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An Investigation on Some Physical and Mechanical Properties of Plantation Grown Paduak

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စာတမ်းအကျဉ်းချုပ်

ယခုသုတေသနလုပ်ငန်းတွင် (၂၂) နှစ်သား ပိတောက်စိုက်ခင်းမှ ပင်ကြပ်နှုတ်မည့် အပင်များအနက် ပိတောက်ပင် (၁၀) ပင်ကို ကျပန်းရွေးချယ်၍ စမ်းသပ်ထားခြင်းဖြစ်ပါသည်။ အဆိုပါ ပိတောက်စိုက်ခင်းသည် တပ်ကုန်းမြို့နယ်၊ ရမည်းသင်းခရိုင်၊ မန္တလေးတိုင်းရှိ ငလိုက်ကြိုးဝိုင်းကွက်အမှတ် (၇၂)တွင် တည်ရှိပါသည်။ ခုတ်လဲစမ်းသပ်ခဲ့သည့် သစ်ပင် (၁၀)ပင်၏ ပျမ်းမျှ ရင်စို့လုံးပတ်နှင့် ပျမ်းမျှအမြင့်သည် ၀.၇၈မီတာ (၂.၅၃ပေ) နှင့် ၂၀.၀၉မီတာ (၆၅.၀၉ပေ) အသီးသီး ရှိကြပါသည်။ သိပ်သည်းခြင်း၊ ရေချိန်သိပ်သည်းဆ၊ ကျုံ့မှုနှင့် ပုံသဏ္ဍာန်တည်မြဲမှု စသည့် ရူပ ဂုဏ်သတ္တိအချို့နှင့် တည်ငြိမ်ကွေးညွှတ်အား၊ ဖိခံနိုင်အားနှင့် မာကျောမှုစသည့် အင်အားဆိုင်ရာ ဂုဏ်သတ္တိအချို့ကို ရေဆင်း၊ သစ်တောသုတေသနဌာန၊ သစ်ဂုဏ်သတ္တိနှင့်အသုံးချမှုဌာနစုရှိ သစ်ရူပနှင့် သစ်အင်အား ဓါတ်ခွဲခန်းများတွင် စမ်းသပ်ခဲ့ပါသည်။ စမ်းသပ်မှုများကို ASTM ၏ စံချိန်စံညွှန်းသတ်မှတ်ချက်များနှင့် အညီဆောင်ရွက်ခဲ့ပါသည်။ စိုက်ခင်းပိတောက်၏ နှစ်ကွင်းနှင့် ထောင့်မတ်ကျုံ့မှု၊ နှစ်ကွင်းနှင့် အပြိုင်ကျုံ့မှု၊ ပုံသဏ္ဍာန် တည်မြဲမှုများသည် ၃.၇၈%၊ ၅.၆၁% နှင့် ၁.၄၈ အသီးသီး ရှိကြောင်း စမ်းသပ်တွေ့ရှိရပါသည်။ ထို့ကြောင့် စိုက်ခင်းပိတောက်သည် အဆင့်မြင့် သစ်အချောထည် ပစ္စည်းများထုတ်လုပ်ရန် အလားအလာ ကောင်းပါသည်။ စိုက်ခင်းပိတောက်၏ အင်အားသည် သဘာဝတောတွင် ပေါက်ရောက်သည့် ပိတောက်၏အင်အားနှင့် ထပ်တူ နီးပါးဖြစ်ကြောင်း တွေ့ရှိရပါသည်။ ယခုစမ်းသပ်ချက်များအရ၊ စိုက်ခင်းပိတောက်၏ ဂုဏ်သတ္တိများသည် သဘာဝပိတောက်၏ ဂုဏ်သတ္တိများနှင့် သိသာစွာမကွာခြားကြောင်း တွေ့ရှိရသဖြင့် သဘာဝပိတောက်ကဲ့သို့ပင် အသုံးပြုနိုင်မည်ဖြစ်ပါသည်။ ထို့ကြောင့် ပိတောက်စိုက်ခင်းများကို ယခုထက် ပိုမိုတိုးချဲ့ တည်ထောင်သင့်ပါသည်။

An Investigation on Some Physical and Mechanical Properties of Plantation Grown Padauk

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Abstract

Ten trees to be thinned were randomly selected from a 22-year old Padauk (*Pterocarpus macrocarpus*) plantation. This plantation is situated in Compartment 72, Ngalaik Reserve Forest, Takkone Township, Yamethin District, Mandalay Division. The average girth at breast height and the average height of the tested trees were found to be 0.78 meter (2.53 ft) and 20.09 meters (65.09 ft), respectively. Some physical properties, such as density, specific gravity, shrinkage and dimensional stability and some mechanical properties, namely, static bending, compression and hardness were tested at the Timber Physics and Timber Mechanics Laboratory of Wood Properties and Utilization Division, Forest Research Institute, Yezin. The tests were done in accordance with the designations in the "American Society for Testing and Materials" (ASTM). Radial shrinkage, tangential shrinkage and dimensional stability of the tested Padauk were found to be 3.78%, 5.61% and 1.48, respectively. According to its shrinkage and dimensional stability, plantation grown Padauk has a good potential for making quality wood products. The strength properties of the tested Padauk were found to be nearly the same as those of natural-grown Padauk. According to the investigated properties, plantation-grown Padauk shows no significant difference in wood properties. It can be used as naturally grown Padauk. Therefore, establishment of Padauk Plantations should be encouraged.

1. Introduction

In Myanmar, forest covers 39.588 million hectares in 1990 and 34.419 million hectares in 2000. Therefore, during this ten years period the actual forest cover degraded at average rate of 1.4% or 517,000 hectares annually. The rate of degradation of country's forested area is even more alarming (FAO, 2001).

The natural forest of Myanmar is declining due to various reasons such as over-exploitation, shifting cultivation, illegal felling, firewood collection, land use changes for agricultural and urban development, and other development activities. Due to the rising demand for forest products, it is necessary to establish large-scale plantation program. Consequently, the choice of species is the important consideration for large-scale plantation.

In the present and future situation, the utilization of forest products from natural forest has become or will be decreased due to short supply of timber. The increase of forest plantation and efficient utilization of wood from plantation-grown trees will partly solve the crisis of demand and supply of timber.

To increase production potential of Myanmar forests, a large scale planting scheme of Teak and other high-valued commercial species such as Padauk, Pyinkado, etc. has been implemented. The oldest teak plantation had been established in Myanmar about the year 1700. Many plantations started in the 1980s and Forest Department categorized four types of forest plantations. The total area of these plantations established during the period 1963 to 2002 amounted to 689,665 hectares. The constituents of forest plantations' according to different types are given in table (1.1).

Table (1.1): Types of forest plantations (1963 to 2002)

Type	Area (ha)	Constituent (Percent)
Commercial	365,522	53
Village Supply	186,210	27
Industrial	55,173	8
Watershed Protection	82,760	12
Total	689,665	100

*Data source: Forest Department (2002).

From table (1.1), it can be seen that commercial plantations have a total area of 365,522 ha, representing 53% of the total planted area. The species planted for commercial plantations in Myanmar primarily include Teak *(Tectona grandis)*, Pyinkado *(Xylia xylocarpa)*, and Padauk *(Pterocarpus macrocarpus)* and *Pinus* spp. Compositions of plantation are given in table (1.2).

Table (1.2): Compositions of plantation timber species (1963 to 2002).

No.	Species	Area (ha)	Percent
1	Teak	268,793	39
2	Pyinkado	54,261	7.9
3	Padauk	15,981	2.3
4	Pinus spp.	17,172	2.5
5	Eucalypt	75,330	10.9
6	Others	258,128	37.4
	Total	689,665	100

Data source: Forest Department (2002).

From table (1.2), it can be seen that plantation program is mainly concentrated on Teak plantation. Total area planted with Padauk until 2002 amounted to 15,981 ha, which constitutes 2.3% of all types of plantations.

However, the world timber market began to notice some of the other beautiful valuable species like Padauk, Thinwin, etc. and very good prices are offered for these timbers, sometimes even surpassing the sale price of Teak. Padauk in particular has been greatly sought for export.

On the other hand, the Forest Department has also begun to realize the danger of monoculture. In consideration of the change in the trend of timber market and the danger of monoculture, the necessity to plant other commercial species apart from teak also arises. Some commercial species (Pyinkado, Padauk, etc.) has been chosen favorably for establishment of commercial plantations, which will also improve the soil condition and accumulation of nutrient budget due to nitrogen fixation. Padauk is an indigenous species and the demand for its timber is high in market. Yearly extraction of natural Padauk exceeds that of planting, so it is imperative to increase the acreage of Padauk plantation in the near future.

Commercially Padauk timber species play an important role for the improvement of the socioeconomics life of the people of the nation. Moreover, at the same time the production of commercial timber species will increase for export.

1.1 General Information of Padauk

The genus *Pterocarpus* that belongs to the family Papilionaceae and to the order Leguminosae has five known species. They are:

(1). *P. dalbergioides* Roxb. (Andaman Padauk)

(2). *P. indicus* Wild. (Malay Padauk also known as Indian Padauk)

(3). *P. macrocarpus* Kurz (Myanmar Padauk)

(4). *P. marsupium* Roxb. (Kino tree) and

(5). *P. santalinus* Linn (Red Sanders).

Except *P. indicus*, which is a roadside-planted ornamental tree, the others are timber trees. The species *P.dabergioides, P. indicus* and *P. macrocarpus* are found in Myanmar, of which P. *macrocarpus* is a wild, native and true Padauk (Hundley, 1956).

P. *macrocarpus* Kurz was known as "Burma-Padauk" by the British or "Myanmar-Padauk" in Myanmar and as "Pradu" in Thailand (Hundley et. ai, 1987). It is a native of Myanmar and Thailand.

Padauk is found most typically in the drier parts of the country, mostly in the Upper Mixed Deciduous Forest. It ranges from 24° N latitude in the Bhamo, Mogoke and Katha Forest Divisions southward to isolated patches in Taninthayi and Mon State. On the east, it is found in Southern Shan State and Kayah State and ranges westward as far as the Arakan and Pakkoku Forest Divisions. It grows abundantly in Shwebo, Pyinmana, Manadalay, Meiktila, Yaw, Pakkoku, Pyay and Thayet Forest Divisions.

Padauk is found in undulating hilly country at elevation up to 762 m and usually most abundant in the drier sites of the ridge top and upper slopes. It occurs in rainfall areas of under 88.9 cm to over 254 cm, but seems to thrive well with a rainfall of 127 to 152.4 cm with a temperature of 45º to 110º F. It grows well on the more sandy soil, especially in a depression between tracts of semi-indaing forests (Doo, 1981).

The tree is leafless for a time in the hot season. The new leaves appear in April-May. The racemes of fragrant yellow flowers appear from March to May. The tree grows to a height of 27-30m and a girth of 3.05 m. However, ordinarily it attains a height of 18-21 m with a clear bole of 6-12 m and a girth of 1.5-2.1 m.

The leaves of Padauk are 15-18 cm long with 7 to 9 coriaceous leaflets. Leaves are compound with alternate leaflets and alternate in arrangement.

The pods are ripening in the cold season, and hang for some months on the trees and fall for the most part during and towards the end of the hot season. The pods are 4.6-7.6 cm in diameter including the wing. They are finely pubescent, light grayish brown when ripen. Their central portion is hard and bony, containing usually one, more rarely two seeds. The seeds are dolabriform, reddish brown and 1.016-1.27 cm long, with a leathery testa.

The timber of Myanmar Padauk is rather harder and heavier than Andaman Padauk, less variable in colour and only moderately coarse in texture. The color is yellowish red to brick red with occasional olden brown. The interlocked grain produces a narrow-ribbon-grain figure (Henderson, 1956). It is one of the commercial timber species of Myanmar.

Padauk can be used for cartwheels, frames of boats, and especially for furniture, gun-carriage wheels and other ordnance purposes. It is also recommended for parquetting, flooring and general cabinet work. Padauk species is fit to use as heavy construction materials. It takes wax or polish equally well. The range of movement is small and the wood may be called definitely steady. Apart from its ornamental appearance, it is the best all-round utility timber other than teak in Myanmar. It is much stronger than teak (Rodger, 1963).

1.2. Problem Statement

Andaman Padauk *(P. dalbergioides* Roxb.) was found to have very few trees with straight non-branchy boles. With Myanmar Padauk *(P. macrocarpus* Kurz) there are some straight clean boles occurring in the forests of Myanmar. With artificially planted Padauk, there are very few trees with straight clean boles (Doo, 1993).

U Saw C Doo (1981) observed that, in the fifty years old planted Padauk in Gwethe Reserve, Compartment (38), North Taungoo Forest Division, with an average height of 30.8 m, more than 50 percent of the trees are strongly forked. In many of those trees, only one 3.05 m long log could be obtained. The trees were planted close together in 1929 and the first thinning was delayed until 1956. Apparently, close spacing had little influence toward control of forking.

In 1980, 10 acres of Padauk plantation was established in Compartment 72, Ngalaik Reserve Forest, Takkone Township, Yamethin District, and Mandalay Division. It was noted that Padauk could be successfully propagated by seedlings and cuttings. However, many planted Padauk have branches in the plantations. To minimize the growth of branches, pruning was tried in the plantations.

After 13 years of growth, it was reported that Padauk produces a straight clean bole after pruning in the second and fourth year. At least two 4.57 m logs will be obtained at the time of maturity. The average height is 10.97 m and the average girth at breast height (gbh) is 0.58 m. The average volume has reached 0.22 m^3 per tree (Doo, 1993).

After 22 years of growth, this Padauk plantation was well developed. According to U Saw C Doo it was learned that, this Padauk plantation should be thinned. From this thinning, 10 sample trees were selected, for analysis of physical and mechanical properties.

According to Khin Maung Sint (2002), it was noted that, many species of wood have unique physical and mechanical properties. In wood utilization, basic information on various aspects of wood properties is inevitably important for efficient utilization of log. The choice of log should be through evaluation of log quality that can be determined by physical features such as size or shape, and also by physical properties such as density, specific gravity and moisture content. Density and moisture content can be used to classify timber species and to determine and specify timber quality such as durability and strength. Log quality can also be assessed by mechanical properties such as modulus of rupture (MOR), modulus of elasticity (MOE), etc, which are important for timber used as construction material.

The physical and mechanical properties of wood are very variable from one locality to another, from one tree to another and within a tree. According to American Society for Testing Materials (ASTM) (Anon, 1971) standard, test material should be selected from two or more localities. In this study, the trees from one locality were used to investigate the physical and mechanical properties because of the limited time and budget.

In this study, the variations in physical and mechanical properties of plantation-grown Padauk were investigated in order to provide the information in the wood quality variation for specifying and classifying the utilization of this Padauk. On this plantation-grown Padauk, physical and mechanical properties has never been investigated .

1.3. Objectives

The objectives of this study are:

(1) to investigate some of the physical and mechanical properties of plantation grown Padauk.

(2) to investigate variations in physical properties within a tree (vertical position at different heights and horizontal position at same height) and among trees.

(3) to investigate variations in mechanical properties within a tree and among trees

(4) to compare the physical and mechanical properties of plantation-grown Padauk and natural-grown Padauk and

(5) to compare the investigated properties of Padauk with those of commercially important timbers of Myanmar.

2. Literature Review

Padauk is one of the commercial timber species in Myanmar. In this research, plantation-grown Padauk is selected for investigation because of the following reasons:-

(1) The experimental plot of plantation-grown Padauk should be thinned at that time

(2) The study area is not very far from Forest Research Institute (FRI) where testing on physical and mechanical properties are to be conducted.

(3) Physical and mechanical properties of plantation-grown Padauk have never been investigated before, although natural grown Padauk had tested (Win Kyi, 1993).

As no data on physical and mechanical properties of plantation-grown Padauk are available, literature on similar problems on teak trees were reviewed. A comparison of plantation-grown Teak and natural-grown Teak are compiled by Michael C. Wiemann (1979) in the following.

Pearson (1911, 1913) compared the relative strength of natural-grown and plantation-grown teak in its native habitat in Myanmar. His first study (1911) showed little difference between natural-grown and plantation-grown teak. The plantation-grown material is somewhat stronger in shear and compression parallel to grain and slightly weaker in modulus of rupture in static bending. While the greater moisture content of plantation-grown samples (10.8% vs. 9.9%) would tend to account for the difference in modulus of rupture values, its effect should be opposite to that obtained in the shear and compression tests. Since specific gravity determinations were not carried out on the test samples, it is difficult to say how much of the strength differences could be accounted for by specific gravity differences. In any case, the tests indicate that plantation-grown and natural-grown teaks are at least roughly equivalent in strength.

Pearson's follow-up study (1913) was also conducted on natural-grown and plantation-grown samples of teak from Myanmar having roughly equivalent moisture contents (the range in moisture content for all samples was 10.8%-13.1%). Some samples were taken from the hill region of Zigon Division of Myanmar, whereas others were taken from the plains region of Zigon. In the tests on these samples, natural-grown teak from the plains region was slightly stronger than the plantation-grown samples from that region. In the case of the hill region teak, the natural grown was of superior strength in shear only, the values for compression and modulus of rupture being some what lower than those found in plantation-grown material. Since the variability between the individual test specimens was considerable, the results of the investigation suggest that there is no real difference in strength properties between plantation grown and natural-grown teak in Myanmar. Extensive tests in India (Sekhar & Rawat, 1966) have given the same results, with neither plantation-grown nor natural-grown teak showing any consistently superior strength properties.

Garratt (1959) tested strength properties on 32-year-old plantation-grown teak from Honduras. The wood had a relatively high specific gravity, and in strength properties was equivalent or superior to Myanmar teak.

Dickinson *et. al.* (1949) tested the properties of plantation-grown teak from Honduras, Their samples came from trees having an age of about twenty years. They compared the results with average values for Myanmar teak and found that, for green wood, their samples were slightly or significantly weaker except for work to maximum load in static bending, hardness, toughness, compression perpendicular to the grain and shear parallel to the grain. Upon air drying, however, the Honduras teak improved in strength to a greater extent than did the Myanmar teak; the only strength properties in which Myanmar teak maintained superiority were modulus of elasticity and modulus of rupture in static bending, tension perpendicular to the grain, and maximum crushing strength parallel to the grain. This is especially noteworthy that the Honduras teak was of lower specific gravity and higher moisture content than the Myanmar teak with which it was compared.

3. Materials and Methods

3.1. Materials

Padauk *(Pterocarpus macrocarpus* Kurz), which is one of the commercial timber species of Myanmar, has been selected for this study. The sample trees were selected from a 22 year old experimental plot established by the Forest Research Institute (F.R.I), Yezin. This plantation is situated in Compartment (72), Ngalaik Reserve Forest, Takkone Towship, Yamethin District, Mandalay Division.

In ASTM standard it is suggested that at least five trees should be tested from one locality. For this study, ten trees were selected as sample trees, since they were smaller than merchantable size.

First U Saw C Doo marked the trees, which should be thinned, in this experimental plot. From the marked trees, ten trees were randomly selected. Before felling, each sample tree was written tree number on a blaze, which was made on the north direction of the trunk.

Then, felling of sample trees was done. The felled sample trees were cut into 1.83 m long logs. Each log was written tree number and log number by silver paint. The logs were transported to F.R.I. on the same day.

The measurement results are shown in table (3.1).

Table (3.1): Girth at breast height (GBH), first fork height, second fork height, height of Padauk sample trees and number of logs from each sample trees.

Tree No.	**GBH (m)**	**First fork height from the base**	**Second fork height from the base (m)**	**Height (m)**	**Number of logs Obtained**
1	0.88	15.24	-	21.34	2
2	0.70	9.57	-	18.29	3
3	0.76	13.72	-	21.34	3
4	0.91	4.57	6.40	23.16	2
5	0.70	11.49	-	20.73	2
6	0.70	8.53	-	22.86	3
7	1.28	3.96	9.45	18.29	4
8	0.98	10.96	-	22.25	2
9	0.88	-	-	6.10	3
10	0.98	8.23	-	26.52	3
AV.	0.78			20.09	

In addition to selection marking, felling and logging, other operations were carried out in fieldwork.

(1) Measurement of the whole length of a felled tree before cutting.

(2) Measurement of first fork height from the base of the felled tree before cutting.

(3) Measurement of second fork height from the base of the felled tree before cutting.

(4) Counting of growth rings at the stump.

Authentication and identification of plant specimens and wood samples were done in the Herbarium Section and Wood Anatomy Section in F.RI, Yezin.

3.2. Study Area

The location of experimental plot is in Compartment (72), Ngalaik Reserve Forest, Takkone Township, Yamethin District, Mandalay Division. The forest type is moist upper mixed deciduous forest at 450 feet above mean sea level. The maximum temperature in 1983, May is 42.5°C and minimum temperature in 1997, January is 12.1°C (for the period 1970-1999). The maximum highest rainfall in 1999 is 1941 mm and the minimum lowest rainfall in 1978 is 898 mm. The average maximum lowest rainfall is in August (270.5 mm) and average minimum rainfall is in February (2.6 mm) [for the period from 1970-1999]. The prevailing type of soil and rocks is loose coarse reddish brown gritty sand, and yellowish sand- stone, with bed of gravel. Soil analysis indicates the acidity of soil (pH 6) and deficiency in phosphate. A ridge from North to South has one slope at eastern aspect and another at western aspect. The slope is approximately 25 percent.

3.3. Methods

Some physical properties such as radial shrinkage, tangential shrinkage, longitudinal shrinkage, density and specific gravity, and some mechanical properties such as static bending, compression parallel to grain, compression perpendicular to grain and hardness tests were tested in this study.

Tests on physical properties and mechanical properties were carried out in Timber Physics and Timber Mechanics Laboratory, F.RI.

For physical properties, the preparation and testing of specimens were conducted, according to ASTM standard 0143-52.

For mechanical properties, the preparation and testing of specimens were based on BS (British Standard) 373: 1957.

All the tested samples were prepared at F.RI. Wood Workshop.

3.3.1 Physical properties

Tests on some physical properties such as radial shrinkage, tangential shrinkage, longitudinal shrinkage, density and specific gravity were carried out in this study.

3.3.1.1 Sample preparation of disks

For sample preparation, two disks, each about 76.2 mm thick, and one disk about 127 mm thick were cut from the base of each log. Physical properties were investigated from each log so that they should be compared in different heights. Before the three disks were cut, one disk at the base of each log was removed in order to avoid end checks and moisture loss. After the disks have been cut from each log, they were marked with silver paint. Each disk had tree number and disk number.

When they were not immediately used for specimen preparation, they were soaked in a water tank to avoid end checks and moisture loss.

3.3.1.2 Preparation of specimen

One disk about 76.2 mm thick was used to prepare specimens for determination of radial shrinkage. It must be noted that, the length of specimen is parallel to the rays. Sanding is necessary process to remove splinters from the specimen.

The other disk 76.2 mm thick was used to prepare specimens for determination of tangential shrinkage. It is of great importance that the length of specimen is perpendicular to the rays. Sanding is a necessary process.

A disk about 127 mm thick was used to prepare specimens for determination of longitudinal shrinkage. It is of great importance that the length of specimen is parallel to the grain. In this study, the specimens for longitudinal shrinkage were used for determination of volumetric shrinkage, density and specific gravity.

Each specimen has tree number (1 to 10), notation for heartwood (H) or sapwood (S), notation for radial (R), tangential (T) or longitudinal (L) shrinkage and the serial number 1 to 6).

In ASTM standard, 1"x1"x 4" size and four specimens from each bolt should be taken for determination of radial and tangential shrinkage and 2"x2"x 6" size and six specimens should be taken for longitudinal shrinkage, volumetric shrinkage, density and specific gravity. In this study, the sizes of specimens cannot be obtained as mentioned in the standard procedure. Therefore, the dimensions of specimens were reduced to the sizes as given in table (3.2).

Table (3.2): Size and total number of specimens for physical properties.

No.	Type of test	Size of scecimen (mm3)
1	Radial shrinkage	25.4x25.4x50.8
2	Tangential shrinkage	25.4x25.4x50.8
3	Longitudinal shrinkage	20x20x80
4	Volumetric shrinkage	20x20x80
5	Density	20x20x80
6	Specific gravity	20x20x80

The green test specimens were soaked in a water tank if they were not tested immediately. The specimens for air-dry tests were air-dried under room conditions to get nearest 12% moisture content.

3.3.1.3 Testing procedures

The specimens were weighed and measured for determination of shrinkage and moisture while green and the data were recorded. For weighing specimens, an electrical digital balance was used and two decimal places were read. And, for measuring the length of the specimens, a manual caliper was used and three decimal places were read. To determine volumetric shrinkage, specific gravity and density, water displacement method was used in determining volume. Then, they were air-dried. They were weighed and measured almost once a week. When they had attained constant weights and measurements under air-drying, the data were recorded. Then, they were oven-dried at a temperature of 103±20ºC until they had attained constant weights. During oven drying, weighing and measuring the samples were carried out every day.

3.3.2. Mechanical Properties

In this study, some mechanical tests such as static bending, compression parallel to grain, compression perpendicular to grain and hardness were conducted. From these tests, some mechanical properties were calculated.

3.3.2.1 Sample Preparation of Sticks

The bolts remained 1.22-1.37 m long after cutting the disks for preparation of specimens for physical tests. The remaining parts of these bolts were used for testing mechanical properties. A sketch was drawn on the top end of the bolts by using a ruler to join cardinal points (East, West, North, South directions) as shown in Fig (3.1). The bolts were marked on the top end into 30 mm x 30 mm square sticks. All test sticks include tree number (1 to 10), cardinal point (East (E), West (W), North (N), South (S)), stick number (1 to 12) and bolt number (a, b, c).

The sticks were divided into two groups, one for green test and the other for air-dry test. The method of selection is shown in table (3.3).

Table (3.3): Sticks for green and air-dry tests

No.	Bolt	Sticks for green test	Sticks for air-dry test
1	a and c	1, 4, 5, 8, 9, etc.	2, 3, 6, 7, 10, 11, etc
2	band d	2,3,6,7,10,11, etc	1, 4, 5, 8, 9, etc.

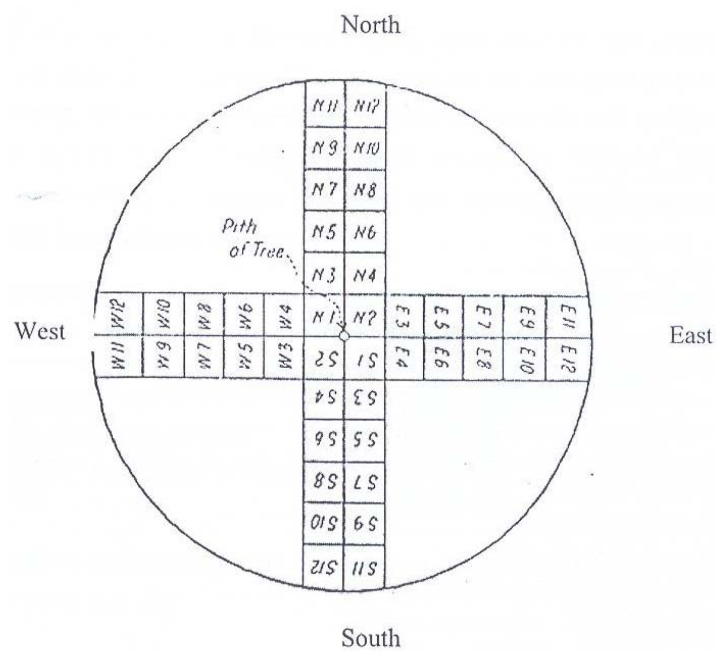

Figure 3.1. Sketch showing method of cutting up the bolt and marking the sticks.

3.3.2.2 Preparation of specimens

For mechanical properties, true flat-sawn sticks were used for the preparation of specimens. All sticks are dressed to 20 mm square and cut into specimens of 300 mm for static bending, 80 mm for compression parallel to grain, 60 mm for compression perpendicular and 60 mm for hardness. A small circular saw machine was used to prepare the specimens for mechanical properties test. These specimens were free from defects such as knots, checks, splits, etc.

The dimensions of specimens prepared for various tests were shown in table (3.4).

Table (3.4): Size of specimens for mechanical properties

No.	Test	Size of specimen (mm3)
1	Static bending	20x20x300
2	Compression parallel to grain	20x20x80
3	Compression perpendicular to grain	20x20x60
4	Hardness	20x20x60

When they were not immediately used for specimen preparation of green test, they were stored under damp saw dust.

3.3.2.3 Testing procedure

For testing of mechanical properties, a Shimadzu Autograph Universal Testing Machine was used.

For static bending, the test piece of size 20 mm x 20 mm x 300 mm was supported and center loading was used with a span length of 280 mm. The load was applied to the center of the specimen at a constant rate of 6.5 mm/ min. The test specimen was placed so that the load will be applied through the bearing block to the tangential surface nearest to the pith. Before testing, the actual dimensions of specimens were taken. The type of failure for each test specimen was recorded.

For compression parallel to grain, the load was applied continuously throughout the test at a rate of motion of the movable crosshead of 0.6 mm/min. Before testing, the actual dimensions and length of specimens were measured. Testing was continued until the specimens came across with failure. The type of failure for each test specimen was recorded. For determination of moisture of test specimens, a moisture section 25.4 mm long was cut near failure.

For compression perpendicular to grain, the load was applied through a metal plate about 20 mm in width, which was placed across the upper surface of the specimen at equidistance from the ends at right angles to the length. The load was applied through the bearing plate to a radial surface at a rate of 0.3 mm/min. Before testing, the actual breadth of specimen was measured. Testing was continued until the specimens came to be a failure.

For hardness tests, an especially hardened steel tool rounded to a diameter of 11.28 mm (0.444 in) is embedded in the specimen to a depth corresponding to half its diameter at a rate of 6.3 mm/min. A record was made of the maximum load, which was required to embed the steel ball into the specimen to the desired depth of 5.64 mm (0.222 in). This test was done on the radial, tangential and end surfaces.

4. Results and Discussion

4.1 Physical Properties of Plantation-Grown Padauk

4.1.1 Radial Shrinkage

The mean of oven-dry radial shrinkage of each sample tree for Padauk is given in table (4.1). The number of specimens per tree, standard deviation, minimum and maximum values, coefficient of variation and 95% confidence limit are also given. The value of coefficient of variation for radial shrinkage can be high up to 15% (Anon, 1974). The average coefficient of variations of sample trees is slightly greater than 15%. This is due to the great difference in shrinkage between heartwood and sapwood.

The significance test of the effects of trees, sections, wood zones and their interactions on oven-dry radial shrinkage of Padauk is conducted with the help of Statistica (Anova/Manova). The investigation on radial shrinkage could not be done for section 'c' of the trees 1, 4, 5 and 8, because section 'c' of these trees is too small to differentiate sapwood from heartwood. Therefore, the design is incomplete to test all trees and all sections. Thus, these trees are omitted in the significance test of these effects.

Table (4.1): Radial shrinkage of Padauk from green to oven-dry (%)

Tree	Means	N	Std. Dev.	Min	Max	CV%	95%conf.
1	3.527	30	0.654	2.873	4.181	18.54	0.234
2	3.445	39	0.818	2.627	4.263	23.75	0.257
3	4.304	30	0.850	3.454	5.155	19.75	0.304
4	3.393	26	0.522	2.871	3.915	15.38	0.201
5	3.710	22	0.422	3.288	4.132	11.37	0.176
6	3.657	26	0.655	3.002	4.312	17.91	0.252
7	3.446	53	0.600	2.846	4.046	17.41	0.162
8	3.300	30	0.367	2.933	3.667	11.12	0.131
9	4.885	36	0.567	4.317	5.452	11.61	0.185
10	4.156	41	0.658	3.498	4.815	15.84	0.201
All Groups	3.782	333	0.611	3.171	4.394	16.16	0.066

The effect of the interaction between trees and zones is not significant, which means that the zonal or horizontal variation is the same for all trees in general.

The effect of the interaction between sections and wood zones is significant, which means that the horizontal variation in radial shrinkage is not the same for all sections.

The interaction effect among trees, sections and wood zones is also significant, which means that the significant horizontal and vertical variation are not the same for all trees.

To investigate which trees show significant difference in oven-dry radial shrinkage among trees, tree means of radial shrinkage are compared for significance by Tukey's HSD test.

According to the test results, every tree shows a significant variation in oven-dry radial shrinkage from some of other sample trees. Trees 2 and 7, with the lowest radial shrinkage of 3.444% and 3.446%, are found to be significantly different from trees 3, 9 and 10. Similarly, tree 9, with the largest radial shrinkage of 4.885%, is found to be significantly different from most of other sample trees. The other trees, which radial shrinkage is not so much different from each other, show significant variation from some of the others.

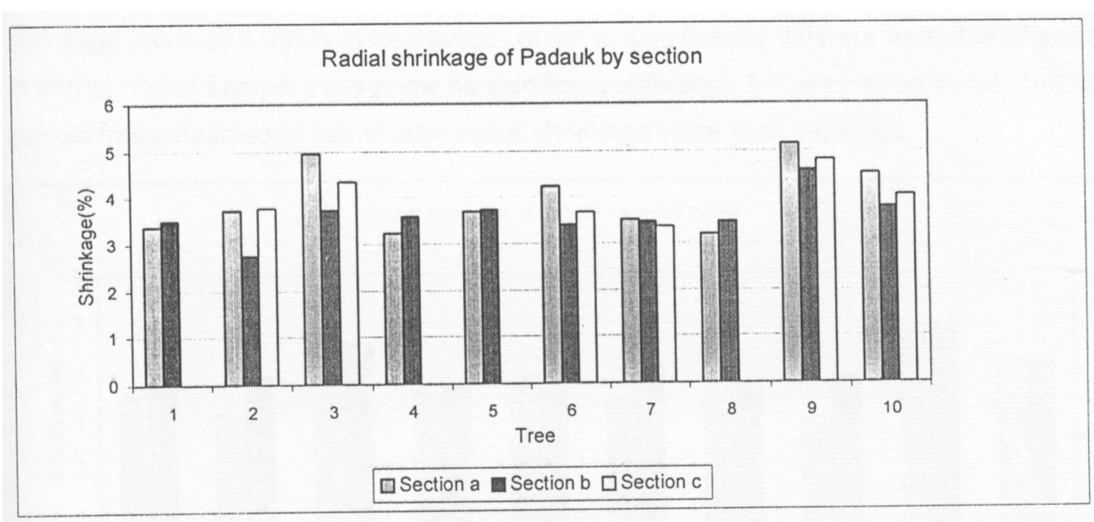

Figure 4.1. Sectional oven-dry radial shrinkage of Padauk.

The Tukey's significant difference test shows that the oven-dry radial shrinkage of section 'a' is significantly different from those of sections 'b' and 'c'. The largest shrinkage is found in section 'a' and section 'c' to have higher shrinkage than section 'b' in most sample trees.

According to two samples T-test for independent variables, oven-dry radial shrinkage of heartwood is significantly different from that of sapwood. It is found that the radial shrinkage of heartwood is less than that of sapwood.

To investigate which trees show significant variation in oven-dry radial shrinkage in vertical direction within trees, sectional means of each tree are compared for significant difference.

Two trees show significant variation in oven-dry radial shrinkage in vertical direction. In tree 2, section 'b' is significantly different from other sections. Section 'b' has the lowest radial shrinkage of 2.757% and section 'c' the highest value of 3.768%. In tree 3, section 'b' is significantly different from other sections. Section 'b' has the lowest radial shrinkage of 3.734% and section 'a' the highest value of 4.954%.

In almost all sample trees, section 'a' has the largest oven-dry radial shrinkage and section 'b' the smallest value. And, section 'c' is larger in the shrinkage than section 'b'. But, there is no definite increasing or decreasing trend with height.

In order to investigate which trees are significantly different in oven-dry radial shrinkage in horizontal direction, average values of each tree are compared by wood zones.

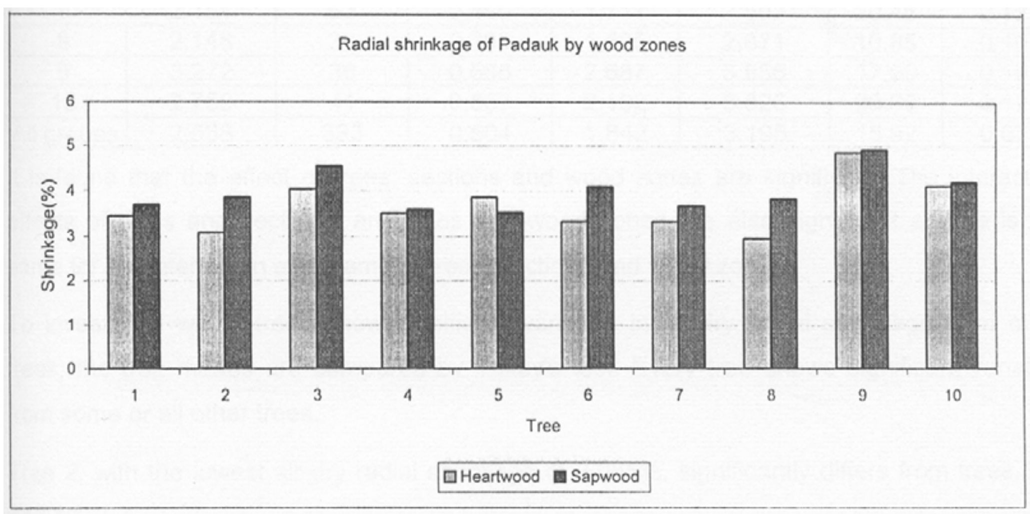

Figure 4.2. Oven-dry radial shrinkage of Padauk by wood zones.

One tree out of six shows significant variations among wood zones. Tree 2 has the least shrinkage value of 3.085% in heartwood, which is significantly different from that of sapwood (3.865%). Other sample trees show no significant difference between wood zones. But, for all sample trees, heartwood has smaller radial shrinkage value than sapwood.

Panshin and de Zeeuw (1980) stated that heartwood containing extractives shrinks less than sapwood of the same species. This statement may perhaps hold true for Padauk trees because in all sample trees, the value of oven-dry radial shrinkage of heartwood is smaller than that of sapwood.

4.1.2. Tangential Shrinkage

According to the investigations carried out for this research, the average values of tangential shrinkage from green to oven-dry conditions are shown in table (4.4). The number of specimens, standard deviation, coefficient of variation, and minimum and maximum values for each sample tree are presented in table (4.4).

Table (4.4): Oven-dry tangential shrinkage of Padauk sample trees (%)

Tree	Means	N	Std.Dev.	Min	Max	CV%	95%confid.
1	5.633	31	0.720	4.913	6.353	12.78	0.253
2	6.204	21	0.895	5.309	7.099	14.43	0.383
3	5.649	18	1.416	4.233	7.065	25.07	0.654
4	5.539	26	0.737	4.802	6.276	13.31	0.283
5	5.600	20	0.600	5.000	6.200	10.71	0.263
6	5.446	13	0.366	5.080	5.812	6.72	0.199
7	5.434	30	0.840	4.594	6.274	15.46	0.301
8	5.614	27	1.339	4.275	6.953	23.86	0.505
9	5.349	23	0.541	4.808	5.890	10.12	0.221
10	5.649	22	0.394	5.255	6.043	6.97	0.165
All Groups	5.612	231	0.720	4.827	6.396	12.83	0.323

The value of coefficient of variation for tangential shrinkage can be high up to 15% (Anon, 1974). In sample trees 3 and 8, the coefficients of variation are larger than 15%. As a result, these values for sample trees 3 and 8 are somewhat high. But, the overall mean of oven-dry tangential shrinkage for Padauk tree is less than 15%, which might mean that the results are to be reliable.

The test of significance of the effect of trees, sections, wood zones and their interactions is conducted with the use of Statistica (Anova/Manova). The investigation of tangential shrinkage could not be done for heartwood and sapwood of trees 6 and 8. The design is incomplete to test all trees and all zones. Thus, the trees are omitted in the test of the effect of significance. The effect of trees and sections is significant and so is the effect of wood zones. This means that there is a general significant variation in oven-dry tangential shrinkage between different heights of a tree and between trees, and between sapwood and heartwood.

The effect of interaction between trees and sections are not significant. This means that the sectional variation will be homogeneous for all trees.

The effect of interaction between trees and wood zones is also significant. So the zonal variation in oven-dry tangential shrinkage will not be the same for all trees. The interaction effect among trees, sections and wood zones is significant. The zonal and sectional variation of one tree will not be the same with those of other trees.

As the effect of trees is significant, the comparison of significant difference is carried out according to Tukey's test. Trees 7 and 9, with the least tangential shrinkage values of 5.434% and 5.349%, are significantly different from tree 2, with the largest tangential shrinkage value of 6.204%. Other sample trees are not significantly different from each other.

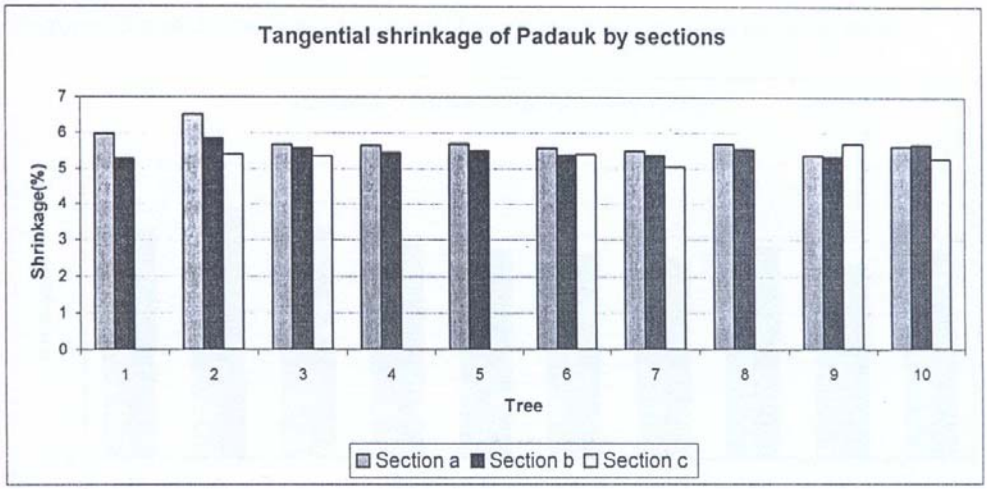

Figure 4.3. Sectional oven-dry tangential shrinkage of Padauk.

In order to investigate which trees show significant difference in oven-dry tangential shrinkage at different heights, the average oven-dry tangential shrinkage values of each tree are compared by sections with the use of Tukey's test. There is no significant difference in different heights of each sample tree. But there is a significant difference between sectional means of all trees. It can be found that section 'a' is significantly different from section 'b'. The largest shrinkage is found in section 'a' and the smallest shrinkage value in section 'b'.

The trend of variation in oven-dry tangential shrinkage is difficult to define. It is not an increasing or decreasing trend with height.

According to two samples T-test for independent variables, oven-dry tangential shrinkage in sapwood is significantly different from heartwood. For all sample trees, the value of tangential shrinkage of heartwood is smaller than that of sapwood.

In order to investigate which trees are significantly different in oven-dry tangential shrinkage in horizontal direction, the average values of each tree are compared by wood zones.

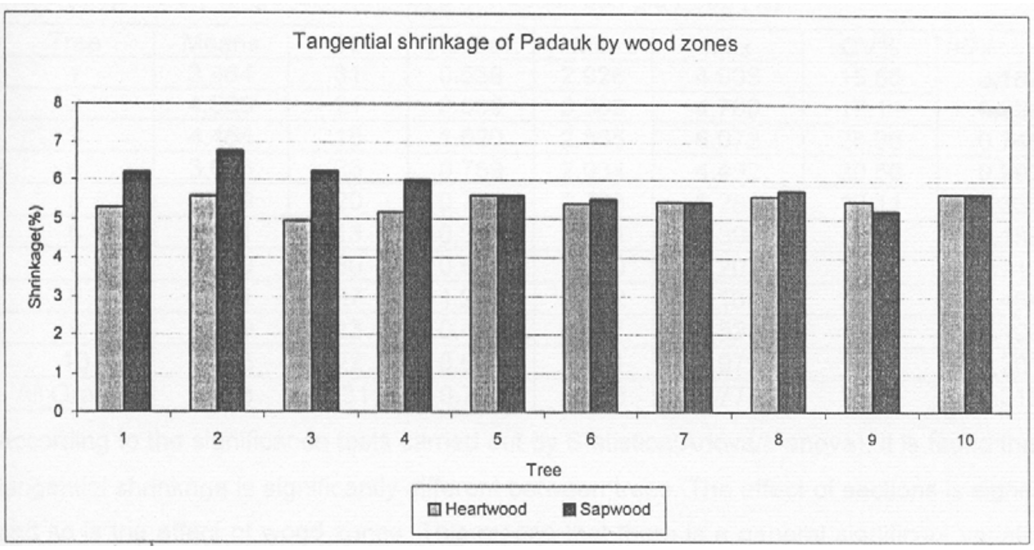

Figure 4.4. Oven-dry tangential shrinkage of Padauk by wood zones.

There are three trees out of six, which show significant variations among wood zones. Tree 1 has smaller shrinkage value (5.276%) in heartwood, which is significantly different from that of sapwood (6.198%).

In tree 2, heartwood, with smaller shrinkage of 5.574%, is significantly different from sapwood, with the value of 6.777%.

In tree 3, heartwood with smaller shrinkage value of 4.946%, is significantly different from sapwood, with the value of 6.212%.

In most trees, heartwood has smaller oven-dry tangential shrinkage than sapwood. It can be firmly said, that oven-dry tangential shrinkage of Paduak is smaller in heartwood than sapwood.

4.1.3. Volumetric Shrinkage

The volumetric shrinkage from green to oven-dry was determined by the formula,

$$VS\% = [(V_g - V_{od}) / V_g] * 100$$

where VS = Volumetric shrinkage in percent.

V_g = Green volume of specimen

V_{od} = Oven-dry volume of the specimen

The volume of the specimen is determined by the water displacement method.

The average values of volumetric shrinkage of Padauk are given in table (4.5). In the table, the number of specimens per tree, standard deviation within trees, minimum and maximum values, coefficients of variation and 95% confidence limits are also given. The average volumetric shrinkage is from 9.925% to 10.383% at 95% confidence level. The value of coefficient of variation for volumetric shrinkage can be high up to 15% (Anon, 1974). The coefficient of variation is around 10% for two sample trees and around 15% for two sample trees. Those of other trees are far greater than 15%, which mean that the individual values of each tree are much dispersed.

The test of significance of the effects of trees, sections, wood zones and their interaction is carried out with the use of Statistica (Anova/Manova). The investigation on volumetric shrinkage could not be done for section 'c' of the trees 1, 4, 5 and 8, because the section 'c' of these trees is too small to differentiate sapwood from heartwood. Therefore, the design is incomplete to test all trees and all sections. Thus, these trees are omitted in the test of the effect of significance.

Table (4.5): Average volumetric shrinkage of Padauk sample trees (%).

Tree	Means	N	Std. Dev.	Min	Max	CV%	95%conf.
1	9.676	35	2.4 79	7.197	12.155	18.62	0.821
2	11.477	32	1.302	10.175	12.779	11.34	0.451
3	10.979	31	3.717	7.262	14.697	17.86	1.309
4	8.967	31	2.257	6.710	11.223	18.17	0.794
5	9.874	20	1.081	8.793	10.955	10.95	0.474
6	11.757	36	3.522	8.235	15.280	19.96	1.151
7	10.337	50	2.517	7.820	12.854	14.35	0.698
8	7.480	31	1.333	6.147	8.812	17.82	0.469
9	10.766	36	2.035	8.730	12.801	18.91	0.665
10	10.227	45	1.545	8.682	11.771	15.11	0.451
All groups	10.154	347	2.179	7.975	12.333	16.46	0.229

The effect of trees is significant on the volumetric shrinkage in Padauk trees, which means that the mean volumetric shrinkage of sample trees are not the same, and volumetric shrinkage varies between trees.

To investigate which trees show significant difference from others, Tukey's test is conducted. It is found that, tree 10 has the smallest value of 10.227% and is significantly different from tree 6 with the largest value of 11.757%. Other trees show no significant difference from one another.

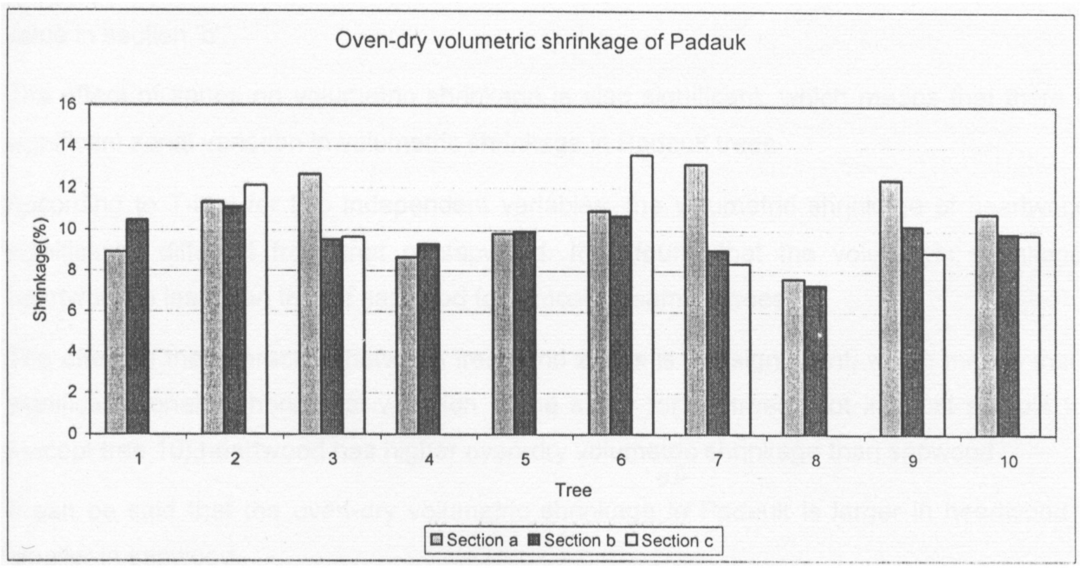

Figure 4.5. Section oven-dry volumetric shrinkage of Padauk.

The effect of sections on volumetric shrinkage is significant, which means that the mean volumetric shrinkage of sections is not the same in general.

The Tukey's significant difference test reveals that the volumetric shrinkage of section 'a' is significantly different from those of sections 'b' and 'c'. There is no significant difference between sections 'b' and 'c'. The largest shrinkage is found in section 'a' and the smallest value in section 'b'.

The effect of zones on volumetric shrinkage is also significant, which means that there is a significant zonal variation in volumetric shrinkage in Padauk trees.

According to T-test for two independent variables, the volumetric shrinkage of heartwood is significantly different from that of sapwood. It is found that the volumetric shrinkage of heartwood is less than that of sapwood for almost all sample trees.

The effect of the interaction between trees and zones is not significant, which means that the significant zonal or horizontal variation is the same for all trees. But in most sample trees (except tree 10), heartwood has higher oven-dry volumetric shrinkage than sapwood.

It can be said that the oven-dry volumetric shrinkage of Padauk is larger in heartwood and smaller in sapwood.

The effect of the interaction between sections and wood zones is significant, which means that the horizontal variation in volumetric shrinkage is not the same for all sections.

The interaction effect among trees, sections and wood zones is not significant, which means that the significant horizontal and vertical variation are the same for all trees.

The effect of the interaction between trees and sections is significant, which means that significant sectional variation (vertical variation) will not be the same for all sample trees.

In order to investigate the vertically significant variation in shrinkage, the values of the sections of each tree are tested for significant difference at 95% probability level. Two trees out of six, show a significant variation in volumetric shrinkage within trees.

In tree 7, section 'a' has the highest shrinkage value of 13.167% and significantly differs from sections 'b' and 'c', but 'b' and 'c' shows no significant variation.

In tree 9, section 'a' shows significant difference from section 'e'. Section 'c' has the smallest shrinkage value of 8.917% and section 'a' has the highest shrinkage value of 12.451%.

In volumetric shrinkage of vertical direction, it is difficult to define the trend of shrinkage with height.

4.1.4. Density of Padauk

4.1.4.1. Oven dry density

It is the ratio of oven-dry weight to oven-dry volume of a specimen. The oven-dry density of each sample Padauk tree is given in the table (4.6). The number of specimens per tree, standard deviation within trees, minimum and maximum values, coefficient of variation and 95% confidence limits are also given in the table. The mean oven-dry density ranges from 754 kgm^{-3} to 874 kgm^{-3} at 95% probability level. The coefficients of variation are found to be lower than 10%, which means that the individual values of each tree are not much dispersed and the result is assumed to be precise.

Table (4.6): Oven-dry density of Padauk (kgm^{-3})

Tree	Mean	N	Std. Dev.	Min	Max	CV%	95%conf.
1	827	35	46.91	780	874	5.67	15.54
2	794	32	62.85	731	857	7.92	21.78
3	808	31	69.30	739	877	8.58	24.39
4	807	31	75.96	731	883	9.41	26.74
5	815	20	51.07	764	866	6.27	22.38
6	817	36	74.09	743	891	9.07	24.20
7	838	50	42.37	796	880	5.06	11.75
8	776	31	40.74	735	817	5.25	14.34
9	849	36	64.19	785	913	7.56	20.97
10	822	45	75.55	746	898	9.19	22.08
All groups	814	347	60.30	754	874	7.41	20.42

In order to investigate the effect of trees, sections, wood zones and their interactions on oven-dry density of Padauk, the significant test is conducted with the use of Statistica (Anova/Manova). The investigation on density could not be done for section 'c' of the trees 1, 4, 5 and 8, because section 'c' of these trees is too small to differentiate sapwood from heartwood. Therefore, the design is incomplete to test all trees and all sections. Thus, these trees are omitted in the test of the effect of significance.

It is found that there are significant effects of trees, sections, and wood zones. The interaction effects between trees and sections, between trees and zones, and also between sections and wood zones are also significant. But the interaction effects among trees, sections and wood zones are not significant.

The significant variation in oven-dry density of Padauk does exist between trees. This also holds true within trees.

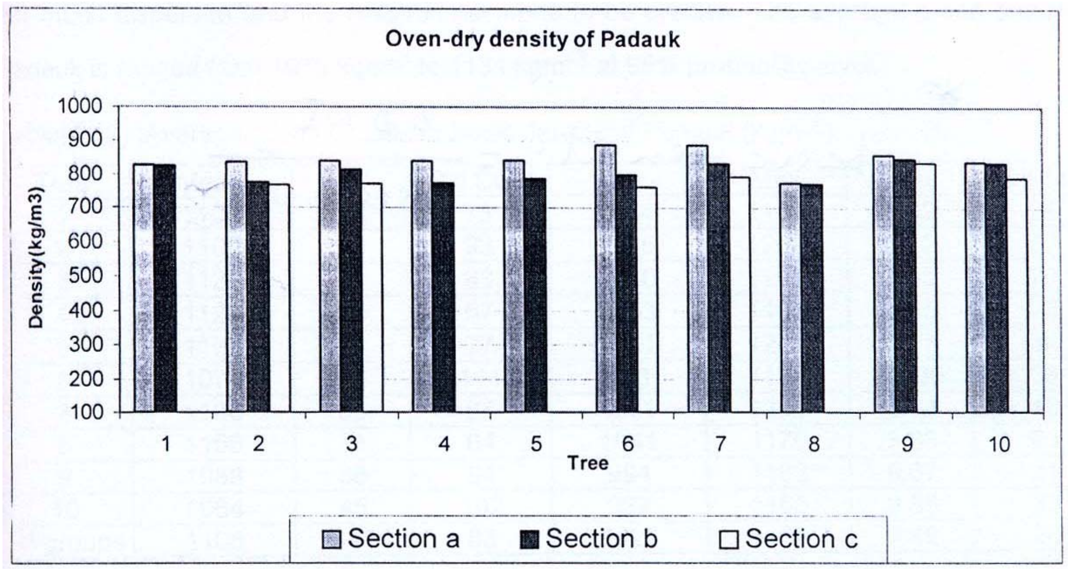

Figure 4.6. Sectional oven-dry density of Padauk.

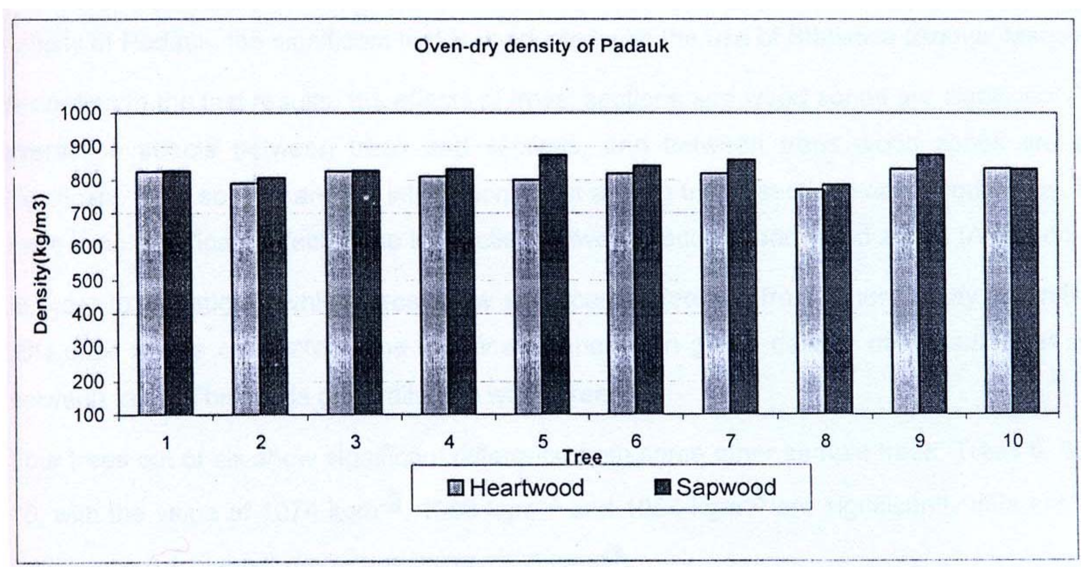

Figure 4.7. Zonal oven-dry density of Padauk.

To investigate which trees show significant difference from others, Tukey's significant difference test is conducted.

Five trees show significant difference in oven-dry density.

It can be seen that, tree 9, with the largest oven-dry density of 849 kgm^{-3} significantly differs from all other sample trees, except tree 7.

Trees 2, 3, 6 and 10 show significant differences from tree 9.

It is found that in Padauk trees, there is a significant variation in oven-dry density in different heights of the same tree. To investigate which trees show significant differences in vertical direction of the same trees, Tukey's test is conducted for comparison of the averages of the sections of each tree.

All sample trees show significant differences within trees in vertical direction.

In tree 2, section 'a' with the largest oven-dry density of 838 kgm^{-3}, is significantly different from sections 'b' and 'c' of the same tree, but 'b' and 'c' show no significant difference among themselves.

In tree 3, section 'a' with the largest oven-dry density of 840 kgm^{-3}, is significantly different from section 'b' and 'c' of the same tree, but these sections show no significant difference among themselves.

In tree 6, section 'a' has the largest oven-dry density of 890 kgm^{-3}, and is significantly different from sections 'b' and 'c'.

In tree 7, section 'a' has the largest density of 889 kgm^{-3}, and shows significant differences from sections 'b' and 'c', which have the smallest value of 834 kgm^{-3} and 793 kgm^{-3} respectively.

In tree 9, section 'a' has the largest density of 860 kgm^{-3}, shows a significant difference from sections 'b' and 'c'.

In tree 10, section 'a' has the largest density value and is significantly different from sections 'b' and 'c'.

It can be firmly said that the oven-dry density decreases with heights in all Padauk sample trees.

Kollmann (1968) stated that the butt log contains wood of the greatest density and that the lowest density occurs in upper portion. Brown *et al* (1951) concluded from their investigation that the density is the highest of the base and lowest in the upper portion. Padauk seems to follows this tendency.

To investigate which trees show horizontal significant differences within trees, "two samples test for independent variables" is conducted.

It is found that only one tree out of six shows a significant difference in oven-dry density between wood zones of the same tree.

In tree 6, sapwood has the larger oven-dry density of 860 kgm^{-3}, and is significantly different from heartwood with the value of 832 kgm^{-3}.

In all sample trees, it is clear in Padauk that heartwood (nearest to pith) has the lower oven-dry density, while sapwood (nearest to the bark) has the larger.

4.1.4.2. Green density

The green density is the ratio of green weight to green volume of Padauk wood. The mean value of each sample tree, the number of specimens per tree, standard deviation within trees, maximum and minimum values, coefficient of variation and 95% confidence limit are given in table (4.7). The coefficient of variation within trees can be high up to 10% (Anon, 1974). In this case, the coefficient values are lower than 10% in most sample trees, and the coefficient of variation is around 10% for tree '6', this means that the individual values of each tree are not much dispersed and the result is assumed to be precise. The average green density of Padauk is ranged from 1078kgm^{-3} to 1134kgm^{-3} at 95% probability level.

Table(4.7) :Average green density of Padauk (kgm^{-3}).

Tree	Mean	N	Std. Dev.	Min	Max	CV%	95%conf.
1	1107	35	73	1034	1180	6.62	24
2	1109	32	93	1016	1202	8.42	32
3	1123	31	83	1040	1205	7.35	29
4	1120	31	67	1053	1186	5.95	23
5	1137	20	77	1061	1214	6.77	34
6	1074	36	111	963	1184	10.30	36
7	1136	50	65	1071	1201	5.74	18
8	1106	31	64	1041	1170	5.83	23
9	1088	36	94	994	1182	8.67	31
10	1064	45	102	962	1165	9.55	30
All groups	1106	347	83	1023	1189	7.49	28

In order to investigate the effect of trees, sections, wood zones and their interactions on green density of Padauk, the significant test is conducted with the use of Statistica (Anova/ Manova).

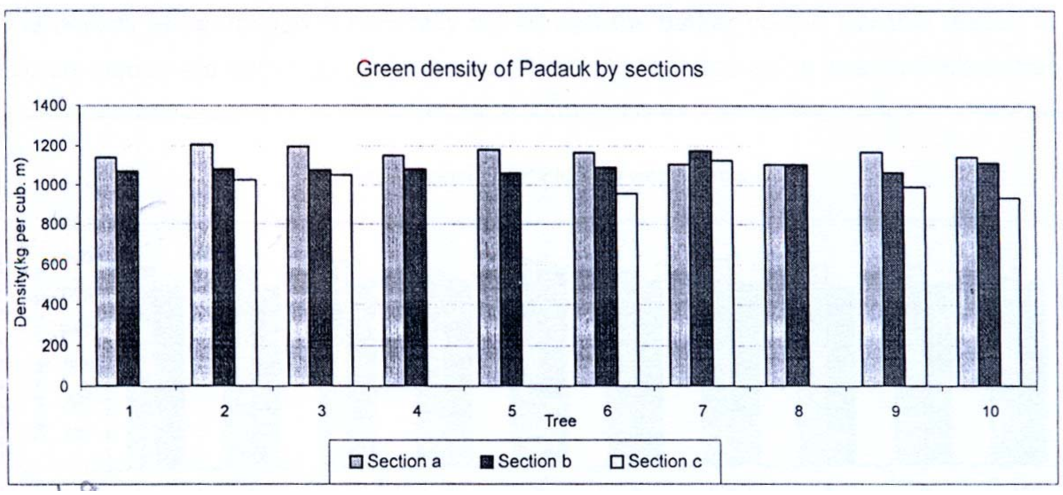

Figure 4.8. Sectional green density of Padauk.

According to the test results, the effects of trees, sections and wood zones are significant. The interaction effects between trees and sections, and between trees wood zones are also significant. And, so also are the interaction effect among trees, sections and wood zones. But, there is no significant effect of the interaction between sections and wood zones.

In order to investigate which trees show significant difference from other, Tukey's significant difference test is conducted. The significant variation in green density of Padauk does exist between trees. This holds generally true within trees.

Four trees out of six show significant difference from some other sample trees. Trees 6, 9 and 10, with the value of 1074 kgm^{-3}, 1088 kgm^{-3} and 1064 kgm^{-3} are significantly different from tree 7, with the highest green density of 1136 kgm^{-3}.

To investigate vertical variation in green density within trees, sectional means of green density are compared for significant difference test at 95% probability level.

According to the test results, all trees show significant vertical variation in green density within tree.

In trees 2, 3 and 9, section 'a' that has the highest green density is significantly different from sections 'b' and 'c'. The largest green density is found in section 'a' and section 'b' to have higher density than section 'c' in these trees.

In tree 6, section 'a' has the highest green density of 1168 kgm^{-3} and is significantly different from section 'c', Section 'c' has the lowest value of 955 kgm^{-3} in that tree. And, section 'c' differs significantly from sections 'a' and 'b'.

In tree 7, section 'b' has the highest green density of 1173 kgm^{-3} and is significantly different from section 'a'. In all sample trees (except tree 7), section 'a' is found to have the highest and section 'b' to have higher green density than section 'c',

As in the oven-dry density, it can be said that the green density decreases with heights in all Padauk sample (except tree 7).

According to Kollman (1968) and Brown *et. al.* (1952), the density is highest at the base and lowest in the upper portion. Therefore, Padauk seems to follow this tendency.

To investigate the horizontal variation in green density of Padauk wood within trees, the zonal means of each tree are again compared for significant differences.

Five trees show significant differences between heartwood and sapwood. In trees 2, 3, 6, 7 and 9, heartwood significantly differs from sapwood. Heartwood has higher green density than sapwood.

The density of heartwood is generally higher with the darker colour. For this reason coloured tropical woods are rather heavy (Kollmann, 1968). This statement is true for Padauk trees.

4.1.4.3. Density of Padauk at 12% moisture content

It is a calculated parameter from the green density. The calculated density of Padauk at 12% moisture content is given in the table (4.8). So it is assumed to have the same trend of variation of green density between trees and within trees. It could not be investigated, as it is somewhat difficult to determine air-dry volume at 12% moisture content. In fact, it is the ratio of the weight of wood to its volume. Both are to be determined at 12% moisture content.

Table (4.8): Density of Padauk at 12% moisture content (kgm^{-3}).

Tree	Mean	N	Std. Dev.	Min	Max	CV%	95%conf.
1	880	35	67.37	845	947	7.66	22.32
2	876	32	79.40	844	955	9.07	27.51
3	940	31	82.70	909	1022	8.80	29.11
4	910	31	96.89	879	1007	10.64	34.11
5	934	20	64.58	914	998	6.92	28.30
6	849	36	105.49	813	955	12.42	34.46
7	897	50	37.31	847	934	4.16	10.34
8	892	31	58.02	861	950	6.51	20.42
9	870	36	68.67	834	939	7.89	22.43
10	873	45	89.19	828	963	10.21	26.06
All groups	892	347	74.96	857	967	8.40	25.51

4.1.5. Specific gravity

4.1.5.1. Basic specific gravity

The basic specific gravity of Padauk is given in table (4.9). The mean basic specific gravity for each sample tree, the number of specimens per tree, standard deviation within trees, minimum and maximum values, coefficient of variation and 95% confidence limit are given in that table. The minimum value is found in tree 6, which is 0.676. The maximum value is 0.740 that is found in tree 3. The coefficient of variation is found to be less than 10% for almost all sample trees, meaning that the individual values within trees are to be precise and they do not deviate too much from their mean.

Table (4.9): Basic Specific Gravity of Padauk.

Tree	Means	N	Std. Dev.	Min	Max	CV%	95%conf.
1	0.698	35	0.048	0.650	0.746	6.83	0.016
2	0.695	32	0.056	0.639	0.751	8.08	0.019
3	0.740	31	0.057	0.682	0.797	7.75	0.020
4	0.719	31	0.068	0.651	0.787	9.48	0.024
5	0.736	20	0.045	0.690	0.781	6.15	0.020
6	0.676	36	0.076	0.600	0.751	11.20	0.025
7	0.710	50	0.026	0.684	0.737	3.70	0.007
8	0.706	31	0.041	0.665	0.747	5.80	0.014
9	0.691	36	0.049	0.642	0.740	7.08	0.016
10	0.693	45	0.063	0.630	0.756	9.13	0.018
All groups	0.706	347	0.053	0.653	0.759	7.50	0.018

The test of significance of the effect of trees, sections, wood zones and their interaction is conducted with the help of Statistica (Anova! Manova). The investigation on specific gravity could not be done for section 'c' of the trees 1, 4, 5 and 8, because the section 'c' of these trees is too small to differentiate sapwood from heartwood. Therefore, the design is incomplete to test all trees and all sections. Thus, these trees are omitted in the test of the effect of significance.

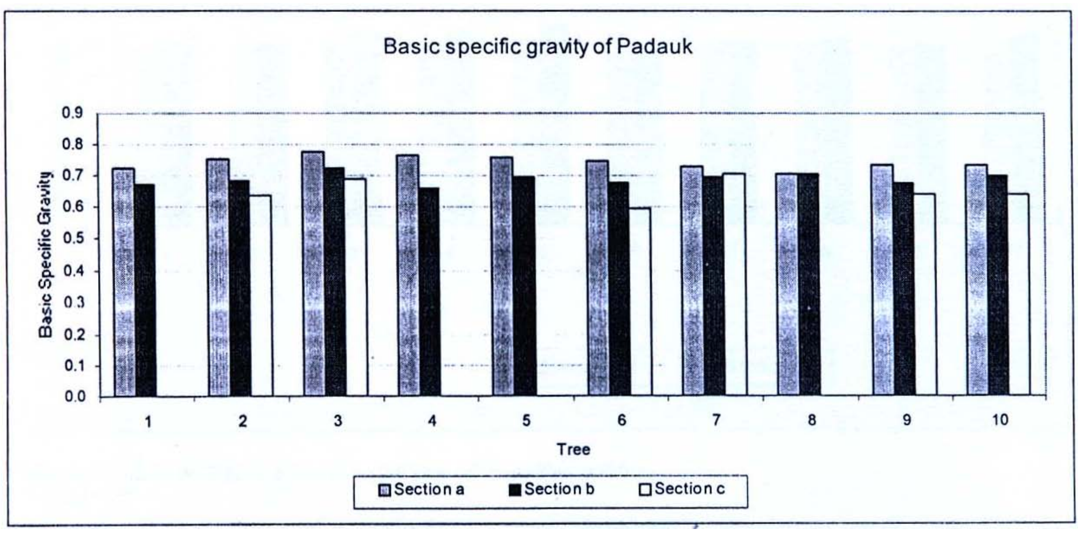

Figure 4.9. Sectional basic specific gravity of Padauk.

The effects of trees, sections, and wood zones on basic specific gravity are significant and so is the interaction effect between trees and sections. But, there is no significant effect on basic specific gravity by the interaction between tree and wood zones, between sections and wood zones and the interaction among trees, sections and wood zones.

In order to investigate which trees show significant differences from others, tree means of basic specific gravity of Padauk are compared by Tukey's test. According to the results, tree 3 with the highest basic specific gravity, significantly differs from every sample trees except 7. Trees 2, 6, 9 and 1O, which have the smallest basic specific gravity show significant differences from tree 3.

The significant difference test is also conducted for basic specific gravity by comparing the means of each tree at different heights to investigate the vertical variation within the same tree. According to the test results, five trees out of six show significant differences in basic specific gravity in vertical direction at 95% probability level. All sample trees show a tendency that basic specific gravity decreases with heights in vertical direction.

In trees 2, 3, 6 and 9, section 'a' has the largest value of basic specific gravity, which shows a significant difference from section 'b' and 'c'. In these trees, section 'c' has the smallest value.

In tree 10, section 'a' has the largest value of basic specific gravity, which shows a significant difference from section 'c'. In that tree, section 'c' has the smallest.

In most trees, it seems that section 'a' has the highest basic specific gravity and section 'b' has higher specific gravity than section 'c'.

It can be firmly said that, basic specific gravity of Padauk sample trees uniformly decreases with heights. Variation of specific gravity with height within the tree in hardwoods follows one of three general patterns: it may decrease upward: it may decrease in the lower trunk and increase in the upper trunk: or it may increase from the ground upward (Panshin and de Zeeuw, 1980). The former statement may perhaps hold true for Padauk.

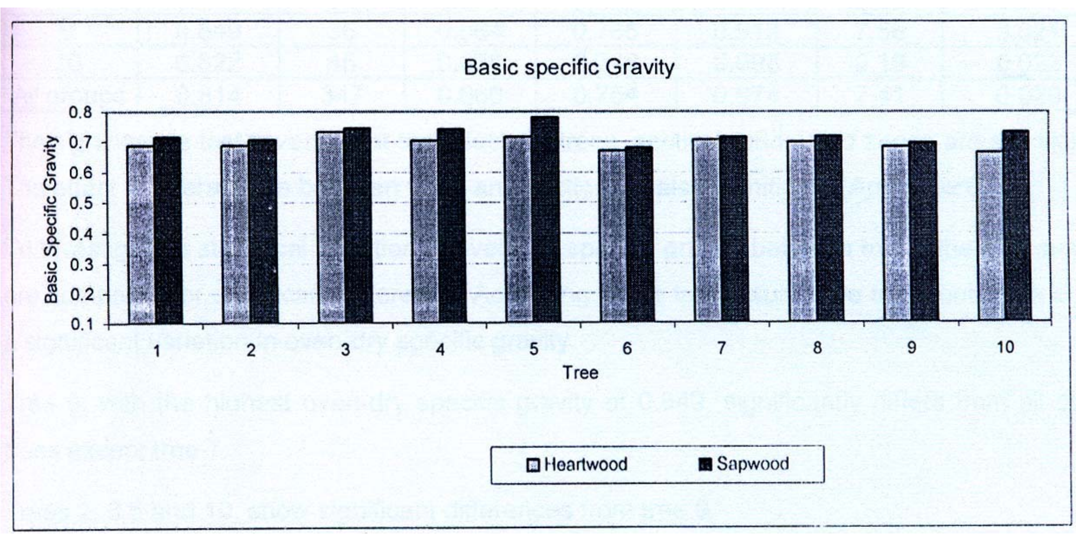

Figure 4.10. Zonal basic specific gravity of Padauk.

In horizontal direction, no sample tree shows significant variation in basic specific gravity. It can, however, be found that sapwood has larger specific gravity than heartwood. The basic specific gravity shows an increasing trend from the pith toward the bark.

Panshin and de Zeeuw (1980) stated that, in the hardwoods a little over half of all the species investigated shows increasing specific gravity from the pith outward. This statement holds true for Padauk because basic specific gravity of sapwood has larger specific gravity than heartwood.

4.1.5.2. Oven-dry specific gravity

The oven-dry specific gravity of Padauk wood is given in table (4.10). The number of specimens per tree, standard deviation, minimum and maximum values, coefficient of variation and 95% confidence limit are also given. The coefficients of variation are less than 10%.

Table (4.10): Oven-dry specific gravity of Padauk.

Tree	Means	N	Std. Dev.	Min	Max	CV%	95%conf.
1	0.827	35	0.047	0.780	0.874	5.67	0.016
2	0.794	32	0.063	0.731	0.857	7.52	0.022
3	0.808	31	0.069	0.739	0.877	8.58	0.024
4	0.807	31	0.076	0.731	0.883	9.41	0.027
5	0.815	20	0.051	0.764	0.866	6.27	0.022
6	0.817	36	0.074	0.743	0.891	9.07	0.024
7	0.838	50	0.042	0.796	0.880	5.06	0.012
8	0.776	31	0.041	0.735	0.817	5.25	0.014
9	0.849	36	0.064	0.785	0.913	7.56	0.021
10	0.822	45	0.076	0.746	0.898	9.19	0.022
All Groups	0.814	347	0.060	0.754	0.874	7.41	0.020

The significance test reveals that the effects of trees, sections and wood zones are significant. The effect of interactions between trees and sections is also significant.

To investigate a statistical variation in oven-dry specific gravity between trees, the tree means are compared for significant difference. According to the test results, five trees out of six show a significant variation in oven-dry specific gravity.

Tree 9, with the highest oven-dry specific gravity of 0.849, significantly differs from all other trees except tree 7.

Trees 2, 3, 6 and 10, show significant differences from tree 9.

To investigate which sections show significant difference from others, Turkey's test is conducted. It is found that every section shows a significant difference from all. The largest specific gravity is found in section 'a' and the value of section 'b' is higher than section 'c'.

To investigate a significant vertical variation within trees, sectional means of each tree are compared for significant difference test. According to the test results, all trees show the vertical variation in oven-dry specific gravity. In all sample trees, section 'a' with the highest value, significantly differ from sections 'b' and 'c' and also from each other. In almost all sample trees, the oven-dry specific gravity of section 'b' is higher than section 'c'.

Thus, it can be firmly said that, Padauk sample trees show a decreasing trend with heights.

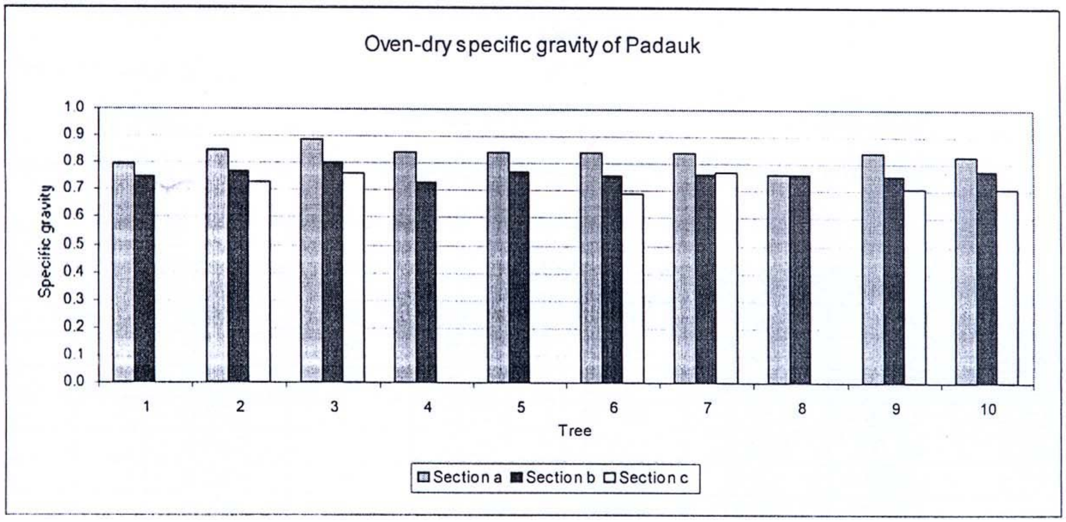

Figure 4.11. Sectional oven-dry specific gravity of Padauk wood.

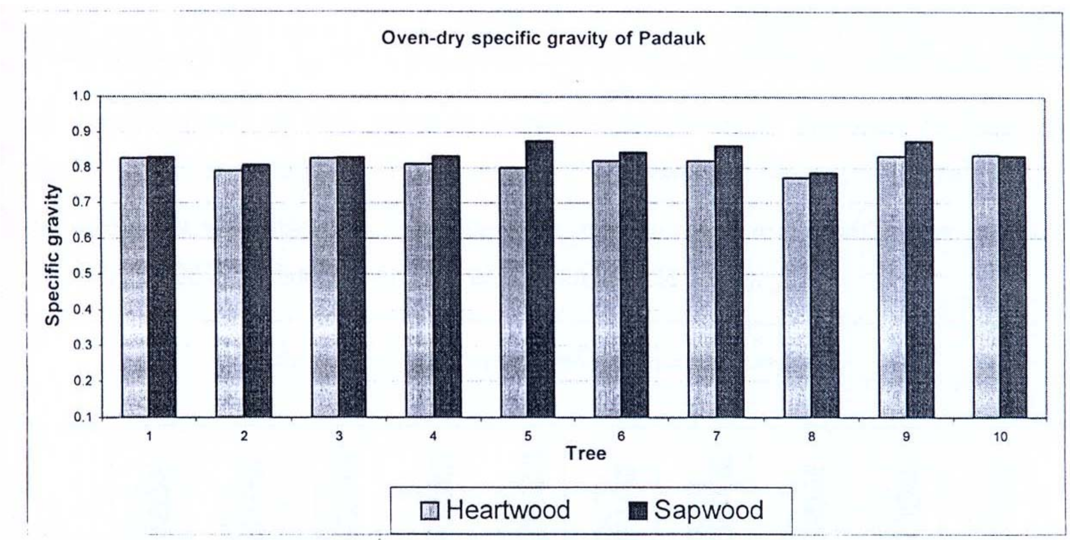

Figure 4.12. Oven-dry specific gravity of Padauk by wood zone.

The effect of interaction of trees and zones is not significant, which means that the horizontal variation in oven-dry specific gravity will be the same for all trees.

According to two samples T-test for independent variables, oven-dry specific gravity in heartwood is significantly different from sapwood. It is found that the oven-dry specific gravity of heartwood is less than sapwood.

It can be said that there is an increasing trend with distance from the pith.

4.1.5.3. Specific gravity at 12% moisture content

The formula is given by

$$Sp.Gr_{12} = Sp.Gr_g / (1-0.159 * Sp.Gr_g) \qquad \text{(Anon, 1999)}$$

where $Sp.Gr_g$ is the basic specific gravity (based on oven-dry weight and green volume)

$Sp.Gr_{12}$ is the specific gravity at 12% moisture content.

Table (4.11): Specific gravity of Padauk 12 % moisture content

Tree	Mean	N	Std. Dev.	Min	Max	CV%	95% conf.
1	0.786	35	0.060	0.726	0.846	7.66	0.020
2	0.782	32	0.071	0.711	0.853	9.07	0.025
3	0.839	31	0.074	0.765	0.913	8.80	0.026
4	0.813	31	0.087	0.726	0.899	10.64	0.030
5	0.833	20	0.058	0.776	0.891	6.92	0.025
6	0.758	36	0.094	0.664	0.852	12.42	0.031
7	0.801	50	0.033	0.768	0.834	4.16	0.009
8	0.796	31	0.052	0.744	0.848	6.51	0.018
9	0.777	36	0.061	0.716	0.838	7.89	0.020
10	0.780	45	0.080	0.700	0.859	10.21	0.023
All groups	0.796	347	0.067	0.730	0.863	8.40	0.023

The specific gravity at 12% moisture content is calculated on the basis of basic specific gravity. So, it is assumed to have the same trend of variation of basic specific gravity.

The number of specimens, standard deviation, minimum and maximum values, coefficient of variation and 95% confidence limit are also given in table (4.11).

4.2. Mechanical Properties

4.2.1. Static Bending

4.2.1.1. Fiber stress at proportional limit

The mean fiber stresses at proportional limit at green and 12% moisture content of Padauk wood are given in tables (4.12) and (4.13). The number of specimens per tree, standard deviation, minimum and maximum values, coefficient of variation and 95% confidence limit are also given. The coefficient of variation for fiber stress at proportional limit can be high up 22% (Anon, 1974). In this case, the coefficients of fiber stress at proportional limit at green and 12% moisture content of Padauk sample trees are to be assumed to be precise and reliable.

Table (4.12): Mean fiber stress at proportional limit of Padauk at green (N/mm^2)

Tree	Means	No.	Std. Dev.	Min	Max	CV%	95% cont.
1	87	12	16.09	71	103	18.44	9.10
2	92	13	14.61	77	107	15.89	7.94
3	78	16	15.18	63	93	19.41	7.44
4	87	15	13.23	74	100	15.24	6.69
5	80	9	11.87	68	92	14.78	7.76
6	91	16	10.39	81	101	11.41	5.09
7	89	32	11.76	77	100	13.27	4.08
8	74	12	10.95	63	85	14.75	6.19
9	88	18	9.65	78	97	11.01	4.46
10	92	27	14.57	78	107	15.79	5.50
All groups	87	170	13.72	73	101	15.79	2.06

Table (4.13): Mean fiber stress at proportional limit of Padauk at 12% moisture content (N/mm^2)

Tree	Means	N	Std. Dev.	Min	Max	CV%	95% cont.
1	94	16	4.89	89	99	5.22	2.40
2	103	14	12.38	90	115	12.05	6.48
3	110	14	6.98	103	117	6.34	3.65
4	104	10	9.41	94	113	9.08	5.84
5	102	9	8.76	93	110	8.61	5.72
6	111	15	13.80	97	124	12.48	6.98
7	112	32	9.06	103	121	8.10	3.14
8	97	14	8.91	88	106	9.16	4.67
9	120	17	10.24	110	130	8.53	4.87
10	107	18	8.58	98	116	8.02	3.96
All groups	106	159	9.30	97	115	8.79	4.77

For significant difference, the effect of trees on fiber stress at green and 12% moisture content is tested with the use of Statistica (One way ANOVA). According to test results, the effects of trees on fiber stress at proportional limit at green and 12% moisture content are significant, which means that there is a variation among trees.

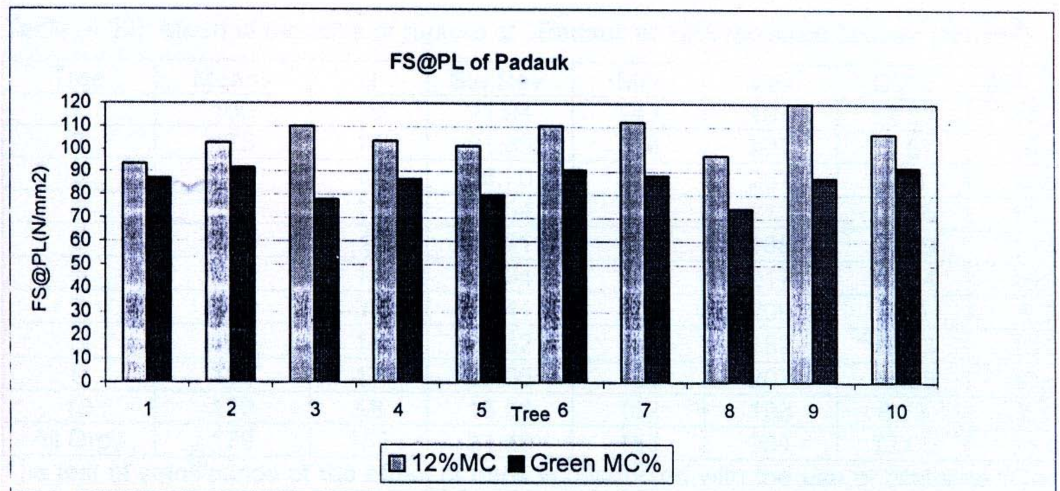

Figure 4.13. Fiber stress at proportional limit in bending test.

4.2.1.2. Modulus of Rupture (MOR)

According to the investigations carried out for this research, the average values of modulus of rupture at green and 12% moisture content of Padauk sample trees are shown in table (4.14) and (4.15). The number of specimens, standard deviation, coefficient of variation, and minimum and maximum values for each sample tree are presented. The value of coefficient of variation for modulus of rupture can be high up to 16% (Anon, 1974). In sample tree 2 and 4, the coefficients of variation of modulus of rupture of green condition are slightly larger than 16%. In sample trees 2 and 6, the coefficients of variation of modulus of rupture at 12% moisture content are slightly larger than 16%. But, the overall means of modulus of rupture of green and 12% moisture content of Padauk tree are less than 16%, which might mean that the results are to be reliable.

Table (4.14): Mean of modulus of rupture of green Padauk (N/mm^2)

Tree	Means	N	Std. Dev.	Min	Max	CV%	95% conf.
1	139	12	19.45	119	158	14.00	11.00
2	127	13	20.88	106	148	16.50	11.35
3	127	16	20.32	107	147	16.00	9.96
4	132	15	21.47	111	154	16.30	10.87
5	116	9	16.33	100	133	14.00	10.67
6	142	16	14.79	128	157	10.40	7.25
7	145	32	13.18	132	158	9.10	4.57
8	120	12	13.17	107	133	11.00	7.45
9	140	18	16.20	121	153	11.80	7.48
10	143	27	18.40	124	161	12.90	6.94
All groups	133	170	17.42	116	155	13.20	8.75

Table (4.15): Mean of modulus of rupture of Padauk at 12% moisture content (N/mm^2)

Tree	Means	N	Std. Dev.	Min	Max	CV%	95% conf.
1	165	16	21.94	143	187	13.32	10.75
2	175	14	31.35	144	207	17.87	16.42
3	191	14	15.70	176	207	8.21	8.22
4	191	10	20.54	170	211	10.76	12.73
5	169	9	19.21	149	188	11.39	12.55
6	186	15	30.94	155	217	16.64	15.66
7	194	32	15.41	178	209	7.95	5.34
8	162	14	20.32	142	182	12.53	10.64
9	184	17	23.06	161	207	12.55	10.96
10	178	18	'15.53	162	193	8.73	7.17
All Groups	179	159	21.40	158	201	12.00	11.05

The test of significance of the effect of trees is conducted with the use of Statistica (One way ANOVA). It is found that the effects of trees at green and 12% moisture content of Padauk sample trees are also significant at 95% probability level.

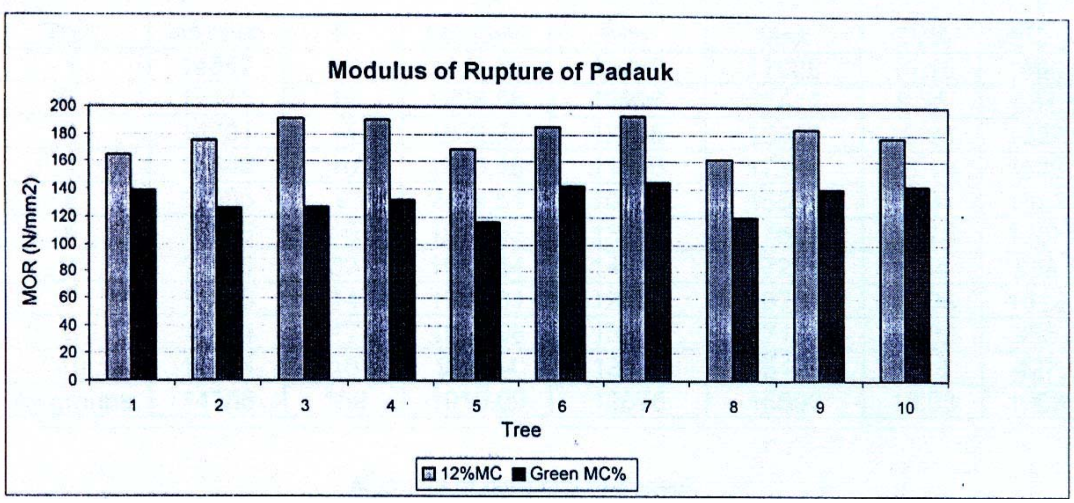

Figure 4.14. Modulus of rupture in static bending test.

4.2.1.3. Modulus of elasticity (MOE)

The average values of modulus of rupture of Padauk at green and 12% moisture content are given in tables (4.16) and (4.17). In these tables, the number of specimens per tree, standard deviation within trees, minimum and maximum values, coefficient of variation and 95% confidence limit are also given. The value of coefficient of variation for modulus of elasticity can be high up to 22% (Anon, 1974). In sample trees 3, 5 and 7, the coefficients of variation of modulus of rupture of green condition are larger than 22%. But, the overall means of modulus of elasticity for green condition of Padauk trees are less than 22% and the coefficient values of Padauk sample trees at 12% moisture content are far much lower than 22%, which might mean that the results are to be reliable.

Table (4.16): Mean of modulus of elasticity of green Padauk (N/mm^2)

Tree	Means	N	Std. Dev.	Min	Max	CV%	95% conf.
1	12395	12	1921.76	10474	14317	15.50	1087.32
2	12290	13	2394.70	9895	14685	19.48	1301.75
3	11700	16	2974.29	8726	14675	25.42	1457.37
4	11683	15	2107.19	9576	13790	18.04	1066.36
5	13699	9	3657.59	10041	17356	26.70	2389.58
6	17293	16	2198.38	15094	19491	12.71	1077.19
7	14773	32	3427.11	11346	18200	23.20	1187.41
8	9048	12	1415.92	7632	10464	15.65	801.12
9	14104	18	3085.57	11018	17190	21.88	1425.43
10	13986	27	2773.02	11213	16759	19.83	1045.97
All Groups	13097	170	3352.22	10081	16786	19.84	1283.95

Table (4.17): Mean of modulus of elasticity of Padauk at 12% moisture content (N/mm^2).

Tree	Means	N	Std. Dev.	Min	Max	CV%	95% conf.
1	14657	16	2367.80	12289	17025	16.15	1160.20
2	15175	14	1268.56	, 13906	16444	8.36	664.50
3	14701	14	1962.39	12738	16663	13.35	1027.94
4	14646	10	2660.16	11986	17306	18.16	1648.75
5	12895	9	2489.51	10405	15384	19.31	1626.45
6	15615	15	1990.32	13625	17605	12.75	1007.22
7	15673	32	1557.54	14116	17231	9.94	539.65
8	14800	14	1933.01	12867	16733	13.06	1012.55
9	15184	17	1946.98	13237	17131	12.82	925.52
10	14504	18	924.64	13579	15429	6.38	427.15
All Groups	14785	159	1910.09	12875	16695	13.03	1003.99

According to test results, the effects of trees of modulus of elasticity at green and 12% moisture content are significant, which means that there are variations among trees.

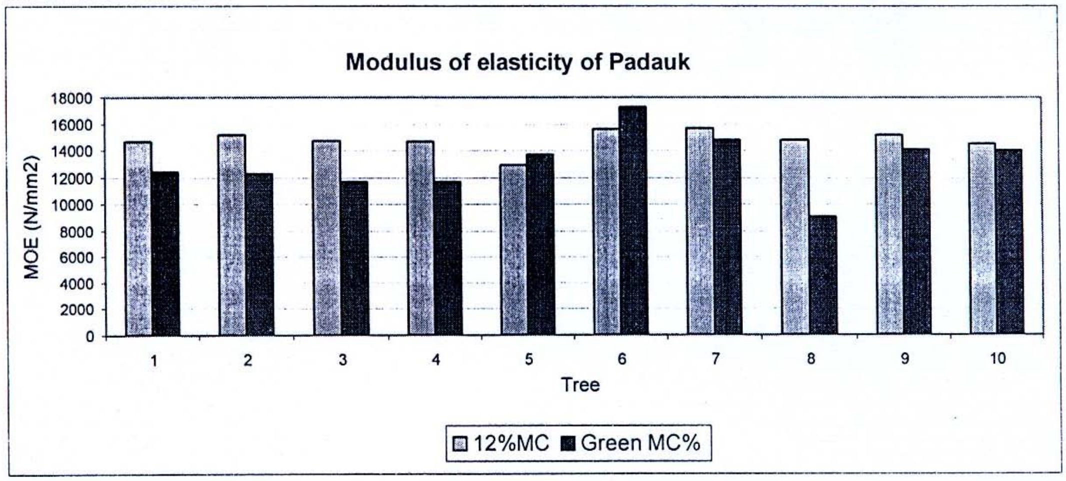

Figure 4.15. Modulus of elasticity in static bending test.

4.2.2. Compression parallel to grain

4.2.2.1 Fiber stress at proportional limit

According to the investigations carried out for this research, the number of specimens, standard deviation, coefficient of variation, minimum and maximum values for each Padauk sample tree at green condition and 12% moisture content are presented in tables (4.18) and (4.19). The value of coefficient of variation for FS@PL can be high up to 24% (Anon, 1974). In sample tree 3 and 4, the coefficients of variation of green moisture content are slightly larger than 24%. But this value for overall mean for green Padauk tree is less than 24%, which might mean that the results are to be reliable. For 12% moisture content, the coefficient values are far much lower than 24%. Thus the results are to be precise and reliable.

Table (4.18): Mean fiber stress at proportional limit of Padauk at green (N/mm^2)

Tree	Means	N	Std. Dev.	Min	Max	CV%	95% conf.
1	31	20	5.28	26	37	16.82	2.31
2	28	10	4.13	23	32	14.99	2.56
3	31	16	7.70	23	38	25.22	3.77
4	29	12	6.99	22	36	24.21	3.95
5	24	7	3.06	21	28	12.51	2.27
6	29	17	6.65	22	35	23.29	3.16
7	31	33	7.24	24	38	23.41	2.47
8	26	14	2.53	23	28	9.85	1.33
9	33	16	7.70	25	40	23.69	3.77
10	31	24	5.06	26	36	16.51	2.03
All Groups	30	169	6.40	23	36	19.05	2.76

Table (4.19): Mean fiber stress at proportional limit of Padauk at 12% moisture content (N/mm^2)

Tree	Means	N	Std. Dev.	Min	Max	CV%	95% conf.
1	48	16	10.38	38	58	21.68	5.09
2	46	14	6.23	40	53	13.41	3.26
3	51	16.	8.00	43	59	15.65	3.92
4	51	14	10.6q	40	62	20.97	5.59
5	48	10	8.13	40	56	16.94	5.04
6	51	17	6.35	45	58	12.35	3.02
7	58	32	10.06	48	68	17.32	3.49
8	46	16	8.26	38	55	17.87	4.05
9	48	18	6.89	41	55	14.43	3.18
10	58	21	9.00	49	67	15.49	3.85
All groups	51	174	8.40	42	59	16.61	4.05

The test of significance of the effect of trees is conducted with the use of Statistica (One way ANOVA). It is found that the effects of trees at green and 12% moisture content of Padauk sample trees are also significant at 95% probability level.

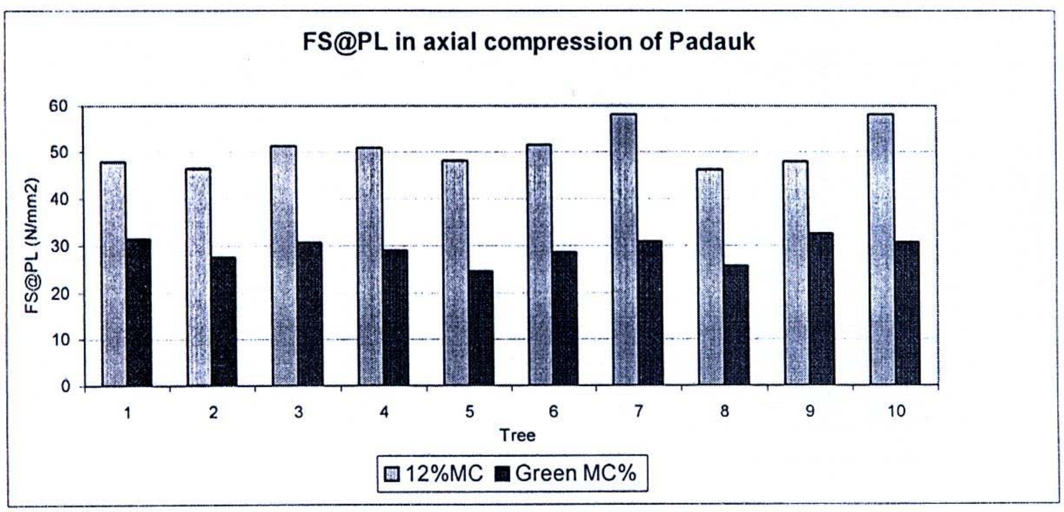

Figure 4.16: Fiber stress at proportional limit in compression parallel to grain.

4.2.2.2 Maximum Crushing Strength (MCS)

The average values of maximum crushing strength of Padauk at green and 12% moisture content are given in tables (4.20) and (4.21). In these tables, the number of specimens per tree, standard deviation within trees, minimum and maximum values, coefficients of variation and 95% confidence limits are also given. The value of coefficient of variation for maximum crushing strength can be high up to 18% (Anon, 1974). In sample trees 3 and 4, the coefficients of variation of green moisture content are larger than 18%. But this value for the overall mean of MCS for green Padauk tree is slightly larger than 18%, which mean that the results are to be acceptable. For 12% moisture content, the overall coefficient values are far much lower than 18%. The results are to be assumed to be precise and reliable.

Table (4.20): Maximum crushing strength of green Padauk (N/mm^2).

Tree	Means	N	Std. Dev.	Min	Max	CV%	95% conf.
1	43	20	7.40	36	51	17.05	3.24
2	40	10	4.75	35	45	11.89	2.94
3	44	16	8.82	35	52	20.20	4.32
4	39	12	9.44	30	48	24.20	5.34
5	33	7	3.85	29	37	11.59	2.85
6	41	17	6.42	35	47	15.67	3.05
7	43	33	6.58	36	49	15.43	2.25
8	35	14	6.08	29	41	17.51	3.19
9	43	16	6.46	37	50	14.99	3.16
10	43	24	8.39	34	51	19.63	3.36
All Groups	41	169	7.61	34	49	18.45	3.37

Table (4.21): Maximum crushing strength of Padauk at 12% moisture content *(*N/mm2*)*.

Tree	Means	N	Std. Dev.	Min	Max	CV%	95% conf.
1	59	16	10.12	49	69	17.14	4.96
2	55	14	5.37	50	61	9.74	2.81
3	65	16	6.73	58	72	10.33	3.30
4	65	14	5.65	60	71	8.65	2.96
5	60	10	4.74	55	65	7.87	2.94
6	60	17	5.35	55	65	8.90	2.54
7	70	32	9.33	60	79	13.40	3.23
8	54	16	15.73	38	69	29.37	7.71
9	61	18	5.72	55	66	9.45	2.64
10	70	21	6.11	64	76	8.75	2.61
All Groups	62	174	8.45	53	70	13.66	1.26

The test of significance of the effect of trees is conducted with the use of Statistica (One way ANOVA). It is found that the effects of trees at green Padauk sample trees are also significant at 95% probability level but not significant at 12% moisture content.

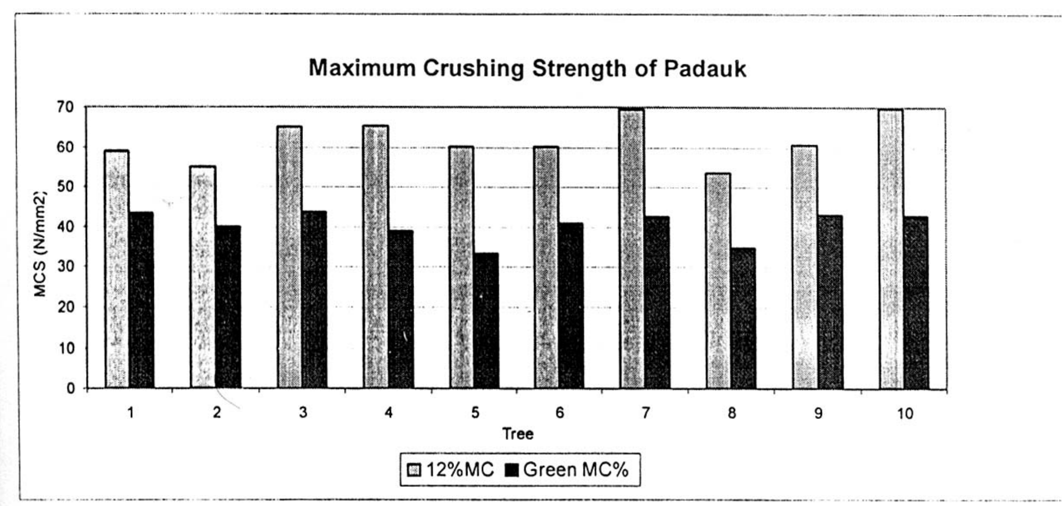

Figure 4.17: Maximum crushing strength in compression parallel to grain.

4.2.3. Compression perpendicular to grain

4.2.3.1. Fiber Stress at Proportional Limit

The mean fiber stresses at proportional limit of green and 12% moisture content of Padauk wood are given in tables (4.22) and (4.23). The number of specimens per tree, standard deviation, minimum and maximum values, coefficient of variation and 95% confidence limit are also given. The coefficient of variation for fiber stress at proportional limit can be high up 28% (Anon, 1974). In this case, the coefficient values of fiber stress at proportional limit at green are less than 28% and the coefficient values of fiber stress at proportional limit at 12% moisture content are smaller than 10%. Thus, the results are precise and reliable.

Table (4.22): Mean fiber stress at proportional limit of Padauk at green moisture content (N/mm^2).

Tree	Means	N	Std. Dev.	Min	Max	CV%	95%conf.
1	11.73	23	2.87	8.86	14.59	24.45	1.17
2	11.62	19	2.13	9.48	13.75	18.37	0.96
3	10.95	21	2.31	8.63	13.26	21.14	0.99
4	10.35	18	2.62	7.73	12.98	25.34	1.21
5	10.01	10	1.43	8.57	11.44	14.34	0.89
6	10.92	17	2.52	8.40	13.44	23.10	1.20
7	11.58	36	2.28	9.30	13.86	19.71	0.75
8	10.50	19	2.79	7.70	13.29	26.61	1.26
9	11.34	22	2.13	9.21	13.46	18.76	0.89
10	11.03	24	1.87	9.16	12.91	16.99	0.75
All Groups	11.11	209	2.36	8.75	13.48	21.24	0.32

Table (4.23): Mean fiber stress at proportional limit of Padauk at 12% moisture content (N/mm^2).

Tree	Means	N	Std. Dev.	Min	Max	CV%	95% conf.
1	20.91	17	2.71	18.20	23.62	12.97	1.29
2	22.54	16	2.72	19.82	25.26	12.06	1.33
3	30.24	14	3.04	27.20	33.28	10.05	1.59
4	30.47	14	2.69	27.78	33.16	8.83	1.41
5	23.16	12	3.21	19.96	26.37	13.85	1.82
6	21.70	16	1.79	19.91	23.49	8.25	0.88
7	29.39	36	3.30	26.09	32.68	11.22	1.08
8	17.97	14	2.63	15.34	20.59	14.61	1.38
9	26.37	21	1.80	24.57	28.17	6.82	0.77
10	26.17	26	2.60	23.57	28.77	9.95	1.00
All Groups	24.89	186	2.65	22.24	27.54	10.64	0.38

The test of significance of the effect of trees is conducted with the use of Statistica (One way ANOVA). It is found that the effects of trees at green condition is not significant but significant at 12% moisture content at 95% probability level.

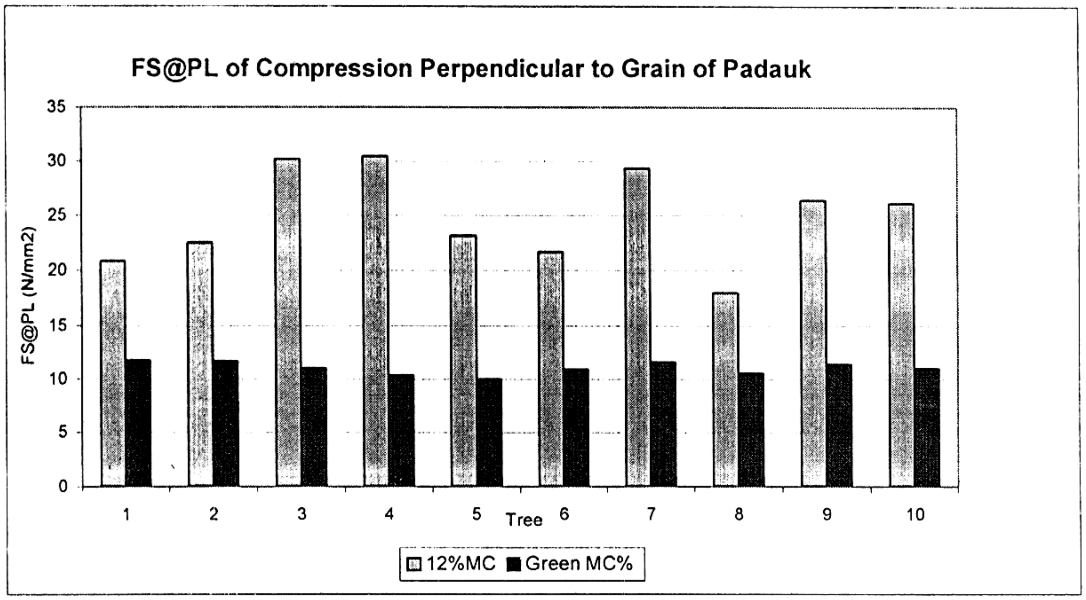

Figure 4.18: Fiber stress at proportional limit in compression perpendicular to grain

4.2.4. Hardness

The average values of hardness of Padauk at green and 12% moisture content are given in tables (4.24) and (4.25). In these tables, the number of specimens per tree, standard deviation within trees minimum and maximum values coefficients of variation and 95% confidence limits are also given. Means are presented for radial, tangential and end surface. The value of coefficient of variation for side hardness can be high up to 20% and the maximum coefficient of variation for end hardness is 10%, which can be high up to 17% (Anon, 1974).

The test of significance of the effect of radial, tangential and end surface on hardness at green condition is not significant but significant at 12% moisture content at 95% probability level. The value of end hardness is always higher than radial, or tangential hardness.

Table (4.24): Hardness of Padauk at green condition (N).

Tree	Surface	Means	N	Std. Dev.	Min	Max	CV%	95% conf.
1	Radial	8646	14	278.69	8367	8924	3.22	146
	Tangential	8903	14	225.31	8678	9129	2.53	118
	End	9017	14	222.46	8795	9240	2.47	117
2	Radial	8549	8	221.22	8328	8770	2.59	153
	Tangential	8653	8	. 204.28	8448	8857	2.36	142
	End	8908	8	269.54	8638	9177	3.03	187
3	Radial	8370	12	923.94	7446	9294	11.04	523
	Tangential	8482	12	882.47	7600	9365	10.40	499
	End	8930	12	274.90	8656	9205	3.08	156
4	Radial	8458	13	416.87	8041	8875	4.93	227
	Tangential	8613	13	244.58	8369	8858	2.84	133
	End	8985	13	445.62	8540	9431	4.96	242
5	Radial	8321	9	441.19	7880	8762	5.30	288
	Tangential	8641	9	293.89	8347	8935	3.40	192
	End	8972	9	471.85	8500	9444	5.26	308
6	Radial	8555	11	251.05	8304	8807	2.93	148
	Tangential	8716	11	231.77	8485	8948	2.66	137
	End	8981	11	216.96	8764	9198	2.42	128
7	Radial	8737	21	337.78	8399	9075	3.87	144
	Tangential	8735	21	358.66	8377	9094	4.11	153
	End	9252	21	311.12	8941	9564	3.36	133
8	Radial	8433	11	359.55	8073	8792	4.26	212
	Tangential	8633	11	348.95	8284	8981	4.04	206
	End	8845	11	282.54	8563	9128	3.19	167
9	Radial	8550	14	258.55	8291	8808	3.02	135
	Tangential	8682	14	186.69	8496	8869	2.15	98
	End	9189	14	257.31	8932	9446	2.80	135
10	Radial	8686	11	323.16	8363	9010	3.72	191
	Tangential	8759	11	254.61	8504	9013	2.91	150
	End	9155	11	260.27	8895	9415	2.84	153
All Grps.	Radial	8551	124	429.55	8121	8980	5.02	76
	Tangential	8690	124	379.99	8310	9070	4.37	67
	End	9365	124	222.46	8795	9240	2.47	117

Table (4.25): Hardness of Padauk at 12% moisture content (N).

Tree	Side	Means	N	Std. Dev.	Min	Max	CV%	95% conf.
1	Radial	9419	15	326.28	9093	9745	3.46	165
	Tangential	9418	15	260.07	9158	9678	2.76	132
	End	9606	15	226.20	9380	9833	2.35	114
2	Radial	9367	17	279.75	9087	9647	2.99	133
	Tangential	9314	17	322.24	8992	9636	3.46	153
	End	9841	17	368.80	9472	10210	3.75	175
3	Radial	9503	18	194.44	9309	9698	2.05	90
	Tangential	9594	18	215.59	9378	9809	2.25	100
	End	9756	18	228.40	9527	9984	2.34	106
4	Radial	9563	15	279.39	9283	9842	2.92	141
	Tangential	9494	15	284.05	9210	9778	2.99	144
	End	9899	15	346.32	9553	10246	3.50	175
5	Radial	9367	12	170.99	9196	9538	1.83	97
	Tangential	9326	12	152.22	9174	9478	1.63	86
	End	9458	12	200.00	9258	9658	2.11	113
6	Radial	9543	16	203.20	9339	9746	2.13	100
	Tangential	9486	16	230.15	9256	9717	2.43	113
	End	9799	16	354.69	9444	10153	3.62	174
7	Radial	9602	30	209.94	9392	9811	2.19	75
	Tangential	9689	30	218.03	9471	9907	2.25	78
	End	9916	30	179.34	9737	10096	1.81	64
8	Radial	9470	19	154.98	9315	9625	1.64	70
	Tangential	9386	19	174.66	9212	9561	1.86	79
	End	9653	19	207.03	9446	9860	2.14	93
9	Radial	9471	17	172.33	9299	9644	1.82	82
	Tangential	9502	17	207.01	9295	9709	2.18	98
	End	9710	17	168.55	9542	9879	1.74	80
10	Radial	9352	21	264.57	9088	9617	2.83	113
	Tangential	9335	21	232.65	9103	9568	2.49	100
	End	9626	21	250.70	9375	9876	2.60	107
All Grps.	Radial	9466	180	240.70	9225	9707	2.46	112
	Tangential	9462	180	223.35	9239	9686	2.36	105
	End	9606	180	226.20	9380	9833	2.35	114

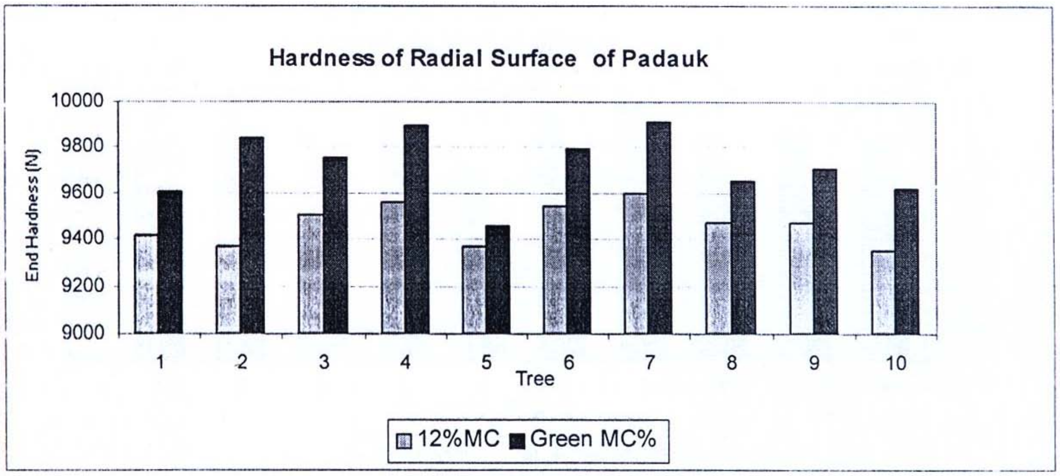

Figure 4.19: Hardness of radial surface of Padauk.

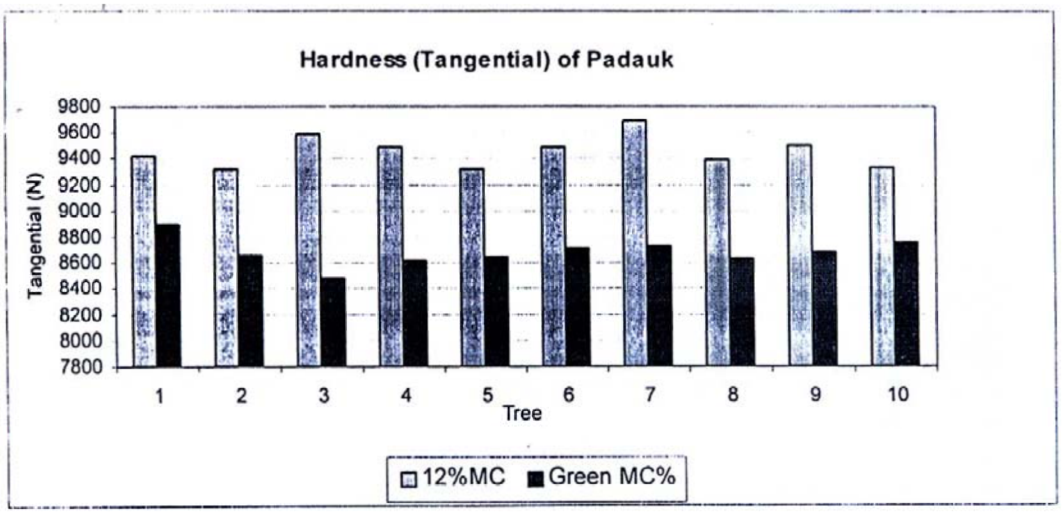

Figure 4.20: Hardness of tangential surface of Padauk.

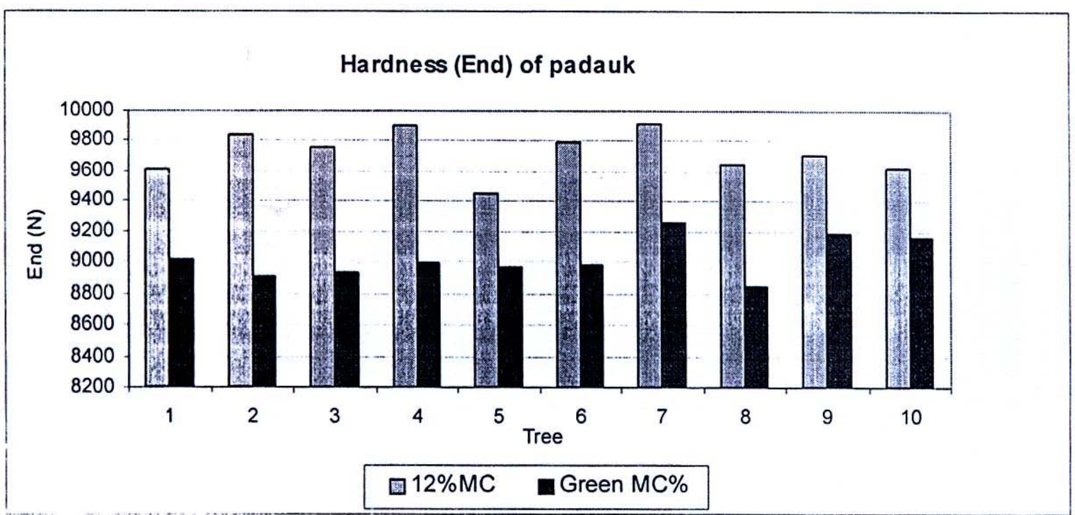

Figure 4.21: Hardness of end surface of Padauk.

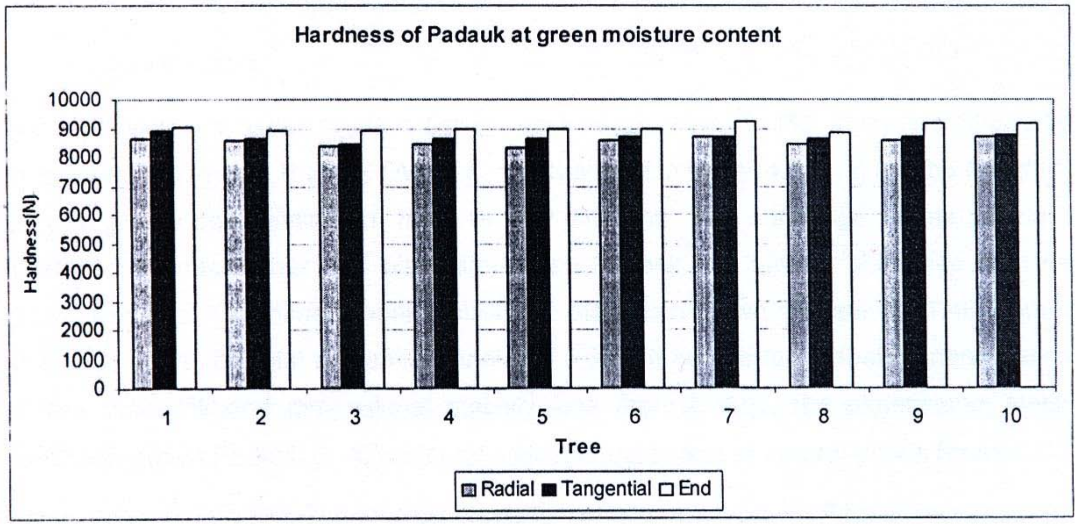

Figure 4.22: Hardness of Padauk at green condition.

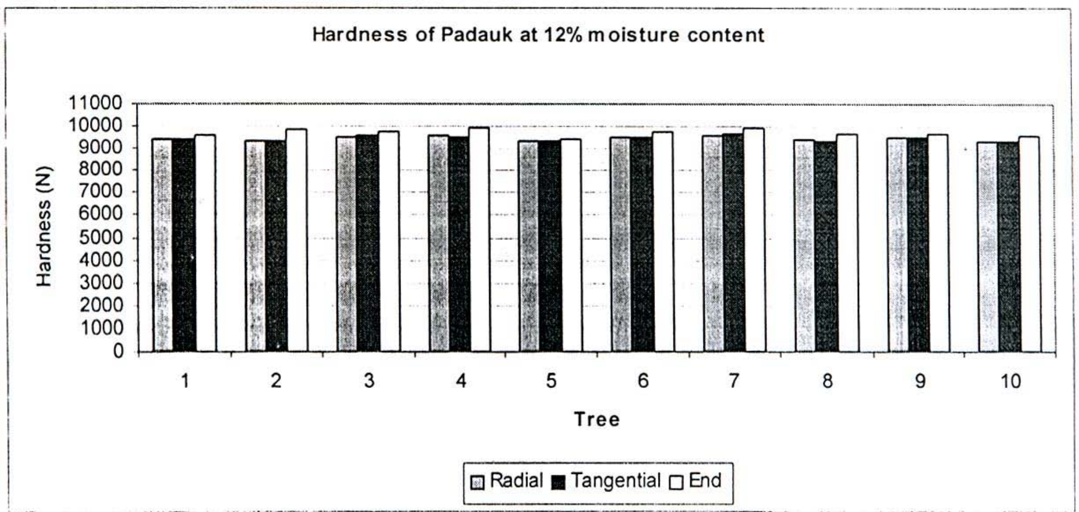

Figure 4.23: Hardness of Padauk at 12% moisture content.

4.3. Comparison of Properties of Plantation-Grown Padauk with Those of Natural Grown Padauk

Some physical properties of plantation-grown Padauk tested in this study are compared with those of natural-grown Padauk (Win Kyi, 1993) shown in table (4.26). It can be found that the specific gravity and density are more or less different. The shrinkage values are not much different from each other. But plantation-grown Padauk has greater shrinkage than natural-grown Padauk. The dimensional stability of plantation-grown Padauk is 1.48 (total radial shrinkage 3.8% and total tangential shrinkage 5.6%). It can be found that tangential shrinkage is less than 7% and dimensional stability less than 2. And, the dimensional stability of plantation-grown Padauk (1.48) is found almost equal to that of natural-grown Padauk (1.50).

Table (4.26): Comparison of physical properties of plantation-grown Padauk investigated for this research and those of natural-grown Padauk.

No	**Species**	**Moisture content (%)**	**Specific gravity**	**Density (kg/mm3)**	**Radial shrinkage (%)**	**Tangential shrinkage (%)**	**Dimensional stability**
1	Padauk (plantation-grown)	58.6 *12.0*	0.706 0.796	1106 892	3.8 2.3	5.6 3.4	1.48
2	Padauk* (natural-grown)	42.8 12.0	0.752 0.854	1074 957	3.4 -	5.1 -	1.50 -

*Source: Physical and mechanical properties of some Myanmar Timbers (Win Kyi, 1993).

The mechanical properties of plantation-grown Padauk investigated for this study are compared with those of natural-grown Padauk as shown in table (4.27). It can be seen that there are some differences between the two means. The strength properties of plantation-grown Padauk are nearly the same to those of natural-grown Padauk.

Table (4.27): Comparison of mechanical properties of plantation-grown Padauk investigated for this research and those of natural-grown Padauk.

No.	Species	Moisture Content (%)	Static Bending. (N/mm^2)			Compression Parallel to grain (N/mm^2)		Compress si-on Per. to grain (N/mm^2)	Hardness (N)		
			FS@ PL	MOR	MOE	FS@ PL	MCS	FS@PL	Radial	Tangential	End
1	Padauk (plantation-grown)	58.6 12.0	86 109	133 182	13097 14953	30 51	43 62	11.1 16.0	8551 9472	8690 9469	9365 9739
2	Padauk (natural grown)	43.8]2.0	65 90	110 145	13080 14464	38 54	57 77	13.6 19.7	8936 9742	9220 9811	9220 9404

*Source: Physical and mechanical properties of some Myanmar Timbers (Win Kyi, 1993)

And, According to classification of basic specific gravity of Negi (1997), plantation-grown Padauk would be very heavy. He added two factors are to be taken into account for end-use of timbers as construction material. They are modulus of elasticity and modulus of rupture. This grouping is based on properties at 12 % moisture content.

According to this grouping, plantation-grown Padauk would be in Group I (MOE 14953 and MOR 182 N/mm^2) and also natural-grown Padauk is to be in Group I (MOE 14464 and MOR 145 N/mm^2).

Table (4.28): Comparison of physical properties of plantation-grown Padauk, natural-grown Padauk and some other commercial timber species of Myanmar.

No	Species	Moisture Content (%)	Specific Gravity	Density (kg/m3)	Radial Shrinkage (%)	Tangential Shrinkage (%)	Dimensional Stability
1	Padauk (plantation -grown)	58.6 12.0	0.706 0.796	1106 897	3.8 2.3	5.6 3.4	1.48 1.48
2	Padauk (natural-grown)*	43.8 12.0	0.752 0.854	1074 957	3.4 -	5.1 -	1.50 -
3	In*	50.3 12.0	0.726 0.821	1090 919	4.4 -	9.1 -	2.07 -
4	Kanyin-ni*	65.7 12.0	0.655 0.731	1090 819	4.2 -	8.9 -	2.12 -
5	Kyun*	51.8 12.0	0.598 0.661	913 740	2.3 -	4.2 -	1.83 -
6	Pyinkado*	48.6 12.0	0.779 0.889	1154 996	3.3 -	6.7 -	2.03 -

*Data source: Physical and mechanical properties of some Myanmar Timbers (Win Kyi, 1993).

Table (4.29): Comparison of mechanical properties of plantation-grown Padauk, natural-grown Padauk and some other commercial timber species of Myanmar.

No.	Species	Moisture Content (%)	Static Bending. (N/mm^2)			Compression Parallel to grain (N/mm^2)		Compress si-on Per. to grain (N/mm^2)	Hardness (N)		
			FS@ PL	MOR	MOE	FS@ PL	MCS	FS@PL	Radial	Tangential	End
1	Padauk (plantation-grown)	58.6 12.0	86 109	133 182	13097 14953	30 51	43 62	11.1 16.0	8551 9472	8690 9469	9365 9739
2	Padauk (natural grown)	43.8]2.0	65 90	110 145	13080 14464	38 54	57 77	13.6 19.7	8936 9742	9220 9811	9220 9404
3	In*	50.3 12.0	48 69	80 124	12093 15546	25 33	39 68	8.4 8.7	6310 8510	6310 8243	6467 9066
4	Kanyin-ni*	65.7 12.0	48 62	76 118	13928 16155	27 29	40 60	6.6 9.2	4536 6559	4487 6041	4713 6377
5	Kyun*	51.8 12.0	49 69	79 103	11535 13011	28 41	40 60	7.3 10.7	4644 5234	4576 5183	4066 5018
6	Pyinkado*	48.6 12.0	66 71	107 132	15617 16851	44 45	55 71	11.7 13.8	8554 9213	8514 10151	8113 8611

*Data source: Physical and mechanical properties of some Myanmar Timbers (Win Kyi, 1993).

4.4 Comparison with Other Commercial Myanmar Timbers

The physical and mechanical properties of commercial timber species that are used to compare with those of plantation-grown Padauk are shown in Tables (4.28) and (4.29). The specific gravity of plantation-grown Padauk at 12% moisture content (0.796) is higher than those of Kanyin (0.731) and Teak (0.661), and lower than those of natural-grown Padauk (0.854), Pyinkado (0.889) and In (0.821).

The density of plantation grown Padauk at 12% moisture content is found to be higher than those of Kanyin (819 kgm^{-3}) and Teak (740 kgm^{-3}), and lower than those of natural-grown Padauk (957 kgm^{-3}), Pyinkado (996 kgm^{-3}) and In (919 kgm^{-3}).

The dimensional stability of plantation-grown Padauk is 1.48 (total radial shrinkage 3.8% and total tangential shrinkage 5.6%). Win Kyi (2000) stated that those timbers which have dimensional stability less than or equal to 2.0 and dimensional changes i.e. radial shrinkage and tangential shrinkage less than or equal to 3.5% and 7.0% are found to be suitable for making high quality wood products. He added again that the tangential shrinkage is mainly taken into account because almost all lumber used in daily practice are flat-sawn. It can be found that, tangential shrinkage is less than 7.0%, radial shrinkage are nearly to 3.5% and dimensional stability is less than 2.0 in the plantation-grown Padauk. Thus, it seems that plantation-grown Padauk could be suitable for making high quality wood products. Plantation-grown Padauk can be found more stable than In (2.07), Kanyin (2.12) and Pyinkado (2.03).

When the mechanical properties of plantation-grown Padauk are compared with those of some Myanmar commercial timber species, plantation-grown Padauk is similar to natural-grown Padauk and Teak, and less than Pyinkado, and more or less inferior to In and Kanyin.

5. Conclusions and Recommendations

5.1. Conclusions

The finding of this study can be summarized as follows:

(1) The radial shrinkage of plantation-grown Padauk from green to oven-dry varies significantly among trees, sections and wood zones. It also varies with heights within trees, but there is no definite trend, ie, it is not increasing or decreasing with height. So the vertical variation in radial shrinkage within tree is not pronounced. It can be said that heartwood shrinks less than sapwood in horizontal direction.

(2) The tangential shrinkage of plantation-grown Padauk from green to oven-dry varies significantly among trees, sections and wood zones. It is not increasing or decreasing with height. It can be firmly said that in oven-dry tangential shrinkage of Padauk, heartwood shrinks less than sapwood in horizontal direction.

(3) The dimensional stability of plantation-grown Padauk is 1.48 (total radial shrinkage 3.8% and total tangential shrinkage 5.6. It can be found that tangential shrinkage is less than 7.0%, radial shrinkage nearly to 3.5% and dimensional stability less than 2.0 in the plantation-grown Padauk. Thus, it seems that plantation-grown Pad auk could be suitable for making high quality wood products. Plantation-grown Padauk can be found more stable than In (2.07), Kanyin (2.12) and Pyinkado (2.03).

(4) The oven-dry volumetric shrinkage of Padauk varies significantly among trees, sections and wood zones. In vertical direction, it is difficult to define the variation trend of volumetric shrinkage with height. In horizontal direction, heartwood shrinks less than sapwood.

(5) The green density of Padauk varies significantly among trees and within tree. In vertical direction, it decreases with heights in all Padauk sample trees. In horizontal direction, heartwood has greater green density than sapwood.

(6) The basic specific gravity of Padauk varies significantly among trees and within trees. It is found to decrease with height in vertical direction. In horizontal direction, it can be firmly said that, the basic specific gravity of sapwood is larger than that of heartwood.

(7) In static bending test, the fiber stress at proportional limit, modulus of rupture and modulus of elasticity of Padauk at green and 12% moisture content are significant among trees.

(8) In compression parallel to grain test, the fiber stress at proportional limit of Padauk at green and 12% moisture content is significantly different between and within trees. The maximum crushing strength of Pad auk varies significantly among trees at green condition, but not at 12% moisture content.

(9) In compression perpendicular to grain test, the fiber stress at proportional limit of Padauk varies significantly among trees at 12% moisture content, but not at green condition.

(10) In hardness, there are significant variations among trees at 12% moisture content, but not at green condition. End hardness is always higher than radial and tangential hardness.

Consideration for the exploration on potential end use of Padauk in this study is based on the physical and mechanical properties only. Physical and mechanical properties are essential requisite to find out the potential end uses of a species. However, other properties such as seasoning properties, workability properties, durability and chemical properties have to be taken into account in making these products.

5.2. Recommendations

Based on the results obtained from the present study, the following recommendations are made and should be considered for further research work.

(1) According to the investigated properties, plantation-grown Padauk shows no significant difference in wood properties. It can be used as naturally grown Padauk. Therefore, establishment of Padauk plantation should be encouraged.

(2) In the plantation-grown Padauk, tangential shrinkage is less than 7.0%, radial shrinkage are nearly to 3.5% and dimensional stability is less than 2.0. Thus, it is suitable for making high quality wood products.

(3) Due to the variability of wood properties, it is advisable to conduct test on physical and mechanical properties of plantation Pad auk of different ages.

(4) If different plantation-grown Padauk is available, they should be tested so that the variability of plantation Padauk can be analysed between localities.

(5) Further investigations on other properties such as seasoning properties, workability, durability and chemical properties of plantation-grown Padauk should be carried out.

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