Oriented Split Straw Board – A New Era In Building Products

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Abstract.

While the utilisation of agricultural residues in panel products has been conducted in many parts of the world for a long time, this application has only been considered commercially viable in North America only recently. To date, the various North American operations have been making non-structural straw panels with a mixed degree of success. Raw material and binder costs plus various technical challenges are making it difficult to achieve commercial viability.

A more attractive area for straw-based panels to enter is the structural panel market. Here, the resin costs are equivalent to wood based panels and the raw material is more cost competitive with round wood. Making straw-based oriented strand board has proven to be a daunting task however. Creating an “open” strand, or split tubule, with any degree of length is difficult; a necessary task to produce structural panels from straw.

The Alberta Research Council’s Forest Products business unit (ARC) has developed a technique whereby a straw tubule can be sheared longitudinally while maintaining a relatively long “strand”. The result of this technology is an “opening up” of the straw tube to allow even distribution of the binder on all strand surfaces. The long strand allows for the development of a high strength to stiffness ratio. This makes the straw based panel comparable to wood-based oriented strand board (OSB) in physical properties at comparable densities.

This paper will outline the technique of straw splitting and present physical data on straw-based OSB panels and straw-wood mixed OSB panels. A comparison in performance to wood-based OSB will also be conducted.

Introduction

The utilisation of straw in composite panels is not a new technical innovation. The process has been around for a long time with some of the groundbreaking work dating back at least 30 years (Groener and Barbour, 1971). Most activity in the use of straw for panel products has been mainly in emerging markets, for lower end crating applications.

The use of straw in large commercial panel product ventures however is somewhat a new phenomenon in North America. Very few commercial plants here date past five years of operation. While in many areas of the world the use of agricultural residues for panel products has been initiated by necessity, North American ventures have been stimulated either by a perceived lower cost raw material, or by the search for “green” alternatives to wood-based panels.

Straw-based particleboard panels have been shown to have properties equal to or superior to wood based panels in lab trials (Manitoba Government, 1995). This work has been scaled up somewhat successfully to the commercial level. The limited success of straw panel commercial ventures to date can be mostly attributed to the newness of the product and limited market exposure. However, there are two areas where straw-based particleboard is not competitive with its wood based counterpart; raw material cost and resin cost.

In most circles, straw has been purported to cost 50% less than wood when delivered to the plant gate. This comparison is somewhat in error since the wood cost used in the comparison refers to round wood whereas in particleboard, wood residues, the chief raw material for this product, cost considerably less than round wood. The result is raw straw cost is very comparable to the raw material used in wood-based particleboard.

With respect to resins, wood-based particleboard uses urea formaldehyde (UF) resin whereas straw based particleboard is bonded with diphenylmethane diisocyante (MDI). MDI is a very effective and efficient binder but it is four times the cost of UF resin. While there now is technology to bind straw with UF resins, there are no commercial operations presently in a position to utilise this new breakthrough (Wasylciw, 2001).

Finally, particleboard is considered to be a low end product when compared to medium density fibre board (MDF) or oriented strand board (OSB). That is, while straw with MDI can produce a superior particleboard product, there is no premium paid for superior particleboard.

In the final analysis using straw to make particleboard is a challenge. Garnering commercial success from a moderately priced raw material combined with a high cost resin to yield a lower end product requires a highly sophisticated and large-scale production facility. In addition, the product market must be strong.

If straw could be used in structural panels however, the cost structure would be more appealing. From a raw material standpoint, structural panels utilise round wood which is much more costly than straw. From a resin standpoint, wood based OSB utilises MDI resin so resin cost is not an issue; unless straw requires more resin to achieve the same properties. Finally, a straw structural panel enters a higher end market with more potential to command a price premium. All shortcomings of straw based panels in particleboard are of no consequence in terms of OSB. There is incentive then to produce structural panels from straw.

Early attempts at producing structural panels from straw were unsuccessful. The lack of success could be attributed to a variety of factors. However, workers at ARC concluded the most likely cause was the limited degree of inter-strand bonding that occurs when binder is applied to an un-split straw tube then pressed. The end result is that binder is only applied to the outside half of the “strand”. This results in insufficient bonding sites between discrete particles and therefore inability for the panel to carry load. It was felt that by splitting the straw tubule longitudinally, while maintaining as much length as possible, a panel could be produced with adequate properties and low enough density to satisfy the requirements for a structural panel.

To test this hypothesis, machinery was developed to split straw longitudinally in sufficient quantities to produce a variety of panels; some with straw alone and some wood mixed with straw combinations. This paper shall outline the straw splitting device, the different panels produced and their properties. Based on these data, the suitability of oriented split straw board (OSSB) to enter the commercial structural panel market shall be addressed.

Experimental

1. Straw Splitting

Contrary to popular belief, cereal straw does have exceptional strength, particularly in tension parallel to the stalk length. ARC tensile strength comparisons between Canadian Red Spring Wheat straw at 10% moisture content and Aspen wood strands yielded comparable tensile strength results of 55 MPa to 50 MPa respectively (Bach, 1999). In comparison tensile strength of straw perpendicular to the tubule is very low, the result is straw that is susceptible to shear either longitudinally or through the cross-section of the tubule. The key to straw splitting is to take advantage of this phenomena by some mechanism. If a shear plane is produced, straw can be split longitudinally while maintaining some degree of stalk length.

The process of shearing straw was developed through examination of the principle of two counter-rotating rollers, rotating at different speeds. This differential velocity results in the shearing action when straw is fed between the rollers. The relative velocity between the rollers determines the degree of shearing action while the absolute velocity determines the capacity of the device. The technique itself is fairly robust as the orientation of the straw tubule is irrelevant. Orientation of the tubules parallel, perpendicular or at some angle in between the direction material flow will result in the necessary shearing action. Once the principle was verified, various elements were incorporated into a prototype splitting device capable of delivering at least one tonne of split straw per hour (Figure 1).

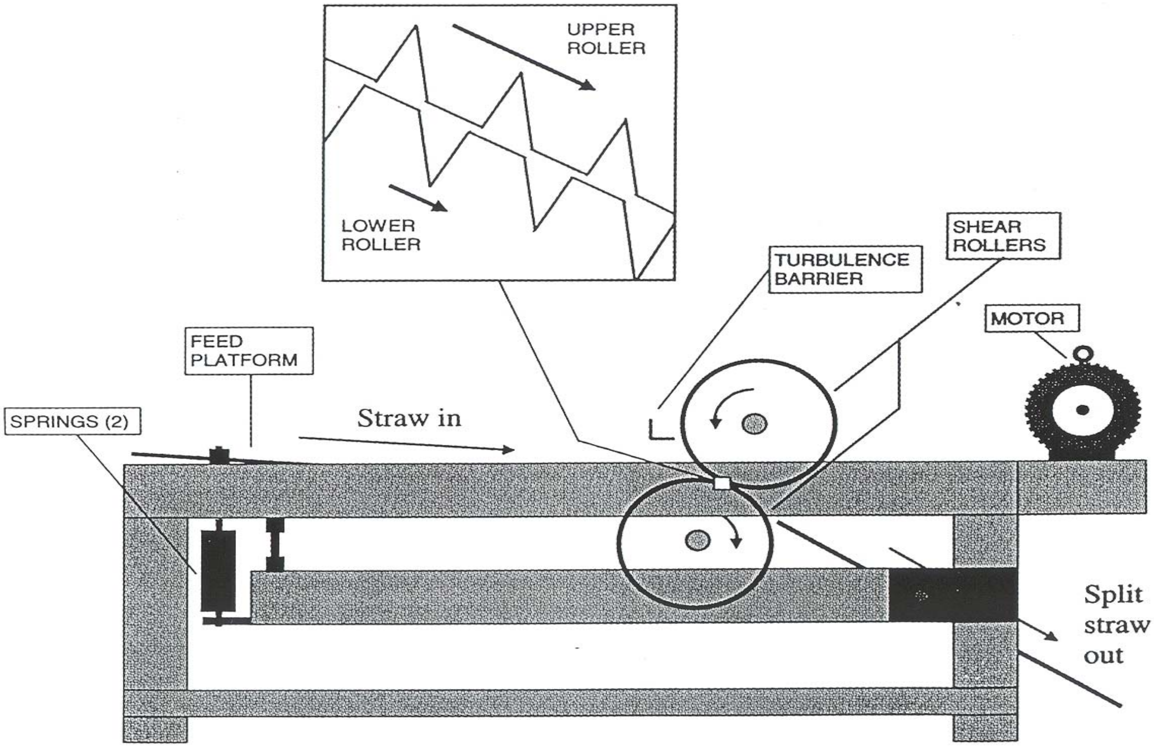

Figure 1. Schematic of the first generation straw splitter prototype

The main features of the device focus on the rollers of course. A variety of roller groove patterns were tested for machine performance prior to design. The most effective combination was determined to be a parallel-grooved pattern perpendicular to rotational motion on bottom or “slow” drum, combined with a spiral-grooved pattern on upper or “fast” drum. The spiral is at 45° from longitudinal axis of the drum in a left hand thread. There is a setting device that allows adjustment of the clearance between upper and lower rollers for different materials. The lower roller is spring loaded; to accommodate thick mats that may be unintentionally fed into the device. This could result in plugging of the device. On the prototype the intent was to manually feed straw into the splitter in a mat less than 15 mm thick. The rollers are 762 mm wide and 400 mm in diameter. The rollers are belt driven by an electric motor that is equipped with a variable speed drive. The speed ratio between the upper and lower rollers is 10:1.

After initial operation, it became evident that one pass through the rollers resulted in roughly 60% to 70% of the straw being split. Two passes through the rollers resulted in over 90% of the straw being split. Therefore a second-generation prototype was developed with two sets of rollers (Figure 2). The result is the splitting of nearly all the straw in one pass. A picture of the first prototype is in Figure 3.

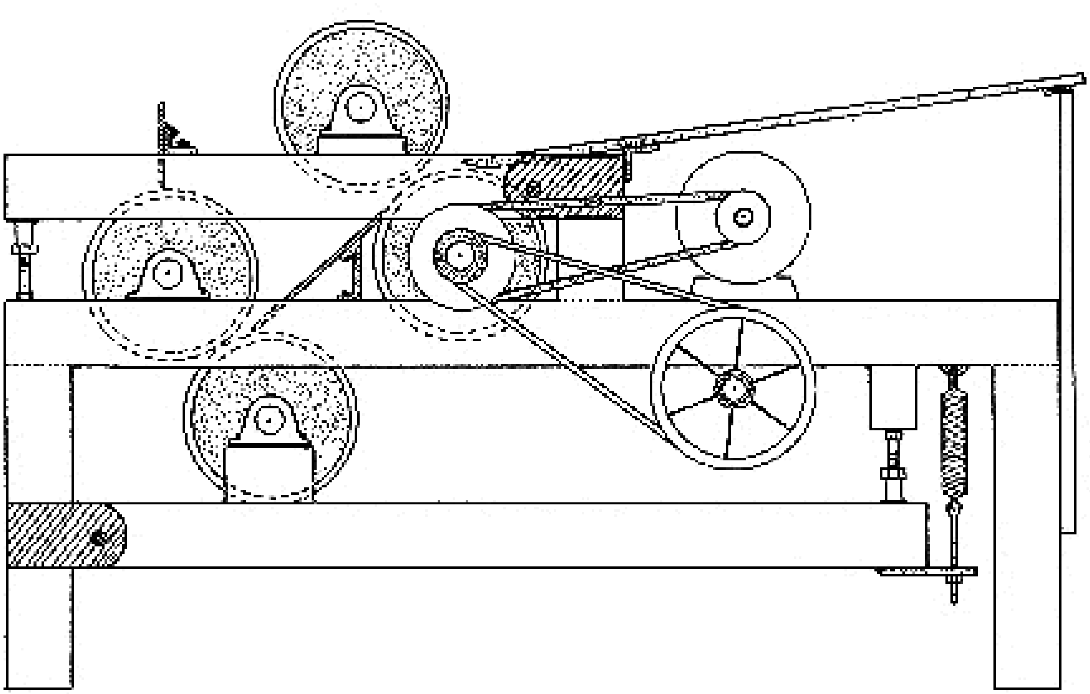

Figure 2. Schematic of the second-generation straw splitter

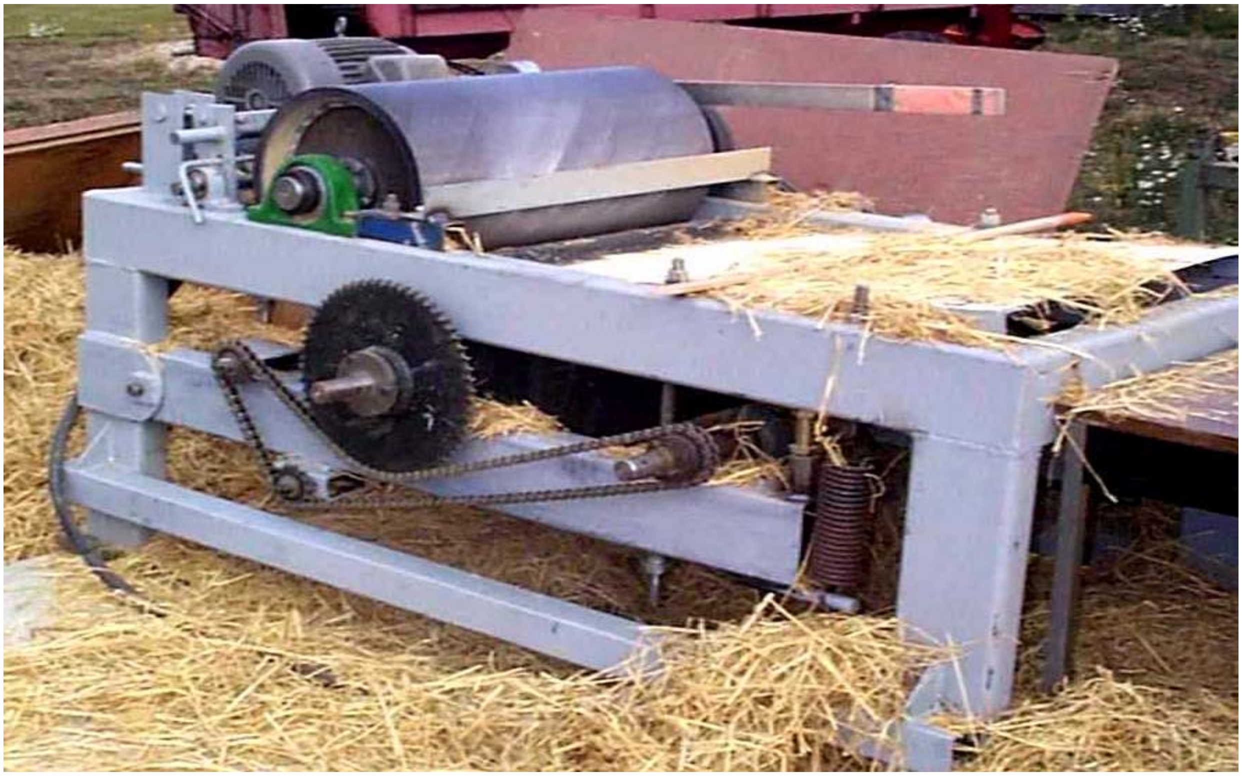

Figure 3. Picture of the first generation Alberta Straw Splitter

2. Panel Manufacture

A whole range of panel production strategies were attempted to ascertain the limits to which structural panels from split straw could be applied. Straw species, straw length, panel resin content, panel density and straw-wood panel combinations were different variables used in different studies to quantify oriented split straw board (OSSB) performance.

Panel evaluation consisted of testing all panels to CSA 0437.1 Standard for commercial OSB. The CSA standard calls for the testing of the following properties to ASTM methods: modulus of elasticity (MOE), modulus of rupture (MOR), internal bond or tension perpendicular to the panel plane (IB), bond durability or strength after two hour boil and thickness swell after 24 hour water soak (TS). Where appropriate, the panels were tested for properties both parallel and perpendicular to machine direction.

All panels were produced in ARC's Forest Products Panel Development Pilot Plant using standard production equipment (dryers, formers, blenders and presses) that can be found in any OSB mill. Pressing was conducted either on ARC's 864 mm x 864 mm or 1200 mm x 2400 mm heated platen presses, using ARC's PressMAN© Press Monitoring System. All panel conditions were replicated at least three times.

Not all data are presented here; only specific topics and properties are presented which shall give the reader an overview of the performance of OSSB. This was done to maintain both clarity and brevity in this paper format.

2.1 Strand Length Effects and Straw Species

The effects of strand length, straw species and particle size distribution on panel performance were investigated by screening various size fractions of split straw. The necessary fractions were then combined to manufacture the appropriate panel type.

With respect to the effects of split strand length, split straw was screened to produce six different strand length classes. The average strand lengths were: 1.5 mm, 4.5 mm, 6 mm, 11 mm, 31 mm and 45 mm. Panels were made exclusively with each size class and the effects were quantified through MOR/MOE data. All panels were 800 mm x 800 mm x 11.1 mm in dimension with a density of 640 kg/m³ using random mat construction. All panels were manufactured using 5% MDI binder.

To test the effects of straw species, solid stem or “sawfly resistant” wheat straw was procured from South Eastern Alberta and run through the splitter. Panels were produced from this straw and compared to regular red spring wheat using the same production parameters. All panels were 800 mm x 800 mm x 11.1 mm in dimension and 640 kg/m³ in density. All strands received a 5% MDI binder treatment and mat construction was either random or oriented with 25% of the mass in each face layer and 50% of the mass in the core layer. Random and oriented panels were produced with “regular” wheat straw in the same fashion.

2.2 Panel Density and Resin Content Effects

Unscreened split straw strands were subjected to different resin contents in combination with different mat weights then pressed into panels. A complete factorial was conducted in the experiment using panel densities of 640, 690 and 740 kg/m³ in combination with MDI resin contents of 2%, 3%, 4% and 5%. All panels were 800 mm x 800 mm x 11.1 mm in dimension and all panels were oriented with a 50:50 face-core mass split.

2.3 Wood-Straw Mixtures

Two different panel types were manufactured in this study.

The first case consisted of split straw sandwiched between two layers of aspen strands. In this case, MDI binder contents of 2%, 3% and 4% were combined with panel target densities of 640, 690 and 740 kg/m³. The panels were 800 mm x 800 mm x 11.1 mm in dimension. All mats were 50:50 face-core mass split with both the face and core materials oriented.

The second case consisted of mixing split straw with aspen strands in progressive straw-for-wood substitution levels from 0% to 100% in 25% increments. The blends of straw and wood received a 3% MDI binder application. The blends were then formed into oriented mats (50:50 face-core mass split) then pressed. The panels were 800 mm x 800 mm x 11.1 mm in dimension and 640 kg/m³ in density.

3. Results

3.1 Straw Splitter Performance

The best machine performance was achieved with the upper roller rotating between 1000 and 1500 rpm and the lower roller between 100 and 150 rpm. The degree of straw splitting increased with a decrease in straw moisture content. However, a decrease in straw moisture content also resulted in an increase in fines. The best balance between degree of straw splitting and fines generation occurred when the moisture content of the straw was between 8% and 12%. Here fines generation was less than 10% and the degree of splitting was 90% or better. The straw splitter also broke up the straw nodes into dust, allowing for the split straw to be uniform with no nodes to cause panel discontinuities. This observation also suggests that the maximum attainable strand length with is method is the internodal distance on straw tubule being split. In most cases, this length would not be more than 200 mm.

3.2 Effects Of Strand Length, Straw Species and Orientation

Both panel stiffness (MOE) and strength (MOR) were affected dramatically with an increase in split straw strand length (Figure 4). The results were most dramatic for panels derived with straw strands above 10 mm. The minimum commercial standard for panel strength (CSA 0437 “02” grade) was easily attained with strand lengths just over 10 mm. For panel stiffness however, strand lengths of over 40 mm are necessary to meet the minimum commercial standard. As expected, the longest strand possible is necessary to produce a panel with a good strength to weight ratio. This is consistent to observations with wood.

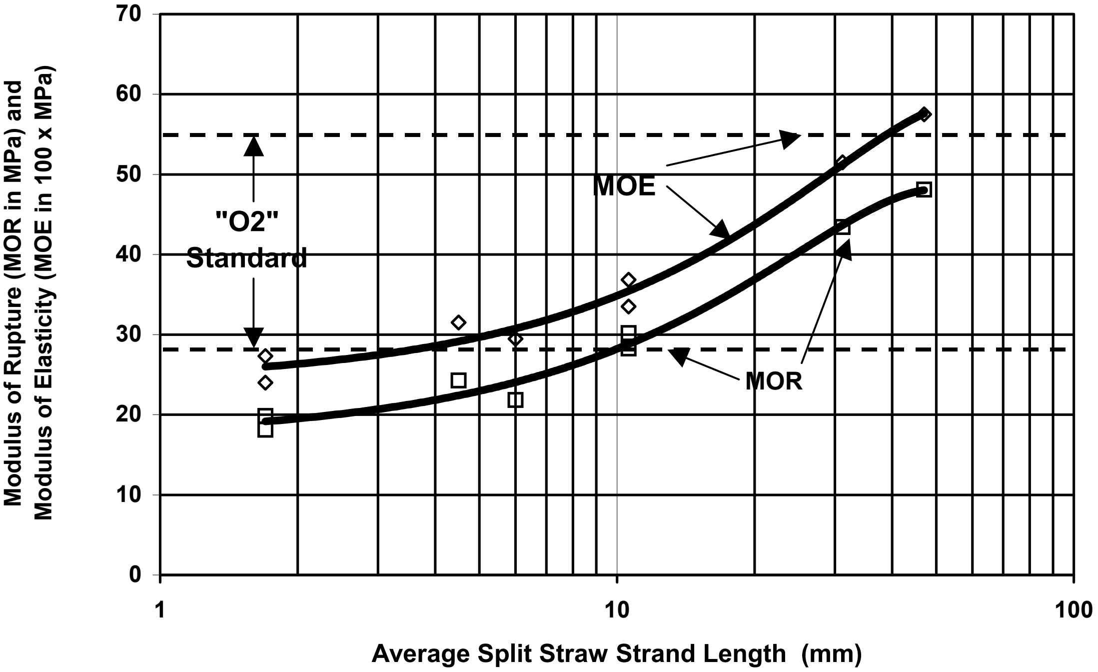

Figure 4. The effect of straw strand length on panel stiffness (MOE) and strength (MOR)

The manufacture of OSSB using solid stem wheat had an effect on panel bending properties. In both random and oriented panels, solid stem wheat showed better panel stiffness (MOE) than regular red spring wheat straw (Figure 5). Similar values were also obtained with respect to panel ultimate strength or MOR (data not shown). This observation is truly important as it illustrates one of the advantages straw has over wood. Through genome selection or genetic manipulation methods, straw can be tailored to produce desirable properties for industrial applications. This process has far less turnaround time with straw than with wood.

Of equal importance, the strength and stiffness data obtained shows OSSB panels can exceed the minimum commercial requirements using typical production parameters encountered in wood OSB. In addition, straw behaves the same as wood regardless if formed into random or oriented panels.

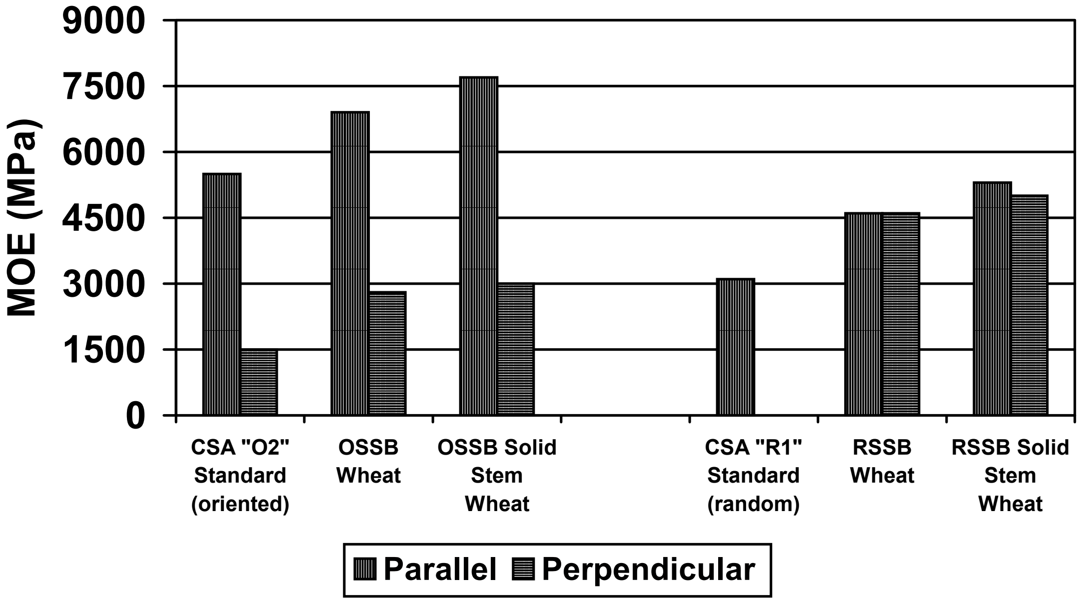

Figure 5. The effects of straw species and strand orientation on panel stiffness (MOE)

3.3 Effects of Resin Content and Panel Density

In wood-based panels, the inter-relationship between internal bond (IB), resin content and panel density has been well reported. The relationship is essentially linear. Thus, for a given resin content, the IB can be adjusted up or down by changing panel density. This observation also holds true for OSSB (Figure 6).

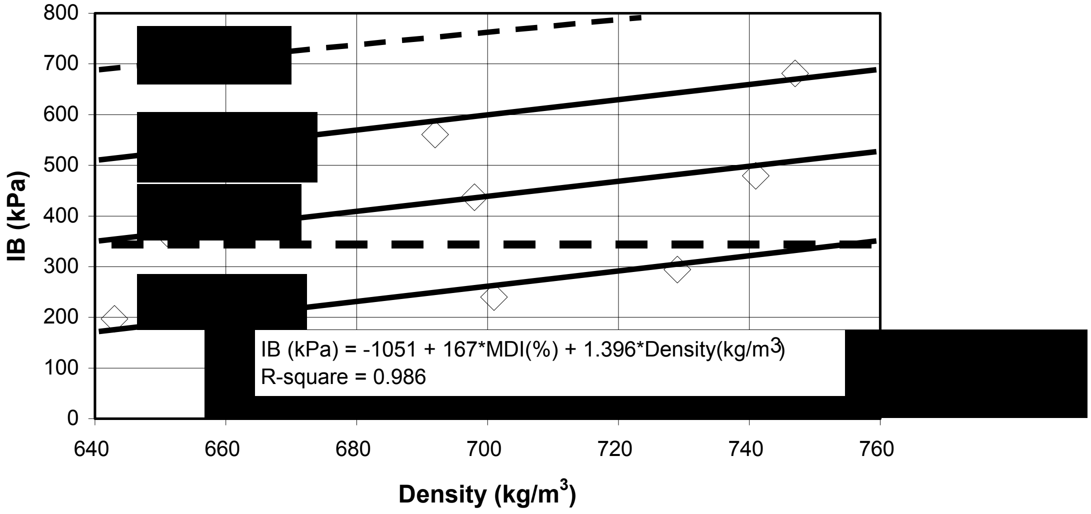

Figure 6. Response of OSSB internal bond (IB) to resin content and density variations

As illustrated, for a given MDI resin content, there is a positive linear response in IB for an increase in panel density. Up to this point in time, MDI is the only available binder that can bond straw in a structural panel with this effectiveness. However, in structural panels this is not an issue. The most important finding is that for an average OSSB panel density of 640 kg/m³, the amount of MDI required to achieve the minimum internal bond requirement of 345 kPa in CSA 0437 is approximately 3%. This is well within established parameters for wood based commercial OSB, thus illustrating the performance of OSSB.

3.4 Wood-Straw Mixtures and Structural Panels

Most likely, if straw panels are to emerge as a building product in North America, the entry point would be as a blend with wood. Supplementing the fibre supply of a mature OSB mill to conserve the wood resource around the mill could be a plausible strategy. What form a wood-straw panel would take is unknown, however for this to occur, some understanding on straw-wood blends in necessary.

3.4.1 Wood-Straw Sandwich Panels

In this case, split straw is placed in the core of the panel (50% of the panel mass) and the faces are made from aspen (25% mass on each face). As expected, the MOR/MOE parallel to machine direction were able to meet the minimum commercial requirements (Table 1). When the MOR/MOE values perpendicular to machine direction are considered, either an increase in resin content or an increase in density is necessary to meet the minimum commercial standard. This is important as the wheat straw core governs bending properties perpendicular to machine direction.

Property	**Units**	**Direction**	**“O2” Std.**	**640 kg/m^3 Density**			**690 kg/m^3 Density**			**740 kg/m^3 Density**		
				2%	**3%**	**4%**	**2%**	**3%**	**4%**	**2%**	**3%**	**4%**
MOR	MPa	Para	**29.0**	36.6	45.7	53.6	37.2	50.3	59.9	43.7	58.5	69.5
		Perp	**12.4**	11.0	10.5	12.6	11.5	15.0	16.6	14.3	15.4	16.0
MOE	MPa	Para	**5500**	8200	9200	9800	9200	9400	10500	10600	10200	11200
		Perp	**1500**	1400	1400	1500	1700	2000	1900	1900	2100	1900
IB	kPa		**345**	230	373	476	255	372	602	245	464	720

Table 1. Properties of various wood-straw sandwich panels in relation to changing density and MDI resin content

The internal bond values obtained were highly responsive to panel resin content and weakly responsive to panel core density. This is in agreement with the findings under Section 3.3 where the greater response term for IB in the linear relationship is resin content. What is most important is the relationship still holds true, that a minimum MDI content of 3% is necessary to achieve the minimum commercial IB value.

Another consideration is the fact that the straw placed into the core of these panels was unscreened. Even in wood-based OSB, fines and unscreened material have a tendency to “steal” resin from the longer strands, causing a decrease in properties. Most likely this was the case observed in the straw sandwich panels.

3.4.2 Straw-Wood Blends

Blending straw and wood together then forming the mixture into a coherent mat proved to be a difficult task. The dissimilar densities, geometries and surface characteristics of split straw and wood led to mixing analogous to mixing oil and water. None-the-less, the two dissimilar materials were combined to produce panels with little consequence.

The main phenomenon observed was the substitution of straw for wood did result in a decrease in panel properties (Figure 7). This was not wholly unexpected given the dissimilar materials and the difficulties encountered in mat forming. Of note however, is even at a 50:50 wood-straw blend the properties obtained were still well above minimum acceptable commercial standards. This bodes well for the extension of an OSB mill's fibre supply with split straw.

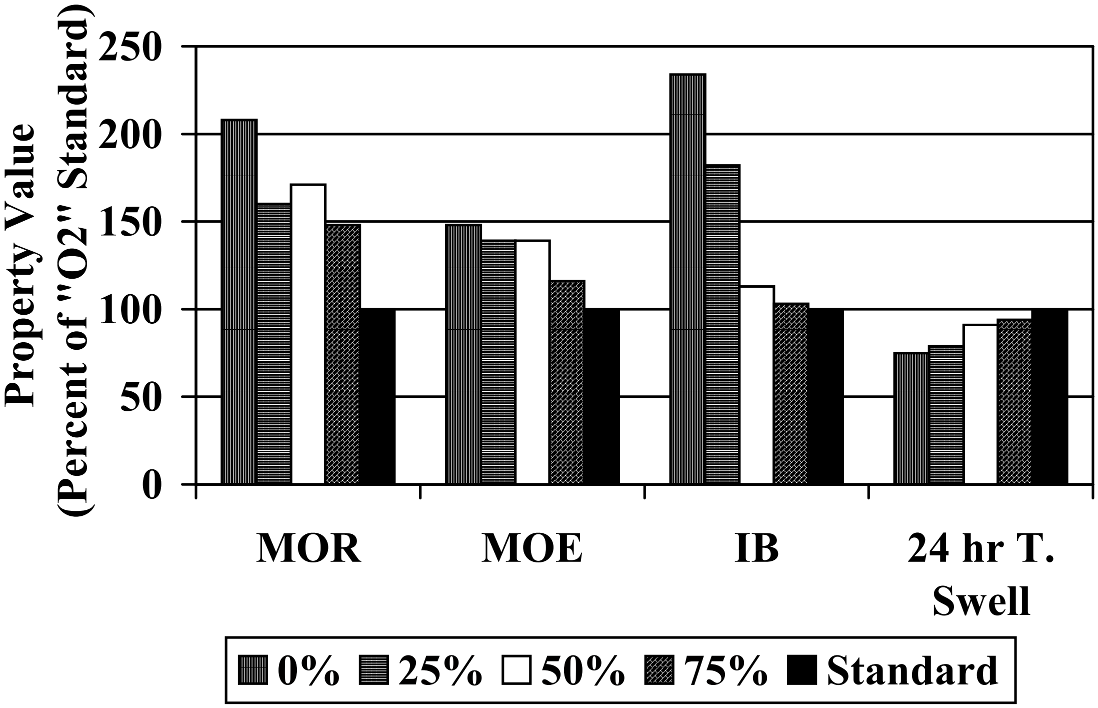

Figure 7. Response of straw for wood substitution in straw-wood blends on various panel properties (0% = 100% wood, straw added in 25% intervals)

Conclusion

From the results obtained, it is clear that structural panels derived from straw can be produced on a pilot scale with little consequence. It is important to stress that the results obtained were done so using readily available equipment that is used in any OSB operation; with the exception of the straw splitter.

While the straw splitter does represent some degree of technical risk, the methods and principles of its operation do not require a huge technical leap. To meet the capacity of current wood-based OSB operations, a commercial straw splitter or splitters would need to produce approximately 30 tonnes of split straw per hour. An equipment manufacturer can only answer how many machines would be necessary and their cost. Given the cost and scale of a log strander, the straw splitter should be cost competitive.

Of greatest importance is the fact that OSSB has all the performance of wood based OSB using the same production parameters. Where straw gains over wood is in lower energy costs to dry and "strand". In addition, less material is lost in terms of shrinkage and bark removal. Where straw loses is in decreased density and the allowances necessary to handle the bulkier material both inside and outside the mill. A preliminary cost analysis indicates that OSSB could be produced for roughly 25% less than wood based OSB however the calculation are crude and do not include the capital cost differences between splitting and stranding.

Straw incorporation into wood panels either in sandwich or blended form does show potential. Modest amounts of straw addition of 50% or less of the panel mass create a negative change in panel properties however the minimum commercial standards can still be easily attained. Attention to minimum core density in sandwich panels, mat formation in blended panels and accommodation for straw's bulk density in both applications are essential for success.

What is most important to note is straw could be manufactured into structural panels with the current technology available to the industry with standard production parameters. The only exception is the straw splitter itself. At this point in time there is enough information to proceed to product commercialization. The question is: are the conditions right for OSSB to emerge as the building product of the new era?

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