Initial investigation on panel manufacture from Sorghum stalk residue

Agri-Science Queensland Innovation Opportunity

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Queensland Government

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Summary

This pilot study was conducted with the aim of carrying out an exploratory investigation into the possibility of using sorghum residue and a new adhesive technology to manufacture a fibre panel. Its purpose was to not only to initiate a protocol for manufacture but to also determine the properties of the panel, establishing any advantageous aspects and highlighting any shortcomings and deficiencies when assessed against current Australian standard specifications. It is our intention that this exploratory study will form the groundwork to allow us to determine which areas need further research to be able to manufacture a panel that could complement the current products available to the construction and furniture manufacturing industries.

The manufacturing process and resulting panels highlighted the following:

1. Most of the properties of the panel were below standard specifications. This result could be directly attributed to the technical characteristics of the equipment used for the resination process. It is believed that the loss of both resin and fibre during this step resulted in a lower than expected outcomes for panel density, glue bond quality, MoE and MoR. Addressing this issue will give tighter control of the amount of resin applied with minimal fibre loss and better determination of the mechanical properties of the panel.
2. Fibre pre-treatment as required when using current formaldehyde based adhesives is not necessary with an eMDI adhesive. This adhesive doesn't have the major inconvenient to release toxic emission of formaldehyde.
3. The waxy nature of sorghum results in a panel that meets Australian standard requirements for fibre swelling with minimal fibre processing. Currently all wood based fibre panels require the inclusion of a water repellent in the form of wax during the manufacturing process to achieve the percentage fibre swelling properties outlined in the Australian standards.

Table of contents

Table of images

Table of tables

Background

Queensland has the largest area of agricultural land of any Australian state and the highest proportion of land area in Australia dedicated to the growth of agricultural field crops. These include sugarcane, sorghum, cotton, summer and winter grains, fodder and pulse crops. The agricultural sector is a significant part of Queensland's economic, social and cultural fabric with the field crop industry employing thousands of people on the land, in food processing, and in other areas along the supply chain.

The State's most widely grown summer grain is sorghum (*Sorghum bicolor*) with approximately 60% of the Australian crop grown in Queensland and valued at just over $260 million as of 2014. Currently the sorghum produced in Australia is used almost exclusively for feed - especially cattle, pigs and poultry - and this totals around 1.4 Mt. None is used for human consumption and a significant market exists in the pet food industry as well as a substantial export market for sorghum, especially to Japan. Sorghum is also being used for the production of biofuel with the Dalby Bio-refinery currently processing about 500 tonnes of sorghum grain a day and approximately 170,000 tonnes a year. Most economic value is derived from the seed head and once this is harvested the sorghum straw is either used for animal feed or ploughed back into the ground with small financial gains for the producer.

This study examines an alternate use for the straw by determining its suitability for the manufacture of an agri-fibre panel and comparing it's mechanical and water resistance properties to current similar wood fibre based products such as particleboard and Medium Density Fibreboard (MDF). Both MDF and particleboard are heavily used in the construction and furniture industry with particleboard consumption currently just below 1 million cubic metres and production well below this at around 900 thousand cubic metres. 2014-2015 showed strong production and consumption of these boards with increases in production of 6% and 10% for particleboard and MDF respectively over the 2014-2015 period. MDF consumption, including imports, was up by 21% to 467 thousand cubic metres. There is now a growing imbalance in supply and demand and Australia's growing population indicates this disparity will worsen with the Australian production not able to meet market demands resulting in a heavy reliance on imported products.

Bio-based products are emerging as a valuable new industry worldwide. The use of agricultural fibre for production of structural and non-structural panels is in its infancy however increasing amounts of research is being carried out in Canada, America, Europe and Australia with a variety of fibres such as bagasse, cotton, hemp, flax and rice. Since 1995 there has been a proliferation of new manufacturing facilities in Canada and the US to produce composite panels from agricultural fibres. With the increase in population placing a heavier demand on our forest resources for the domestic and export markets, as well as the growing concern about the environment, these new and emerging technologies must be considered if Australia is to meet its future demands.

Project Objectives

Chipboard, fibreboard, and particle board are engineered materials made by gluing wood chips, flakes or strands together using a suitable adhesive system under high pressure and elevated temperatures. These products have multiple uses within the construction industry including furniture manufacture, flooring and other structural applications. The Australian standards (AS/NZS 1859.1:2004 and AS/NZS 1859.2:1997) outline the specific physical and mechanical parameters that the product is required to meet according to its end use.

The primary aim of this project was to assess the potential use of ligno-cellulosic agricultural fibre residue materials as feedstock for panel manufacturing and to evaluate the properties of the panel fabricated with regard to the relevant Australian standards. This study pursued the following two specific objectives:

1. Investigate new adhesive technologies with a common Queensland agricultural crop residue will remove the need for fibre pre-treatment as required for more classical formaldehyde based adhesives.
2. Compare the effect of two different fibre sizes on the mechanical properties of the panel as outlined in the Australian Standards for particleboard and medium density fibreboard (MDF)

Methodology

Initial discussions were held with Professor David Jordan at the Hermitage Research Station situated in Warwick to determine which fibre crop would be the most suitable for the study. The recommendation was made to use sorghum (*Sorghum bicolor)* as Queensland produces approximately 60% of the Australian crop with around 700,000 hectares planted every year resulting in a large fibre residue volume.

Sorghum fibre residue was supplied by the Gatton Research Station as a round bale consisting mainly of large stalks and foliar material. This was broken open into a large steel container where it was mixed to achieve particles homogeneity. Samples were taken randomly from different places within the mix and moisture content determination was carried out by oven dry weight.

The following manufacturing sequence was applied:

Grinding: Two panels were manufactured using different fibre sizes. 30Kg of sorghum fibre was passed through a Hansa C7 chipper with the knives set at a distance of 1mm from the anvils. 12Kg was weighed and manually sieved through a 1.5mm mesh to remove fine particles and set aside for use in the manufacture of the **first panel**. The remaining material was passed through a Crompton series 2000 rotary hammermill fitted with a 5mm screen and the grindings collected in a large plastic bag. This material was also sieved through a 1.5mm mesh to remove fine particles resulting from the grinding process. The 5 mm grindings were used in the manufacture of the **second panel**. (Image 1)

Image 1- Different stages of grind. Unground (left), Hansa Chipper (middle) and Crompton 5mm hammer mill (right)

In order to comply with current standards, the density for both panels was required to be in the range 650-700kg/m^3. A custom designed panel retaining mould was specifically designed and manufacture to produce 900 mm square panels with a thickness of 12 mm (Image 2).

Image 2- Custom mould for panel production.

The weight of sorghum fibre mat needed to give the targeted density range was between 6.3kg and 6.8kg.The panel manufacturing process was the same for both grades of fibre sizes.

Resinating: Following consultation with a number of major adhesive manufacturers, the adhesive selected was an emulsifiable methylene diphenyl diisocyanate (eMDI), I-Bond PB EM 4352 supplied by Huntsman Polyurethanes. This class of adhesive is quite new in wood manufacturing industry and provides a high adhesion capacity on many materials. 6.8kg of ground sorghum fibre was weighed into a container on a floor standing balance before being transferred to a rotary mixer made from a modified concrete mixer. The mixer was started and adhesive was applied at a rate of 4% of total fibre weight (equating to 272g) using an oscillating spray nozzle sprayed directly into the rotary mixer.

Pressing: After resinating, the mix was transferred to a 1000mm x 1000mm pressing mould that had been pre-treated with the releasing agent I-Release OSB 9111 (Huntsman polyurethanes), to prevent the eMDI resin and subsequently the pressed panel to adhere to the mould. A 900mm x 900mm plywood retainer mould was manufactured to contain the fibre mix and stop it spilling over the edge of the pressing mould. The resinated fibres were spread as evenly as possible over the whole area within the retaining mould and manually compacted down using a square timber block. Special attention was paid to the edges and corner to ensure good compaction and then the retaining mould was slowly removed so as not to break the edges (Image 3). An aluminium sheet (1200mm x 1200mm) treated with the release agent was carefully placed on top of the mix. The pressing mould was placed into a single daylight hot press set at 170˚C and the pressure was increased until the platens were in contact with retaining edges (12 mm). A pressure of 200 bars was maintained during 2 minutes followed by a progressive release ramp of 2 minutes. The pressing mould was immediately removed from the press and the agri-fibre panel carefully removed with a long steel spatula. It was then placed on a flat surface to allow cooling to room temperature.

  

Image 3 - Plywood retaining mould (left), manual press (centre) and panel prior to automated pressing (right)

Trimming: Panels were trimmed to 800mm square on a panel saw to remove edge effects.

Both panels were submitted to the Engineered Wood Product Association of Australasia (EWPAA) for testing in accordance with the relevant Australian Standards. Testing was carried out for:

1. Modulus of elasticity/ Modulus of rupture (MoE/MoR) , (AS/NZS4266.5:2004 Reconstituted wood based panels- methods of test. Method 5: Modulus of elasticity in bending and bending strength).

   The modulus of elasticity measures the panel's stiffness and is a good overall indicator of its strength. Technically it's a measurement of the ratio of stress placed upon the panel compared to the strain or deformation that the wood exhibits along its length. MoR referred to as bending strength, is a measure of a specimen's strength before rupture. It can be used to determine the overall strength of a panel.

2. Internal bond (IB): AS/NZS4266.6:2004 Reconstituted wood based panels- methods of test. Method 6: Tensile strength perpendicular to the plane of the panel (internal bond strength).

   Chipboard, fibreboard, and particleboard are engineered materials made by gluing wood chips or wood particles together with an adhesive under high pressure. The internal bond strength test is a fundamental measure of the adhesive performance in wood composites by pulling apart the faces of the panel and measuring the stress at rupture.

3. Glue bond quality (GBQ): AS/NZS4266.9:2003 Reconstituted wood based panels- methods of test. Method 9: Thickness stability and glue bond quality.

   This test is the same as MoR but carried out after the sample has been fully impregnated with water.

4. Swelling: AS/NZS4266.8:2004 Reconstituted wood based panels- methods of test. Method 8: swelling in thickness after immersion in water.

   The swelling is an indicator of how much water is absorbed into the fibres of the panel. The durability and service of life of a panel is dependent upon low swelling.

5. Density.

The cutting pattern to determine sample location was performed in accordance with AS/NZS 4266.1:2004. (Image 4)

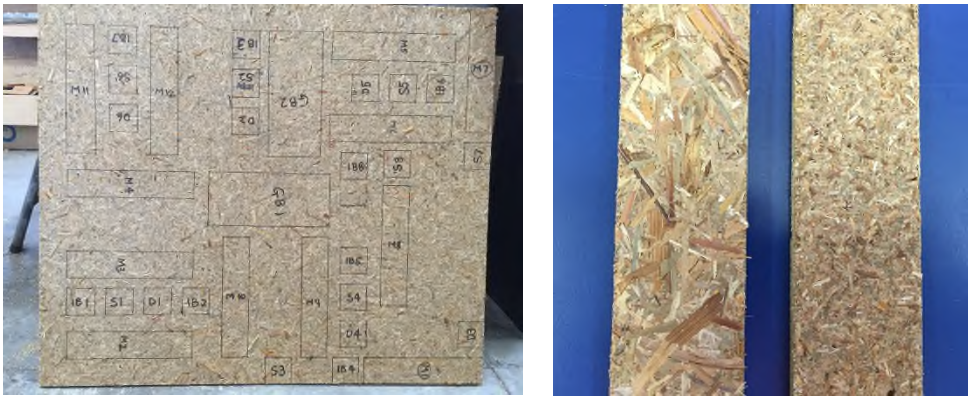

Image 4 – Final panel with cutting pattern for mechanical testing and off-cuts of final samples

Results

Testing of the two variants of the sorghum fibre boards by the EWPAA produced the following results (Table 1).

Table 1 – Mechanical properties of two fibre size variants of Sorghum fibre panels and Australian standards requirements

Test	Units	Number of samples	Mean results panel 1 - large fibres	Standard deviation – Panel 1	Mean results panel 2 - 5mm fibres	Standard deviation – Panel 2
GBQ	MPa	2	3.55	0.35	3.05	0.07
IB	MPa	8	0.14	0.03	0.2	0.07
MoE	MPa	12	878.3	128.43	1116.9	287.91
MoR	MPa	12	7.42	1.18	7.5	2.26
Swelling	%	10	7	1.94	10.5	3.30
Density	Kg/m^3	6	589	86.66	624	63.04

Table 2 –Australian standards requirements

Test	Units	Australian standard minimum requirements			
		General purpose particle board	Flooring particle board	Moisture resistant particle board	General purpose MDF
GBQ	MPa	-	8.60	-	-
IB	MPa	0.28	0.55	1	0.50
MoE	MPa	2800	2750	3000	2400
MoR	MPa	13	19	19	28
%	%	18	8	7	15

Swelling					
Density	Kg/m^3	660-700	680-700	670	775

Densities for both panels were below the target density range of 650-700Kg/m^3 with panel 1 giving the lowest density. Both panel densities were less than the requirements set out in the Australian Standards. The internal bond test shows that panel 2 gives a marginally better bond strength in comparison to panel 1 indicating a stronger adhesive bond between the smaller ground fibres which is also reflected in the panel's higher MoE result. The MoR for both panels gave similar outcomes to each other. Panel 1 constructed with the larger fibres had better glue bond quality and percentage fibre swell results possibly indicating that the panel manufactured from the larger fibres had less affinity for water than the one made from the smaller ground material. Most of the results for both panels failed to meet the requirements set out by the Australian standards with the exception of percentage fibre swell for both panels falling within the range for general purpose particleboard and MDF while only panel 1 fell within the range for moisture resistant particle board.

The mechanical properties for both fibre sizes, except for some instances of the percentage fibre swell, failed to meet the requirements of the Australian standards for all grades of particleboard and general purpose MDF. We believe that this outcome is a direct result of the problems encountered during our manufacturing process, especially during the resinating stage, having an effect on all tested mechanical properties and the density. After consideration of the options available it was decided that we would employ a similar resination process that we had used previously with good success for the manufacture of a composite panel made of sugar cane bagasse. This setup consisted of a rotary mixer used to mix and agitate the sample and a spray gun to apply the resin to the fibres. To minimise the amount of fibre material lost during the resinating process due to the rotary action of the mixer combined with the air pressure from the spray gun, a number of layers of screen mesh were placed over the opening of the mixer to catch the fibrous material and stop it from flying out of the mixer. A small hole was cut in the centre of the screen to allow resination using the spray gun (Image 5). Although this process proved partially successful in minimising the amount of fibre lost from the mixer, it was still noted that a significant amount of the smaller particles that could pass through the mesh screen were still blown out of the mixer drum during the resination stage. This in turn resulted in a lower density than expected due to the loss of material. Another downside to using this form of resination was that there was no control on the amount of resin being lost from the mixer during the resinating process as a result of using compressed air as a delivery method. Although some actions were tried to minimise this issue, none proved to be totally effective. In a mix of 6.8kg of sorghum fibre, a 4% by weight of eMDI adhesive application resulted in 272g of adhesive. As it was applied as an aerosol to allow total resination of all fibres, a significant amount of adhesive was blown back out of the drum under pressure during the resination stage. This resulted probably in a significantly lower adhesive application rate than the 4% required for attaining the performances required in the relevant Australian standards. As a consequence mechanical properties such as bonding properties, elasticity and rupture performances were lower than expected.

High standard deviations were exhibited for % swelling and MoR for the 5mm fibre panel and MoE for both panels. This is an indication of uneven resination of the panel as a result of both an inefficient resination process and decortication process. Decortication results in the separation of the useful high density, compacted fibre bundles from the pith which is normally of vascular bundles surrounded by weak tissue and thin-walled parenchyma cells. The process we have used to break down the sorghum material into useful fibre lengths has involved grinding the whole stalk, including the pith and then relying upon manual sieving of the sample to remove the finer particulate pith material. This material needs to be removed as it does not contribute to the strength of the panel and may consume a high quantity of glue. The strength is attributed to the adhesion of a network of intermingled fibres on multiple contact points to form the panel. The finer particles do not contribute to this network. Finer particles also have a relatively higher surface area when compared to that of the coarser fibres which in turn results in a higher adhesive uptake, thus resulting in less resin being applied to the larger fibres. Recent studies carried out have shown that fibre geometries contributed significantly to improved bending properties, tension parallel and perpendicular to the surface and an interaction between surface area and the amount of adhesive applied (1). During the panel lay out phase an uneven distribution of resin throughout the mix prior to pressing could provide a differential bond quality in the final product. The mechanical properties samples are taken from a number of different locations on the panel which in turn would result in the variation exhibited with the high standard deviations.

As this trial was an exploratory exercise to determine the possibility of using sorghum waste as an alternative to wood to manufacture a composite panel, limited funding was made available to further investigate the concept. High on our list of necessary equipment is a proper laboratory scale resinating drum. This technology would allow us to precisely apply the correct amount of adhesive directly to the agitated fibres in a totally sealed environment. This would remove the possibility of loss of fibre material during mixing and ensure that all resin stayed within the chamber during the process maximising the coating on all fibres. Online research and communications with industry made it evident that such small scale equipment could not be sourced in Australia and the only availability was through the Italian based IMAL PAL group. Our communications quickly established that the purchase price for this equipment was in excess of A$ 70000 delivered, and well beyond our operating budget of $6537. Laboratory scale decorticators are also not directly available for purchase in Australia. Availability would be through China, but once again price and delivery times proved unacceptable for the budget and duration of the project.


Image 5 – Using a rotary mixer for resinating and minimising fibre loss

More success was achieved with the percentage of total swelling of the panels. The large fibre panel was well below the maximum allowable values required for general purpose particle board and MDF and on the limits for the more stringently regulated flooring and moisture resistant particle boards. The

5mm ground panel still met the criteria for both the general purpose particle board and MDF but failed to achieve the values required for the flooring and moisture resistant particle boards. In the manufacture of timber based particle boards, waxes or other hydrophobic substances are added to increase the water repellence of the product, thus reducing water absorption which is the main cause of swelling and adhesive breakdown. Although no such additives were used in the manufacture of the sorghum residue panels, research shows that sorghum is an inherently waxy plant with wax being produced on both the leaf and the stalk, a property which makes it very drought tolerant (2). Most research carried out in the use of agricultural residues for the manufacture of composite panels has involved a treatment step prior to resination to remove the naturally present waxes on the agricultural fibres as the classical water based formaldehyde adhesives used in these studies would not adhere properly to the waxy substrates. This step was not included in our study so there is still a considerable amount of wax present within the manufactured panels. The obvious reason for the reduced swelling of the panel manufactured with the larger fibres is due to the decreased exposed surface area and a larger intact waxy surface area of the larger intact foliar and stalk material. The 5mm ground fibre would have a considerable portion of this wax removed in the mechanical grinding process as well as exposing larger volumes of material with no wax coating to possible moisture absorption. Since no hydrophobic additives have been included in the manufacturing mix there is no mechanism in place to reduce the ingress of water into the panel.

Conclusions/Significance/Recommendations

This exploratory study into the use of agricultural residues has established that sorghum residue comprising of stalk and foliar material can be used to manufacture a composite fibre panel using an eMDI adhesive. It has established that fibre pre-treatment as required when using current formaldehyde based adhesives is not necessary with this adhesive and that the waxy nature of sorghum results in a panel that will meet Australian standard requirements for fibre swelling with minimal fibre processing. Currently all wood based fibre panels require the inclusion of a water repellent in the form of wax during the manufacturing process to achieve the percentage fibre swelling properties outlined in the Australian standards. It has also highlighted the importance of the tight quality control requirements during the manufacturing process. It is believed that the loss of both resin and fibre during the resination process due to the technical characteristics of the equipment utilised would normally be used in such a trial resulted in a lower than expected outcomes for panel density, glue bond quality thus lower MoE and MoR than envisaged. Addressing this issue will give tighter control of the amount of resin applied with minimal fibre loss and correct values of the mechanical properties of such panel in future research.

Key Messages

The study has shown that it is possible to use agricultural sorghum residue to manufacture a composite panel when coupled with an eMDI adhesive. However due to the small quantity of samples tested it is difficult to determine the actual properties of the panel when compared to a better controlled production method. With equipment used in industrial manufacturing it will be possible to examine the suitability of this adhesive without prior fibre treatment and whether there is a benefit for use of different fibre sizes in panel properties.

Where to next

Further technical adjustment needs to be carried out to improve the resination process. Investment in suitable equipment along with collaboration with partner institutions may help us resolve this specific issue by giving us opportunity to use dedicated equipment and/or to help us to establish an alternate method that gives a better outcome.

Further investigations into mechanical pre-treatment of the fibres will help to define the level of processing required to match or surpass current commercial products.

Alternate methods can also be investigated into fibre production such as decortication which will give longer fibres with less pith material and comparative studies can be carried out to see how this will improve panel properties.

Economic feasibility study would need to be carried out to determine the economic impact upon primary producers of using the crop residue for panel manufacture as well as logistical and manufacturing costs compared to current practices.

References

1 – Lee,S, Shupe,T.F, Hse, C.Y. 'Mechanical and physical properties of ago-based fibreboard', *Holz als Roh und Werkstoff* (2006) 64: pp. 74-79

2 – Cannon,C, Kummerow, F.A. ' A comparison of plant and grain wax from two varieties of Sorghum', *The Journal of the American Oil Chemists Society* October 1957, Volume 34, Issue 10, pp 519-520

Budget Summary

Total salary spent $34,556

Total Operating spent $6,537

Total budget spent $41,093