IMPROVING CORE BOND STRENGTH OF PARTICLEBOARD THROUGH PARTICLE SIZE REDISTRIBUTION

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Abstract. Novel particleboard furnish mixtures were formulated to improve the core-bonding and screw-holding of industrial particleboard without increasing resin content or board density. Single-layer (uniform vertical density with core furnish only) and conventional 3-layer particleboards were manufactured at two density levels from four novel mixes plus control (unscreened industrial core furnish). Board mean and core density, internal bond strength, edge screw withdrawal resistance, and moduli of rupture and elasticity were measured.

The core of commercial furniture-grade particleboard appears to contain too many fine particulates and insufficient coarser particles. Uniform density profile single-layer boards containing novel mixes with higher-coarse (>2 mm) and lower-fines (<1–2 mm) fractions than industrial furnish had higher bond strength and screw-holding. In three-layer boards of low target density, replacing 20% fines particle content of the total furnish with coarse particles increased internal bond strength by 40% and screw-holding by 18%. The results from this study suggest that not only fines content but also the ratio of all particle-size fractions strongly affect particle packing-efficiency and bond strength. This suggests that industrial particleboard core furnish be screened into three size-fractions, and some of the fines replaced with two coarser-particle fractions.

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INTRODUCTION

The size and shape of particles influence the mechanical properties, appearance, and machinability of particleboard (PB). Since its inception the strength-to-weight ratio of particleboard has been greatly improved through the adoption of a 3-layer structure (smooth high density surface and lower density core containing coarse particles) and advances in resin and press technology; however, low edge-screw withdrawal resistance (SWR) is still an issue for producers and users of particleboard today. A recent investigation (Semple et al 2005) of the mechanical properties of Canadian-made particleboards showed that of the 6 plants surveyed, boards from only one plant met the minimum ANSI A208.1 (ANSI 1999) standard for edge-SWR. This was attributed to the possible variability in press schedules, resin formulation and content between plants, and partially to the varied and complex particle shapes and sizes in the core, which created numerous large voids within the core. These interparticle voids are a source of discontinuities in structure and of bondlines in the board core that act as flaws, and facilitate delamination of interparticle bonds (Conrad et al 2004; Lei and Wilson 1980; River 1994).

Particle size and shape strongly influence the availability of particle surfaces for gluing, and the number and area of interparticle contact points between adjacent particles, which then determines the degree to which the inherent particle strength can contribute to the overall final panel strength (Kollmann et al 1975; Lynam 1959; Marra 1954). The relationships between particle length, width, and thickness are known to influence different panel properties. For instance, flexural properties generally increase with increasing slenderness ratio (length-to-thickness ratio) (Brumbaugh 1960; Heebink and Hann 1959; Post 1958, 1961), but decrease with increasing aspect ratio (length-to-width ratio). In contrast, internal bond (IB) strength increases for thicker and shorter flakes (ie, lower slenderness ratio and higher aspect ratio). Post (1961) suggested that SWR could be improved as slenderness ratio approaches unity, while Kimoto et al (1964—as cited in Moslemi 1974), recorded no increase in SWR for slenderness ratios > 0.5.

In contemporary 3-layer particleboard, the surface consists of finer and more uniform particles, whereas the core is composed of larger and coarser particles of variable sizes and shapes. Efficient combinations of particles of various sizes in multilayer and 3-layer boards with the aim of efficient resin usage and mechanical property improvement have been pursued. Comparing the IB strength of two particleboard formations, Maloney (1970) constructed a 3-layer board with about 50% coarse core-content comprised of particles of varied sizes and a multilayer board with a graduated core, whose center consisted of 20% of particles > 2 mm Tyler mesh-size. He found the IB strength of the 3-layer boards to be greater. The inclusion of fines and wood dust in the core of boards has been shown to increase IB strength (Kakaras and Papadopoulos 2004; Talbott and Maloney 1957; Nemli 2003), but reduce static bending and modulus of elasticity (MOE) (Mottet 1967; Nemli 2003). The increase in IB strength has been attributed to the filling of void spaces between the larger particles with fines to produce a higher degree of interparticle contact (Nemli 2003).

Although the effect of core fines-content on flexural properties and IB strength has been the focus of several investigations, the effect on edge-SWR and the threshold at which addition of fines would be unfavorable to IB strength have not been studied. The hypothesis of this study is that the particle-size mixture in most Canadian-made industrial particleboard is sub-optimal for IB strength and edge-SWR, and that a better core mixture can be produced by transferring some fines to the core. This is based on the idea that increasing the fines content in the core of particleboard will fill the void spaces, leading to increased bonding and edge-SWR. Since the key properties for nonstructural particleboard are SWR and IB strength, this study aims to find a core particle-size mixture which will increase these without increasing board density and resin requirement or adversely affecting the flexural properties. Specific objectives of the study are:

1. Determine the effect on edge-SWR and IB strength by varying the ratios of coarse and fine particles in uniform vertical density profile (UD) particleboard.
2. Determine the effect on vertical density profile (VDP), edge-SWR, IB, and flexural properties (modulus of rupture (MOR) and MOE) of different particle-size mixes in the core of 3-layer particleboards.
3. Compare the properties of boards manufactured with customized particle-size mixes with those containing unscreened industrial furnish.

MATERIALS AND METHODS

Furnish preparation

Dried face and core industrial PB furnish were collected from a particleboard mill in Alberta, Canada, and screened with a mechanical shaker-table using 3 different screens with square openings of 2.0, 1.0, and 0.5 mm (Tyler mesh sizes: 9, 16, and 32, respectively). Based on telephone conversations with personnel from different particleboard plants (Semple et al 2005), these screen sizes are representative of those used in particleboard plants across Canada. Screening the furnish through this set of screens resulted in 4 particle-size classes, with the smallest particles (P1) passing through the 32-mesh screen. The next smallest particles (P2) passed through the 16-mesh screen, but not the 32 mesh; the next size (P3) passed through the 9-mesh screen, but not the 16-mesh screen; and the largest particles (P4) were those retained on the 9-mesh screen.

Compilation of customized particle-size mixes

Four artificial particle-size mixtures (M1 to M4) were compiled from the screened size-fractions, with the proportions of the particle-size fractions in each mix shown in Table 1. The contents of control mix (CTL) were determined by screening the industrial core furnish as received, and found to contain equal proportions of P3 and P4 particle sizes with comparatively little dust. The custom mixtures were therefore formulated around the CTL, ranging from 100% coarse (M1) to 100% fine (M4). Two intermediate size mixtures were formulated with the objective to fill void spaces between coarsest particles first with the P2 particles, and then smaller voids with the dust (P1).

Blending and mat formation

The mill that supplied the furnish also supplied surface and core urea-formaldehyde (UF) resin for blending of boards. To determine the volumetric resin distribution in the different blended batches, hydrated $CuSO_4$ solution was added to the industrial resin following a method used by Feng and Andersen (2004), which reduced the

TABLE 1. *Particle-size classes and amounts in furnish mixtures.*

Particle size (based on Tyler mesh)	Classification	Mesh opening size (mm)	Percentage of particle size in mixture (%) M1	M2	M3	CTL	M4
P4 retained on 9 mesh	coarse	2.0	100	60	40	42	0
P3 retained on 16 mesh	medium	1.0	0	20	20	42	0
P2 retained on 32 mesh	fines	0.5	0	20	20	11	0
P1 retained in pan	fines	<0.5	0	0	20	5	100
		Total:	100	100	100	100	100

Note: CTL = control

solids content from 65 to 60%. Doped resin was applied to the furnish in a Drais particleboard batch-blender equipped with an air-atomizing nozzle. In the blender, the resin is sprayed on the particles as they are stirred by rotating paddles within the blender cavity. Face and core furnish were blended separately, and in each batch, sufficient furnish was blended to make 3 boards. All furnish was conditioned to about 6% moisture content before blending.

From discussions with particleboard producers, the total resin content of commercial particleboard varies between 9 and 13% of the oven-dry furnish mass. Because resin consumption increases with increased specific surface area of furnish, ie, the ratio of mass to total surface area (Maloney 1970; Moslemi 1974), it is expected that the properties of a board made with furnish containing a large amount of fines will be lower for the same resin content compared with a board made from larger furnish particles. Since the objective was to increase bond strength with reduced resin requirement, resin content at the lower end of the industrial range, ie 9%, was used. The UD boards containing only core-furnish mixtures were blended with core UF-resin at a resin content of 6% of oven-dry weight of furnish. For the 3-layer boards, the face layers were blended with surface UF-resin at 9% (oven-dry weight) resin content, while the core layers were blended with 6% resin. All furnish mats were hand-formed.

Manufacture of uniform density boards

Particle mixtures were first tested in UD boards, and then in the standard 3-layer board configuration found in industrial particleboard. A set of 20 boards (4 replicates per mixture) were made from the 4 custom furnish mixtures M1, M2, M3, and M4, plus the control as shown in Table 1. Boards were pressed to 11-mm thickness and 530-kg/m^3 target density. This density was based on the average core density of commercial boards in our previous investigation of Canadian-made particleboards (Semple et al 2005). To obtain a flat, uniform VDP board, a pressing procedure described by Wong et al (1999) was used. The mats were first cold-pressed in an electrically heated Pathex press to target thickness; the temperature was then increased from room temperature to the target of 160°C and maintained for 3 min, at which point the press was opened. The outer edges (50-mm width) of boards were trimmed leaving a 250- × 250-mm square from which 3 edge-SWR specimens and 4 IB-strength specimens were cut. Restricted board thickness required the use of 25-mm No. 6 wood screws (1.6 mm per thread) to test edge-SWR. Specimen dimensions were measured, and physical and mechanical properties testing procedures were done in accordance with ASTM D 1037 (ASTM 2000). All specimens were conditioned for a minimum of 2 wk at 20°C and 65% RH before testing. Mechanical property tests were conducted on a Sintech 30D universal test machine.

Manufacture of three-layer boards

Larger 3-layer boards were made after analyzing the results of the UD boards. The analysis showed that the properties of boards containing 100% dust P1-particles were substantially lower than the others. As a result the experimental design was modified to exclude the M4 mixture. The 3-layer boards were made with the core comprising 54% of the total furnish mass and each face comprising 23% of the total furnish mass. This ratio was chosen based on work by Maloney (1970) and is similar to that of commercial particleboard. The top and bottom surface-layer furnish of all boards was as received from the particleboard company. With the exception of the core of the CTL boards, board cores contained customized furnish mix (M1, M2, or M3) of screened particle sizes.

Blended furnish for the 3-layer boards was distributed evenly by hand into a 710- × 710-mm forming box. Unlike the UD boards, the 3-layer boards were hot-pressed without cold prepressing using an electrically heated Pathex press to a target thickness of 16 mm at a maximum platen temperature of 160°C. Due to the higher moisture content of the mats caused by the excess water used to dissolve the hydrated $CuSO_4$, the press cycle was lengthened to a total of 13.75 min, instead of the usual 3–7 min, to permit the additional water vapor to escape. The press cycle consisted of 15-s closing time, 590-s cooking time, and 220-s degassing time to avoid delamination. Each board was then cooled at room temperature, trimmed to 660 × 660 mm, and cut as shown in Fig 1. The VDP of the IB specimens were measured prior to gluing-up the IB specimens. The VDP was measured with an X-ray density-profilometer (Quintex Measurement Systems; Model QDP-01X).

Design of experiments

A factorial experimental design was used to determine the effect of different mixtures of particle-size fractions on PB mechanical properties. The construction of UD board was necessary to test the effect of the mixtures on bond strength in core furnish without any possible confounding effects of highly compressed, densified surface layers. The UD boards study was designed and analyzed as a single factor experiment with 5 furnish types (M1 to M4, plus CTL furnish), and 4 board replicates. The response variables were edge-SWR (3 specimens per board) and IB strength (4 specimens per board).

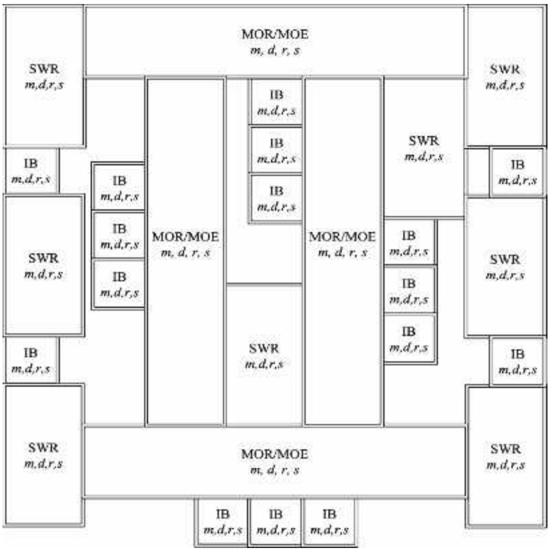

FIGURE 1. Cutting pattern of the 3-layer board (660 by 660 mm) for specimen sampling (m–furnish mixture; d–density; r–replicate; s–specimen).

For the 3-layer boards, a 2-factor experimental design and analysis was used with 4 furnish types (M1, M2, M3, and CTL) for the core and 2 densities, 650 and 700 kg/m^3, giving a total of 8 combinations. M1, M2, M3, and CTL furnish were of the same composition as used in the UD boards. Three replicates of each mix-density combination were made for a total of 24 boards and the following properties were measured: edge-SWR, IB strength, MOR, and MOE as shown in Table 2. The factors, response variables, and specimen numbers are listed in Table 2. A 2-factor ANOVA was used to assess the effect of and interaction between particle-size mix and board density. The significance level for results in both experiments was $p \leq 0.05$.

RESULTS AND DISCUSSION

Uniform density particleboards

Mean density and vertical density profile. The cold-pressing technique adopted from Wong et al (1999) resulted in the desired uniform VDPs in the UD boards, as shown in Fig 2. Although all VDPs were roughly flat, their mean densities were considerably higher than the target density of 530 kg/m^3, which could have been caused by over-compression of mats during hot-pressing in the pressure mode. Mean board density was not significantly different between boards; however, M1 and M2 boards with 80% or more medium to coarse particles had lower mean densities compared with M3 and M4 boards having 60% or fewer coarse to medium particles. Boards made from control furnish (CTL) having a relatively high proportion of medium to coarse particles (84%) also had higher mean density. The relative proportion of particle sizes in the mat appeared to affect board density. In the M1 and M2 mixes, higher compaction ratio experienced by the thick particles likely influenced board den-

TABLE 2. *Treatment structure of factors and response variables of 3-layer boards.*

Factor	Levels	Response	Number of specimens/ board	Units
Particle-size mixture	M1	edge-SWR	8	N
	M2			
	M3	IB strength	16	MPa
	CTL			
Board density	650	MOR/MOE	4	MPa/GPa
	700			
Replicate	3	core density	8	kg/m^3

Note: CTL = control

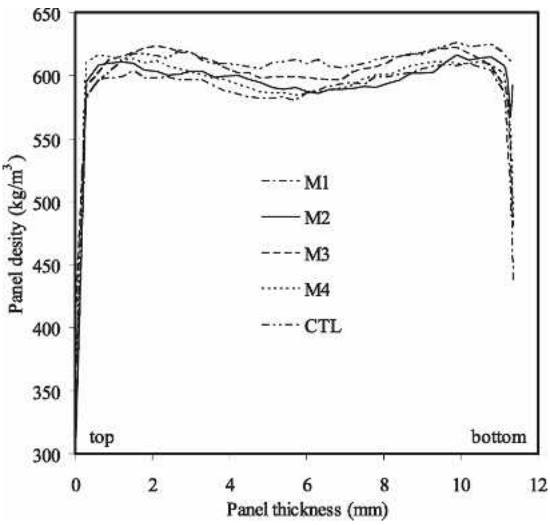

FIGURE 2. Vertical density profile of the UD boards at a target density of 530 kg/m^3.

sity, whereas particle packing-efficiency may also have influenced board density in the mixes containing more fine particles. With thicker particles, more and larger voids are present after reaching maximum compaction compared with the more homogenous packing achieved when finer particles are present.

IB strength and edge-SWR of UD particleboard. Table 3 shows the average values for IB strength, edge-SWR, and mean density of the UD boards. Mean IB-strengths of boards made from the M1 and M2 mixtures were significantly higher than the controls at the same resin content, and higher than the minimum requirements of 0.45 MPa in the ANSI A208.1 (ANSI 1999) standard. The IB strength from M2 boards was 34% higher than the control, while M1 and M3 boards were 22 and 17% higher than boards made with normal industrial core furnish respectively. The all-dust M4 boards were significantly lower in IB strength than the rest. Failure mode in the M4 IB specimens was similar to MDF, occurring near the surface, leaving a thin, 1- to 2-mm surface layer detached from the bulk of the specimen.

The pattern of mean edge-SWR of the UD laboratory-boards made with different particle-size mixtures is very similar to that of mean IB strength, which follows the close correlation between edge-SWR and IB strength found in our previous studies on industrial particleboard (Semple et al 2005). The all-dust M4 boards were significantly lower than the rest of the UD board types for edge-SWR. Unlike the IB results, no statistically significant differences were found between M1, M2, M3, and CTL boards. However, mean values of edge-SWR of M1 and M2 boards were 18% higher than the control, whereas M3 (containing more fines) was only 6% higher. The edge-SWR values were not directly comparable with the ANSI A208.1 (ANSI 1999) standard minimum values, because smaller screws (No. 6) were used for the test.

Effects of mass fraction of fine particles on IB strength and edge-SWR of UD boards. Figure 3 shows the relationship between the mean values of board density, IB strength, and edge-SWR and mass fraction of fine particles in the board. Interestingly, the higher densities of the control and M4 boards did not translate into higher IB strength or edge-SWR, which indicates that changes in these properties were not due to density but were strongly influenced by particle-size mix.

Previous research has found that adding fines to core PB increases IB strength (Kakaras and Papadopoulos 2004; Nemli 2003; Talbott and Maloney 1957), but our findings indicate that the increase is limited. It can be seen from Fig 3 that increasing fines from 0 to 20% in the cus-

TABLE 3. *Mean values for the properties of the UD single layer boards.*

	M1	M2	M3	M4	CTL
MD (kg/ m^3)	570 (3.0)	568 (2.2)	580 (3.1)	588 (3.8)	580 (1.8)
IB (MPa)	0.50 (11.3)	0.55 (8.8)	0.48 (12.5)	0.18 (23.8)	0.41 (8.3)
SWR (N)	579 (11.3)	582 (10.8)	523 (19.9)	235 (28.9)	492 (31.6)

MD = mean density; coefficient of variation (COV) is given in parenthesis.

tomized mixtures leads to an initial increase in IB strength, which then decreases as fines content increases above 20%. However, boards from the control mixture with a lower proportion of fines than the M2 boards did not follow this trend. This indicates that changes in the property values are not caused purely by changes in fines content, but also by the proportions of the various particle sizes in the furnish.

For the laboratory-made UD boards, the findings partially refute our hypothesis that increasing fines will increase IB strength and edge-SWR. It is rather the combination of compaction ratio and packing efficiency that cause an increase in the properties. Having the right proportions of different particles leads to higher packing efficiency, whereby the large voids created in the packed P4 (coarse) particles are filled by medium P3 particles and the resulting smaller voids then filled by finer particles. This could help explain the lower values obtained from boards made from the control furnish, where the proportion of coarse to medium to fine was 42/42/16, while M2 mix had a proportion of 60/20/20.

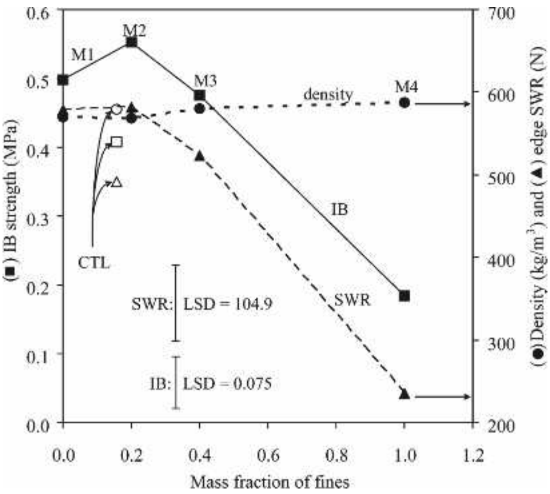

FIGURE 3. Mean values from UD boards for IB strength (■), board density (●) and edge-SWR (▲) loads for all particle-size mixes. Note that the fines and dust content of boards, increases from M1 to M4 and the open symbols indicate mean values of CTL boards.

For edge-SWR of the UD boards, our findings support the suggestions from Post (1961) and Maloney (1993) that SWR could be increased by using thicker and longer particles, which are present in greater quantities in the M1 and M2 mixes. It also confirms the findings of Haselein et al (2002), who observed an improvement in screw-holding strength, when average core particle thickness increased from 0.5 to 1 mm. This is because fine particles are less effective in transferring stress from particle-to-particle compared with coarse or medium particles. The cumulative stress concentration locations in the furnish containing more finer particles is higher, and leads to critical discontinuity in the stress field, inducing more microfracture and ultimately failure (River 1994; Smith et al 2003). The improvement in edge-SWR with increasing coarse particles can also be attributed to the higher resin-spread-rate on coarse particles resulting from lower relative surface area of coarse particles as compared with fines (Duncan 1974; Moslemi 1974; Hill and Wilson 1978). Furthermore, higher compaction ratio leads to more interparticle contact and better bonding, as was the case here for the M2 boards with fewer fines. The effect of replacing coarse particles with fines is more pronounced in the case of IB strength.

Three-layer particleboards

Summary of statistically significant effects of particle-size mix on the properties of 3-layer particleboard. The main effects of, and interactions between density and particle-size mix on

TABLE 4. *Effects of mixtures and target density on properties of 3-layer boards.*

Effect	Core density	IB strength	Edge-SWR	MOR	MOE
Density	$p = 0.004$	$p < 0.0001$	$p = 0.0001$	$p < 0.0001$	$p < 0.0001$
Mixture	$p = 0.03$	$p = 0.0004$	$p = 0.05$	n.s	n.s
Density * mixture	$p = 0.04$	$p = 0.0009$	$p = 0.02$	n.s	n.s

n.s. = not significant at the 5% confidence level; $p < 0.001$ = significant at the 0.1% level.
* = interaction between density and mixture

the properties of 3-layer particleboards are shown in Table 4. As expected, board target density significantly affected all mechanical properties. There was a small, but statistically significant increase in board density as the proportion of fine particles in the core mix increased. Particle-size mix significantly affected board core-density and IB. There was a borderline significant effect ($p = 0.05$) of core particle mix on edge-SWR. MOR and MOE were not affected by particle-size mix in the core.

Mean density and VDP of the 3-layer particleboard. The U-shaped VDP of the 3-layer boards are shown in Fig 4. As expected, the core densities of the higher density (HD) boards were slightly higher than those of the lower density (LD) boards. As shown in Fig 4a, the core and face densities of the LD boards containing more fines (M3) and CTL were higher than the rest in the same density category. This was also the case for the UD boards, and could be attributed to the fact that fines are effectively compacted leaving very little void space (Nemli 2003), resulting in higher density. From Fig 4b, it can be seen that HD boards containing higher fines content in the core (M3) and CTL were thinner than those containing M1 and M2 mixes. Mats containing many fines offer less resistance to compaction from more effective filling of void space than those containing thicker core particles (Maloney 1993). The greater thickness in M1 and M2 boards may also be attributed to higher residual stress existing in boards containing thicker particles leading to a greater springback (Wong et al 1999).

Average values for properties of the 3-layer boards of the 2 target densities and 4 different core mixes are shown in Table 5; IB strength and

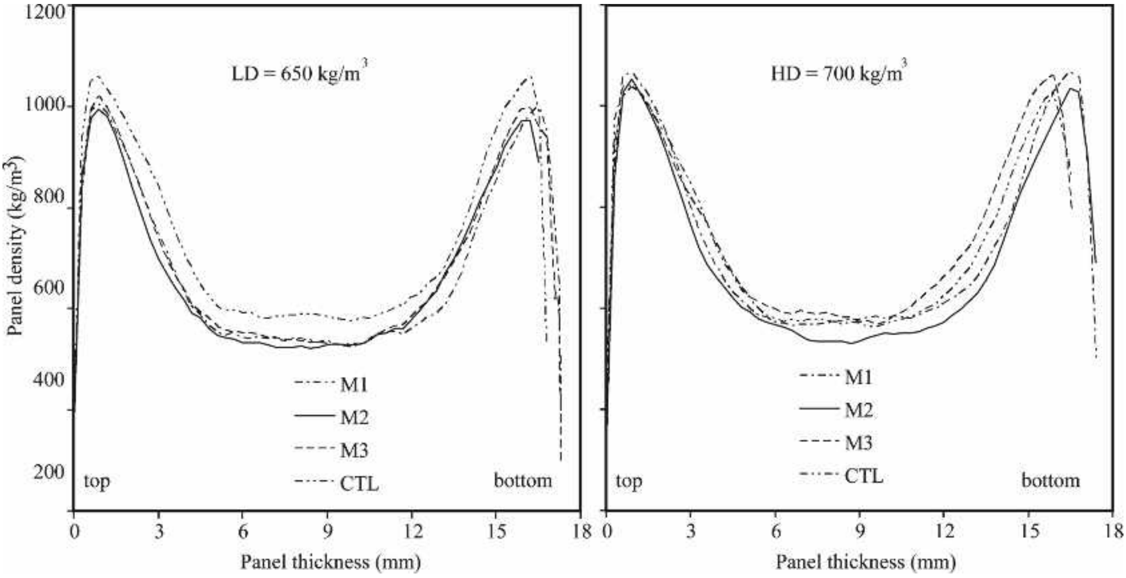

FIGURE 4. Vertical density profile of the 3-layer particleboard at a target density of (a) 650 kg/m^3 and (b) 700 kg/m^3.

edge-SWR are shown graphically in Fig 5. The LD boards containing the M2 mix (ie 60% coarse, 20% medium, and 20% fines) had the highest IB strength (0.66 MPa) and edge-SWR (779 N), representing a 40% increase in IB strength and 18% increase in edge-SWR compared with LD boards containing control mix. For the HD boards, the M1 boards were 23% higher in IB and 18% higher in edge-SWR than the CTL boards.

As can be seen in Fig 5, there is an interactive effect between particle mixtures and board density for IB and SWR. The most obvious feature is that the particle-size effect on bonding and screw-holding is masked to a large extent in the HD boards. The greater compaction of the mat likely offset some of the adverse effects that high quantities of fines and dust had on less compacted boards by closing up void spaces. The interaction between board density and particle-size mix is comparable to a study done by Fakhri et al (2006) who found a similar interaction between density and core fines content affecting the transverse permeability of OSB boards.

When compacted to higher density, the M1 mix (all coarse) produced higher IB strength and edge-SWR than boards containing some fines. This is attributed to the fact that under the same ram pressure, a mat containing 100% thick particles will undergo a higher compaction and therefore have better interparticle contact (Heinemann et al 2002). The reduced bond strength in the LD boards containing the M1 mix may have been caused by void space that was closed in the HD boards resulting in a higher bond strength.

Effect of mixture on flexural properties of the 3-layer boards. The flexural properties (MOR and MOE) of 3-layer boards as listed on Table 5 were not significantly affected by particle-size mix in the core, and their values were all above the minimum required levels of ANSI A208.1 (ANSI 1999). The controlled addition of fine particles to the core of particleboard did not re-

TABLE 5. *Mean values for the properties of the 3-layer boards with novel furnish mix core.*

	Target density: LD – 650 kg/ m^3					Target density: HD –700 kg/ m^3				
	CD (kg/m^3)	IB (MPa)	SWR (N)	MOR (MPa)	MOE (GPa)	CD (kg/m^3)	IB (MPa)	SWR (N)	MOR (MPa)	MOE (GPa)
M1	552 (7.0)	0.55 (10.6)	731 (20.0)	18.3 (9.7)	2.87 (6.8)	590 (3.6)	0.75 (10.1)	923 (16.6)	22.2 (7.6)	3.34 (4.2)
M2	548 (8.7)	0.66 (11.9)	779 (33.2)	19.6 (12.5)	2.94 (10.6)	588 (2.3)	0.65 (11.5)	764 (17.3)	20.9 (6.7)	3.26 (6.3)
M3	538 (4.2)	0.41 (11.8)	585 (19.8)	18.3 (10.2)	2.77 (8.6)	574 (4.0)	0.67 (13.5)	857 (16.7)	20.8 (6.33)	3.24 (7.9)
CTL	604 (4.6)	0.47 (16.0)	660 (28.5)	17.8 (12.4)	2.75 (8.2)	586 (3.68)	0.61 (15.5)	783 (20.4)	21.6 (7.3)	3.41 (8.1)

CD = core density; coefficient of variation (COV) is given in parenthesis under each mean.

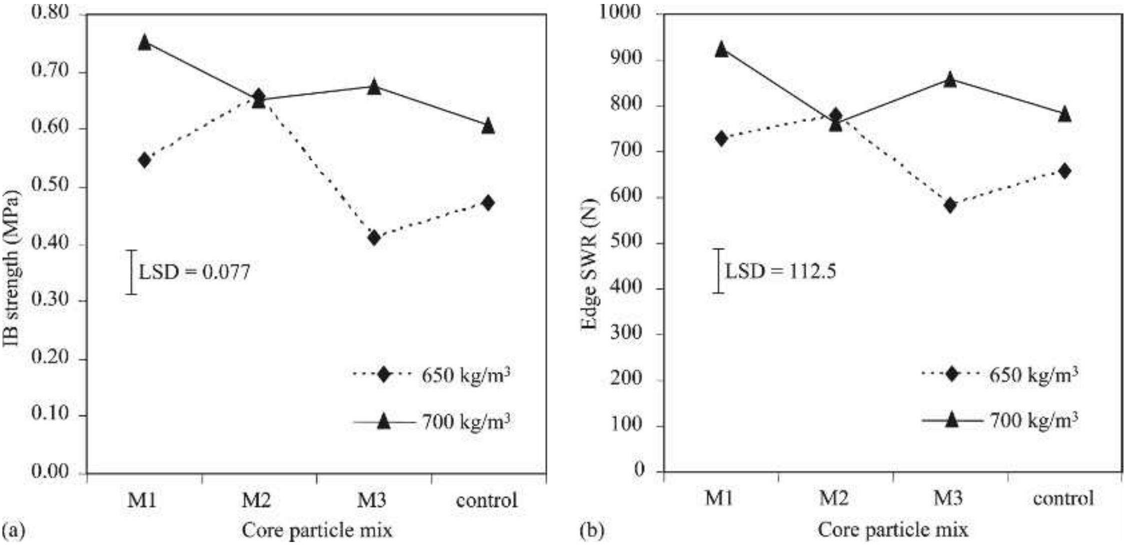

FIGURE 5. Graph of mean values of 3-layer boards for (a) IB strength and (b) edge-SWR loads for each core particle-size mix and target board density. Note that the fines and dust content of boards increases from M1 to M3.

sult in reduced bending strength and stiffness, because the flexural properties of particleboard are largely influenced by the composition and consolidation of face furnish material, pressing conditions, and density gradient (Kelly 1977), all of which were similar for the boards in this study.

CONCLUSIONS

Our initial hypothesis was that adding fine particles to the core of particleboard would improve consolidation and bonding in the core by filling void spaces, and that this would improve screw-holding properties of particleboard. However, our results from laboratory-made uniform-density single-layer boards indicate only a slight increase in bond strength and edge-SWR after replacing 40% of the coarse particles with medium and fine particles, and decreased with further increase in fines content. Although the trend of results of the 3-layer did not follow that of the single-layer boards, the effect of fines in the particle mix of 3-layer boards was especially perceptible in boards compressed to low density. Boards made with cores containing a customized mix of particle sizes were up to 40% higher in IB strength and 18% higher in edge-SWR, than boards made from industrial furnish. Results from uniform and low density 3-layer boards suggest that the core of commercial furniture grade particleboard contains too many fine particulates and dust, and this may be responsible for reducing edge-SWR to below the suggested minimum levels. The ratios of particle sizes present in commercial particleboard core-furnish may also not be optimized for the best particle packing efficiency. Increasing the coarse particle (> 2 mm) content of the core of contemporary particleboard and optimizing the particle-size mixture of the core could improve edge-SWR and IB strength of particleboard, especially for lower density boards. Flexural properties of the 3-layer boards with differential VDP were unaffected by core fines content. For better evaluation of the effect of mixtures on 3-layer boards, thickness swell, and water absorption, further investigation using mixture design is being undertaken.

Since most plants partition particleboard furnish into two size-classes (fine surface and coarse core material), our findings suggest that significant benefit in IB strength and edge-SWR could be obtained by adopting three size-classes of particles: coarse, medium, and fine.

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