Effect of Seasons and Sticker thickness on *Sclerocarya birrea* (Humied) Wood Drying in Kadogli Area, South Kordofan State, Sudan.

By

Moatassim Ismail Amin Yousif

B•Sc. in Forestry,

University of Sudan for Science and Technology
2001

A thesis submitted in fulfillment of the degree of M.Sc.in Forestry

Supervised By Dr. Abdelazim Yasin Abdelgadir

Department of Forest Products and industries Faculty of Forestry
University of Khartoum

May 2007

DEDICATION

To my parent's soul,
To my extremely respected brothers and sisters,
To my beloved family.

ACKNOWLEDGMENT

First of all thanks to Allah the Almighty, who gave me health and strength to complete this work.

I would like to express my recognition and truthful admiration to my supervisor Dr. Abdelazim Yasin Abdelgadir for his supervision, precious honest guidance, generous assistance and valuable advice through the improvement of the research, by infinite patience.

Distinctive thanks and warm gratitude are extended to Ustaz Abdeltief eltayeb (Forest Research Center; Khartoum-Soba), for to his unlimited encouragement, his visit to the research experiment site from time to time, and his valuable advice.

Particular thanks are also due to South Kordofan State Forestry Division staff: Mr. Hammed elniel Abdelrahim Rushash, Mr. Makki Saaied Ibrahim and Mr. Eltegany Hussien Abdullah for their spiritual support and financial assistance for collection of logs and preparation of the samples for the study.

Special thanks are extended to Mr. Yousif Suleiman (Blue Nile State Forestry Division) for his personal-financial support. Best regards are due to Tyessir M. Ahd., Shiema Taha., and Leylah M. Ahd., and Tessabih Adam (Singa Extension unit) for their help typing this thesis.

Lastly but not least I am very grateful to my family and brothers for their absolute cooperation and encouragement in this matter

Abstract

The effect of seasons and sticker thickness on *Sclerocarya birrea* (Humied) wood drying in Kadogli area, South Kordofan State, Sudan.

The aim of this study was to investigate the variation between seasons (autumn, winter and summer) and sticker thickness on the air drying of *Sclerocarya birrea* (humied) wood. The study was undertaken in Kadogli Town, South Kordofan State. The wood material was collected from mature and healthy trees growing in Kegga-jerro natural forest. The logs were cut from three hundred and ten trees, about 30 cm above the surface of ground. The logs were flat-sawn, 1080 planks were prepared and 360 planks were used in each season. The stacks of the wood were piled on the drying yard, loaded on a firm foundation, built by using bricks, cement and sand. Nine stacks were piled for the study, three stacks in each season, using three sticker sizes (1.25 cm, 2.5 cm and 3.75 cm). Each stack was built using 120 randomly selected planks, which were sawn in equal dimensions of about 5 cm ×15 cm×200 cm. Each stack was divided into fifteen rows and each row consists of eight planks

Fifty four test blocks, measuring 2.5 cm×5 cm×15 cm, were cut from twenty seven sample planks, about 30 cm from either end of the planks to determine the initial moisture content using the oven dry method. The data were obtained by weighting the twenty seven sample planks which were randomly selected and placed in three different locations within the drying stacks (three sample planks in each stack) every three days until a constant weight was attained.

The relationship between the moisture content and the drying time (days) was investigated using regression analysis. Although this relationship could be significantly explained by second, third or fourth-order polynomial equations, the fourth order had the best fit. The statistical analysis of variance indicated

that there were significant differences between the trends of the relationship between the seasons (autumn, summer and winter) in terms of the equilibrium moisture content and the drying time. Summer had the highest equilibrium moisture content and longest drying time compared with autumn and winter seasons. No significant differences were found among sticker thicknesses in the equilibrium moisture content and the drying time.

The percentage of warping defect was higher in winter season than the other two seasons, while the magnitude of the warped planks was greater in autumn. However, the percentage of surface-checked planks was greater in summer than in winter and autumn, while the percentage of end-checked planks was very high in autumn compared with winter and summer.

The high number and percentage of drying defect was expected to be associated with stacks for sticker 3.75 cm thickness, but the defect was found unevenly distributed between the three sticker sizes. The magnitude of drying defects (warping, checking) and the numbers of the defected planks indicate that *Sclerocarya birrea* wood can successfully be air-dried, with acceptable level of drying.

ملخص الدراسة

تأثير الفصول و سمك السدائب على تجفيف خشب الحميض بمنطقة كادقلى ولاية جنوب كردفان- السودان

استهدفت الدراسةِ التعرف علي أثر الإختلافَ بين الفصول (خريف وشتاء وصيف) وأحجام السدائب في سرعة التجفيف الهوائي لألواح خشب الحميض. أجريت الدراسة في مدينة كادقلي (ولاية جنوبِ كردفان). جمِعت مادة الخشب من°غابة كيقاجرو الطبيعية. قطعت الكتل من ثلاثمائة وعشر شجرات ناضجة وخالية من العيوبِ بارتفاع ثلاثون سنتمترا فوق سطح الأرض حيث نشرت الكتل مماسيا لإنتاج ألف وثمانين لوحاً خشبياً بمقاس 200 ×15×2.5 سم بواقع ثلاثمائة وستين لوحا لكل فصل. تم رص الخشب المنشور فوق قاعدة بنيت من الطوب والرملة والأسمنت في فناء التجفيف. تم عمل تسعة رصات خلال فترة الدراسة بواقع ثلاثة رصات في الفصل الواحد باستخدام ثلاثة أحجام من السدائب(1.25، 2.5 و3.75 سم3). تم استعمال مائة وعشرون لوحا خشبياً في كل رصه، تتكون كل رصه من خمسة عشر صفا يحتوى كل صف على ثمانية ألواح.

تم اختيار سبعة وعشرين لوحا كعينةِ عشوائية ووضعتْ في ثلاث مواقع مختلفة داخل الخشب المرصوص، ومن هده العينات قطعت أربعة وخمسين عينة اختباريه (15×2.5×2.5 سم^3) علي بعد 30 سم من طرفي اللوح لتحديد المحتوي الرطوبي للعينات بإستعمال فرن التجفيف. المعلومات المطلوبة للدراسة جمعت بوزن السبع والعشرين عينة العشوائية كُل ثلاث أيامِ حتى وصلت للوزن الثابت.

حددت العلاقة بين المحتوى الرطوبي والفترة اللازمة لتَجفيف الأخشاب بإستعمال تحليل الانحدار من الدرجة الثانية والثالثة والرابعة. بالرغم من أن جميع هذه المعادلات توضح العلاقة بين المحتوي الرطوبي والزمن بمستوي جيد إلآ أن المعادلة الرابعة هي الأفضل.

أوضح تحليل التباين وجود اختلافات معنوية بين الفصول في المحتوى الرطوبي المتزن والفترة اللازمة للتَجفيف. أوضحت النتائج أن زمن التجفيف كان طويلا في فصل الصيف كما إن معدل المحتوى الرطوبي المتزن كان أعلا في فصل الصيف مقارنة بفصلي الشتاء والصيف. أوضح تحليل التباين عدم وجود اختلافات معنوية بين أحجام السدائب في المحتوى الرطوبي المتزن والفترة اللازمة للتَجفيف.

أشارت الدراسة إلي زيادة معدلات وأعداد ألواح الخشب التي تعرضت لعيوب التجفيف المتمثلة في الإلتواءات في فصل الشتاء بينما سجل فصل الخريفِ أعلا مستوي في حجم الإصابة بهده العيوب. كانت النسبة المئوية لمعدل الإصابة بالتشققات السطحية لألواح الخشب أعلا في فصل الصيفِ ، بينما كانت التشققات في أطراف الواح الخشب أعلا في فصل الخريف. كان من المتوقع ظهور العدد العالي والنسبة المئوية المرتفعة لعيوب التجفيف مع رصات الخشب ذات السدائب التي بسمك 3.75 سم إلا أن العيوب كانت موزعة بدون انتظام بين السدائب الثلاث. أثبتت الدراسة أمكانية تجفيف خشب الحميض بمستوي عالي في منطقة كادقلي بناءاً علي إنخفاض أعداد ومعدلات العيوب التي ظهرت بعد عملية التجفيف.

Table of Contents

CHAPTER I
INTRODUCTION

CHAPTER II

LITERATURE REVIEW

CHAPTER III

MATERIALS AND METHODS

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

List of Figures

List of Plates

List of Tables

CHAPTER I
INTRODUCTION

Scope and justification

Sclerocarya birrea (A. Rich; Kalkm) tree species, locally known as Humeid, is available in many regions of Sudan, including South and West Kordofan, South and West Darfour and Blue Nile States. The tree is found mixed with other species, such as *Boswellia papyrifera* (Terak terak), *Ximenia*

Americana L. (Um medika) *Anogeissus leiocarpus* (Sahab) and *Terminalia spp* (Thirakaul 1984).

Sclerocarya birrea tree is medium to large tree, and usually 9-12 meters tall, but it may attain 18 meters high with single bole up to 120 cm in diameter (Teichman 1983). The wood is favoured as splinter-free, soft and easily worked or carved into the shapes required for domestic articles, from large items, such as mortars and trays to spoons and forks. The wood of the tree is used for production of carvings, furniture, floorings, production of veneers and match sticks. Most of the wood is found in standing trees and in green form (Shone 1979). The absence of scientific research concerning the utilization of its wood generally renders it not to compete with exotic wood and other native woods.

Shone (1979) noted that, until the 1980, there was no major research relevant to commercial exploitation of *Sclerocarya birrea*; commercialization has since moved swiftly with liqueur production. He concluded that the commercial interest and wood research will proceed next century.

Seasoned wood is considered to be superior to green wood for practically all purposes. The primary aim of wood seasoning is to render it as stable as possible, thereby, keeping the wood movement to minimum and reducing wood degradation. Drying of wood is closely dependant on time factor and on the climatic conditions (temperature relative humidity) prevailing in the area where the product is expected to serve. It, also, depends on, the shape, volume and the species of the product. The art of drying wood is a very complex process, because green wood requires a great deal of energy to be consumed for the evaporation of the moisture during the drying process (Pratt 1974). Different methods of wood drying, whether artificially or left to dry naturally are available. Air-drying is the natural method of wood drying. The artificial methods include the conventional kilns, solar heated dryers, dehumidifiers, radio-frequency heating dryers and drying by using chemical substances (Haygreen and Bowyer 1989).

The principles of air-drying are to demonstrate the best use of prevailing wind, sun (temperature) and the relative humidity to produce well seasoned wood free from defects which lower the wood grade and quality (Pratt 1974).

In Sudan, which is one of the developing countries, most of the wood users and small furniture-makers do not have the necessary funds to establish conventional kilns, which are expensive to build. Air-drying method is the most appropriate method for small custom furniture-makers, because it is easy to carry-out and apparently it is cheaper than conventional kilns, beside these advantages, Sudan has relevant environment for air-drying.

Wood of living trees and freshly cut logs consist of considerable amount of water which causes significant problems if the wood is manufactured in green form. As soon as the logs are cut from trees the drying process of wood take place and the wood begins to loose water to the surrounding environment. The loss of water continues till the wood reaches the fiber saturation point, (the wood looses the free water from its cavities, while its cell walls are still saturated with water) and consequently, below this point the wood, starts to shrink. The shrinkage is different along each of the three principal axes of wood and therefore, causes the seasoning defects such as warping, checking, splting and shaking (Camphell 1969).

The Objectives of Study

This study is undertaken to explore the behavior of *Sclerocarya birrea* wood، during the drying process. The specific objectives are to investigate the variations between seasons and sticker thicknesses on the equilibrium moisture content, the time required to reach the equilibrium moisture content and the defects which may develop during the seasoning of the wood.

CHAPTER II

LITERATURE REVIEW

The relation between water and wood

The wood of living trees and freshly felled logs contain great amount of water, which constitute greater proportion by weight than the solid wood. In some tree species the weight of water may exceed twice the weight of the solid wood. Wood in use will serve best if this water is removed, because most of the desirable properties of wood are negatively correlated with its moisture content and because dry wood is less subject to decay than moist wood. Intended for these reasons it is desirable to know the location of water in the wood and the manner of its movement (Clark and Schroeder 1977).

Moisture content in living trees

The moisture content in hardwood varies considerably among species, among trees, within the same species and within trees.

Among-species variation

The variations among species are to some extent related to specific gravity. The stem wood specific gravity is inversely correlated with the moisture content. The continuous changing nature of the tree populations make it difficult to obtain the pure average values which will represent the wood moisture content of each species. Schroeder and Philips (1973) found considerable variations in the stemwood of seven species of southern hardwood trees 6 to 22 inches diameter sampled in various regions of North Carolina, Tennessee and Georgia. Also, they found significant variations in moisture content in the stemwood and the bark of the same species. The stemwood has higher moisture content than the bark.

Within-species variation

The moisture content of hardwood may vary with tree specific gravity, age, geographic location, genetic background and possibly with the season of the year. Choong and Cassens (1976) found in their study at two Louisiana sawmills, a wide variations in the moisture content between the sapwood and the bark of the same tree. The sapwood has higher moisture content than the bark. In trees aged between 20 to 60 years sampled throughout Southeast Carolina, Kellison and Zobel (1971) found great variation among trees in stemwood moisture content. Sweetgum has highest moisture content than Oak, Maple and Ash green. However, Jett and Zobel (1975) indicated that the moisture content of the trees decreases as the trees became older. No common pattern associating these variations of moisture content with the site. For example, sweetgum has highest moisture content on upland slopes (132%) while in muck swam it averaged only (105%). Red maple moisture content is lowest on upland (59%) and highest in Red River bottoms (76 %). Clark and Schroeder (1977) found little differences in the moisture content between the heartwood and the sapwood in the stemwood of hickory growing in South Carolina. The moisture content of the heartwood is higher and more variable than that of sapwood. They, also, pointed that the stemwood of hardwood moisture content varies with the seasons of the year. The highest moisture content values recorded are in the rainy-season.

Within-tree variation

The moisture content in stemwood of hardwood varies with the radial position in the stem, including the differences between sapwood and heartwood and with the height above the ground. The radial variations of the moisture content in stemwood of southern hardwood are expressed as differences between heartwood and sapwood. The heartwood has lower moisture content than sapwood in white oak, sweetgum, black tupelo and yellow-polar. In water oak, heartwood and sapwood have the same moisture content. In white ash, American elm, bitternut hickory, mockernut hickory, pignut hickory, northern red oak and southern red oak, the heartwood has higher moisture content than sapwood (Ward and Zeikus 1974).

Trees vary in the moisture content between stemwood and branchwood. Some trees has higher moisture content in the branchwood than in stemwood (Red maple, yellow poplar), while in some trees the stemwood has higher moisture content than the branchwood (Blackjack, Shumard and scarlet oaks). Kellison and Zobel (1971) in their study on the variation of the moisture content with height in the stem, found, in hickory, the sapwood has lower moisture content at upper stem (48.5%) than at butt sections (52.9); heartwood, however, varies little with height in stem, 69.6 at upper portion and 70 at butt section.

Location of water in the wood

Water in green or freshly harvested wood is located either, within the cell-wall, which is termed bound-water, or found in the cell-lumen which is called free-water, or capillary water. The moisture is also found as water vapor within cell-lumen. The water amount within the cell-wall structure (bound water) of the living trees remains essentially constant, however, the cell-wall of the wood in use always contain some water vapor. The amount of water remaining within the cell wall of a finished product depends upon the extent of drying during the manufacture and the environment into which the product is placed. After once removed by drying, water will recur in the lumen only if the product is exposed to liquid water. This could result from placing wood in the ground or using it where rain may come in contact with it (Henderson and Choong 1968).

Nature of water in the wood

Wood is a hygroscopic material, it has tendency to take up and retains the moisture when it is exposed to water vapor or liquid water. The wood holds water in three forms: free water as water vapor presents in air state within cell-lumen and as enclosed liquid within cell-lumen or bound water which is adsorbed by the cell-wall polymers.

Free water and water vapor do not form close associations with wood structure, while the bound water is more closely bounded with the cell-wall structure. Wangaard and Granados (1967) noted three mechanisms in their review of concept of adsorption:

-Formation of monolayer of water molecules, held by hydrogen bonds at polar sites on molecular structure surface, in the non crystalline regions of the cell-wall. The monomolecular adsorption predominates at low relative humidity.

-Attraction of polymolecular water held in solid solution or as multi-layers on the first-formed monolayer. The polymolecular adsorptions take place in the intermediate and higher ranges of relative humidity.

-Capillary condensation and the extent of capillary condensation are limited by the volume of voids in the cell-wall. However, it is found that the maximum voids may be represented by about 4% of the dry wall volume.

Movement of water during the drying process

The movement of water in wood during the drying process takes place as mass movement of liquid-water or as diffusion of individual water molecules. Diffusion involves both bound-water in the cell-wall and water vapor in the cell-lumen. Diffusion is a phenomenon that occurs as water moves from an area of higher concentration to that of lower concentration with moisture gradient or vapor pressure gradient across the cell-wall. The rate of diffusion is related to temperature, steepness of moisture gradient across the cell-wall and the characteristic of diffusion in species. The rate of diffusion in species can be expressed as the diffusion coefficient. Diffusion through individual cells occurs only below the fiber saturation point, since above the fiber saturation point the cell-walls are saturated and there is no concentration gradient exists as a driving force. Above the fiber saturation point the free water moves out of wood as a result of surface drying and moves by capillary forces and the wood cell can be thought as a series of partially filled tubes with water evaporating from one side.

Some species have wood structure that contains tyloses, aspirated pits and deposits of extractive which inhibit the mass-movement of the water and therefore, the movement of water takes place by diffusion, which slow the drying rates. Wood of some species consists of impermeable pockets or localized zones and thus making the drying of wood is very difficult and complex process (Siau 1971).

Moisture content determination

The properties of wood depend so much on the amount of moisture it contains and it is necessary to know the exact moisture content of a particular sample and how much water is present in the sample. The moisture content is defined as the weight of water in wood expressed as a percentage of the oven-dry weight of the wood. Different methods and instruments are now available to measure the moisture content of wood, these methods include:

The oven-dry procedures

This is the most common method used for determining the moisture content. It is carried out by cutting sample block, and weighing it immediately while it is still wet, then drying it by placing the sample block in an oven with temperature of about 103 ± 2° C to drive off the water, till it reaches a constant weight. The moisture content as described by Koch (1985) is computed by the following equation:

$$\text{Moisture content (MC) \%} = \frac{\text{green weight-dry weight x 100}}{\text{dry weight}}$$

The oven-dry procedure is accepted for all wood in use and has the advantages of being simple and direct. It also gives a precise and reliable indication of moisture content for a wide variety of wood products. The disadvantage of this method is considered as slow test. Some species contain volatile components beside the water which can be driven off during the drying process; resulting in incorrect high moisture (Hejjas and Salamon 1977).

The electrical moisture meters

These meters are less precise than other methods of determining the moisture content. Their advantages are: easy to operate and non-destructive methods. They are well suited for industrial applications. The hand-held resistance moisture meters are the most commonly used meters for measuring the moisture content of the wood. They measure the electrical resistance between the driven pins into the wood. The disadvantage of these kinds of meters is that they are reliable only in the range of 6-30% moisture content and they need corrections if the wood temperature is significantly different from the calibration temperature indicated by the manufacture.

Some electric meters depend on the behavior of wood as a capacitor, when placed in high frequency field. The disadvantages of these meters act only between 0-30 moisture content percent. The moisture content can be measured by using a combination of neutron and gamma gauge, where the water content is measured by neutron gauge and the total mass is measured by gamma radiation gauge. The moisture content of the wood also can be calculated by microwave power absorption method (Hejjas and Salamon 1977).

The fiber saturation point

During the drying process the free water leaves the cell-lumen before the bound-water. The moisture content percent at which the cell-wall are still saturated with water, while there is no free water remains in the cell cavities is defined as the fiber saturation point. The fiber saturation point is a critical stage of drying. Above the fiber saturation point most of the strength properties of the wood are constant, but below it they are negatively correlated with moisture content (Haygreen and Bowyer 1989).

The fiber saturation point varies considerably between and among tree species. The variations occur according to the differences in chemical composition of wood, crystallinity of cellulose, compactness of cell-walls, specific gravity, and extractive content and with the experimental procedure of drying used (Choong *et, al.* 1991). The values of the fiber-saturation point based on the initiation of the shrinkage are ranged from a low of 27.8% to a high of 33.1%, however, 30% moisture content is considered as standard average value for fiber-saturation point (Spalt 1972).

Gartner (1997) stated that never-dried wood has higher fiber saturation point, than once dried wood. He also noted a negative co-relation between specific gravity and fiber saturation point, especially in low specific gravities. Wood with large amount of extractive content may display abnormally low fiber saturation point, because the extractives bulk the cell-wall and preclude the water from occupying the cell-lumen

Rays in hardwood have lower fiber saturation point than do surrounding tissues, due to their different chemical composition. The wood cellulose has higher fiber saturation point than solid wood while the carbonized wood has substantially lower fiber saturation point in water than normal wood (Beal *et al* 1974).

The equilibrium moisture content

The amount of bound water in a piece of wood is determined by the conditions of the surrounding air, specially temperature and relative humidity. For any given temperature, and relative humidity of the air there is only one equilibrium moisture content of wood. When there is no interchange of water between wood and air, the relationship is in equilibrium. This particular moisture content is known the equilibrium moisture content. If the temperature is held constant, the equilibrium moisture content will increase as the relative humidity increases and conversely, if the relative humidity decreases, then the moisture content will decrease. The equilibrium moisture content varies considerably with the product and the location at which the product serves. The relative humidity is usually determined from simultaneous readings on two thermometers, one of which the wet bulb and the other the dry bulb (Armadas 1989).

Sorption hysteresis

Wood has adsorptive nature, because it can take water vapor from the surrounding air (adsorb) until it is in equilibrium moisture content with air and loses water (desorbs), when the surrounding environment and air becomes drier, until it is in equilibrium moisture content with the surrounding atmospheric conditions and thus the wood is termed a hygroscopic material. The term sorption is applied to the combined phenomena of desorption and adsorption. The equilibrium moisture content attained during desorption is greater than that attained during adsorption at any condition of temperature and relative humidity.

The difference between adsorption and desorption is referred to as Hysteresis loop. Hysteresis is common to many types of physiochemical phenomena. The simplistic view which may help to visualize the dynamic nature of the water-wood equilibrium process is described as follows:
In green condition the hydroxyl groups of the cellulosic cell-wall are satisfied with water molecules, when drying occurs these groups move closer together allowing a formation of weak cellulose to cellulose bonds. When adsorption of water occurs, fewer sorption sites are available for water than the original case. However, in dry condition, the wood which has lost its bound water, the shrinkage of wood brings the polar hydroxyl groups close together to satisfy each other, resulting in diminished adsorption when rewetted (Shupe and Chow 1996).

Factors affecting the equilibrium moisture content

Species and tissue type

At high relative humidity the equilibrium moisture content, varies slightly among species, while at low relative humidity the difference appears to be minimal. Choong and Manville (1976) noted at 25-50 percent relative humidity there are no significant differences in equilibrium moisture content among species. At 25 percent relative humidity the equilibrium moisture content, averages 5.1% with coefficient of variation of 3.4%, while at 50 percent relative humidity, the equilibrium moisture content averages 8.5% with coefficient of variance of 2.8%. Differences among species are significant at 71-85 percent relative humidity. Okoh's (1976) found during adsorption, sweetgum has higher equilibrium moisture content 23.5%, while red and black maple, scarlet and southern red oaks have lower equilibrium moisture content 20.6% to 20.8%. The permeability of the cell-wall varies with species and it influences the equilibrium moisture content values of green wood during desorption. The high equilibrium moisture content values attributed to free water trapped in completely saturated imperforate cells.

The stem-wood equilibrium moisture content of the heartwood may vary with radial distance from the pith of the stem. The wood close to the pith but not necessarilly heartwood averages significantly less than that of outer sapwood. Different tissues within stemwood of species, may altimately attain the same equilibrium moisture content during desorption, but their rate of moisture loss may vary. The ray tissue therefore, dries faster than surrounding tissue, resulting in shrinkage stresses which increase the formation of surface checks in ray ends on the tangential face of flat-sawn planks. Hardwood sorption characteristic may be altered by fungal attack (Choong and Manville 1976).

Stress

There is a lowering of the equilibrium moisture content of wood when it is subjected to a compressive stress and the reverse effect when a tensile stress is applied. It is most pronounced when a given stress is applied in the direction in which maximum hygroscopic swelling takes place, that is, in the tangential direction for normal wood. Moreover, it also, causes a reduced moisture sorption in wood which is restrained from swelling when it is exposed to a higher humidity (Choong and Manville 1976).

Temperature

The equilibrium moisture content of wood is correlated with temperature ranges from 25 to 100 C^0. The increment of temperature decreases the equilibrium moisture content. If the dry wood is heated to 200C°or 300C° for a short time, or heated to 100 C° for prolonged periods it will experience permanent decrease both in hygroscopicity and tendency to shrink and swell. For most purposes it is assumed that wood attains the same equilibrium moisture content under the same relative humidity and temperature conditions (Simpson and Rosen 1981).

Wood shrinkage and swelling

Being a hygroscopic material, wood shrinks or swells when it desorbs or adsorbs water respectively. During the drying process the wood loses the moisture content (free water) till it reaches the fiber saturation point. If the drying proceeds below the fiber saturation point, it loses some of its bound-water and it shrinks and there will be changes in its external dimension. In living trees this is not a problem, as Koch (1985) pointed out, because the cell wall of green wood are always in the fully swollen condition; that is the green moisture content is higher than the fiber saturation point. Therefore, there is no hygroscopic shrinkage in the living trees except for the small amount which occurs as a result of changes in the fiber saturation point with temperature. The shrinkage of hardwood doesn't occur uniformly, and therefore the wood may check and warp.

The changes in longitudinal dimensions are very small, and may be about 0.1 percent, compared with radial and tangential directions where appreciable shrinkages occur. In radial and tangential directions shrinkage may occur as high as 7 and 14 percent, respectively. Tangential shrinkage values are usually as high as twice that in the radial direction. In some species the tangential shrinkage may be slightly greater than in radial direction, but in some species it may be as mush as six times greater. The differences in shrinkage have direct influence on the amount of distortion that occurs during the drying process of the wood. The differences of shrinkage result from size, shape, density and the drying rates of wood. The amount of shrinkage is generally proportional to the amount of water that is removed from the cell-wall of wood (bound water). High density species shrinks more than low density species, because high density wood loses great amount of water (Koch 1985).

The shrinkage values were different in each of the three principle directions of the piece of swan wood. The differences between longitudinal and horizontal shrinkage are due to microfibrillar angle of the S_2 layer of the cell-wall. As the water is removed from the matrix of the surrounding crystalline core of the microfibrils, they move close together and the horizontal component of this movement is several times greater than longitudinal component. The shrinkage of swan wood in actual practice, may commence before the moisture content drops below the fiber saturation point, as a result of shrinking in the surface layer of wood that dries rapidly while the core is still wet (Koch 1985).

Factors affecting normal shrinkage

The volume percent of the shrinkage observed is correlated to species, specific gravity, extractives and the chemical constituent of the wood. The shrinkage starts below the fiber saturation point and approximately correlated to moisture content between the fiber saturation point and the oven dry condition. The continuous changing age and diameters of tree population make it difficult to derive average shrinkage values truely representative for each tree species. However, the relationship between shrinkage and moisture content is nearly always straight line.

High specific gravity in hardwoods tends to have more radial, tangential and volumetric shrinkage, than that of low specific gravity species. The correlation between longitudinal shrinkage and specific gravity varies both within and among species and may be either positive or negative correlation (Boyd 1974). The presence of extractives and the chemical constitution of hardwoods, make them have less lignin and more hemicellulose than softwoods, therefore, their cell-walls have slightly higher density (Schroeder 1972). The volumetric shrinkage is usually correlated inversely with lignin, and positively with density and hemi cellulose content. So far hardwoods shrink slightly more than softwoods (Boyd 1977).

Transverse anisotropy

Wood shrinks more tangentially than in the radial direction.The difference between tangential and radial shrinkage is attributed to the restricting effects of the rays on the radial plane, levels of lignifications between the radial and tangential walls, differences in microfibrillar angle between the two walls and the increased thickness of the middle lamella in the tangential direction, compared with that in radial direction (Zang *et al.* 1992).

In ring porous hardwoods, tangential shrinkage and swelling are largely controlled by the late-wood, since this tissue has less vessel volume and is denser than early-wood, therefore, the late-wood shrinks more than early-wood. Radial shrinkage results from the summation of the contribution of early-wood and latewood. The lamellar nature of wood explains part of the transverse anisotropy in shrinkage of the hardwood (Zang *et al.* 1992). The low shrinkage of rays and their high stiffness in the radial direction reduces radial shrinkage and swelling. Panshin and de Zueew (1980) measure shrinkage in early-wood and late-wood without broad rays, they stated a tangential and radial shrinkage ratio for early-wood is about 2, while that for latewood is about 1.The difference between tangential and radial shrinkage values causes considerable distortion in the shape as the wood dries.

Tension wood and longitudinal shrinkage

Tension wood is prevalent in hardwoods. Choong and Manville (1976) concluded that in tension wood the absence of restraint thick lignified S_2 layer permits substantial longitudinal shrinkage, while the gelatinous layer in tension wood fibers do not contribute significantly to longitudinal shrinkage, nor impede longitudinal shrinkage of the S_1 layer. Tension wood occurs in the upper side of the leaning hardwood stem, and then the longitudinal shrinkage displays more on the upper side than on the lower side. There is no relationship between longitudinal shrinkage and the stem height. However, the variations of shrinkage from the outer-most circumference to the centre of the tree are small (Chowdhury *et, al*. 1994).

Permeability of wood

The capacity of wood to allow passage of fluid under pressure is called its permeability. The mass movement of molecules under pressure is distinct from the random motion of single molecules during diffusion to equalize concentration gradients. Permeability is numerically expressed in units termed DARCY, that are equal to the flow of specified fluid through a cubical specimen of 1cm on a side with a pressure gradient between surfaces through which the flow occurs 1 atmospheric/cm multiplied by the fluids viscosity in centipoises (Chen 1974).

The permeability of wood is affected by its drying history. Air dried wood distorts, but does not break and significantly increases the radial and longitudinal permeability of hardwoods (Chen 1974). The dissolving extraneous materials or modifying anatomical structure, particularly pin membranes will block the flow of fluids. The permeability is correlated with the treatability of wood, as measured by penetration and retention of fluids (Choong *et al.* 1974).

The moisture content of the wood significantly affects longitudinal permeability. Gas permeability decreases with an increase in moisture content from zero to 20 percent. Traverse permeability, however, is less in wood at 20 percent moisture content, than when oven-dry. The relationship between the height of the stem and the longitudinal permeability generally, is not significant (Chen 1974). In most species the sapwood has higher longitudinal permeability than core-wood, even in species where the heartwood is not readily distinguished from sapwood. The traverse permeability is significant only among the trees, while within-tree species it is not significant (Choong *et al.* 1974).

Wood drying

Wood drying is a very complex process. It is costly and time consuming process. It is considered as the most important step in converting raw-wood into finished product. The whole art of successful wood drying lies in maintaining a balance between the evaporation of water from the surface of wood and the movement of water from the interior portion of wood to the surface, until the wood reaches the equilibrium moisture content. Wood, whether, artificially or naturally seasoned it requires great amount of energy to be consumed to evaporate the water from it. Haygreen and Bowyer (1989) pointed that each pound of water requires 1000 Btu for the evaporation to take place perfectly. The removal of water below 30% (fiber saturation point) requires additional energy to heat the wood in order to separate the moisture from the hygroscopic forces that bind it to the wood, increasing the movement of water from the interior of wood to the surface: the higher the wood temperature and the lower relative humidity the faster the drying.The atmosphere adjacent to the board surfaces must be able to receive the moisture removed from the interior of wood. Air movement through stacks of drying wood must be adequate to remove evaporated moisture, to bring in heat energy and to maintain desired relative humidity in the atmosphere adjacent to wood surfaces.

Importance of drying

Many reasons make the drying of wood an important step of converting wood into manufacural product. Koch (1972) pointed some of the most important benefits of wood drying. He noted that wood drying, increases the strength properties of wood, where most of wood species increase their strength characteristics by 50% or more during the drying process to 15% moisture content. Moreover, wood drying increases the fastener holding power and thereby joint strength. It reduces the chance of insect attack, decay or stain. The wood, that is dried below 20% moisture content is not susceptible to decay or sap staining. Wood drying improves the paintability and glueability of wood and increases the electrical resistance, thermal properties and the dimensional stability of wood.

Methods of wood drying

Different procedures of wood drying are available. But the most common methods which are widely used for the drying of wood are: air sometimes called natural drying and kiln, often called artificial drying, although in commercial practice a combination of the two methods will be more satisfactory and economical. Other methods include the following:

Fan predryers: Wood protected from rain by a shed roof and is exposed to ambient temperature as in air-drying, but the fans force air circulation. Humidistants are arranged to switch fans on and off to achieve some control over relative humidity. No heat is added, so final moisture content is determined by ambient temperature and relative humidity.

Heated low-temperature dryers: Resemble the fan predryers, but control of temperature (70 to 110 F) and humidity, through addition of heat or moisture spray. Air velocities are commonly from 300 to 600 fpm.

Solar-heated kiln: A third type of low-temperature dryer, but due to expense of solar energy collection, is largely restricted to outputs of less than 100,000 board feet annually.

Vapor drying: In this method an organic liquid is used with boiling point above 100C°. The drying chamber contains the wood and the organic vapor. The condensation of these vapors on the wood heats the wood rapidly, driving out the water, which is then separated from the solvent vapor in condenser and separator.

Radiofrequency dielectric heating: The principles of this method of drying involve placing wood between two electrodes and subjecting it to an electric field oscillating at high frequency, generating heat and thus driving the water off. In easily dryied wood, the internal temperature tends to rise slightly above the boiling point until the free water is gone. However, in impermeable woods, the temperature may rise to destructive levels.

Combination of radio frequency heating and vaccum drying: Wood is heated dielectrically at 7-9 MHz while it is in a chamber in which partial vaccum can be created. Therefore, the water will boil at a lower temperature, speeding up the drying process. Such kilns, capable of drying 10,000 board feet of wood, have been built and good results are reported.

Press drying: Wood is dried by placing it between two heated platens. Heat is transfered by conduction, from the metal to the wood, and thus the wood is dried rapidly. It is used commercially for high-quality veneer, but only one commercial application for wood has been reported. This drying method can be combined with high pressures to produce a densified product.

Kiln drying: It is carried out in closed chamber, providing maximum control of air circulation, humidity, and temperature. In consequence, drying can be regulated so that shrinkage occurs with the minimum of degrade, and lower equilibrium moisture contents can be reached than that with air seasoning. The great advantages of kiln seasoning are its rapidity, adaptability and precision. It also ensures a dependable supply of seasoned timber at any season of the year (Haygreen and Bowyer 1989).

Air drying

The green wood is exposed to outside environment, preferably protected from direct rainfall and sun by a portable shed. Temperature is ambient and the control of drying rate is minimal. Final moisture content is determined by ambient temperature, relative humidity and drying time; 20 to 25% final moisture content is usual within southern pine growing in South Carolina and South Virginia (McMillen and Wingers 1978).

Air drying has several advantages compared to other types of drying. These include low initial cost and easy to carry out. Air-drying has the advantages for large-scale users or producers who must carry inventories to balance periods of low production. Air-drying reduces the chance of mold, stain and decay during bulk-piled storage and shipment and its substantial energy saving is lower. The disadvantage of air-drying it requires long time for drying and large yards for stacking the wood. Another disadvantage of air-drying is the lack of absolute control of drying conditions and it may possess some hazards of excessive degrading. Moreover, the wood may deteriorate if the drying is prolonged beyond the time needed to bring the moisture down to equilibrium moisture content (McMillen and Wengert 1978).

Piling methods

McMillen and Wengert (1978) described five piling methods**.** The selection among these methods depends on the size, grades and susptability of wood to decay or insect attack.

Close-piling: The boards or planks are stacked without stickers; it is fruitful cause of staining and it may result in serious fungal and decay, if prolonged beyond the required for drying.

Self-piling: It is common with softwood in Scandinavian countries. In this method wood of the same dimensions are used as stickers, with small distances between stickers.

Vertical piling: The wood is stacked in soft roofing manner. It is suitable for wide planks and boards, such as railway sleepers.

Box-piling: The sawnwood **(**Boards or planks) is stacked in straight corners on both edges. The boards or planks are loaded on a foundation and stacked with sticker's alighned vertically with the foundation.

Log-piling: The sawn wood is staked in log form with stickers.

Pilling techniques

Stackng techniques is the most important factor in air drying, because such points as the position and the orientation of the stacks and their method of construction, largely govern air circulation. The site of drying yard shoud naturally well-drained, sufficiently away from buildings to guard against the accumulation of stagnant air or the creation of air eddies. Bualks of wood are commonly used for the foundations of the stacks, but concrete or bricks are better. The height of the foundation is governed by the nature of the drying yard: a height of 20 to 30 cm is sufficient with concrete foundation. For the production of high quality material, wood drying requires good piling, perfect spacing and orientation, proper height and width of stacks and well protected from rains by seasoning sheds (McMillen and Wengert 1978).

Stickers

Air circulation through the stack is secured by separating the successive layers of timber by strips of wood termed stickers. The stickers should be from sound, seasoned wood, not harder than the timber in the stack, preferable to use softwood stickers to safe-guard against introduction of powder-post beetles. However, sticker of lowest grades of wood is preferable (Pratt 1974).

The thickness of stickers depends on the thickness of the wood to be seasoned, its quality and the season of the year for stacking. 37.5 mm is suitable for thin stock species, while 12.5 mm is reasonable for thicker planks. Wood stacked in autumn can be stacked with sticker's greater than in winter and in summer. The width of stickers must be more than the thickness of stickers. The maximum width of the stickers is supposed to be 50 mm; too narrow stickers are not preferred, because it causes indentation of the timber. The stickers at the ends of stacks should be wide, the remainder must project slightly 12.5 mm beyond the side-ends of stocks (Pratt 1974).

Stickers impede air circulation; they must not be very numerous; on the other hand, the insufficiency of the stickers results in sagging of boards and planks. The distance between stickers depends on the thickness of the stock and its liability to warp. Boards of 12.5 mm thick require sticker spacing between 600-900 mm, while planks of 50 mm thick need stickers spacing between 1200-2400 mm; a part, because the spacing between stickers increases with the increase in the thickness of the planks (McMillen and Wengert 1978).

End-protection

End protection is provided by coatings of various, more or less water proof, substances, or by strips of wood, or metal nailed to the ends of wood.

Strips or cleats of wood are thoroughly bad for any wood but thick planks, because the small longidutinal shrinkage of the strip is opposed to the much greater transverse shrinkage of the wood, with the result that shrinkage is restricted between the points of attachment of the strip and stresses are set up which tend to nduce end splitting. The materials used for coating must be impermeable to water-vapor and have the ability to adhere to wet-wood surface and remain in the position as the wood dries and shrinks. The common substances used to fulfill this condition are waxes, which can be used as a hot dip on the end of stock or an emulsion applied by brush to planks and boards. The most effective substance is a thick bituminous paint to be applied by brush. The material has the advantage in that it remains effective at higher temperatures used in the drying kiln if this temperature is subsequently found to be necessary (McMillen and Wengert 1978).

The final moisture content for wood in use

The moisture content of wood varies considerably by the product and the location at which the product serves. The wood must be dried to final moisture content about mid-range of the expected moisture content in service to avoid shrinkage, warping, checking and splitting. The wood serves in exterior exposure, but protected from rains in humid regions should equilibrate at about 12% moisture content, while in arid regions the wood must equilibrate between 6-9% moisture conten. Wood serves in air-conditioned and heated interior sites shoud equilibrate about 8% moisture content. Wood installed over rediantly heated floors should be equilibrating about 6% moisture content. Wood used for bending services in grages or in constructing unheated barns or outdoors, must be dried to 12% moisture content or slightly below. Wood to be bent in a hot press or machined for trim and flooring in boats and buildings that are heated only occasionally should be dried to 12% or 18% moisture content (McMillen and Wengrat 1978).

Time required for air-drying

The drying of green timber is more rapid during the first 3-4 days after they are cut. The wood must be immediately placed on stickers when it is freshly sawn where air will circulate through the piles. This should be done even if the wood is soon to be kiln-dried. Haygreen and Bowyer (1989) noted that, light-weight hardwood dries rapidly under favorable conditions, while heavy wood requires longer time for drying. The specific gravity is a rough guide to drying time, where the permeability and defusability of water thought it affects that relationship. Generally, heartwood is less permeable than sapwood; therefore it takes longer time to dry up.

The drying time is affected by the sawing pattern (Pratt 1974). Quarter-sawn timber dries slower than flat sawn timber, because in quarter sawn the wood rays are intersected on the board surfaces, while in flat sawn more rays were exposed. The size of the stock determines the time-required for drying. Thin stock dries faster than do thick stock. The time required to dry 2 inches thickness for example, may be three or four times as long as for 1-inch thickness. Also, the climatic conditions are the most effective factor in the drying rates. Wood stacked in areas of low temperatures and high relative humidity requires longer time to dry than in areas with high temperature and low relative humidity. Wood placed in humid weather with continuous re-wetting cycles does not dry at all (Haygreen and Bowyer (1989).

Air-drying time for one inch thick, (pine-site hardwoods) vary from 40-75 days for easy-drying species to 100-280 days for lowland oaks and it may attain 20% moisture content during this period under best weather conditions.

The drying time for 2-inch-thick varies from 170-220 days for easy-drying species to 240-360 days for the upland white oaks and the wood will reach 25 to 27% moisture content, under favourable climatic conditions (Pratt 1974).

Wood movement and environmental conditions

The dimensional changes related to varying moisture content of wood are referred to as wood movement. Wood, which is used where the humidity fluctuates, will continually change its moisture content and therefore, changes its dimensions. If the humidity changes are small the dimensional changes will not have impact on the satisfactory use of wood. The large fluctuations in humidity may have little effect if they last for short periods, and the wood does not have time to come to the new equilibrium moisture content. However, the problems can arise, when the wood product is used under-widely varying humidities and temperature conditions if the design and application of that product has not anticipated changes in dimention. If green framing wood is used, the dimentional changes may be large enough to cause problems. To avoid such problems the user should carefully consider the moisture content of wood being used, the species, the condition of use and the amount of dimensional changes which will be expected later (McMillen and Wengert 1978).

Wood stabilization

The fundamental approach for greater stability of wood is to reduce the accessibility of the matrix constituent to water. There are several means of reducing dimensional changes of wood. None of these can entirely eliminate the dimensional changes, but some come very close. McMillen and Wengert (1978) stated some approaches used to reduce the dimensional changes in wood.

Impregnating the cell-walls with chemicals is one of these approaches, which hold the cell-walls in swollen state even after the removal of water. The wood can also be impregnated with low-viscosity liquid polymers, which impregnate the cell-wall coating, the cell cavities and therefore, minimizing dimensional changes. Also, they stated that prevention of moisture sorption, by coating the product with pigmented paints, waxes and synthetic resins, or impregnate wood with plastic monomers such as methyl methacrylate and styrene acrylontrile which can improve the stability of wood and increase hardness and wear resistance.

Seasoning defects

Seasoning defects occur in wood after the tree is cut and converted into sawn wood. Defects develop because of the anisotropic and hygroscopic nature of the wood. As wood dries below the fiber saturation point it shrinks, and the shrinkage is not uniform in all directions. Moreover, the outer layers of wood tend to dry more rapidly than the interior portions, resulting in temporary or permanent distortion of wood and even in the sepration or rupture of the tissues. Permanent distortion gives rise to various forms of warping, and ruptures of tissues to checks, spilts and shakes (Haygreen and Bowyer 1989).

Warping

In the broad sense, the term warping is used to describe any distortion from the true plane that may occur in a piece of wood during seasoning. Different types of warping are recognized and are easily detected by the appearance of the deformed piece, each arising from different cause. The principal types of warping are;

Twisting: It is spiral or cork-screw form of deformation of a board or plank in longitudinal direction as it dries, which, in extreme cases, render the wood values. Twisting can usually be traced to spiral or interlocked grains, although it may result also from unequal shrinkage brought about by variation in density within plank or a board.

Bowing: It happens from end to end of a piece of board or plank along the length. Bowing results from too wide spacing between stickers, which causes the plank or a board to sag under its own weight.

Crooking: It is longitudinal curvature, edge-wise, form straight line drawn from end to end of a piece. It results from differences in shrinkages on the edge of a board or plank.

Cupping: It signites the curving of the face of the board or the plank so that it assumes a troughlike shape, the edges meanwhile, remaining approximately parallel to each other. Cupping arises as aresult of the discreapancy existing between tangential and radial shrinkages across the grain frequently develops in plain-sawn wood. Cupping also may result when casehardened wood is resawn or is pressed more on one side than the other (Haygreen and Bowyer 1989).

Checking

Checks are ruptures in wood along grains, they occur for two reasons. The differences in radial and tangential shrinkage result in stresses of sufficient magnitude to cause the failure of wood along planes of great weakness at juncture of longitudinal tissue with rays or differences in shrinkage of the tissues and the development of stresses of different magnitude in th adjacent portions of wood, occasioned by varying moisture content. Checking occurs in the following forms:

Surface checking: Is more common in rough timber than in planed smooth timber. Before drying, surface checks result from the separation of the thinner-walled early-wood cells; they also follow the rays and therefore confined largely to the tangential surfaces, and may extend into wood for varying distances. As drying progresses deeper into the wood, many of the checks close up, but if the timber is exposed to damp condition, and once the fibers have separated, they can't join together again. Checks and splits are present even if they are invisible (Haygreen and Bowyer 1989).

End-checking: Is the separation of a fiber which does not extend through the broad or plank from one face to another.

End-splitting: Is the separation extending from face to face. It occurs at the end of log or a piece of broad or plank.

Shakes: Shakes are serious splits. It is the separation of a fiber in the wood of large size or logs. Shakes may originate from other causes than drying stresses such as carelessness of trees felling. Shakes are of two types, ring-shake where the separation follows the growth rings, and star-shake where the ruptures radiate outwards from the pith.

Ring-failure: This failure occurs parallel to the growth rings. Ring failure appears to be similar to shakes. It occurs in perfect sound stock in the end of grains during the initial stages of drying and extends in depth and length as drying progresses. Ring failure can be controlled by end-coating of the stock (Ward, *et. al* 1972).

Checked and loose knots: Knots are the commonest defects in wood. Knots are live or dead branches enclosed within the trunk wood of the tree. Knot checks occur due to the differences in shrinkage parallel and across the growth rings and the more rapid drying of the end grain in the knot wood, compared with the longitudinal grain of the board in which it is embedded. Knots generally become loose during the drying of wood, because they are not physically attached to the surrounding wood and their wood is usually denser and thus shrinks more than the surrounding wood tissues. Knots shrink considerably in cross section, while the board in which they are located shrinks only in width, and little in length. As a result knots become smaller than the knot whole and easily fall out during machining and handling (Ferrari 1998).

Case-hardening

Case-hardening is a term applied to dry wood with uniform moisture content, but characterized by the presence of residual stresses, tension in interior of the piece and compression in the outer layers of cells. These stresses are due to shrinkage strains, which are inevitable during the drying of wood but whose magnitude depends on the severity of the prevailing drying conditions. When wood is dried more rapidly, the outer layer tends to shrink, while the interior portion is still saturated, the stress is set up and the outer layers are restrained from shrinking normally. Case-hardened wood can be removed by steaming to restore the moisture to outer-layers (McMillen and Wengerts 1978).

Collapse

Some wood are liable to a defect known as collapse if kiln dried slowly at too high humidies, or at too high temperature. Collapse is a defect that sometimes develops when very wet heartwood of certain species is dried. It is usually evidenced by abnormal and irregular shrinkage. It occurs in rapid air-drying for green wood for few species. The cells are flattened in drying and manifested in more porous early-wood, producing a corrugated surface. Collapse results in excessive and irregular shrinkage, which may lead to appreciable distortion (Ferrari 1998).

Honey-comb

This defect, also called hollow horning, is traceable to internal checking and splitting, generally along the rays, occurring in some wood as it dries. The splits generally do not extend all the way to the surface, although one form of honeycombing develops through the closing of surface checks. If the case-hardening is not relieved by steaming, the outer layers set without shrinking the normal amount and when the interior dries below the fiber saturation point it, is restrained from shrinking, and interior checks may result. The most causes of honey-combing are the internal stresses that develop in case-hardening and collapse. The stresses set up are greatest tangentially, because shrinkage is greater in this direction, resulting in separation of the fibers and is always initiated where the tissues are weakest. Honey-combing can be detected by cutting a plank through about 30 cm from the end noting whether there are any internal checks along the rays on the freshly exposed ends (Ward *et. al* 1972).

Control of defects

The commercial control for surface check include stacking wood together in hot dry-weather, covering the piles with burlap, or stacking the wood under shed where wind velocities are low (Ferrari 1998). End split develops during early stages of drying; the key for control is to slow the drying rates of the ends, by end coatings, burlap coverings and stacking the wood so tightly end to end (Ward *et. al* 1972). Warp is usually not much of a problem as the majority of the furniture cuttings are not wide or long. Proper stacking with stickers aligned vertically perfect level foundation and uniform wood thickness, heavy seasoned wood or heavy stones placed on the top of the stacks will control warp (McMillen and Wengerts 1978).

Studied Species (*Sclerocarya birrea*) Humeid

Introduction

The sixty genera of *Anacardiaceae* comprising some 600 species of trees and shrubs are distributed throughout the tropics and also found in warm temperature regions of Europe, eastern Asia and the Americans. Many species have been widely cultivated beyond their limited area of origin, because of their economic value as source of timber, lacquer, oil, wax, and for their often edible transits or nuts. The most important fruit is the mango from *Mangifera indica*, whilst the most important nuts are the cashew (*Anacardium occidentale L.)* and marula *Sclerocarya birrea* (A.Rich) Hochst.

Taxonomy

Scientific name: *Sclerocarya birrea* (A.Rich) kalkm.

Synonym(s): *Sclerocarya caffra* (A.Rich) Hoechst; *Spondias birrea* (A. Rich); *Sclerocarya caffa* sond.

Family: *Anacardiaceae.*

Local names: *Sclerocarya birrea* tree is called humied (Arabic) in Sudan. In Kenya, it is known Lovedu-marula; Pocket, Meru and Dania; Kamba in (Hausa). English names: Jelly plum, cat thorn, marula, and cider tree (Shone 1979; Roodt 1988).

Sclerocarya comprises only two species *Sclerocarya gillettii kokiwaro* being a small tree or shrub endemic to Kenya. Three subspecies of *Sclerocarya birrea* are distinguished *subspp.birrea*, *subspp.Caffra* (sond) and *subspp. multifoliolata* (Eng). *Kolewaro subspp., caffra* occurs widely in southern Africa and is distinguished by its lower leaflets having petiolutes 5-30 mm; long (in *subspp. birrea* leaflets obtuse and petioloues up to 5 mm). The large number of leaflets (25-129) distinguishes *subspp multifoliolata,* which is restricted to Tanzania and perhaps in Kenya. *Subspp birrea* occurs north of the equator and extends south into Kenya and Tanzania. *Sclerocarya birrea* is strictly African (Madagascan) species and all closely related genera are African. *Sclerocarya* is occurring in wooded grassland and riverine woodland and bush landed frequently on / or associated with hills. It prefers warm, frost free climate but is also found at high altitudes where temperatures may drop below freezing point for very short period in winter. The tree is frost sensitive and moderately drought resistant (Teichman 1983).

General description

Sclerocarya birrea is a medium to large tree, usually 9-12 meters tall, but trees up to 18 meters have been recorded. It is single stemmed with short bole up to 120 cm in diameter, dense spreading crown, and deciduous foliage. The bark is grey and usually peels off in flat, round disks, exposing the underlying light yellow young twigs, which are thick digital form, with spirally arranged composite leaves at their ends. It has a thick relatively short taproot reaching depths of 2.4 meters. Leaves are compound grey-green in color, but change to pale yellow just before shedding. The leaves of about 18-25×8×15 cm, composite containing 2-23 leaflets. The leaflet is long elliptic with petioles of 20 mm in length (Thirakaul 1984).

The canopy is round and is flowering in unbranched sprays 5-8 cm long. Although male and female flowers occasionally occur on the same tree, it is considered dissections. Male flowers are borne in groups of threes on racemes below the new leaves; they are dark red when young and turning pink or white when open. The female flowers are blood red, but change color from purple to white, after opening. They occur below the leaves on long peduncles and consist of 4 curling petals, numerous infertile stamens and long shiny ovary. Fruits are round or oval, drupe, usually wider than it is length, with a diameter of 30-40 mm, which turn buffer- yellow when ripe.

Distribution, climate and soils

Sclerocarya birrea occurs throughout most of sub-Saharan Africa. It is recorded eastwards from the Senegal coast 17°02 W and Mauritania through Cameroun and the Central African Republic to Eritrea and Western Ethiopia. In Sudan, the range reaches 16°42’N at Abushendi. From Sudan and Western

Ethiopia, the range extends south, passing east of the Lake Victoria basin, to Tanzania, Mozambique, and South Africa (the southern limit) at 31°00’5 near port shepstone and westwards from these countries to the Atlantic coast in Angola. To the east, the range extends to 50°09’E in Madagascar (Teichman 1984).

Sclerocarya birrea is constituent of low elevation (mosty < 1600 m). All three *subspecies* have, however, been reliably reported from elevation of at least 1500m. In Sudan *Sclerocarya birrea* occurs on elevations around 1700 m in Jebal Marra area. The tree may occur in elevations above 2000m, such as in the Loita and Ngong Hills in Kenya. In Senegal they are present in coastal areas within few meters of sea level.

Sclerocarya birrea is associated with strongly seasonal rainfall pattern. The mean annual rainfall is ranging usually from 500 to 1250 mm; with average monthly rainfall usually exceed 50 mm in 4-7 months. The tree may occur in more arid conditions 2-3 month ≥ 50 mm, with mean annual rainfall of about 250-500 mm in Sehelian reigns.

The soils where the species occurs are derived from geological formations ranging from basalts, basement complex rocks and sedimentary rocks of various ages to Quaternary deposits. Most comments about the soils associated with *Sclerocarya birrea* are restricted to the general sandy texture, while sandy loam texture is regarded as unsuitable soils. However, in parts of the range heavier soils also support well established populations of the species (Maydell 1986).

Cultivation and yield

Marula is raised from seeds, but vegetative propagation may be achieved through cuttings. Cuttings are about 11-15 mm in diameter; 2 meters in length, are planted at depth of one meter. The trees can be coppiced regenerating rapidly. Generally Marula is the fast growing and fairly drought resistant plant (Roodt 1988).

The wood properties and uses

The wood of *Sclerocarya birrea* is soft, diffuse porous, of low to medium density and medium texture. The color is mainly grayish, but there are reddish bands and streaks, brown patches, pale when freshly cut but darkening to pale reddish brown on exposure. The sapwood has been described as very wide, and it is not sharply differentiated from the heartwood. The working properties of the wood are pleasant and can be worked without difficulty (Goldsmith and Carter 1981).

The drying history of the wood is subject to some seasoning complications. However, there is conflicting guidance on whether the wood should be dried as rapidly as possible to counter discoloration, or slowly to minimize a tendency to distort and collapse severely. The wood is durable when well-seasoned and is not easily impregnated. The density of wood air-dried to 10% moisture content, averages from 530 to 670 kg/m^3, while the density of wood in green state has been determined at 1121 kgm^3 (Bryce 1967). Untreated wood is rich in starch component; therefore, it is very susceptible to insects (powder post-beetles-Lyctus, termites and fungi) attack (Shone 1979).

Despite the low strength, light weight and soft texture the timber of *Sclerocarya birrea* is widely and diversely used. The wood of the tree is widely used for, domestic utensils, mortars, pestles. It can also be used for the production of crafts and boxes, carvings, craftwork, general furniture, construction, roofing, flooring, agricultural implement (handles), match-stick production, beehive and preparation of plywood and veneer (Shone 1979 **).** Considering the volume of literature on the species, and its wide distribution, comments on its use for fuel are few; this paucity is a reflection of the poor energy value of the soft light wood. The wood is used as domestic fuel, and even processed into charcool in areas where there is no alternative tree species (Teichman 1983).

The fruit of the tree is used for production of nutritional materials, preparation of creams, juice drinks, jelly and venson pie, alcoholic beer drinks and production of drugs and medicines, while the nuts is used for preparation of high quality oils (Roodt 1988).

CHAPTER III

MATERIALS AND METHODS

Sampling and samples preparation

This study was carried on sawnwood (planks) of *Sclerocarya birrea* (humeid). The logs were collected from Kegga-jerro Forest, which is natural, uneven-aged forest. This forest is located some 60 kilometers north of Kadogli (the capital of South Kordofan state). The forest extends on both sides of the highway road between Kadogli and Delang. The trees which were chosen to provide the study with the required logs were healthy, free from rotting and dead branches. The diameters of the trees were selected according to the capability of the saw-mill accessible in the study area (Kadogli) and they were ranging from 40 cm to 50 cm diameter at the breast height.

The logs were cut from three hundred and ten trees, about 30 cm above the surface of ground. The logs were flat-sawn, 1080 planks (about 200x 15x $5cm^3$) were prepared and 360 planks were used for piling the drying stacks for each season.

Foundation and stickers

The sawn planks were stacked on the drying yard, which was an open space, away from permanent buildings and obstacles to allow the normal movement of the air through and around the stacks. The drying yard was flat, well drained and clean from weeds, stones, broken bricks and wood pieces. For each stack, a firm foundation of about 180 x 150 cm^2 was built using bricks, cement and sand. The foundation consists of three rows; each row was 150 cm in length, 20 cm in width and 30 cm above the ground surface. The rows were 60 cm apart. The stickers were prepared from the same timber of the studied species. The stickers were 5 cm in width, 150 cm in length and their thickness was 1.25, 2.50 or 3.75 cm.

Stacking of the wood

Nine stacks of sawnwood (planks) were piled to investigate the study. In each season (autumn, summer and winter), three stacks were piled using three sticker sizes (1.25 cm, 2.5 cm and 3.75 cm). Each stack was built using 120 randomly selected planks, which were sawn in uniform dimensions of about 5×15×200 cm^3. Each stack was divided into 15 rows, and each row consists of eight planks. The width of the stack was about 130 cm and the height varied considerably between the stacks according to stickers' thickness. The stack height was 122.5 cm for sticker 1.25 cm, 150 cm for sticker 2.5 cm and 167.5 cm for sticker 3.75 cm. The above mentioned heights include the foundation and the planks.

The stacks were boxed-piled (Plate 1). The planks were loaded on the foundation and they were projecting 10 cm outwards rear and front of the foundation. The stickers were aligned vertically just over the middle of each row of the foundation and they were projecting 5 cm beyond the width of the planks on both sides. The stickers were at constant distances of about 75 cm from each other. The orientation of the stacks was perpendicular to the wind-direction, and they were stacked from east to west in one-line type stacking. On the top of the stacks a load of heavy stones and thin boards were aligned vertically with the stickers and the foundation.

Three sample planks were located inside each stack, at different elevations. One sample was located approximately in the middle of the stack (row 8), while the other two samples were placed two columns beneath and above the major sample and two columns to the left and right of the major sample, respectively.

Plate 1. Stack of *Sclerocarya birrea* planks stacked on 30-cm foundation and using 2.5-cm stickers, with stones loaded on the top of the stack.

Determination of initial moisture content

Fifty four test blocks, measuring 2.5×5×15 cm, were cut from twenty seven planks (samples), about 30 cm from either end of the planks. The green weights of the freshly-sawn, test blocks were determined using a sensitive weighing read-out balance (Meller make) with accuracy of ± 0.01 gram. Then, the test blocks were oven-dried in a Heraeus drying oven at a constant temperature of 103 ± 2° C, until they reach a constant weight. The initial moisture content percent of the samples were calculated by employing the oven-dry equation mentioned below:

$$\text{Moisture content (MC) \%} = \frac{\text{green weight-dry weight x 100}}{\text{dry weight}}$$

Rate of drying

The middle parts of the twenty seven sample planks ($135x15x5cm^3$) were used to determine the drying rate. The data were obtained by weighting the three sample planks in each stack every three days using a simple readout balance. The weighing of the samples (27 samples) continued until they reached a constant weight (equilibrium moisture content). The effect of seasons and stickers on equilibrium moisture content and drying rate of *Sclerocarya birrea* (humied) wood was studied by stacking the sawnwood off the ground, resting on three supports laid out front and rear parallel to the face of the stack. The sawnwood was stacked to expose the wood to relative humidity changes. Three investigational experiments were established in each season, using three sticker thicknesses and with wood planks of equal dimensions (200 cmx15cmx5 cm^3).

The first drying period was started on the beging of the rainy season, in mid Jully and extended to the first week of December, which was later called autumn season experiment. The sample planks were prepared from stemwood of trees felled when their leaves were present. The second period, which was termed winter season, started on the end of December and extended till mid of March. The samples were cut from the trees after they droped most of their leaves. The third trial, which was called summer season, started at the end of March and extended till mid of August. Summer trial started in the designated season, but ended in the next season (autumn). The samples were prepared from stemwood of the trees felled after complete leaf sheding.

The data collected from this experiment were used to investigate the relationship between the moisture content and drying time, seperately for each season and sticker thickness. The polynomial regression (second, third and fourth order) was used to describe the trends of these relationships for each of the samples (27 samples). Results from these analyses were used to select the appropriate equation for the relationship between moisture content and drying time for each sticker thickness in each of the three seasons.

Analysis of variance was conducted to investigate the significance of differences between seasons and between stickers with regards to moisture content at selected days (days 15, 30, 45 and 60), coefficients of the regression equations and the equilibrium moisture content. Duncan's Multiple Range Test was used to separate the means.

The seasoning defects

The seasoning defects which were developed during the drying process were determined as soon as the stacks were removed. Two kinds of defects were observed with the air-seasoning of the *Sclerocarya birrea* wood, namely, warping (bowing, crooking and twisting) and checking (surface and end-checks). Warping was measured by using a ruler. The planks were placed on a leveled base line, and the size of the defect was recorded as the largest deviation (cm) of the board. The depth of checks was measured by using a metallic pin inserted inside the crack and then the marked length on the pin was measured by the ruler. The width and the length of check were directly measured by the ruler.

CHAPTER IV

RESULTS AND DISCUSSION

The relationship between moisture content and time

Many factors affect the rate of dryiny. Two main factors were investigated in this study; these factors were sticker's thicknesses and the seasons of the year. The effect of seasons is a collective effect of climatic factors including relative humidity, temperature and wind velocity. Trends of the relationship between moisture content and time for *Sclerocarya birrea* (humeid), and the results of the regression analysis are shown in Figures 1-12, for each of the samples by sticker thicknesses and seasons.

The results showed that the sample planks of humied started at different initial moisture content values, which ranged between 68% and 142.42%. This indicates that there is great variation in moisture content of the stem wood among and within trees. These results are in agreement with the findings pointed by Philips and Schroeder (1973), Choong and Cassens (1976) and Kellison and Zobel (1971).

In each of the three seasons, the sample planks of humied attained comparable equilibrium moisture content values with the exception of 2 samples, these were sample 3 for sticker 3.75 cm in winter season (18.84%) compared with the other samples which ranged between 2.07% to 9.6 % and sample 2 for sticker 1.25 in summer season (19.89%) compared with the other samples in summer which ranged between 13.08% to 16.78%. However, the planks reached equilibrium moisture content in different periods of time ranging from a short time of 55 days in winter to long time of 165 days in summer. These results are in agreement with the findings pointed by Haygreen and Bowyer (1989), wood stacked in areas of high relative humidity requires longer time to dry than in areas of low relative humidity.

Autumn

Changes in moisture content of the samples and their means with time during the autumn experiment are illustrated in Figures 1-3 for each of the three stickers. The initial moisture content of the samples varied widely between 68 and 121 %, while the equilibrium moisture content attained varied between 3.7 and 7.4 %. The time needed to reach equilibrium moisture content varied among samples between 55 and 115 days. The moisture content showed an initial steep drop during the first 3 to 22 days.

Table 1. Results of linear regression analyses of the relationship between humied wood moisture content and time (days) in autumn.

Sticker (cm)	Equations	R^2%
1.25	$M = 64.3 - 0.745D + 0.00021D^2$	92.9
	$M = 72.3 - 1.5897\ D + 0.0204\ D^2 - 0.0001\ D^3$	96.1
	$M = 81.1 - 3.1501\ D + 0.0815\ D^2 - 0.0009\ D^3 + 4E\text{-}06\ D^4$	99.2
2.5	$M = 93.2 - 1.818\ D + 0.0097\ D^2$	99.3
	$M = 98.1 - 2.3648\ D + 0.0222\ D^2 - 8E\text{-}05\ D^3$	99.9
	$M = 98.5 - 2.4413\ D + 0.0253\ D^2 - 0.0001\ D^3 + 2E\text{-}07\ D^4$	99.9
3.75	$M = 94.8 - 1.828\ D + 0.0096\ D^2$	97.7
	$M = 103.4 - 2.731\ D + 0.0291\ D^2 - 0.0001\ D^3$	99.3
	$M = 105.9 - 3.2292\ D + 0.0486\ D^2 - 0.0004\ D^3 + 1E\text{-}06\ D^4$	99.5

Note: M= Moister Content%, D= Day

The results of polynomial regression of various orders of the mean moisture content values on time are given in Table 1, independently, for each sticker thickness. The results showed that the regression coefficients were highly significant (p=0.0001) for the three polynomial equations. However, R^2

increased significantly with increasing regressors in the model from 92.9 to 99.2% for sticker 1.25 cm, from 99.3 to 99.9% for sticker 2.5 cm and from 97.7 to 99.5 %for sticker 3.75 cm. These results suggest that, depending on the required degree of precision and simplicity, any of the three equations can be satisfactorily used to predict the moisture content of humied planks during autumn.

Summer

The performance of the moisture content with time of the three replicate samples and their means during summer is shown in Figures 4-6 for three sticker thickness. The initial moisture content for the samples varied between 102 to 136.6 %, while the equilibrium moisture content attained varied amongst samples from 13.1 and 19.9%. The time needed to reach equilibrium moisture content varied among samples between 106 and 165 days. As the drying proceeded, the moisture content showed profound fall during the first 3 to 25 days (time).

The results of polynomial regression of an assortment of orders of the mean moisture content values on time are given in Table 2, independently, for each sticker thickness. The results show that the regression coefficients were highly significant (p=0.0001) for the three polynomial equations. However, R^2 increased significantly with increasing regressors in the model from 86.2 to 98.2% for sticker 1.25 cm, from 76.5 to 96.7% for sticker 2.5 cm and from 80.1 to 97.2 % for sticker 3.75 cm. These results explain that, depending on the required degree of precision and simplicity, any of the three equations can be effectively used to estimate, the average values of moisture content of humied planks at a specified day during the drying period in summer.

Table 2. Results of linear regression analyses of the relationship between humied wood moisture content and time (days) in summer.

Sticker (cm)	Equations	R^2%
1.25	$M = 88.8 - 1.6735\,D + 0.0087\,D^2$	86.2
	$M = 107.0 - 3.2131\,D + 0.0354\,D^2 - 0.0001\,D^3$	96.2
	$M = 116.04 - 4.4731\,D + 0.0742\,D^2 - 0.0005\,D^3 + 1E\text{-}06\,D^4$	98.2
2.5	$M = 71.7 - 1.2699\,D + 0.0063\,D^2$	76.5
	$M = 90.4. - 7359\,D + 0.0298\,D^2 - 1E\text{-}04\,D^3$	92.1
	$M = 101.8 - 4.2025\,D + 0.0715\,D^2 - 0.0005\,D^3 + 1E\text{-}06\,D^4$	96.7
3.75	$M = 75.0 - 1.4578\,D + 0.0078\,D^2$	80.1
	$M = 94.9 - 3.0452\,D + 0.0352\,D^2 - 0.0001\,D^3$	94.1
	$M = 105.4 - 4.5059x + 0.0801\,D^2 - 0.0006\,D^3 + 2E\text{-}06\,D^4$	97.2

Figure 1.Relationshi between moisture content and time (days) for sticker 1.25 cm in autumn.

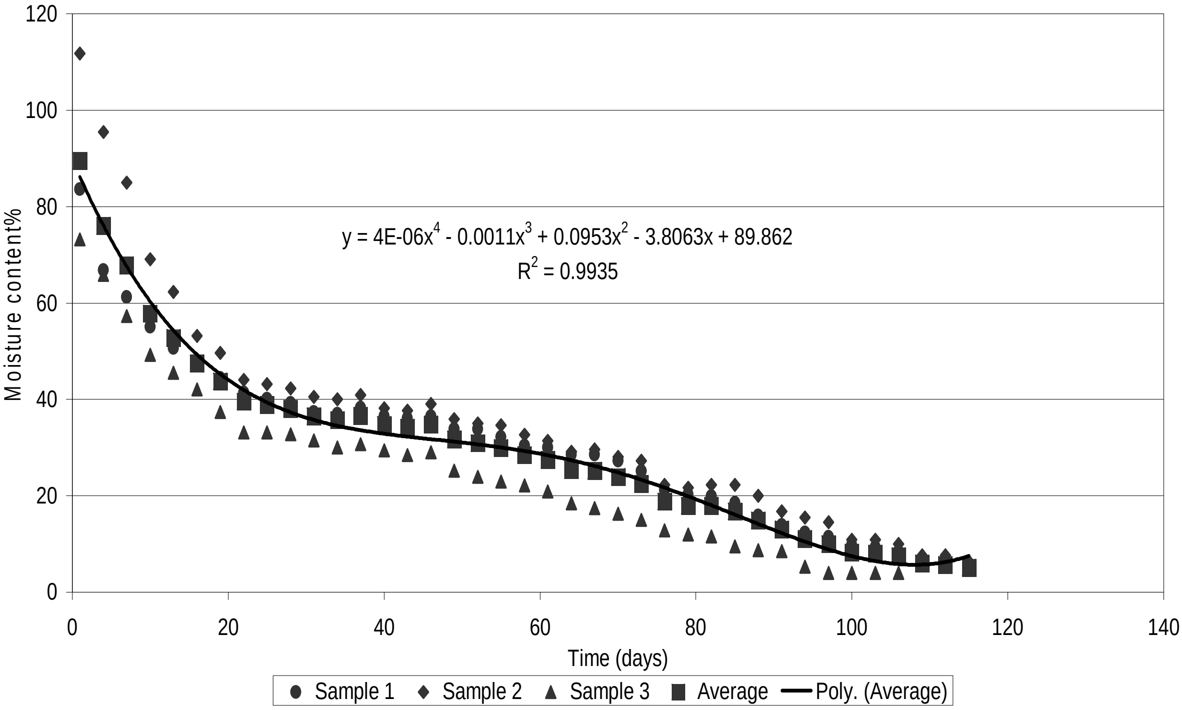


Figure 2. Relationship between moisture content and time (days) for sticker 2.5 cm in autumn.

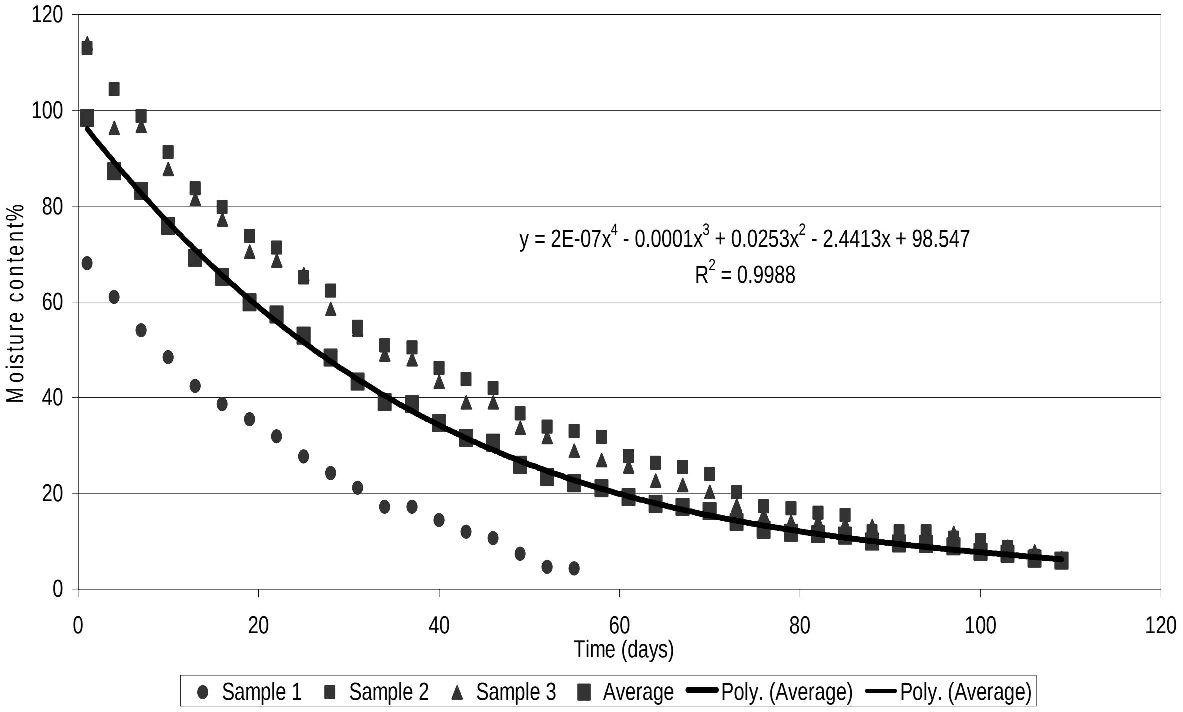
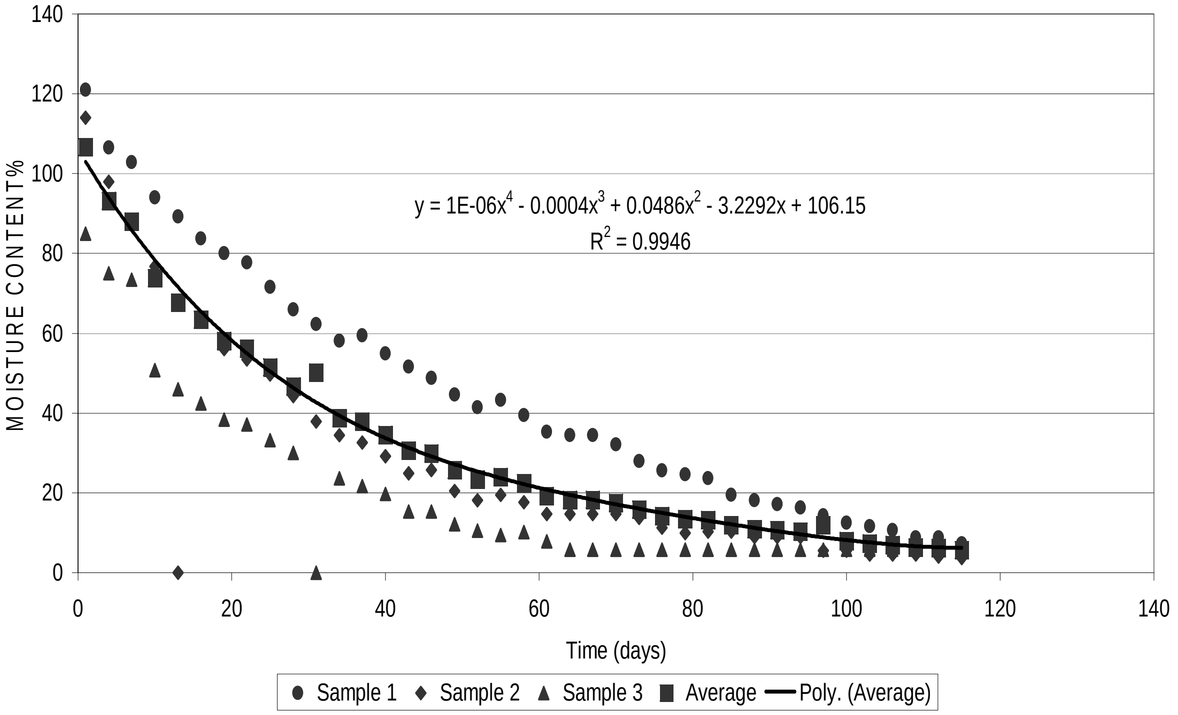


Figure 3. Relationship between moisture content and time (days) for sticker 3.75 cm in autumn.



Winter

The behavior of the moisture content with time of the three replicate samples and their means during winter is shown in Figures 7-9 for the three sticker thicknesses. The initial moisture content for the samples, ranged from 85.9 to 142.4%, while the equilibrium moisture content reached, varied among samples between 2.1 to 18.8%, as the drying proceeded the moisture content showed steep drop during the first 3 to13 days (time).

The results of polynomial regression of various orders of the mean moisture content values on time are given in Table 3, separately, for each sticker thickness. The results showed that the regression coefficients were highly significant (p=0.0001) for the three polynomial equations. However, R^2 increased significantly with increasing regressors in the model from 94.1 to 97.5% for sticker 1.25 cm, from 96.8 to 99.0% for sticker 2.5 cm and from 97.2 to 99.6% for sticker 3.75 cm. These results suggest that, depending on the required degree of accuracy and simplicity, one of the three equations can be acceptably used to symbolize the drying rate of humied planks during winter.

The trends of the association between moisture content and drying time for the three seasons and sticker thicknesses indicate that the relationship is curvilinear and can be presented by any of the second, third and fourth order polynomial regression equations. However, the fourth polynomial regression model is particularly the most suited regression equations that can explain this relationship. The fourth-order trend curves, in each experiment, follow the means of the moisture content with high similarity, and, also, their coefficients of determination (R^2), which ranges from 97 to 99%, were higher than those of the second (76.5-99.3%), and third (92.1-99.9) regression orders.

Table 3. Results of linear regression analyses of the relationship between humied wood moisture content and time (days) in winter.

Sticker (cm)	Equations	R^2%
1.25	$M = 81.2 - 2.1346\ D + 0.0144\ D^2$	94.1
	$M = 90.4 - 3.315\ D + 0.0456\ D^2 - 0.0002\ D^3$	96.4
	$M = 97.3 - 4.8449\ D + 0.1188\ D^2 - 0.0014\ D^3 + 6E\text{-}06\ D^4$	97.5
2.5	$M = 90.2 - 3.0217\ D + 0.0276\ D^2 +$	96.8
	$M = 98.7 - 4.4558\ D + 0.0764\ D^2 - 0.0004\ D^3$	98.8
	$M = 101.9 - 5.3642\ D + 0.1325\ D^2 - 0.0016\ D^3 + 8E\text{-}06\ D^4$	99.0
3.75	$M = 118.0 - 3.4675\ D + 0.0284\ D^2$	97.2
	$M = 129.4 - 5.2784\ D + 0.0876\ D^2 - 0.0005\ D^3$	99.2
	$M = 134.6 - 6.6966\ D + 0.1714\ D^2 - 0.0022\ D^3 + 1E\text{-}05\ D^4$	99.6

Note: M=Moisture content%, D = Days.

Figure 4. Relationship between moisture content and time (days) for sticker 1.25 cm in summer.

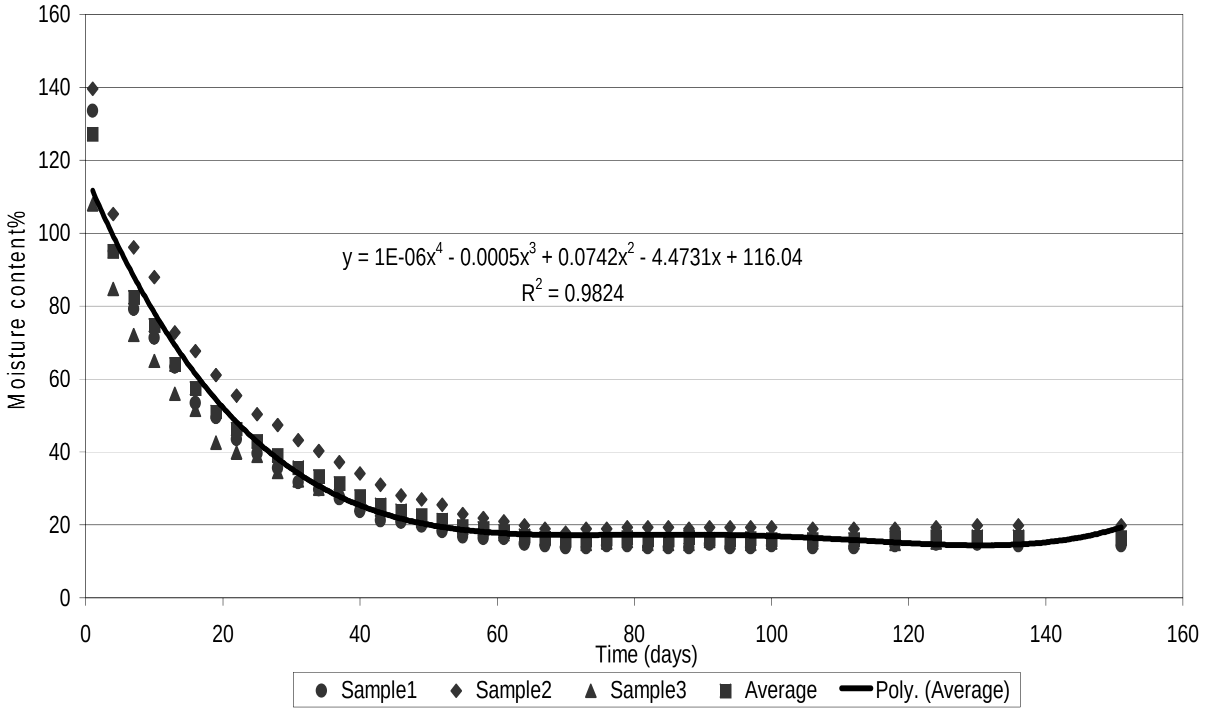


Figure 5. Relationship between moisture content and time (days) for sticker of 2.5 cm in summer

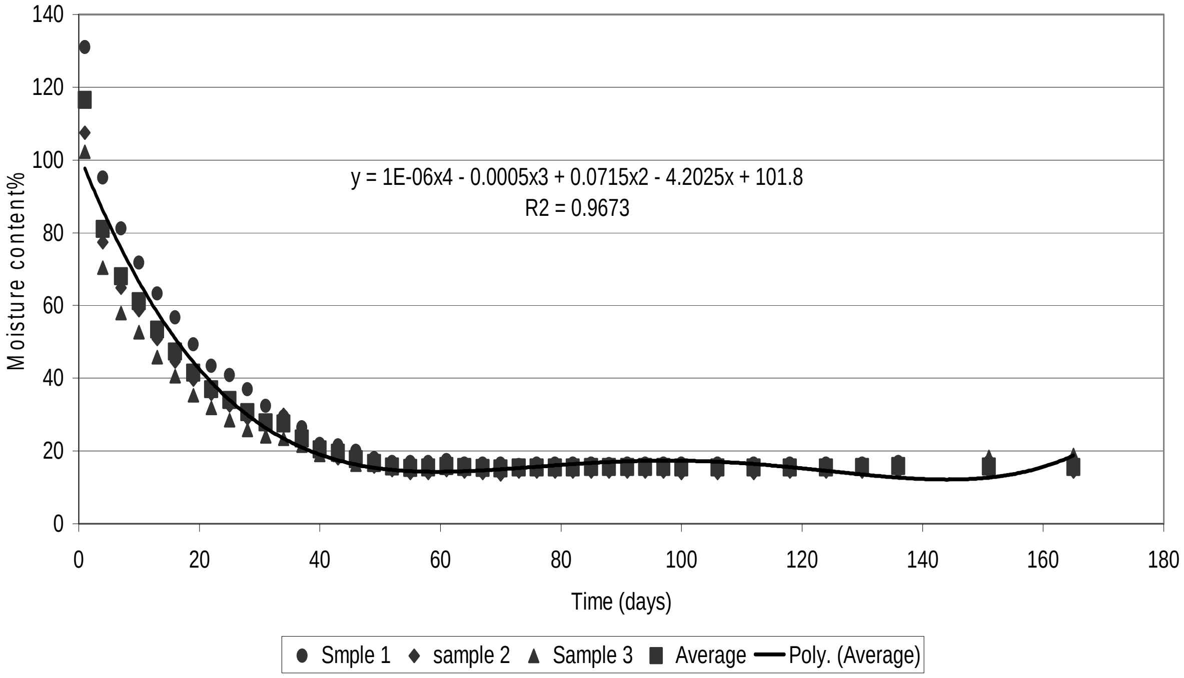


Figure 6. Relationship between moisture content and time (days) for sticker of 3.75 cm in summer.

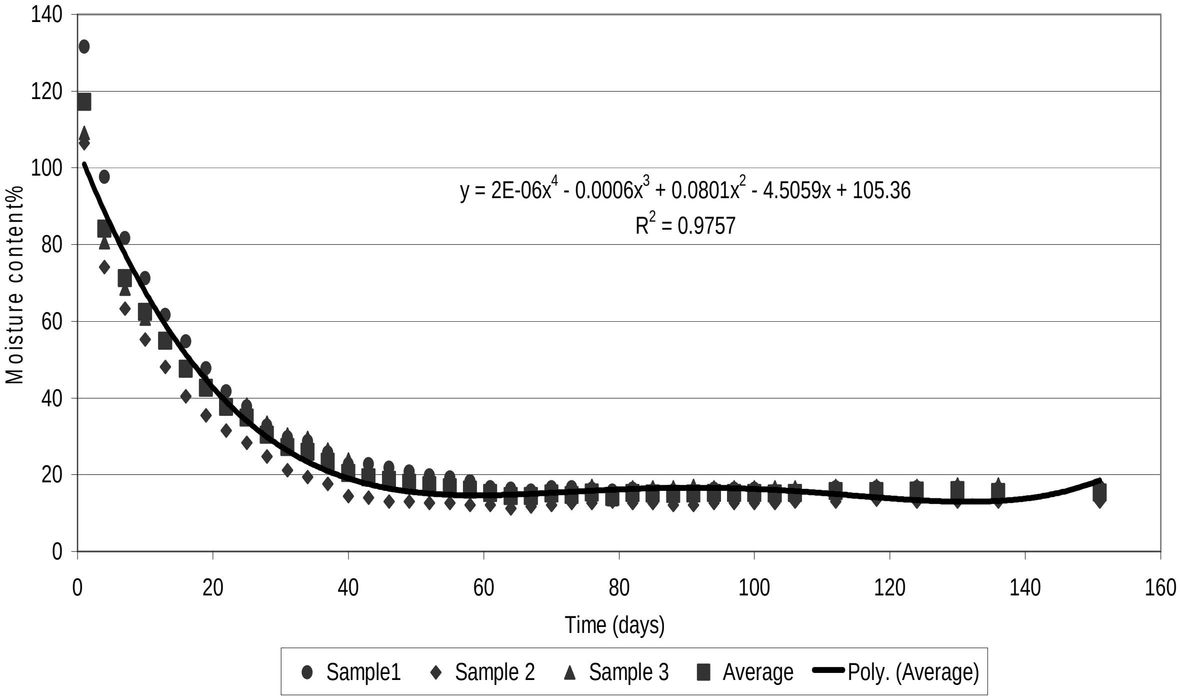


Figure 7. Relationship between moisture content and time (days) for sticker 1.25 cm in winter.

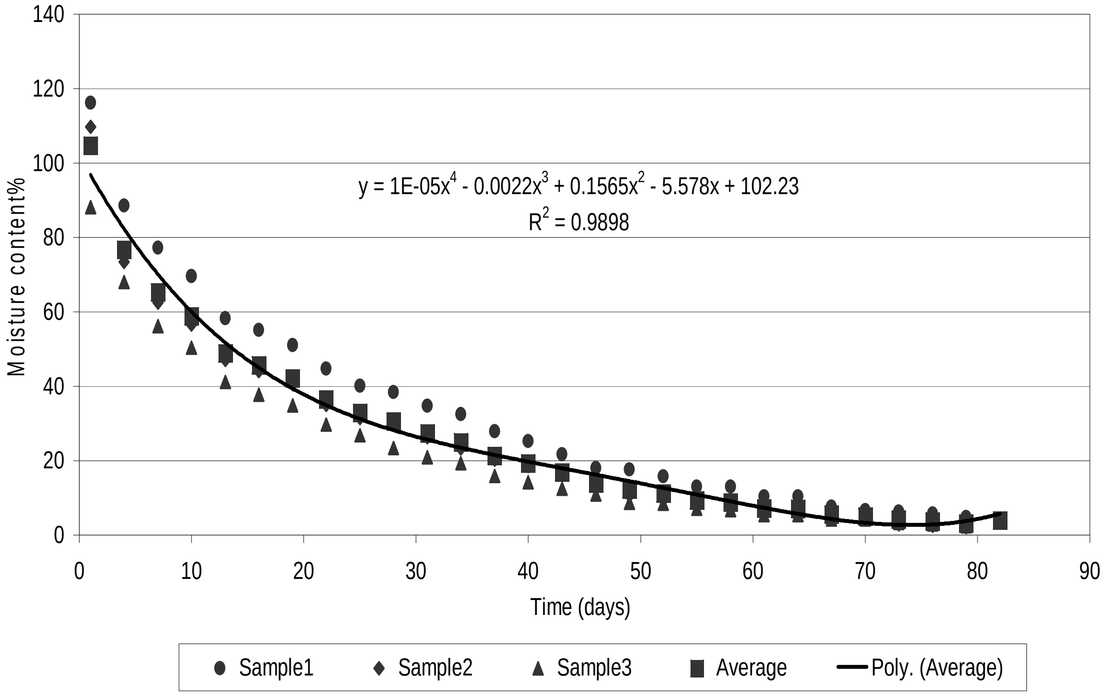


Figure 8. Relationship between moisture content and time (days) for sticker 2.5 cm in winter.

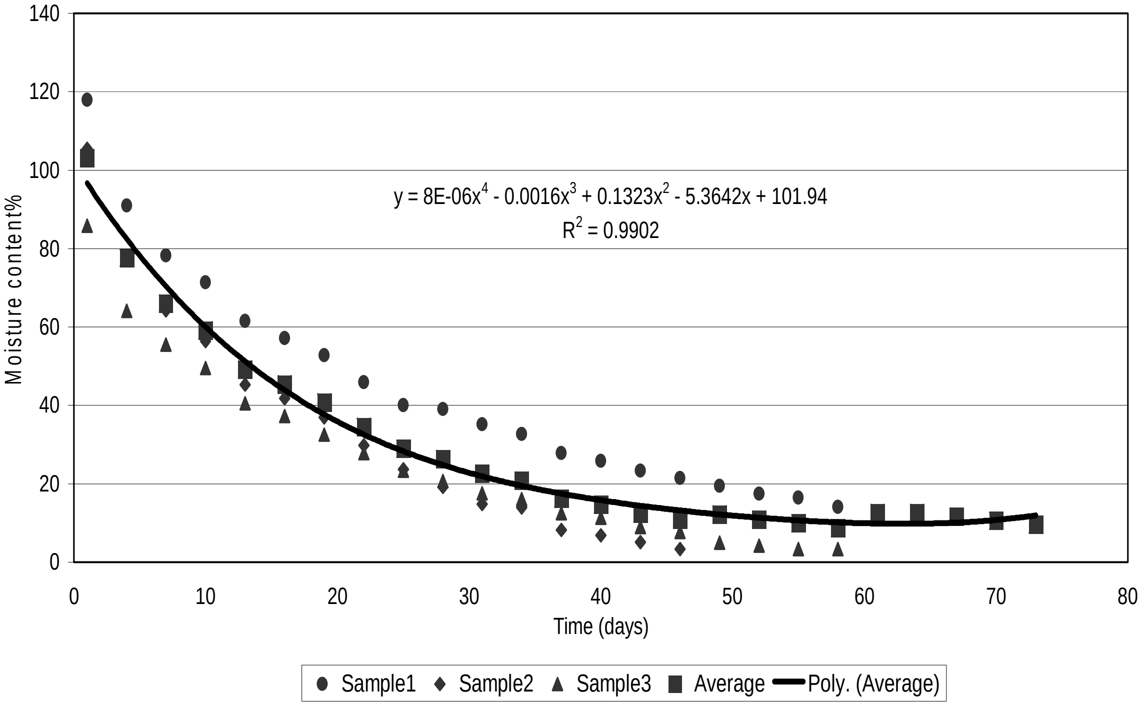
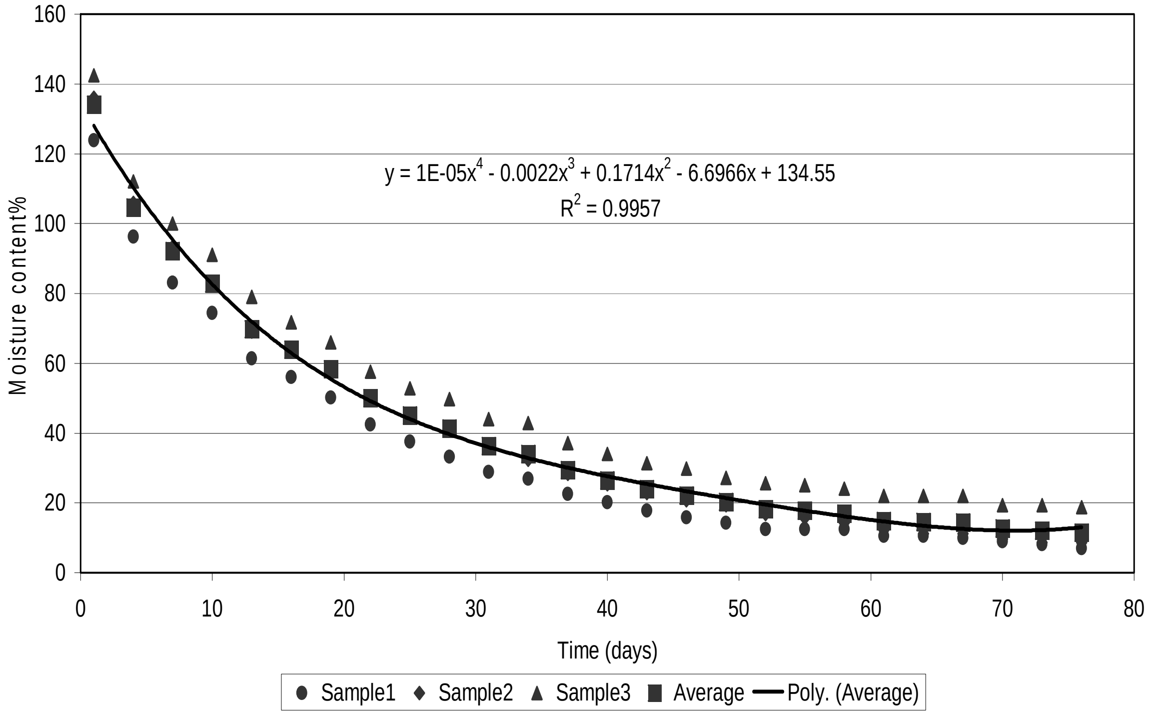


Figure 9. Relationship between moisture content and time (days) for sticker 3.75 cm in winter.



Effect of seasons and stickers on the moisture content on selected days

The effect of seasons and stickers on the moisture content was studied for selecting four days in each season (days 15, 30, 45 and 60). Means of moisture content in the selected days for the three seasons and results of Duncan's Multiple Range Test are given in Table 4. In day 15, there were no significant differences between seasons. Significant differences were found between seasons in the moisture content on days 30 (p=0.06), 45 (p=0.003) and 60 (p=0.006).

In day 30, there were no significant differences between autumn and summer, or between summer and winter. However, autumn had significantly higher moisture content than winter, where moisture content values were about 39.6 and 28.7, respectively. In day 45, autumn had significantly higher moisture content than summer and winter, which were not significantly different from each other. In day 60, the results were similar to day 30; autumn had higher moisture content than winter.

Table 4. Effect of season on moisture content on selected days

season	Moisture content			
	Day 15	Day 30	Day 45	Day 60
Autumn	58.7 A	39.6 A	31.8 A	21.9 A
Summer	50.8 A	30.2 AB	22.1 B	16.4 AB
Winter	51.7 A	28.7 B	15.6 B	9.5 B

In the same column, means with the same letter(s) are not significantly diffrent

Table 5. Effect of sticker thickness on moisture content on selected days

Sticker (cm)	Moisture content			
	15	30	45	60
3.75	58.3 A	35.1 A	25.3 A	16.5 A
2.50	52.6 A	30.2 A	19.7 A	13.9 A
1.25	50.2 A	33.2 A	24.2 A	17.7 A

In the same column, means with the same letter(s) are not significantly diffrent.

The effect of stickers on the mean moisture content was studied by four selected days in each season (days 15, 30, 45and 60). Means of the moisture content, in the selected days for the three stickers, and results of Duncan's Multiple Range Test are given in Table 5.

In day 15 there were no significant differences between the stickers. Sticker 3.75 cm was higher than sticker 2.5 and sticker 1.25 cm, which of about 58.3. In day 30 there were no significant differences between stickers. Sticker

3.75 cm was higher than sticker 1.25 and sticker 2.5 cm. In day 45 there were no significant differences between sticker 3.75 and sticker 1.25 cm. Sticker 2.5 cm had lower value than sticker 3.75 and 1.25 cm which of about 19.7. In day 60, there were no significant differences between sticker 1.25 and sticker 3.75 cm, while sticker 2.5 cm had lower value than them (13.9). The results showed that there was no significant effect of the sticker thicknesses on the moisture content obtained in the selected days

Differences in regression equations between seasons and stickers

To study the variations between seasons and stickers in the trend of drying, comparisons were made between the regression coefficients of the equations relating moisture content and time (days) for the three seasons. The shape of the fourth polynomial regression, made it possible to investigate the effect of seasons and stickers on the rate of drying into four curve segments. Means of the estimates of regression coefficients of the seasons and results of Duncan’s Multiple Range Test are given in Table 6.

Differences between seasons in intercepts were not significant. This indicates that the extension of the regression lines of the three seasons intersect with the y-axis at adjacent points. There were significant differences between seasons ($p=0.0001$ to 0.021) in the regression coefficients controlling the trends of the rate of drying (b_1, b_2, b_3 and b_4).

There were significant differences in b_1 between winter (-5.87) and autumn (-3.47); winter had a steeper slope than autumn at the initial segment of the regression line. However, there were no significant differences in b_1 between summer and autumn, or between summer and winter.

There were significant differences in b_2 between winter and the other two seasons, but there were no significant differences between summer and autumn.

There were significant differences in b_3 between winter and the other two seasons, while there were no significant differences between summer and autumn. These results indicate that the effect of the squared and cubed values of days is more prominent in winter than in summer or autumn data. There were significant differences in b_4 between winter and the other two seasons, while there were no significant differences between summer and autumn.

Means of the estimates of regression coefficients of the stickers and results of Duncan's Multiple Range Test are given in Table 7. There were no significant differences between stickers thickness **(**$p = 0.15$ to 0.86**),** in the regression coefficients controlling the trends of the rate of drying (b_1, b_2, b_3 and b_4)

The results of variations between seasons and stickers in moisture content of selected days and in the regression coefficients indicate that, for drying humied planks (200x15x5 cm^3), there is no need to have separate drying rate (moisture content Vs time) for different stickers in the various seasons. It is satisfactory to have separate equations for the seasons.

Table 6. Means of regression coefficients for the relationship between mean moisture content and time (days) for seasons,

Season	Intercept	B_1	B_2	B_3	B_4
Winter	114.843 A	-5.8728 B	0.21423 A	- 0.0038959 B	0.00002527 A
Summer	108.668 A	-4.6328 AB	0.08563 B	- 0.0006889 A	0.00000204 B
Autumn	99.392 A	-3.4741 A	0.06066 B	- 0.0009491 A	0.00000251 B

In the same column, means with the same letter are not significantly different

Table 7. Means of regression coefficients of the relationship between mean moisture content and time (days) for stickers

Sticker thickness	Intercept	B_1	B_2	B_3	B_4
1.25	104.003 A	-4.9569 A	0.11552 A	- 0.0016617 A	0.00000828 A
2.50	102.331 A	-4.6424 A	0.12821 A	- 0.0024987 A	0.00001639 A
3.75	116.573 A	-4.3804 A	0.11678 A	- 0.0013734 A	0.00000514 A

In the same column, means with the same letter are not significantly different

Effect of seasons and stickers on the equilibrium moisture content and the drying time

The results of analysis of variance showed that the effect of seasons was highly significant on equilibrium moisture content and drying time (p=0.0001) Means of the equilibrium moisture content of the seasons and results of Duncan's Multiple Range Test are given in Table 8. The results showed that, the equilibrium moisture content had higher value in summer season (15.9) and significantly different from winter (6.4) and autumn (5.6). There were no significant differences in the equilibrium moisture content between autumn and winter. However, the three seasons were significantly different from each other in the number of days to reach the equilibrium moisture content. Summer season had the longest time (141.4 days) followed by autumn (99.0 days) and then winter (71.3 days).

On the other hand, the results in Table 9 indicate that there were no significant variations between the three stickers in the equilibrium moisture content **(**p=0.58**)** or the drying time (p=0.16). Also, the interaction between seasons and stickers was not significant.

Table 8. Effect of seasons on equilibrium moisture content and drying time (days)

Seasons	Equilibrium moisture content	Days
Summer	15.9 A	141.4 A
Autumn	5.6 B	99.0 B
Winter	6.4 B	71.3 C

Means with the same letter(s) are not significantly different.

Table 9. Effect of stickers on equilibrium moisture content and drying time (days)

Stickers (cm)	Equilibrium moisture content	Days
3.75	10.9 A	103.0 A
2.5	8.8 A	99.6 A
1.25	8.2 A	109.2 A

Means with the same letter(s) are not significantly different**.**

The above results showed that there were significant differences between seasons in the moisture content at selected days, the regression coefficients for the relationship between the moisture content and time, equilibrium moisture content and time required to reach the equilibrium moisture content. However, these variables had no significant differences between stickers. These results suggest that the regression equations should be developed separately for each season. Results of the second, third and fourth-order polynomial regression analysis for the relationship between moisture content and drying time are given in Table 10. The trends of the three stickers and the fourth-order equation for each of the three seasons are illustrated in Figures 10-12.

The high values of the coefficient of determination (adjusted R^2) showed that, high proportions of the variations in the moisture content were explained by the number of days of the drying process. The highest R^2 value was obtained in autumn (99.6%) followed by summer (95.8%) and then winter (92.5%). It worth mention, that the regression coefficients of the second and third-order polynomial regression equations in Table 10, are all significant ($p=0.0001$) and might be satisfactory to explain the drying rate of humied wood growing in Kadogli area, but are less fitting to the data than the fourth-order equations.

The equations can be used to estimate the moisture content at any given number of days of drying. For example, to estimate the moisture content after 10 days of drying in winter, the equations in Table 10 will give 69.1%, 69.0% or 70.7% when using the second, third or fourth-order regression equations, respectively. These results showed that no differences were found between the second and the third orders in the values of the moisture content in day 10.

Table 10. Trends of the relationship between average moisture content and time (days) in the three seasons.

Season	Equations	Adjested R^2 (%)
Autumn	$M = 85.8 - 1.5345 D + 0.0076 D^2$	97.5
	$M = 93.8 - 2.3772 D + 0.0258 D^2 - 0.0001 D^3$	99.3
	$M = 99.3 - 3.371 D + 0.0639 D^2 - 0.00059 D^3 + 0.000001998 D^4$	99.7
Summer	$M = 79.1 - 1.4984 D + 0.0079 D^2$	82.6
	$M = 97.4 - 3.033 D + 0.0344 D^2 - 0.0001 D^3$	94.9
	$M = 111.9 - 5.569 D + 0.132596 D^2 - 0.001529 D^3 + 0.00000668 D^4$	97.9
Winter	$M = 93.0 - 2.5199 D + 0.018 D^2$	94.9
	$M = 106.0 - 4.3129 D + 0.0686 D^2 - 0.0004 D^3$	98.6
	$M = 106.3 - 4.214 D + 0.0696 D^2 - 0.000483 D^3 + 0.000001192 D^4$	99.0

Note: M= Moisture content, D = Days.

Figure 10. Relationship between average moisture content and time (days) for 3 stickers in autumn.

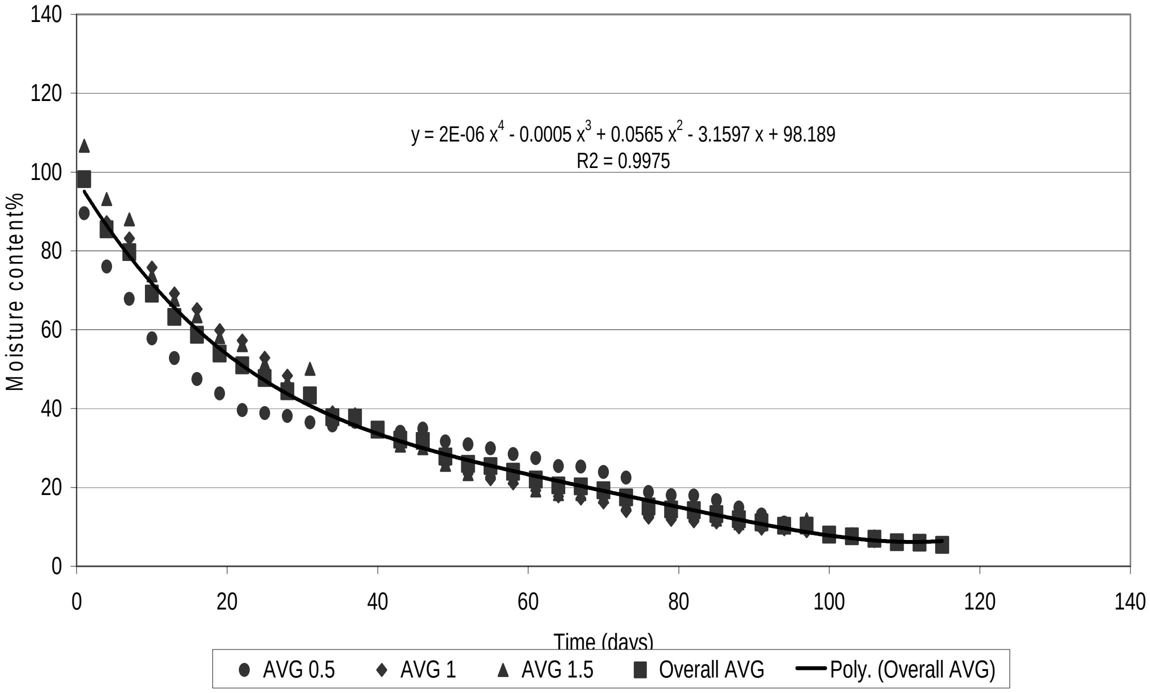


Figure 11. Relationship between average moisture content and time (days) for 3 stickers in summer.

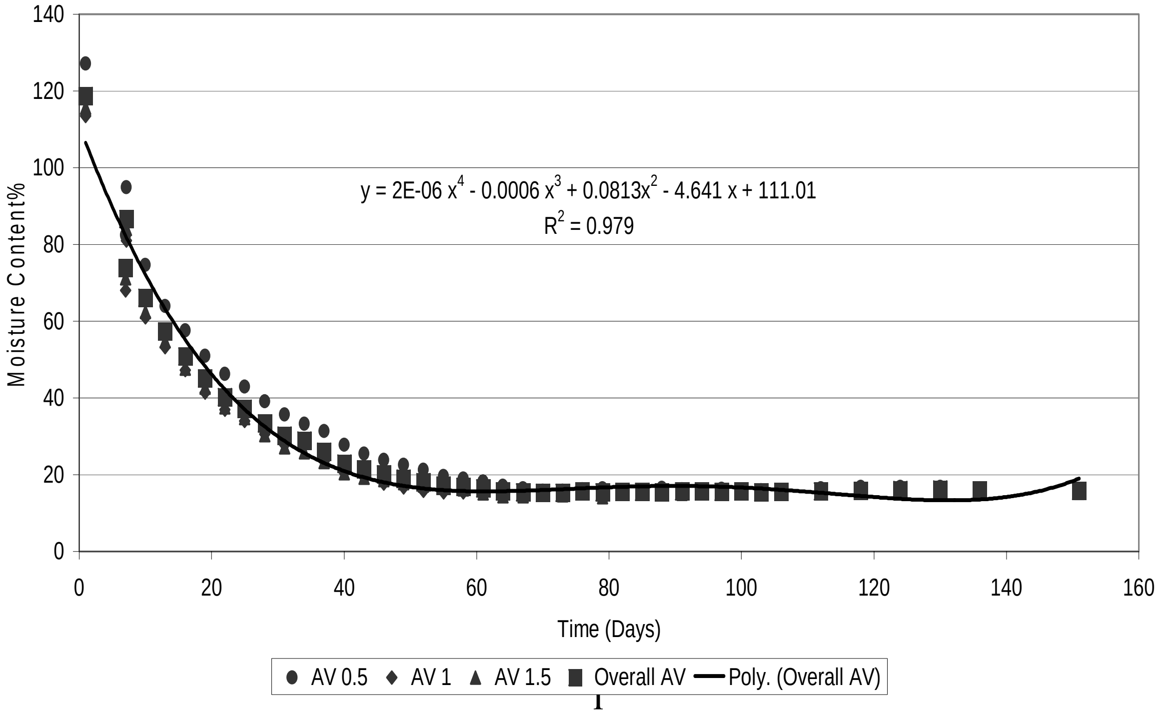
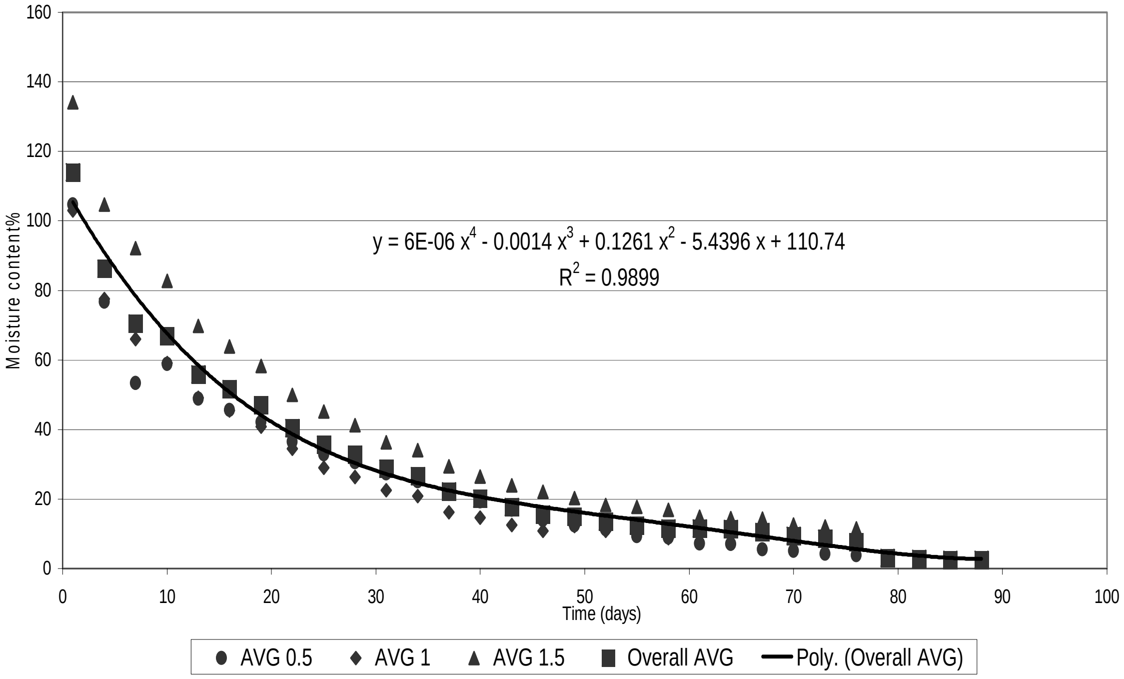


Figure 12.Relationship between averge moisture content and time (days) for 3 stickers in winter.



Seasoning defects

Results in this study, describe the effect of seasons and stickers on the development of various defects during the drying process of humied planks. The defects observed include warping (twisting, bowing, crooking and cupping), checking (surface, end check and ring failure) and collapse. The percentage of defected planks and the average values of dimensions of the defects at the end of the drying period are given in Tables 11 to 15 for warping and cheking.

Bowing

The results of the association between the rate of drying and the formation of bowing were shown in Table 11, separately, for each sticker thickness and season.

In autumn, the bowing defect was present in about 19.6% of the planks for sticker 1.25 cm, which was considerably higher than for stickers 2.5 and 3.75 cm. The defect extent was greater for sticker 2.5 cm (2.16 cm) compared with stickers 1.25 and 3.75 cm. In summer, there were no considerable differences between the three stickers in the percentage of the defected planks and in the dimension of the defects.

In winter, there was no obvious variation between stacks of stickers 1.25 and 2.5 cm, and they had considerably higher bowing values than sticker 3.75 cm (13.6%). The magnitude of the defect was greater in sticker 2.5 cm (2.3 cm) compared with stickers 1.25 and 3.75 cm thickness. The percentage of bowed planks were higher in winter (17.1%) than in autumn and summer, while the extent of bowing was greater in autumn (1.97 cm) than in summer and winter

Crooking

The results of the association between the rate of drying and the formation of crooking were shown in Table 12, separately, for each sticker thickness and season.

No variations were found in autumn between stickers 2.5 and 3.75 cm in the percentage of crooked planks, while the crook value for sticker 1.25 cm was lower than them (12.8%). The amount of the crooking defect was higher for sticker 2.5 cm (2.95 cm) compared with stickers 1.25 and 3.75 cm and there were no differences between them in the extent of the defect. In summer, there were no considerable variations in the total percentage and the magnitude of defect between the three stickers. In winter, there were considerable differences between the three sticker sizes in the percentage of the planks affected by crooking defect. The percentage of crooked planks was greater for sticker 2.5 cm (36.7%) than for stickers 1.25 and 3.75 cm; however; there were no sizeable differences between the three stickers in the magnitude of the defects. The percentage of crooked planks was higher in winter (25%) than in autumn and summer, while the magnitude of crooking was higher in autumn (2.5 cm) than in winter and summer

Twisting

The results of the association between the rate of drying and twisting were shown in Table 13, separately, for each sticker thickness and season.

In autumn trails, the planks affected by twisting defect were about 9.4, 11.8 and 12.8% of the planks in the stacks of stickers 1.25 cm, 2.5 cm and 3.75 cm, respectively. The magnitude of twisting was greater in the stacks of sticker 1.25 cm (averaging 2.9 cm) compared with stickers of 2.5 and 3.75 cm. In summer, there was no considerable variation between stickers 1.25 and 2.5 cm in the percentage of planks with twisting and the average size of the defect. These values were comparatively greater than those for sticker 3.75 cm. In winter season, the percentage of the planks affected by twisting represented about 26.4% for sticker 1.25 cm, while for stickers 2.5 and 3.75 cm; it was 22.2% and 12.8%, respectively. There were no noticeable differences between the extents of the defect associated with the three stickers which was ranging from 1.9 to 2.07 cm. The percentage of twisted planks was greater in winter (20.5%) than in autumn and summer, while the extent of twisting was higher in autumn (2.33) than in summer and winter.

Means of the number and percentage of warped planks and the magnitude of the bowing defect shown in Tables 11, 12 and 13 indicate that the percentage of bowed planks were higher in winter (17.1%) than in autumn and summer, while the extent of bowing was greater in autumn (1.97 cm) than in summer and winter. The percentage of crooked planks was higher in winter (25%) than in autumn and summer, while the magnitude of crooking was higher in autumn (2.5 cm) than in winter and summer. In winter, the percentage of twisted planks was greater (20.5%) than in autumn and summer, while the extent of twisting was higher in autumn (2.33) than in summer and winter.

The results in Tables 11, 12 and 13, also indicate that the percentage of warping defects was higher in winter season compared with the other two seasons; this was due to the faster drying rate during the first stages of drying in winter. However, the results showed that the magnitude of the warped planks was greater in autumn and this was probably due to the continuous wetting and drying cycle of the wood during autumn.

The higher percentage of the warped planks was expected to be found in the stacks with 3.75-cm sticker thickness, but the results showed that the warped planks were irregularly distributed between the three stickers. A rough guide for illustrating this phenominon might be the presence of other factors such as extractives, wood specific gravity, and the chemical composition of wood. These factors together with seasons and stickers are reported to have direct effect on wood drying (Gartner 1997).

Table 11. Number and percentage of bowed planks and the average size of bowing defect.

Seasons	Stickers (cm)	Numberand % of boards with defects		Average (cm)
Autumn	1.25	23	19.6%	1.95
	2.5	14	11.9%	2.16
	3.75	16	13.6%	1.82
Mean			15.0%	1.97
Summer	1.25	15	12.8%	1.67
	2.5	17	14.5%	1.80
	3.75	18	15.3%	1.48

Mean			14.2%	1.65
Winter	1.25	23	19.6%	1.36
	2.5	21	17.9	2.13
	3.75	16	13.7%	1.60
Mean			17.1%	1.69

Table 12. Number and percentage of crooked planks and the average size of cooking defect.

Seasons	Stickers (cm)	Numberand % of boards with defects		Average (cm)
Autumn	1.25	15	12.8%	2.21
	2.5	28	23.9%	2.95
	3.75	29	24.7%	2.44
Mean			20.5%	2.5
Summer	1.25	23	19.6%	1.89
	2.5	22	18.8%	1.90
	3.75	21	17.9%	1.62
Mean			18.8%	1.80
Winter	1.25	26	22.2%	1.97
	2.5	43	36.7%	1.98
	3.75	12	10.2%	1.93
Mean			23.0%	1.97

Cupping

The number of planks showing cupping defect was negligable in this study. In winter and summer seasons no cupping defect was observed; only three planks developed cupping in autumn.

Collapse

Regardless of the sticker thicknesses, the percentage of planks showing collapse was greater in winter (50%) than in summer (24%) and autumn (19%). In winter, the relative humidity in the surrounding atmosphere where the wood was stacked fell down to seven percent, especially in mid March, resulting in a faster rate of drying and therefore, increased the incidence of collapse on a larger percentage of planks.

Table 13. Number and percentage of twisted planks and the average extent of the twisting defect.

Seasons	Stickers (cm)	Numberand % of boards with defects		Average (cm)
Autumn	1.25	11	9.4%	2.90
	2.5	14	11.9%	2.23
	3.75	15	12.8%	1.88
Mean			11.4%	2.33
Summer	1.25	15	12.8%	1.90
	2.5	13	11.1%	1.96
	3.75	7	5.9%	1.64
Mean			9.9	1.99
Winter	1.25	31	26.4%	2.07

	2.5	26	22.2%	2.00
	3.75	15	12.8%	1.90
Mean			20.5%	1.83

Surface-checking

The results of the association between the rate of drying and the formation of surface checking were shown in Table 14, separately, for each sticker thickness and seasons.

In autumn, there were no considerable differences between the stickers in the percentage of the planks affected by surface check. The average percent of the affected planks for the three stickers ranged from 5.1 to 6.8 %. There were no variations between stickers 1.25 and 2.5 cm in the average length of the defect, and they were both higher than sticker 3.75 cm. However, the average width for stickers 1.25 and 2.5 cm was lower than for sticker 3.75 cm. There were no differences between stickers 1.25 and 3.75 cm in the average depth of the defect, and they were both higher than sticker of 2.5 cm.

Table 14. Number and percentage of checked planks and the average extent of surface- checking the defects.

Seasons	Stickers (cm)	Number and % of defected planks		Average length (cm)	Average width (cm)	Average depth (cm)
Autumn	1.25	8	6.8%	29.20	0.25	1.35
	2.5	6	5.1%	30.40	0.34	0.74
	3.75	6	5.1%	22.50	0.41	1.20
Mean		6.7	5.7%	27.30	0.33	1.09
Summer	1.25	16	13.6%	32.50	0.20	0.69

	2.5	8	6.8%	46.80	0.16	0.36
	3.75	4	3.4%	41.50	0.22	1.40
Mean		9.3	7.9%	40.20	0.19	0.81
Winter	1.25	4	3.4%	16.37	1.17	0.22
	2.5	12	10.2%	17.51	0.19	1.32
	3.75	6	5.1%	24.00	0.18	1.41
Mean		7.3	6.2%	19.20	0.51	0.98

In summer, the average percentage of planks subjected to surface checking was greater for sticker 1.25 cm (13.6 %) than stickers 2.5 and 3.75 cm. The average length of the crack was lower for sticker 1.25 cm (32.5) than for stickers 2.5 and 3.75 cm. The average width of the crack was lower for sticker 2.5 cm (0.16 cm) than for stickers of 1.25 and 3.75 cm. The average depth of the defect was greater for sticker of 3.75 cm (1.4 cm) than for stickers 1.25 and 2.5 cm.

In winter, the percentage of the defected planks was more for sticker 2.5 cm (10.2%) than that for stickers 1.25 and 3.75 cm. The average length of the defect was greater for sticker 3.75 cm (24.0cm), while there were no detectable variations between stickers 1.25 and 2.5 cm. The average depth of the defect was minimal for sticker 1.25 cm (0.22 cm) compared with stickers of 2.5 and 3.75 cm, where there were no differences between them in the amount of the defect. However, there were no noticeable variations between the stickers in the average width of the defect.

End-check

The results of the association between the rate of drying and the formation of end-checking were shown in Table 15, separately, for each sticker thickness and season. End-checks started during the first three days of the wood stacking, where the initial moisture content loss from the planks was more than 30%. However, in some planks the defect started to close up fifteen days later.

In autumn, the percentage of the defected planks was higher for sticker 3.75 cm (24.7%) compared with that for stickers 1.25 cm and 2.5 cm. On the other hand, the magnitude of the average length of the crack was greater for sticker 3.75 cm (2.23 cm) than for stickers 1.25 and 2.5 cm, where there were no observable differences between them. There were no considerable variations between the three stickers in the average width of the defect. However, the extent of the average depth of the defect was 0.34 cm, 0.26 cm and 0.17 cm for stickers 1.25, 2.5 cm and 3.75 cm, respectively.

In summer, there were differences between the three stickers in the average percent of the defected planks. The magnitude of the average depth of the defect was greater for sticker 1.25 cm (7.8 cm) than for sticker 2.5 and 3.75 cm. However, the average length and width of end-checking for stickers 1.25 and 2.5 cm were comparable, while it was undetected for sticker 3.75 cm. No considerable differences between the stickers in winter were found in the percentage of the planks affected by end checking defect. The amount of average length of the defect was higher for the sticker 2.5 cm (4 cm) than for stickers 1.25 and 3.75 cm and there were no considerable variations between them. There were no sizeable differences in the average width of end cheking between the three stickers. The extent of the average depth of the defect was not noticeable between stickers 1.25 and 3.75 cm and they were wider than that for sticker 2.5 cm.

Table 15. Number and percentage of checked planks and the average extent of the end- checking defects.

Seasons	Stickers (cm)	Number and % of defected planks		Average length (cm)	Average width (cm)	Average depth (cm)
Autumn	1.25	20	17.0%	1.81	0.34	1.53
	2.5	16	13.6%	1.96	0.20	2.14
	3.75	29	24.7%	2.23	0.17	4.52
Mean		21.7	18.4%	2.0	0.23	2.73
Summer	1.25	3	2.5%	2.70	0.26	7.86
	2.5	4	3.4%	2.75	0.20	0.20
	3.75	0	0	0	0	0
Mean		2.3	2.0%	1.81	0.15	2.68
Winter	1.25	4	3.4%	3.15	0.10	5.57
	2.5	3	2.5%	4.0	0.10	3.10
	3.75	3	2.5%	3.23	0.16	6.90
Mean		3.3	2.8%	3.46	0.12	5.19

Means of the number and percentage of the checked planks and the extent of checking (Tables 14 and 15) showed that the percentage of surface-checking was greater in summer (7.9%) than in winter and autumn. The magnitude of surface-checking showed deeper cracks in autumn (1.09 cm), wider cracks in winter and longer cracks in summer (40 cm). However, the percentage of end-checked planks was very high in autumn (18.4%) compared with winter and summer (<2.5 cm). The end-checking showed slightly deeper and longer cracks in winter (5.19 cm) than in the other two seasons.

It was noticed that surface checking was more obvious on the upper-most planks, which were exposed directly to sun rays, than on the planks inside the stacks. These observations suggest that it is advisable to stack *Sclerocarya birrea* (humied) wood under shade at all times of the drying process to slow the rate of drying as noted by Koch (1972).

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

According to the results obtained from this study the following points can be concluded:

In summer season the wood of *Sclerocarya birrea* attained the mean equilibrium moisture content (15.9%) during 141.4 days. The mean equilibrium moisture content in autumn (6.4%) and winter (5.6%) were attained in 99.0 and 71.3 days, respectively.

The relationship between the moisture content and time for *Sclerocarya birrea* wood planks can be explained by the second, third or fourth-order polynomial regression equations. However, the fourth-order polynomial equation had clearly explained the greatest proportion of the variation in moisture content. Each of the second, third or fourth-order polynomial regression equations can be used to estimate the moisture content after any given number of days of drying.

There were significant differences between the trends of the relationship between the seasons (autumn, summer and winter) in terms of the equilibrium moisture content and the drying time.

There were no significant differences among sticker thicknesses in the equilibrium moisture content and the drying time.

The percentage of warping defect was more in winter season compared with the other two seasons, while the magnitude of the warping was greater in autumn.

The percentage of surface-checked planks was greater in summer than in winter and autumn, while the percentage of end-checked planks was very high in autumn compared with winter and summer.

The high number and percentage of drying defect was expected to be associated with stacks for sticker 3.75 cm thickness, but the defect was found unevenly distributed between the three sticker sizes

Recommendations

To dry *Sclerocarya birrea* (humied) wood in Kadogli area in the shortest period drying should start during winter.

In future research, it is recommended to investigate the effect of thicker stickers than those used in this experiment (>3.75 cm) and the effect of using end coating to minimize the extent of end-checks.

REFERANCES

Armadas, S. 1989. Evaluation of there variable models for the prediction of equilibrium moisture content in wood. *Wood Science and Technology* 23: 251-258.

Beal, F.C.; P.R. Blankenhorn, and G.R. Moore. 1974. Carbonized-wood physical properties, and use as an SEM preparation. *Wood Science*: 212-219.

Boyd, J.D. 1977. Relationship between fiber morphology and shrinkage of wood. *Wood Science and Technology* 11: 3-22.

Boyd, J. D. 1974. Anisotropic shrinkage of wood: Identification of the dominant determinations. Journal of Japan *Wood Research Society* 20 (10): 473-482.

Bryce, J.M. 1967. The Commercial Timber of Tanzania. *Utilization Section, Tanzania Forest Division*. 139 pp.

Camphell. R. N. 1969. Fungus sap-stains of hardwoods. *South. Lumberman* 199 (2489): 115-120.

Schroeder, J.G. and D.R. Philip. 1973. Some physical properties of yellow-poplar wood and bark. Part 11: Variation with height in the tree. *Wood Science* 6:123-126

Schroeder, H.A. 1972. Shrinking and Swelling. Differences between hardwoods and Softwoods. *Wood and Fiber* 4:20-25.

Chen, P.Y.S. 1974. A note on the effect of air-drying on vessel openings and air-blockage in yellow-poplar. *Wood and Fiber* 5: 308-311.

Choong, E.T. and S.S. Achaia. 1991. Effect of extractives on moisture sorption and shrinkage in tropical woods. *Wood and Fiber* 23(2): 185-196.

Choong, E.T.and F.G. Manville. 1976. Dimensional and relative hygroscopic propertiesof hardwood from southern pine sites. *Wood Science* 9:39-43.

Choong, E.T.; F.O. Tensor and F.G. Manville. 1974. Permeability of twenty-two small diameter hardwoods growing on southern pine sites. *Wood and Fiber* 6: 91-101.
Choong, E.T. and D.L. Cassens. 1976. Physical characteristics of bark of several delta hardwoods. LSU *Wood Utilization*. Note No. 28, 4p. Agricultural. Experiment. Stun. Res. Reel., La. State University. and A and M. Coil., Baton Rouge, La.

Chowdhury,M.J.A.; M.M. Hossain;M.Jashimudddin.and K. Misbahuzzaman. 1994. Effect of trees age on specific gravity and shrinkage of wood: Paraserianthes falcataria. *Chittagon- University-studies-Science* 18: (2): 175-177.

Clark, A. and J.G. Schroeder. 1977. Bio-mass of yellow-poplar in natural stands in western North Carolina. *U. S. Department of Agriculture, Forest Service and Research*. Paper SE-165. 41p.

Ferrari, G. 1998. Eucalyptus wood shrinkage and collapse. *Monti-Boschi*, 49: 1 P 48-53.

Gartner, B.L.; H. Lei and M.R. Milota. 1997. Variation in the anatomy and specific gravity of wood within and between trees of red alder (*Alnus rubra* Bong). *Wood and Fiber Science* 29: (1): 10-20.

Goldsmith,B.and D.T. Carter. 1981. The Indigenous Timbers of Zambabwe. *Zambabwe Forestry Commission and Research Bulletin* 9: 1-406.

Haygreen, J.G. and J.L. Bowyer. 1989. Forest Product and Wood Science. *Iowa State University Press*. Ames, 500.

Hejias, J. and M. Salamon. 1977. Measurement of lumber moisture content- A critique. *Wood Science* 10: 56-61.

Henderson, L.G. and E.T Choong, 1968. Variation in moisture content of standing sweetgum trees in Louisiana LSU for. Notes No 81. Agricultural Experiment. Sta. Research. *Reel., La. State University. & A & M Coll. Baton Rouge, La.*

Jett, J.B. and J. Zobel. 1975. Wood and pulping properties of young hardwoods. *Tappi* 58(1): 92-96.

Kellison, R.C and B.J. Zoble. 1971. Wood specific gravity and moisture content of the hardwood species of the Southern United States. *J. Service*. Paper. No.3408, 13 p. Agri. Exp. Sta., N.C. State Unit., Raleigh.

Koch, P. 1972 Utilization of the Southern Pines. *U.S.Department of Agriculture and Forest Service. Agricultural Handbook* 420. 1663 p. 2 vol.

U.S. Government Print. Of Washington, D.C.

Koch, P. 1985. Utilization of Hardwoods Growing on Southern Pine Sites. Vol. 1. Raw material. *U.S. Department of Agriculture, Forest Service. Print. Of Washington, D.C.*

Von Maydell, H.J. 1990. Trees and Shrubs of the Sahel, Their Characteristic and Uses. *GTZ Josef Margrave, Eschborn, Germany.*

McMillen J.M. and E.M. Wengert's. 1978. Drying eastern hardwood lumber.

Okoh, I.K.A. 1976. Moiture sorption and electrical resistivity of some woods and barks. Ph.D. Thesis. State University of New York *College of Environmental Science and Forestry. Syracuse*, N.Y.

Panshin, A.J and C.H. de Zeeuw. 1980. Textbook of Wood Technology. Volume 1. *McGraw-Hill. New York.*

Pratt, G.H. 1974. Timber Drying Manual. *BRE Report HMSO*.

Roodt, V.1988. The Shell field guide to the common trees of Okavano Delta and Moremi Game Reserve. *Shell, Botswana*. 63. pp

Shone, A.K. 1979. Notes on marula. South Africa Department of Forestry *Bulletin*, 58: 1-89.

Siau, J. F. 1971. Flow in Wood. *Syracuse University Press.*

Simpson W. T and H. N. Rosen 1981 Equilibrium moisture content of wood at high temperatures. *Wood and Fiber* 132: 150-158.

Spalt, H.A. 1972. Water vapor sorption by wood of high extractives content. *Virginia Polytechnical Institute and State University.*

Shupe, T.F.and P. Chow. 1996. Sorption, shrinkage and fiber saturation point of Kempas (*Koompassia malaccensis*). *Forest Products Journal* 46: 94-96.
Teichman, I.V. 1983. Notes on the distribution, morphology, importance and

uses of indigenous *Anacardiaceae*. The importance and uses of *Sclerocarya birrea* (the marula) *Trees in South Africa* 35: 2-7.
Teichman, I.V. 1984. Notes on the distribution, morphology, importance and uses of indigenous *Anacardiaceae*. 1. The distribution and morphology of *Sclerocarya birrea* (the marula) *Trees in South Africa* 34 (3): 35-41.

Thirakaul, S. 1984. Manual of Dendrology. Canadian Internation Department Agency (CIDA), Forest Inventory and Market Demand Survey Project, Bahr el Ghazal and Central Regions, Democratic Republic of Sudan. *Quebec*, Canada

Wangaard, F.F. and L.A. Granados. 1967. The effect of extractives on water-vapor sorption by wood. *Wood Science and Technology* 1: 253-277.

Ward, J.C.; R.A. Hann; R.C. Baltes and E.H. Bulgrin. 1972. Honeycomb and Ring Failure in Bacterially Infected Red Oak Lumber after Kiln Drying. *U.S.A., Forest Service, Forest Products Laboratory, Research* Paper 165.

Zhang, S.Y. and Y. Zhong. 1992. Structure property relationship of wood in East Liaoning oak. *Wood Science and Technology* 26 (2): 139-149.