Oriented Structural Boards from Split Wheat Straw: Effects of Straw Length, Panel Density, and Resin Content

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Wheat straws were split longitudinally using a specially designed straw splitter. Oriented structural boards made from the split straw strands were fabricated with polymeric diphenylmethane diisocyanate (pMDI) resin. The effects of the split straw strand length, resin content, and panel density on the properties of oriented structural straw board (OSSB) were investigated. Dimensional analysis showed that the average length of split straw strands after screening of the fines was 83.74 mm. More than 70% of the straw strands were in the range of 50 to 90 mm in length. The bending properties of the OSSB were highly related to the length of the split straws. The modulus of rupture (MOR) and modulus of elasticity (MOE) increased significantly as the split straw length was increased, particularly from 11 mm to 45 mm. The preferable length of the split straw was at least 40 mm to satisfy the MOE requirements. For a given pMDI content level, the internal bond (IB) strength increased linearly with an increase in panel density, which is consistent with previous results for wood-based panels. This study demonstrated that satisfactory OSSB can be made using approximately 3% pMDI at an average panel density of 640 kg/m³ to comply with the North American OSB products standard.

Keywords: Wheat straw; Structural panel; Straw splitting; Oriented strand board; Panel properties

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INTRODUCTION

Straws, the stalks of cereal plants, are agricultural by-products. They make up about half of the yield of cereal crops. Attempts have been made to make composite panels from straw for more than 30 years (Li *et al*. 2010). Experimental straw particleboard has been shown to have properties equal or superior to wood-based panels (Manitoba Government 1995). Generally, wood-based particleboard uses urea formaldehyde (UF) resin as an adhesive, whereas straw particleboard must use polymeric diphenylmethane diisocyanate (pMDI), which is much more expensive than UF resin. Grigoriou made particleboards from wheat straw using UF resin, pMDI resin, and various UF:pMDI combinations (Grigoriou 2000). It was demonstrated that pMDI can be an efficient adhesive in bonding straw materials. Although pMDI is an effective and efficient binder (Kojima *et al*. 2009), it is still not cost-competitive with UF resin. As a result, straw particleboard production is still limited worldwide. Indeed, no large-scale production mills have survived the acute competition from wood particleboard mills. In recent decades, research has been conducted in China on straw-based composite panels in terms of manufacturing processes and applications due to the shortage of wood resources and the adverse environmental impact from burning straw (Han *et al*. 2001, 2010a).

Oriented straw strand board (OSSB) has been developed for structural panels and has been produced commercially in China since 2009 (Han *et al*. 2010b). However, making straw-based structural board has been a rather discouraging experience. Early attempts at producing structural panels from straw were unsuccessful due to a variety of reasons. The root cause was that there was little or no bonding between the consolidated inner walls of individual hollow straws when the straws were not split to expose their inner walls to resin.

Contrary to popular belief, cereal straw does have exceptional strength, particularly in tension parallel to the stalk length. Wheat straw at a 10% moisture content has a tensile strength of 55 MPa, which is comparable with that of aspen (50 MPa) wood strands (Bach 1999). The tensile strength of straw perpendicular to the tubule is very low compared with the longitudinal tensile strength. This suggests that straw is susceptible to shear fracture, either longitudinally or through the cross-section of the tubule. To take advantage of these special attributes of straw, straw can be split longitudinally while maintaining some degree of stalk length through a shear plane.

The overall objective of this study was to investigate the feasibility of making structural panels using split wheat straw strands. Specifically, the effects of cereal species, split straw strand length, resin content, and panel density on the panel properties are discussed.

EXPERIMENTAL

Straw Splitting

The straw of wheat (*Triticum aestivum* L.) used in this study was collected from Alberta, Canada. To make split straw strands, straws were passed between a pair of rollers of a straw splitter. They were sheared to split and move forward due to the fact that the bottom rollers of the splitter rotate faster than the top rollers. The relative velocity between the top and bottom rollers determines the shear force induced, while the absolute velocity determines the capacity and efficiency of the splitter.

Panel Manufacture

Both random and oriented structural straw boards bonded with pMDI resin (BASF M20FB) were fabricated from split straw strands. Mats were manually formed and then pressed at 200 ^{o}C for 6 min to make 800 mm × 800 mm × 11.1-mm panels. Three replicates were made for each combination of experimental variables.

Effects of split straw length and straw species

To determine the effects of split straw length on panel-bending properties, regular wheat split straws were screened into six fractions based on the average straw strand length, *i.e.*, 1.5 mm, 4.5 mm, 6 mm, 11 mm, 31 mm, and 45 mm. Random structural panels using different groups of straw strands were made with a panel density of 640 kg/m^3 and a resin content of 5%.

Two types of wheat straw, *i.e.*, regular hollow straw and solid stem straw, were used to evaluate the effects of straw type. Random and oriented structural panels bonded with 5% pMDI were made from each species of split straw strands that were not screened and classified. The panel density was 640 kg/m³. For the oriented panel, the weight ratio of face/core/bottom layer was 25/50/25.

Effects of resin content and panel density

Panels with oriented mat construction were fabricated from unscreened split straw strands at different resin contents (*i.e.*, 2%, 3%, and 4%) in combination with different panel densities (*i.e.*, 640, 690, and 740 kg/m³). The weight ratio of face/core/bottom layer was 25/50/25. Two replicates were used for each condition, and a total of 18 panels were manufactured.

Panel Evaluation

All experimental panels were conditioned at 20 ^{o}C and 65% relative humidity (RH) until reaching equilibrium moisture content prior to testing. Panel evaluation was conducted in accordance with the CSA O437.1-93 standard (CSA 1993), which includes the modulus of elasticity (MOE), the modulus of rupture (MOR), the internal bond strength (IB), and the thickness swell (TS) after a 24-h water soak. Where appropriate, the panels were tested for properties both parallel to and perpendicular to the surface strand orientation direction.

RESULTS AND DISCUSSION

Morphology of Split Straw Strands and Splitting Performance

Figure 1 is an image of split straws screened over a 1/8" deck screen. The hollow straw tubes were nicely opened up, and the inner walls of individual hollow straws were exposed to receive resin, which is important to assure a good resin distribution on the straw strands. Figure 2 shows the strand length distribution of split straws after screening. The average length of split straws was 83.74 mm. More than 70% of the straw strands were in the range of 50 to 90 mm in length. Straw strands with a length above 150 mm were less than 5% of the total. It was observed that the length of split wheat straw was much longer than that of the straw particles through conventional hammermilling process (Grigoriou 2000), which could contribute in higher bending performance. Maintaining the straw strand length as much as possible is technically required in the process of straw splitting. Observations of the straw splitting process indicated that the straw moisture content had a significant influence on the performance of the straw splitter. As the strand moisture content was reduced, both the degree of straw splitting and the generation of fines increased. The optimum straw moisture content for straw splitting was found to be in the range of 8% to 12%. At this moisture range, the straw splitter also broke straw nodes into dust. Therefore, the maximum attainable strand length was equal to the length of the internodes of straw, which are normally not longer than 200 mm for wheat straws. The crushing of the straw nodes resulted in the elimination of high-density spots due to the presence of straw nodes.

Effects of Strand Length and Straw Species

Figure 3 shows the effects of straw strand length on the modulus of elasticity (MOE) and the modulus of rupture (MOR) of the boards. In the study range, both the MOE and the MOR increased significantly as the split straw length was increased, particularly from 11 mm to 45 mm, for a given resin content. The results indicated that the random structural panels made from split straws longer than 11 mm complied with the minimum requirement for the MOR specified by CSA O437's "O-2" grade. However, to comply with the minimum requirement for the MOE, the minimum length of the straw strands must be at least 40 mm. This result suggests that it is desirable to produce split straw with the greatest possible length to achieve high specific moduli. This agrees with previous findings on wood composites (Suzuki 2000).

Fig. 1. Image of split wheat straws

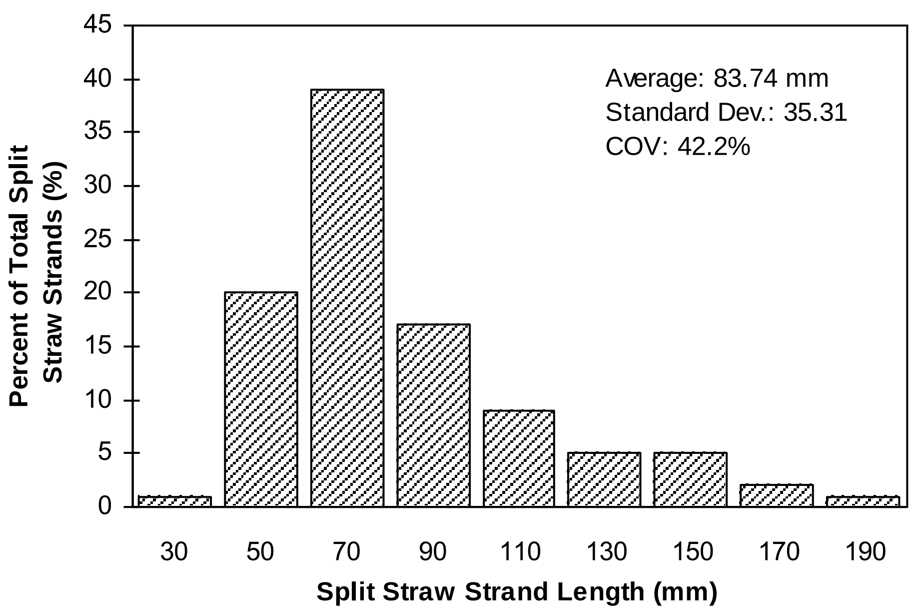

Fig. 2. Distribution of split straw strand length

Figure 4 shows the effects of straw species and strand orientation on panel stiffness. Boards made from solid wheat straw stems tended to have a higher MOE than those made from the regular spring wheat straw (hollow) stems. The higher MOE of the boards from the solid wheat straw stems could be related to the natural structure of the solid straw stems. The properties of panels from both species were able to meet the requirement for the MOE specified by CSA O437's "O-2" grade. Similar to wood OSB (oriented strand board), strand orientation had a significant effect on the bending performance of the OSSB. Boards with oriented structure had a higher MOE in the direction parallel to the surface strand orientation compared with the random structural panels. The results demonstrated that oriented structural boards from split wheat straws could exceed the minimum commercial requirements in bending strength and stiffness using production parameters similar to those used for wood OSB.

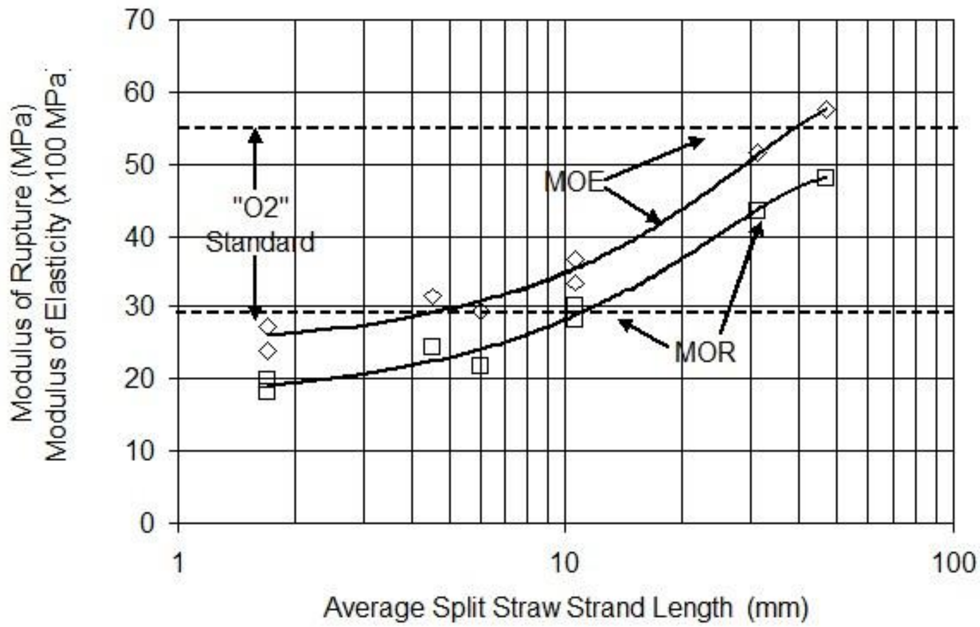

Fig. 3. Effects of straw strand length on the modulus of elasticity (MOE) and the modulus of rupture (MOR) of the boards

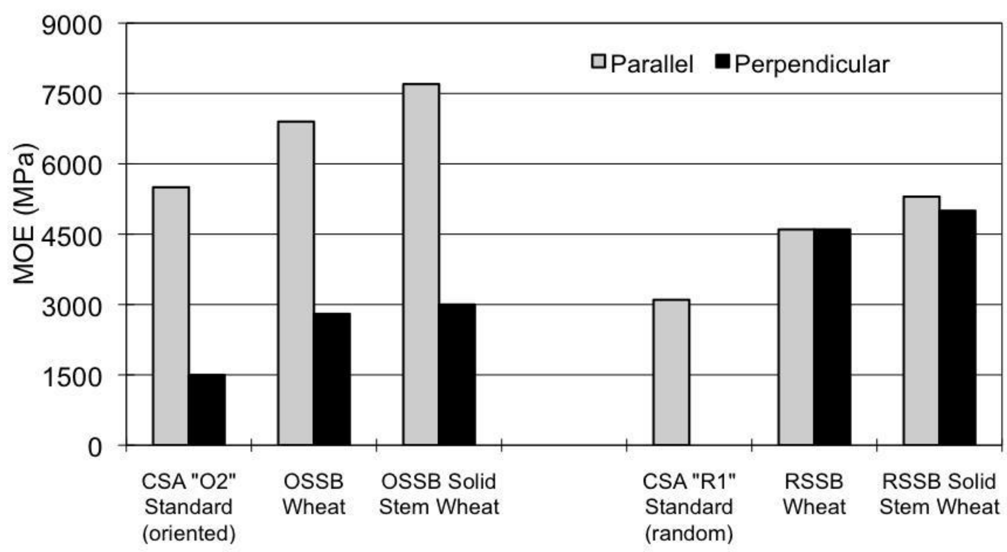

Fig. 4. Effects of straw species and strand orientation on panel stiffness (MOE). RSSB = random structural straw board

Effects of Resin Content and Panel Density

At present, pMDI is the only effective resin adhesive for making straw structural panels. However, it is relatively more expensive than phenol-formaldehyde resins for producing unit structural panels. Therefore, a small increase in pMDI content will increase production costs substantially, and the pMDI content required is thus of great concern for board producers.

Table 1 shows the panel properties at various resin contents and density levels. As expected, the MOR and IB strength increased as panel density and pMDI content increased. The panel properties increased markedly when resin content was increased from 2% to 4%. Figure 5 shows the IB strength of OSSB as a function of resin content and panel density. Similar to wood-based panels, the IB strength increased linearly with increasing resin content and panel density (Kelly 1977). Within the scope of this experimental study, approximately 3% pMDI was sufficient to make an OSSB panel at an average panel density of 640 kg/m³ to comply with the requirements specified in the CSA O437 standard for its O-1 grade. However, boards with 2% resin content failed to meet the requirements.

Table 1. Summary of Panel Properties at Various Resin and Density Levels

Target Density (kg/m^3)	pMDI Content (%)	Actual Density (kg/m^3)	Parallel		Perpendicular		TS (%)
			MOR (MPa)	MOE (GPa)	MOR (MPa)	MOE (GPa)	
640	2	643 (12)	21.9 (1.12)	4.0 (0.09)	13.9 (0.59)	2.2 (0.05)	20.6 (2.23)
	3	651 (9)	30.8 (1.26)	4.5 (0.13)	18.2 (0.94)	2.4 (0.08)	12.3 (1.11)
	4	652 (10)	33.1 (1.82)	4.4 (0.15)	19.1 (1.05)	2.4 (0.12)	9.2 (0.09)
690	2	698 (13)	25.2 (1.34)	4.4 (0.11)	16.8 (0.87)	2.5 (0.06)	19.4 (1.89)
	3	692 (15)	37.2 (0.92)	5.4 (0.07)	21.2 (0.99)	2.7 (0.05)	11.6 (0.14)
	4	701 (8)	34.4 (1.67)	4.8 (0.26)	22.6 (1.02)	2.9 (0.08)	8.4 (0.23)
740	2	729 (14)	29.5 (0.76)	4.9 (0.08)	19.2 (1.11)	2.9 (0.11)	15.1 (1.45)
	3	742 (9)	39.8 (1.45)	5.4 (0.10)	23.8 (0.78)	3.0 (0.14)	9.3 (0.88)
	4	747 (7)	39.6 (1.89)	5.2 (0.12)	26.0 (1.03)	3.1 (0.13)	8.0 (0.16)
CSA-0437 Grade O-1			23.4	4.5	9.5	1.3	15

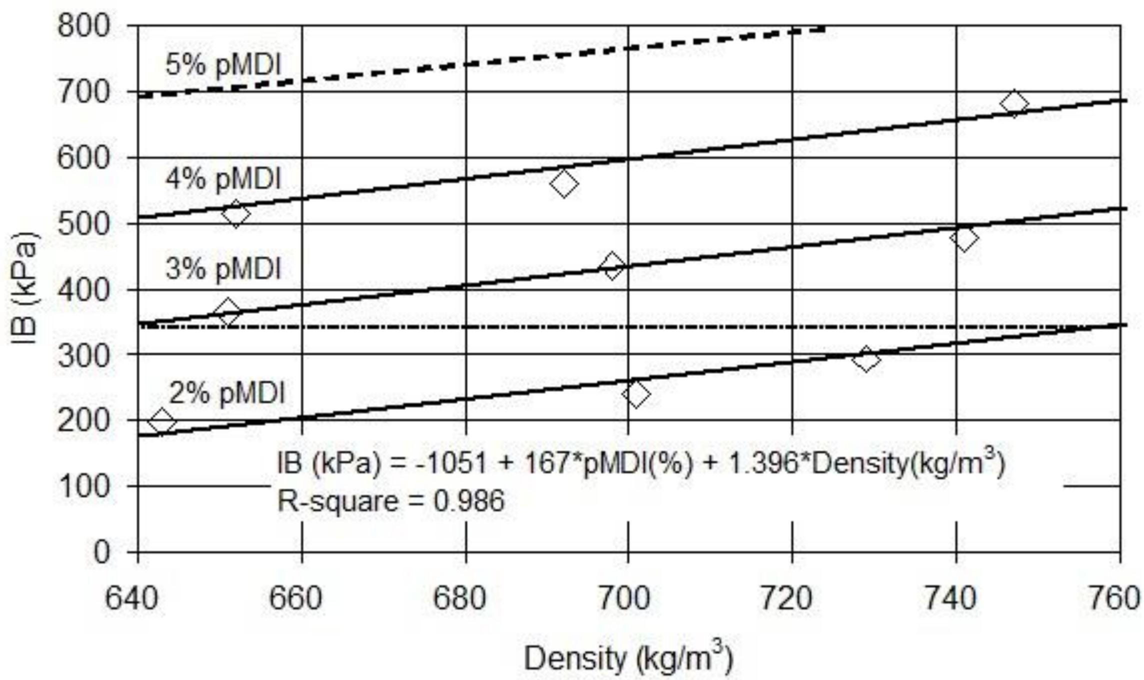

Fig. 5. The internal bond (IB) strength of oriented structural straw board as a function of resin content and panel density

CONCLUSIONS

1. By splitting the wheat straw tubule longitudinally, while maintaining as much length as possible, a panel was produced with adequate properties at a density level comparable with OSB to comply with the requirements for a structural panel.

2. The study also demonstrated that the optimal straw moisture content is in the range of 8% to 12% for splitting straws. The straw splitter breaks straw nodes to dust; thus, the maximum length of a split straw strand is equal to the length of the internodes of straw. Solid wheat straw stems tend to provide a higher bending MOE than regular spring wheat straw (hollow) stems.

3. Similar to wood-based OSB, the bending properties of OSSB increase, the IB increase, and TS decrease as the length of split straw, resin content, and panel density increase. The preferable length of split straw is at least 40 mm, to comply with the MOE requirement specified in CSA 0437 for its O-2 grade.

4. Although straws can be split and then manufactured into structural panels, the capacity and efficiency of a straw splitter are much less than those of a strander or a flaker. Therefore, it is essential to improve the capacity and efficiency of straw splitters.

5. Within the scope of this study, the main conclusion is that it is technically feasible to make structural board from split straws.

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