels were tested on an air-dried 50 × 50 × 12 mm specimen from each board at 6%–7% moisture content in accordance with the American Society for Testing Materials (ASTM C 518-76).

Normal incident sound absorption coefficients of sandwich panels were tested on an 84 mm diameter 12 mm thick specimen in accordance with JIS A 1405 (test for sound absorption of materials by the tube method). The standard sound frequency range (100–2000 Hz) was used in the test.[11]

Results and discussion

Mechanical strength of low-density sandwich panels

Figure 1 shows dry MOR and MOE of veneer-overlaid low-density fiberboard, that is, sandwich panels compared to those of low-density fiberboards manufactured in the same manner and size[7] using the same fiber with the core of sandwich panels. The MOR and MOE were shown in relation to board density, because the core density of sandwich

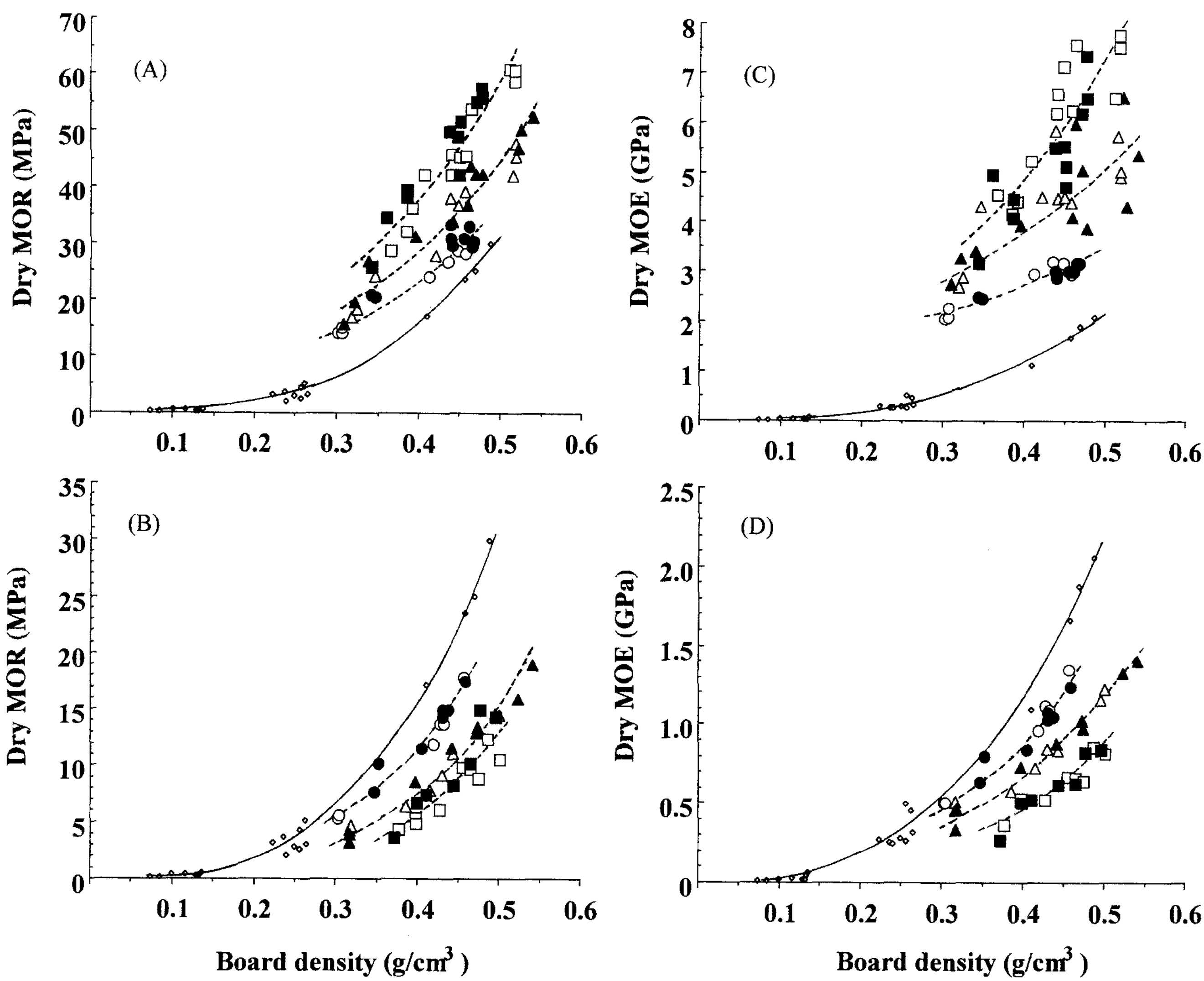

Fig. 1. Dry bending properties of sandwich panels and low-density fiberboards. Dry MOR in parallel (**A**) and perpendicular (**B**) directions and dry MOE in parallel (**C**) and perpendicular (**D**) directions. Veneer thickness of sandwich panels are 0.55 mm (*circles*), 1.0 mm (*triangles*), and 2.0 mm (*squares*). Core layer resin contents of sandwich panels are 10% (*open symbols*) and 30% (*filled symbols*). *Small diamonds*, low-density fiberboard

panels was almost as same as the board density within the density range. When the board density was less than, equal to, and more than 0.47 g/cm^3, the core density was a little less than, equal to, and more than the board density, respectively, assuming the face density is 0.47 g/cm^3. This trend was more obvious in the panel with thicker veneer.

The bonding strength between the core and face of sandwich panels was sufficiently high, and no failure at the interface between the core and veneer was observed during any of bending tests. The effect of resin content of sandwich panels was negligible, in contrast to that in fiberboard,[7] because the faces were used to carry the loads in a sandwich construction. The regression curves were calculated regardless of resin contents but taking into account the veneer thickness.

As shown in Fig. 1A, the dry MOR of sandwich panels in the parallel direction showed values much superior to those for fiberboard. The sandwich panels overlaid with thicker veneer showed higher MORs. The parallel MOR of sandwich panels with 2.0 mm thick veneer at a density of 0.4–0.5 g/cm^3 showed values as high as 40–60 MPa, which were more than twice as high as those of homogeneous fiberboard (15–30 MPa). According to these values, sandwich panels are viable for structural use. The specific MORs (MOR/density) of sandwich panels were 100–110 MPa/(g/cm^3) and were equal to or even greater than those of commercial plywood: 100 MPa/(g/cm^3), assuming that the average MOR of plywood with a density of 0.5 g/cm^3 is 50 MPa.[1] The specific MORs of sandwich panels were also greater than those of other wood-based composite panels with higher density, as the specific MOR, from high to low, of commercial panels is generally plywood, veneer-overlaid particleboard, OSB, WB, and particleboard.[1]

At a density of 0.45 g/cm^3, the parallel MOR of board overlaid with 0.55, 1.0, or 2.0 mm thick veneer was 30, 35, or 50 MPa, respectively, which was 1.5–2.5 times higher than that of fiberboard (20 MPa). At a density of 0.35 g/cm^3, the parallel MORs of sandwich panels were around 20–30 MPa, which is 2.0–2.5 times higher than that of fiberboard. This improvement effect of veneer-overlaid fiberboard was generally similar to the results of the theoretical simulation on 20 mm thick chipboard with 0.65 g/cm^3 density, where the MOR improved more than twofold when 1.5 mm thick veneer was overlaid.[12]

The effect of thickening face veneers on strength was less obvious in lower-density sandwich panels. With decreasing board density, the rate of decreasing the MOR of panels with thicker veneer was higher than that with thinner veneer, because the rate of decreasing core density of panels with thicker veneer is even higher than that of thinner veneer, as mentioned above. This means that lowering the density of board and retaining high strength is more difficult in panels with thick veneers.

Whereas the panels of high density (more than 0.4 g/cm^3) exhibited tensile failure at the bottom veneer surface during static bending in the parallel direction, panels with a density of less than 0.4 g/cm^3 experienced preceding horizontal shear failure in the core because of the lower shear strength in the core in lower-density panels. Further analysis of the stress distribution of sandwich panels in relation to bending failure can optimize sandwich construction.

According to the parallel MOR of sandwich panels, a board density of more than 0.3 g/cm^3 is required, and 10% resin content is enough for structural use. These results can be applied to manufacturing thick low-density sandwich panels for structural use.

As shown in Fig. 1B, the dry MORs of sandwich panels in the perpendicular direction satisfy the requirements for structural use, even though showing lower values in the panel with thicker veneers and similar to or less than those of homogeneous fiberboards. The tensile failure at the bottom veneer surface was observed in almost all of the boards during perpendicular bending. The bending failure occurred more easily in parallel to the grain of the surface in sandwich panels than in fiberboards. The panels with a thicker veneer had more anisotropy because thicker veneer has more anisotropy. This defect can be improved by using plywood or isotropic surface materials instead of veneers.

Figure 1C,D shows parallel and perpendicular MOEs, respectively, of sandwich panels in the dry condition. The dry MOE in parallel and perpendicular directions of sandwich panels with 2.0 mm thick veneer at densities of 0.4–0.5 g/cm^3 were 5–8 GPa and 0.5–0.9 GPa, respectively, which were 4.0 and 0.5 times as much as those of homogeneous fiberboards. The effect of thickening the face veneers on MOE and anisotropy was more prominent than on MOR in the parallel and perpendicular directions. At a density of 0.45 g/cm^3, the parallel MOEs of panels using 0.55, 1.0, and 2.0 mm thick veneers were 3.0, 4.5, and 6.0 GPa, which were two, three, and four times as high as that of fiberboard (1.5 GPa). The parallel MOEs of panels satisfy the requirement for structural use. According to the perpendicular MOE of panels, the board density of panels overlaid with 0.55, 1.0, and 2.0 mm thick veneers require more than 0.3, 0.35, and 0.4 g/cm^3, respectively, for structural use.

Figure 2 shows wet MORs and MOEs of sandwich panels in parallel and perpendicular directions. The effects of resin content on these properties were negligible, and the regression curves were calculated regardless of resin contents, although the veneer thickness was taken into account. The trends of the effects of thickening veneers and anisotropy in the wet condition were similar to those in the dry condition. The difference between the MOE values of panels with 0.55 and 1.0 mm thick veneers was less significant in the wet condition than in the dry condition. During the wet bending test horizontal shear failure or a local dimple on the compression face into the core were observed in boards in the parallel direction, and tensile failure at the bottom veneer surface was observed in the perpendicular direction. The MORs and MOEs in the wet condition were more than or as half as those in the dry condition, and satisfied the requirements for structural use. The water resistance of sandwich panels was good even under the hard condition.

Figure 3 shows the IB of sandwich panels and fiberboards in relation to board density. As the bonding strength between the core and face are sufficiently high, no failure at the interface between the core and veneer was observed for any of the IB tests. The IBs of sandwich panels were almost the same as those of fiberboard because IB depends much on the compaction ratio of board[7,13,14] and hence on the core density of the sandwich panel. The effect of resin content on IB was observed in higher-density sandwich panels. The density of the sandwich panels must be more than 0.35 g/cm^3 so that it has the required IB strength of 0.3 MPa for structural use; 10% resin content is enough. The IB of panels with board density of around 0.3 g/cm^3 was less than that of fiberboards at the same density because the core density of sandwich panels were a little less than fiberboards for lower-density panels, as mentioned above.

As shown in Fig. 4, the compressive MOE in the thickness direction of sandwich panels with a mean board density of 0.40 g/cm^3 showed almost the same values regardless of the surface thickness. The compressive MOE of sandwich panels were the same as those of fiberboards at the same density and much superior to those of commercial thermal insulation materials[7] such as fiberglass wool, rock wool, and flexible polyurethane foam.

Dimensional stability of low-density sandwich panels

Figure 5 shows the thickness changes of sandwich panels with a mean board density of 0.40 g/cm^3 under accelerated weathering conditions. The dimensional stability of these panels was excellent, as the final thickness of the panels after the test was almost the same as the original thickness. Springback was rarely observed. The thickness swelling (TS) of sandwich panels of 10% and 30% resin content levels were less than 7% and 5% after condition W1 (soaking in 20°C water for 24 h), less than 10% and 7% after condition W2, and less than 11% and 8% even after condition W3, respectively.

The TS of sandwich panels were superior to those of homogeneous fiberboards,[7] as the TS of the fiberboards

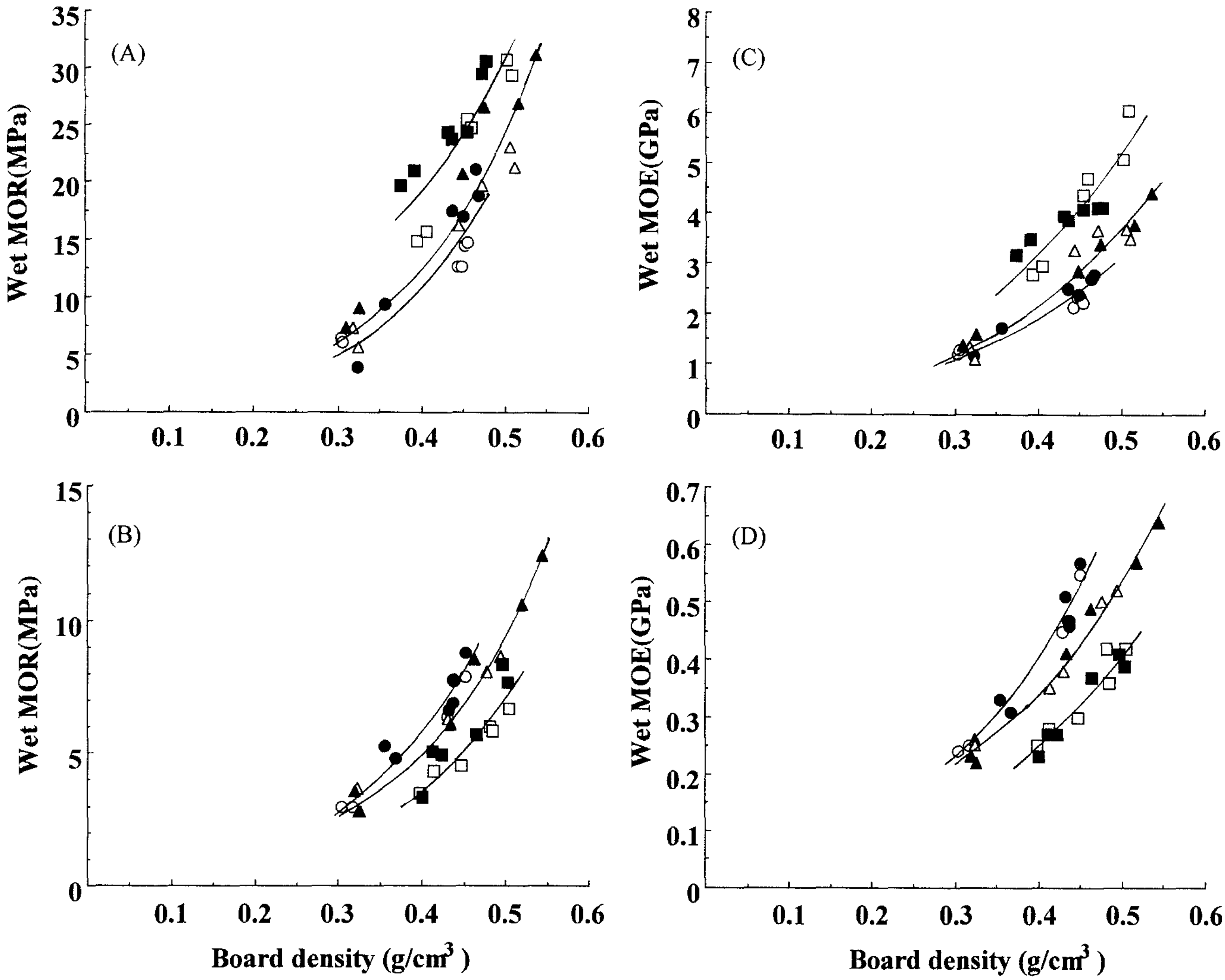

Fig. 2. Wet bending properties of sandwich panels. Wet MOR in parallel (**A**) and perpendicular (**B**) directions and wet MOE in parallel (**C**) and perpendicular (**D**) directions. Veneer thicknesses of sandwich panels are 0.55 mm (*circles*), 1.0 mm (*triangles*), and 2.0 mm (*squares*). Core layer resin contents of sandwich panels are 10% (*open symbols*) and 30% (*filled symbols*)

with a density of $0.4\,g/cm^3$ with 30% resin content level were less than 6% and 9% after conditions W1 and W2, respectively. The sandwich panels with thicker veneers showed less TS because the smaller amount of compacted core fiber caused less swelling in these boards. The effect of board density on the TS of sandwich panels was less obvious within the density range, whereas the TS of fiberboards was increased with an increase in density. Generally, increasing the board density causes a high compaction ratio and less water absorption of elements by the board. The TS of fiberboard was directly affected by a high compaction ratio. In sandwich panels, on the other hand, the smaller amount of core fiber caused less swelling, and the surface veneer and bonding layer resisted the swelling of core fibers.

Figure 6 shows the LE and TS of sandwich panels with a mean board density of $0.40\,g/cm^3$ during the moisture absorption and desorption processes in relation to the RH. The residual LE and TS after the cycle were negligible. There was no significant effect of resin content on these properties.

The panels with thicker veneers showed lower LE and less obvious hysteresis of LE. At a density of $0.4\,g/cm^3$ and 30% resin content, the LE of panels with 2.0 mm thick veneers were two-thirds as high as that with 0.55 mm veneers; the LE of the panels with the thicker veneers were 0.1%, 0.16%, and 0.21% in 33%, 67%, and 98% RH during the absorption process, respectively, whereas those of the thinner veneers were 0.14%, 0.24%, and 0.31%, respectively.

The LEs of all sandwich panels were less than half that of homogeneous fiberboard at the same density. In the previous study[7] the average LEs of fiberboard with a density of $0.4\,g/cm^3$ and 30% resin content were 0.3%, 0.5%, and 0.8% in 33%, 67%, and 98% RH, respectively. At higher RH, the LEs of sandwich panels showed a much lower value, 0.2%, which was one-fourth that of fiberboard. The core fibers were fixed to the veneer surfaces by resin adhesives. The expansion of the core fiber layer was restrained by the overlaid veneer, which has negligible expansion along the fibers. The LE of panels during the desorption process

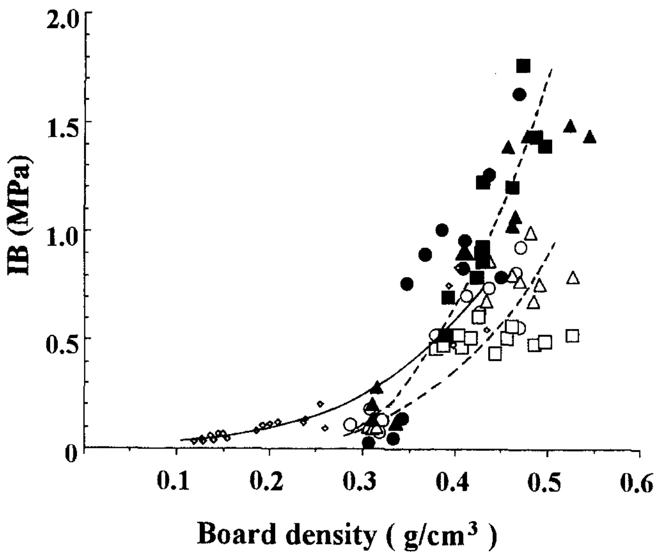

Fig. 3. Internal bond strength of sandwich panels and low-density fiberboards. Veneer thickness of sandwich panels are 0.55 mm (*circles*), 1.0 mm (*triangles*), and 2.0 mm (*squares*). Core layer resin contents of sandwich panels are 10% (*open symbols*) and 30% (*filled symbols*). *Small open diamonds*, low-density fiberboard

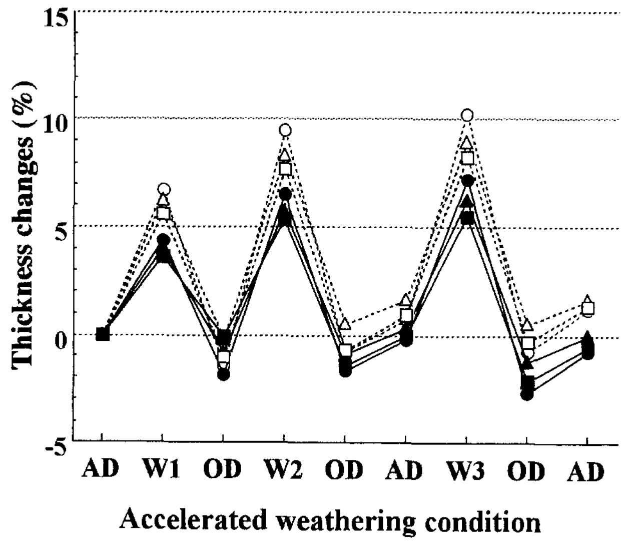

Fig. 5. Thickness changes of sandwich panels with the mean density of 0.4 g/cm³ under accelerated weathering conditions. Veneer thicknesses of sandwich panels are 0.55 mm (*circles*), 1.0 mm (*triangles*), and 2.0 mm (*squares*). Core layer resin contents of sandwich panels are 10% (*open symbols*) and 30% (*filled symbols*). *AD*, air drying at 20°C and 60% RH; *W1*, cold water soaking at 20°C for 24 h; *OD*, oven drying at 60°C for 24 h; *W2*, hot water soaking at 70°C for 24 h; *W3*, boiling for 2 h and cold water soaking at 20°C for 1 h

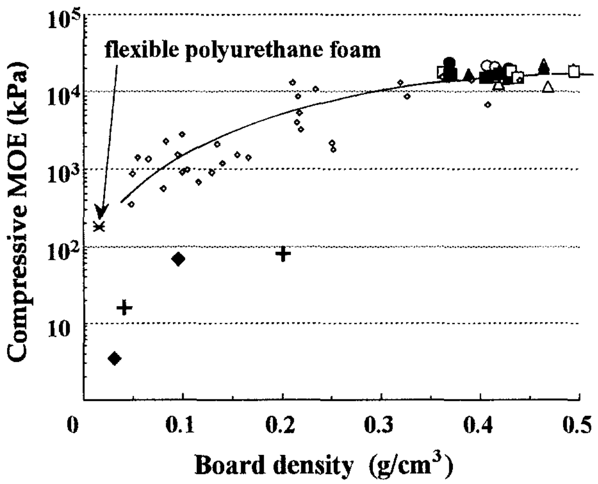

Fig. 4. Compressive MOE in the thickness direction of sandwich panels and other materials. Veneer thickness of sandwich panels are 0.55 mm (*circles*), 1.0 mm (*triangles*), and 2.0 mm (*squares*). Core layer resin contents of sandwich panels are 10% (*open symbols*) and 30% (*filled symbols*). *Small open diamonds*, low-density fiberboard, *filled diamonds*, fiberglass wool; *cross*, rock wool

was similar to or less than that during the absorption process, in contrast to the LE of fiberboard of 0.4 g/cm³, whose LE was higher during the desorption process than during the absorption process.

The TS of panels with thicker veneers were somewhat lower during the moisture absorption and desorption processes because of the smaller amount of core fiber, causing less swelling in these panels. The TS of panels were higher during the desorption process than during the absorption process.

The EMC of all sandwich panels within the density range were about 6%, 10%, and 22% under 33%, 67%, and 98% RH, respectively. These EMC values were almost the same as or a little more than those for fiberboard.

Thermal insulation properties of low-density sandwich panels

Figure 7 shows a comparison between the thermal conductivity (λ) of low-density sandwich panels and that of some other materials.[15–17] The λ of low-density sandwich panels within the density range were low, from 0.05 to 0.08 kcal/mh °C, which is much lower than those for commercial plywood, particleboard, and hardboard with a higher density. The λ of sandwich panels depends more on density than on the structure and is equivalent to those of fiberboard at the same density. There was no significant difference in the λ of these sandwich panels even at different orientations of the veneer.

The λ of wood composites is also affected by moisture content, as the λ of water at a temperature range of 0°–20°C is about 0.50 kcal/mh °C. In a previous study on the relation between λ and the moisture content of wood within a density range of 0.20–0.50 g/cm³, the variation in λ was only about 0.01 kcal/mh °C when the moisture content changed from 0% to 10%.[18] For particleboard with a density ranging from 0.4 to 0.9 g/cm³, λ is almost constant when the moisture content changes from 0% to 20%.[19] Because the densities of sandwich panels in this experiment were low and their moisture contents were 6%–7%, the moisture content had a minimal effect on λ. The effects of material temperature

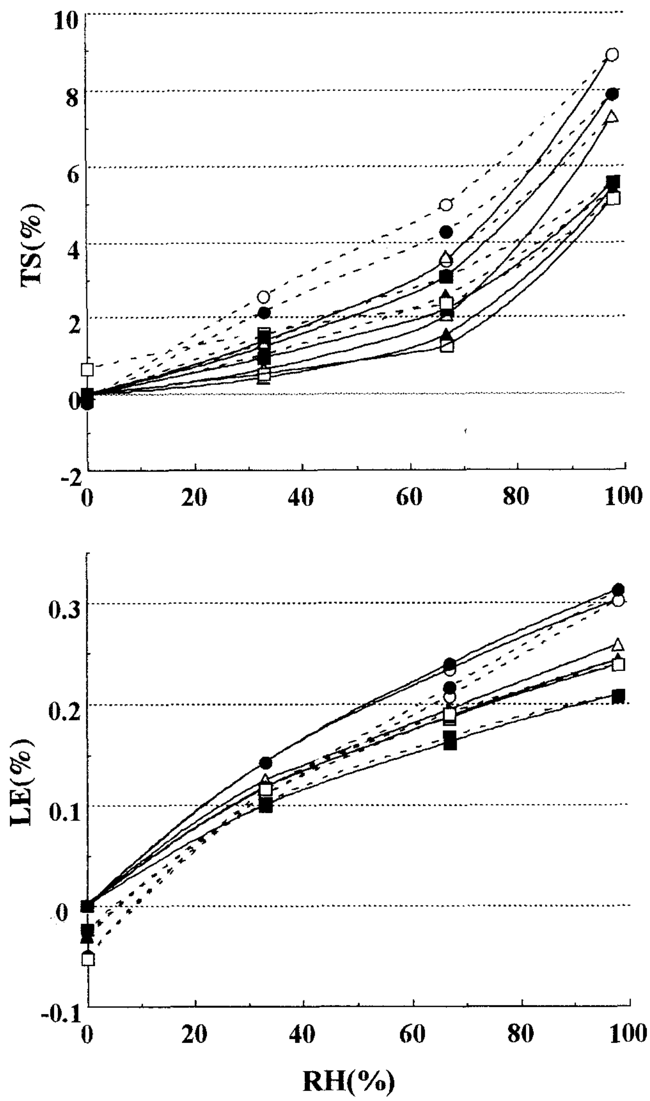

Fig. 6. Linear expansion (LE) and thickness swelling (TS) of sandwich panels with a mean density of $0.4\,g/cm^3$ in relation to the relative humidity (RH) during moisture absorption (*solid lines*) and desorption (*dotted lines*) processes. Veneer thickness of sandwich panels are 0.55 mm (*circles*), 1.0 mm (*triangles*), and 2.0 mm (*squares*). Core layer resin contents of sandwich panels were 10% (*open symbols*) and 30% (*filled symbols*)

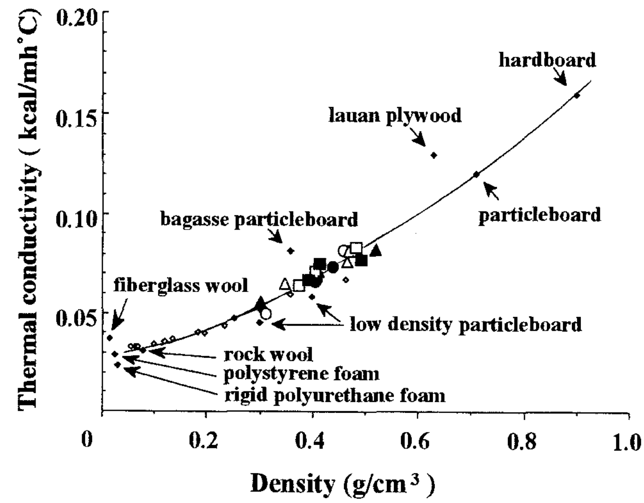

Fig. 7. Thermal conductivity of sandwich panels and other materials. Veneer thicknesses of sandwich panels were 0.55 mm (*circles*), 1.0 mm (*triangles*), and 2.0 mm (*squares*). Core layer resin contents of sandwich panels were 10% (*open symbols*) and 30% (*filled symbols*). *Small open diamonds*, low-density fiberboard

and resin content on λ are less significant than that of moisture content.[19,20]

The thermal diffusivity of a material is characterized by the ratio of heat transport within the material, which is calculated from the thermal conductivity divided by the volumetric specific heat. A low value means better thermal insulation.

The specific heat of wood or fiberboards with a density range of $0.40–0.80\,g/cm^3$ is estimated[18] to be 0.42. Using this value for calculations, the thermal diffusivity of the sandwich panels are 0.00040 and $0.00038\,m^2/h$ at densities of 0.30 and $0.50\,g/cm^3$, respectively. These are only 0.03 to 0.20 times as much as those of fiberglass wool, polystyrene foam, rigid polyurethane foam, and rock wool, whose thermal diffusivities are 0.012, 0.0039, 0.0026, and $0.0019\,m^2/h$, respectively,[15] and less than that of plywood ($0.00049\,m^2/h$).[16]

Lower-density panels show somewhat higher thermal diffusivity, a finding that appears contrary to the general tendency that thermal diffusivity decreases with a decrease in the density of the material. This is because the thermal conductivity approaches a constant value of 0.02 kcal/m h °C of dry air at 20°C, when the core density largely decreases.

It can be concluded that low-density sandwich panels are excellent materials for thermal insulators. This is in addition to their superior strength compared to that of common insulation materials such as fiberglass wool and polystyrene foam.

Sound absorption properties of low-density sandwich panels

The sound absorption coefficients of sandwich panels were almost zero, whereas those of fiberboard were high.[7] This means that the sound was not absorbed by the plate vibration of veneer and may have been reflected off the surface of the veneer. Hence these sandwich panels may be excellent sound insulation material. Though the sound insulation property of high-density boards such as particleboard is generally good, sandwich construction panels are advantageous for sound insulation considering their light weight. The sound insulation performance of sandwich panels must be investigated.

Conclusions

Sandwich panels of veneer-overlaid low-density fiberboard with densities ranging from 0.30 to $0.50\,g/cm^3$ can be manufactured effectively by one-shot steam injection pressing technology using an isocyanate resin adhesive. These lightweight sandwich panels of veneer-overlaid fiberboard are environmentally friendly with many-functions, such as good dimensional stability, high mechanical properties, and good thermal and sound insulation performance. For structural use of these sandwich panels, a board density of more than $0.35\,g/cm^3$ is required with 10% resin content being sufficient. The anisotropy of mechanical properties can be improved by overlaying with some isotropic surfaces.

These results can be applied on the manufacturing of thick (100mm) low-density sandwich panels intended for structural use, for example as assembled wood composite wall with good thermal insulation. Such additional properties as shear strength, screw withdrawal resistance, and dimensional stability in terms of expansion or warping in the plane direction under water absorbing conditions will be determined in a future study.

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