Comparing Properties of North American Manufactured Particleboard and Medium Density Fiberboard - Part II: Medium Density Fiberboard

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The properties of medium density fiberboard (MDF) derived from different manufacturing plants were compared. Each plant provided 5 full-sized (2440 by 1220 mm) 155-grade panels that were tested according to ANSI A208.2-2009. None of the panels met the recommended value for Internal Bond (IB). Mean values for Thickness Swell (TS) were all significantly different, with one manufacturer below the standard. Three manufacturers exceeded the recommended face Screw Withdrawal Resistance (fSWR) values, one was equal to it, and one failed. Three manufacturers exceeded the edge SWR (eSWR) standard, and the remaining two fell below. Two manufacturers met the standard for Modulus of Rupture (MOR), and only one manufacturer failed to meet the Modulus of Elasticity (MOE) requirements. Linear Expansion (LE) was evaluated for a RH change from 50 to 90%. The panels made with pMDI-resin consistently had some of the highest mean values for MOR, MOE, fSWR, and IB and exhibited good performance in the TS test.

Keywords: Medium density fiberboard; Internal bond; Mechanical properties; Thickness swell; Linear expansion; Vertical density profile; Screw withdrawal; Survey

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INTRODUCTION

With the goal of collecting up-to-date data on the properties of Canadian- and US-manufactured particleboard (PB) and medium density fiberboard (MDF), 63 manufacturers were contacted and asked to participate in a mechanical and physical properties comparison study. This is the second of two papers presenting the results of the MDF evaluation. Samples from five different manufacturing facilities across Canada and the United States were evaluated. To the best of our knowledge this is the only properties comparison of 155-grade MDF panels in the public domain. We believe, that these results will be very valuable for MDF manufacturers, particularly those in North America.

EXPERIMENTAL

Materials and Methods

Similar to the PB panels that were analyzed in the first paper, MDF manufacturers who participated in the survey were each asked to provide five 155-grade (ANSI 208.2-2009) 4 by 8 foot panels. Three MDF sets were donated by interested plants, one was purchased from a local building supplies store (Home Depot), and one was obtained with the help of a resin company colleague encouraging plants to participate in the study. The various sets of panels were received between July and September of 2012. A total of 25 MDF panels were tested.

The preparation of samples was identical to that of the PB samples as described in the first paper, as was the statistical analysis of the results (Dettmer and Smith 2015).

Properties of interest

The properties of interest are listed in Table 1 and include the internal bonding (IB), vertical density profile (VDP), thickness swelling (TS), linear expansion (LE) in both directions (parallel (ǁ) and perpendicular (⊥) to the machine direction), face screw withdrawal resistance (fSWR), edge screw withdrawal resistance in both directions (eSWR ǁ, eSWR ⊥), modulus of rupture in both directions (MOR ǁ, MOR ⊥), and modulus of elasticity in both directions (MOR ǁ, MOR ⊥).

Table 1. Specimen ID and Number of Samples Measured per Manufacturer, Panels, and Sub-Panel

Property	Specimen ID	Number of Samples		
		Manufacturer	Panel	Sub-panel
IB & VDP	1	40	8	4
Thickness Swelling (TS)	2	40	8	1
MOE/MOR ǁ	3	40	8	1
MOE/MOR ⊥	4	40	8	1
fSWR	5	40	8	1
eSWR ǁ	6	40	8	1
eSWR ⊥	7	40	8	1
Linear Expansion ǁ	8	40	8	1
Linear Expansion ⊥	9	40	8	1

Specimen IDs correspond with the label numbers in Fig. 3b.

RESULTS AND DISCUSSION

Table 2 contains all means and coefficients of variation (CV) of the physical and mechanical properties studied.

Moisture Content, Specific Gravity, Vertical Density Profile, and Internal Bond

The MC for the MDF samples, as shown in Fig. 1a, was between 8.9 (Manufacturer H) and 10.7% (Manufacturer K) with a relatively large CV range of 1.9 (Manufacturer G) to 13.7% (Manufacturer K). Statistical analysis revealed that the assumption of equal variances was not met. Therefore, the Games-Howell multiple comparison procedure was employed to identify differences among the means.

No LSD is shown in Fig. 1a. Similar to the tested PB, some MDF samples did not exhibit significant differences between means. Manufacturers G, I, J, and K had similar mean values, whereas Manufacturer H had significantly lower MC than all other manufacturers.

Table 2. Means and Coefficients of Variation (CV) of Physical and Mechanical Properties for Boards from MDF Manufacturers

Property		Manufacturer				
		G	H	I	J	K
MC	Mean (%)	10.0	8.9	10.3	10.4	10.7
	CV (%)	1.9	6.4	11.5	6.0	13.7
SG	Mean	700.9	677.3	664.0	691.9	713.9
	CV (%)	0.8	0.8	0.9	1.1	2.2
Density Core	Mean (kg/m^3)	691.8	693.5	671.5	669.4	715.8
	CV (%)	1.4	1.2	1.7	2.7	2.3
Density S1	Mean (kg/m^3)	1124.5	1096.7	985.2	975.9	1031.8
	CV (%)	2.1	2.2	2.9	3.6	2.5
Density S2	Mean (kg/m^3)	1126.3	1052.7	974.2	949.8	1038.0
	CV (%)	2.1	1.5	2.7	4.4	3.0
IB	Mean (MPa)	0.83	0.75	0.59	0.50	0.87
	CV (%)	10.5	18.6	15.6	19.5	15.5
TS	Mean (%)	6.0	5.3	6.6	10.8	7.5
	CV (%)	4.9	5.3	4.5	6.2	6.5
WA	Mean (%)	17.2	10.2	13.8	19.3	17.6
	CV (%)	5.7	7.1	10.0	7.9	12.9
LE ǁ	Mean (%)	0.27	0.19	0.23	0.23	0.16
	CV (%)	11.6	12.5	18.5	11.2	18.2
LE ⊥	Mean (%)	0.27	0.19	0.24	0.22	0.18
	CV (%)	8.0	11.5	16.1	17.14	10.6
eSWR	Mean (N)	1331.5	1406.5	1033.9	1053.2	1455.7
	CV (%)	3.4	5.7	5.7	9.6	7.3
fSWR	Mean (N)	1539.5	1315.7	1200.9	1307.6	1523.0
	CV (%)	4.1	5.4	7.4	7.4	6.5
MOR ǁ	Mean (MPa)	31.3	27.9	20.2	26.6	31.1
	CV (%)	5.1	6.3	8.9	11.1	9.3
MOR ⊥	Mean (MPa)	31.6	27.3	22.3	29.1	29.9
	CV (%)	6.0	9.0	6.3	13.1	9.0
MOE ǁ	Mean (GPa)	3.5	3.5	2.7	3.3	3.4
	CV (%)	3.9	4.9	8.3	10.7	6.5
MOE ⊥	Mean (GPa)	3.5	3.5	2.7	3.5	3.2
	CV (%)	4.8	4.9	7.8	10.5	6.5

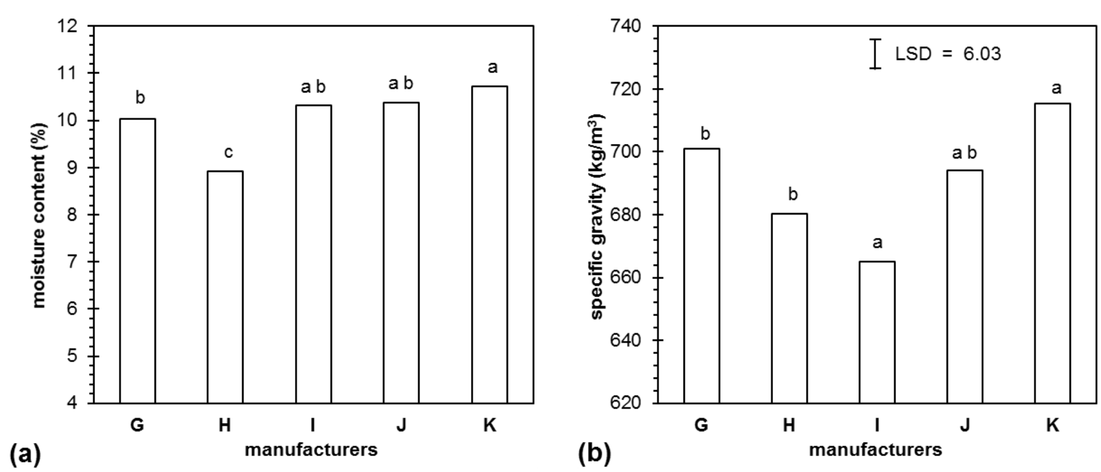
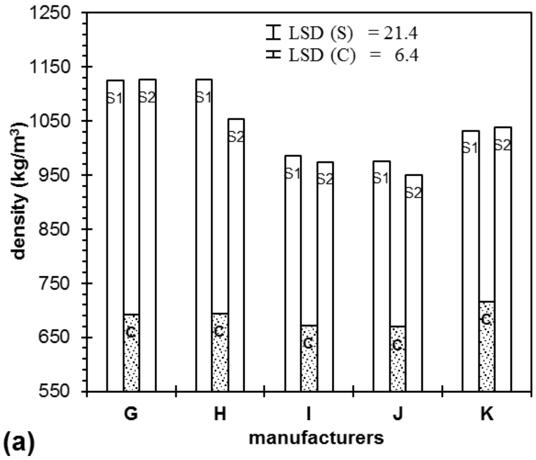


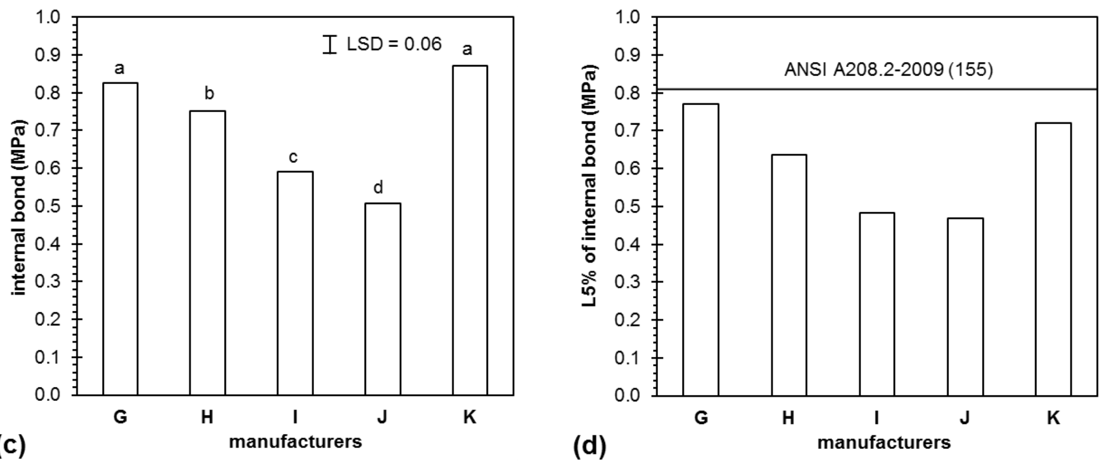
Fig. 1. The (a) moisture content and (b) specific gravity of MDF by manufacturer. Each mean value represents 40 tested samples. Means with the same lower case letter above the columns were not significantly different at $\alpha = 0.05$



(a)

(b)

Means with the same letter in the t-Grouping are not significantly different at α= 0.05			
t Grouping	Peak Face Density	N	Manuf. & Surface
a	1126	40	G-S2
a	1125	40	G-S1
b	1097	40	H-S1
c	1053	40	H-S2
c	1038	40	K-S2
c	1032	40	K-S1
d	985	40	I-S1
d	976	40	J-S1
d	974	40	I-S2
e	950	40	J-S2



(c) (d)

Fig. 2. The (a) VDP, expressed as the means of peak density surface 1 (S1), core density averaged over a 6-mm zone (C), and peak density for surface 2 (S2) for the five tested MDF sets and (b) the significance grouping for the peak density. The means are sorted from highest to lowest. Note: The letters in the t-Grouping do not correspond with the manufacturer letters. The (c) means for IB strength for the five MDF manufacturers, with each mean representing 40 samples. The horizontal line (d) indicates the minimum IB value required to meet the voluntary ANSI standard A208.2-2009.

All manufacturers had significantly different mean SG values that ranged from 664 (Manufacturer I) to 713.9 (Manufacturer K). CVs were within a tight range of 0.8 to 2.2% (Table 2). Core densities (CDs), as shown in Fig. 2a, were between 669.4 (Manufacturer J) and 715.8 kg/m^3 (Manufacturer K). Fisher's LSD procedure revealed no significant differences between Manufacturers G and H and Manufacturers I and J. Peak face densities (PFD) ranged from 1126.3 (Manufacturer G - S2) to 949.8 kg/m^3 for S2 of Manufacturer J (Fig. 2b). The CVs for the VDP were within a small range of 1.2 to 4.4% (Table 2).

Except for Manufacturers G and K, all had significantly different IB strengths (Fig. 2c) ranging from 0.5 (Manufacturer J) to 0.87 MPa (Manufacturer K). Similarly to the tested PB samples, the CVs for IB were high, between 10.5 (Manufacturer G) and 19.5% (Manufacturer J).

The known correlations between density and IB for PB applied to MDF as well. Manufacturer K, with the highest SG, also had the highest IB. Manufacturer J, with the lowest IB, did not have the lowest SG but had the lowest CD. Visually comparing IB and CD, Figs. 2a and 2c show an overall positive relationship between the two properties. Nevertheless, none of the tested MDF panels complied with the voluntary ANSI A208.2-2009 standard for 155-grade MDF (Fig. 2d). Examination of the VDPs for Manufacturers G, I and J showed the typically U-shape profile. The VDPs for Manufacturers H and K had significant differences in the PFD between the two faces (S1 and S2). Typical VDPs are shown in Fig. 3 for each manufacturer. Part of the reason for this difference may be due to differening press stradegies used by each plant with panels from Manufacturer H made on a continuous press and those from Manufacturer J on a batch press (Table 3).

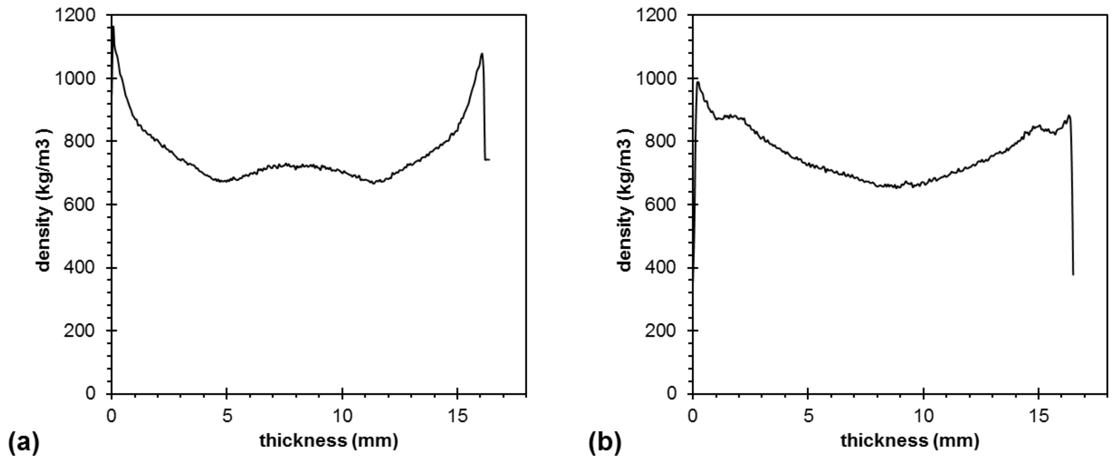


Fig. 3. Comparison of typical VDP plots from (a) manufacturer H and (b) manufacturer J. Manufacturer H has a more symmetrical VDP

PFDs of the two faces, although significantly different, were more pronounced for Manufacturer H (Fig. 3a) than for Manufacturer J. Overall, the shape of Manufacturer H's VDP was more symmetrical. Similarly to the study of PB, possible reasons for the inconsistent VDPs include differences between furnish parameters, excessive sanding, springback of the mat during press opening (Wang *et al*. 2004), resin distribution, or resin pre-curing (Xing *et al*. 2004).

Thickness Swelling and Water Absorption

Thickness swelling, as shown in Fig. 4a, is based on the conditioned sample thickness and represents the swelling, in percent, after 2 and 24 h. It ranged from 5.3% for Manufacturer H to 10.8% for Manufacturer J. Coefficients of variance were between 4.5 (Manufacturer I) and 6.5% (Manufacturer K). All means were significantly different. Figure 4b shows the upper 95th percentile of the normally distributed TS in accordance with ANSI standard A208.2-2009 (155). All manufacturers except Manufacturer J were well below the recommended maximum value for TS.

Water absorption, based on the initial conditioned sample weight, is shown in Fig. 4c. All manufacturers except Manufacturers G and K were significantly different. Manufacturer J had the highest WA (19.3%) and Manufacturer H had the lowest (10.2%). The variation in panels from the same manufacturer was up to 100% higher than for TS, with CVs ranging from 5.7 (Manufacturer G) to 12.9% (Manufacturer K).

To better understand and compare the results, Table 3 presents an overview of the known parameters for the boards from each manufacturer.

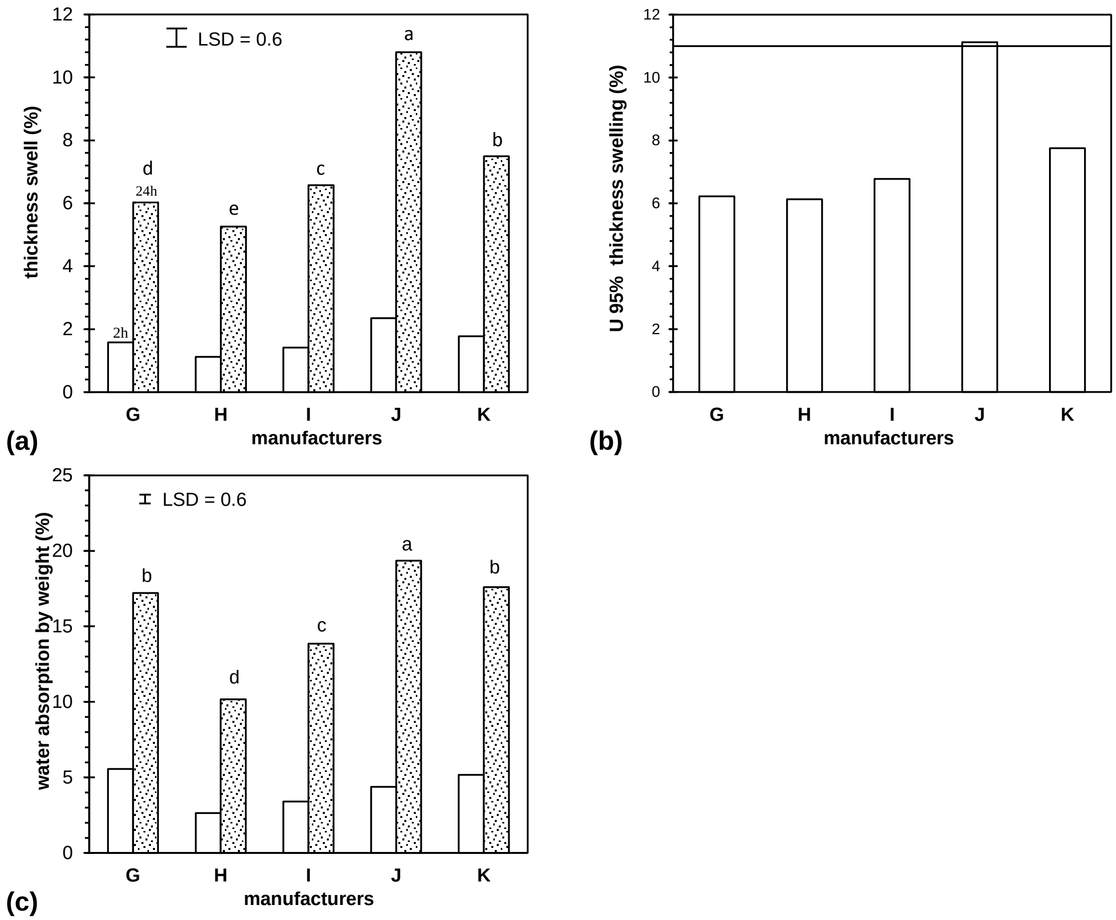


Fig. 4. The (a) mean values for TS after 2 and 24 h; the (b) upper 95th percentile of the normally distributed TS values, with the horizontal line representing the ANSI recommended value; and (c) the WA after 2 and 24 h. Means with the lower case letter were not significantly different at α = 0.05.

Table 3. Comparison of Known Parameters of the Five Evaluated MDF Manufacturers

Property	Manufacturer				
	G	H	I	J	K
CD (kg/m^3)	691.8	693.5	671.5	669.4	715.8
SG	700.9	677.3	664.0	691.9	713.9
Wood species	Spruce (10%) Pine (80%) Fir (10%)	Spruce, Pine, Fir, Oak, Maple, Birch, Aspen, Cedar	Pine, Spruce, Fir, Maple, Birch, Oak, Poplar	n.a.	Lodgepole Pine, Douglas Fir, Larch
Press type	continuous	continuous	continuous	batch	batch
Resin type/ Resin content	pMDI/ n.a.	UF/ 12.3% (od)	UMF/ n.a.	n.a.	MUF face/UFcore 9 - 11% (od)
TS – 24 h (%)	6.0	5.3	6.6	10.8	7.5
WA – 24 h (%)	17.2	10.2	13.8	19.3	17.6

As expected, Manufacturer G, using pMDI resin, exhibited low TS. It is known that pMDI resins yield excellent dimensional stability (Pizzi and Mittal 2003; Pilato 2010). However, Manufacturer H, using UF resin, exhibited the lowest TS. Papadopoulos (2006) investigated and compared the performance of PB bonded with pMDI and UF resins. He found that boards made with UF resin content above 10% had roughly the same TS as pMDI-bonded boards with resin content just above 3%. Papadopoulos concluded that in order to achieve similar board properties using UF and pMDI resins, the latter could be used at considerably lower dosage.

A clear trend can be observed when comparing the TS and WA of Manufacturers H to K: higher TS corresponded to higher WA.

Linear Expansion

Machine direction only had a significant effect on the LE of boards from Manufacturer K. Linear expansion parallel to the machine direction for this manufacturer was the lowest, at 0.16%. Manufacturer G had the highest mean LE of 0.27%. Coefficients of variance ranged from 8 (Manufacturer G⊥) to 18.5% (Manufacturer I∥). A comparison of all means is shown in Fig. 5.

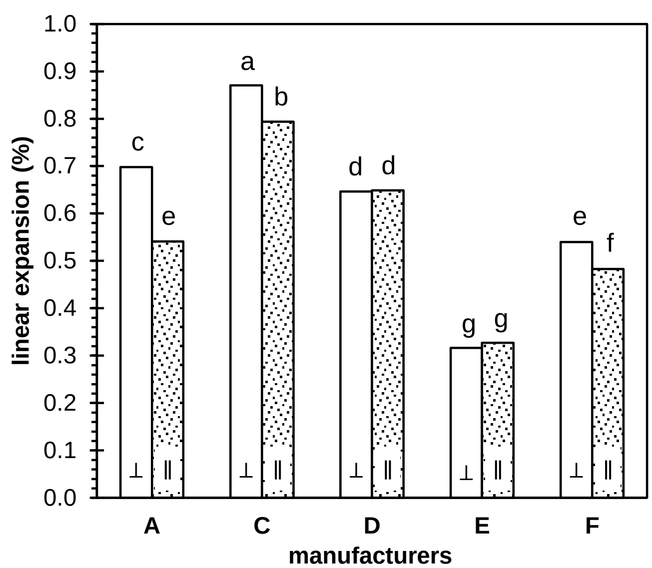


Fig. 5. Mean LE values. Each pair of columns represents one manufacturer and the two sample orientations tested (n⊥ = 40, n∥ = 40). Means with the same lower case letter above the column were not significantly different at α = 0.05 (a = highest mean, e = lowest mean).

Similar to the test procedures for PB, these results are based on a RH change from 50 to 90%. Therefore, results were not compared to the ANSI standard requirements. Interestingly, Manufacturer G, using pMDI, had the highest LE. Xu and Suchsland (1997) explained LE in MDF as similar to that in solid wood, occurring *via* swelling in the cell walls. In this study, no correlation was found between density and LE, which agrees with the conclusions of Xu and Suchsland (1997) but contradicts Ayrilmis (2007), who discovered a significant relationship between density, LE, and TS for MDF and high density fiberboards (HDF). The 11-mm-thick boards were manufactured (dry process) using industrially-sized equipment with a mix of beech and pine fibres, UF resin (RC, 10% based on oven-dry fibre weight), and target densities of 720, 760, and 800 kg/m^3. Linear expansion and contraction, TS, and thickness shrinkage increased with increasing density.

Similar to the results presented in this study, values for TS were higher than LE values. Complex correlations between input, output, and process parameters, some of which were unknown during this study, make it difficult to compare panel products from different manufacturers and draw final conclusions.

Screw Withdrawal Resistance

Face screw withdrawal resistance

The highest mean value for fSWR was 1540 N for Manufacturer G, and CVs ranged between 4 and 7% (Table 1). Manufacturer I, with the lowest mean fSWR of 1201 N, was the only manufacturer that did not comply with the voluntary ANSI standard (Fig. 6b). As illustrated in Fig. 6a, the mean values for Manufacturers G and K and for Manufacturers H and J were not significantly different.

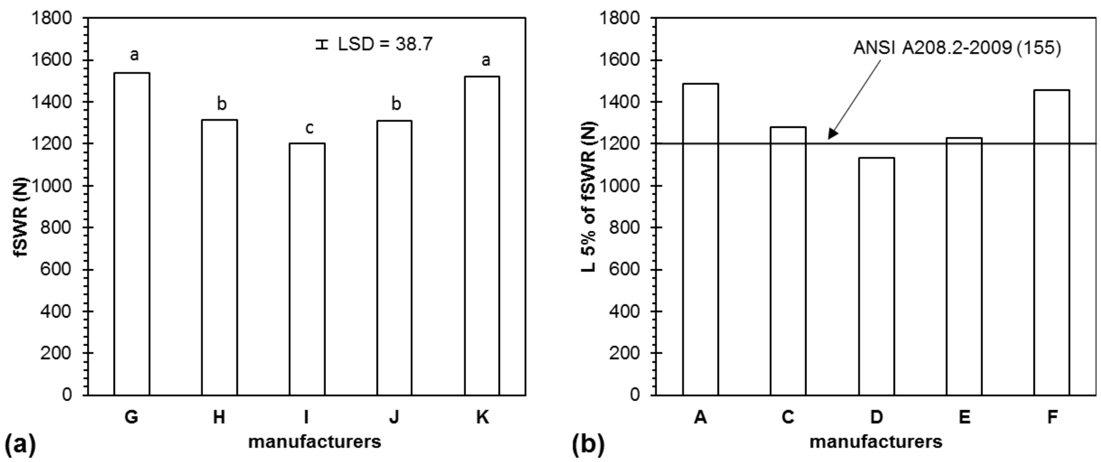


Fig. 6. The (a) mean fSWR values. Each column represents one manufacturer (n = 40). Means with the same lower case letter above the columns were not significantly different at $\alpha = 0.05$ (a = highest mean, c = lowest mean). The (b) lower 5th percentile of the fSWR values distribution in accordance with ANSI standard A208.2-2009.

A correlation similar to that of PB between PFD and fSWR was not found, but there was a trend of increasing fSWR with increasing SG. One possible explanation is that the surface layers of MDF are thinner than those of PB due to the higher compaction ratio (Xu and Winistorfer 1995). Comparing the results of IB and fSWR, a similar trend can be observed. Higher IB led to higher fSWR. It should also be mentioned that Manufacturer G, using pMDI (Table 2), achieved the highest fSWR. The combination of the mechanical and chemical bonding of pMDI-bonded panels makes it possible to manufacture high strength boards at significantly lower resin content (Papadopoulos 2006). Manufacturer K achieved similarly high values for fSWR *via* a combination of MUF and UF at resin contents between 9 and 11%. The high fSWR can likely be attributed to the significantly higher SG (Fig. 1b).

Edge screw withdrawal resistance

Similarly to the evaluated PB panels, the machine direction had no significant effect on the eSWR. Measured values for each sample were averaged across the machine direction and re-analyzed. Figures 7a and 7b show the means and ANSI standard comparisons.

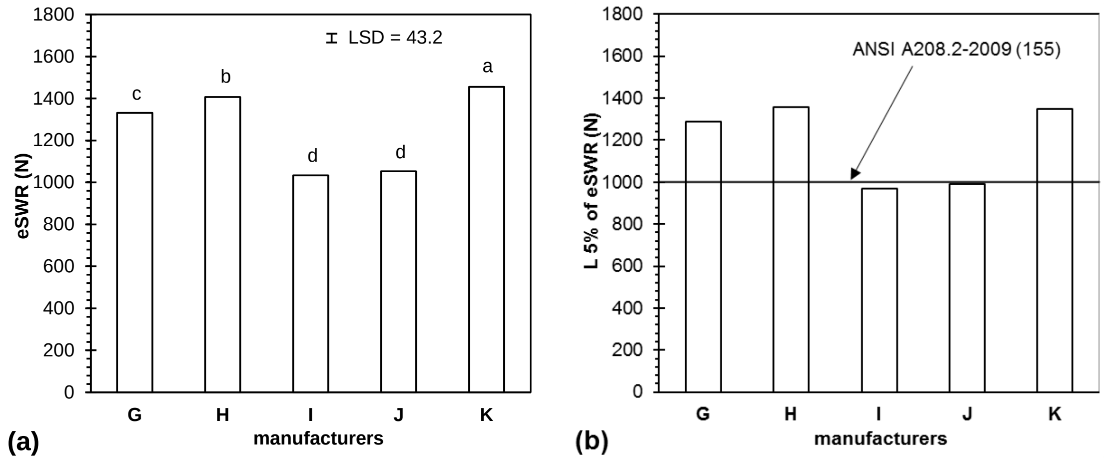


Fig. 7. The eSWR for the evaluated MDF manufacturers. The (a) mean values (n=40). Means with the same lower case letter above the columns were not significantly different at α = 0.05. The (b) lower 5th percentile of the normally distributed eSWR, presented in accordance with the new ANSI standard from 2009.

Except for Manufacturers I and J, all had significantly different mean eSWR values. K had the highest value of 1455.7 N (CV = 7.3%) and Manufacturer I had the lowest, 1033.9 N (CV = 5.7%). I and J did not meet the recommended ANSI value of 1001 N for the lower 5th percentile of a normally distributed eSWR. When comparing eSWR and CD (Fig. 2a), higher CD corresponded to higher eSWR. Manufacturer H had higher eSWR than fSWR. Possible reasons include densification of the core furnish, the asymmetrical VDP (Figs. 2a and 3a) that may have negatively affected fSWR, and furnish composition.

Modulus of Rupture and Modulus of Elasticity

The results for the mean MOR comparison (Fig. 8a) were more complex than those of the previously discussed MDF properties. Mean values ranged from a maximum of 31.6 (Manufacturer G⊥) to a minimum of 20.2 MPa (Manufacturer I∥).

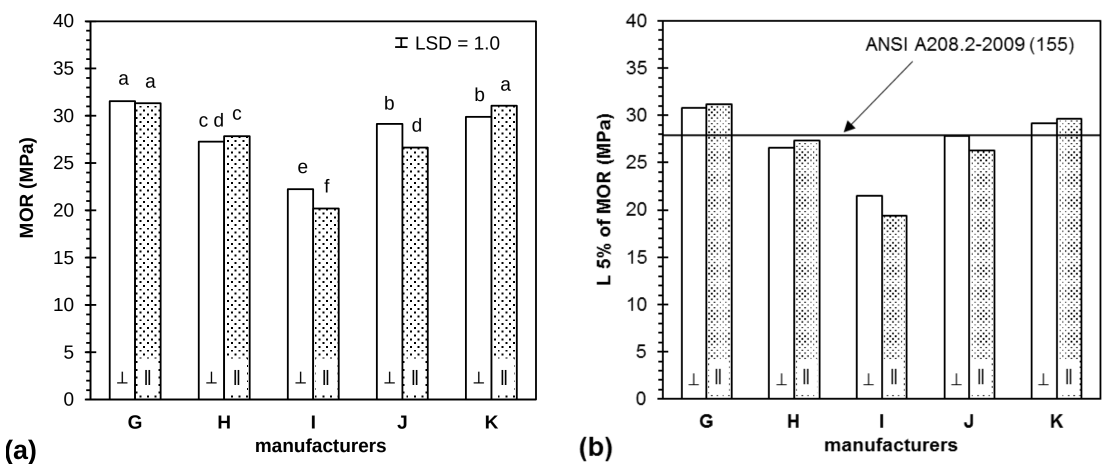


Fig. 8. The MOR for the MDF manufacturers evaluated for both machine directions. The (a) mean MOR values (n=40) of each manufacturer. Means with the same lower case letter above the columns were not significantly different at $\alpha = 0.05$. The (b) lower 5th percentile of the normally distributed MOR, presented in accordance with the new ANSI standard from 2009.

Only Manufacturers G and K exceeded the ANSI standard, whereas the remaining three manufacturers did not meet the voluntary standard. Manufacturer J had the highest CVs for both machine directions (⊥ = 13.1%, ∥ = 11.1%) and Manufacturer G the lowest (⊥ = 4.8%, ∥ = 3.5%). The relatively high CVs for Manufacturer J explain the larger difference between the mean values (Fig. 8a) and the values for the lower 5th percentile (Fig. 8b).

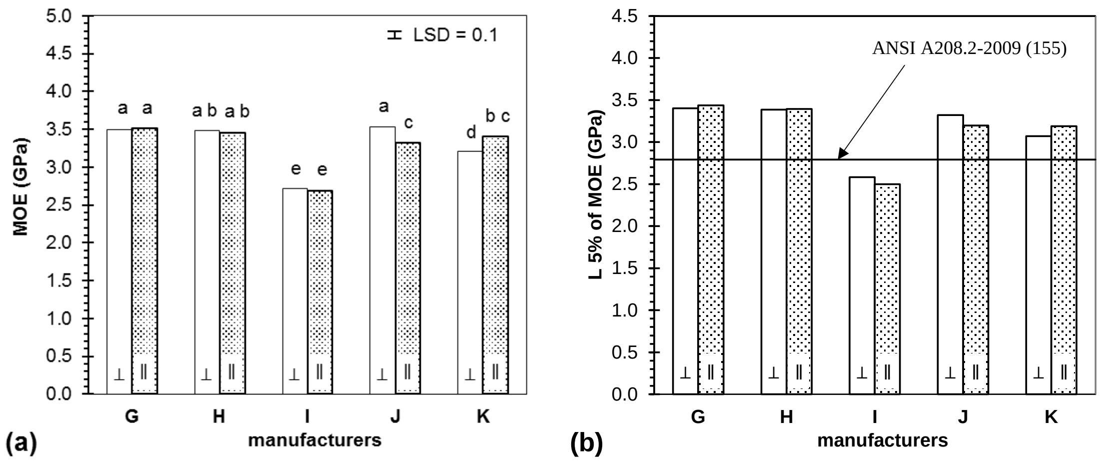


Fig. 9. The (a) mean MOE values for both machine directions for each manufacturer. Means with the same lower case letter above the columns were not significantly different at $\alpha = 0.05$. The (b) lower 5th percentile of the normally distributed MOE, presented in accordance with the new ANSI standard from 2009.

MOE values exhibited a similar trend as the MOR but had fewer differences with regard to the machine direction. It had no significant impact on Manufacturers G, H, or I. Further, means for Manufacturers G⊥, ∥, H⊥, ∥, and J⊥ were not significantly different. Figure 9a and Table 1 show detailed comparisons of the means for each manufacturer and machine direction. Mean values ranged from 2.7 (Manufacturer I) to 3.5 GPa (Manufacturers G and H). Coefficients of variance showed very similar results. The highest CVs were found for Manufacturer J for both machine directions (⊥ = 10.5%, ∥ = 10.7%), and the lowest were found for Manufacturer G (⊥ = 4.8%, ∥ = 3.9%). In contrast to the MOR, only Manufacturer I did not comply with the ANSI standard (Fig. 9b).

Manufacturer G had the highest MOR and MOE values, similarly to other mechanical properties. As discussed earlier, this can be partly attributed to the use of pMDI. Lee and Park (2012) studied the effects of different mole ratios of UMF resin on MDF properties and compared them to boards bonded with UF, concluding that UMF-bonded panels had similar mechanical properties. Manufacturer H used UF at 12.3% (o. d.), Manufacturer I used UMF at unknown resin content, and Manufacturer K use MUF/UF (face/core) at 9 to 11% (o. d.). It was observed that Manufacturer I had the lowest bending strength properties but complex interactions between unknown parameters such as resin content, press schedule, and exact furnish composition made it difficult to determine the definite factors responsible for the results observed.

Even though some manufacturers did not meet the appropriate voluntary ANSI standards, it is clear that these manufacturers are competitive within the wood composites market, can sell their products, and meet in-use performance requirements. This strongly suggests that the prescribed performance requirements (MOR and eSWR) may be set too high. Furthermore, some test procedures (*e.g.*, linear expansion) test boards at levels far beyond their intended use, significantly increasing testing time and costs. Revising the values and testing procedures or creating sub-categories for PB and MDF grades for specific target groups could offer a more transparent, competitive wood composites market.

CONCLUSIONS

1. None of the five tested sample sets met the recommended ANSI A208.2-2009 value for IB.
2. Mean values for TS were all significantly different, and one manufacturer did not comply with the standard.
3. Similarly to the test procedures for PB, LE was evaluated for a RH change from 50 to 90%.
4. Three manufacturers exceeded the recommended fSWR values, one was equal to the recommended value, and one failed to meet the requirements.
5. Three manufacturers exceeded the eSWR standard value, and the remaining two fell below the standard.
6. Two manufacturers met the standard for MOR, and only one manufacturer failed to meet it for MOE.
7. With the exception of the LE, manufacturer that used pMDI resin had properties that were consistently higher than for the other manufacturers.

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