Enhancing key elements of the value chains for plantation-grown wood in Lao PDR

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ABSTRACT

The utilisation of small dimensions, plantation timbers usually requires joining multiple small elements into larger components. Knowledge on wood properties, surface preparation, and bonding conditions are of particular importance for species difficult to glue such as teak (Tectona grandis) and Eucalyptus camaldulensis. The actual lack of knowledge affects the quality of wood products and limits returns to Lao wood product manufacturing companies. In this study, the shear strength mechanical property of joints made from both above mentioned species were assessed using four different types of non-structural adhesives: cross-linking polyvinyl acetate emulsion, polyvinyl acetate emulsion, polyurethane, and epoxy. Joints were conditioned to different exposure conditions in accordance with ASTM D5751. Additional factors such as wood properties, timber preparation and adhesive application were considered. A comparative analysis assessing the shear strength of joints and wood failure allowed finding that both high slope of grain and number of surface marks when planing wood sawnboards prior to gluing have a highly significant impact. Both species performed well with cross-linking PVA laminated eucalyptus providing the best individual results of all tested combination. However, PVA was the only tested adhesive to meet all the shear strength requirements for all exposure conditions. On the other hand, none of the tested adhesives met the wood failure requirements suggesting that further research needs to be conducted so that the wood products meet high quality standards required for international markets.

1. INTRODUCTION

Laos has an emerging forest plantation industry. The Lao PDR forestry strategy envisages a substantial forest plantation estate by 2020 with a target of 500,000 ha of tree plantations (Midgley et al. 2011). The plantation resource, comprising fast growth species such as teak (*Tectona grandis*) and *Eucalyptus camaldulensis*, has the capacity to provide significant benefits to smallholders while offering further value through primary and secondary wood processing. Wood and partly processed wood products already play a significant role in the economy of the country being one of the main exports (Anonymous 2011). However, challenges and opportunities need to be addressed in order to support the development of a competitive value-added wood industry. Although the industry has grown steadily over the past decades, the export value of high-value finished wood products (*e.g.* joinery, flooring, and furniture) remained modest (Tong 2009). Research and development is needed in the manufacturing sector to enable the production of high-value wood products. The overall aim of the project is to improve livelihoods for farmers and processing workers and the international competitiveness of Lao PDR wood industries through improved efficiency of key elements of the planted wood value chain. Specific objectives include: 1) improving the value and quality of wood products for domestic and export markets; 2) enhancing the competitiveness and capacity of wood processing industries.

The utilisation of small dimensions, plantation timbers requires joining multiple small elements into larger components and gluing is arguably one of the most important steps in a wood product manufacturing process (Rivers et al. 1991, Marra 1992, Pizzi and Mittal 2003). Adhesives play a crucial role in the efficient utilization of wood resources by allowing most types and sizes of wood to be converted to functional products (Frihart 2015). Teak is a species known to bond with difficulty because of its oily nature where extractives interfere with the direct adhesive contact, leading to poor bond strength (Frihart and Hunt 2010, Wood solution 2013). On the other hand, *Eucalyptus*

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camaldulensis is a hard and dense species making it difficult to machine. The timber is also reactive to changes in humidity, generating high swelling pressure causing delamination. Lower joint strength is usually expected when using plantation wood because of increased proportion of early-wood which has been associated with increased porosity (Frihart 2015). The harvest of smaller, faster growing trees can also result in larger growth rings, coarser-textured wood, and higher percentages of juvenile wood in the lumber (Rivers et al 1991). In some species, faster growth means broader bands of difficult-to-bond latewood and possibly differences in the amount of extractive materials. Knowledge of wood properties, surface preparation, and bonding conditions are of particular importance for young plantation timbers. However, the literature is scarce on the listed topics, in particular in relation to the two species listed above. Therefore, this study aimed to assist the Lao wood processing and manufacturing industry by identifying the most appropriate practices for machining and bonding of plantation grown *teak* and *Eucalyptus camaldulensis*. The interest here being to assess current gluing methods in secondary wood processing industries and provide recommendations to improve the value and quality of wood products for domestic and export markets.

2. MATERIAL AND METHODS

A comparative analysis was performed to assess the shear strength mechanical property of glued joints made with 15 to 20 years old plantation grown Teak and *Eucalyptus camaldulensis* (later identified as eucalyptus). Kiln-dried plain sawnboards for both species were selected as recommended by ASTM standard D5751 (2012) whenever possible. The boards were surfaced prior to bonding with a hand-feed moulder machine. Every surface to be glued was visually assessed following surfacing and the number of knife marks was counted to assess the impact of wood preparation on the joint shear strength mechanical property. The slope of grain was determined for every sawnboard giving a total of two values per joint. The two values per joint were then identified either as the lowest or highest value in the joint to allow assessing the impact of both sawnboards forming a joint. The same methodology was applied when measuring the number of growth rings.

Four types of nonstructural adhesive were evaluated: a polyvinyl acetate emulsion (*PVA*); a cross-linking polyvinyl acetate emulsion (*xPVA*); a polyurethane (*PUR*); and an epoxy. The joints were tested for two different uses as prescribed in the previously mentioned standard: dry and wet use and the exposure conditions applied prior to testing were: for dry use 1) cured or no treatment; 2) three-cycle soak; 3) high temperature and wet use 4) boil. Conditions of adhesive application, including assembly and curing conditions, were conducted as prescribed by the adhesives manufacturer. For all types of adhesive, one coat of adhesive at 25˚C was applied to one surface with a paint roller. The rate of spread was measured by weighting the boards before and after manual application of adhesives or as prescribed by the manufacturer. Adhesive-coated sawn boards after being assembled were then pressed using a commercial hydraulic press. The joints, upon removal from pressure were conditioned at a relative humidity of 65 per cent and 20°C for a period of 14 days. Following the curing period, jointed boards were cut to prepare block shear specimens and then exposed to a specific treatment or exposure condition. The specific gravity at 12% (*SG*) and moisture content (*MC*) of each sawnboard were determined after gluing. Two measurements per sawnboard were used to calculate an average *MC* and *SG* (*i.e.* oven-dry based on volume at test) and from end blocks taken outside the glued surface area (*i.e.* one from each end, Figure 1). The average value of each sawnboard forming one joint were then compared and identified either as the highest or the lowest value as mentioned previously. For all possible combinations (*i.e.* 2 species x 4 types of adhesives x 4 exposure conditions = 32 combinations), twenty block shear specimens, representing at least four different joints, were prepared and tested using a universal testing machine (Instron 5569, MA, USA). A wood failure assessment was conducted following the shear test in compression loading.

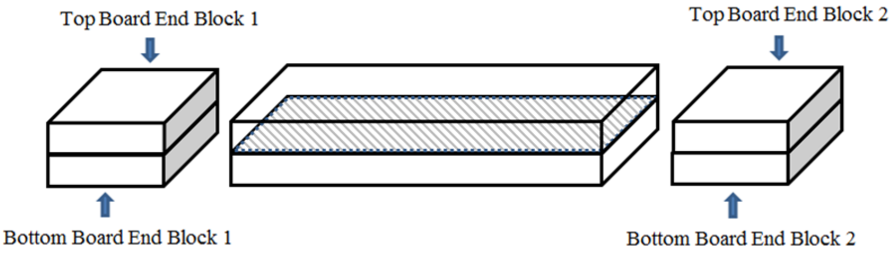

Figure 1: Schematic view of jointed sawnboards and end blocks out of the glued surface area (hatched area) used for the determination of specific gravity and moisture content

Results were then compiled and evaluated against shear strength and wood failure requirements for laminated joints of teak and eucalyptus determined according to a method defined in ASTM standard D5751 (2012, Tables 1-2). The shear strength of the test specimens was expressed as a percentage of the average shear strength of the wood species at 12 % MC.

Table 1: Shear strength and wood failure requirements for teak laminated joint at 12% moisture content as per ASTM D5751 (2012)

Performance classification and exposure conditions [A]	Laminate joint in shear [C]			
	Shear strength [B]		Wood failure [D]	
	Average (MPa)	Individual minimum (MPa)	Group average (%)	Individual minimum (%)
Dry use				
Cured (dry)	7.15	3.58	30	No requirement
Three-cycle soak	3.58	1.79	No requirement	No requirement
Elevated temp.	4.77	2.38	20	No requirement
Wet use				
Cured (dry)	7.15	3.58	30	No requirement
Boil	5.96	2.98	25	No requirement
Elevated temp.	4.77	2.38	20	No requirement

[A] 20 specimens required for each classification and exposure; [B] Using an average shear strength parallel to grain of 11.92 MPa at 12% moisture content (Negi et al. 2004). [C] Parallel to the grain; [D] Group 4 hardwoods that bond with difficulty such as teak are listed at 50 % of the softwood value, with no requirement if the wood failure value calculates to 15 % or less.

Table 2: Shear strength and wood failure requirements for *Eucalyptus camaldulensis* joint at 12% moisture content as per ASTM D5751 (2012)

Performance classification and exposure conditions [A]	Laminate joint in shear [C]			
	Shear strength [B]		Wood failure [D]	
	Average (MPa)	Individual minimum (MPa)	Group average (%)	Individual minimum (%)
Dry use				
Cured (dry)	8.27	4.14	30	No requirement
Three-cycle soak	4.14	2.07	No requirement	No requirement
Elevated temp.	5.52	2.76	20	No requirement
Wet use				
Cured (dry)	8.27	4.14	30	No requirement
Boil	6.90	3.45	25	No requirement
Elevated temp.	5.52	2.76	20	No requirement

[A] 20 specimens required for each classification and exposure; [B] Using an average shear strength parallel to grain of 13.79 MPa at 12% moisture content (Banks 1954). [C] Parallel to the grain; [D] Group 4 hardwoods that bond with difficulty such as teak are listed at 50 % of the softwood value, with no requirement if the wood failure value calculates to 15 % or less.

3. RESULTS AND DISCUSSION

SG for teak and eucalyptus were found to be respectively 0.57 and 0.85 which is in accordance with the literature (Banks 1954, Wanneng 2011, Negi et al. 2004). The number of growth rings was found to be similar for both studied species, ranging between 5.6 to 6.4 and 5.2 to 6.4 per 19.1 mm for teak and eucalyptus, respectively. The slope of grain for teak was on average 1.0:12 and 1.3:12 for eucalyptus. The presence of interlocked grains explains the higher slope of grain for eucalyptus (Ahmad 2015). *MC* for all sawnboards was ranging between 9.8-12.2%. The number of knife marks per 25.4 mm was ranging between 15.2 to 19.6 for epoxy and PUR, opposed to 11.3-12.2 for both polyvinyl acetate emulsions. Due to limitation of laboratory space and long time required to complete each cycle of tests, the gluing experiment had to be divided into two groups. PVA and cross-linking PVA laminated boards were prepared two months after the epoxy and PUR laminated boards. Thus, the surface preparation procedure could not be identical for both groups.

A multi-factorial ANOVA was performed on the shear strength data using MatLab statistical software. Species, types of adhesive, and exposure conditions all contributed individually to significant differences on shear strength properties with significant interactions between them (Table 3). A non-parametric Kruskal-Wallis transformation was performed for wood failure data to achieve normality and conduct individual ANOVA for all studied parameters. Again, species (*Chi-square*=30.12), types of adhesive (*Chi-square*=31.16), and exposure conditions (*Chi-square*=182.72) all contributed individually to highly significant differences on wood failure results ($p < 0.01$).

The highest slope of grain factor (*F*-value=1.40) was found to have a highly significant effect ($p < 0.01$) on the joint shear strength in compression loading (*LSD*=8.73 N mm^{-2}). Both studied species averaged higher slope of grain than the maximum slope of 1:14 recommended by ASTM standard (2012). Small dimensions fast growing trees make the task of getting boards with perfectly straight grain rather difficult, especially in case of the eucalyptus. This species is known to be prone to interlocked grains resulting in a higher slope of grain (Ahmad 2015). This result emphasizes why slope of grain is an important factor when gluing timber. Understanding the impact of the slope of grain on the shear strength of a glued joint is of prime important for furniture makers using those specific species. Extra care during board preparation and selection is essential to avoid an eventual delamination resulting in failure of the furniture item. None of the other wood property factors (i.e. high *SG* value, low *SG* value, high number of growth rings value, low number of growth ring value, and low slope of grain value) had a significant effect on the joint shear strength. The analyses for wood preparation also confirmed that the number of knife marks (*F*-value=2.12) had a highly significant effect on the joint shear strength (*LSD*=5.0 N mm^{-2}). As mentioned by Hoadley (2010), the best surface for finish lumber is produced with 12 to 25 knife marks per 25.4 mm. Both polyvinyl acetate emulsions averaged number of knife marks closer to the lower limit where PUR and epoxy always remained between those limits. Nonetheless, both PVA emulsions averaged higher results for cured samples than PUR and epoxy.

Table 3: ANOVA (*F*-values) results for shear strength mechanical property as a function of species, adhesives, and exposure conditions

Source of variation	***F*-value**	**Pr > *F*[a]**
Species (*S*)	16.28	<0.0001*
Adhesive (*A*)	103.16	<0.0001*
Treatment (*T*)	524.09	<0.0001*
S x *A*	34.76	<0.0001*
S x *T*	22.18	<0.0001*
A x *T*	30.93	<0.0001*
S x *A* x *T*	19.48	<0.0001*

[a] Asterisk indicates significance at $\alpha = 0.01$.

The analysis of the cured specimens allowed to identify three groups (*LSD*=1.2 MPa) in relation with shear strength by compression loading (Table 4). Cross-linking PVA laminated eucalyptus provided significantly higher results than all other tested combinations (including teak), with average shear strength of 14.273±2.616 MPa (superscript ^{a} in Table 4). The result is not surprising considering that teak is known to be very difficult to glue. A second group (superscript ^{b}), composed of cross-linking PVA laminated teak (10.515±2.162 MPa), PVA laminated teak and eucalyptus (10.281±2.741 and 10.064±2.414 MPa, respectively), and polyurethane laminated teak and eucalyptus (10.210±1.267 and 9.984±2.570 MPa) provided statistically similar results. Lastly, significantly lower results were obtained when using epoxy for both species with average shear strength of 7.339±2.021 and 5.529±2.138 MPa for eucalyptus and teak, respectively (superscript ^{d}). This observation was rather surprising considering that epoxy usually provides high dry strength properties (Frihart and Hunt 2010). With the exception of epoxy, all types of adhesive met the average shear strength requirements for cured laminated joint in compressive loading. Only eucalyptus showed a significant improvement when using cross-linking PVA instead of PVA. A similar trend, although not significant, was observed for teak.

Table 4: Average shear strength (MPa) by compression loading per species and treatment

Adhesive	Species	Treatment			
		Cured	**High temperature**	**3-cycle soak**	**Boil**
Cross-linking PVA	Teak	10.515^{b}	5.047^{e}	3.207^{f}	0.397^{g}
	Eucalyptus	14.273^{a}	5.308^{de}	2.390^{g}	0.610^{g}
PVA	Teak	10.281^{b}	4.802^{e}	6.630^{d}	3.688^{f}
	Eucalyptus	10.064^{b}	7.332^{cd}	7.771^{c}	4.016^{f}
Polyurethane	Teak	10.210^{b}	4.203^{f}	3.590^{f}	4.753^{e}
	Eucalyptus	9.984^{b}	1.520^{g}	3.884^{f}	0.008^{g}
Epoxy	Teak	5.529^{d}	2.068^{g}	8.371^{c}	1.444^{g}
	Eucalyptus	7.339^{cd}	0.299^{g}	0.296^{g}	0.127^{g}
LSD (p=0.05)					1.2

* Entries with different superscripts are significantly different to one another ($p < 0.05$).

Both cross-linking and PVA emulsions provided the average shear strength values meeting the requirement for laminated teak exposed to high temperature. However, only PVA laminated teak met the individual minimum requirement for shear strength in this exposure condition. As for eucalyptus, only PVA met the average requirement (*i.e.* 5.52 MPa) with 7.332 MPa though cross-linking PVA laminated samples, with 5.308 MPa missed the requirement (5.52 MPa). Otherwise, both adhesives met the individual requirement for the elevated temperature exposure condition. All tested adhesives met the average requirements for the three-cycle soak test when using teak, with the exception of cross-linking PVA. However, none of the tested adhesives met the individual minimum requirement. As for eucalyptus, only PVA laminated specimens met the average requirement when exposed to a three-cycle soak test. The PVA laminated eucalyptus combination was also the only one meeting the individual requirement. Standard PVA adhesives offered significantly higher results than cross-linking PVA for both species. Interestingly, epoxy laminated teak specimens gave the best results following the three-cycle soak test, statistically on par with PVA laminated eucalyptus. Indeed, epoxy and polyurethane adhesives are usually known to have limited resistance to repeated wetting and drying (Frihart and Hunt 2010). As expected, poor results were obtained for most combinations following the boiling treatment. Polyurethane laminated teak specimens provided significantly higher results than all other combinations, followed by PVA laminated eucalyptus and teak. Again, significantly higher results were obtained for both species when laminated with PVA instead of cross-linking PVA. This is rather surprising considering that cross-linking PVA would normally show improved resistance to warm temperature and moisture (Frihart and Hunt 2010). None of the tested combinations were able to meet the requirement for wet use application.

Polyurethane adhesive performed well with teak as highlighted by the strength test results for cured specimens. Only specimens exposed to high temperature were not able to meet the average strength requirement, missing the minimum requirement by 0.5 MPa. On a positive note, only 15% of the specimens failed to meet the individual minimum strength requirement. Such result is promising from a dry use perspective considering that PUR usually has limited resistance to prolonged and repeated wetting and drying (Frihart and Hunt 2010). Interestingly, 60% of the specimens met the individual minimum requirement following the three-cycle soak test and that figure increased to 85% following the boil test. The latter test is arguably a lot tougher on laminated wood specimens. Such result appears rather promising for both wet and dry uses if wood preparation and adhesive application are carefully conducted. For example, a more accurate control of the pressing pressure might allow PUR laminated teak to meet both requirements for dry and wet use. Low pressures near 0.7 MPa are usually suitable for low-density wood such as teak because the surfaces easily conform to each other, thus ensuring intimate contact between adhesive and wood without (Frihart and Hunt 2010). In addition, excessively high pressing pressure might cause the adhesive to move out of the bondline reducing the shear strength. As highlighted by Martins et al. (2013) evaluating the impact of pressing pressure and machining of PUR adhesive on eucalypts, a change from 0.7 to 1.0 MPa was enough to affect shear strength where machining was also found to have a significant impact on shear strength.

Unlike teak, polyurethane laminated eucalyptus was not able to meet the requirement for high temperature test. An explanation might be the higher specific gravity of eucalyptus that generates high pressure at the bondline as a result of wood shrinkage. Eighty per cent of the specimens met the individual minimum requirement following the three-cycle soak test where the average strength of specimens missed the mark by 0.25 MPa. Wisden et al. (2006), assessing different Australian eucalypt species, concluded that species with poorest polyurethane gluability are usually characterised by a high density. Knowing that the specific gravity for the laminated specimens was on average 0.82, this tends to confirm that good PUR gluability for eucalyptus would require careful attention when preparing the wood surface and applying the adhesive. It is difficult at this stage to fully assess the performance of PUR laminated eucalyptus but, as in the case of teak, having a close control of the pressing pressure might help improving gluability. High pressures up to 1.7 MPa are usually enough for high density woods, which are difficult to compress (Frihart and Hunt 2010). The lower thermal resistance of PUR bonded wood joints have also been reported in the literature and thermal resistance of PUR adhesives is still an issue (Stoeckel et al. 2013).

Epoxy laminated teak did not perform well with the exception of specimens exposed to a three-cycle soak test. For this specific test, only one sample performed under the individual minimum strength requirement and the average strength of those specimens was clearly above the required average shear strength. As suggested for PUR, a higher than required pressing pressure might be at the origin of the problem causing the adhesive to move out of the bondline and reduce mechanical properties. Thus, epoxy would not be recommended for dry or wet use applications for the two species at this stage. Considering that epoxy is known to perform well in situation where gaps between components exist (*e.g.* tenoning) and resist breakdown by heat while being relatively insensitive to moisture (Marra 1992) additional tests with closely controlled pressing pressure would be necessary to adequately assess the potential of using epoxy for the two plantation timbers. As for teak, epoxy laminated eucalyptus did not perform well. Considering the results for eucalypts and teak, additional tests with better control of pressing pressure would be recommended. They are also relatively insensitive to moisture. However, unlike teak, high density species such as eucalyptus generate a lot of stress when its *MC* varies from one extreme to another. The adhesive also tends to delaminate with repeated wetting and drying (Frihart and Hunt 2010).

PVA adhesive outperformed all the other types of adhesive when used in laminated teak joints. Only one single specimen failed to meet the individual minimum strength requirement following the three-cycle soak test which prevented PVA to meet all the requirements for dry use applications. In a similar study comparing the performance of different types of adhesives, it was found that PVA adhesive produced the strongest bonds on ipé (*Handroanthus spp.*), a tropical wood hard to glue, similarly to teak (Schofield 2007). The study concluded that PVA was the adhesive providing the "*best value*" where cross-linking PVA proved to be the "*best all-around choice*" for its ease of use, moderate cost, and overall performance. The results obtained in this study are also promising for wet use applications, with 65% of the specimens met the individual minimum requirement following the boil test. However, such adhesive might not be recommended for wet use applications because it is recognized as having low resistance to moisture and elevated temperatures (Frihart and Hunt 2010). Wood preparation and adhesive application would also need to be closely controlled to insure constant quality bondline. PVA also outperformed all the other types of adhesive when laminating eucalyptus. A single cured specimen failing to meet the individual minimum strength requirement prevented the adhesive to meet all the requirements for dry use applications. Results are also promising for wet use applications with 85% of the specimens meeting the individual minimum requirement following the boil test. Considering that such adhesive has low resistance to moisture and elevated temperatures, it might not be ideal for wet use applications unless wood preparation and adhesive application are perfectly controlled (Frihart and Hunt 2010).

Cross-linking PVA performed well with teak as highlighted by the strength test results for the cured specimens. Only the specimens exposed to a three-cycle soak test were not able to meet the average strength requirement, missing the mark by 0.4 MPa. Thirty per cent of the specimens failed to meet the individual minimum strength requirement. Fifteen per cent of the specimens failed to meet the individual minimum strength requirement for high temperature. Nonetheless, it still did not prevent to meet the required average specimens strength. Specimens exposed to boil test conditions performed poorly which was surprising considering that such adhesive is known to have improved resistance to moisture when compared with standard PVA. A reason to explain such result might be that the product was closed to the expiration date when applied on the boards. A pressing pressure higher than recommended which was used for specimens' preparation might also partly explain such result. Cross-linking PVA performed well with eucalyptus as highlighted by the strength test results for the cured specimens. However, the adhesive was not able to meet the required average strength following three-cycle soak and high temperature tests. Interestingly, all specimens met individual minimum strength requirement when exposed to high temperature but the group average could not meet the mark, falling by 0.2 MPa only. The fact that the product was closed to the expiration date when applied on the boards might explain poor results of this adhesive.

Results of wood failure assessment indicated that none of the combinations tested were able to meet the 20% wood failure requirement for specimens exposed to high temperature. The highest result was obtained for teak laminated with epoxy where the other combinations typically scored 7% or lower. PVA adhesives are known to have rather low resistance to elevated temperature cause by the glue bond softening (Marra 1992, Frihart and Hunt 2010). However, higher results were expected from adhesives with improved resistance to high temperatures such as cross-linking PVA and epoxy. It appears that high-density lumber such as eucalyptus laminated with epoxy cannot withstand wide swings in moisture content because of high wood shrinkage values. Shrinkage for teak caused by the presence of juvenile wood might also explain lower results with epoxy adhesive. It is worth mentioning that other standards such as ASTM D4317 (2011) for polyvinyl acetate-based emulsion adhesives do not require any temperature treatment to meet intermediate and dry use applications. However, requirements for cured specimens are much higher (*i.e.* 19,306 MPa) and the humidity exposure test would be necessary to comply with the standard.

When laminating teak, both cross-linking and standard polyvinyl acetate emulsions met the 30% wood failure requirement with an average of 44% and 55%, respectively. These two combinations were also the only ones where no individual result scored 0% of wood failure for cured specimens. On a downside note, neither combination met the average requirements following high temperature and boil tests. This prevents PVA and cross-linking PVA to be considered suitable for dry and wet use applications at this stage. As for the three-cycle soak test, no requirements are specified by ASTM standard. Neither cross-linking PVA nor PVA allowed meeting the wood failure requirements for cured specimens when laminating eucalyptus with 13% and 15%, respectively. Results lower than the required average were also observed following high temperature and boil tests. Again, this prevents PVA and cross-linking PVA to be considered suitable for dry and wet use applications at this stage for eucalyptus.

On the other hand, polyurethane adhesive met the requirement for cured specimens when laminating eucalyptus (43%). The high temperature results would not be sufficient to meet the requirement following high temperature and boil tests. The same success could not be achieved with teak although surprisingly high results were obtained following the three-cycle soak test (46%). Finally, the results from the wood failure assessment for both species with epoxy were both lower than the other combinations as observed for the shear strength tests.

4. CONCLUSION

This study aimed to gain a deeper understanding of the relationship between wood property, wood preparation, and adhesive application factor on the shear strength of joints of teak and *Eucalyptus camaldulensis*. Both tested species performed reasonably well. Cross-linking PVA laminated eucalyptus provided the best average shear strength results compared to all the other studied combinations for cured samples. However, PVA adhesive was the only tested adhesive to meet the requirements for all the exposure conditions.

A high slope of grain has been found to have a highly significant effect on the joint shear strength in compression loading. The finding is important for the wood secondary processing industries aiming to produce high-quality wood products for domestic and export markets. Optimisation through improved efficiencies of the primary wood processing sector could help limiting the impact of this factor and improve the overall performance of glued joints.

A second factor found to influence the joints strength was found to be the number of knife marks when surfacing sawnboards prior to gluing. The implementation of a regular quality control program would help manufacturing higher quality productsand would allow improving productivity and increase competitiveness of wood processing industries. Improved product quality and compliance with market quality requirements will not only facilitate access to higher value markets and global markets but also improve competitiveness of wood processing industries by promoting adoption of industry best standards already used in major neighboring markets. Improved quality control procedures will also provide additional tools to improve product development. The quality of wood products can be significantly improved through the implementation of optimal parameters and methods used in joining wood elements and components.

Additional research would be required to fully assess the impact of pressing pressure on the mechanical properties of joints. The impact of knife wear on the gluability of planed surfaces is another factor that should be further investigated.

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