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STANDARDIZATION OF KILN SEASONING SCHEDULE FOR COCONUT (*Cocos nucifera* L.) WOOD

By
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(2017-17-001)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

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DECLARATION

I hereby declare that the thesis entitled **"Standardization of kiln seasoning schedule for coconut (*Cocos nucifera* L.) wood"** is a bonafide record of research done by me during the course of research and that this thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara
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CERTIFICATE

Certified that the thesis, entitled **"Standardization of kiln seasoning schedule for coconut (*Cocos nucifera* L.) wood"** is a record of research work done independently by Gayathri Mukundan (2017-17-001) under my guidance and supervision and that it is not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Place: Vellanikkara
Date: 21|10|19

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Dedicated to my
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Introduction

1. INTRODUCTION

Wood is in short supply to industries that rely on traditional high-quality timbers. This specific scenario encourages the forest based industry to lookup for alternative timber varieties that have good market value yet are not commonly employed by forest based industries. Wood is a good plus aesthetically pleasing material with regard to building, utilized by man. Right now there is limited knowledge concerning the properties of a sizable proportion of timber-grade solid wood species. Strengthening the information is essential for better and efficient utilization associated with the less known underutilized timber trees.

The coconut tree (*Cocos nucifera* L.) has many uses. It is one of the most versatile and economically important palm in the tropical and sub-tropical regions (Subramanian, 2003). Coconut wood is also called porcupine wood owing to its good looking, spotty appearance. Ever increasing population and living standards of people have elevated the demand of wood products. There is a huge gap between the demand and supply of wood and a solution to this problem is utilisation of available wood sources and other lignocellulosic materials (Amartey *et al.*, 2006; Arancon, 1997). Among the challenges in tropical forest management today is appropriate utilisation of lesser-known wood species (Basri et al., 2007). Several potentially important trees such as coconut tree are under-utilised. Considering that few tree species are usually being utilized a commercial sense, there is an incorrect impression that there is usually an insufficient raw material base for timber industries.

There are increasing number of senile coconut palms in Kerala and Tamil Nadu that demands replanting. The conversion of coconut plantations into house plots requires removal of coconut trees and timber of which are available for efficient utilisation. It is often widely recognized that the particular most effective way associated with disposing the coconut trunks is to convert all of them into saleable wood items which may also help appropriate disposal of the coconut palms whilst creating work and income to coconut growers.

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Even if there is a wide usage of coconut and its leaves, there is not much popularity for coconut wood. Potentiality of the wood of coconut on a large scale scale has been only identified in the previous decade or so, the use of wood from coconut has used locally, since the very beginning. In more recent times, wood of coconut have been greatly utilized in a number palm growing countries like Philippines, Sri Lanka, Fiji, Indonesia, the Tonga Islands and many more. (Mosteiro, and Arnaldo, 1980).

Coconut wood is equally good as wood of conventional timber species matching with durability and strength. This utilization of coconut wood as an alternative material for building could bring down the price of housing units. This will be because its cost is half or a little more than half the price of conventional wood.

Appropriate utilization of any specific wood species must become based on both fundamental properties and processing properties. Drying properties are a set of the most important processing properties. A proper seasoning process will be the main key to efficiently utilize and ensure high quality wood products (Hoadley, 2000). For the majority of timber products pre-seasoning are crucial. It reduces the presence of water in the particular wood and therefore decreases the danger of motion of water, once the particular timber is within use. This also reduces the attack of fungal damages plus seasoning enhances the mechanised properties of the wood.

Coconut wood is hard, lasting and volumetric shrinkasge associated with the wood is lesser. The palm is non-branching and trunk is without knots. It has various shades of brown, that mark the grain and texture. There is absolutely no separation between hardwood and sapwood. (Killmann, 1983).

Coconut palm wood has a good initial moisture content per cent varying from 60 per cent (high density) upward to 230 per cent (low density). The particular success drying lies in maintaining an equilibrium between the evaporation associated with water from the surface area of timber and the particular movement of water through the interior of the particular wood to the outer face. (Desch, 1981).

Coconut wood being a good source of timber, wood conversion and working must be developed regionally to produce quality products. This can help in making a good market for the coconut wood and also lead to a significant shift in the raw material base for the wood industries.

The objective of the study titled "Standardization of kiln seasoning schedule for coconut (*Cocos nucifera* L.) wood" aims to standardise kiln seasoning schedule for medium and high density coconut palm wood under the prevailing local climatic condition.

Review of literature

2. REVIEW OF LITERATURE

2.1 Back ground

Coconut, (Cocos nucifera L) continues to be described as "the shrub of life" or “the tree of plenty” plus nature’s greatest surprise to man. Each part associated with the coconut tree works extremely well to produce items associated with value for the neighborhood. Coconut products provide foods, shelter and energy in order to households, and works extremely well in order to make several commercial plus professional products (Arnon, 1997). Coconut wood is an excellent replace for many conventional hardwoods. Similar to conventional wood, coconut palm wood is also durable, strong and versatile and are available at lower cost. The particular cost of coconut wooden is merely about half the cost of conventional wood useful for structural purposes traditionally (APCC, 2000). This fact is specifically appealing to countries with restricted budgets for housing regarding their growing populations. As a result, there is a need to have a study on the situation plus prospects for coconut wood utilization in coconut increasing countries. A vast reference of coconut wood is usually available throughout the exotic countries of the planet. This resource could end up being derived from an incredible number of over-mature or senescent palms.

Taper of coconut palm is insignificantly small of about 5 mm (FAO, 1985) and the sawn recovery from a mature palm is about 0.15 m^3 to 0.3 m^3 (Gnanaharan, 1987; Arancon, 1997). The average height of the tree which is commonly used for constructional purpose ranges from 15 to 20 meter or two-third of the trunk (Khairul *et al.*, 2009). Almost entire part of the coconut wood trunk can be utilized effectively, if it is used for appropriate purposes. All density class wood can be used for furniture and interior decoration. In the case of structural loading or bearing components denser part of the coconut wood should be used. Partitions and other internal members of the building where that much strength is not required can be substituted with coconut products (Adkins *et al.*, 2010; Jayabhanu, 2011).

Because reported in 2002 you will find 12. 12 million hectares under coconut palm globally. This area increased to 12. 16 million in 2005 but decreased later on by three per penny to 11. 794 million in 2006. From 2002 to 2006, coconut places in the region remained almost unaltered at almost 10. 5 million hectares with little variation at about 86 per cent of the world's total coconut area. This implies that almost nine hectares out of every ten hectares of coconut places on the planet are situated in the Asia-Pacific region (APCC, 2006).

Coconut tree has a slender stem that grows to a height of 25 metres with diameter of 300 mm. The toughest, densest part of the wood is found on the outer part of the trunk, which gives the palm its strength, and high silica content gives elasticity. In the direction of the centre of the trunk, the wood gets relatively softer. The tree fruits for approximately 60 years of age, where age it will be considered to have reached the finish of its productive life after which it is felled and replanted. Several such palms are felled through the tropics, yearly.

Without treatment coconut wood has restricted natural durability, suggesting it cannot be used in weather-exposed conditions (Keating and Bolza, 1982). However, above-ground strength more than ten years has been observed for higher density wood. Good density, dry coconut wooden is not attacked by powder-post beetle and it is well suited for use in various applications. Without treatment coconut wood has no resistance to termite strike (Bailleres *et al*, 2010).

Effective processing and utilization of coconut trunks can cope with socio-economic problems particularly when the coconut character decides to fell his senile palms for replanting (Killmann and Fink, 1996). Because of the relatively high sugars ,high moisture content and high starch content, coconut wood quickly prone to and insects during natural-seasoning. A chemical treatment by dipping before stacking is therefore very important. For high and medium density coconut wood, shrinkage is reasonable. The low density materials, however, tends to develop cell collapse (Meier,1991).

Coconut wood has the following properties

The high density of coconut wood is good for merchendise like furniture like chairs ,tables but they are heavy compared to timber species.

Coconut palm wood is resistant to insect borers Coconut wood has fair to good working ability when in comparison to other species. Cocowood gets good finish when applied with good varnishes.

Numerous furniture and novelty manufacturers find coconut wood similar to the traditional wood varieties popular in the furnishings industry. With effective advertising of coconut as the new ‘exotic’ material with regard to furniture, novelty along with other higher value products can possibly have a superior share of household and world markets.

2.2 Wood density

The conditions density and specific gravity (SG) are both used to describe the mass of a material per unit volume. These conditions are often used interchangeably although they each have exact and different definitions (Bowyer and Smith, 1998). Haygreen and Bowyer (1996) defined specific gravity as the percentage between mass per unit volume of water while wood density is defined because mass or weight per unit volume of water .Quite simply, both conditions are utilized to indicate the amount of actual wood substance present in a unit volume of wood and also both conditions can be calculated from one another (Zobel and Jett, 1995). Zobel and Jett (1995) pointed out that wood density is, in truth, not a single wood property but a mixture of wood properties (latewood percent, wall thickness, cell size, and others). However , despite its complexity, wood density reacts generally as though it were a solitary, simple characteristic. The major reason for density variant in coconut wood, ensuing in variable properties, is seen in (1) the quantity and distribution associated with vascular bundles (VBs), (2) the dimension as well as thickness associated with the cell walls of bundles (Fathi and Fruhwald, 2014).

Coconut shows broad range of variant in density along the particular radial and longitudinal path. Arancon (1997) observed that will basic density decreases along with increasing height of the particular stem with any provided height increases through the inner portion to the bark.

Coconut wood has three densities within trunk:

- ○ High-density wood: basic density of 600-900 kg/m^3.
- ○ Medium-density: basic density of 400-600 kg/m^3.
- ○ Low-density wood: basic density of 200-400 kg/m^3.

2.3 Shrinkage and swelling

During drying of green wood, the freely available water evaporates easily, mainly due to low binding makes. This has no impact on the wood measurements. Nevertheless , as soon as the moisture content drops below the fibre vividness point, the more highly bound water evaporates from the cell walls. Hence, the drying velocity decreases and the wood changes its size with transforming moisture content (Bauer, 2003). Shrinkage and swelling may occur in wood when the moisture content is changed (Reeb, 1995).

The inhomogeneous density distribution inside wood leads to non uniform shrinkage and thus deformations (Walker *et al.*, 1993).

2.4 Wood drying

Wood drying may be described as the art of ensuring that gross dimensional changes through shrinkage are confined to the drying process. Ideally, wood is dried to that equilibrium moisture content as will later (in service) be attained by the wood. Thus, further dimensional change will be kept to a minimum (Wengert, 2006). Drying timber is one method of adding value to sawn products from the primary wood processing industries (Attah *et al.*, 2005).

Dried timber is lighter, and the transportation and handling costs are reduced, dried timber is stronger than green timber in most strength properties. In the field of chemical modification of wood and wood products, the material should be dried to certain moisture content for the appropriate reactions to occur. Dry wooden works, machines, finishes plus glues better than eco-friendly timber. Paints and surface finishes last longer on dried out timber. The electrical plus thermal insulation properties associated with wood are improved simply by drying. Prompt drying associated with wood immediately after felling therefore drastically upgrades plus adds value to uncooked timber. Drying permits significant lasting economy by optimising the application of timber resources (Wengert, 2006).

2.5 Classification of wood according to density and refractory type

Redman (2000), divided timbers into three types according to the drying and drying degrade. These are:

Highly Refractory Wood : woods which are difficult and slow to dry. These need high protection and care during drying for better results.

Moderately Refractory Wood: They show medium tendency to defects during drying. These can be dried without deformalities with medium drying conditions.

Non-Refractory Wood: woods can be rapidly dried without any seasoning defects even at high temperatures. They will develop colouration and fungal attack on the outside of the wood (Redman, 2000; Shrivastava, 2000).

2.6 Moisture content of wood

Water distribution in trees depends upon both the wood varieties as well as the environmental conditions. Dampness may either be similarly distributed in the entire log or substantial dampness gradients can exist within radial or longitudinal path. Apart from moisture variations in a single log, there may also exist substantial variations of moisture variance and distribution between records of the same varieties growing in the exact same local conditions (Reeb, 1995).

Water is needed mainly in trees for translocation of nutrients and minerals. Wood has water in cell walls and cell cavities. Water present in the wood cavities is known as free water due to low force of attraction. Water present in the cell walls are bounded very well so called bound water (Reeb, 1995). If both bound water and freewater is present then it is called the Fiber Saturation Point (FSP). Average FSP for softwoods is 25% and hardwoods is 27% (Bauer, 2003). The moisture content of coconut wood varies between 50 per cent to 400 per cent from bottom to top core portion respectively (Arancon, 1997).

2.7 Equilibrium moisture content

Wood is a anisotropic and hygroscopic material. It absorbs water from the atmosphere if the relative humidity of air is higher than the wood moisture.

At a point the moisture content in the wood will be in equilibrium with the moisture content of the atmosphere, called Equilibrium moisture content (Siau, 1995).

2.8 Influence of temperature, relative humidity and rate of air circulation on wood drying

Temperature, relative humidity and rate of air circulation affect wood drying.

2.8.1 Temperature

Under constant relative humidity, drying will be faster with increase in temperature. The drying rate is influenced by temperature by increasing the relative humidity of the air, also by increasing the diffusion rate of water through the wood. The temperature in a kiln is called dry-bulb temperature, by inserting a thermometer with a dry bulb. The temperature wet bulb temperature is noted by finding the readings on a wet knob of a mercury thermometer.

There must be atleast a flow of air at 2m/s to prevent air stagnation inside the chamber (Walker *et al.*, 1993). When the air passes over the wet sleeve, water gets vapourised and thus cools wet-bulb thermometer. The dry-bulb and wet-bulb temperatures difference is called wet-bulb depression, is used to findout the relative humidity (Walker *et al.*, 1993). A greater difference between the dry-bulb and wet-bulb temperatures denotes less relative humidity .

2.8.2 Relative humidity

Relative humidity is defined as the partial pressure of water vapour divided by the saturated vapour pressure at the same temperature and total pressure (Siau, 1995.) Relative humidity is usually given as percentage. (Basri *et al.*, 2009). Relative humidity is inversely proportional to the temperature and drying of wood.

2.8.3 Air circulation rate

Uniform circulation of air is very important for the evenly drying of the timber in an oven. At constant temperature and relative humidity, as air circulation rate increases, wood drying will be faster (Wengert, 2006). Sometimes, higher drying rate is not desirable for some woods,which has a tendency to develop defects faster. When air speed is less,evewn if temperature is increased in a kiln no much effect is on drying of timber (Walker *et al.*, 1993). Lower effectiveness of heat transfer is not a problem if moisture movement inside wood is the limited (Pordage & Langrish, 1999).

2.9 Methods of drying wood

A lot emphasis is put upon creating seasoned timber when and economically as feasible inside the quality limits associated with specified standards. Drying associated with timber is generally carried out by air drying, kiln drying or a blend from these two (Redman, 2000).

2.9.1 Air drying

Redman (2000), described air drying out since the process where wood is racked either outdoors or under a roofing and is subjected to weather conditions naturally. There exists nearly no control regarding the temperature, relative dampness or speed of typically the air getting through the hardwood stacks. The speed of drying is therefore dependent about the whims in the regional climate and can change from practically zero on a new calm, damp day to be able to fast enough to result in timber degrade on a new dry, windy day (Wengert, 2006).

2.9.2 Kiln drying

As opposed to air drying, a regular drying kiln provides temperature and humidity control in addition to a steady satisfactory movement of air within the wood surface (Shrivastava, 2000). Fans control the rate of air flow and direction and the temperature and relative humidity of the air can be adjusted to suit the species and sizes of timber being dried. Kiln drying generally boosts the rate of drying by raising the drying heat to the maximum value that one timber species can tolerate without excessive weakening (Basri et al., 2009). Relative humidity can be used to control the moisture in wood that is not sharp enough to cause drying defects due to stress. In a kiln ,rapid drying can be controlled and can be used to get wood dried for particular purposes.

2.9.3 Combined air and kiln drying

For that sizes and wood species sizes that consume a relatively more time to kiln season,it tends to be uneconomical. Consequently such species of wood are air dried upto 25-30% water content before completing drying in the kiln (Redman, 2000).

the advantage of this method will be lost if the wood is highly vulnerable to drying deformalities and fungus during air drying.

2.10 Classification of kilns by its working

According to working, kilns are classified into two:

2.10.1 Progressive kilns

Progressive-type kilns are kilns which involves a continuous process in which the stacked timber enter one side of the kiln and are moved forward through progressively more higher drying conditions until exiting the dead end of kiln. As wood enters a the one end a load will be taken dried from other end. The temperature and humidity acts viceversa as wood move from one phase to the next along the length of kiln.

2.10.2 Compartment type kilns

In a compartment type kilns ,wood undergo a batch process means kiln is completely loaded with stacked wood in one operation, and wood remains stationary in that compartment during the entire drying procedure. Inside the kiln temperature and relative humidity are kept as uniform and are provided with a wide range of temperature and humidity. A well established drying schedule is very important during the compartment kiln drying procedure ,which is inevitable based on moisture or time.

2.11 Formulation of kiln drying schedules

Simpson, (1991) and Wengert, (2006) explained seasoning schedule as a set of temperature, relative humidity and moisture contents of wood . The seasoning schedule is species dependent. The major problems for wood based industries is to lessen the time and the loss due to defects. Longer the drying time for refractorys result in less defects and vice versa. Satisfactory temperature and humidity must be given for better drying of the wood. This is fulfilled by applying kiln-seasoning schedules. The required objective of a suitable schedule is to ensure drying wood at the quickest rate without much degrades (Wengert, 2006; Shrivastava, 2000). Wood drying is an important step for preparing products that require the timber to be a stable state in use. One of the important factors in wood drying is proper drying schedule. Seasoning schedule can be described as series of dry and wet-bulb temperatures that will establish temperature plus relative humidity in the kiln and are used at various stages associated with a drying process (Simpson, 1991). Wood Drying Working Party had suggested the importance of well revised drying schedule for wood (Vermaas, 1983) especially in tropical species (Simpson, 1992). Among the rapid methods to create drying schedules one developed by Terazawa (1965), w showed satisfactory results to develop proper seasoning schedules schedule (Ilic and Hillis, 1986; Jankowsky, 1992). Building seasoning schedules should consider wood properties within a species (Boone et al., 1988). Density, heartwood percentages, lumber size play important role in making seasoning schedule (Durand, 1985; Simpson, 1996). Different lumber thickness is also considered influence on developing drying schedule due to the severe moisture gradient between surface and centre specimen may occur during the process.

2.12 Kiln drying schedules

Deciding drying schedule is based on experience and trial and error methods. This procedure can be very expensive due to the time required for testing (Listyanto *et al.*,2016). Seasoning schedules differ from species, thickness, moisture content, and end use of wood (Simpson, 1991). There are two kinds of kiln seasoning schedules are moisture content schedules and time based schedules. Mainly wood are dried by moisture content schedules. The temperature and relative humidity are changed according to change in moisture content of wood during drying. By the time the wood has reached EMC, the temperature is as high as 85 per cent (Simpson, 1991).

Materials and methods

3. MATERIALS AND METHODS

This chapter provides an outline of the parameters used in selecting the samples and methods used to gather data for the study. They are discussed under the following headings: facilities, wood species used, sample and sampling procedures, experimental methods and data analysis. The properties investigated in this study were the moisture content, basic density, tangential, radial and longitudinal shrinkage and drying behaviour of coconut wood.

3.1 Study location

Experiments were conducted at Forest Products and Utilisation Laboratory, College of Forestry, Kerala Agricultural University, Vellanikara and Krishna Ayyapa saw mill at Madakathara , Thrissur.

3.2 Materials

Chainsaw, circular saw, band saw, cross cut saw, and the wood planer were used in preparing the samples. Laboratory oven was used in drying the samples at $103 \pm 2\ ^{0}$ C. Venier caliper, and micrometer screw gauge were used in measuring the dimensions of the samples. Electronic balance(Shimadzu AUY 220) with precision of 0.001g was used in weighing the samples.

3.3 Methods

Parametres such as moisture content, basic density and shrinkage of samples were determined by standard procedures.

3.3.1 Moisture content

The wood were planed, trimmed and cut off to 2 cm x 2 cm x 2.5 cm cubes. The green mass (Wi) of the specimen cubes was determined and over-dried at 103 ± 2^{o}C until constant mass (Wod) was obtained. Moisture content (MC) of the specimen cubes were then calculated according to the formula:

Moisture content = [(Wi-Wod) / Wod] x 100% ....(1)

3.3.2 Basic density

Small clear wood specimens of 2cm × 2cm× 2.5 cm dimension were made out according to IS :1708 (ISI, 1986) . The samples were then oven-dried at 103 ± 2°C to constant weight and their oven dry masses determined using precision electronic balance (Shimadzu AUY 220) and were weighted corrected to 0.001g. Basic densities for the samples were calculated using the formula.

Basic density = oven dry weight/green volume

3.3.3 Quick drying test

According to Terazawa (1965), wood specimens of small dimension, when submitted to drastic drying in laboratory equipment, will present proportional defects to those of industrial kiln-dried boards. The method used in this experiment was the quick drying test at 100 ° C developed by Terazawa (1965) as described by Ofori and Brentuo (2010) and Ofori and Appiah (1998). All the chosen boards which were in green condition were planed, trimmed and crosscut to specific sizes of 2 cm x 10 cm x 20 cm in thickness, width and length respectively.

The initial weight, length, width and thickness of the test specimens were measured and placed edge-wise in an oven at 103 ± 2°C until oven-dry condition was reached. During the first eight hours, the test specimens were weighed and critically observed for drying defects. Afterwards, two observations and measurements were made on the 24th and 30th hours on the second day and on the 48th hour on the third day. When the specimens reach an equilibrium moisture content of 12 per cent, it is taken out to examine the seasoning defects occurred. Different kinds of defects are noted and each defect is scaled according to Terasawa method. A scale of 1 to 8 was used to evaluate the defects and the highest scale is considered as the overall grade of particular defect. Grades of the deformation types will be correlated to the kiln drying temperature settings (ITTO,2014). Emphasis will be placed on method of determination of control parameters such as initial dry bulb temperature (DBT), initial wet bulb depression (WBD) and final dry bulb temperature.

Plate 1. Collection and conversion of samples

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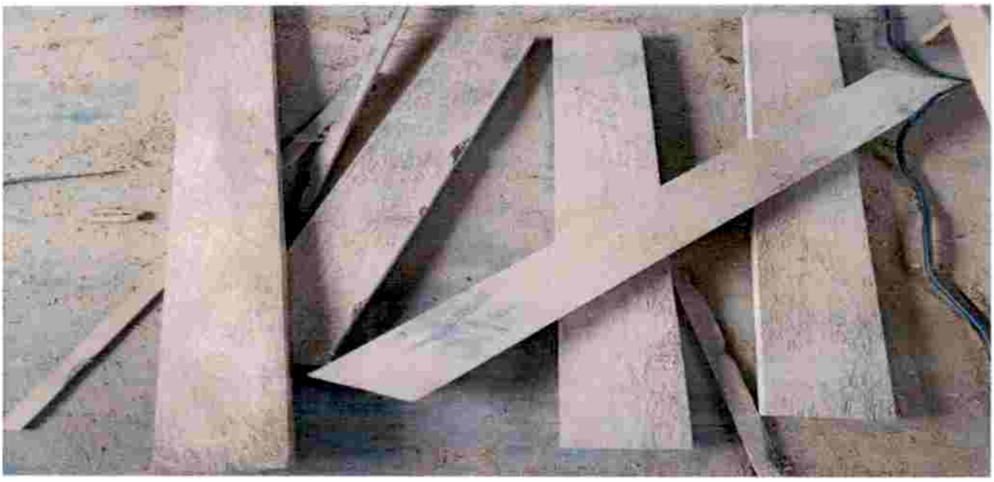
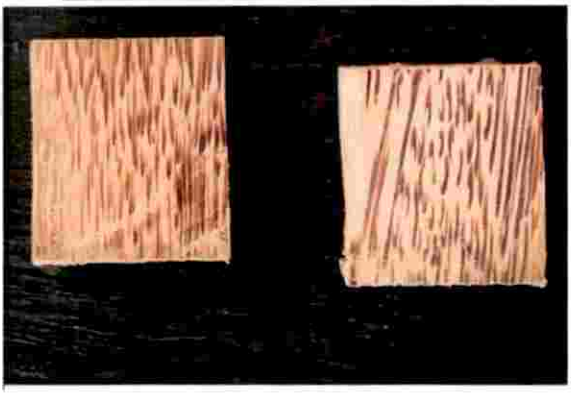
Sawing of coconut logs



Sawn samples

Sanding of samples

Plate 2.Profiling of samples for physical parameters and quick drying test



Samples for physical properties estimation

Weight estimation of samples

a.

b.

c.

a.b.c. Samples for quick drying test

Plate 3.Quick drying test and grading of samples

Samples in hot air oven

Observation for grading samples after quick drying test

Plate 4.Samples with seasoning defects after quick drying test

Endsplitting

Surface cracking

Twisting

Cupping

3.3.4 Kiln Drying Schedule

Initial moisture content, initial dry bulb temperature and initial wet bulb depression from standardised table was selected for combination of moisture content and dry bulb temperature to match the dry bulb temperature ,wet bulb temperature and drying time. Initial moisture content from standardised combination of moisture content range and wet bulb depression (ITTO, 2010) was selected to match the drying time and initial moisture content. Fit wet bulb depression from combination of moisture content range and wet bulb depression to match the dry bulb temperature, wet bulb temperature and drying time. A drying schedule was then drawn for both high density and medium density.

3.3.5 Drying schedule test

The drying schedule was be then imposed on one inch thickness planks of coconut in kiln and observations was recorded. Twenty samples of both high density and medium density coconut wood was studied in dry schedule test.

3.3.6 Air drying of coconut palm wood

The coconut planks were stacked in open crib model and allowed continuous air circulation. Moisture content of the specimens was recorded weekly with moisture meter and time was recorded to reach the equilibrium moisture content.

3.3.7 Statistical analysis

Computation of the drying schedules were conducted using the Terazawa tables and charts for classifying deformations, after which the schedules were arranged based on the general wet-bulb depression, and moisture content classes for hardwoods developed by U.S.F.P.L .and Terazawa methods.

Plate 5. Treatment application into kiln

Results

4. RESULTS

Results of the data gathered from the experiments conducted in the course of the study are outlined in this chapter. Results of the analysis of green moisture content, basic density, shrinkage and drying tests of coconut palm wood are presented based on a sequence of the experiments.

4.1 Physical properties

Physical properties such as basic density, moisture content, volumetric shrinkage, and dimensional shrinkage of coconut palm wood are discussed below.

4.1.1 Basic density and Pilodyn Penetration Depth

The basic density ranged from 214.83 kg /m^3 to 977.19 kg/m^3 for coconut palm wood. The Pilodyn Penetration Depth (PPD) was recorded as 0 mm -11 mm for high density wood and 12 mm - 35 mm for medium density wood. PPD above 35 mm for low density wood. There was a significant difference between PPD and basic density of coconut palm wood.

Since PPD and wood basic density are correlated, a regression analysis was conducted. Linear relationship exists between basic density and PPD of coconut palm wood. The R^2 value obtained was 0.94 and was significant. The regression equation was $Y= -0.02096 (X) + 1.077583$, where Y is the density of coconut wood in g/cm^3 and X is the PPD in millimetres.

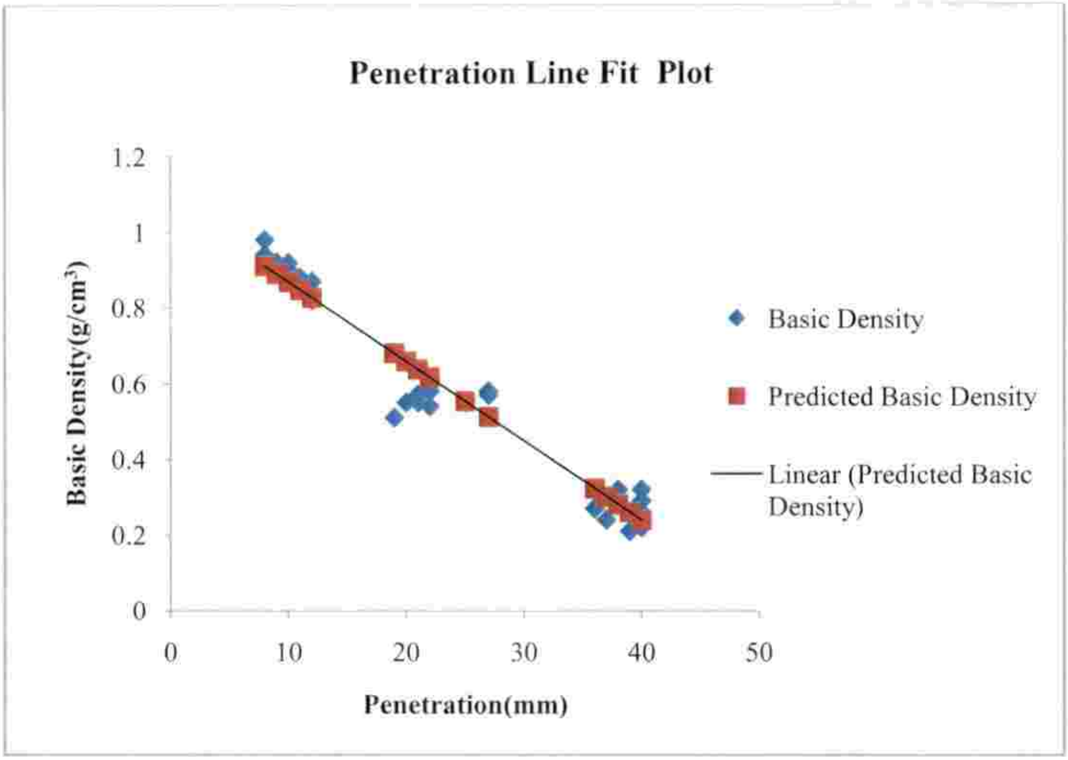


Figure 1. Relation between basic density (g/cm^3) and penetration depth (mm) in coconut palm wood

4.1.2 Moisture content on fresh weight basis

According to Duncan's multiple range tests, moisture content of coconut palm wood across different density classes showed significant differences. The mean moisture content of 52.76 per cent for high density wood. Mean moisture content was 103.95 per cent for medium density coconut palm wood. In low density coconut palm wood, the moisture content averaged as 186.54 per cent.

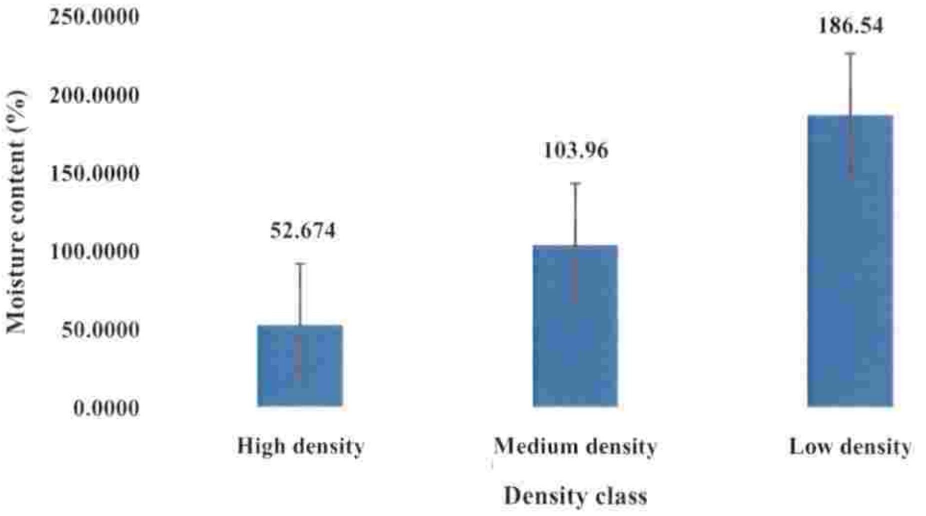


Figure 2. Moisture content of coconut palm wood of different density classes

4.1.3 Volumetric shrinkage

The volumetric shrinkage ranged from 9.03 per cent to 13.74 per cent for high density wood with a mean of 11.01 per cent. For medium density wood, the volumetric shrinkage ranged from 7.68 per cent to 12.86 per cent with a mean of 9.89 per cent. The range of volumetric shrinkage was 9.14 per cent to 20.27 percent with a mean 12.03 per cent. There was no significant difference in volumetric shrinkage across density classes.

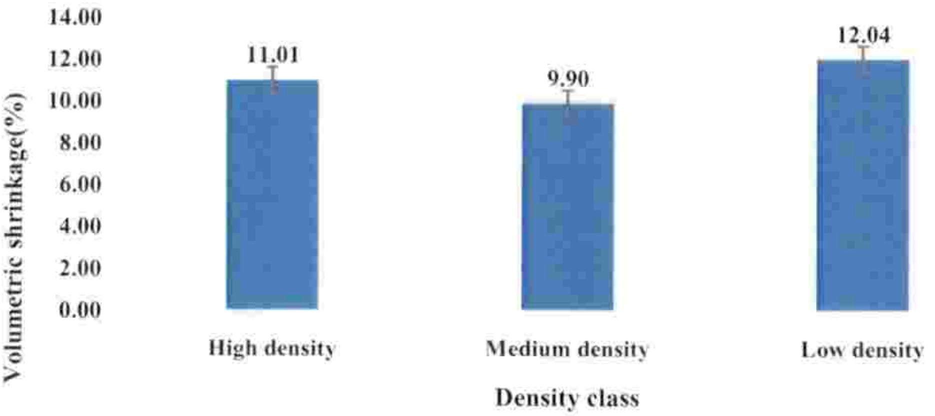


Figure 3. Volumetric shrinkage of coconut palm wood of different density classes

4.1.4 Dimensional shrinkage

Dimensional shrinkage ranged from 0.12 per cent to 0.96 per cent for high density coconut palm wood with a mean of 0.36 per cent. For medium density coconut palm wood, the dimensional shrinkage ranged from 0.48 per cent to 1.52 per cent with a mean of 0.96 per cent. The range of dimensional shrinkage for low density coconut palm wood is 0.72 per cent to 2.68 per cent. There was significant difference in the dimensional shrinkage between different density classes.

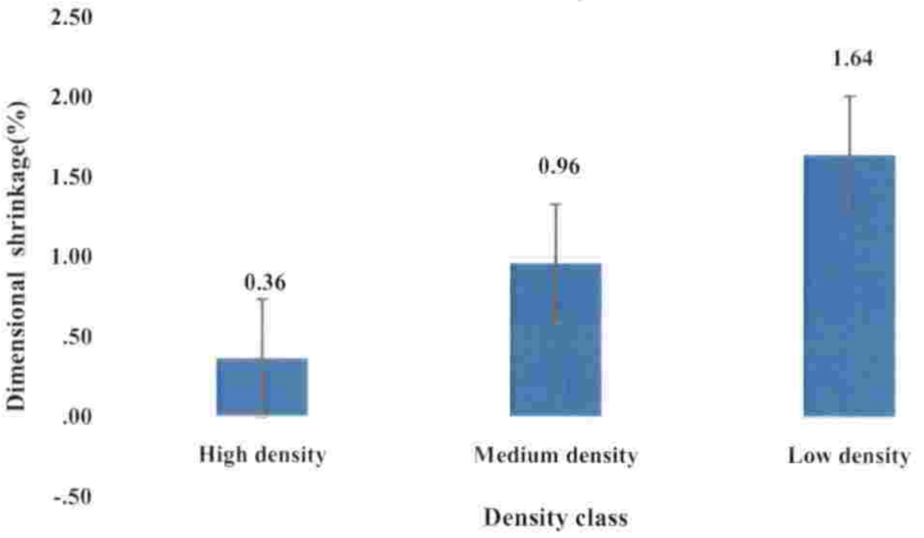


Figure 4. Dimensional shrinkage of coconut palm wood of different density classes

Table 1. Mean of physical properties of coconut palm wood under different density classes

Density classes	**Moisture content (%)**	**Dimensional shrinkage (%)**	**Volumetric shrinkage (%)**
High density	52.67 ± 1.3^{a}	0.36 ± 0.08^{c}	11.01 ± 0.49
Medium density	103.95 ± 0.83^{b}	0.96 ± 0.12^{b}	9.90 ± 0.53
Low density	186.54 ± 1.2^{c}	1.64 ± 0.18^{a}	12.04 ±. 1.04
Total		0.99 ± 0.12	10.98 ± 0.44
P	<0.001**	<0.001**	0.140^{ns}

***significant at 1 per cent level and 'ns' indicate non- significant*
Values with the same superscript along the column are homogenous

4.2 Susceptibility to drying defects

A quick drying test was conducted to understand the type and grade of seasoning defects, coconut palm wood would undergo when it was dried in a hot air oven. The results of the quick drying test are shown in Tables 2 and 3. Visual observations of seasoning defects were made with respect to seasoning defects based on the Terasawa scale (Terasawa, 1965). The major seasoning defects observed in coconut palm wood were surface cracking, end splitting, twisting, cupping and bowing. The highest degree of each defect was considered for concluding the kiln seasoning schedule treatments. The drying condition was inferred from the most severe grade of defects such that it would be the mildest one and more safe.

Table 2. Degrees of seasoning defects in high density coconut palm wood observed during the quick drying test.

Sample	**Surface cracking**	**End splitting**	**Twisting**	**Cupping**	**Bowing**
1	5	5	7	3	4
2	6	6	8	4	5
3	5	7	8	4	5
4	6	6	7	4	5
5	5	6	8	3	5
6	5	6	8	3	5
7	6	5	7	3	5
8	4	5	7	4	5
9	5	7	8	3	5
10	4	7	7	4	5
11	6	5	7	4	5
12	6	6	7	4	4
13	5	6	8	3	5
14	6	5	7	3	5
15	6	5	7	3	5
16	6	6	7	3	5
17	5	5	8	4	5
18	6	5	8	3	5
19	6	6	8	3	5
20	6	5	8	4	5
Highest degree	**6**	**7**	**8**	**4**	**5**

Scaling based on Terasawa scale of ranks 1 to 8

Table 3. Degrees of seasoning defects in medium density coconut palm wood observed during the quick drying test.

Sample	Surface cracking	End splitting	Twisting	Cupping	Bowing
1	7	6	6	4	5
2	7	5	6	4	5
3	6	5	7	4	5
4	7	7	7	3	5
5	7	7	6	3	5
6	7	5	7	3	5
7	6	6	7	3	6
8	6	5	5	4	5
9	7	6	5	3	5
10	7	7	7	4	5
11	7	6	7	4	6
12	7	6	7	4	5
13	7	5	5	3	5
14	6	6	7	3	5
15	7	7	7	3	6
16	6	6	7	3	5
17	7	6	6	4	5
18	5	6	6	3	6
19	6	6	7	3	5
20	6	5	6	4	5
Highest degree	**7**	**7**	**7**	**4**	**6**

Scaling based on Terasawa scale of ranks 1 to 8

4.3 Degree of defects in high and medium density coconut palm wood

Surface cracking, end splitting, twisting, bowing and cupping are the seasoning defects in coconut wood and the results are presented in this section.

4.3.1 Surface cracking

Surface cracking was one of the drying defects observed in high density coconut palm wood during the initial hours of quick drying test. Surface cracking was evidently visible during the first three hours of quick drying test. According to the Terasawa scale, the highest rank for surface cracking was observed to be 6 and 7 for high density and medium density coconut palm wood respectively. The set of drying schedule corresponding to the ranks are given below. Table 4 and Table 5 show treatment 1 (TSH1 and TSM 1) for high density and medium density coconut palm wood respectively.

4.3.2 End splitting

End splitting was the drying defect observed in coconut palm wood after the occurrence of surface cracking. The highest degree of end splitting observed in high density and medium density coconut wood according to Terasawa scale was rank 7. The set of drying schedule corresponding to the rank 7 given in Table 4 considered as next set of treatment for high density coconut palm wood (TSH2) for drying schedule test conducted in a convection kiln. Since for medium density wood the ranking is same for surface cracking and end splitting, the treatment will also remain same (TSM1).

4.3.3 Twisting

Twisting was the most serious drying defect observed in the quick drying test of high density and medium density coconut palm wood. The highest degree of twisting was ranked to be 8 in high density and rank 7 for medium density, which resulted in a complete distortion of palm wood. The set of drying schedule corresponding to the rankings are given in Table 4, which was the treatment 3 (TSH3) in the drying schedule test in a convection kiln for high density. Since for medium density wood the ranking is same for surface cracking, end splitting and twisting, the treatment will also remain same (TSM1).

4.3.4 Cupping

Cupping was observed during the later stages of quick drying test when the moisture content was around 20 to 30 %. The severity of cupping was evident during the eighth hour of drying in the quick drying test. The highest degree of cupping observed in high density and medium density coconut palm wood was 4. The set of drying schedule corresponding to the degree of cupping is given in Table 4 and Table 5, which was the treatment 4 for high density (TSH4) and medium density (TSM2) coconut palm wood in a convection kiln respectively.

4.3.5 Bowing

In high density coconut palm wood, the degree of deformation regarding bowing was observed as 5. In medium density coconut palm wood, the highest degree deformation was observed to be 6. The corresponding set of drying schedule is given in Table 4 and Table 5 which were the treatment 5 (TSH5) for high density and medium density (TSM 3) coconut palm wood in a convection kiln respectively.

4.4 Determination of drying schedule

A kiln drying schedule is a series of temperatures and relative humidities that are applied at various stages of drying. Using the adopted classes for each drying defect, possible drying conditions (initial temperatures, initial wet bulb depression and final temperatures) were obtained from the table of Terazawa (1965). The detailed procedure can be seen in Terazawa (1965) which was modified and adjusted by Jankowski (1992).The drying condition is inferred from the most severe grade of defects so it would be the mildest one and more safely. Table 4 shows a summary of the drying schedule treatments used in the convection kiln to determine the best drying schedule for high density coconut palm wood. There are five treatments for high density coconut palm wood. Table 5 shows the summary of kiln seasoning schedule treatments for medium density coconut palm wood. Since the highest degree of defects was same for surface cracking, end splitting and twisting, there are three treatments for medium density coconut palm wood.

Table 4. Drying schedule treatments used in the convection kiln to determine the best drying schedule for high density coconut palm wood.

Defects observed	**Treatment**	**Initial DBT(^{0}C)**	**Initial WBD(^{0}C)**	**Final DBT(^{0}C)**
Surface cracking	KSH1	50	2.3	81
End splitting	KSH2	47	2	80
Twisting	KSH3	45	1.8	79
Cupping	KSH4	49	3.3	73
Bowing	KSH5	50	3.6	77

Table 5. Drying schedule treatments used in the convection kiln to determine the best drying schedule for medium density coconut palm wood.

Defects observed	**Treatments**	**Initial DBT(^{0}C)**	**Initial WBD(^{0}C)**	**Final DBT(^{0}C)**
Surface cracking, End splitting, Twisting	KSM1	47	2	80
Cupping	KSM2	55	3.6	83
Bowing	KSM3	50	2.3	81

4.5 Drying schedule test

The drying schedule treatments were then imposed on one inch thick planks of coconut in kiln and observations were recorded. The kiln treated coconut wood were again subjected to grading procedure using the Terasawa scale and each defects observed during quick drying test were graded separately. Table 6 shows grades of surface cracking under different treatments for high density coconut palm wood. The highest score of 5 for surface cracking was observed in treatments KSH1 and KSH5, whereas the least score for surface cracking was observed in treatment KSH3. Table 7 shows grades of end splitting under different treatments for high density coconut palm wood. The highest score of 6 for end splitting was observed in treatments KSH1, whereas the least score for end splitting was observed in treatment KSH3. Table 8 shows grades of twisting under different treatments for high density coconut palm wood. The highest score of 5 for twisting was observed in treatments KSH1, KSH3 and

KSH5, whereas the least score of 3 for twisting was observed in treatment KSH3. Table 9 shows grades of cupping under different treatments for high density coconut palm wood. Table 10 shows grades of bowing under different treatments for high density coconut palm wood. There is reduction in the grades of defects like cupping and bowing while under different treatments. Figure 5 shows the grades of defects for each treatment, from which the best treatment for high density coconut palm wood is KSH3.

Table 11 shows grades of surface cracking under different treatments for medium density coconut palm wood. Table 12 shows grades of end splitting under different treatments for medium density coconut palm wood. Table 13 shows grades of twisting under different treatments for medium density coconut palm wood. Table 14 shows grades of cupping under different treatments for medium density coconut palm wood. Table 15 shows grades of bowing under different treatments for medium density coconut palm wood. For medium density coconut palm wood, the least degrees of defects were observed in treatment KSM1, which is given in the Figure 6.

Table 6. Grades of surface cracking under different treatments for high density coconut palm wood

No. of samples	KSH1	KSH2	KSH3	KSH4	KSH5
1	4	3	2	4	4
2	4	3	2	4	4
3	4	3	2	3	4
4	4	3	1	3	4
5	4	3	3	4	4
6	3	3	1	3	4
7	2	4	1	3	4
8	2	3	1	3	4
9	3	3	2	3	4
10	3	4	1	3	4
11	4	4	1	2	4
12	3	4	1	2	4
13	4	4	3	2	4
14	2	4	1	3	4
15	2	4	1	3	3
16	3	4	2	4	3
17	4	4	2	4	3
18	5	4	2	4	3
19	4	4	2	4	5
20	3	4	2	4	5
Highest grade	5	4	3	4	5

Table 7. Grades of end splitting under different treatments for high density coconut palm wood

No of samples	KSH1	KSH2	KSH3	KSH4	KSH5
1	5	4	3	4	3
2	5	4	2	4	3
3	5	4	1	5	4
4	5	4	2	5	4
5	5	4	2	5	4
6	5	4	3	5	4
7	5	4	3	5	4
8	5	3	3	4	4
9	5	3	2	4	2
10	5	4	2	3	4
11	4	3	3	3	4
12	5	3	3	2	5
13	5	3	2	5	5
14	6	3	3	3	5
15	6	4	3	3	5
16	5	3	2	3	4
17	5	3	3	2	4
18	5	4	3	3	4
19	5	4	3	3	4
20	5	3	3	3	4
Highest grade	6	4	3	5	5

Scaling based on Terasawa scale of ranks 1 to 8

Table 8 . Grades of twisting under different treatments for high density coconut palm

No of samples	KSH1	KSH2	KSH3	KSH4	KSH5
1	5	3	2	5	4
2	4	3	2	5	3
3	4	3	2	5	3
4	4	3	2	5	3
5	4	3	2	4	3
6	4	3	2	5	3
7	4	3	2	4	4
8	4	3	3	4	4
9	4	3	2	4	4
10	4	4	2	4	4
11	4	3	2	4	5
12	4	3	2	5	5
13	4	2	1	5	5
14	4	2	3	5	5
15	4	2	1	4	4
16	5	2	1	5	5
17	4	2	2	5	4
18	4	2	2	5	5
19	4	3	2	4	5
20	4	2	2	5	5
Highest grade	5	4	3	5	5

Scaling based on Terasawa scale of ranks 1 to 8

Table 9. Grades of cupping under different treatments for high density coconut palm wood

No of samples	KSH1	KSH2	KSH3	KSH4	KSH5
1	1	1	0	1	0
2	1	0	0	1	1
3	1	0	0	0	1
4	1	1	0	1	1
5	1	1	0	1	1
6	1	1	0	1	1
7	0	1	0	0	1
8	0	1	0	1	1
9	0	1	1	1	1
10	0	0	0	0	1
11	0	0	0	1	0
12	0	1	1	1	1
13	0	1	0	1	1
14	0	1	1	2	1
15	2	1	0	0	0
16	0	1	1	1	0
17	2	1	1	1	0
18	1	1	1	0	0
19	1	1	0	2	0
20	1	1	1	1	1
Highest grade	**2**	**1**	**1**	**2**	**1**

Scaling based on Terasawa scale of ranks 1 to 8

Table 10. Grade of bowing under different treatments for high density coconut palm wood

No of samples	KSH1	KSH2	KSH3	KSH4	KSH5
1	3	3	2	3	2
2	3	3	1	3	3
3	3	3	2	3	3
4	3	3	1	3	3
5	3	3	1	2	3
6	3	3	1	2	4
7	3	3	1	2	4
8	3	2	1	2	4
9	3	3	1	2	4
10	2	3	1	2	4
11	2	2	1	2	4
12	2	3	1	2	4
13	2	2	1	2	4
14	2	3	1	2	4
15	2	2	1	2	4
16	2	2	1	2	4
17	4	3	2	2	4
18	4	3	2	2	4
19	4	3	2	3	4
20	4	3	1	2	4
Highest grade	**4**	**3**	**2**	**3**	**4**

Scaling based on Terasawa scale of ranks 1 to 8

Table 11. Grades of surface cracking under different treatments for medium density coconut palm wood

No of samples	KSM1	KSM2	KSM3
1	3	5	4
2	4	5	5
3	3	5	4
4	3	5	5
5	3	5	4
6	3	5	5
7	3	5	5
8	3	5	5
9	3	5	5
10	3	4	5
11	3	5	4
12	3	5	3
13	3	5	5
14	3	4	5
15	2	5	5
16	2	4	5
17	2	5	5
18	4	5	5
19	4	5	4
20	4	5	5
Highest grade	**4**	**5**	**5**

Scaling based on Terasawa scale of ranks 1 to 8

Table 12. Grades of end splitting under different treatments for medium density coconut palm wood

No of samples	KSM1	KSM2	KSM3
1	3	4	4
2	2	4	4
3	3	3	3
4	3	3	4
5	2	3	4
6	2	3	4
7	3	3	4
8	2	3	4
9	3	3	4
10	3	3	4
11	2	4	4
12	2	4	4
13	2	4	4
14	2	4	4
15	3	3	4
16	3	5	3
17	3	4	3
18	2	4	3
19	3	4	3
20	3	4	3
Highest grade	3	5	4

Scaling based on Terasawa scale of ranks 1 to 8

Table 13. Grades of twisting under different treatments for medium density coconut palm wood

No of samples	KSM1	KSM2	KSM3
1	3	5	3
2	3	5	3
3	3	5	4
4	1	4	4
5	2	4	3
6	2	4	4
7	3	3	4
8	3	3	4
9	3	3	3
10	3	3	3
11	2	2	3
12	2	2	3
13	2	3	3
14	2	4	3
15	2	5	4
16	2	5	4
17	2	4	4
18	2	5	3
19	2	5	3
20	3	5	4
Highest grade	**3**	**5**	**4**

Scaling based on Terasawa scale of ranks 1 to 8

Table 14. Grades of cupping under different treatments for medium density coconut palm wood

No of samples	KSM1	KSM2	KSM3
1	1	2	3
2	0	3	3
3	0	3	2
4	0	2	3
5	1	2	2
6	1	2	2
7	1	2	2
8	1	1	2
9	1	1	2
10	1	2	1
11	1	1	2
12	1	2	1
13	1	1	1
14	1	2	1
15	1	1	1
16	1	2	2
17	1	2	3
18	1	2	2
19	0	2	2
20	1	2	3
Highest grade	**1**	**3**	**3**

Table 15. Grades of bowing under different treatments for medium density coconut palm wood

No of samples	KSM1	KSM2	KSM3
1	2	3	2
2	2	3	2
3	2	3	2
4	2	3	1
5	2	2	1
6	1	3	1
7	1	2	1
8	2	3	1
9	2	2	2
10	2	3	2
11	2	3	0
12	1	3	2
13	2	3	2
14	2	3	1
15	2	3	2
16	2	3	1
17	2	3	2
18	2	3	1
19	2	2	2
20	2	3	2
Highest grade	**2**	**3**	**2**

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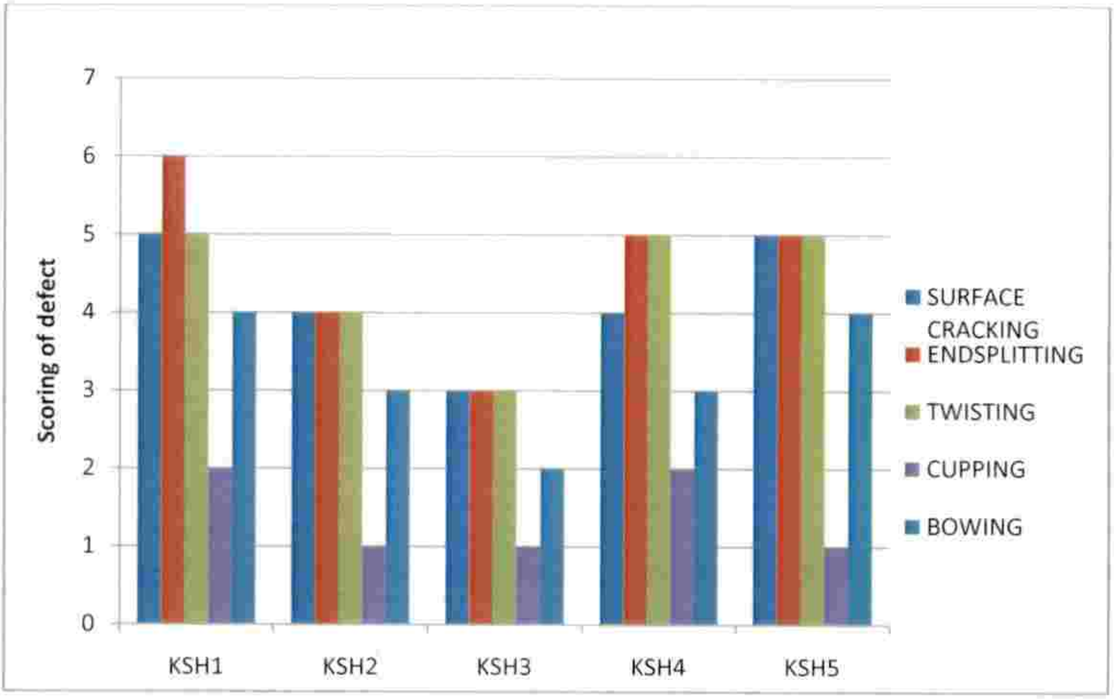

Figure 5. Highest scoring of seasoning defects under each drying treatments for high density coconut palm wood

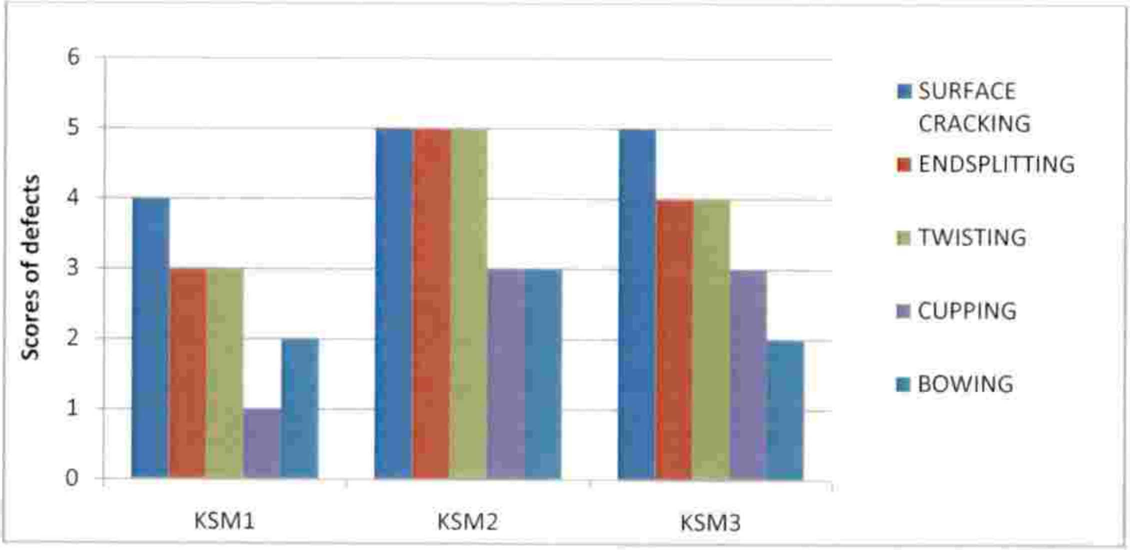

Figure 6. Highest scoring of seasoning defects under each drying treatments for medium density coconut palm wood

4.6 Construction of kiln drying schedule

From the figure 5, for high density wood the best treatment was found to be TSH3. The stages of kiln drying schedule are based on the initial moisture content of the material. The average initial moisture content was 53 per cent for high density and the 104 per cent for medium density coconut wood. There were nine stages for drying in high density wood and this schedule is a mild schedule to ensure the best result. There were 12 stages of drying in for medium density wood and this is a very mild schedule.

Table 16. Kiln drying schedule for high density coconut palm wood

Moisture content %	**DBT (^{0}C)**	**WBT (^{0}C)**	**WBD (^{0}C)**	**RH(%)**
60-40	45	43	2	43
40-35	45	42	3	41
35-30	45	40	5	38
30-25	50	42	8	29
25-20	55	37	18	15
20-15	60	30	30	5
15-10	80	50	30	6
EQUALISING	80	50	30	6
CONDITIONING	80	50	30	6

Table 17.Kiln drying schedule for medium density coconut palm wood

Moisture content %	DBT(^{0}C)	WBT(^{0}C)	WBD(^{0}C)	RH%
110-70	50	48	2	38
70-60	50	47	3	36
60-50	50	45	5	33
50-40	50	42	8	29
40-35	50	39	11	25
35-30	50	36	14	21
30-25	55	38	17	16
25-20	60	38	22	11
20-15	65	43	22	10
15-10	80	50	30	6
EQUALISING	80	50	30	6
CONDITIONING	80	50	30	6

DBT – Dry Bulb Temperature
WBT- Wet Bulb Temperature
WBD- Wet Bulb Depression
RH – Relative Humidity

4.7 Results of drying time in kiln seasoning of coconut palm wood

Since the kiln schedule developed was based on moisture content of the wood and not time based, the drying time is of least importance and highly variable based on the capacity of the kiln used. The kiln used during research had 20 cu m^{-3} capacity. The best treatment was applied again to check the drying time. The drying time for high density wood was 11 days whereas for medium density wood the drying time was 12 days. The figures clearly show the relationship between moisture content and drying days for the particular kiln. There is a linear relationship between the kiln drying time and the moisture content per cent for high density and medium density coconut palm wood. The regression equation for high density coconut wood is $Y = (-0.1335\times X) + 11.737$, where Y is the kiln drying time in days and X is the moisture content in percentage. The R^2 for high density coconut wood is 0.95. Figure.7 shows relation between moisture content and drying time of high density coconut palm wood.

The regression equation for the medium density coconut palm wood was $Y = (-0.08503 \times X) + 11.0064$, with an R^2 was 0.91. Figure 8 shows the relation between moisture content and drying time of medium density coconut palm wood.

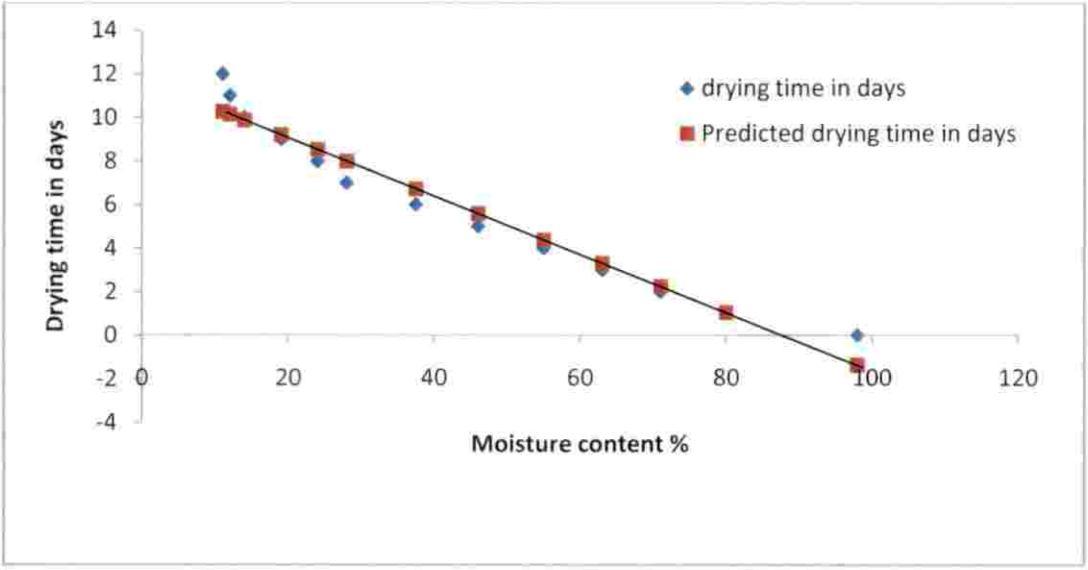

Figure 7. Relation between moisture content and drying time of high density coconut palm wood

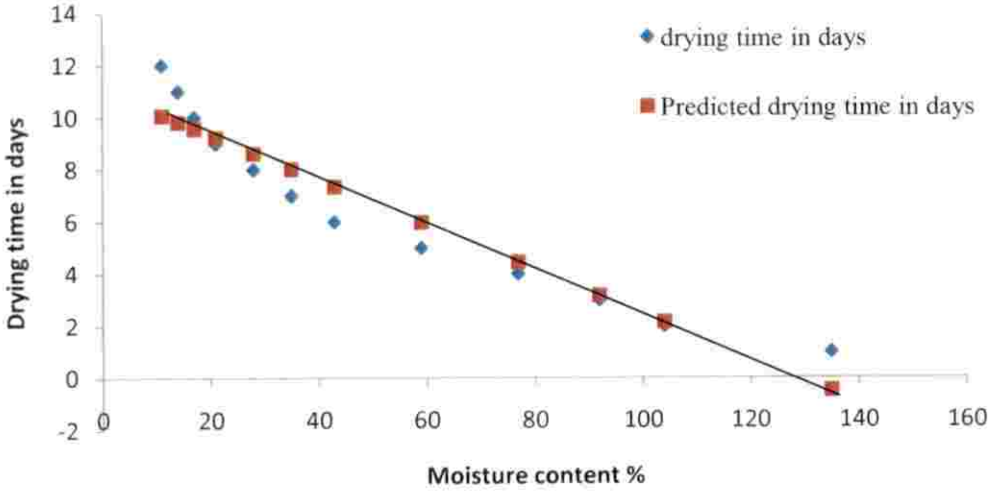

Figure 8. Relation between moisture content and drying time of medium density coconut palm wood

4.8 Results of air drying of coconut palm wood

Air drying of coconut palm wood was difficult compared to the kiln drying, particularly due to the high moisture and sugar content, which makes it prone to fungi and insects. Stacks of wood were protected from direct sunlight and rain and properly ventilated. Weekly readings of moisture content were recorded using a moisture meter. The air drying of coconut palm wood took 13 weeks for high density wood and 15 weeks for medium density wood to reach the equilibrium moisture content. Table 18 and table 19 show the grading of defects in coconut palm wood which were air seasoned. The grades of defects are relatively less compared to those which are kiln seasoned. The highest grade of surface cracking for air seasoned high density coconut palm wood was 3. All other defects were negligible. In medium density, the highest grade of defect was found as 2 for surface cracking and all other defects were negligible.

Table 18. Degrees of seasoning defects in high density coconut palm wood observed during air drying

Sample	Surface cracking	End splitting	Twisting	Cupping	Bowing
1	1	1	1	0	0
2	1	1	0	0	0
3	2	0	0	0	0
4	2	1	0	0	0
5	2	0	0	0	0
6	1	0	0	1	0
7	1	0	0	0	0
8	2	0	0	1	0
9	1	0	0	1	0
10	2	0	0	1	1
11	2	1	0	0	0
12	1	0	0	0	0
13	2	1	0	0	1
14	2	0	0	0	0
15	2	0	0	1	0
16	3	0	1	0	1
17	3	1	0	0	0
18	2	0	0	0	0
19	3	0	0	0	0
20	2	0	0	1	0
Highest grade	**3**	**1**	**1**	**1**	**1**

Table 19.Degrees of seasoning defects in medium density coconut palm wood observed during air drying

Sample	**Surface cracking**	**End splitting**	**Twisting**	**Cupping**	**Bowing**
1	1	1	0	0	0
2	2	1	0	0	0
3	2	0	1	0	0
4	2	1	0	1	1
5	2	0	0	0	0
6	2	0	0	1	0
7	1	0	0	0	0
8	2	0	1	0	0
9	1	0	0	0	0
10	2	0	0	1	0
11	2	0	1	0	0
12	1	0	0	0	0
13	2	1	0	0	0
14	2	0	0	0	0
15	1	0	0	1	0
16	1	1	0	0	0
17	1	1	0	0	0
18	2	0	0	0	0
19	2	0	0	0	0
20	2	0	1	1	0
Highest grade	**2**	**1**	**1**	**1**	**1**

Discussion

5. DISCUSSION

The results of the study entitled "Standardisation of kiln seasoning schedule for coconut (*Cocos nucifera* L.) wood" are discussed hereunder. The study investigated the physical properties of coconut palm wood and also attempted to standardise kiln seasoning schedule for medium and high density coconut palm wood under the prevailing local climatic condition.

5.1. Physical properties

Different physical properties are discussed here.

5.1.1 Basic density

Basic density is one of the most important physical property which has an effect on other wood properties and the durability of the wood (Jerome *etal.*, 2006).The basic density of wood generally increases from the core of the trunk toward the dermal area. Density variations directly affect the strength and also drying properties of coconut wood. The main reason for density variation, resulting in variable mechanical properties, is seen in (1) the number and distribution of vascular bundles (VBs), (2) the dimension (diameter) as well as thickness of the cell walls of the bundles, and (3) the cell wall thickness of the parenchyma as ground tissue of the wood (Fathi and Fruhwald,2014).

Analysis of the data of pilodyn penetration revealed that the depth of pilodyn penetration was inversely proportional to the basic density of coconut palm wood. Greaves *etal.*,(1996) observed a similar trend in Eucalyptus and stated that this can be due to the cell wall thickness variation. This is also attributed to the anomalous secondary growth in the coconut wood cells and also due to the fibers of the vascular bundle sheaths (Tomlinson, 1961). Figure 1 shows the perfect fit between pilodyn penetration depth and basic density in a linear scale. Ponneth *etal.*, (2014) findings also go along with the trend of pilodyn penetration and different density classes.

5.1.2 Moisture content

The moisture content profile shows a similar trend as compared to the green dicotyledons wood, with high moisture content for the low density wood and low moisture content for the high density wood. This may be due to the higher number of parenchymatous cells in the low density wood and higher number of fibrous bundle caps in high density coconut wood. The study of Bakar *etal.* (2013), also goes in line with the findings. Moisture content in the wood is one of the key factors in the utilisation of coconut palm wood. The moisture content makes the wood more susceptible to mould and fungi. Figure 2 clearly shows the trend of moisture content gradient across basic density classes. This is mainly attributed to the non-homogenous nature of palm wood as stated by Killman (1983).

5.1.3 Shrinkage

There was no significant difference in the volumetric shrinkage and the different density classes. Figure 3 shows an irregular trend in the volumetric shrinkage among different density classes. As already observed by Richolson and Swarup (1977), there was little difference between tangential radial shrinkages, on an average, tangential shrinkage was slightly higher than radial shrinkage.

Dimensional shrinkage shows a significant difference among the different density classes, which is clearly shown in the Figure 4. There is a general trend in the dimensional shrinkage across density classes. The pioneering work done by Prayitno (1995), shows a similar trend in palm wood. The study clearly states that dimensional shrinkage is dependent on the density of wood in contradiction to the volumetric shrinkage. The results of work done by McQuire (1979) supports the findings.

There is an irregularity in the shrinkage in coconut palm wood as compared to the wood of dicotyledons. This is one of the major factors which restrict the utilisation of the coconut palm wood (Arancon, 1997). Monocotyledons do not show any distinction in between the radial and tangential planes. The data from the study showed that maximum volumetric shrinkage was observed in low density coconut palm wood. Maximum dimensional shrinkage was observed in low density but not in the same trend as volumetric shrinkage.

5.2 Susceptibility to drying defects

Major seasoning defects in coconut palm wood are surface cracking, end splitting, twisting, cupping and bowing. Enhanced spiral grain in coconut wood can be the reason for the susceptibility to drying defects (Bailleres *etal.*, 2010). In high density coconut palm wood, the highest degree of surface cracking observed was 6 while in medium density coconut palm wood, it was 7. The major reason of increasing severity of defects in medium density coconut palm wood can be attributed to the difference in moisture content and also anatomical difference. Medium density coconut was more susceptible to defects than high density wood during the quick drying test. This could be due to the lesser number of vascular bundles and more parenchymatous cells in medium density coconut wood. The study conducted by Brown (1988), also has similar findings.

Among the defects, the most severe defect was twisting which showed highest grade of deformality in high density and medium density coconut palm wood. The main reason for the seasoning defects was irregular drying of wood. Major defects like twisting, cupping and bowing was observed during the later stages of drying while defects like surface cracking and end splitting were observed during the early stages of drying.

The purpose of timber drying is to remove the water without defects developing in the wood. The art of successful seasoning lies in maintaining a balance between the evaporation of water from the surface of timber and the movement of water from the interior of the wood to the surface (Desch, 1973). In order to achieve this, the moisture content in the wood has to be monitored during the seasoning process.

To allow timber to dry evenly, it has to be stacked properly, irrespective of the drying method applied. Between the stacked layers of boards, stickers have to be placed to allow ventilation of the stack. In order to produce homogenous seasoning results during kiln-drying and to prevent seasoning defects, the batches should always consist of boards belonging to the same density group. During kiln-drying it is recommended to put weight on top of the stack to prevent bow or twisting. This can be achieved with clamps and cement bricks. Bailleres *etal.*(2010) also states un-weighted stack of coconut wood is highly susceptible to seasoning defects.

5.3 Drying schedule

Convection-drying is the conventional way of seasoning lumber. For this method, the wood was stacked in a kiln equipped with a heating system and fans. The fans move the warm air through the stacks. The humidity of the air was controlled by regulating the temperature, by admitting water vapour through steam sprays. Similar ways are advocated by FAO (2015). Too much emphasis cannot be laid on the fact that no matter how well a kiln is designed, timber cannot be satisfactorily seasoned without the use of a suitable schedule. The best seasoning schedule is the schedule which helps to dry wood with least defects and in the shortest time. Figure 6 and Figure 7 explain the degrees of defects that happened to coconut palm wood on testing each treatment in a convection kiln.

The drying schedule selected for high density and medium density wood is categorised as mild schedules, because of the highly vulnerable characteristic of coconut palm wood to drying. The high amount of moisture present in this wood cannot be removed on a stretch due to the peculiar anatomical properties. Therefore the drying schedule must be subtle enough to handle the high scope of seasoning defects. Initially low temperature and high humidity is provided into the drying kiln, which was very gradually altered to attain the equilibrium moisture content.

5.4 Kiln drying time

The major advantage of kiln drying over air drying is the short time required to season the wood. The best schedule for high density and medium density took around 12 days to reach the equilibrium moisture content. The time for drying varies based on factors like the capacity of the kiln and thickness of the wood boards. The drying time is always a factor which varies and cannot be fixed for a particular drying schedule. The work done by Duranth (1985) shows varying time for same drying schedule when tested in different kilns and concluded that time cannot be taken into account for a moisture based kiln seasoning schedule.

5.5 Air drying

Air drying of coconut palm wood consumes more time in comparison to other dicotyledons wood. This can be inferred due to the high moisture content in the coconut palm wood. The drying period for medium density and high density wood is nearly the same, in spite of huge difference in moisture content. This may be due to the anatomical peculiarities of coconut wood. The moisture in the parenchymatous cells can be eliminated easily than in the vascular bundle. The degree of defects is much low in air seasoning than kiln seasoning. This can be attributed to the sudden escape of moisture from wood during kiln seasoning which causes the wood structure to collapse. In air seasoning the treatment naturally removes the moisture content from wood, which allows the wood to be dimensionally stable. Results of Simpson (1983) prove that rapid drying process of wood can lead to more distortion of wood structure which results in high economic loss.

Summary

6. SUMMARY

Proper seasoning is a pre-requisite for producing quality wood products. Proper processing techniques are very important for the better utilisation of lesser known timbers like coconut palm wood. Through present study the kiln seasoning schedule for high density and medium density coconut palm wood was standardised.

The salient findings of the study are as follows

1. The pilodyn penetration in coconut palm is significantly influenced by the basic density of the wood. The pilodyn penetration depth (PPD) decreases with increase in basic density. Linear relationship exists between basic density and pilodyn penetration. The regression equation is $Y = -0.02096(X) + 1.077583$ where Y is the density of coconut wood in g/cm^3 and X is the pilodyn penetration depth in mm.
2. The moisture content of coconut palm wood is quite high and varied from 43.72 % to 208.59 % and basic density had significant influence on the moisture content. The moisture content increased with decreasing basic density.
3. Volumetric shrinkage of coconut palm wood was not significantly influenced by basic density. Volumetric shrinkage reached upto 20.27 % where the palm wood tends to collapse.
4. Dimensional shrinkage of coconut palm wood was significantly influenced by basic density. Dimensional shrinkage was negatively correlated with basic density. Dimensional shrinkage varied from 0.12 % to 2.68 %.
5. The most severe seasoning defect observed in high density and medium density coconut palm wood was twisting. Coconut palm wood was least susceptible to bowing during drying.
6. Air drying of coconut palm wood took 13 weeks for high density wood and 15 weeks for medium density wood to reach the Equilibrium Moisture Content (EMC) to 11-12 % of dry weight.

7. The kiln drying schedule for high density coconut palm wood was standardised. The best kiln conditions for high density wood were with initial Dry Bulb Temperature (DBT) of 45°C, final DBT of 80°C and initial Wet Bulb Depression (WBD) of 1.8°C.

8. The kiln drying schedule for medium density coconut palm wood was standardised. The best kiln conditions for medium density wood were with initial Dry Bulb Temperature (DBT) of 49°C, final DBT of 80°C and initial Wet Bulb Depression (WBD) of 2 °C.

9. The regression equation for drying time in kiln of high density coconut wood is $Y = (-0.1335 \times X) + 11.737$, where Y is the kiln drying time in days and X is the moisture content in percentage.

10. The regression equation for drying time in kiln of the medium density coconut palm wood is $Y = (-0.08503 \times X) + 11.0064$, where Y is the kiln drying time in days and X is the moisture content in percentage.

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STANDARDIZATION OF KILN SEASONING SCHEDULE FOR COCONUT (*Cocos nucifera* L.) WOOD

by

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ABSTRACT

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ABSTRACT

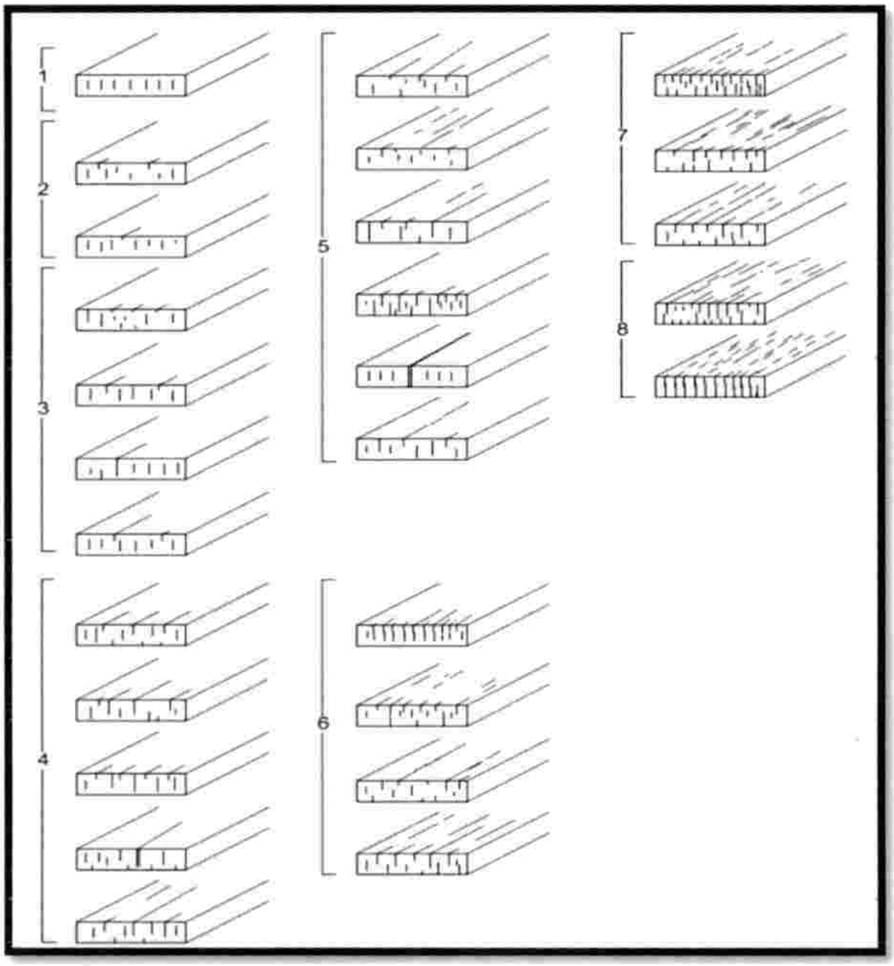
Coconut palm is a versatile and commercially important palm grown in the tropical and sub-tropical regions of the world. Technological up gradation of the coconut wood processing methods can bring in improvement in quality of products and greater preference by the consumers. The purpose of the present study is to popularise the commercial value of coconut as a timber species through improved processing. This study titled aims at standardising kiln seasoning schedule for high and medium density coconut wood, which are mainly used for structural purposes. Drying is one of the most important processing techniques, because a proper drying process will be the main key to ensure high quality wood products. Freshly cut samples were collected from farmer's plot and converted into desirable sizes. Pilodyn standardisation was done to sort the coconut wood into different density classes. The regression equation formulated for basic density and Pilodyn Penetration Depth (PPD) was Y= -0.02096 (X) + 1.077583, where Y is the density of coconut wood in g/cm3 and X is the PPD in millimetres. Fundamental physical properties of wood like moisture content, dimensional shrinkage and dimensional shrinkage were also studied. Moisture content of coconut palm wood across different density classes showed significant differences. The mean moisture content for high density wood was 52.76 per cent. Mean moisture content was 103.95 per cent for medium density coconut palm wood. In low density coconut palm wood, the moisture content averaged at 186.54 per cent. There was no significant difference in volumetric shrinkage across density classes. There was significant difference in the dimensional shrinkage between different density classes. Quick drying test was conducted in the laboratory in a hot air oven to study the degree and type of defects during drying. The major seasoning defects observed in coconut palm wood were surface cracking, end splitting, twisting, cupping and bowing. Defects were 2 graded according to Terasawa scale. Seasoning schedule treatments were determined for both high density and medium density wood. There were five treatments for high density coconut wood and three treatments for the medium density wood. Samples were given different seasoning schedule treatments in a convection kiln to determine the best treatment based on grading of defects. The best kiln conditions for high density wood were with initial Dry Bulb Temperature (DBT) of 45°C, final DBT of 80°C and initial Wet Bulb Depression (WBD) of 1.8°C. The best kiln conditions for medium density

wood were with initial Dry Bulb Temperature (DBT) of 49°C, final DBT of 80°C and initial Wet Bulb Depression (WBD) of 2 °C. The drying time for high density wood was 11 days whereas for medium density wood the drying time was 12 days in a convection kiln of 20 cubic meters. The regression equation for high density coconut wood is $Y = (-0.1335\times X) + 11.737$, where Y is the kiln drying time in days and X is the moisture content in percentage. The regression equation for the medium density coconut palm wood were $Y = (-0.08503\times X) + 11.0064$. Air drying of coconut palm wood took 13 weeks for high density wood and 15 weeks for medium density wood to reach the equilibrium moisture content.

Appendix

APPENDIX 1

1.1 Terasawa scale of grading for surface cracking (Terasawa,1965)



1.2 Drying conditions according to the degrees of surface cracking (ITTO,2006)

Deformation	Degree	1	2	3	4	5	6	7	8
		Drying conditions (°C)							
Surface checks (appearing during initial stage of drying)	Initial DBT	70	65	60	55	53	50	47	45
	Initial WBD	6.5	5.5	4.3	3.6	3.0	2.3	2.0	1.8
	Final DBT	95	90	85	83	82	81	80	79

1.3 Combination of moisture content and dry bulb temperature (ITTO,2006)

Moisture content (%)	Dry bulb temperature (°C)													
Initial MC-30	38	40	45	45	50	50	55	55	60	60	65	70	75	80
30–25	42	45	50	50	55	55	60	60	65	65	70	75	80	90
25–20	42	50	55	55	60	60	65	65	70	70	70	75	80	90
20–15	45	55	60	60	65	65	70	70	70	75	80	80	90	95
Under 15	50	65	70	80	70	80	70	80	70	80	80	80	90	95

1.4 Combination of moisture content range and wet bulb depression (high density wood) (ITTO,2006)

Initial MC of wood (%)	40	50	60	75	90	110	Wet bulb depression (°C)							
Range of MC for drying schedule	40-30	50-35	60-40	75-50	90-60	110-70	2	2	3	4	6	8	11	15
	30-25	35-30	40-35	50-40	60-50	70-60	2	3	4	6	8	12	18	20
	25-20	30-25	35-30	40-35	50-40	60-50	3	5	6	9	12	18	25	30
	20-15	25-20	30-25	35-30	40-35	50-40	5	8	10	15	20	25	30	30
	15-10	20-15	25-20	30-25	35-30	40-35	12	18	18	25	30	30	30	30
	under 10	under 15	under 20	under 25	under 30	under 35	25	30	30	30	30	30	30	30

1.5 Combination of moisture content range and wet bulb depression (medium density wood) (ITTO,2006)

Initial MC of wood (%)	40	50	60	75	90	110	Wet bulb depression (°C)							
Range of MC for drying schedule	40-30	50-35	60-40	75-50	90-60	110-70	1.5	2	3	4	6	8	11	15
	30-25	35-30	40-35	50-40	60-50	70-60	2	3	4	6	8	11	14	17
	25-20	30-25	35-30	40-35	50-40	60-50	3	5	6	9	11	14	17	22
	20-15	25-20	30-25	35-30	40-35	50-40	5	8	8	11	14	17	22	22
		20-15	25-20	30-25	35-30	40-35	8	11	11	14	17	22	22	22
			20-15	25-20	30-25	35-30	11	14	14	17	22	22	22	22
				20-15	25-20	30-25	14	17	17	22	22	22	22	22
					20-15	25-20	17	22	22	22	22	22	22	22
						20-15	22	22	22	22	22	22	22	22
	under 15	under 15	under 15	under 15	under 15	under 15	30	30	30	30	30	30	30	30