LIGHTWEIGHT SANDWICH PANEL FROM OIL PALM WOOD CORE AND RUBBERWOOD VENEER FACE

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SRIVARO S, CHAOWANA P, MATAN N & KYOKONG B. 2014. Lightweight sandwich panel from oil palm wood core and rubberwood veneer face. Low-density sandwich panels with a density ranging from 400 to 450 kg m^{-3} were manufactured from oil palm wood for the core and were overlaid with rubberwood veneer. Physical and mechanical properties of the sandwich panel were investigated and compared with commercial wood-based products. Two manufacturing parameters were examined, i.e. two types of grain orientation of the oil palm wood core (parallel and perpendicular to board surface) and three levels of adhesive melamine urea formaldehyde (MUF) resin content (150, 250 and 350 g m^{-2} solid basis). Results showed that the sandwich panel made from oil palm wood as core material with rubberwood veneer as facing had better or similar properties compared with commercial products. Core grain orientation had significant effect on various board properties such as thickness swelling, modulus of elasticity and thermal conductivity. On the other hand, level of resin content within the range studied did not influence any property of the boards. With regard to mechanical and thermal conductivity properties, oil palm sandwich panel could be used as a structural insulated material in the building sector.

Keywords: Low-density panels, oil palm biomass, core grain orientations, physical and mechanical properties, thermal insulation

SRIVARO S, CHAOWANA P, MATAN N & KYOKONG B. 2014. Panel apit ringan berteras kayu kelapa sawit dan muka venir kayu getah. Panel apit berketumpatan rendah antara 400 kg m^{-3} hingga 450 kg m^{-3} dihasilkan menggunakan kayu kelapa sawit sebagai teras dan dilapisi dengan venir kayu getah. Ciri-ciri fizikal serta mekanik panel apit dikaji dan dibandingkan dengan produk berasaskan kayu komersial. Dua parameter dikaji iaitu dua jenis haluan ira teras kayu kelapa sawit (selari dan menegak ke permukaan papan) dan tiga kepekatan kandungan resin perekat formaldehid urea melamina (MUF) (150 g m^{-2}, 250 g m^{-2} dan 350 g m^{-2}). Keputusan menunjukkan bahawa panel apit yang dibuat daripada kayu kepala sawit sebagai teras serta venir kayu getah sebagai muka mempunyai ciri-ciri yang lebih baik atau serupa dengan produk komersial. Haluan ira teras mempunyai kesan signifikan terhadap ciri- ciri papan seperti ketebalan bengkak, modulus kekenyalan dan kebolehaliran terma. Sebaliknya, kepekatan kandungan resin dalam kajian ini tidak mempengaruhi mana-mana ciri papan. Dari segi ciri kebolehaliran terma, papan apit kayu kelapa sawit dapat diguna sebagai bahan struktur tertebat dalam sektor pembinaan.

INTRODUCTION

Oil palm tree is one of the most important economic crops in South-East Asian countries It is used in the commercial production of palm oil. In Thailand in particular, the area of oil palm plantations had increased from 2300 km^2 in the year 1998 to about 6700 km^2 in the year 2012 partly because of the Thai government's proposal to use crude palm oil as raw material for biodiesel production (Anonymous 2012) After 25 to 30 years of age, palm oil production has become uneconomical and these trees are felled and new trees are planted. Even though oil palm wood is available in large amounts throughout the year, this material has not been fully utilised due to great variations in physical and mechanical properties (Lim & Khoo 1986), which have caused many difficulties in using the wood for applications.

Oil palm is a monocotyledon species, which exhibits great variation in density values at different parts of its stem. Density values range from 200 to 600 kg m^{-3} with an average density of 370 kg m^{-3}. Mechanical properties of oil palm wood reflect the density variation observed in

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the trunk both in horizontal as well as in the vertical direction (Lim & Khoo 1986, Haslett 1990). The use of oil palm wood should focus on effective utilisation of various properties related to such low density. Using oil palm wood as the core of lightweight sandwich panel is therefore of interest to have a high strength-to-weight ratio and low heat conduction.

A sandwich panel is a panel made up of a lightweight and thick core overlaid with two thin facings (Allen 1969, Zenkert 1997). Usually, the thin facings are made of strong and dense material because they have to bear nearly all of the applied edgewise-loads and flatwise-bending moments (Moody et al. 1999). The core, which is made of weak and low density material, separates and stabilises the thin facings and provides most of the shear rigidity of the sandwich construction. Normally, honeycomb, balsa or foam can be used as the core. They can reduce weight and increase strength (Ashby et al. 2000, Gibson & Ashby 1997).

The aim of this study was to develop a low-density sandwich panel using oil palm wood as core overlaid with rubberwood veneer for structural uses. Fundamental physical, mechanical and thermal insulation properties related to the grain direction of oil palm core and resin content were investigated. Results were compared with commercial wood-based products and previous research.

MATERIALS AND METHODS

Materials

Commercially peeled rubberwood veneers from 25–30 years old rubber trees were obtained from Phang-Nga Timber Industries Co., Ltd. in Phang-Nga, Thailand and used as the face of the sandwich panels. Density and thickness of the veneers were 630 ± 46 kg m^{-3} and 2.7 ± 0.2 mm respectively. They were placed in a conditioning room at 20 °C with relative humidity of 65%. Final average moisture content was 12% at the time of the glue spreading.

Oil palm trunks (25 years old) were collected from a plantation located in Surat Thani and transported to the Wood Science and Engineering Research Unit of Walailak University. Oil palm sawn timber was dried in the laboratory drying kiln at dry-bulb and wet-bulb temperatures of 70 and 50 °C respectively to a final moisture content of 8%. Two types of oil palm wood core were prepared according to the grain direction, namely, parallel to the flat plane orientation with dimensions of 13 cm (longitudinal direction) × 13 cm (tangential direction) × 20 mm (radial direction) and perpendicular to the flat plane orientation with dimensions of 13 cm × 13 cm (cross-section) × 20 mm (longitudinal direction) as presented in Figure 1 (a) and (b) respectively. Average density of the core material was 323 ± 22 kg m^{-3}. Both sides of the flat planed oil palm wood pieces were abraded with rough 40 grit sandpaper to achieve a final thickness of 14.6 mm. Residual sanding dust on the wood surface was removed by blowing with dry compressed air. All specimens were placed in a conditioning room at a temperature of 20 °C and relative humidity of 65% to achieve a final average moisture content of 12% at the time of board manufacturing.

Melamine urea formaldehyde adhesive (MUF: code number 14L698) was used to bond the face and the core layers. Properties of the adhesive used are presented in Table 1.

Production of the sandwich panels

Oil palm wood pieces having similar grain direction were bonded together side by side with polyvinyl acetate adhesive to achieve a core of 260 mm (width) × 520 mm (length) × 14.6 mm (thickness). MUF resin was blended following the supplier's suggestion and spread onto one surface of the rubberwood veneer sheets using a hand brush. Three levels of resin contents (150, 250 and 350 g m^{-2} solid basis) were used on the single glue surface. Two veneers were overlaid in parallel directions at the top and bottom of the oil palm core. Two types of panels were fabricated in this experiment according to grain direction of oil palm core, namely board with core grain direction oriented parallel to the surface (PR, Figure 2a) and board with core grain direction oriented perpendicular to the surface (PP, Figure 2b).

After lay-up, the assembled mats were transferred to a single-opening hydraulic laboratory hot press (60 cm × 60 cm) and pressed into boards having final thickness of 20 mm. Three replications were performed in each treatment. In this study, 18 boards were produced by employing a pressing temperature of 160 °C at 2 MPa for 5 min.

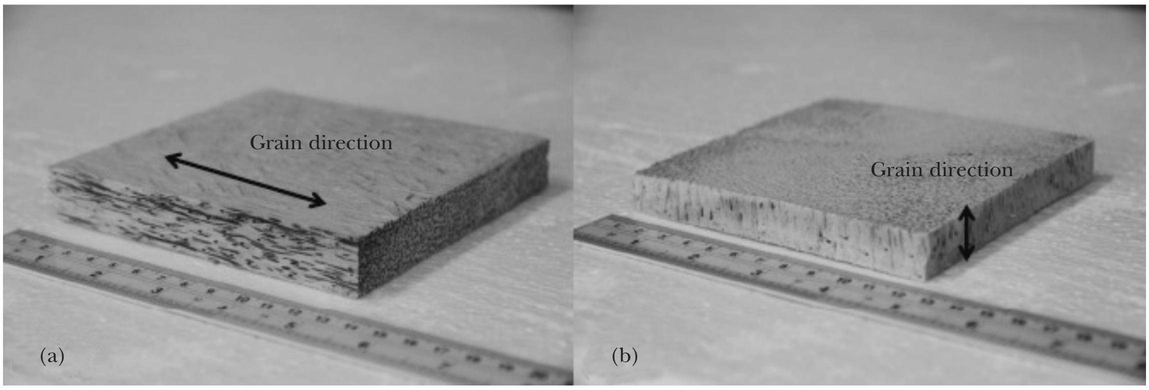

Figure 1 Grain orientations of oil palm wood specimens (a) parallel and (b) perpendicular to the flat plane

Table 1 Work properties of the melamine urea formaldehyde adhesive used in the study

Property	Detail
Appearance	Milky white liquid
Solid content	55.2%
pH value at 30 °C	9.36
Viscosity at 30 °C	190 cps
Density at 30 °C	1.21 g cm^{-3}

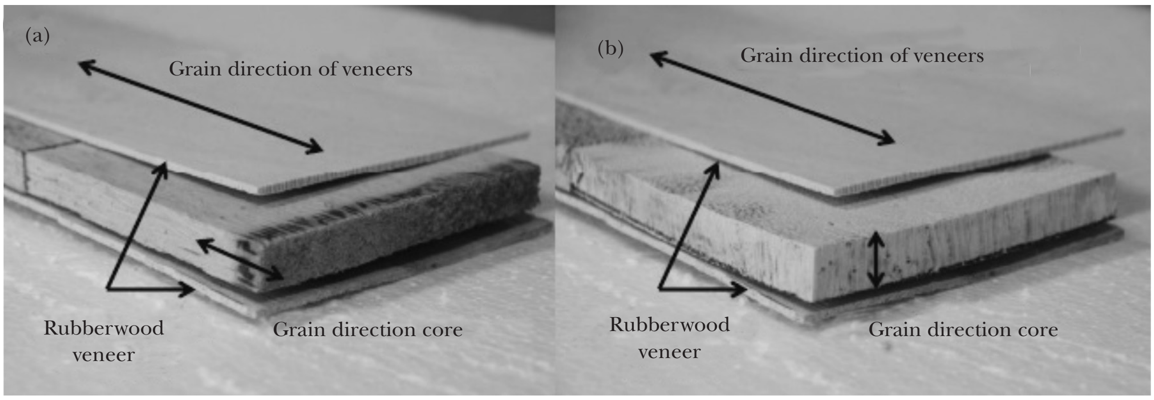

Figure 2 Sandwich panel composed of two sheets of rubberwood veneer and oil palm core having different grain directions (a) parallel and (b) perpendicular

Physical and mechanical properties

The produced sandwich boards were machined into test specimens and placed in a conditioning room maintained at 65% relative humidity and 20 °C for at least 4 weeks until a constant weight was attained. The following properties of the sandwich boards were determined:

(1) density was measured from specimens with dimensions of 50 mm (width) × 50 mm (length) × 20 mm (thickness) following EN 323 (European Standard 1993c)

(2) thickness swelling and water absorption were measured from specimens with dimensions of 50 mm (width) × 50 mm (length) × 20 mm (thickness) by immersion in water at 20 °C for 24 hours in accordance with the EN 317 (European Standard 1993b) and ASTM D1037-12 (ASTM 2012) respectively

(3) thermal conductivity was measured from specimens with dimensions of 190 mm (width) × 190 mm (length) × 20 mm (thickness) in accordance with the ASTM C177-10 (ASTM 2010) using thermal conductivity analyser

(4) modulus of rupture (MOR) and modulus of elasticity (MOE) were determined by three-point static bending test on specimens with dimensions of 50 mm (width) × 500 mm (length parallel to the veneer grain direction) × 20 mm (thickness) in accordance with EN 310 (European Standard 1993a) using a 150 kN Universal testing machine
(5) screw withdrawal resistance was determined for both face and edge sides from specimens with dimensions 75 mm (width) × 75 mm (length) × 20 mm (thickness) in accordance with EN 320 (European Standard 2011) using a 150 kN Universal testing machine.

Effects of the two core grain directions and the three resin contents on properties of the boards were evaluated by analysis of variance (ANOVA) at 0.01 and 0.05 levels of significance. Duncan's range tests were conducted to determine significant differences between mean values.

RESULTS AND DISCUSSION

Average values of physical and mechanical properties of the sandwich panels are shown in Table 2. ANOVA results for the physical and mechanical data are illustrated in Table 3.

Density

Board density ranged from 393 to 424 kg m^{-3} (average 405 ± 32 kg m^{-3}, Table 2). Wood-based panels with density below 500 kg m^{-3} are classified as lightweight materials (Youngquist 1999). This shows that a lightweight panel can be manufactured using oil palm wood as core and rubberwood veneer as faces. This result showed that the different core grain directions and resin contents did not have significant effect on density values of panel (Table 3).

Thickness swelling and water absorption

Dimensional stability of the sandwich panels evaluated by thickness swelling is shown in Table 2. Thickness swelling values observed ranged from 1.9 to 4.6%. Core grain directions significantly affected thickness swelling of the sandwich boards (Table 3). PP boards had lower thickness swelling than PR boards. Thickness swelling values of PP boards (average 2.1 ± 0.8%) were about half that of PR boards (4.0 ± 1.2%). Different grain direction might have caused the different thickness swelling. In general, most of the microfibril orientations in fibre cell walls of oil palm wood are aligned nearly parallel to

Table 2 Physical and mechanical properties of oil palm wood core sandwich panels produced in this study

Sandwich panel	Resin content (g m^{-2})	Physical property				Mechanical property			
		ρ (kg m^{-3})	TS (%)	WA (%)	K (W/mK)	MOR (MPa)	MOE (MPa)	SWR (N) Face	SWR (N) Edge
PR	150	397 (23)	3.8 (0.3)	77 (18)	-	48 (3)	7609 (879)	-	-
	250	415 (23)	3.7 (1.5)	71 (17)	0.08[1]	51 (4)	7732 (484)	637 (159)	546[2] (83)
	350	393 (62)	4.6 (1.5)	81 (17)	-	52 (4)	8458 (929)	-	-
PP	150	424 (52)	2.3 (0.9)	79 (5)	-	52 (2)	7276 (763)	-	-
	250	398 (15)	1.9 (0.8)	82 (21)	0.11[1]	51 (3)	6979 (498)	636 (168)	409[3] (155)
	350	406 (9)	2.1 (0.9)	76 (4)	-	52 (3)	6538 (1226)	-	-

PR = board with core grain direction oriented parallel to the surface, PP = board with core grain direction oriented perpendicular to the surface, ρ = density, TS = thickness swelling, WA = water absorption, K = thermal conductivity, MOR = modulus of rupture, MOE = modulus of elasticity, SWR = screw withdrawal resistance; values are means of three replications with standard deviations in parentheses; [1]measurement was performed on single specimen, [2]screw was drilled into the oil palm core in and across fibre directions, [3]screw was drilled into the oil palm core across fibre direction

Table 3 Variance analysis for properties of oil palm sandwich panel

Source of variation	F value						
	ρ	TS	WA	MOR	MOE	SWR (Face)	SWR (Edge)
Core grain direction	0.21 ns	14.25**	0.11 ns	2.27 ns	19.69**	0.00 ns	0.256 ns
Resin content	0.15 ns	0.39 ns	0.03 ns	1.05 ns	0.14 ns	-	-
Interaction	0.57 ns	0.33 ns	0.42 ns	1.90 ns	4.43*	-	-

ρ = density, TS = thickness swelling, WA = water absorption, MOR = modulus of rupture, MOE = modulus of elasticity, SWR = screw withdrawal resistance;**significant at the 1% level of probability, *significant at 5% level of probability, ns = not significant

the longitudinal axis (Sjöström 1993). Thus, thickness swelling of oil palm wood in the longitudinal direction is less than those in radial and tangential directions. Sulaiman et al. (2012) also reported that radial and tangential swellings of oil palm wood (2.2%) soaked in distilled water were more uniform and were lower than those observed in rubberwood (3.2 and 5.7% in the same directions respectively). Most of the parenchyma cells within the oil palm wood which were roughly spherical in shape with extremely thin walls and a large lumen, contributed more or less to the approximate similarity of the shrinkage/swelling values in both radial and tangential directions. By means of a rule of mixtures and by assuming that thickness swelling of the resin was negligible (Table 3), thickness swelling value of sandwich panel (TS) could be expressed in terms of thickness swellings of the face (TS_f) and of the core (TS_c) as:

$$TS = TS_f f + (1 - f)TS_c \quad (1)$$

where f = volume fraction occupied by the face. For PR boards, by substituting TS_f = 3.2%, TS_c = 2.2% and f = 0.27 into equation 1, thickness swelling value obtained was 2.5%. The calculated thickness swelling value was slightly lower than that observed for PR boards (4.0 ± 1.2%). Additional swelling due to densification in the oil palm wood core after pressing which had not yet been taken into account, should also contribute to the observed thickness swelling value. Nevertheless, equation 1 provided good approximation for thickness swelling of the sandwich boards and the significance of the oil palm wood core which possessed relatively low swelling value. Generally, lower-density board has lower thickness swelling value. However, thickness swelling of the boards in this study was very low compared with southern pine plywood with density of 530 kg m^{-3} (thickness sweling 8.31%). The latter has been successfully produced for structural uses (Biblis & Lee 1984).

Water resistance of the sandwich panel was evaluated by water absorption after 24 hours of soaking (Table 2). Water absorption values ranged from 71 to 82%. However, water absorption was not significantly dependant on the core grain direction and resin content (Table 3). Sandwich panels made from oil palm wood overlaid with rubberwood veneers showed 1.5 and 3.6 times greater water absorption after 24 hours of water immersion compared with sandwich panels made from rice husk particleboard overlaid with European ash strands (Kwon et al. 2012) and medium-density fibreboard laminated with European beech veneer (Büyüksari et al. 2012) respectively. Notably, the oil palm sandwich panels had the lowest density than the other two panels. Water absorption of wood is greater with increasing porosity (Skaar 1972).

Thermal conductivity

Thermal conductivity values for PR and PP boards were 0.08 and 0.11 W mK^{-1} respectively (Table 2). Thermal conductivity is a measure of the material ability to transfer heat which is, in wood, mainly by conduction through the cell wall and by convection of air in cell lumens. Factors affecting heat transfer in wood are density, moisture content, direction of heat flow with respect to the grain and relative density of late wood and early wood (Avramidis & Lau 1992). Thermal conductivity through the sandwich panel in this study depended on heat flow through the oil palm core and through the rubberwood veneer. Since samples had the same rubberwood veneer thickness, density and grain direction, thermal conductivity was therefore determined mainly by grain orientation of the oil palm core. Thermal conductivity in the longitudinal direction of softwood and hardwood species has been reported to be about 2.25–2.75 times greater than that of the transverse direction (Suleiman et al. 1999, Thunman & Leckner 2002). Thermal conductivity value of the PP board in this study was about 1.38 times greater than that of the PR board. This ratio is slightly lower than those reported for softwood and hardwood species (Suleiman et al. 1999, Thunman & Leckner 2002). Thermal conductivity of oil palm wood is, therefore, more isotropic than those of softwood and hardwood. A larger portion of uniform spherical parenchyma cells within oil palm wood (Sulaiman et al. 2012) compared with longitudinally elongated cells in softwood and hardwood had contributed to the lower ratio observed.

Thermal conductivity of the oil palm sandwich panel was comparable with that of structural insulated wall developed using low-density fibreboard core overlaid with red meranti veneer (0.07 W mK^{-1}) (Kawasaki & Kawai 2006). In addition, compared with other insulation materials such as asbestos wool (0.07 W mK^{-1}), polystyrene foam (0.03 W mK^{-1}) and gypsum board (0.17 W mK^{-1}) (Ashby 1992) as well as insulation board (0.06 W mK^{-1}) (Anonymous 1973), the oil palm sandwich panel had good potential as structural insulated panel for use in building construction.

Modulus of rupture and modulus of elasticity

Static bending properties of oil palm sandwich panels are illustrated in Table 2. During the bending test, there was no bonding failure between the face and the core layer as well as along glue lines which joined oil palm pieces together in the core section. So the effects of resin content and glue lines in the oil palm wood core section on bending strength of the board can be ignored (Table 3). All specimens failed with face yielding because the tensile stress in the bottom face exceeded the allowable tensile stress of rubberwood veneer. Hence, bending strength values of PR and PP boards with similar board density and veneer thickness were governed by strength of rubberwood veneer in the bottom face. Grain orientation of the core did not have any effect on bending strength. MOR values of PR and PP boards were 50.5 ± 4.0 and 51.9 ± 2.7 MPa respectively. It showed that the different core grain directions and the resin content did not have significant effect on MOR value.

On the other hand, grain direction of the core influenced MOE value at $p = 0.01$ (Table 3). PR boards had slightly higher MOE value than PP boards. MOE values of PR and PP boards ranged from 7609–8458 MPa and 6538–7276 MPa respectively. In general, stiffness of wood in the transverse direction of grain is lower than that in the parallel direction (Bodig & Jayne 1982). Thus, PR boards could have had higher resistance towards applied transverse load and, hence, the greater MOE value. As with the rest of the properties, MOE was not significantly dependent on resin content (Table 3).

MOR and MOE values of oil palm wood sandwich panels met values of standard plywood (density 400–600 kg m^{-3}), i.e. 33.72–42.61 MPa and 6960–8550 MPa respectively (Cai & Ross 2010). The oil palm sandwich panel showed comparable MOR and MOE values with respect to other lightweight sandwich panels made from low-density fibreboard overlaid with red meranti veneer (40–60 and 5000–8000 MPa respectively, Kawasaki et al. 1999). However, the panels had higher MOR value than foam core material (8 MPa, Shalbafan et al. 2012).

Finally, in order to be used as a structural lightweight panel, the strength to weight ratio should also be considered. Comparison of specific bending strength of oil palm core sandwich panel, low-density fibreboard core sandwich panel (Kawasaki et al. 1999) and standard plywood (Cai & Ross 2010) which were developed for wall and floor applications are listed in Table 4. Oil palm core sandwich panel possessed the highest strength to density ratio. The MOR:density ratio of oil palm core sandwich panel was approximately 1.8 times higher than that of standard plywood. Thus, oil palm core sandwich panel could be used as load-bearing insulated board in dry conditions such as interior fitments or walls.

Screw withdrawal resistance

Screw withdrawal resistance values of oil palm sandwich panel produced in this study are shown in Table 2. Results showed that screw withdrawal resistance of the PR and PP boards were similar in both the face and edge directions. The

Table 4 Comparison of properties of oil palm wood core sandwich panel, low density fibreboard core sandwich panel and plywood

Type	Density (kg m^{-3})	Specific bending strength (MN m kg^{-1})	
		MOR/density	MOE/density
Oil palm wood core sandwich panel[1]	400	0.13	20
Low-density fibreboard core sandwich panel[2]	500	0.12	16
Plywood[3]	600	0.07	14

[1]Current study, [2]Kawasaki et al. (1999), [3]Cai and Ross (2010); MOR = modulus of rupture, MOE = modulus of elasticity

holding strength of screws in the face and edge directions were not significantly dependent on grain direction of the oil palm core (Table 3).

It was also observed that screw withdrawal resistance from the face side was higher than that of the edge side. Different materials in the face and core layers had contributed to the different screw withdrawal resistance observed. Screw withdrawal resistance value increased with increased wood density (Celebi & Kilic 2007). In general, rubberwood showed higher density than oil palm wood. When the screw was inserted in the edge side, it passed only the oil palm wood with the lower density. The portion of screw embedded in rubberwood veneer could improve the screw withdrawal resistance value on the face side. The resistance to axial withdrawal of screws obtained in this work (636 ± 155 N) was higher than that of minimum requirement of fibreboard specifications according to the European Standard EN 622-3 (European Standard 2006).

CONCLUSIONS

Lightweight sandwich panels with density ranging from 400 to 450 kg m^{-3} can be effectively made from oil palm wood for the core and be overlaid with rubberwood veneers using MUF glue. The panels exhibited superior dimensional stability and good mechanical and thermal insulation properties. Thermal conductivity, thickness swelling and MOE were significantly influenced by oil palm wood core grain direction. The sandwich panel made using oil palm wood as core could add the value of left-over residue of oil palm trunks by converting it into strong lightweight panels. This product has good potential for structural insulated uses such as walls or ceilings in building construction.

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