

ACIAR FST/2009/062 Development of advanced veneer and other products from coconut wood to enhance livelihoods in South Pacific communities

DAF Report – Cocoveneer product development

Report 2 – Structural products

April 2016



This publication has been compiled by Rob McGavin, Henri Bailleres, Rod Vella and Johannes Fehrmann of Agri-Science Queensland, Department of Agriculture and Fisheries.

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Summary

The Pacific's senile coconut plantations have the potential to provide a significant volume of feedstock for the manufacture of wood products. Until recently, wood processing options for coconut stems was largely limited to sawmilling with traditional rotary veneer approaches being mostly unsuccessful. However, rotary-veneer processing using spindleless lathe systems has been demonstrated as an alternative and attractive method of conversion.

Coconut rotary-veneer, or 'cocoveneer' has the potential to be used in the manufacture of a range of products including structural products, appearance products or products that demand both structural and appearance qualities. Identifying suitable products for cocoveneer that have a clear connection to profitable markets will be critical for the successful development of a commercial cocoveneer industry in the Pacific region. To provide guidance on the suitability of cocoveneer for structural products, a product development trial was undertaken that included the assessment of key mechanical properties that are achieved from plywood and laminated veneer lumber (LVL) manufactured using a range of cocoveneer qualities. Four different construction strategies were adopted that utilised a range of cocoveneer qualities.

Key mechanical properties testing and bond quality assessments followed product manufacture which revealed a range of final product qualities. Bond qualities overall were very good with 93% of samples meeting the requirements of an A-bond test. There was a clear gain in product properties by choosing higher density veneers, although 'D' construction strategy provided an example of how mixing qualities (i.e. 40% high density group and 60% medium density group veneers) in an efficient manner is able to produce satisfactory product qualities.

Shear strength was identified as a major limiting property across all four construction strategies. This is almost certainly due to the brittle nature of coconut rotary veneer. More efficient construction strategies may provide some gain in shear strength however more suitable gains are probably best achieved by supplementing the construction strategy with high shear strength veneers from traditional forest resources.

The suitability of the construction strategies used in the trial and the resulting product properties are dependent on the target end-use. The construction strategies that utilised lower density veneers produced products with low mechanical properties in general and may be more suitable for non-structural applications. Construction strategies that utilised higher density veneers produced products with mechanical properties more suited to structural applications however they reflect the lower end of structural products that are manufactured for traditional forest resources. Opportunities exist to further improve and customise product mechanical properties once the target end use is identified and mechanical performance requirements are understood. These construction strategies may include all cocoveneer or a blend of cocoveneer and veneer from more traditional forest resources.

Table of contents

1	Introduction	4
2	Material and methods	5
2.1	Veneer	5
2.2	Veneer-based products	7
2.2.1	Plywood.....	7
2.2.2	Laminated veneer lumber	9
2.3	Manufacture protocols.....	10
2.4	Product performance.....	11
3	Results	14
3.1	Plywood	14
3.1.1	Flexure Modulus of Elasticity	14
3.1.2	Flexure Modulus of Rupture.....	15
3.1.3	Panel shear strength.....	17
3.1.4	Summary- assigned F grades.....	19
3.1.5	Hardness	19
3.1.6	Bond quality	21
3.2	Laminated veneer lumber (LVL).....	21
3.2.1	Flexure Modulus of Elasticity and Modulus of Rupture on edge	21
3.2.2	Shear strength.....	23
4	Discussion	25
5	Acknowledgements	27
6	References cited	28

Table of images

Image 1.	Veneer processing using a spindleless rotary veneer lathe	5
Image 2.	Rotary-peeled cocoveneer	5
Image 3.	Rotary-peeled cocoveneer exiting the jet box drier	6
Image 4.	Veneer selection and sorting in preparation for product manufacture	6
Image 5.	Example of plywood manufactured from cocoveneer blended with veneer from other forest resources	8
Image 6.	Example of laminated veneer lumber manufactured from cocoveneer	9
Image 7.	Adhesive being applied to cocoveneer	10
Image 8.	Cocoveneer products being pressed.	11
Image 9.	Testing equipment used for mechanical properties determination	12
Image 10.	Bond testing using the chisel test	13



Table of figures

Figure 1 – Plywood MoE in flexure parallel to the face grain for each construction strategy.	14
Figure 2 – Plywood MoE in flexure perpendicular to the face grain for each construction strategy.	15
Figure 3 – Plywood MoR in flexure parallel to the face grain for each construction strategy.	16
Figure 4 – Plywood MoR in flexure perpendicular to the face grain for each construction strategy. ...	17
Figure 5 – Plywood MoR in shear parallel to the face grain for each construction strategy.....	18
Figure 6 – Plywood MoR in shear perpendicular to the face grain for each construction strategy.	18
Figure 7 – Plywood Janka hardness for each construction strategy.	20
Figure 8 – LVL MoE flexure on edge for each construction strategy.....	22
Figure 9 – LVL MoR flexure on edge for each construction strategy.	22
Figure 10 – LVL shear MoR on edge for each construction strategy.	23
Figure 11 – LVL shear MoR on flat for each construction strategy.	24



1 Introduction

The Pacific's senile coconut plantations have the potential to provide a significant volume of feedstock for the manufacture of wood and wood-based products. Coconut wood differs significantly from hardwood, softwood, and even the wood of other palm stems in terms of tissue anatomy, fibre orientation, and density distribution (Bailleres *et al.* 2015). Until recently, wood processing options for coconut stems was largely limited to sawmilling with traditional rotary veneer approaches being mostly unsuccessful. However, rotary-veneer processing using spindleless lathe systems has been demonstrated as an attractive method of conversion for small-diameter plantation hardwoods and has demonstrated potential in preliminary coconut processing research trials (McGavin and Bergmaier-Massau 2016, McGavin 2015, McGavin *et al.* 2014). Using relatively low-cost spindleless lathes, more attractive product recoveries can be achieved when compared to classical sawmilling approaches. In addition, veneer processing also enables the large radial variability of properties, a characteristic of senile coconut palms, to be more efficiently managed (Bailleres *et al.* 2010).

Identifying suitable products for coconut veneer (or 'cocoveneer') that have a clear connection to profitable markets will be critical for the successful development of a commercial cocoveneer industry in the Pacific region. While established markets exist for solid wood products manufactured from predominately sawn coconut stems, viable markets and products for cocoveneer and/or cocoveneer-based products are yet to be fully explored.

To determine the suitability of products manufactured from cocoveneer for structural applications, the Queensland Department of Agriculture and Fisheries (DAF) have undertaken a product performance trial. The objective of the trial was to establish the product mechanical properties that are achieved from plywood and laminated veneer lumber (LVL) manufactured using a range of cocoveneer qualities. This information will guide the selection of target products and markets for the utilisation of cocoveneer. The trial was part of the Australian Centre for International Agricultural Research (ACIAR) project, *FST/2009/062 Development of advanced veneer and other products from coconut wood to enhance livelihoods in South Pacific communities*.

2 Material and methods

2.1 Veneer

Veneers used for the test product manufacture were produced during the Veneer Processing Trial 4, conducted in June 2015 at the Valebasoga Tropikboards commercial plywood mill located in Labasa, Fiji. For the trial, 153 coconut palm billets (25.1 m³) were processed into rotary veneer within a commercial production environment providing 12.5 m³ of dried coconut veneer or 'cocoveneer' (Images 1 to 3).



Image 1. Veneer processing using a spindleless rotary veneer lathe



Image 2. Rotary-peeled cocoveneer



Image 3. Rotary-peeled cocoveneer exiting the jet box drier

Resulting veneers were packaged and transported to the DAF Salisbury Research Facility in Brisbane, Australia for further assessment. More detailed description of the processing trial and grade quality assessments are described by McGavin and Bergmaier-Massau (2016).

Veneers were selected and allocated for the test product manufacture primarily based on veneer sheet air-dry density (Image 4). Four density categories were chosen to segregate the veneer feedstock as detailed in Table 1. These categories were then used to guide veneer selection in line with test product specific construction strategies.

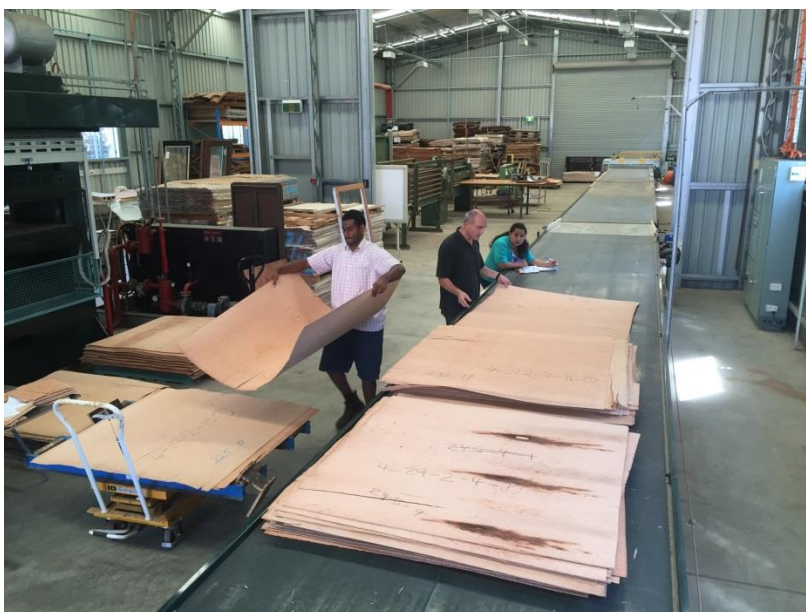


Image 4. Veneer selection and sorting in preparation for product manufacture

In addition, veneers were further segregated into two groups based on veneer visual characteristics and defects such as surface roughness, splits, compression etc. The two groups aligned with veneers to be used on the exposed faces of the test products (i.e. face veneers) and those concealed within the test products (i.e. core veneers). The grading criteria for these groupings basically followed the criteria detailed by McGavin and Bergmaier-Massau (2016) for grades 2 and 3 respectively.

Table 1. Veneer sheet density categories and proportion of processing trial production

Density group	Veneer sheet density (kg/m ³)	Proportion of processing trial production (%)
Low	≤ 450	22
Medium	451 - 600	32
Medium-high	601 - 750	35
High	≥ 750	11

2.2 Veneer-based products

Cocoveneer has the potential to be used in the manufacture of a range of products including structural products, appearance products or products that demand both structural and appearance qualities. Specific products and their target market will demand certain veneer qualities in line with non-technical expectations (e.g. colour preference) and/or technical requirements (e.g. mechanical properties). A sample range of potential cocoveneer products has been reported by McGavin *et al.* (2015).

To determine the suitability of cocoveneer for the manufacture of structural products requires information and understanding of the mechanical performances that the products can provide. These product mechanical performances are influenced by a range of variables including veneer properties and qualities, product construction strategies and the manufacturing processes. Opportunities exist to adopt construction strategies that use entirely cocoveneer or use cocoveneer blended with other veneers from more traditional forest resources. The selection of veneer qualities within any construction strategy depends on the final product performance requirements. For the study, two common veneer-based engineered wood products were selected and included plywood and laminated veneer lumber (LVL).

2.2.1 Plywood

Plywood is a major traditional use of rotary-peeled veneer and is comprised of layers of veneer known as plies, glued together with the grain of adjacent plies alternating by 90° (Image 5).

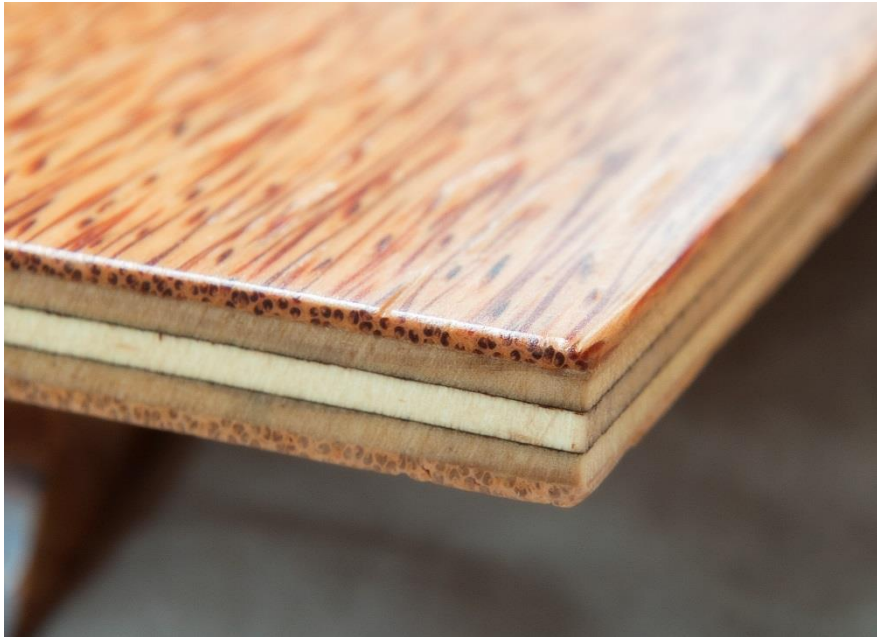


Image 5. Example of plywood manufactured from cocoveneer blended with veneer from other forest resources

The high-volume uses for rotary-peeled veneers from traditional forest resources that are made into plywood panels are:

- structural plywood for sheathing and bracing
- form ply for concrete construction
- plywood flooring, usually covered with carpet, tiles or solid timber overlay
- plywood for noise barriers along highways
- marine ply for boat building applications
- truck, trailer and horse float trays and beds
- shipping container flooring
- stair treads and risers
- train, bus and tram floors
- bridge decks
- soffits and fascias
- plywood box beams
- webs in I-beams and trusses
- exterior residential cladding
- sign boards
- wall and ceiling lining
- kitchen and laundry benches
- walkways
- aircraft components.

Four different plywood construction strategies were selected to manufacture nominally 15 mm thick, 5-ply plywood panels to provide an indication on the range of

mechanical performances that might be possible from plywood manufactured entirely from cocoveneer. The construction strategies were:

1. A - Low density veneers;
2. B - Medium density veneers;
3. C - Medium-high density veneers; and
4. D - High density face veneers with medium density core veneers.

2.2.2 Laminated veneer lumber

Laminated veneer lumber (LVL) is a solid wood substitute manufactured from rotary-peeled veneers adhered in parallel layers to form a beam (Image 6). This product has made in-roads to many markets as a substitute for sawn timber or steel, especially in load carrying beam applications such as:

- lintels and headers over windows, doors, verandahs and other openings in construction;
- sub-floor framing as joists and bearers;
- internal framing;
- furniture; and
- bridge components.

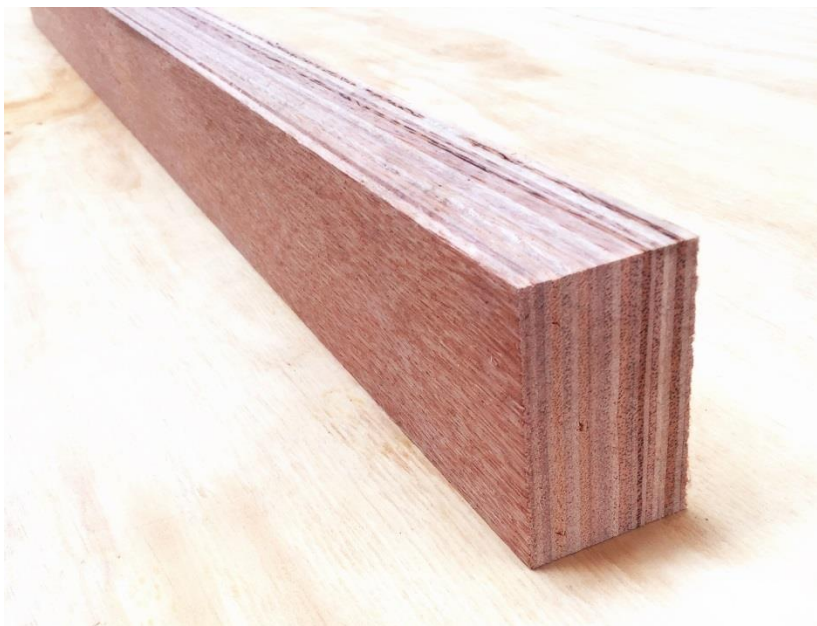


Image 6. Example of laminated veneer lumber manufactured from cocoveneer

Four different LVL construction strategies were selected to manufacture either 13-ply or 12-ply LVL panels to provide an indication on the range of mechanical performances that might be possible from LVL manufactured entirely from cocoveneer. The 'A' construction strategy utilised one extra veneer to achieve the nominal product thickness of 33mm due to the high level of compressibility of the lower density veneers used. The panels were further processed to provide LVL beams. The construction strategies were:

1. A - Low density veneers (13-ply);
2. B - Medium density veneers (12-ply);
3. C - Medium-high density veneers (12-ply); and
4. D - High density face veneers with medium density core veneers (12-ply total, 8 medium density core veneers and 2 high density outer veneers per face).

2.3 Manufacture protocols

All veneers were conditioned in a controlled environment to a moisture content of approximately 9% prior to veneer selection and panel manufacture.

A phenol formaldehyde resin system was applied to both faces of each core veneer at a spread rate of 200 gsm (grams per square metre) using a double roller glue spreader (Image 7). The face and back veneers were fed through the spreader at the same time concealing the surface to be exposed on the product ensuring only the inner surfaces of these veneers had adhesive applied.



Image 7. Adhesive being applied to cocoveneer

The laid-up veneers had an open assembly time limited to a maximum of five minutes prior to pre-pressing for 15 minutes at 1 MPa (Image 8). A 25 minute closed assembly time preceded a final hot-press at 135°C and 1.2 MPa. The final hot-press time was 12 minutes and 30 minutes respectively for the plywood and LVL.

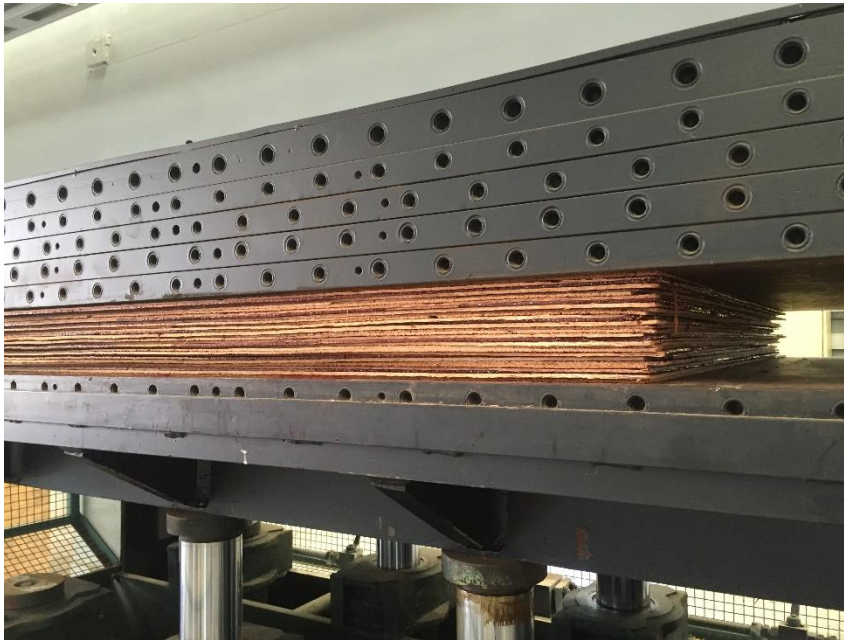


Image 8. Cocoveneer products being pressed.

2.4 Product performance

All mechanical properties tests were conducted within DAF's NATA registered engineering laboratory located within the Salisbury Research Facility. A Shimadzu AG-X universal testing machine (Image 9) was used to conduct the static bending, shear and hardness tests.

The manufactured cocoveneer plywood test panels were used to undertake the following tests:

1. Four-point bending parallel to the face grain;
2. Four-point bending perpendicular to the face grain;
3. Panel shear strength parallel to the face grain;
4. Panel shear strength perpendicular to the face grain;
5. Janka hardness; and
6. Bond quality (chisel test).

The manufactured cocoveneer LVL test beams were used to undertake the following tests:

1. Four-point bending on edge;
2. Shear strength on edge (perpendicular to the glue line); and
3. Shear strength on flat (parallel to the glue line).



Image 9. Testing equipment used for mechanical properties determination

While additional mechanical qualities are required to completely characterise the structural performance of a veneer-based product, static bending stiffness (Modulus of Elasticity), static bending strength (Modulus of Rupture) and shear strength were selected as being the mechanical characteristics that will most likely limit the products final structural grade. Janka hardness was included to provide an indication of the influence varying construction strategies (in this case density of veneers) had on product hardness for end-uses such as flooring, table tops, stairs etc.

The plywood static bending and panel shear test samples were prepared and tested in accordance with AS/NZS 2269.1:2012—Plywood structural—Part 1: Determination of structural properties—Test methods (Standards Australia 2012c).

The LVL static bending and shear test samples were prepared and tested in accordance with Australian and New Zealand standard AS/NZS 4357.2:2006—Structural laminated veneer lumber (LVL)—Part 2: Determination of structural properties—Test methods (Standards Australia 2006).

Hardness was in principle tested using the Janka hardness test as described by Mack (1979). This test method requires a steel ball with a diameter of 11.28 mm to be pressed into a test piece until the ball has penetrated to a depth equal to half its diameter. This test was completed on the face of plywood samples measuring approximately 150 mm x 85 mm.

Bond quality was performed in accordance with AS/NZS 2098.2: 2012 – Methods of test for veneer and plywood – Method 2: Bond quality of plywood (chisel test) (Standards Australia 2012a). A subset of plywood samples (measuring 150 mm x 75 mm) from each construction strategy were prepared for evaluation to A-bond criteria (6hrs steamed at 200 kPa). This test involves the forceful separation of veneers along the glue line and the subsequent evaluation of the ratio of wood fibre and glue failure on the separated sections (Image 10).

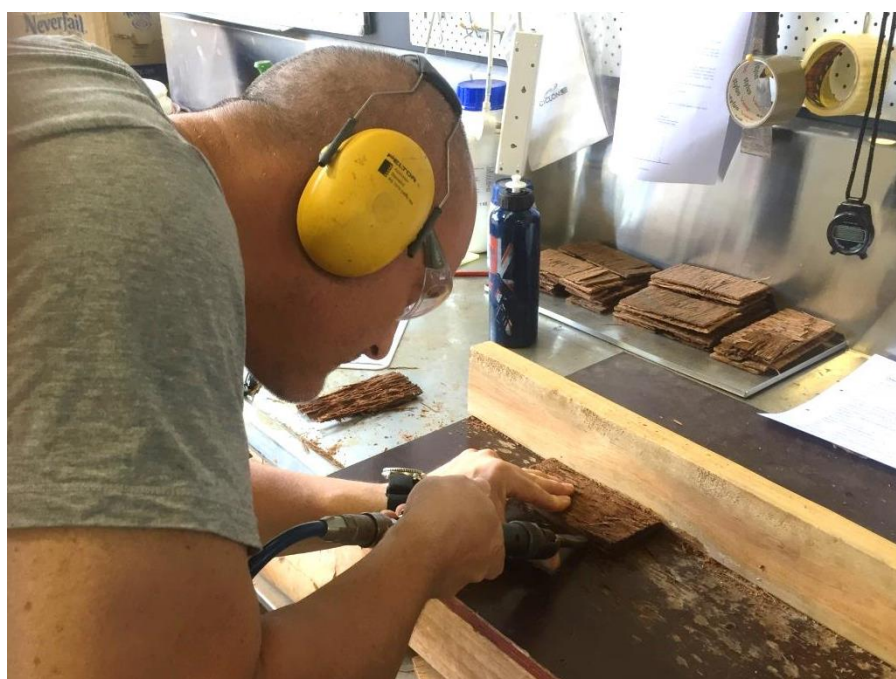


Image 10. Bond testing using the chisel test

3 Results

3.1 Plywood

3.1.1 Flexure Modulus of Elasticity

Figures 1 and 2 show the Modulus of Elasticity (MoE) for the four different construction strategies of plywood tested in the parallel and perpendicular to face grain direction respectively.

Figure 1 shows a positive regular trend of increasing MoE from the 'A' construction strategy through to the 'D' construction when testing parallel to the face grain. Large MoE variation exists within each construction strategy as a result of the expected density disparity within each batch which covers a wide spread of density. It is further exacerbated by a significant thickness variation between veneers and their positioning within manufactured panels. The average MoE values for strategies 'A' to 'D' were 5804, 8007, 10787 and 12286 MPa respectively.

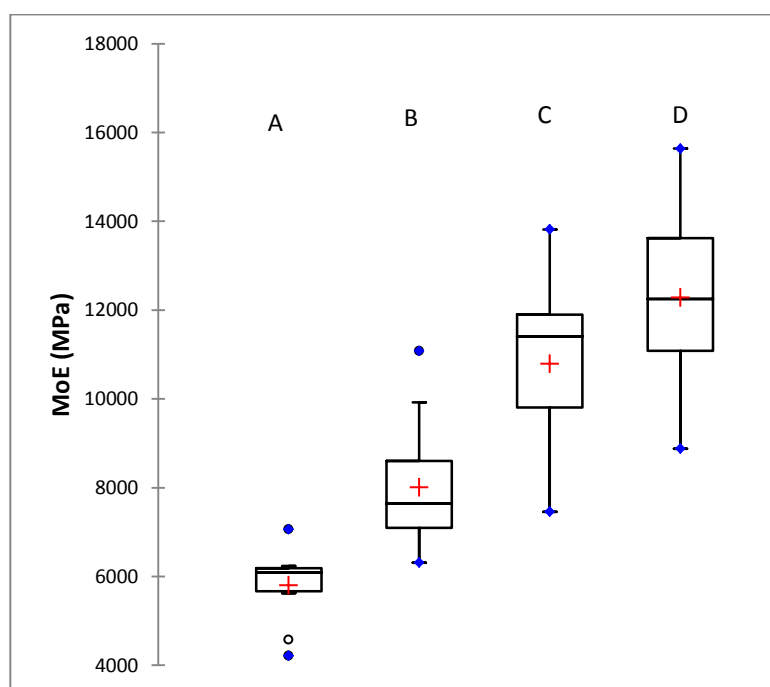


Figure 1 – Plywood MoE in flexure parallel to the face grain for each construction strategy. N=65 total (A=10, B=15, C=20, D=20)

Figure 2 shows a positive trend of increasing MoE from the 'A' through to the 'C' construction strategy when testing perpendicular to the face grain, however dissimilar to the MoE parallel to the face grain, the 'D' construction strategy provided results comparable to the 'B' group. This decline is explained by the quality of veneers used in the cross bands of the 'D' construction strategy which typically

contributes to the stiffness of the panel when testing in this configuration and which are similar mechanically to those included in the 'B' construction strategy (i.e. between 451 – 600 kg/m³). The average MoE values for strategies 'A' to 'D' were 6632, 9476, 11304 and 8829 MPa respectively.

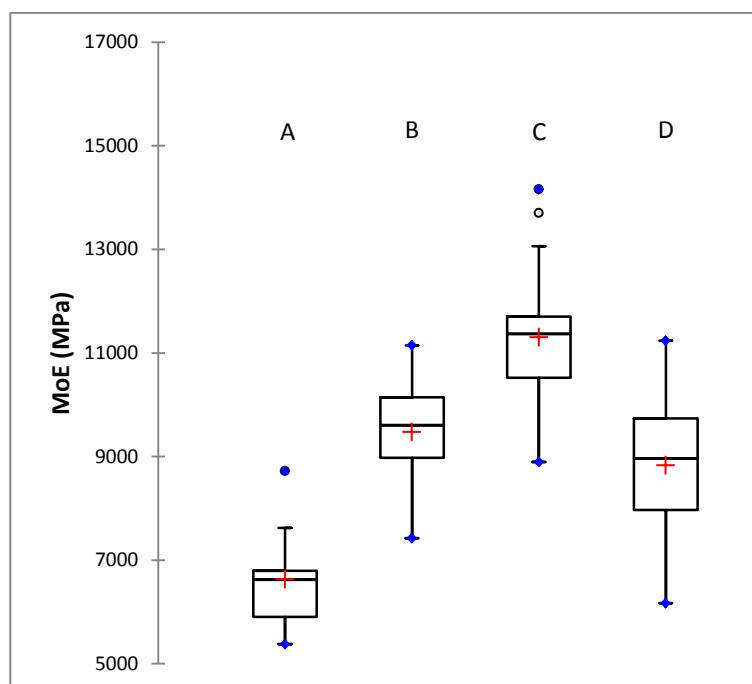


Figure 2 – Plywood MoE in flexure perpendicular to the face grain for each construction strategy.

N=65 total (A=10, B=15, C=20, D=20)

3.1.2 Flexure Modulus of Rupture

Figures 3 and 4 show the Modulus of Rupture (MoR) for the four different construction strategies of plywood tested in the parallel and perpendicular to face grain direction respectively.

Figure 3 shows a positive regular trend of increasing MoR from the 'A' construction strategy through to the 'D' construction strategy when testing parallel to the face grain. As noted in section 3.1.1, wide variation in MoR exists within each construction group as a result of the expected density disparity within each group which covers a wide spread of density. It is further exacerbated by a significant thickness variation between veneers and their positioning within manufactured panels. The average MoR values for construction strategies 'A' to 'D' were 36.2, 45.2, 52.6 and 60.7 MPa respectively.

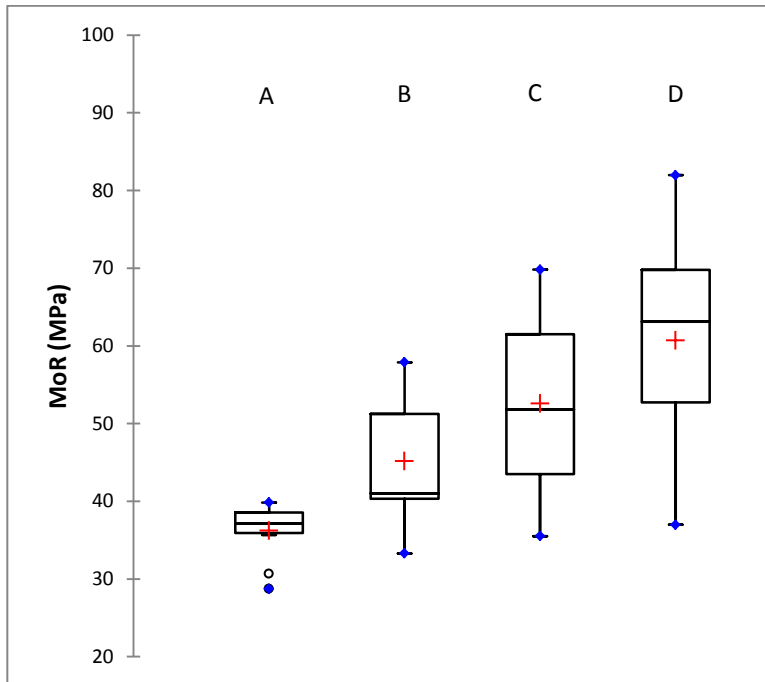


Figure 3 – Plywood MoR in flexure parallel to the face grain for each construction strategy. N=65 total (A=10, B=15, C=20, D=20)

Similar to the MoE results (3.1.1), figure 4 shows a positive trend of increasing MoR from the ‘A’ construction strategy through to the ‘C’ construction strategy when testing perpendicular to the face grain, however the ‘D’ construction strategy provided results similar to the ‘B’ group. As explained in section 3.1.1, this result is explained by the performances of the cross band veneers which are mechanically similar to the cross bands of the ‘B’ construction strategy. The average MoR values for construction strategy ‘A’ to ‘D’ were 51.4, 73.7, 83.2 and 72.8 MPa respectively.

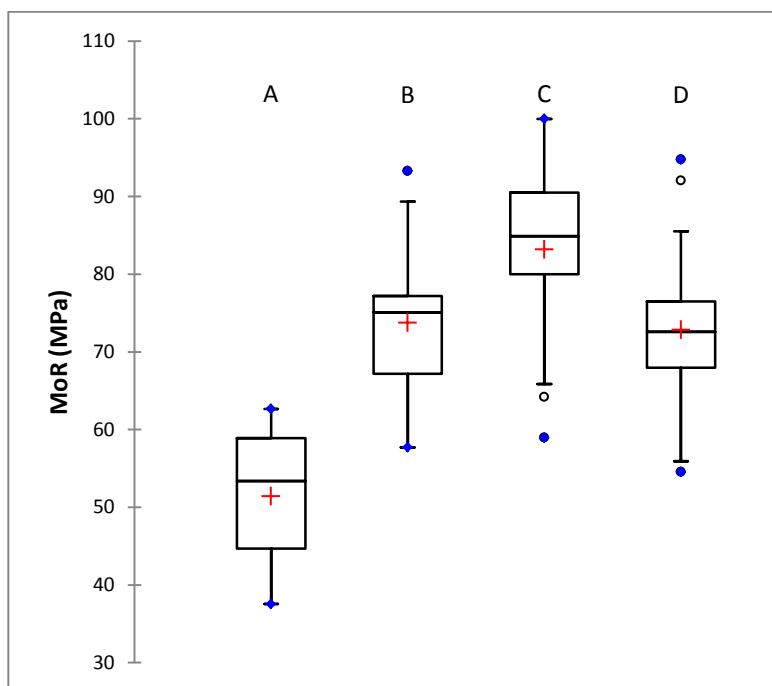


Figure 4 – Plywood MoR in flexure perpendicular to the face grain for each construction strategy.

N=65 total (A=10, B=15, C=20, D=20)

3.1.3 Panel shear strength

Figures 5 and 6 show the shear strength distribution for the four different construction strategies of plywood tested parallel and perpendicular to the face grain respectively.

Figure 5 shows an increasing trend of shear strength from the ‘A’ through to the ‘C’ construction strategy when testing parallel to the face grain as the density of the constitutive veneers increase. The ‘C’ construction strategy provided similar shear strength to the ‘D’ construction group as no extra gain was observed in the latter test configuration due to the higher density of the face veneers. The quality of the core veneers of the ‘D’ construction strategy were similar to the ‘B’ construction strategy, consequently the higher density of the face veneers of the ‘D’ group had a positive influence on the shear strength since the shear strength of the ‘D’ construction strategy was higher than the ‘B’ construction group. The average shear values for construction strategies ‘A’ to ‘D’ were 3.2, 4.5, 5.6 and 5.5 MPa respectively.

Figure 6 shows an increasing trend of shear strength from the ‘A’ through to the ‘D’ construction strategy when testing perpendicular to the face grain. In this configuration, as expected, the higher density face veneers of the ‘D’ construction strategy generates proportionally an improvement of the shear strength perpendicular to the face grain when compared to the improvement of the shear

strength parallel to the face grain. The average shear strength values for construction strategies 'A' to 'D' were 3.4, 4.7, 6.0 and 6.6 MPa respectively.

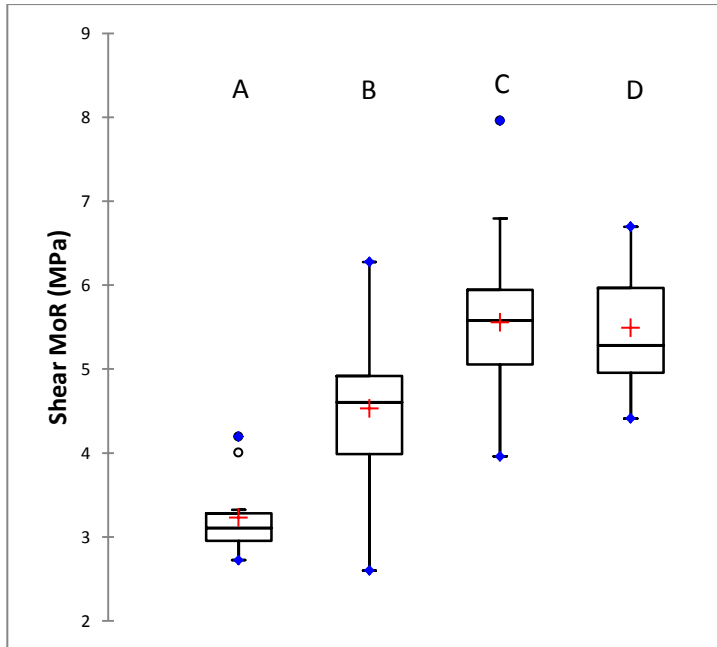


Figure 5 – Plywood MoR in shear parallel to the face grain for each construction strategy N=64 total (A=10, B=15, C=19, D=20)

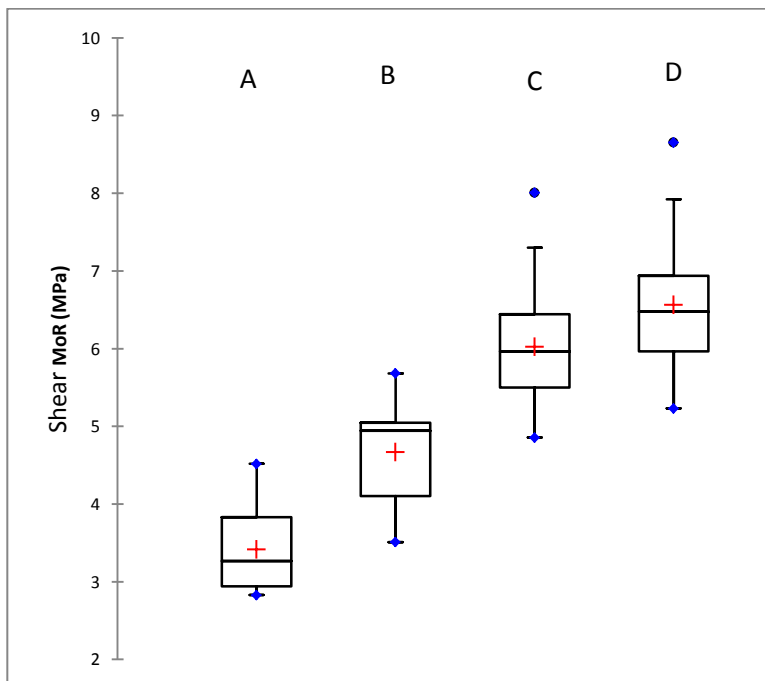


Figure 6 – Plywood MoR in shear perpendicular to the face grain for each construction strategy.

N=64 total (A=10, B=15, C=19, D=20)

3.1.4 Summary- assigned F grades

Table 2 details the assigned F-grade for each construction strategy and each test method when calculated in accordance with AS/NZS 2269.0.2012 (Standards Australia 2012b). It is noted that the calculations for determining the assigned grades for each construction strategy were based on limited sample replicates. This approach involved the application of a penalising sampling factor to determine the characteristic values as inferred from the method described in the standard. A larger number of samples would provide more accurate F-grades, however the current results provide useful preliminary information.

These F-grades confirm the wide variation in final product properties that result from the variable quality veneer. There is a clear gain in product properties by choosing higher density veneers, although 'D' construction strategy provides an example of how mixing qualities (i.e. 40% high density group and 60% medium density veneers) in an efficient manner is able to produce satisfactory product qualities.

Panel shear strength, and in particular in the direction parallel to the face grain is a major limiting property across all four construction strategies. This is mainly due to the heterogeneous tissue of coconut wood combined with the veneer brittleness induced by rotary peeling. More efficient construction strategies may provide some gain in shear strength however more suitable gains are probably best achieved by designing a construction strategy using some high shear strength veneers from traditional forest resources (e.g. tropical pines).

The suitability of these construction strategies and the resulting properties is dependent on the target end-use, however they are in line with the lower end of structural products that are manufactured from traditional forest resources.

Table 2. Assigned F-grades on cocoveneer plywood for each construction strategy and test method

Construction strategy	Bending MOE (E)		Bending MOR (f'_b)		Panel shear (f'_s)	
	Para	Perp	Para	Perp	Para	Perp
A	F4	F4	F8	F11	F4	F4
B	F5	F8	F11	F17	F4	F4
C	F11	F11	F11	F22	F5	F11
D	F11	F7	F14	F17	F8	F14

3.1.5 Hardness

Figure 7 shows the distribution of Janka hardness results for the four construction strategies. Wide variation existed between the construction strategies which reflects the wide spread of veneer densities that are recovered from coconut stems. As expected, there is an increase in product hardness as the veneer density is increased. Construction strategy 'D' produced a lower hardness result than the 'C' construction strategy due to the lower density of the core veneers comparatively to the C construction group (i.e. 'D' construction group contained high density face

veneers with medium density core veneers equivalent to the B construction strategy). The average Janka hardness values for construction strategies 'A' to 'D' were 2.5, 4.2, 7.8 and 6.5 kN respectively.

Examples of Janka hardness values for common timber species, as reported by Bootle (2010) include:

- Radiata pine (*Pinus radiata*) 2.8 – 3.6 kN
- Hoop pine (*Araucaria cunninghamii*) 3.4 kN
- Douglas fir (*Pseudotsuga menziesii*) 2.6 – 3.4 kN
- Teak (*Tectona grandis*) 4.5 – 4.6 kN
- Spotted gum (*Corymbia citriodora*) 11 kN.

In traditional wood applications and as a guide, timbers which have Janka hardness of around 6 kN or higher have been generally regarded as being suitable for high traffic decorative flooring. Timbers that fall below this threshold may still be used as flooring but their use is often restricted to light traffic areas such as bedrooms etc.

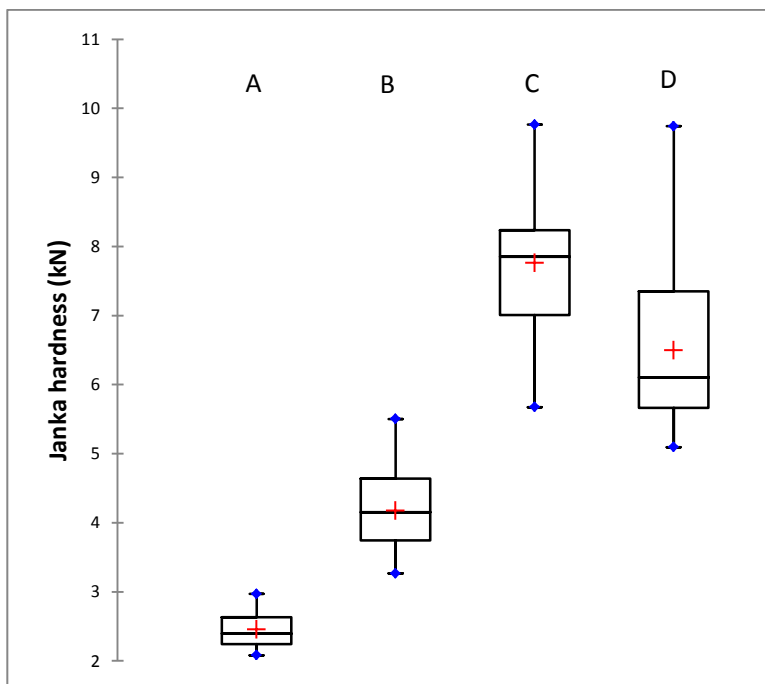


Figure 7 – Plywood Janka hardness for each construction strategy.

N=65 total (A=10, B=15, C=20, D=20)

3.1.6 Bond quality

At the completion of veneer separation and drying, individual veneers from each glueline were assessed to determine the estimated percentage area covered by wood fibre failure and a bond quality score from one to 10 was assigned for each glueline. In accordance with AS/NZS 2098.2:2012 (Standards Australia 2012a), each sample (containing 4 glue lines) was assigned either a 'pass' or 'fail'. To pass, the sample was required to have an average bond quality score of not less than five with any individual glue line not less than a bond quality score of two.

In total, ten plywood samples per construction strategy were evaluated for bond quality (i.e. 40 plywood samples or 160 individual glue lines). 93% of the samples passed the requirements for an 'A-bond'. Type A bonds are intended to withstand prolonged exposure to severe exterior conditions without failure of the glueline. Type A bonds are normally suitable for weather exposed, structural and marine applications where rigidity and durability are required. They have a design durability life for more than 50 years in fully exposed situations and indefinite durability in semi-exposed and interior applications.

The samples that failed to meet the requirements of an A-bond were limited to one construction strategy and were confined to one manufacturing batch. It is therefore likely that the failures are a result of an inconsistency during the manufacturing process.

3.2 Laminated veneer lumber (LVL)

There are no generic grades for LVL. Each LVL manufacturer is required to design and test their products in accordance with AS/NZS 4063.2:2010 (Standards Australia 2010) to determine their design properties. This engineering data is available from the relevant manufacturers, together with span tables for common applications.

3.2.1 Flexure Modulus of Elasticity and Modulus of Rupture on edge

Figures 8 and 9 show the MoE and MoR distributions for the four construction strategies. Results from both test methods show similar trends with improvements realised from the increased veneer density. The 'D' construction strategy achieved a marginally lower MoE compared to the 'C' construction strategy as a direct result of the mixing of high density and medium density veneers within the 'D' construction strategy. The high density face veneers of the 'D' construction strategy improved the MoR of the LVL when compare to the 'B' construction strategy which had similar core veneers.

As noted above, the suitability of these construction strategies and the resulting properties is dependent on the target end-use, however they reflect the lower end of structural products that are manufactured for traditional forest resources.

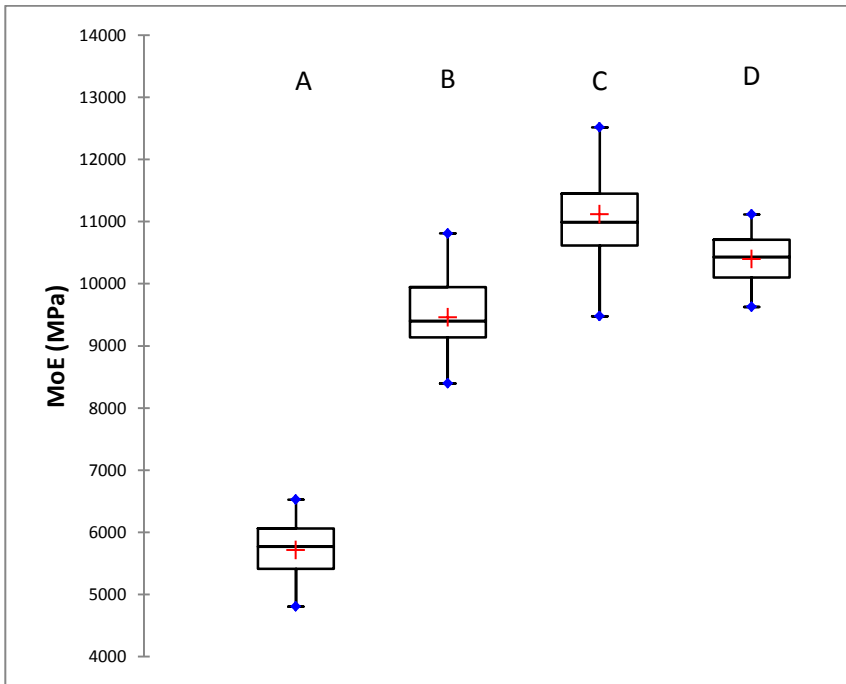


Figure 8 – LVL MoE flexure on edge for each construction strategy.
N=77 total (A=21, B=21, C=21, D=14)

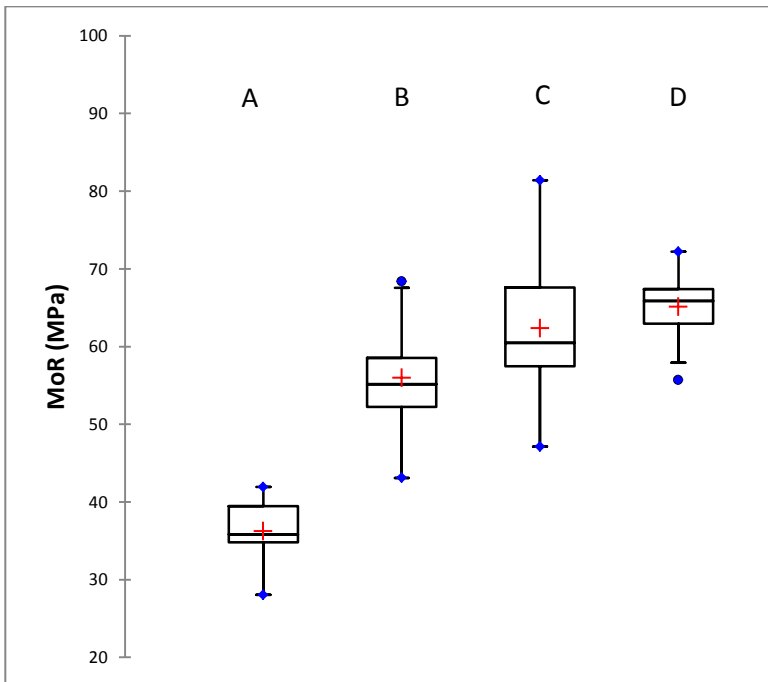


Figure 9 – LVL MoR flexure on edge for each construction strategy.
N=77 total (A=21, B=21, C=21, D=14)

3.2.2 Shear strength

Figures 10 and 11 show the distribution of shear strength for the four LVL construction strategies when tested on edge (perpendicular to the glue line) and flat (parallel to the glue line) orientations respectively.

For the edge configuration, the shear strength increased proportionally to the average density of veneers within each construction strategy group. Consequently, the 'D' construction strategy provided a similar distribution compared to the 'C' construction strategy.

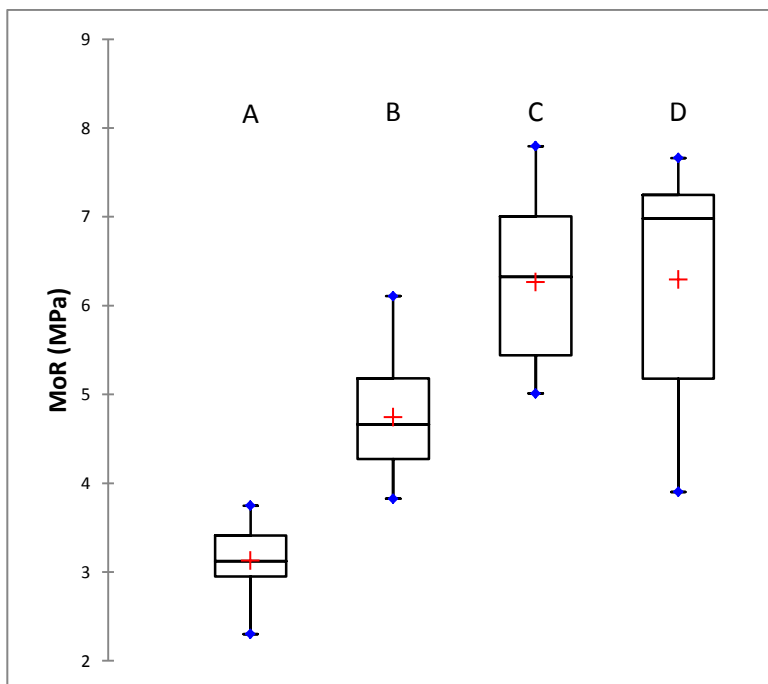


Figure 10 – LVL shear MoR on edge for each construction strategy.

N=55 total (A=15, B=15, C=15, D=10)

For the flat configuration, as the maximum shear stress occurs in the centre on the test section, the application of high density veneers on the faces didn't improve notably the shear strength. However, the 'D' construction strategy is slightly higher than the 'B' group proving a positive influence of the face veneers.

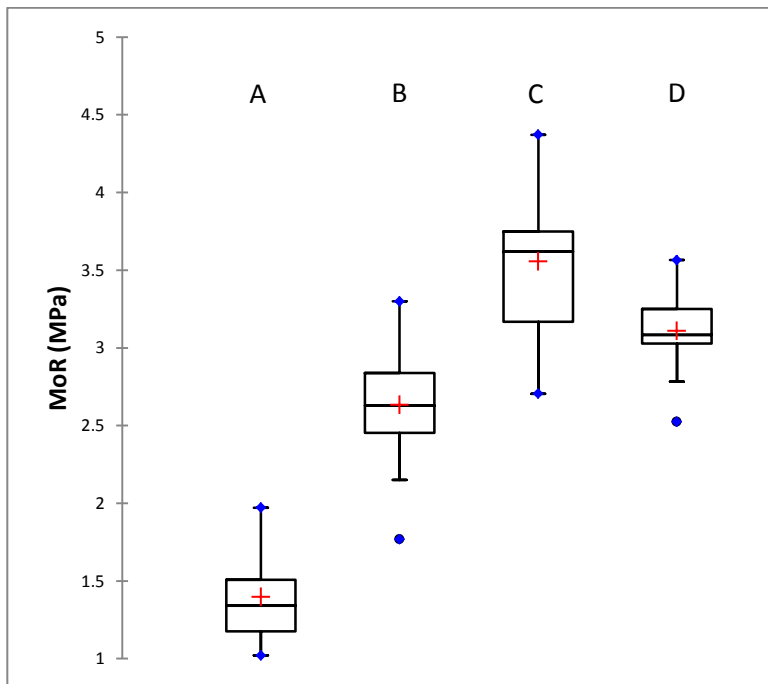


Figure 11 – LVL shear MoR on flat for each construction strategy.
N=58 total (A=15, B=15, C=14, D=14)



4 Discussion


Similarly to conventional timber species, a range of potential products could be manufactured from cocoveneer. The trial has demonstrated there is an opportunity to utilise cocoveneer in the manufacture of structural products. The construction strategies that utilised lower density veneers produced products with low mechanical properties in general and as a result, lower density veneer may be more suitable for the manufacture of non-structural products. Construction strategies that utilised higher density veneers produced products with mechanical properties more suited to structural applications however they reflect the lower end of structural products that are manufactured for traditional forest resources.

The trial adopted veneer selection strategies primarily based on veneer density. This approach provided a relatively simple and easy to replicate sorting method that requires minimal capital expenditure and technical expertise. An alternative method that would provide a higher level of accuracy and greater segregation opportunities would be through the measurement and use of veneer MoE. Acoustic methods are a useful technique to provide veneer MoE measurement however a higher level of technical skill and infrastructure are required. This method has been widely adopted in larger-scale veneer operations to improve the efficiency of veneer utilisation and improve the predictability of the manufactured products. Further assessment of this approach and the protocol refinement specifically for cocoveneer may be necessary as identified by McGavin and Bergmaier-Massau (2016) to ensure accurate and reliable measurements are gained.

The trial has identified that the global performances of the cocoveneer-based products is not as high as expected given the range of densities included in the study. The net effect of this is that the weight of a cocoveneer-based product is likely to be heavier than if it was made from traditional forest resource veneer to achieve the same mechanical properties. This may or may not be a disadvantage and is dependent on the product type and the final application.

Hardness is a useful indicator of timbers ability to resist wear and indentation and the results of the trial indicate that the higher density veneers fall within the hardness range considered suitable for applications where resistance to wear and indentation is critical (e.g. feature timber floors in high traffic areas). With the anatomical structure of coconut, an opportunity exists to further explore the link between hardness and wearability with the possibility that the wearing properties of cocoveneer are better than indicated by the Janka hardness test. Indeed the high minerals content of coconut wood as reported by Hopewell and House (2010) could be a specific advantage of cocoveneer-based products providing high wearability performances.

Opportunities exist to further improve and customise product mechanical properties once the target end use is identified and mechanical performance requirements are



understood. These construction strategies may include all cocoveneer or a blend of cocoveneer and veneer from more traditional forest resources in order to take advantage of unique characteristics or performances of coconut wood such as appearance, hardness, wearability, lyctus resistance, lightness etc and/or to enhance the performance of conventional products.



5 Acknowledgements

The *Development of advanced veneer and other products from coconut wood to enhance livelihoods in South Pacific communities* (FST/2009/062) project was supported by the Australian Centre for International Agricultural Research (ACIAR). The project was undertaken in collaboration with ACIAR, the Queensland Government Department of Agriculture and Fisheries (DAF), the University of Tasmania (UTAS), the Pacific Community (SPC), the Fiji Ministry of Fisheries and Forests, Samoa Ministry of Natural Resources and Environment, and Solomon Island Ministry of Forestry.

The author acknowledges the contributions to the project made by ACIAR, DAF, UTAS, the Fiji Ministry of Fisheries and Forests and SPC.


The individual contributions of DAF research staff including Eric Littee, Dan Field and Rica Minnet and SPC research staff including Moana Bergmaier-Masau and Ilikimi Carati-Bokadi are acknowledged.

The support provided by DAF through the provision of the unique facilities located at the Salisbury Research Facility is acknowledged as critical to facilitate product manufacturing studies of this nature.

The *FST/2009/062* project team are acknowledged for their contributions towards the supply of cocoveneer.

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