A TECHNICAL EVALUATION OF VENEER CUTTING AND BORING OF COCONUT (*Cocos nucifera* L.) STEM WOOD

by

ARJUN M S

(2019-17-014)

THESIS

Submitted in partial fulfilment of the

requirements for the degree of

MASTER OF SCIENCE IN FORESTRY

Faculty of Forestry

Kerala Agricultural University

DEPARTMENT OF FOREST PRODUCTS AND UTILIZTION

COLLEGE OF FORESTRY

VELLANIKKARA, THRISSUR, 680 656

2022

DECLARATION

I, hereby declare that this thesis entitled **"A TECHNICAL EVALUATION OF VENEER CUTTING AND BORING OF COCONUT (*Cocos nucifera* L.) STEM WOOD"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"A TECHNICAL EVALUATION OF VENEER CUTTING AND BORING OF COCONUT (*Cocos nucifera* L.) STEM WOOD"** is a record of research work done independently by Mr. Arjun M.S under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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ACKNOWLEDGEMENT

I take this opportunity to acknowledge National Agricultural Higher Education Project (NAHEP), Centre for Advanced Agricultural Science and Technology (CAAST), funded by World Bank for the financial assistance for my project under Knowledge and skill development on coconut Based secondary Agriculture.

I extend my deepest sense of gratitude to ***Dr. E. V Anoop****, Chairman of my advisory committee, for giving me the freedom to think beyond and work my thoughts at my own pace. He has made me self-reliant to find a better way through interacting with many peoples. He has been a facilitator for the entire course of my Masters programme. His guidance and support help me to complete my work even during this pandemic.*

There are no enough words to express my gratitude to ***Dr. Rob McGavin,*** *Research Facility and Project Manager in Department of Agriculture and Fisheries, Queensland Government, Australia for the constant encouragement and relentless support. He gave me the foundation for my research and teach me the best version to conduct any research.*

I am grateful to my advisory committee members, ***Dr. S. Gopakumar,*** *Professor and Head Dept. of Supportive and Allied courses, College of Forestry, to act as a mentor during my masters and gave the best motivation to find me the best opportunity during the pandemic. I also thank to* ***Dr. K. Vidyasagaran*** *former Dean, College of Forestry,* ***Dr. C. M. Jijeesh,*** *Assistant Professor, Dept. of Silviculture and Agroforestry, College of Forestry to giving valuable suggestions and guidance to complete my work.*

I am extremely thankful to ***Dr. Vishnu R, Anish M.C*** *(Assistant Professor,Forest products and utilization, College of Forestry) and* ***Dr. Pavin Praize Sunny*** *(Teaching assistant, Forest products and utilization, College of Forestry) for moral and mental support to complete my work. I am also expressing my sincere gratitude to* ***Dr. Bijeesh, Mrs. Divya, Mrs. Sindu, Mrs Anju*** *who are* working in Forest Products Utilization for helping me. I also sincerely thankful to **Mr. Midun** who helped me a lot during the wood working related works

I cannot express my thanks through words to **Mr. Azhar Ali A, Mr. Vivek Noel, Mr. Sooraj Dev, Mr. Jaseel Mr. Sankara Narayanan, Mr. Alfas** who work with me to complete my work. Without their kind help and support, it is not possible to complete this work on time. I also thank to **Mr. Deepak Ranjan Sahoo** and **Mr. Shibu C** for their valuable comments and support. I also thank to **Mr. Shijith S Nair, Mr. Shifin S R, Mr Sreehari K Mohan, Mr Bhavane Akash Kailash, Mr Santhosh D T, Mr Sankar Thampuran, Mrs Shahina N N, Mrs. Neha Tamnakar, Mrs. Devi S R, Mrs. Mamtha N A, Mr. Kiran Mohan, Mr Abin M Sunil, Mr. Bibin N V** for the assistance during my work.

The also thank to **C M Engineering** works Mannuty for their technical support for completion of my work. I also thank to **Mr Noushad**, Member of Plywood association Perumbavoor for their kindness for providing me the technical assistance and support for completion of my work. I also thank to Fathima industry in Vallom, Perumbavoor and Salim industry at Pulluvazhi, Permbavoor for providing the technical support.

I also thank to **Mr. Abu, Mr. Vinod** for providing me the proper guidance to complete the work successively. I also express my gratitude toward **Mr. Hariharan** for helping me to get the contacts of various personality for helping my work. I also thank to **Mr. Krishna**, manager of Coco-products, Gubbi, Karnataka, for immense support for my work. I also thank to **Dr. Lohith, Dr. Punnet** and **Mr. Manikandan** in Siddaganga Institute of technology, Thumkur, Karnataka for their kindness and support.

I also thank to Rhythm musicals Koorkanchery for providing me technical support for my work. I also thank to ST Marys industry for providing me raw materials for my project. I also thank to **Mr. Sanju**, Kezhekkevayalar, Alappuzha for the support and guidance.

Words are not enough to express my gratitude towards my family who keep me support and for their blessings and love.

Arjun M S

CONTENTS

LIST OF TABLES

LIST OF PLATES

LIST OF FIGURES

1. INTRODUCTION

Kerala is known as the land of coconut. Coconut tree is described as "the tree of life" or the tree of plenty and nature's greatest gift to man. Coconut is a tree with plenty of utility including food, energy, and also shelter to farm households. Coconut is also value-added for many product diversifications and enhanced its potential utility. It is known as "Kalpavrisham" because of if the usefulness of the entire parts (ENVIS, 2014). One of the largest production holdings of coconut belongs to India in the world and accounting productivity of 9345 (Nuts/ha) with 2.17 million hectares of planted area. The productivity of coconut is declining from past decades and it was declined from 11481 (Nuts/ha) in the 2016-17 to 9345 (Nuts/ha) in 2019-2020 (CBD,2021). In Kerala, senile and diseased palms were the major reasons for this rapidly declining coconut production. The productive capacity of coconut palm is found to be reduced after reaching 60 to 80 years of age, thus becoming senile (Arancon, 2009; Oduor and Githiomi, 2006; Ohler, 1999). Arancon (2009) observed that 20 percent of the total Indian palms were at senile stage eligible for replanting. In the case of Kerala, Anoop *et al*. (2011) figured out that 50 percent of the area under coconut plantation in the state and border districts of Tamil Nadu were under high threat of root wilt diseases. It was also found that a large number of senile and diseased palms require replanting to bolster coconut production and to ensure sustainable supply of coconut. In a pilot project on replanting and rejuvenation of palms Coconut Development Board, Ministry of Agriculture and Farmers Welfare, CDB (2016) enumerated the removal of about 16.72 lakh of coconut palms from the district of Thiruvananthapuram, Kollam, and Thrissur districts in Kerala from 2009 to 2013. CDB (2021) estimates about 48960 disease advanced, old and senile palms to remove from Kerala under the scheme of Replanting and Rejuvenation of Coconut gardens in Kerala 2019-20. The study by Hass and Wilson (1985) showed that wood volume productivity from a mature or over-mature plantation is about 100 m^3/ha considering 100 palms per hectare. About 0.15-0.2 m^3 of the sawn sizes of lumber could be obtained from an average size of a fully mature coconut palm (Muralidharan and Jayashree, 2011).

The most of the palms removed as part of the above-mentioned pilot project in Kerala remained unused to eventually resulting as breeding ground for pathogens and various other environmental issues. According to Oduor and Githiomi (2006), the wood obtained from the senile palms could act as a good renewable source for timber and a potential substitute for traditional hardwoods.

Coconut palm stem is difficult for the conversion and the density variation from very low to very high makes them challenging for the better efficient utilisation. Gonzalez *et al*. (2014) and Bailleres *et al*. (2010) has plotted the density and diameter patterns variation from the bottom to the top of the palm stem. The range of density variation was not worthy from 100 kg/m³ in the center of the trunk to more than 1000 kg/m³ on the periphery. It was also pointed out that at the same height, the average density of coconut palm stem and from the center-to-periphery density variation can differ significantly between trees and it is mainly influenced by the age of palm (Bailleres *et al.,* 2010; Hopewell *et al.,* 2010). The cylindrical stem of the coconut stem is described as a primary vascular bundle which is embedded in a ground tissue of parenchyma (Butterfield *et al.,* 1997). The palm stem is nonbranching and knots-free and has a great decorative potential. The wood is durable, hard, and also with significantly lowers volumetric shrinkage (Anoop *et al.,* 2011). Like conventional wood, the coconut stem is durable, versatile, and sturdy and can be obtained at a considerably lower cost as compared to other conventional hardwoods. The material cost of coconut wood is low and about half the price or little more than half the price as compared to the market price of conventional wood used for construction purposes (APCC, 1998). The proper utilization of coconut palm is difficult because of its higher density variation within the tree. Coconut wood is unique from other hardwoods, softwoods and even it is different from the wood of other palm stems in terms of fiber orientation, tissue anatomy, and density distribution (Bailleres *et al.,* 2015).

Increasing demands on wooden products and to reduce the impact on the environment due to over felling of trees from the natural forest, wood scientist is searching for an alternative to this solution. Coconut could be adoption for panelling and interior decoration due to its durability, unique beautiful figure, and fresh look. Through efficient sawing, seasoning or drying, treated coconut wood with high density are suitable for all the construction purpose that required strength property, like for window frames, doors, trusses, floor tiles (parquet), grids, flooring, railings and other bearing structures (Arancon, 2009 and Muralidharan and Jayashree, 2011). However, Nolan *et al*. (2019) forwarded that traditional methods of sawing resulted from coconut stem log. Sawing of coconut logs gives only an average recovery of 30-35 percent of the log and the rest are waste with limited uses (Bailleres *et al.,* 2010). One alternative solution for enhancing the recovery of the coconut palm is peeling off the log. But peeling the log using a spindle peeler is not feasible since the spindle cannot hold the soft inner part of the coconut and a spindle less peeler may be an alternative.

In Kerala, coconut and coconut products are one of the main ingredients for Kerala's delicious dishes. Current researches mainly focused on the potential of coconut oil because of its health benefits and make it one of the main parts of the entire formulation of Ayurveda firms in Kerala. The coconut as wood is least explored and efficient utilization of coconut wood is still a barrier for the scientific community due to the varying properties in a single piece of wood. The coconut wood having a great potential to substitute the conventional hardwood species hence it can decrease the overexploitation of the hardwood.

The unique decorative value of the coconut palm makes it a suitable for value added products. The coconut pillars were used in the houseboats had a greater natural look and making the houseboat more attractive in Alappuzha region of Kerala. But the using of coconut log as whole leads to splitting and fungal damage due to the soft inner core of the log. It is also very hard to remove the soft core in the whole length due to the technology constrains. Hollow cylindrical logs of coconut can be produced by boring the coconut logs in the whole length also have better decorative utility.

The present study is an attempt to enhance the utility of coconut wood especially for decorative potential through optimising peeling, sawing, and boring of coconut stem wood for veneer-based products and other structural application. The unique texture and appearance of coconut wood veneer have a high decorative utility. The study also hypothesis that the value addition of the coconut palm wood will pave the way for the introduction of an additional source of income to coconut farmers from the senile coconut palm.

The objectives of study titled "A technical evaluation of veneer cutting and boring of coconut stem wood"

1. To evaluate the potential of coconut stem wood for veneer production
2. To evaluate the potential of boring of coconut stem wood for various structural applications.

2. REVIEW OF LITERATURE

Palm wood is considered as revolutionary material for the 21st century construction uses. It has unique property and a good substitute for commercial timbers. The following sections have been discussing several aspects of coconut palm stem including its properties and coconut veneer manufacture process

2.1 The Coconut palm

Angiosperms are subcategorized into monocotyledons and dicotyledons. Palms are flowering monocotyledons plants that produce comparatively large-diameter stem reinforced by fibers while the material inside the palm stem is not true wood with different characteristics. Coconut palm, *Cocos nucifera* belongs to the family monocotyledons is distributed widely in the tropical and subtropical regions (Killmann and Fink, 1996; Arancon, 1997; Chan and Elevitch, 2006; Broschat and Crane, 2000). Coconut palms are distributed along the sandy shoreline naturally. Well-drained soils including sand to clay are the best of coconut palms (Broschat and Crane, 2000; Chan and Elevitch, 2006). The inability of palm to undergo dormant stages during unfavourable external environmental conditions makes its distribution limited to tropics and subtropics (Tomlinson, 2006). Oduor and Githiomi (2006) pointed out sandy soils and alluvial soils are most preferable for the coconut palm. Coconut requires 1000 mm of annual rainfall and 27°C of annual temperature with 20°C as a lower limit (Oduor and Githiomi, 2006). Chan and Elevitch (2006) suggested that coconut palms required annual rainfall of 1500–2500 mm. Broschat and Crane (2000) pointed out that coconut required a minimum temperature of 22°C and annual rainfall of around 760 - 1250 mm or more for better growth.

Today coconut palm is one of the important commercial grown crops in many regions of the Pacific and Southeast Asia. Coconut is described as "the tree of life" (Chan and Elevitch, 2006; Oduor and Githiomi, 2006; Ohler, 1999), "tree of heaven" (Chan and Elevitch, 2006), and nature's greatest gift to man (Oduor and

Githiomi, 2006). Almost all the parts of the coconut are using and because of this, the coconut palm is regarded as “Kalapavrisham” (Khairul *et al.*, 2009). Copra which is used for the production of coconut oil is the major product of coconut (Broschat and Crane, 2000; Killmann and Fink, 1996). A lot of other products like mats, brushes, ropes and strings, foods, drinks (coconut milk, neera, toddy, tender coconut juice), brooms, thatch, baskets, and mats from the coconut leaves, fuel from the dried shells, timber from the mature stem, tool handles, furniture, boat building and building construction materials are made from various parts of coconut (Chan and Elevitch, 2006; Oduor and Githiomi, 2006; Ohler, 1999; Killmann and Fink, 1996).

2.2 Properties of coconut palms

Unlike other conventional timber species, the coconut palm is monocotyledon with the absence of a cambium and taproot system. The coconut cannot repair itself by new growth after the injury due to the absence of cambium. The absence of cambium is the same reason for the inability of coconut to increase its diameter on age (Oduor and Giothiomi, 2006; Ohler, 1999). The wood-like structure is primary tissue and it cannot compare to the wood in angiosperm and gymnosperm (Tomlinson and Zimmermann, 1967). The coconut palms are characterized by being free from knots makes their stem smooth with devoid of knots. There is no relation between the age and diameter in the coconut and is mainly influenced by the site characteristics and environmental factors. The denser and harder part of the stem is found on the peripheral parts and softer parts can be seen towards the centre part (Arancon, 2009).

Palms are characterized by higher resistance to fire, pathogens, and also wind-hardy species. The palms are almost cylindrical with low tapering due to the absence of the secondary growth, because of the absence of the vascular cambium in the monocotyledons (Weiner and Liese, 1988)

Cocos nucifera L. has a smooth, slender, and straight or marginally bent trunk which can attain the height of 20-25 meters with an average diameter of 30 cm-40 cm with slightly swollen in basal part (Arancon, 2009; Ohler, 1999; Odour and Githiomi, 2006). Chan and Elevitch (2006) stated that 40-year-old coconut palm will reach a height of 20-22 m and 80-year-old coconut palm can reach a height of 35-40 m. According to Ohler (1999), the coconut palms have normally grown to the height of 25 m and abnormal cases to 30 m, which is mainly depends on the environmental conditions and age. Chan and Elevitch (2006) remarked the first fruit will produce by 5-6 years from planting. The coconut palms will produce their first fruits after 6-10 years after planting and reach full potential at 15-20 years old (Broschat and Crane, 2000). The productivity was found to be decrease from 60 to 80 years and the tree becomes senile (Arancon, 2009; Oduor and Githiomi, 2006; Ohler, 1999).

2.3 Structure of the Coconut palm stem

The cross-section of the palm can be distinguished into 3 zones: dermal, sub-dermal, and centre core zone. The dermal region is the peripheral region just below the hard epidermis; the sub-dermal is the region found between the dermal and center core; the core is the inner softest part of the stem. (Arancon, 1997; Ohler, 1999; Oduor and Githiomi, 2006). The hardest and densest part of the coconut wood is the outer peripheral region, which gives the palm strength and can withstand the wind; the silica content in the wood is responsible for the elasticity of the palm. The palm strength will decrease towards the centre and top of the stem (Arancon, 2009). The coconut palm can divisible into root, stem, and crown and is also characterized by the absence of bark. Instead of bark, the hard epidermis acts as the protective role. The stem consists of soft ground tissue of parenchyma in which fibrovascular bundles are embedded in it. The arrangement of hard vascular bundle in the parenchyma tissues resulted in the formation of reinforced material (like concrete in steel) (Tomlinson 1990; Fathi, 2014).

The apical meristem which is the terminal growing point is protected by the layer of leaves. Once the palm is grown laterally to a maximum girth, it will start to grow its height. This growth is very slow and can be lasted for many years because the apical bud should reach a particular height before the trunk develops (Cousins and Meylen, 1975).

Killmann and Fink (1996) described the arrangement of fibre bundles in the ground tissue of parenchymatic cells. These contain the vascular bundles for the transportation of water and nutrient through the palms and also the thickly walled fibres give the palm stem its strength. The ground tissue made of parenchyma has the main function of storage and contains starch. These anatomical features result in the non-homogenous characteristics of physical and mechanical properties in both cross-sections wise and height wise. The coconut palm stem consists of fibrovascular bundles, ground tissues, and fibrous bundles. The fibrovascular bundle contains xylem, phloem, thick-walled sclerenchyma fibers, and axial parenchyma. The cell wall thickness of sclerenchyma fibers gradually gets thicker from the core centre to the peripheral region. The xylem is covered by parenchyma cells and usually consists of two wide and large vessels, a combination of small and wide vessels, or several small and wide vessels in a cluster form. The ground is mainly parenchymatous and the cell wall thickness gets declined from the peripheral region to the inner core region (Arancon, 1997).

2.4 Coconut as Wood Material

As the coconut stem is almost cylindrical in nature and the taper of the stem is very small of about 5 mm (FAO, 1985), the recovery through sawing the coconut palm is about .15 m^3 to 0.3 m^3 (Gnanaharan, *et al.*,1986; Arancon, 1997). The diseased and root wilt does not affect the sawn timber recovery (Gnanaharan *et al*., 1986). The scientific data indicated that coconut stem wood can be regarded as a good substitute for conventional timber species. Like the conventional timber species, the coconut stem is sturdy, durable, and versatile, and characterized by the low cost of raw material (APCC, 2000). In the lumber market, coconut stem wood is known to be 'Porcupine wood' due to its hard fibrovascular bundle. Wellseasoned and finished wood has a very attractive grain and a fresh look (Moore, 1948).

The bottom of the coconut palm will reach a maximum diameter of around 25-35 cm (FAO, 1985; Killmann and Fink, 1996; Odour and Githiomi, 2006; Arancon, 2009). This is comparatively smaller as compared to other conventional sawn timber and thus the recovery of sawn lumber is limited in coconut due to its small diameter. The reasonable thickness and width of boards that are recovered from coconut stem wood are 50 mm and 25 mm (Arancon, 1997). The average height of the tree can be reached up to 15 m to 25 m but only 1/3 (5m to 8 m) of the stem can be feasible for construction purposes or regarded as a viable material for load-bearing structures or structural applications. The wood of the top portion of the tree is too light even in the dermal portions and not useful for any constructions. The coconut stem is converted into wooden products in a small-scale setup and used for substituting for conventional woods in bridge construction, building, for tools, toys, handicrafts, furniture, and others (Khairul *et al*., 2009). Coconut palm is traditionally used for the construction of fishing boats in the Maldives. The potential of coconut wood for paneling, construction, stairs, door jambs and windows, power poles, and flooring mainly depends on the portion of the coconut stem used (Mead, 2001). Some palm species produce stems that are satisfactory for manufacturing local lumber constructions (Shmulsky and Jones, 2011; Walker, 2006)

Research findings are showing that almost all the hard-dense peripheral regions and subdermal regions can be used for construction purposes while the softcore part is not suited for any structural application. High-density portions are best for making load bearing structures. The trusses and internal applications are made using sub-dermal medium density portions and can be used for the development of a wide range of advanced designs for the former (FAO, 1985; Arancon, 2009; Adkins *et al.,* 2006; Jayabhanu, 2011). House flooring and steps can be made using these hard portions and the internal linings of the wall can be made by using medium-density portions (Anoop *et al*., 2011).

The performance of the coconut stem wood for industrial application mainly depends on the physical, anatomical, and mechanical properties (Mitchell, 1964; Gurfinkel, 1973). Hasemann, (2011) studies showed that high and medium-density coconut palms can be used in load-bearing applications. Medium-density portions are good for non-load-bearing applications like roof, wall, and flooring. The sawing of the coconut palm is mainly based on the density class to obtain better quality lumber for special purposes (Killmann and Wong, 1988). The low durability of medium density portions restricted the usage of medium density in outdoor applications. To enhance the durability, appropriate wood preservation is required (Fruhwald *et al.*, 1992). The palm stem is lacked branching and resulting in a knot-free stem and the natural defects have no effects on the strength of the wood (FAO, 1985). Marino (2010) also proposed the manufacturing of high valuable flooring, furniture, and benchtop from senile coconut palms. Hopewell (2010) put forward the usage of a low-density core of the coconut stem for ethanol distillation, potting media, compost, core plates, and for the production of door and flooring, a high-density portion is recommended. Coconut fiber-cement boards (CFB) are manufactured by mixing cement and coconut chips with a ratio of 3:7 (Arancon, 2009). The result obtained by Lertwattanaruk and Suntijitto (2015), shows good results with this CFB with density (550-650 kg/m^3), thermal conductivity (0.09 W m^{-1} K^{-1}), and bending strength (8.3 kg/m^2).

Sulc (1983) suggested the use of coconut stem wood for transmission poles, in sawmill structures, wood drying open side sheds, agriculture auxiliary buildings and woodworking shops. Sudo (1980) recommended the usage of the most recently grown part of the mature and over mature stem or younger stems are suited for pulping process. Moderate strength was shown by both unbleached and bleached coconut palms (Zerudo and Escolano, 1976). According to Killmann and Fink (1996), recommended that coconut is not a feasible product to make face veneer for plywood manufacturing because the veneer obtained will collapse on drying. It is technically possible to manufacture pulp and paper from coconut but at the same time, it is uneconomical too.

Coconut stem wood sawdust potential for cattle field also explored. Gonzalez (1979) shows that coconut sawdust can be utilized for cattle feed on treating with 1 percent of nitric acid and fodder quality is also comparable with conventional silage. Coconut wood also can be used as fuel, it has decent calorific value, and brick kiln workers prefer coconut wood due to its low cost and burning the coconut wood along with cashew wood increase the reddish tint in the bricks due to resins in the wood (Gnanaharan, 1987). It can be also used for the production of charcoal. The dermal high-density portion yields better quality charcoal as compared to the low-density parts (Gnanaharan *et al*., 1988; Arancon, 2009). Coconut charcoal is suited for producing activated carbon which can be used as a good source of carbon for the production of various products and applications (Arancon, 1997).

2.5 Physical properties

Arancon (1997) and Palomar (1990) pointed that, coconut palm physical properties are influenced by the moisture content, density, and shrinkage. Variation in the distribution of fibrovascular bundle, fiber proportions to other types of cells in a vascular bundle, and cell thickness of ground parenchyma and fibers are contributed to the difference in the palm physical properties (Sudo, 1980). The coconut stem wood density and the distribution and concentration of fibro-vascular bundles per unit area is some of the important characteristics for mechanical or visual grading (Sulc, 1983).

Density is one of the most important characters depends on the physical and mechanical properties and determines the wood materials for particular end-use (Mitchell, 1964; Gurfinkel, 1973). The cortical region of the palm wood is one of the hardest tissues in the plant kingdom (Wiesberg, and Linick, 1983). The coconut stem wood shows a wide variation in the density along the length-wise and cross-section-wise. Hopewell *et al.* (2010) show that the density can be more than 1000 kg/m^3 in the peripheral part of old senile palms. Jayabhanu (2011) also observed the reduction of density in the coconut palm from top to bottom and also from core to the peripheral region. Arancon (2009) remarked that only the portion above 600 kg/m^3 is applicable for load-bearing structures, the coconut stem wood with less than 400 kg/m^3 is not suitable for load-bearing applications. A single palm stem shows the density variation from balsa to ironbark (Marino, 2010). Because of the non-homogenous nature of palm wood Oduor and Githiomi (2006), try to classify the palm wood as light and heavy due to density variation over height and cross-section.

We can notice a drastic reduction in the basic density from the bottom to the top of the palm and from peripheral to the centre core. Ranges of density varies from 100 to 110 kg/m^3 at the centre part of the top region and about 850 to 900 kg/m^3 at the dermal portion of the bottom region (Arancon, 1997). The moisture content also increases with height and decreases from the softcore to the hard-dermal portion.

Sulc (1983) put forward the classification of coconut palm based on the density groups including hard high density (above 600 kg m^3), medium density (400-600 kg m^{-3}), and soft low density (below 400 kg m^3). Desch and Dinwoodie (1981) try to classify based on the hardness level including soft, intermediate, and hard based on the density; low density (below 350 kg m^3), medium density (between 500 kg m^3 and 350 kg m^3) and high density (above 500 kg m^3). The coconut stem wood between 15 m to 20 m or above 20 m height, the density will be low or medium even in the outer peripheral region and the top portions are mainly low-density region (Jensen and Killmann, 1981). As the age increase, the density at any height or cross-section will increase. The density of the coconut palm is most influenced by the proportion of vascular bundles per unit area. This parameter also depends on mechanical properties (Darwis *et al*., 2013). We can also notice the density variation within an individual piece of coconut stem due to the variation in the proportion of the bundles at any point (Peters *et al*., 2014).

The swollen butt has usually a lower density as compared to the region above that (Richolson and Swarup, 1977). Sclerenchyma fibres are the most affected by density (Meylan, 1978). Hopewell *et al*. (2010) pointed out that, there is no significant difference in density between the sites including low coastal and high inland for similarly aged groups from Fiji and Samoa. He also pointed out that wide variation can be observed within a palm and these variation ranges are similar from site to site. There is also texture variation that can be observed due to the difference in the size and distribution of the fiber. A higher density is also noticeable by colour variation and denser wood is being darker as compared to lighter wood (FAO, 1985).

The ground parenchyma cells wall gets thicker and darker from the core to the outer periphery of the palm stem (Kloot, 1952). Hopewell *et al.* (2010) put forward contrary results stated that the colour is not an acceptable indicator for the density and even pale colored wood are suitable for high valued flooring application. Gnanaharan *et al.* (1986) stated that there are no significant changes in the density of the coconut palm from the outer specimen of the basal and middle portions of the palms. The mineral content in the coconut wood also influences the density of the wood and it depends mainly on the edaphic and climatic conditions of the site (Peters *et al*., 2014).

The potential of the wood for end-use is mainly dependent on the natural durability and it is highly density-dependent factor. The lower density portions are not suitable for structural and constructional application due to the defects that occur mainly during the drying process (FAO, 1985). The higher density portions are less susceptible to insect and fungi attacks (Jourez *et al.*, 2012). The resistance of the coconut stem against the fungus is decreasing from the epidermal to core regions and from the bottom butt end to the top (Ballon, 1984). The researcher also reported that the higher density (more than 1000kg m^3) is less vulnerable to termite attack as compared to lower density portions. However, untreated coconut wood is not considered to have termite resistance property (Hopewell *et al*., 2010; Owoyemi *et al*., 2013; Peters *et al*., 2014). Density and dry salt retention show a highly inverse relationship showing the treatability nature of the palm wood (Gnanaharan and Dhamodaran, 1989).

2.6 Mechanical properties of coconut palm wood

Anatomical characters mostly influence the mechanical property of a wood (Wegst, 2011). The conventional wood species do not vary significantly in their mechanical properties and due to the lignifications in the fibres as age increases while mechanical property in the palm species show variations (Rich, 1987; Tomlinson, 2006). The coconut palm has high resistance to splitting on the impact on felling is due to the fibre orientation under higher tensions in the bottom portion of the palm (Hopewell *et al*., 2010). Mechanical properties of the wood show the resistance capacity of the wood against various forces externally, static or dynamic, (Sekhar *et al.,* 1962; Panshin and Zeeuw, 1970; Killmann and Lim, 1985). Mechanical properties are varied between the trees and also within the tree due to the variation in the fibre orientation and also influenced by moisture content, defects, and temperature of wood. Higher proportion and higher density of vascular bundles result in the higher mechanical strength in coconut (Gibson, 2012). These strength properties are mainly observed in the senile coconut palm. The higher amount of the wood materials resulted in the higher density is responsible for higher strength (Limaye, 1952; Sekhar *et al*., 1962; Panshin and Zeeuw, 1970; Killmann and Lim, 1985). It is observed that the mechanical properties are more than 50 percent in the outer region as compared to the inner core (Khairul *et al.*, 2009). Mechanical properties are observed by the estimation of modulus of rupture (MOR) and modulus of elasticity (MOE) in the longitudinal and transverse direction (Kuo-Huang *et al*., 2004; Bahtiar *et al*., 2010).

Oduor and Githiomi (2006) estimated MOR (Modulus of Rupture) of the bending strength and compression strength as 16.34 N/mm^2 - 109.21 N/mm^2 and 9.84 N/mm^2 - 77.56 N/mm^2) respectively for coconut palm and shows the ranges from very strong to very weak. Killmann and Wong (1988) compare the mechanical property of palm with the assessed report of the coconut by Sulc (1983). All the mechanical property of the coconut is more than the oil palm wood (Fathi *et al*., 2014). This result is due to a high percent of denser tissue in coconut (60 percent) as compared to 30 percent in the palm. Kloot (1952) finds the bending strength of coconut as 47.4 Mpa and compared with other commercial timbers including lodgepole pine (air-dry) 44.1 MPa, Western red cedar (oven dry) 47.9 MPa, and Red pine (green) 48.0 MPa. Mechanical properties like compression strength, bending strength, shear strength, and impact bending are studied by Fruhwald *et al.* (1992), of the coconut growing in Indonesia and found that coconut strength properties are comparable with the common conventional timbers and the basic density are 20 percent -30 percent lower compared to other traditional timbers. This drawback can be reduced by selecting the high-density coconut stem.

Fathi (2014) studies the MOR and MOE of an individual fibro-vascular bundle in the peripheral region and core region and found that the peripheral region shows higher MOE (344 MPa) and MOR (25144 MPa) than the core, where MOE and MOR are (228 MPa) and (17636 MPa) respectively. She also compared the coconut palm with oil palm and date palm and found the mechanical properties of coconut are higher as compared to date and oil palm. MOE and MOR are higher in the bottom dermal portion and lower at the core and they will decrease with the stem height and across cross-sections from dermal to core regions (Bahtiar *et al.,* 2010 and Fathi, 2014).

The studies by Kothiyal and Kamala (1996), show the comparison between the mechanical properties of coconut and teak and found that the coconut show higher values except in the shear strength. Bahtiar *et al.* (2010) show the result of Young's modulus (8118 MPa - 8596 MPa) and MOR (118 MPa - 224 MPa) of coconut stem wood and the result found to be comparable with the traditional species used for construction purposes in the USA. Gnanaharan (1987) compared the MOR and MOE of coconut with some species in Kerala like *Terminalia paniculata, Xylia xylocarpa, Albizia odoretissima, A. hirsutus, and Artocarpus heterophyllus* and found that the lower portion of coconut from mature and over mature senile palms are comparable with common construction timbers in Kerala. Strength property expects MOE does not influence the age of the palm (Gnanaharan and Dhamodaran, 1989; Okai *et al.,* 2004). The hardness test in the peripheral region of the coconut stem shows a higher value of 10950 N as compared to European oak (5550 N) and teak (5550 N) (FAO, 1985).

2.7 Log specification, grading, and pre-processing

Veneer operation success depends on three main factors including the supply of suitable logs, use of suitable techniques of processing the log, and effective marketing program and sales. A lot of factors depending on the veneer quality are species, silviculture, growing condition, and overall health of the tree. This includes the growth rate, age, stem form, knots, insect, and other decays (McGavin *et al*., 2019).

2.7.1 Grading of peeler log

System of log grading managed for many common traditional woods and they vary from place to place, the principles for log grading are almost same. The log grading process mainly aims for identifying grade limiting defects, measuring and assessing those defects, identifying those grade enhancing characters. Finding out other important characters such as size and assigning a particular grade to logs (McGavin *et al*., 2019). Grading of the log before veneer production is mainly for evaluating the quality of the log and hence the veneer quality that can be peeled from that log. Log grading is mainly done by visual assessment of log external features that are figured out for each log grade classification. Dimension of logs, log forms, and presence of defects (both external and internal) is the major factor that is considering for the log grade. McKenzie *et al.* (2003) classified eucalyptus log based on grade factors like length, small end diameter, large end diameter, bumps, end splitting, scars and evidence, roundness, and sweep. Visual grading is the most common method of grading logs based on the external appearing characteristics. Bayatkashkoli *et al.* (2016) classify popular species in 3 grades, based on the visual characteristics like defects including knots, holes or cavities, stains or discoloration specks, decays on the surface, irregular shapes, etc. He also pointed out that, peeling mills will not purchase the popular logs having frost cracks, irregular shapes, or sweepers.

2.7.2 Log pre-conditioning

Preconditioning treatment mainly includes heating the logs with steam or boiling the logs with water to increase the temperature of the log during the peeling process to enhance the quality of veneer, reduce the cutting force and reduce the damage on veneer and lathe (Lutz, 1960; Baldwin, 1995; Yamauchi *et al*., 2005; Marchal *et al*., 2009; Dupleix *et al*., 2012).

According to Aydin *et al.* (2006), heating especially the steaming of the log before the peeling process is one of the most important processes in veneer manufacturing, and steaming softens the log temporarily and makes it more plasticity and helps to enhance the quality of veneer obtained.

During the conditioning process, logs are heated in a submerged hot water tank, hot water spray chamber, or steam chamber (Resch and parker, 1979). The heating of logs is important for knotty species like pines, hardwood, and frozen logs (Chen *et al.*, 2021). Preconditioning is different for different species and mainly aimed at softening the wood fibres for enhancing the veneer quality, reduce the lathe power consumption, and also reducing the damage of lathes, especially knives. Peeling with high temperature reduces the deep lathe checks (Meriluoto, 1965; Dupleix *et al*., 2012) and also improves the veneer quality (Rohumaa *et al*., 2016a, 2018). Excessive heating causes negative effects on veneer sheets like surface fuzziness, sheets discoloration, hydro degradation, and energy wastage process (Dai *et al.*, 2002). Optimum heating is required for save energy and improve the quality of sheets. A lot of works on optimizing the log soaking temperature and enhancing the veneer quality of different wood species have been studied (Aydin *et al*., 2006; Dupleix *et al.*, 2012; Rohumaa *et al.*, 2014, 2016a, 2016b, 2017, 2018; Stefanowski *et al*., 2020). However, log conditioning will change according to the type of lathe used. The optimum temperature for peeling ranges for white spruce is 29–35 °C, lodgepole pine 35–38 °C, and Douglas fir 43–

49 °C. Peeling at this preferred temperature reduces the depth of lathe check, knife wear, cutting force, and vibration of the lathe (Chen *et al.,* 2021)

McGavin *et al.* (2019) heated the logs on 50 °C, 60 °C, 70 °C, or 80 °C and found that in preconditioning from temperature from 50 °C to 80 °C helps to reduce the cutting force by 50 percent. The preferable temperature for peeling is found to be 70 °C to 80 °C. Preconditioning depends on many factors including peeling equipment, quality of peeled veneer requirements, and choice of species. Pre-conditioning involves heating logs with saturated steam or hot water. McGavin *et al.* (2019) show the advantages and disadvantages involved during log- pre-conditioning. Pre-conditioning veneer shows the least thickness variations among sheets. Log pre-conditioning also leads to the premature peeling failure, additional energy expense and steaming may result in the decline of natural durability of veneer-based products due to the loss off water-soluble extractives.

McGavin *et al*. (2019) pointed out the different preferred temperatures of coconut logs for optimum peeling based on the air-dry density. Approximately peeling temperature of 50-70 °C for coconut log ranging air density less than 600 kg/m³, 70-90 °C is preferred for coconut log with density more than 600 kg/m³, peeling of softwood required 50-60 °C for getting good recovery and quality veneer sheets, a peeling temperature of 50-70 °C is required for hardwoods with air density of range 500- 700 600 kg/m³ and for density over 700 kg/m³ hardwoods preferred log temperature is 70-90 °C. Chong (1977) also used a log preconditioning tank to increase the peeling temperature of slash pine logs for getting quality veneer and to reduce the force of peeler on veneer sheets.

Dupleix (2012) Studies showed that, for beech, spruce, and birch, the log which is treated with low temperature produce veneer having deeper and wider spaced checks as compared to the log which is treated with high temperature. Aydin *et al.* (2006) evaluated the effect of log temperature of spruce (*Picea orientalis*) logs during the peeling process on the properties like surface roughness, adhesive wettability, veneer colour variation, and shear strength of plywood made from those veneer sheets. The result is showing the improvement of surface roughness on peeling with high temperature. Colour variation is showing less significance with the peeling temperature. The shear strength observed was more on plywood which is produced by using higher log temperature.

2.8 Veneer and veneer production

The wood processing industry is one of the important socially relevant activities in the highly populated tropical countries with more forest cover (Gopakumar *et al.,* 2013). Veneer based wood industry is one among the significant industry in India. Forest is the major supply unit for timber in our country and by the 1980s, Indian forestry makes a paradigm shift from the production aspects to conservation forestry. Forest policy 1988, remarks on the important of forests on the ecological stability and pointed out the important factors to their conservation for vital subsistence of all the life forms including humans, wild animals, and plants (NFP, 1988). The forest policy in 1988, pointed out the requirements of forest-based industry for the production of their raw material for meeting their requirements. Since the natural forests are no longer a supply pool for the woods, industries are trying to find other alternatives. Even the draft of forest policy 2018 strictly adhered to environmental stability and biodiversity conservation and highly restricting the conversion of natural forest for other purposes (NFP draft, 2018). The demand for timber increased as the trend in the economic sector developed (NFP, 1988). FAOSTAT (2013) figured out the increase of plywood and veneer production from 2002-2012.

As the demand increased and supply decreased, the wood industries are forced to find alternatives to meet the supply-demand gap. Veneer and veneer-based products demand are increased recently, due to the high price and high dimensional stability of the veneer products. The tree outside the forest is getting more demand as the forest plantations in our country are unable to supply to meet the requirements. ISFR 2019 assessed the total tree cover outside the forest is about 29.38 million hectares, which is about 36.40 percent of the total tree and forest cover in India. From my experience, Kerala wood industry somehow maintains their requirements by the TOF, especially from the Kerala home gardens and rubber plantations in Kerala. While the supply chain is limited and Kerala wood industry should find alternatives for their raw material requirements. Now in Kerala, common species used for veneer manufactures include rubber (*Hevea brasiliensis*), mahogany (*Swietenia macrophylla*), Jack (*Artocarpus heterophyllus*), Chadachi (*Grewia robusta*) and mango (*Mangifera indica*, etc. But most of the species are confined to Kerala home gardens and rubber plantations. Resource limitations and increasing of raw material cost makes vulnerable to the veneer industry to sustain and compete with the external supply of veneers and veneer-based products from other countries. The common species used for the plywood production or manufacture of veneer are rubber, vatta (*Macaranga peltate*), eucalyptus species, silver oak (*Grevillea robusta*), kadukka (*Terminalia chebula*), vellapine (*Vateria indica*), mahogany, jack, anjili (*Artocarpus hirsutus*), are some important species (Krishnankutty and Chundamannil, 2012).

The traditional plywood industry in Kerala were depending on forest timber are closed or transformed into rubber wood-based units. But the rubber wood itself cannot continuously supply the raw material as the demand for veneer-based products is increasing. So, the plywood industries are under the threat of shutting down their industry or choose an alternative to meet the requirement.

Veneer production for wood has been done for a long time before. Records are showing the practice of the art of veneer cutting and applying in thin sheets by Egyptians probably 3000 or more years (Wilkinson, 1878). In 1805, commercial production of veneer begins in England and was ripping very thin sheets from the block with a hand saw. The advancement in the engineering field enhances the production and quality of veneer produced.

The veneer is a thin sheet of wood. It can be produced on a lathe, saw, or slicer. It can be used as a single ply or lamination of ply glued together as in the case of plywood (Madison, 1962). A veneer can be cut in different thicknesses. In Kerala, most of the veneer manufacturers use 1.9 mm thickness as standard. Wood logs can be peeled or sliced or sawed in varying thicknesses according to the end-use, species, lathe settings.

The veneer is mainly produced by 3 methods including sawing, slicing, and rotary cutting. Sawn and sliced veneers are extensively used for the manufacture of decorative veneer. The most common method of veneer manufacture is the rotary peeling process for the production of the continuous sheet of wood. The rotary veneer is the major raw material for the industrial production of plywood and laminated veneer lumber (Lutz, 1974). In rotary peeling, the wooden log is mounted in the chucks of the lathe and turned continuously against a knife. This is the common method of manufacture for the production of commercial veneer for construction purposes from softwood. In slicing, the wood log is stationary and a knife is moved towards the logs. Veneers produced through slicing are narrow strips and long. According to the mounting of flitch to the knife, the sliced veneer can be classified into quarter sliced, rift-grained, flat- grained (Ozarska, 2003). The principle of the rotary cutting was well explained by (Koch, 1964; Lutz, 1974). Various studies had done in the lathe settings for the better yield of quality veneer. Since today most of the lathe settings are automatic and the sensor will adjust accordingly, the working on lathe settings has drastically reduced. The thickness of the veneer depends on the rate of advancement of the knife per rotation of the bolt. For example, to get a veneer thickness of 3 mm, the knife has to advance at a rate of 3 mm per revolution. The nose bar compression is about 10-20 percent, so about 90-80 percent of nominal veneer thickness will escape through the gap. If the nose bar opening is too large, then the veneer will not be compressed significantly, resulting in the uneven thickness and if the nose bar gap is very small, result in too much compression beyond the veneer elastic limit and will not be recovered to the nominal veneer thickness. Too much compression will also consume more power.

Sawing of veneer is mainly used for decorative purposes. They are sawn to the thin strip of wood. It is mainly used for face stock in veneered panels. Veneers are mainly classified into construction and decorative veneer. Construction veneers are manufactured for the production of laminated veneer lumber and plywood. Plywood is a veneer bonded structure and ply are glued at the right angle to the direction of the grain. Laminated veneer lumber is parallel gluing of veneer and makes the product similar to the sawn wood. The decorative veneer is produced for the aesthetic appealing of the surface (Ozarska, 2003).

2.9 Veneer based products

A veneer can be used as a raw material for the manufacturing of varying products including composite boards, laminated boards, plywood, and other construction materials. Lot of new interventions is in the field of veneer-based products in recent years due to the immense potential of veneer-based products for varying purposes.

2.10 Veneer based products advantages

The plywood industry was started in Portland, Oregon, USA in 1905 although the patent for plywood industry was issued in 1865 to John K Mayo (Shi and Walker, 2006). The main advantages of using veneer products are the dimensions, high strength, various shapes, and low cost compared to solid wood (Hiziroglu, 2009). Veneers sheets are mainly used for the production of plywood and laminated lumber. In plywood, veneers are glued in cross-laminated construction and laminated veneer lumber is somewhat similar to solid wood, the arrangement of each sheet is in the same direction as the grain direction. But in laminated lumber, we can construct materials of large size compared to solid wood (Baldwin, 1995). Among the construction materials, laminated veneer lumber is one of the strongest wood-based materials relative to its density. This is because of the homogenous characterization by limiting the defects in the end products (Bowyer *et al.*, 2007). Hiziroglu (2009) also pointed out the defects like warping due to the improper storage and handling and high initial investment cost as disadvantages of laminated veneer lumber. One of the main advantages of veneer-based wood products is their recovery and it is mainly due to the low production of sawn waste. The rapid drying of veneer sheets reduces the energy cost, storage issues and makes the production faster (Corkhill, 1979)

Another important advantage of veneer-based wood product is their ability to withstand changes in external environmental conditions. The cross-lamination implies the grain of the veneer sheets are alternate by 90 degrees and it reduces the tangential movement in adjacent veneer improves the shear strength and impact resistance of veneer-based wood products (Corkhill, 1979). Various product diversifications, greater control on variability, greater creep resistance, and impact resistance are some of the advantages of veneer-based products that make their dominance in the engineered construction materials (Leggate and McGavin, 2017). The importance of PF (Polyphenol) resin in the durability of veneer-based products are remarkable while the greater mechanical strength and stiffness-to-weight ratios of the plywood products make it a good choice for the range of applications flooring, shipbuilding, lining of cargo holds, packing, and other construction purposes (Hughes, 2015). The veneer-based products have several advantages over the solid wood, the dimensional stability, strength uniformity, splitting resistance, decorative potential, and adaptability toward various applications (Matuana and King, 2003). The greater resistance of splitting and the ability to resist racking force makes the veneer-based products for better application in earthquake-prone areas (Shi and Walker, 2006).

2.10.1 Plywood panels

Plywood is the major product manufactured from the veneer sheets. Plywood is composed of layers of veneer sheets arranged in cross-laminated construction of desired thickness of the end products. The minimum of plies (veneer sheets) for the manufacture of veneer sheets is 3 and about 35 veneers are used to produce 50-mm thick plywood of birch species (Handbook of Finnish Plywood, 2002). In Kerala, most of the plywood used for construction purposes is 7 ply, 9 plies, and even more. 5 plies are generally used for construction purposes that do not get damage by much load or impacts. Plywood panels range from 1200 mm X 1200 mm up to 1525 mm X 3660 mm (Hughes, 2015). Plywood panels are used for structural application, concrete construction, flooring, noise barriers, boat building, shipping container flooring, stair treads and risers, train bus and tram floors, bridge decks, soffits and fascias, box beams, webs in I-beams and trusses, exterior residence cladding, temporary hoarding, signboards, wall and ceiling lining, kitchen and laundry benches, walkways and aircraft components (Leggate and McGavin, 2017; Tenorio *et al*., 2011; Sellers, 1985; Elmendorf, 1920; Burnard *et al*., 2019; Miyamoto *et al.*, 2020; Countryman, 1967)

Aydin *et al*. (2006) studied the effect of moisture on the emission of formaldehyde of poplar and spruce plywood mechanical properties. He founds that the mechanical properties especially shear strength values are influenced by the type of adhesive used and the addition of melamine in Urea-formaldehyde increases the bonding strength and shear strength. The moisture content of veneers of 4-6 percent shows better mechanical properties. He also pointed out the effects of bending strength, modulus of elasticity of poplar, and spruce on moisture content and types of gum used. The surface roughness is one of the most important properties influencing the bonding of veneer sheets and improving the surface roughness enhances the bonding during the pressing process (Lemaster and Beall, 1996; Mitchell and Lemaster, 2002; Taylor *et al.*, 1999). Tenorio *et al*. (2011) stated that most of the mechanical properties of plywood and laminated veneer lumber of *Gmelinia arborea* are different and are mainly influenced by the veneer orientation. Mechanical properties are almost the same as compared to solid wood.

2.10.2 Laminated veneer lumber

In Laminated veneer lumber, the veneers are arranged in such that the direction of the grain is laminated in the same direction. It is a solid wood substitute and is mainly used for load-bearing construction purposes (Leggate and McGavin., 2017). Laminated veneer lumber (LVL) has the potential for economic and aesthetic properties. It is similar to solid wood and produces to meet the demand of consumers for their appearance requirement. Recent development helps to produce any length by continuous lamination of veneer sheets. The homogeneity reduces the defects and improves the mechanical strength of laminated veneer lumber (Eckelman, 1993). Various properties of structural composite laminated veneer lumber products are showing that the dominance of mechanical properties in the laminated veneer lumber compared to solid wood (Bohlen, 1974; Youngquist *et al.*, 1984; Koch, 1972; Moody and Peters, 1972). Kamala *et al.* (1999), showed that the LVL from the rubber wood (*Hevea brasiliensis),* shows similar strength properties concerning the *Calophyllum elatum* (Poon), *Tectona grandis* (Teak), *Cedrus deodar* (Deodar), *Artocarpus lakoocha* (Lakooch), *Palaquim ellipticum* (Pali), *Gmelina arborea* (Gamari) and *Lagerstroemia lanceolate* (Benteak).

Many researches show the application of laminated veneer lumber for the headers and lintels over the window, verandas, Doors and other construction openings. Framing of sub-floor as joints and bearers, internal framing, various furniture, components of bridges, and for parts of aircraft including propellers (Youngquist *et al*.,1984; Rahayu *et al.,* 2015; Gilbert *et al.,* 2017; Vlosky, 1994). Bao *et al.* (2001) tested some mechanical properties of LVL and the result remarks the flatwise toughness is more compared to edgewise toughness. Bal (2014) studies shows the splitting strength and flexure properties of popular reinforced with woven glass fibers using the adhesive phenol-formaldehyde and reported the increasing of splitting strength, modulus of elasticity, and modulus of rupture. Suliman *et al.* (2009) highlighted the result of some adhesive in the manufacture of LVL from rubberwood and oil palm and reported the amount and type of adhesive that affect the density, water absorption, shear strength of LVL. As the number of adhesives penetrates in to veneer sheet increases, mechanical properties like modulus of rupture (MOR), hardness, and modulus of elasticity (MOE) increase (Wang and Chui, 2012). Bal (2014) studies show the physical properties of LVL increased and reinforced laminated veneer products also shows an increase in their impact bending strength, modulus of elasticity and reduce their tangential shrinkage, volumetric shrinkage compared to the normal laminated veneer lumber.

2.10.3 Novel Hybrids

The combination of wood with other materials like metals, fibres, plastic, etc. enhances the properties of plywood and can be used for many structural applications. Hybrids are mainly developed to maximize the best properties and increase the value of each resource. Boomsiter (1948) was the pioneer researcher in the field of plywood reinforcement. Laufenberg *et al*. (1948) studied the laminated veneer lumber's economic feasibility with synthetic fibre reinforcement. Bal (2014) shows the improvement in mechanical properties and impact bending strength of laminated veneer lumber with glass fibre fabric reinforcement. Bal *et al.* (2015) reported an increase in the mechanical properties of plywood panels of poplar which are reinforced with glass fibre fabric.

2.11 Veneer peeler and sawing machine

Recent advancement in the spindle less peeler for the processing of logs effectively is well demonstrated (McGavin *et al*., 2014, 2014; Peng *et al*., 2014; McGavin *et al*., 2015 ,2015; Leggate and McGavin., 2017; Belleville *et al*., 2018). Rotary cutting of veneer processing helps for higher recovery from the logs of smaller dimensions and the production of veneer-based products will helps to randomization of the defects (Leggate and McGavin., 2017). The conventional spindle peeler allows the veneer recovery to a residual core of diameter of greater than 0.15 m, whereas in spindle-less peeler can make the residual core of less than 0.05 m. The spindle-less peeler helps for higher returns on the processing of smaller logs (Arnold *et al*., 2013; Leggate and McGavin., 2017). The spindle-less lathe as the name suggests has no spindle and rotary drive is provided by two backup rollers and a driven roller nose bar. The inability of the spindle peeler to hold the softcore inner part of the coconut has been overcome by the spindles peeler and makes the possibility of peeling of coconut logs (McGavin *et al.*,2019).

2.12 Optimum lathe settings

The quality of veneer sheets is highly influenced by the lathe settings. Optimum lathe settings are determined by different parameters and conditions including the supporting infrastructure, lathe capacity, log size, species, log quality, the density of wood, production speed, and veneer requirements (Bailleres *et al.*, 2015). A large number of spindle and spindle-less peelers are available today.

The majority of spindle-less peeler lathe settings have limited capacity to change the lathe settings. This simply means that the opportunity to optimize lathe settings to perform a suitable operation is limited.

According to Feihl (1986), the knife angle commonly maintained during the rotary peeling process ranges from 19 to 21 degree for hardwoods and 21 to 25 degree for softwood. Fondronnier and Guillern (1979) showed that at a 21degree, the minimum spinning force of the log was achieved. Marchal and Negri (1997) shows that the pitch angle or knife clearance angle was most influenced by the quality of thin veneer. The cutting speed also has a great influence on the veneer quality. Increasing the cutting speed by 60 meters per minute or even to 90 meters per minute could improve the veneer surface quality (Sales, 1990; Porankiewicz *et al.,* 2005). However, increasing the speed of cutting could be harmful to the knife life Darmawan *et al.* (2012), particularly in high-density coconut wood, which is due to the high mineral content (Bailleres *et al.,* 2010; Hopewell *et al.,* 2010).

Bailleres *et al.* (2015) has studied the rotary peeling parameters of high-density coconut wood. The heating of logs reduces the cutting force, improves the quality of the surface, and reduces premature knife damage. The roller pressure bar with a low compression rate of 10 percent reduces the checks and improves the surface quality. The minimum thickness of the veneer is reduced to 2 mm, because of the size of fibrovascular bundles. Due to the hardness of the coconut fibrovascular bundle, the use of a micro-bevel knife helps to improve the service life of the knife and reduce the cutting force (Feihl, 1986). The usage of angular nose bar causes the unusual cutting characteristics of coconut stem (Djouadi *et al.,*1999). McGavin *et al*. (2019) show the usage of roller pressure bar compared to angular pressure bar helps in significantly better results in continuity of ribbon, check frequency, check depths and quality of a surface.

2.13 Veneer Grading

Veneers are graded visually for the segregation of sheets into different categories for their end-use and price or value. The price and values of veneers are functions of physical properties and aesthetics. The standards of veneer grading are set up by the industry or individual companies based on the requirements of consumers. Veneers are graded for face veneers, substrate veneers, laminated veneer lumbers, and plywood. The grading system consists of some criteria for grading based on visual differentiation and other characteristics. It is based on the colour of veneer sheets, uniformity of colour, the pattern of grains, defects, sapwood presence, and also based size of the veneer sheet.

Grade criteria include natural features of defects or defects due to wood processing that occurs during the manufacture and handling of veneer sheets. Numbers or letters are assigned for each grade where the best grades are assigned as A or 1 and subsequent grades of lower quality veneer. Grading can be done visually by an experienced grader or using automatic grading systems. Visual gradings are done against pre-determined standards based on visual characteristics. For large-scale productions, the automatic veneer grading system is used based on the scanners and cameras. Mechanical grading is also done based on the veneer mechanical characteristics like modulus of rupture or modulus of elasticity (McGavin *et al*., 2019)

The automatic grading system for the lumber industry is initiated by (Conners *et al*., 1983; Juvonen, 1986; Thunell, 1985) and this system is not suited for veneer grading because of the inability of this system for detection of color variations. Boardman *et al.* (1992) develop a colour-based system for the walnut veneer grading to differentiate colour variations within heartwood and sapwood and detection of defects in the veneer sheets with reasonable consistency. It also helps in defects size classification. The main advantages of this calorimeter system are the accuracy, numeric evaluation, and helps in comparison of sheets grades.

Luo *et al.* (2013) showed the grading system for 5-year-old clones of eucalyptus based on visual grading into 5 grades based on the CNAS 2002 standard of veneer grading in China for rotary veneers. Dai and Wang (2000) graded veneer sheets in 3 grades A, B and C based on the number and size of knots, roughness, pitch pockets, splits, and other defects

A lot of advanced technologies today lead to a better grading system based on computerized software. Ma *et al.* (2021) developed an automatic grading system of veneer based on the vision of the machine. The system automatically classifies the veneers of different levels of qualities. This will also reduce the production cost and labour input and helps to enhance the quality of veneer used for different end uses.

Australian and New Zealand standards as AS/NZS2269.0:2012 have classified the veneer sheets into 5 grades like A, S, C, D, and F as a reject grade. A grade is a high quality suitable mainly for decorative purposes. S grade is similar to A grade with some defects makes it for decorative purpose and in further grades, the quality of veneer sheets gets reduced and F grade is rejected grade veneer which cannot be used for any structural and decorative application (McGavin *et al.*, 2019).

2.14 Veneer recovery

Preliminary research McGavin. (2016) and Hopewell *et al.* (2010), showed the significant higher recoveries on the conversion of the plantation hardwoods into veneer as compared to the timber sawing process. New technology in recent years helps for better utilization of resources and enhanced the recovery and quality. Spindle-less peeler replaces the conventional spindle peeler mainly due to the potential of former ineffective utilization of small diameter log resource (Arnold *et al.*, 2013). His studies showed the impact of the spindle-less peeler on China's veneer processing industry.

McGavin *et al.* (2014) calculated the veneer recovery of eucalyptus plantation using spindle-less technology on four veneer recovery calculations including green veneer recovery, gross veneer recovery, net veneer recovery and graded veneer recovery. He studied recovery analysis of 6 eucalyptus species including *Corymbia citriodara, Eucalptus colenzia, Eucalptus dunni, Eucalptus pellita, Eucalptus nitens, Eucalptus globulus*. His result showing the green veneer recovery is between 68 percent and 77 percent. *Eucalyptus globulus* shows the highest recovery. Gross and net veneer recovery is different for different species and found that highest for *Eucalyptus coleziana* of 54 percent to 65 percent recovery respectively. Graded veneer recovery is highest for D grades and lowest for A grades. D grade is suited for the non-appearance structural panels and also suited for core veneers in structural applications.

Yanti *et al.,* (2010) studied the veneer recovery of coconut veneer produced by the rotary peeling process and found that the recovery rate decreases from the bottom to the top portion of the coconut stem. The mean value of green veneer recovery in the bottom, the middle, and top portions of the stem were 53.71 percent, 48.41 percent, and 47.00 percent respectively. He also found the insignificance between the diameter classes.

Even though the value of veneer-based products is ultimately influenced by the graded recovery rate, it is important to enhance the green veneer recovery to maximize the profitability of the rotary peeling process (Shi and Walker, 2006). Green veneer recovery is the recovery percent of green billet volume before the roundup and peeling process. Green veneer recovery is influenced by the log roundup and residual core diameter. Green veneer recovery can be increased by reducing the roundup loss and also by reducing the size of residual peeler diameter (McGavin *et al*., 2014; Luo *et al*., 2013). Log taper is the most significant factor that influences the green veneer recovery and can be calculated by finding the difference between large end diameter under bark (LEDUB) and small end diameter under bark (SEDUB) and divided by the log length (Warensjo and Rune, 2004).

Hamilton *et al*. (2015) founded that factors like sweepness of log, taper, and roundness are mainly influencing the green veneer recovery of eucalyptus plantation in temperate regions in the rotary peeling process. Dobner *et al.* (2013) studies show the quality and recovery rate of veneer from 30-year-old *Pinus taeda* L. logs on rotary peeling process and average recovery rate ranges from 54 percent to 72.6 percent and shows the rate of recovery is higher for bigger logs as compared to smaller ones. Silviculture management like optimized thinning and pruning strategies enhances the quality and recovery of veneer peeled. Peeling of high-density coconut stem wood increases the product recovery as compared to sawing of coconut logs. About 45.4 percent was the recovery rate of trimmed veneer and gross green recovery of the sawn board is very low (Hass and Wilson, 1985).

2.15 Boring of coconut log

Boring of coconut log is a new prototype for load bearing applications especially for decorative utility. The veneer based hollow sections were produced in Australia (Gilbert *et al.*, 2014; Gilbert *et al.*, 2017;). This work had done using veneer sheets and there was no any research had done on the boring of timber for the production of hollow cylindrical sections. It is mainly due to the economic importance of central core part of hardwood and softwood. But in coconut palm stem, the central core part is waste and need to be removed for the better utilisation. Currently in Kerala, the hollow structure made of coconut logs were carried out by splitting the log in to two sections and trimming of inner core parts and finally gluing together. But these products have limitations during the load bearing and splitting of log in glued area required proper maintenance.

3. MATERIALS AND METHODS

The study was carried out to understand the potential of coconut palm wood for veneer production and the boring of coconut palm for structural applications. The study was conducted from the

3.1 Location

The present study was carried out in Thrissur district (between N 10° 11' 8.16" and N 10° 41' 2.76" latitude; E 75° 58' 2.64" and E 76° 53' 29.04” longitude) of central Kerala, India.

The study was carried out in

1. Department of Forest Products and Utilization, College of Forestry: Sawn veneer production and veneer quality assessment
2. Perumbavoor sawmill industries: Peeling of coconut logs
3. Coco products, Gubbi Karnataka: Boring trails of coconut logs
4. Siddaganga Institute of Technology, Tumkur, Karnataka: Boring trails of coconut logs
5. Kerala Engineering Research Institute, Peechi: Mechanical testing of samples
6. Wood testing laboratory-Rubber Board, Kottayam: mechanical testing of samples

3.2 Materials Required

Table1: Various tools used and their purposes

Sl No.	Materials/ Tools/Equipment used	Purposes
1.	Coconut Boiler	Pre-treatment of coconut log
2.	Saw blade tooth setter	Setting of saw blade

3.	Band saw blade tooth setter	Setting of the tooth
4.	Wood mizer portable sawmill LX 50	Sawn veneer manufacture
5.	4ft Spindle less Veneer Peeling Machine	Peeling of coconut logs
6.	Heavy type 4ft Spindle less Veneer Peeling Machine high speed	Peeling of coconut logs
7.	Semi-automatic extra heavy-duty lathe machine TMT	Boring of coconut log
8.	log debarker	Debarking of log
9.	Moisture meter	Moisture measurement
10.	Vernier calliper	Length measurement
11.	Bosch Portable Sander Machine	Sanding
12.	Resorcinol formaldehyde	Adhesives

3.3 Methodology

The methods adopted to carry out the study have been discussed below.

3.3.1 Collection and sorting of coconut palms

Coconut stems of age more than 50 years were collected from various farmers and mills. Bucking of coconut logs of 130 cm (4 ft) and loge are classified separately based on the portions from the butt end, middle portions, and top portions. The logs which have a serious taper, defects, and bends were removed due to the huge wastage of peeling those logs on the peeler. A total of 15 cylindrical coconut logs were sorted and chosen for the peeling process. They were having more high-density portions on the dermal portions.

3.3.2 Log storage and preconditioning

The logs which are cut from the field have high moisture content and it is more vulnerable for splitting and other fungal and insect attacks. So, in order to keep the logs safe from the splitting, logs were immersed fully in the water up to the day of peeling.

Preconditioning is mainly done for reducing the cutting force, reduced damage of machine and also improves the quality of veneer. The hard fibers in the soft parenchyma cells are more likely to form checks on the application of pressure during the sawing and peeling of coconut logs. McGavin *et al.* (2019) pointed out the ambient temperature requirement for peeling of coconut logs ranges from 70 °C or 80 °C. In current study the precondition of logs was done by steaming and boiling of coconut palms in the pretreatment chamber and peeled the coconut log as soon as possible when they reach approximately 50 °C to 60 °C.

3.3.3 Spindleless Peeler and Portable sawn mill

Spindleless peeler was used for rotary peeling of coconut logs and portable sawn mill for the production of sawn veneer. The veneer was peeled in 2.5 mm thickness in two types of spindle-less peeler. The debarking was done in the debarker for removing the outer cortex region of coconut logs. The veneers were sawed by 2.5 mm thickness and sawn up to the subdermal portions of the coconut logs using portable sawn mill. The veneer sheets were clipped to width 68.58 cm and length 127 cm.

Plate 1: Coconut logs

Plate 2: Storing of coconut logs

Plate 3: Pretreatment of coconut log

Plate 4: Debarking of coconut log

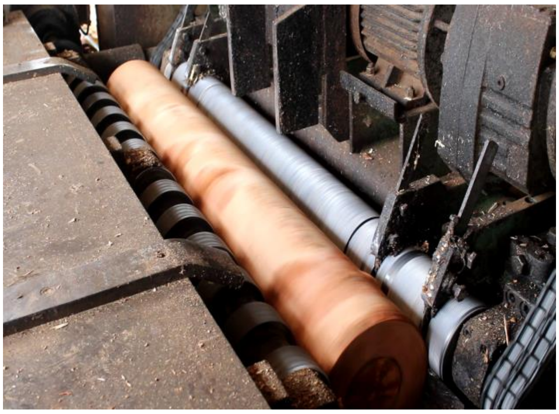

Plate 5: Peeling of coconut log

Plate 6: Saw blade sharpening

3.3.4 Lathe settings

Automatic Chinese spindle-less peeler is very limited in the manual adjustment and the mode of adjustment was varying from model to model. The nose bar gap was adjusted to 4 mm, production speed of 70 meter per minute, cutting width of 570 mm were adjusted in the spindle-less peeler for peeling the coconut logs.

3.3.5 Saw blade settings

The saw blade was set in one left 20 degree, one right 20 degree and other one of 0 degree. So, the alignment of blade is on left, right and straight for sawing the hard coconut logs. The saw blade then set into portable saw mill after sharpening the teeth with sawn teeth sharpener. Appropriate tension and alignment of saw blade was adjusted to sawn properly to get quality sawn veneer

3.3.6 Veneer Drying

Veneer was dried by horizontal stacking in open air. Crossers were placed in appropriate places during stalking to maximize the air flow through veneer sheets and appropriate weight also placed above the stalked veneer sheets to reduce the bending, twisting of veneer sheets. Moisture content of veneer sheets were constantly evaluated using moisture meter.

Plate 7: Moisture content analysis using moisture meter

Plate 8: Setting of blades

Plate 9: Sawing of coconut log using portable sawing machine

Plate 10: Sawn Veneer

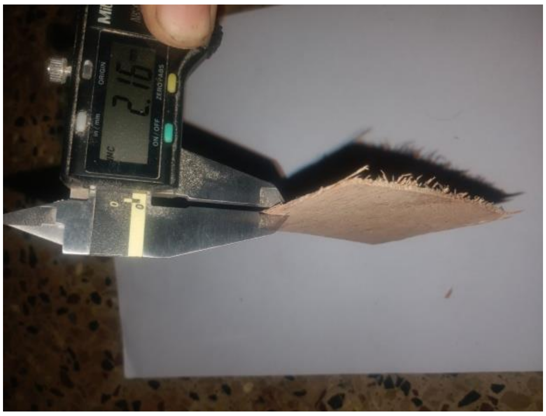

Plate 11: Thickness measurement of veneer using Digital Vernier calliper

Plate 12: Static bending test of coconut plywood

3.3.7 Veneer Visual Grading

Veneer sheets were visually graded after drying process using Australian and New Zealand standards **AS/NZS2269.0:2012.** The Australian and New Zealand standards AS/NZS2269.0:2012 is a standard which gives the requirements of minimum performance and specifications on the manufacturing of structural plywood. The standard is applicable for both softwoods and hardwoods while have some relevance on coconut veneer (McGavin *et al*., 2019).

There are 5 grades of veneer as A, S, B, C and D and also a rejected grade F where:

- **A grade** veneer sheets are high quality sheets in appearance and suitable for the clear finishing. This grade is mainly preferable for the face veneer in plywood where appearance of surface is the primary importance
- **S grade** veneer has similar characteristics to A grade. But some features and external characteristics which are not permissible for grade A are allowed when used for the decorative purposes. These include minor knots, holes, discoloration and other defects agreed between customers and manufactures.
- **B grade** veneer sheets are suitable for high quality painting finishing. These sheets are preferable for the applications where high-quality paint finish is using.
- **C grade** veneer sheets are used for structural applications where appearance is not the primary consideration and they are non-appearance grade veneer sheets.
- **D grade** veneer sheets are used in the structural application and they are not suitable for any decorative purposes and they are the lowest quality veneer sheets.
- **F grade** veneer sheets are rejected grade and not suitable for any application and not meeting the minimum requirement of the above grades.

3.3.8 Veneer sheet thickness variations

The thickness of veneer sheets was measured using digital Vernier calliper. 20 Veneer specimens of 5×5 cm^2 taken randomly from the veneer sheet and the thickness of each veneers were assessed for finding the range and thickness variation within the sheet.

3.3.9 Green Veneer Recovery

Green Veneer Recovery (GNR) provides a measure of the maximum recovery, considering log geometry (sweep, taper, circularity) and lathe limitations (e.g. peeler core size). GNR disregards internal log quality. GNR (Percent) for a batch of veneer billets can be calculated as follows:

$$GNR = \frac{(L \times \Sigma veneer (GTmean \times GW)) \times 100}{\Sigma billetV}$$

where GT mean is the average green veneer thickness (m), GW is the green veneer width (m) perpendicular to the grain (as measured prior to clipping and excluding any major defects, e.g. wane or undersize thickness, that are present at the beginning or end of the veneer ribbon), L is the veneer length (m) parallel to the grain, and V is the billet volume (m^3).

3.3.10 Veneer Defects

Veneer defects evaluation is important for the production of quality veneer products. The common defects used for the valuation are

- End split
- Roughness
- Collapse

- Fungal Decay
- Holes and tear out
- Waviness
- Insect tracks

The extend of defects were visually assessed for all the veneer sheets produced in order to find the quality of veneers produced.

3.3.11 Plywood making

The veneer sheets were dried up to 10 percent moisture content and resorcinol formaldehyde glue was used as adhesive for bonding the veneer sheets.

3.3.12 Coconut Boring

Coconut boring was done in semi-automatic extra heavy-duty lathe machine. The coconut log was cut in to pieces and placed within the chunk having 4 jaw. The coconut log was debarked using a bit fixed in tool post and boring was done using bit fixed in tool post. The length of coconut bored was about 30 cm and the 12.5 cm are the bored portion diameter.

Plate 13: Lathe for boring coconut log

Plate 14: Chunk for holding coconut log

4. RESULTS

4.1 Coconut palm wood processing

Conventional pretreatment chamber has been used for the pretreatment including both boiling and steaming of coconut logs. Due to the limitation of temperature control over the pretreatment chamber, most of the peeling and sawing of coconut logs was done with log temperature of 40-52 degree. This shows a great negative impact on the veneer quality obtained. However, those coconut palms which have peeled with log temperature of more than 60 degree shows comparatively good quality veneer sheets. Log heating for sawing also reduce the tear out and damage on the thin sawed veneer sheets of less than 2.5 mm thickness.

9 coconut logs of total approximately 0.455 m^3 were processed for peeling and 6 logs of .43 m^3 were processed for sawn veneer. 107 total veneer sheets were obtained. The thickness of veneer sheet were 2.5 mm and clipped at dimension of length and breadth of 1.3 meter and .68 meter respectively. For peeling purposes 3 logs from lower, middle and upper part were peeled. Large diameter coconut logs were preferred for sawn veneer production for the higher recovery and to reduce the density variation within the sheets.

4.2 Green Veneer Recovery

Green Veneer recovery is obtained by the formula described in the materials and methods in 3.3.8.

Table 2: Green veneer recovery of peeled coconut billets; L (Lower part), M (Middle part), U (Upper part)

Coconut log	Volume (m^3)	Length (m)	Width (m)	Number of veneer sheet
L1	0.055	1.3	0.68	9
L2	0.042	1.3	0.68	12
L3	0.048	1.3	0.68	12
M1	0.047	1.3	0.68	15
M2	0.045	1.3	0.68	14
M3	0.054	1.3	0.68	16
U1	0.061	1.3	0.68	8
U2	0.041	1.3	0.68	11
U3	0.062	1.3	0.68	10
Total	0.455			107

From the table 1, average green recovery of peeled veneer of approximately 51 percent was achieved. Lower portions of the coconut palms show average green recovery of 49 percent and middle portion of coconut palm show average recovery of 66 percent and the upper part of coconut palm able to achieve approximately 38 percent of the recovery.

Sawn veneer recovery: sawn veneer recovery achieved about 35 percent.

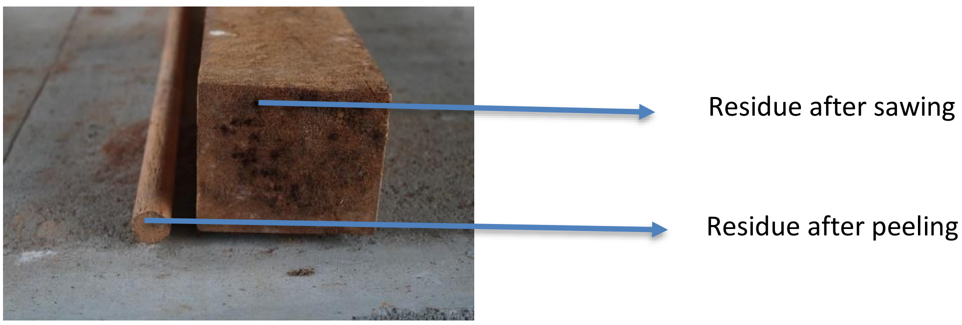

Plate 15: Comparison of residue after rotary peeling and sawing of veneer

4.3 Veneer Defects

Veneer defects are important characteristics for determining the end use of the material. It determines the quality of the product. Roughness grade score, handling split, collapse, end splits, fungal decay, holes and tear outs and waviness are the important defects in veneer determines the quality.

Table 3: Types of defects and score classification

Defects	Number of veneer sheets									
	Score 1	Score 2	Score 3	Score 4	Score 5	Score 6	Score 7	Score 8	Score 9	Score 10
Roughness grade score	0	8	35	32	10	8	6	8	0	0
Handling split	32	25	18	2	17	0	0	0	9	4
Collapse	0	8	12	32	2	10	16	8	3	16
End splits	11	22	17	3	2	19	6	8	11	8
Fungal decay	103	2	2	0	0	0	0	0	0	0
Holes and tear outs	91	2	3	1	1	2	3	1	2	1
Waviness	97	10	0	0	0	0	0	0	0	0

Table 3, showing the different defects and its score based on the extent of defects. End split is one of the severe defects in the coconut veneers. Collapsed sheets also dominated.

4.3.1 Veneer roughness

Veneer roughness assessment will help to understand the quality of veneer produced and a major factor deciding the veneer end uses. Rough surface will affect the decorative value of veneer sheets and it will also make the handling difficult.

It is very hard to get veneer sheets having smooth surface with score 1 from coconut logs. Veneer sheets of score 2, 3 and 4 can make to smooth after normal sanding process. Sheets with score 5 and 6 are difficult to smooth and fibres are tear off from the sheets after continuous smoothing. 7 and 8 have no any role in the decorative applications and limited usage in structural applications.

During the trail, no veneer sheets were obtained having smooth surface with score 1. Most of the veneer sheets are dominated with score 3 and 4 indicating that veneers can be made to smooth after proper sanding. Some veneer sheets also have score of 7 and 8 indicates that challenging for obtaining acceptable surface smoothness. Surface smoothness mainly influencing the bonding strength of adhesive in wood and affects the durability and strength of the veneer-based products. Figure 1, shows the distribution of roughness of coconut veneer sheets

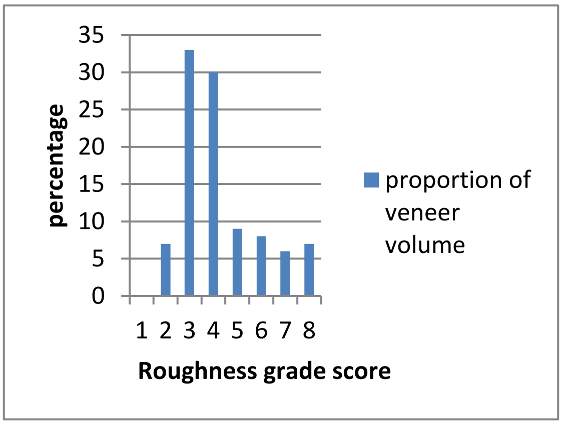

Figure 1: Distribution of roughness score

Plate 16: Example of roughness in veneer

4.3.2 Handling splits

Handling splits are entirely different from the normal splits which were due to the separation of fibres. In coconut wood splitting is common. Handling splits were caused mainly during the handling of veneer sheets. Proper care is required for handling the veneer sheets especially when veneer sheets are carried from veneer drier. Dried veneers are more vulnerable for handling splits as compared to the initial veneer sheets obtained from the peeler. Sawn veneers are also prone to splits due to the high-density difference in single sheets. As the size of sheets increase chances for splitting of veneer sheets also increased. Handling veneer sheets from clipper to stalking of veneers was also an important source of veneer

About 50 percent of veneer sheets were affected by the splits during handlings. Some veneer sheets also split across the entire length during handling. Distribution of handling split grade score plotted in figure 2.

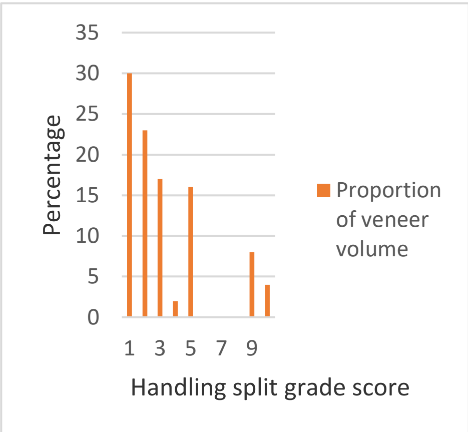

Figure 2: Distribution of handling split score

Plate 17: Example of veneer split

4.3.3 Collapse

Collapse of veneer sheets are common in coconut veneer production especially dealing with the low-density part. A severally collapsed veneer sheet is not suitable for any purposes. Log pre-conditioning is important while considering collapse. Proper pretreatment with comparatively high peeling temperature helps to reduce the defects especially collapse in the veneer sheets.

Peeling temperature with more than 60 ºC reduces the collapse significantly and peeling temperature with less than 40-60 ºC show more collapse. Peeling without pretreatment results in severe collapse and makes the veneer sheets unsuitable for any structural or decorative purposes.

Most of the veneer sheets were grade 4 and there were no any sheets obtained with grade1. More than 50 percent were collapsed during the initial trail without proper pretreatment. Pretreatment of log by heating significantly reduced the collapse and improves the veneer quality. Figure 3, showing the distribution of veneer sheets with various collapse grade score.

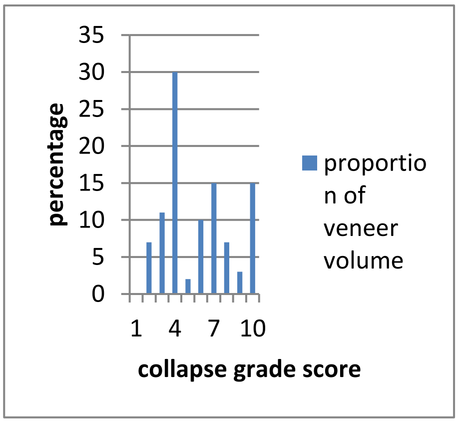

Figure 3: Distribution of collapse score

Plate 18: Example of collapsed veneer

4.3.4 End splits

End splits are mainly occurred during the shrinkage, compression, and other stress on the log especially during the peeling process. Splits occurred during the handling are excluded from this split. Splits are common defects occurred during the peeling compared to other defects. Splitting makes the veneer sheets unsuitable for decorative purposes and it also decrease the log recovery.

About 30 percent of veneer sheets have large splits and failed to obtain a single veneer sheet. So, they are mainly used as non-decorative veneer sheets other than face veneer. About 50 percent of veneer sheets was between score 1 and 4. Log preconditioning and suitable veneer thickness affects splits. Peeling of veneer sheets with more than 2.25 mm shows significant reduction in the splitting. Figure 4, showing the proportion of veneer sheet volume with split grade score.

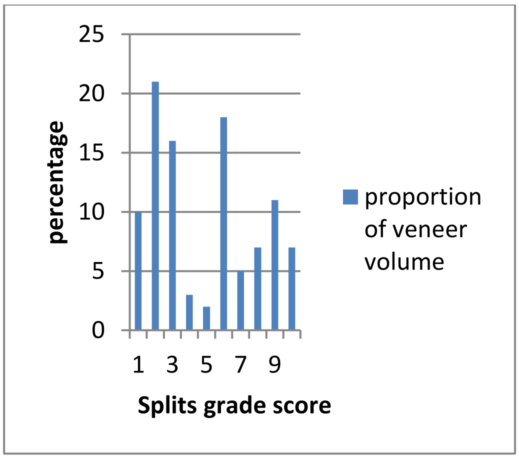

Figure 4: Distribution of split score

Plate 19: Example of veneer split

4.3.5 Fungal Decay

Decay was present on only 4.0 percent of veneer sheets. Decay in veneer sheets are due to the presence of moisture content in the veneer sheets. Veneer production soon after harvesting and veneer processing soon after veneer production decrease the chance of fungal formation.

During the trail 96 percent of veneer sheets were free from decay. Figure 5, shows the proportion of veneer volume in decay grade score. The drying of veneer sheets after peeling process is important to reduce the attack of fungus on the veneer sheets. Due to higher moisture content in coconut, they are more vulnerable to fungal attack than softwoods and hardwoods. Proper handling of veneer sheets after peeling process in necessary for coconut veneer sheets to get good quality sheets

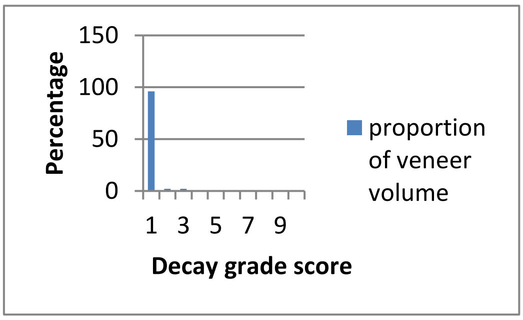

Figure 5: Distribution of decay score

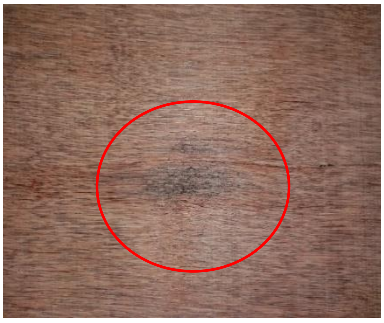

Plate 20: Example of veneer decay

4.3.6 Holes and tear out

Holes and tear out in veneer sheets were also affected mainly during handling of veneer sheets. Mechanical damage during the felling also resulted in holes and tear out. Proper handling of coconut logs during conversion can reduce these defects significantly.

During the trail 85 percent of veneer sheets were free from these defects. Only a few sheets were affected by extreme holes and tear out and make it unsuitable for any applications. Figure 6, showing the proportion of veneer sheets volume affected by the holes and tear out under different grade score.

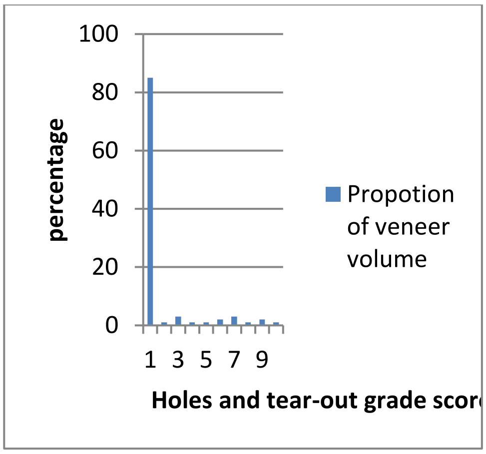

Figure 6: Distribution of holes and tear-out score

Plate 21: Example of veneer tear-out

4.3.7 Waviness

Waviness of veneer sheets are resulted due to the insufficient rounding of log before veneer manufacturing. Waviness of veneer sheets cause the overlapping of veneer sheets over another during pressing and result thickness variation in the veneer-based products especially plywood.

About 90 percent of veneer sheets were free from any waviness and 10 percent of veneer sheets were affected by waviness and none of the veneer sheets were seriously affected by the waviness during the trail. Figure 7, showing the proportion of veneer sheets affected by the waviness by waviness grade score.

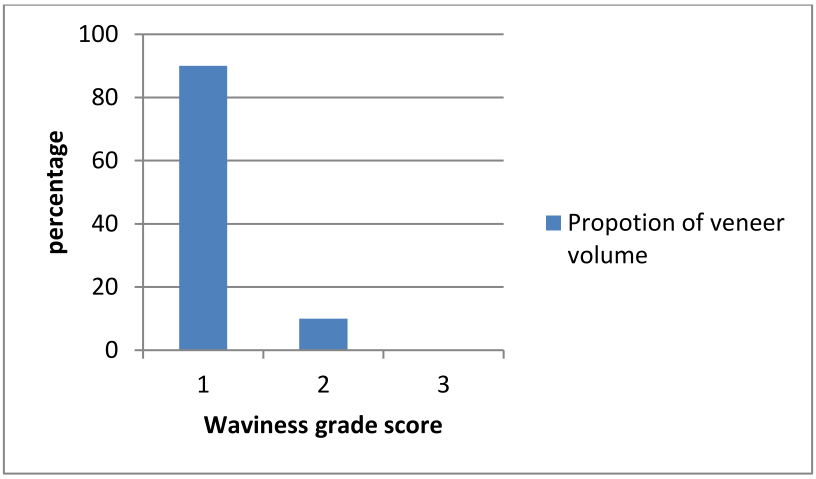

Figure 7: Distribution of waviness score

4.3.8 Insect track

There is no any sign of insect tracks in the veneer sheets during the trail.

4.4 Veneer visual grading

Veneer sheets were visually graded after drying process using Australian and New Zealand standards **AS/NZS2269.0:2012.** During the peeling of coconut log, there is no veneer sheet obtained having A grade. Most of the veneer sheets were obtained under D grade and F grade. During the first trail with no pretreatment resulted in more D and F grade veneer sheets. A subsequent trail with increased log temperature improves the veneer quality. Favourable lathe settings also enhance the quality of sheets produced. Figure 8, show the comparison of peeled and sawn veneer visual grading score.

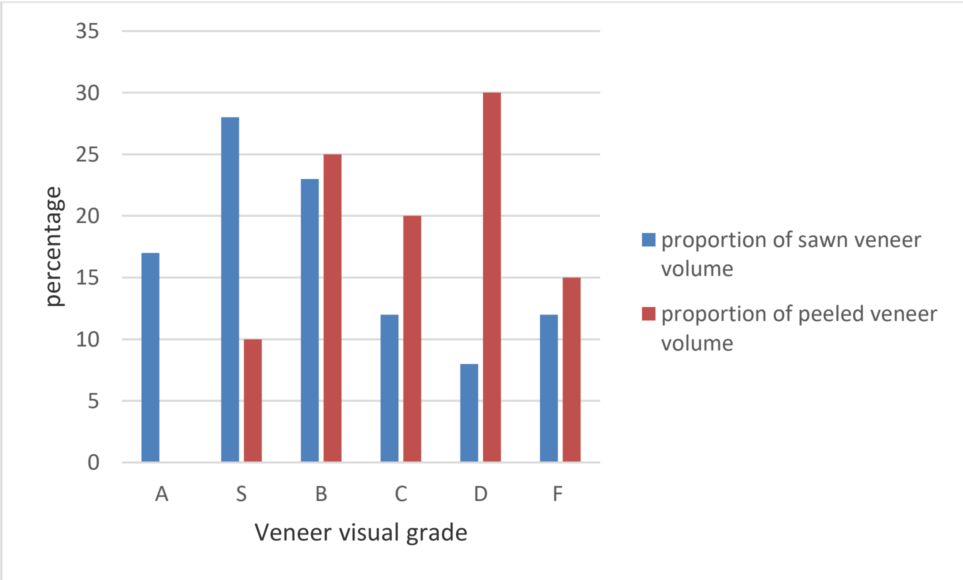

Figure 8: Distribution of veneer visual grade score

Figure 8, shows the proportion of sawn veneer and peeled veneer volume. In the present study, the visual grading recovery of peeled veneer is higher for D grade (30 percent) and no veneer sheets were obtained in A grade. The visual grading recovery of sawn veneer is higher for S-grade (28 percent) and lower for D grade (8 percent).

4.5 Veneer sheet thickness variations

Thickness of veneer sheets variation will negatively impact the overall quality of final products. Slight changes in the lathe setting will significantly affect the veneer thickness in the veneer sheets. Peeled veneer sheets of thickness 2.5 mm show thickness variation in the range 2.1 mm to 2.88 mm. Sawn veneer sheets of thickness 2.5 mm show thickness variation in range 1.98 mm to 4.01 mm. Figure 9, shows the thickness variation of peeled veneer.

Table 4: Thickness variation of sawn veneer and peeled veneer

Veneer Type	Average Thickness (mm)	Standard Deviation	Coefficient of variance (Percent)
Peeled Veneer	2.49	0.2162	8.682730924
Sawn Veneer	2.73	0.55	20.14652015

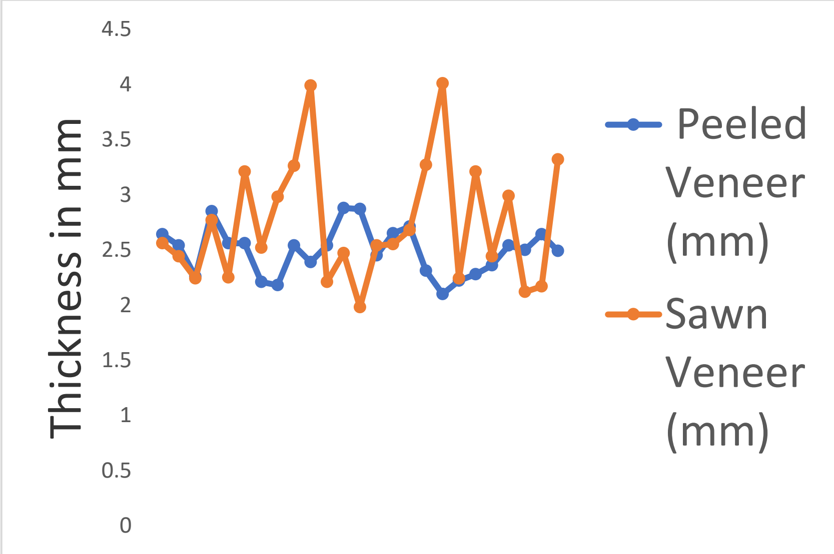

Figure 9: Thickness variation of veneer sheets of 2.5 mm

The coefficient of variation is 8.68 percent for the peeled veneer and it is about 20.14 percent for the sawn veneer (table 4)**.** From the figure 9, it is clear that large thickness variation is observed in sawn veneer sheet as compared to peeled veneer sheets.

4.6 Mechanical properties of plywood

The sample plywood tested according to the IS 303:1989 plywood for general purpose specification on BWR (Boiling Water Resistance) grade and MR (Moisture Resistance) for static bending test in parallel and perpendicular direction of grains along the face veneer

Table 5: Minimum requirement of plywood as per Indian Standard

Tests	Test method& Cl No	Requirement as per IS 303:1989
A. Modulus of Rupture (MOR), N/mm²		BWR grade Cl No. 11.4
I) Perpendicular to the face veneer		(Boiling Water Resistance)
(a) Average	IS 1734:1983(RA 2003) Part 11	20 N/mm²
(b) Minimum individual		18 N/mm²
II) Parallel to the face veneer		MR grade Cl No. 11.4 (Moisture Resistance)
(a) Average		30 N/mm²
(b) Minimum individual	IS 1734:1983(RA 2003) Part 11	27 N/mm²
B. Modulus of Elasticity (MOE), N/mm²		
I) Perpendicular to the face veneer		BWR grade
(a) Average	IS 1734:1983(RA 2003) Part 11	2500 N/mm²
(b) Minimum individual		2200 N/mm²
i) Parallel to the face veneer		MR grade
(a) Average	IS 1734:1983(RA 2003) Part 11	4000 N/mm²
(b) Minimum individual		3600 N/mm²

Table 6: Static bending test of plywood under IS 1734: 1983 (RA2003)

Number of layers	Type of plywood	Density	Perpendicular grain		Parallel grain	
			MOR N/mm²	MOE N/mm²	MOR in N/mm²	MOE N/mm²
3	Coco rubber Ply	400-700 kg/m³ (Medium density-MD)	16.37	2542.28	33.53	4340.76
3	Coco rubber Ply	above700 kg/m³ (High density-HD)	25.86	4452.38	34.99	4297.36
5	Coco rubber Ply	400-700 kg/m³	89.18	4063.21	40.29	4980.32
5	Coco rubber Ply	above700 kg/m³	114.81	5503.24	36.27	4539.47
3	coconut ply	400-700 kg/m³	25.86	2964.95	12.93	3475.33
3	coconut ply	above700 kg/m³	42.33	3271.64	25.87	3401.83
5	coconut ply	400-700 kg/m³	30.73	3241.86	57.65	6773.54
5	coconut ply	above700 kg/m³	55.93	3758.06	65.85	8834.64

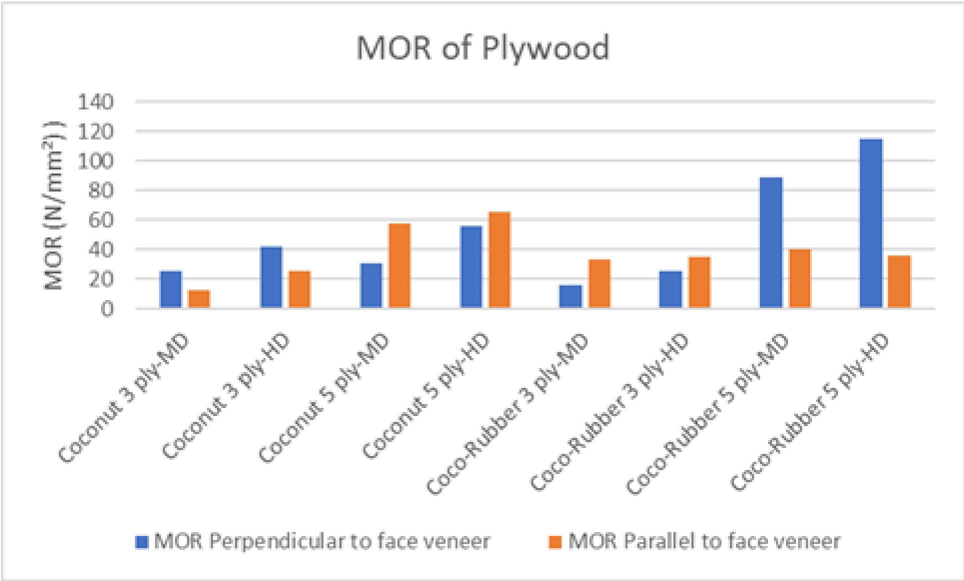

Figure 10: MOR of plywood

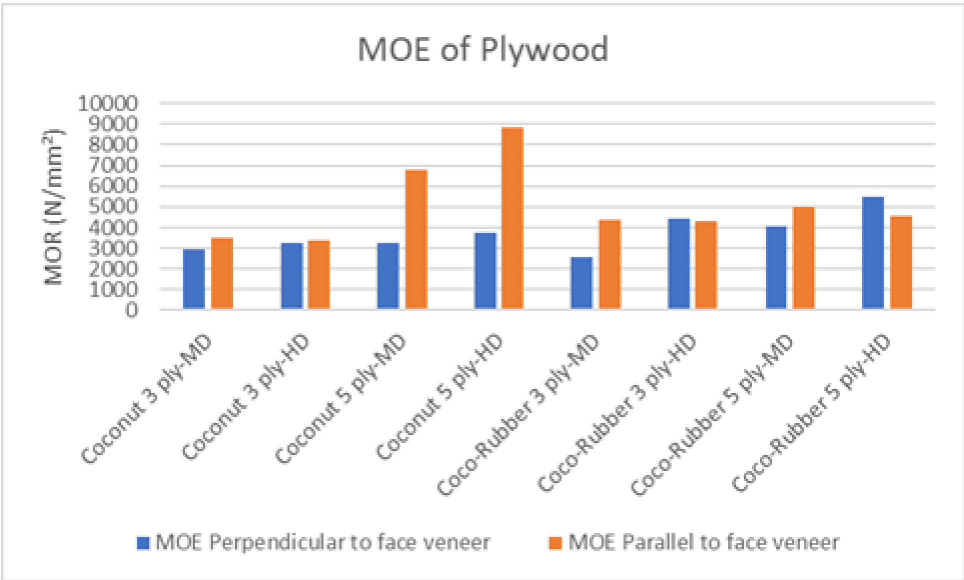

Figure 11: MOE of plywood

4.6.1 Static bending test of coconut plywood

The static bending test of coconut 5-ply shows the average MOR in N/mm^2 perpendicular as 30.73 N/mm^2 and 55.93 N/mm^2 in density classes of 400-700 kg/m^3 and above 700 kg/m^3 respectively. The MOE perpendicular to face veneer of coconut 5-ply shows the average 3241.86 N/mm^2 and 3258.06 N/mm^2 in density classes of 400-700 kg/m^3 and above 700 kg/m^3 respectively. The static bending test of coconut 5-ply shows the average MOR in N/mm^2 parallel as 57.65 N/mm^2 and 65.85 N/mm^2 in density classes of 400-700 kg/m^3 and above 700 kg/m^3 respectively. The MOE parallel to face veneer of coconut 5-ply shows the average 6773.54 N/mm^2 and 8834.64 N/mm^2 in density classes of 400-700 kg/m^3 and above 700 kg/m^3 respectively.

The static bending test of coconut 3-ply shows the average MOR in N/mm^2 perpendicular as 25.86 N/mm^2 and 42.33 N/mm^2 in density classes of 400-700 kg/m^3 and above 700 kg/m^3 respectively. The MOE perpendicular to face veneer of coconut 3-ply shows the average 2964.95 N/mm^2 and 3271.64 N/mm^2 in density classes of 400-700 kg/m^3 and above 700 kg/m^3 respectively. The static bending test of coconut 3-ply shows the average MOR in N/mm^2 parallel as 12.93 N/mm^2 and 25.87 N/mm^2 in density classes of 400-700 kg/m^3 and above 700 kg/m^3 respectively. The MOE parallel to face veneer of coconut 3-ply shows the average 3475.33 N/mm^2 and 3401.83 N/mm^2 in density classes of 400-700 kg/m^3 and above 700 kg/m^3 respectively.

4.6.2 Static bending test of coconut rubber plywood

The static bending test of coconut rubber wood 5-ply shows the average MOR in N/mm^2 perpendicular as 89.18 N/mm^2 and 114.81 N/mm^2 in density classes of 400-700 kg/m^3 and above 700 kg/m^3 respectively. The MOE perpendicular to face veneer of coconut rubber 5-ply shows the average 4063.21 N/mm^2 and 5503.24 N/mm^2 in density classes of 400-700 kg/m^3 and above 700 kg/m^3 respectively. The static bending test of coconut rubber 5-ply shows the average MOR in N/mm^2 parallel as 40.29 N/mm^2 and 36.27 N/mm^2 in density classes of 400-700 kg/m^3 and above 700 kg/m³ respectively. The MOE parallel to face veneer of coconut rubber 5-ply shows the average 4980.32 N/mm² and 4539.74 N/mm² in density classes of 400-700 kg/m³ and above 700 kg/m³ respectively.

The static bending test of coconut rubber 3-ply shows the average MOR in N/mm² perpendicular as 16.37 N/mm² and 25.86 N/mm² in density classes of 400-700 kg/m³ and above 700 kg/m³ respectively. The MOE perpendicular to face veneer of coconut rubber 3-ply shows the average 2542.28 N/mm² and 4452.38 N/mm² in density classes of 400-700 kg/m³ and above 700 kg/m³ respectively. The static bending test of coconut rubber 3-ply shows the average MOR in N/mm² parallel as 33.53 N/mm² and 34.99 N/mm² in density classes of 400-700 kg/m³ and above 700 kg/m³ respectively. The MOE parallel to face veneer of coconut rubber 3-ply shows the average 4340.76 N/mm² and 4297.36 N/mm² in density classes of 400-700 kg/m³ and above 700 kg/m³ respectively.

Plate 22: Static bending test of coconut plywood

Plate 23: Samples of testing bending test parallel to face veneer of coconut plywood.

4.7 Boring of coconut log

Boring of coconut log was done using heavy duty lathe machines. The inability of conventional wood lathe machines chunk to hold the coconut due to the soft central core can overcome using the chunk which hold the peripheral circumference in the heavy-duty metal lathe. But boring of coconut stem with larger dimension is difficult due to the heavy weight and rotating in single axis. Boring of coconut log up to 1 m is practically possible with heavy duty lathe and lathe cannot hold the log beyond that due to heavy weight and splitting of logs occurred due to the jerking during the rotational motion. Figure 12, shows the model of lathe which can be used for boring of coconut log. The machine consists of a supporter at the centre which rotate freely in ball bearing system. So, the coconut can hold in it without jerking and the tail stock of the lathe with drill bit can easily move towards the coconut for drilling process. The chunk of the lathe will hold the coconut in the peripheral region and holding portion is slightly modified to some extend for better gripping and holding of coconut log.

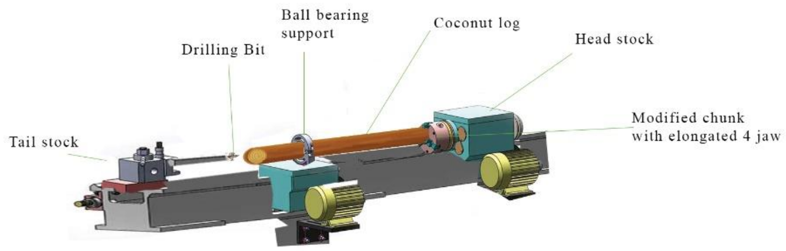

Figure 12: Lathe model for drilling of coconut log

5. DISCUSSION

The results of the study entitled "A technical evaluation of veneer cutting and boring of coconut stem wood" are discussed hereunder.

The study investigated the property of coconut palm wood, green veneer recovery, grading of veneer sheets, mechanical properties of coconut and composites plywood.

5.1 Coconut palm wood

The temperature has a very crucial impact on the peeling and sawing of the coconut logs used. The veneer which was obtained by peeling the log at the temperature between 40-52 ^{o} C as of low grade as compared to the veneer which was obtained by peeling the veneer at a temperature more than 60 ^{o}C which was of high grade.

The use of heat as a pre-treatment softens the logs, making peeling easier, and improves the quality of the veneer produced. The logs are usually heated before peeling throughout the manufacture of veneer and plywood. There are a variety of techniques for hardening logs, but the most common are steaming or soaking in hot water (Sellers, 1985). The major reason for heating the logs is to soften the wood (Marchal *et al*., 2009; Dupleix *et al*., 2012) in order to get a smoother veneer and reduce the severity of knife checks (Marchal *et al*., 2009; Dupleix *et al*. 2013; Meriluoto 1965,). The glass transition temperature (Tg) of the wood polymers is exceeded, causing the softening of logs prior to peeling (Salmén 1982; Placet *et al*., 2007). This reduces the amount of glue required for proper bonding (Sellers, 1985) and softens the knife damage (Bailleres *et al*., 2015). Elevated soaking temperature has also been demonstrated to impact the colour of wood (Mayer and Koch 2007; Yamamoto *et al*., 2015b) as well as the chemistry of the wood sap, which has been linked to veneer colour (Yamamoto *et al*., 2015a; Yamamoto *et al*., 2015b).

Temperatures for log heating are dependent on a variety of parameters, and it is impossible to prescribe a single optimal temperature for a specific species of wood that will result in the best cutting under all circumstances. The temperature of soaking in industrial manufacturing is determined by the wood species, the manufacturer, and the soaking season (Fleischer, 1959). Most heating schedules necessitate trade-offs in order to save time, heating capacity, or money (Kontinen *et al.*, 1992). Fortunately, acceptable cutting results can usually be achieved across a reasonably large temperature range. The temperature that produces the finest cutting in hardwood species is roughly proportional to the density of the wood (Fleischer, 1959). Low density wood species (less than 400 kg/m^3) can be cut at room temperature, medium density wood (about 460 – 550 kg/m^3) at 60 – 70°C, and dense wood (600 kg/m^3 and above) at around 90°C. Furthermore, for large diameter logs, the 'time-temperature relationship' is frequently used during soaking. This indicates that the soaking water could be significantly hotter than the log core's projected end temperature. When logs are withdrawn from the soaking facility, the outside half of the log, which is at a greater temperature, begins to cool, while the log's core temperature continues to rise (Sellers, 1985). The log's core and outer part should be at equal temperatures at the time of peeling. The soaking period will be cut in half; however, the log core and exterior part will have a different temperature history prior to peeling.

In this study also it was founded that, the peeling temperature has greater impact on the quality of veneer sheets. The trail which was conducted without pre-treatment was a failure and all the sheets obtained was not suitable for any decorative or construction purposes. Boiling or heating of log to appropriate temperature, current study shows a temperature higher than 50-60 °C enhance the quality of veneer sheets and also reduce the cutting force of the peeler. Even though it consumes some power for heating the logs, the recovery of quality veneer sheets will definitely compromise that.

5.2 Green veneer recovery

The green veneer recovery is the recovery percent of green billet volume before the log roundup and peeling process. It is mainly influenced by log roundup process and residual core diameter. Since the coconut palm stem is almost cylindrical in nature, there is limited loss of wood material during the roundup process. Most of the coconut palm logs cannot possible to peel up to the peelable limit of the peeler machine due to the lower density in the central core region of the coconut palm stem. Logs from the basal portion can be peeled up to the machine limit, but the recovery is low due to the high taperness in the lower part as compared to other parts. In the current study the average green veneer recovery obtained by means of rotary peeling is approximately 51 percent and sawn veneer showed a recovery rate of 35 percent. From the table 2. It is clear that the middle portions of the coconut log have higher recovery. The recovery of lower portion, middle portion and upper portion is 49 percent, 66 percent and 38 percent respectively. The sawn veneer recovery is only 35 percent. This is due to the large residue left after sawing as show in the plate 15.

The current recovery is percent is lower as compared to hardwoods and softwoods like *Eucalptus gobulus* (74-77 percent) (McGavin *et al.*, 2015), and young eucalyptus(57 -67 percent) (Beleville *et al.*, 2018). McGavin *et al.* (2014) evaluated the veneer recovery of eucalyptus species and obtained a green veneer recovery for *Corymbia citriodora* (68 percent), *Eucalyptus cloeziana* (73 percent), *E. dunnii* (70 percent), *E. pellita* (74 percent), *E. nitens* (75 percent) and *E. globulus* (77 percent). Luo *et al.* (2013) showed a range of 28 percent to 51 percent of green veneer recovery for the eleven-year-old eucalyptus clones. The average green veneer recovery obtained from the peeling of rubber wood was 64.1 percent (Benoit *et al.*, 2020). Study conducted by Kadir, A.Y. (2015), on the green veneer recovery of coconut palm showed that recovery for bottom, middle and top portion was 53.71percent, 48.41percent and 47.00 percent respectively. Current recovery result showing higher recovery as compared to Kadir, A.Y. (2015). The McGavin *et al.*(2019) obtained a green veneer recovery of 50-60 percent of coconut log volume during the peeling process. The recovery percent will vary from species to species and mainly influenced by the taperness of the log. The recovery percent will also vary from age of the species as the green veneer recovery for 6 to10 year-old eucalyptus was 40 -65 percent (Peng *et al*., 2014) and 5 -year-old eucalptus with recovery of 28.4- 50.5 percent (Luo et al., 2013). The palm species has generally lower recovery due to the low conversion of material to veneer sheets. Tarmezi *et al*. 2008 showed green veneer recovery of oil palm was about 45-50 percent.

The current study shows a similar result with the recovery of veneer sheets on peeling of the palm species. The large range of recovery percent in the coconut log is due to varying diameter of peelable portions in the coconut log and will vary according to the density difference within the log. Higher taperness in the upper portion and lower peelable portion on the stem result in the lower recovery of veneer

5.3 Veneer Defects

Table 2. shows various defects and its classification based on the score. Defects are most important characteristics determines the end use of the veneer-based products. Common defects used for veneer grading in the current study includes surface roughness, handling splits, collapse, end splits, fungal decay, holes and tear outs, waviness and insect tract. McGavin *et al.* (2019) studied the density, colour, surface roughness, splits, brittleness, fungal decay, holes and tear-out, waviness, wane and insect tract for grading coconut veneer sheets. Leggate and McGavin (2017) classify the veneer grading based on the defects like knot, hole, splits, gum pockets, gum vein, insect attack, discoloration, grain tear-out, knife mark, fungal decay, waviness and cumulative defects.

5.3.1 Veneer roughness

The assessment of veneer roughness gives a good indication of the suitability of process settings, the appropriateness of the veneer for various manufacturing enterprises. During the experiment the veneer roughness obtained were dominated with the score with 3 and 4 which can be smoothened by means of sanding. It is nearly similar to the results obtained during the course of study by Nolan *et al.* (2019), where most of the surface roughness obtained was under the score of 3. No veneer was obtained with score 1. Veneers which were obtained score 7 and 8 cannot be smoothened because of there is difficulty during sanding and caused tear off.

The veneer obtained from coconut wood was expected to be rough because of the unique feature which is associated with the coconut wood as mentioned by (Bailleres *et al.*, 2010). Sanding to remove roughness in the veneer obtained from coconut wood can be done only in the final product so; good care has to be taken for the product during the manufacturing stages. Roughness is a great problem for obtaining reliable and efficient glue application. The roughness that is present in the coconut log naturally can be controlled to a certain extend by optimizing the pre-conditioning temperature, lathe settings etc.

5.3.2 Handling splits

Splits that are expected to be caused due to veneer handling are called handling splits and these types of splits are entirely different from the other types of splits that are a result of compression, shrinkage or because of other stress factors. During the trial about 50 percent of the veneer sheets were affected by handling splits and most of the veneer were in the score 1 of the handling split which indicated no splitting and a smaller number of veneers were under the score 4 which indicated moderate splitting. These findings were comparable with the study conducted by Nolan *et al.* (2019), where he concluded that almost 60 percent of the veneers under trial were affected by handling split.

In a study conducted by USDA in 1977 revelled that under heating will result in a less tight veneer, as well as excessive handling splits and thickness fluctuations. In tension, loosely cut veneer is weakly perpendicular to the grain. As a result, it is more likely to split or break during its handling. As a result, lowering the veneer grade will result in less tight veneer and may result in excessive handling splits and veneer thickness fluctuations. Green veneer taping is a new technique for controlling handling splits. Experiments revealed that applying 12.7 mm broad tape to the spurred ends of the green veneer reduced end waviness. Drying rotary cut veneer on a continues ribbon using a wire mesh conveyor in a mechanical dryer is another way to reduce handling splits.

Along with these techniques proper care should be given to the veneer sheets especially during transferring the veneer sheets from the veneer drier as dried veneers are more susceptible to handling splits and the veneer thickness must also be kept optimum for managing the handling splits efficiently.

5.3.4 Collapse

Veneer collapse is a condition in which the obtained veneer shows wear and tear and is not suitable for its incorporation in plywood making. Proper care should be given while making veneer from the log. Coconut because of its special anatomical feature is expected to be highly susceptible to collapse. During the experiment it was found out that the collapse was less under the peeling temperature of 60 ºC as compared to 40 ºC as it the former temperature is believed to be sufficient to soften the coconut wood tissues and lowered the collapse rate.

During the experiment it was found out that most of the veneer sheets obtained was coming under grade 4 which indicated they are moderately susceptible to collapse as compared to grade 1 which includes veneer which are not susceptible to collapse. These results are compatible with the findings by Nolan *et al.* (2019), where he came out with the finding that almost 84. percent of the veneer obtained came under grade 3. Yang and Liu (2018) during their study concluded that when the cells are tightly packed or occluded with cytoplasm debris or other extraneous material then the wood is highly susceptible to collapse which can be implied to the coconut wood also. Pretreatment which was given before the veneering helped in reducing the collapse. It was also suggested by McGavin *et al.* (2014), that optimized lathe conditions during the coco veneer production can also have a great contribution towards reducing the collapse that are expected to occur.

Haslett and Kininmoth (1986); Kong *et al.* (2018) suggested that preheating the timber before the veneering followed by steaming could probably reduce the collapse. The wood ductility can also be reduced improving its viscoelastic properties, and at last resulting in reduced cracks (Calonego *et al.,* 2010).

5.3.5 End splits

Splits are a common defect found during veneer making from a log. During the course of study, it was found out that 30 percent of the veneers obtained contained large splits and these veneers were not suitable for usage as a decorative veneer sheet and also as face veneers. Almost 50 percent of the veneers obtained were having the score between 1 and 4 indicating that these veneer sheets were having no or less amount of splitting. It was also found out that peeling of veneer with a thickness of 2.25 mm showed a reduction in the splitting. The study by Nolan *et al.* (2019) obtained veneer that were having splits with score between 1 and 3 for grade 1 veneer (high-quality appearance grade veneer) followed by score less than or equal to 6 for grade 2 and 3 veneer (suitable for high-quality paint finishing and non-appearance grade veneer with a solid surface respectively). It can also be supported by the study by Gavin *et al*. (2014) where they obtained veneer with scores in between 1 and 3.

Splits can have a negative impact in veneer making. Belleville *et al.* (2020) found out that the reason of downgrading of veneer obtained from Eucalyptus was downgraded from grade 3 to grade 5 was because of the presence of splits which accounted to 31 percent. These can be attributed to the special anatomical structure that is present in case of coconut wood. Optimization of storage conditions and billet preconditioning i.e., temperature and method of heating will enable to improve the peeled veneer qualities and allow for more effective veneer making (McGavin, *et al.,*2016).

5.3.6 Holes and Tear out

Holes and tear out form a major issue during the handling of veneer sheets. During the experiment it was found out that 85 percent of the veneers obtained were free from any holes and tear outs and only a few were affected by extreme holes and tear out. Majority of the veneer sheets were having a score of 1 which indicated that majority were free from any holes and tear outs. The study by Nolan *et al.* (2019) obtained veneer that were having holes and tear out with score between 1 and 2 for grade 1 veneer (high-quality appearance grade veneer) followed by score less than or equal to 4 for grade 2 (suitable for high-quality paint finishing) and score less than or equal to 7 for grade 3 veneer (non-appearance grade veneer with a solid surface). It can also be supported by the study by McGavin *et al.* (2014) where majority of the obtained veneer were under scores 1.

Holes have a serious impact in the quality of the veneer produced. Belleville *et al.* (2020) found out that the reason of downgrading of veneer obtained from Eucalyptus was downgraded from grade 3 to grade 5 was because of the presence of holes which accounted to 17 percent. This defect can be influenced by a variety of factors like decay, lower level of thickness and also the mechanical damage that were caused to the log. Most of these can be managed by proper maintenance of the stand, quality control and also by optimized quality control protocols.

5.4 Veneer sheet thickness variation

Uniformity in veneer thickness is very important character which affects the quality of end products made from the veneer sheets. The bonding strength of glue with sheets are mainly influenced by the uniformity in veneer sheets. Normally in Kerala, peeling of veneer sheets was done at 1.6 mm thickness. It can also range from 1.5 to 2 mm generally. But peeling of coconut with 1.6 mm is very difficult due to the hard fibrovascular bundles which makes the veneer sheets more collapsed. So, peeling of coconut at 2.5 mm or more is ideal for veneer production. From the table 3, it is clear that peeled veneer show less variation as compared to sawn veneer sheets. The proper alignment of log is very important for sawing the coconut log. The vibration of the sawing machine making the changes in alignment affects the veneer sheets and causes large variation.

In the present study the coefficient of variation of peeled veneer and sawn veneer is 8.68 percent and 20.14 percent respectively. The present result shows that variation in veneer thickness is low for peeled veneer and high for sawn veneer. The variation of 0.78 mm and 2.03 mm is observed in peeled and sawn veneer sheets.

The present study result is higher as compared to (Peng *et al.*, 2014), showed that only 4.1 percent variation as compared to desirable thickness in eucalptus veneer sheets. The coefficient of thickness variation obtained on peeling Sengon (*Paraserianthes moluccana*), was 5.3 percent, 5.8 percent and 5.9 percent for intended veneer thickness of 1. mm, 1.5 mm and 2.0 mm thickness (Darmawan *et al*., 2015), the coefficient of thickness variation obtained on peeling *Anthocephalus macrophyllus* was 5.19 percent and 3.58 percent for 1.5 mm and 3 mm thickness (Cahyono *et al.*, 2016). Current result is 2-fold times higher for peeled veneer sheets as compared to sawn veneer sheets and the coefficient of variation of sawn veneer is much higher (about 4 times) as compared to (Darmawan *et al*., 2015). The coefficient of variance of peeled veneer of present study shows comparable result with khoo *et al*. (2018), where the coefficient of variance for 1 mm, 2 mm, and 3 mm thickness rubber wood veneer sheets are 10.7 percent, 8.4 percent and 9.4 percent respectively.

The large thickness variation in coconut log may be due to the storage of log prior to peeling in water, which is explained by Shmulsky, (2011). Chen *et al*. (2021) also stated that increasing log temperature will increase the thickness variation and surface roughness but decrease the lathe checks.

5.5 Visual Grading recovery of veneer sheets

Visual grading recovery is important for classifying the veneer sheets for its end use. There is no specific visual grading standard for coconut veneer sheet and in present study, veneer grading was done according to Australian and New Zealand standards **AS/NZS2269.0:2012.**

Figure 8, shows the proportion of sawn veneer and peeled veneer volume. In the present study, the visual grading recovery of peeled veneer is higher for D grade (30 percent) and no veneer sheets were obtained in A grade. The visual grading recovery of sawn veneer is higher for S-grade (28 percent) and lower for D grade (8 percent). McGavin *et al*. (2015, 2015) studies represented a higher recovery percentage of average 84.7 percent and 70.13 percent for D-grade in *Eucalyptus globulus* and *Eucalyptus nitens.* No veneer sheets were obtained in A grade from *Eucalyptus globulus*. Similar result was obtained from McGavin and Leggate, (2019), where veneer visual grade recovery was dominated by D-grade and no veneer sheet obtained for A-grade for species *Corymbia citriodara* and *Callitris glaucophylla*. Leggate and McGavin, (2017) showed the higher recovery obtained in D-grade for Acacia hybrid, *A. mangium* and *Eucalptus urophylla*. Farrell *et al.* (2011) showed the higher recovery of eucalyptus species in D-grade.

5.6 Mechanical properties of plywood

Mechanical property of any material determines its degree of resistance which can withstand on external force applied. Modulus of elasticity (MOE) and Modulus of Repture (MOR) are important parameter in the wooden material showing the overall strength and applications of the material.

Table 6, shows the average MOR in N/mm² and MOE in N/mm² for both parallel and perpendicular direction to the face veneer of the plywood types manufactured. 8 types of plywood were manufacture in the current study. The maximum MOR perpendicular and parallel to face veneer is for coconut rubber 5 ply and coconut 5-ply of density more than 700 kg/m³ respectively (Figure 10.). Figure 11, shows the MOE of plywood and the maximum MOE perpendicular and parallel to face veneer is for coconut 5 ply and coconut rubber 5-ply of density more than 700 kg/m³ respectively.

Table 7, shows the comparison of MOE and MOR in both parallel and perpendicular of face veneer of different plywood. Maximum MOR of 114.81 N/mm^2 perpendicular to face veneer is obtained during the current study as compared to other species. The MOR parallel to face veneer of 5 ply in the current study shows comparable result with *Pinus oocarpa* (Reis *et al.,* 2019),coconut veneer (McGavin, 2016), *Pterocarya fraxinifolia* (Gungor *et al.,* 2007) and *Populus euramericana* (Bal and Bektaþ,2014). MOE perpendicular to face veneer of coconut and coconut rubber plywood shows lower values as compared to McGavin, (2016). In current study maximum value of MOE parallel is for coconut rubber 5-ply of above 700 kg/m^3 (5503.24 N/mm^2) and is lower to Engineered coconut trunk veneer (Izran, 2013), coconut (McGavin, 2016), Eucalptus (Islam *et al.,* 2012), *Albizia richardiana* (Rahman *et al.,* 2014) and Bamboo mat plywood (Rahman *et al.,* 2012).

From the table 11, it is clear that MOE parallel to face veneer of 5 ply-of coconut shows higher values as compared to the 5 ply-of coconut-rubber plywood. The maximum MOE parallel was found as 8834.64 N/mm^2 for Coconut-5-Ply-above700 kg/m^3 and the result is comparable with Bamboo mat plywood (Ashaduzzaman *et al*., 2011), coconut plywood (McGavin, 2016), *Albizia richardiana* (Rahman *et al.,* 2014). Current result is significantly higher as compared (Bal and Bektaþ, 2014; Rahman *et al.,* 2021; Rahman *et al.,* 2014; Reis *et al*., 2019). MOE perpendicular to face veneer shows lower values as compared to parallel to face veneer.

From the table 11, it is clear that the 5-ply made of coconut and coconut and rubber composites shows higher MOE and MOR and satisfy the minimum requirement as per Indian Standard. The MOR of current result show higher values as compared to previous work on coconut by McGavin (2016), and maximum value of MOR perpendicular to face veneer is obtained during the current study. But the MOE values are lower as compared to (McGavin, 2016). Current result also shows higher values as compared to many other softwood and hardwoods as seen in the table 11.

Table 7: Comparison of MOR and MOE of some commercially available plywood.

Sl no.	Plywood species	MOR perpendicular (N/mm$^{2)}$	MOR parallel (N/mm$^{2)}$	MOE perpendicular (N/mm$^{2)}$	MOE parallel (N/mm$^{2)}$	Reference
1	*Populus euramericana*	27.2 N/mm^2	59 N/mm^2	2191 N/mm^2	6875 N/mm^2	Bal and Bektaþ,2014
2	*Neolamarckia cadamba*	49.46 N/mm^2	40.04 N/mm^2	5362 N/mm^2	4272 N/mm^2	Rahman *et al.*, 2021
3	*Fagus Orientalis*	38 N/mm^2	89. N/mm^2	2661 N/mm^2	8636 N/mm^2	Bal and Bektaþ,2014
4	*Eucalyptus grandis*	41.1 N/mm^2	79.9 N/mm^2	2939 N/mm^2	9346 N/mm^2	Bal and Bektaþ,2014
5	*Paraserianthes falcataria*	29.76 N/mm^2	20.38 N/mm^2	3867 N/mm^2	2733 N/mm^2	Rahman *et al.*, 2021
6	*Bombax ceiba*	26.91 N/mm^2		3870 N/mm^2		Islam *et al.*, 2012
7	Bamboo mat plywood	89.62 N/mm^2		8110.02 N/mm^2		Rahman *et al.*, 2012
8	*Albizia richardiana*	62.79 N/mm^2		6997.20 N/mm^2		Rahman *et al.*, 2014
9	*Pterocarya fraxinifolia*	37.5 N/mm^2	59.6 N/mm^2	3358 N/mm^2	5617 N/mm^2	Gungor *et al.*, 2007
10	Eucalptus	68.6 N/mm^2		7879 N/mm^2		Islam *et al.*, 2012
11	Coconut veneer plywood 451-600 kg/m³	73.7 N/mm^2	45.2 N/mm^2	9476 N/mm^2	8007 N/mm^2	McGavin, 2016
12	Coconut veneer plywood 601-750 kg/m³	83.2 N/mm^2	52.6 N/mm^2	11304 N/mm^2	10787 N/mm^2	McGavin, 2016
13	Coconut veneer plywoodAbove 700 kg/m³	72.8 N/mm^2	60.7 N/mm^2	8829 N/mm^2	12286 N/mm^2	McGavin, 2016

14	Engineered coconut trunk veneer	86.66 N/mm^2		10124.07 N/mm^2		Izran, 2013
15	*Melia azedarach*	58.33 N/mm^2		3950.01 N/mm^2		Rahman *et al.*, 2014
16	*Bombax ceiba*	32.52 N/mm^2		3224.15 N/mm^2		Rahman *et al.*, 2014
17	*Acrocarpus fraxinifolius*	49.4 N/mm^2	96.8 N/mm^2	2709 N/mm^2	8496 N/mm^2	Reis *et al.*, 2019
18	*Pinus oocarpa*	31.5 N/mm^2	56.8 N/mm^2	1808 N/mm^2	4912 N/mm^2	Reis *et al.*, 2019
19	Bamboo mat plywood	89.62 N/mm^2			8110.02 N/mm^2	Ashaduzzaman *et al.*, 2011
20	Redwood	42.61 N/mm^2		6960 N/mm^2		Cai *et al.*, 2021
21	Coco rubber-3-Ply-400-700 kg/m^3	16.37 N/mm^2	33.53 N/mm^2	2542.28 N/mm^2	4340.76 N/mm^2	Current study
22	Coco rubber-3-Ply-above700 kg/m^3	25.86 N/mm^2	34.99 N/mm^2	4452.38 N/mm^2	4297.36 N/mm^2	Current study
23	Coco rubber-5-Ply-400-700 kg/m^3	89.18 N/mm^2	40.29 N/mm^2	4063.21 N/mm^2	4980.32 N/mm^2	Current study
24	Coco rubber-5-Ply-above700 kg/m^3	114.81 N/mm^2	36.27 N/mm^2	5503.24 N/mm^2	4539.47 N/mm^2	Current study
25	Coconut-3-Ply-400-700 kg/m^3	25.86 N/mm^2	12.93 N/mm^2	2964.95 N/mm^2	3475.33 N/mm^2	Current study
26	Coconut-3-Ply-above700 kg/m^3	42.33 N/mm^2	25.87 N/mm^2	3271.64 N/mm^2	3401.83 N/mm^2	Current study
27	Coconut-5-Ply-400-700 kg/m^3	30.73 N/mm^2	57.65 N/mm^2	3241.86 N/mm^2	6773.54 N/mm^2	Current study
28	Coconut-5-Ply-above700 kg/m^3	55.93 N/mm^2	65.85 N/mm^2	3758.06 N/mm^2	8834.64 N/mm^2	Current study

5.7 Boring of coconut stem

Conventional method of making hollow cylindrical coconut structures are by cutting the whole log longitudinally and remove the core part mechanically and then glued together using strong adhesives like epoxy adhesives. There are lot of limitation regarding this method. There are more chances of splitting of glued part especially during the dry seasons. So, the bored material without splitting has better durability and strength. The inability of coconut stem to hold in the chunk makes practical difficult for boring the stem to larger dimensions. It can be used for load bearing structures with or without reinforcement with cement or concrete based on the mode of applications. Currently bored coconut has greater demand as a decorative pillar in house, hotels, houseboats and other tourism areas. Proper technology may overcome the limitations of current research

6.SUMMARY

Coconut palm wood is very common in Kerala and become senile after 50 years and productivity decrease drastically. Farmers are replanting the palm without proper utilisation of the palm wood. The coconut palm stem is left in their field and get decayed or pave a way for breeding ground for pathogens. Coconut has a potential to substitute the conventional timber species. The unique grain pattern and natural fresh look enhance the demand of coconut in indoor applications. This project's goal was to explore the potential of coconut logs for veneer production and boring of coconut logs for construction application to enhance the utility of this neglected logs and also to enhance the income to coconut farmers. The salient findings from the study

1. Coconut logs are monocotyledons and it is entirely different from the other conventional softwood and hardwood. So, the peeling process is entirely different form other logs.
2. Selection of coconut logs also important since the middle portion of a palm is better for peeling process due to higher recovery (66 percent) and quality veneer sheets. The lower portions show higher variation in the density within a sheet due to higher tapering.
3. Lower part can be used for production of sawn veneer. Higher decorative veneer sheets can be produced form the lower part through sawing even though recovery is very low (35 percent)
4. Pretreatment is necessary for peeling of coconut logs. A temperature of more than 50^{o}-60 ^{o}C is required for improve the surface quality and also to reduce the cutting force in coconut logs
5. Prolonged storing of coconut log before peeling in water increase the thickness variation in the veneer sheets.

6. The minimum peelable veneer thickness is 2.5 mm being limited by the fibrovascular bundle size
7. Collapse and end splits are most common defects in the coconut veneer sheets. Handling splits also dominated and can be reduced by proper handling of veneer sheets.
8. The highest visual grading recovery of coconut veneer sheets were in D-grade and No veneer sheets were obtained in A-grade during peeling, but sawing of coconut log for sawn veneer enhance the quality of veneer sheets and highest visual grading recovery obtained in S-grade.
9. Peeled veneer sheets show lower thickness variation as compared to sawn veneer. The coefficient of variation of peeled and sawn veneer was 8.6 percent and 20.14 percent respectively.
10. The 3-ply made of coconut failed to meet the IS 303:1989 under BWR grade and MR grade on testing bending test parallel to face veneer
11. The 5-ply made of coconut and rubber (3 coconut and 2 rubber wood) shows the best strength properties in perpendicular to face veneer of MOR 89.1, 114.81 N/mm^2 in 400-700 kg/m^3 and above700 kg/m^3 respectively. MOE 4063.21, 5503.2 N/mm^2 in 400-700 kg/m^3 and above700 kg/m^3 respectively.
12. The 5-ply made of coconut shows the best strength properties in parallel to face veneer of MOR 57.6, 65.85 N/mm^2 in 400-700 kg/m^3 and above700 kg/m^3 respectively. MOE 6673.5, 8834.6 N/mm^2 in 400-700 kg/m^3 and above700 kg/m^3 respectively.
13. The boring of coconut log is limited to 1 meter due to the splitting of coconut log
14. The mechanical properties of wooden material are not completed due to the absence of Indian Standard for testing this prototype.

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A TECHNICAL EVALUATION OF VENEER CUTTING AND BORING OF COCONUT (*Cocos nucifera* L.) STEM WOOD

by

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(2019-17-014)

THESIS

Submitted in partial fulfilment of the

requirements for the degree of

MASTER OF SCIENCE IN FORESTRY

Faculty of Forestry

Kerala Agricultural University

DEPARTMENT OF FOREST PRODUCTS AND UTILIZTION

COLLEGE OF FORESTRY

VELLANIKKARA, THRISSUR, 680 656

2022

8.ABSTRACT

Increased usage of wood products and a decline in supply of wood creates a major gap in the demand and supply chain. Severe restrictions in the felling of trees from natural forests create pressure on the plantations. But the limited supply from plantations alone will not be sufficient for meeting the current demand. Here, the role of trees outside forest especially from the home gardens is significant. Coconut, widely cultivated in home gardens of Kerala is considered as “Kalpavriksha” since, the entire part of the coconut palm is used. However, the coconut palm stem is underutilized and even considered as waste and farmers have to pay high prices to remove the old, diseased and senile palms from their field.

Coconut palm stem has huge potential to substitute the hardwoods and softwood, their use is limited to fewer applications like conventional furniture mainly. Conversion of the coconut palm wood is very difficult due to the hard fibrovascular bundle distribution and low recovery rate leads to avoiding this cheap wood material despite its tremendous potential to replace more conventional species. The wood industry, especially the small and medium enterprises are reluctant to saw the coconut palm stem due to the damage caused to their machineries due to the hard fibro vascular bundles.

Veneers are thin sheets produced by sawing, slicing or the rotary peeling process. Veneer production is another method for better utilization of logs for enhancing the recovery percentage. Peeling of coconut palm is also not practically feasible using the conventional spindle peeler because of its soft core which does not have enough strength to hold the chunk of the conventional peeler machines. Spindle less peeler is the only option for peeling coconut logs in an efficient way. Veneers produced by peeling of coconut logs using spindle less peeler can be used for the production of veneer-based products like plywood, laminated wood etc. Veneer-based products has lots of advantages as compared to solid wood. They have better strength, dimensional stability, durability and low shrinkage as compared to solid wood and also have lower costs.

Our study shows that pre-treatment of coconut log using steam or boiling makes the fibers soft and reduces the cutting force and also enhances the quality of veneers produced. We also found that peeling temperature is an important factor for peeling of coconut logs to reduce the cutting force and enhance the veneer quality. Above 50-60^{0}C is considered necessary for peeling the coconut logs of high density and temperature will vary according to the density of coconut logs. Appropriate lathe setting is necessary for peeling operations and will be different from species to species. Peeling and sawing at 2.5 mm thickness is considered ideal for veneer production coconut stem wood. Peeling at 4 mm nose bar gap reduce the thickness variations within the sheets. The setting of saw blade is important for the sawing and for the coconut log it is about 20 degree for left and right and zero degree for straight which is considered ideal for reducing the saw marking and also to remove the saw dust from the log without jamming the blade inside.

The green veneer recovery of coconut log on peeling was higher for the middle part (66 %) of the coconut palm stem and lower for the upper portion (49 %) and the lower part of coconut palm stem has about 49 % of recovery. The average green veneer recovery of the peeling and sawing as about 51 % and 35 % respectively. It is lower as compared to other timber species. But peeling of coconut log showed enhanced recovery as compared to sawing due to the low residue left after the process. The veneer defects classification is important for the determination of the end uses of the veneer sheets. The coconut veneer sheets show significant defects like roughness, collapse and handling splits. All of these defects can be reduced by appropriate lathe settings and pretreatment of the coconut logs prior to peeling.

Veneer can be used for manufacture different veneer-based products and composites. Coconut plywood with 3-ply and 5-ply and coconut rubber wood plywood with 3-ply and 5-ply were manufactured using resorcinol formaldehyde adhesive. In this study we developed 8 types of plywood from coconut and coconut composites. The static bending test of coconut plywood with (IS 1734: 1983) shows the maximum MOR of 114.81 N/mm² for the 5-ply coconut rubber plywood of density more than 700 kg/m³ in the perpendicular direction of the face veneer. The MOE of 8834.6 N/mm² is the highest MOE for the 5-ply coconut plywood of density more than 700 kg/m³ with parallel direction of the face veneer. On the other hand, the 3-ply coconut plywood with density 400-700 kg/m³ had lowest MOR and MOE of 12.93 N/mm² and 2964.95 N/mm². 5-ply plywood using both coconut and coconut rubber plywood showed good results and can be used for construction purposes like load bearing. All the plywood samples made of 5-plies meet the minimum requirement as per the Indian standard and also showed significant results compared to other plywood species.

The boring of coconut log for the construction of hollow cylindrical prototype was not successful due to the failure in the holding of the log with larger dimension on the single chunk of the lathe. The coconut log was able to bore only up to 1meter length with 4 inches of bored diameter. The coconut log can be bored to longer dimension by appropriate modifications on the lathe by providing support for the log for holding during the rotation of the logs.