PD 528/08 Rev.1 (F):
Towards sustainable indigenous Mahogany production in Ghana: Phase II, refining the silviculture "tool kit" and practical training for industrial-foresters and community farmers

Wood and Lumber Quality of Plantation Grown *Khaya ivorensis*

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FOREWORD

Khaya ivorensis, also known as African mahogany, is one of the most important timbers for plantations, since the trees grow quickly and produce high-quality wood. It is distributed across Africa in Benin, Ghana, Ivory Coast, Sudan, Togo, D.R Congo and Uganda. A member of the family Meliaceae, it occurs in semi-deciduous forests, especially in drier types and in savannah, but in the latter case usually along water courses, in areas with 1200-1800 mm annual rainfall and a dry season of 3-5 months.

In Ghana, these species are becoming scarce in the wake of dwindling forest cover. A reduction in volume of about 100,000 m3 of exported Khaya in 1950 to 17,000 m3 in 2005, is clear evidence of its steady decline in Ghana. Declining availability of natural *Khaya ivorensis* in the timber market is due to over-exploitation for cabinetwork, furniture, sliced veneer, ship building, open boats, light carpentry work, interior and exterior paneling and joinery, and veneer for back or face of plywood and export demands from other countries.

There is therefore the need to find the right substitute for the dwindling natural *Khaya ivorensis*; hence, plantation establishment is being pursued. In spite of the problems encountered in mahogany plantations such as pest attack by *Hypsipyla robusta*, plantations in the tropical hemisphere cover more than 100,000 hectares. Efforts geared towards the establishment of indigenous species like African mahogany have been intensified across the tropics. Many international organizations, such as International Tropical Timber Organization (ITTO) have supported projects aimed at increasing forest cover with both exotic and indigenous species. It is now generally accepted that conservation and sustainable utilization of mahogany can be realized when successful plantations are established.

Through the Project No: PD528/08 REV.1(F) entitled: Towards sustainable production of mahogany species in plantations in tropical Africa, Wood and lumber quality of plantation and natural grown ones were assessed. This book covers the various empirical finding of different aspects of wood quality. I believe it will be a very useful information in the support for the establishment of plantation in the tropics especially mahogany and other indigenous species.

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CHAPTER ONE

Distribution, Properties and Uses of Khaya Species.

By

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1.0 Introduction

Mahogany (*Khaya spp*) is ranked as one of the best-known and most valuable tropical timbers on the international market (ITTO, 2004). Mahoganies are distributed across Africa in Benin, Ghana, Ivory Coast, Sudan, Togo, D.R Congo and Uganda (Fig 1). A member of the family Meliaceae, it occurs in semi-deciduous forests, especially in drier types and in savannah, but in the latter case usually along water courses, in areas with 1200-1800 mm annual rainfall and a dry season of 3-5 months. There are different species of *Khaya* spp which include the following species.

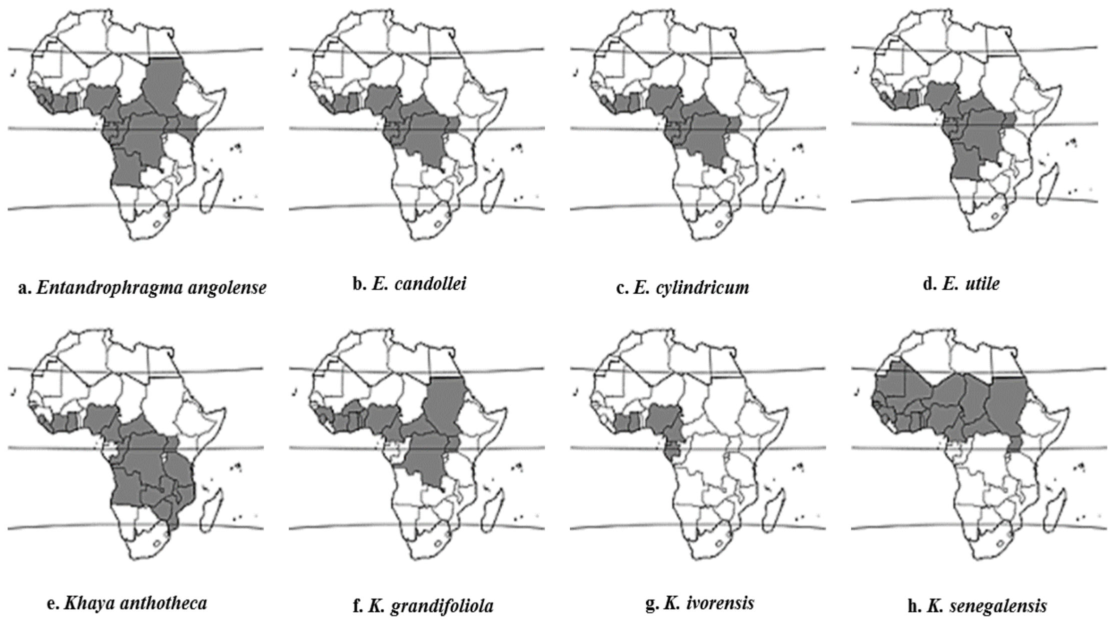

Figure 1.1: Distribution of the eight target African mahogany species

Sources: www.prota.org

1.1 Khaya anthotheca

Khaya anthotheca locally called *'Krumben'* is one of the most important African Mahogany largely found in Sierra Leone through Congo, Angola to Uganda and found in Ghana in the moist semi-deciduous (North West Subtype) and moist evergreen forests with 1200–1800 mm annual rainfall and a dry season of 3–5 months.

The tree grows up to a height of 60m with cylindrical bole of girth about 3m. It has grey colored, smooth or slightly scaly bark with its slash being deep red. The bark is also thick and bitter. The crown is round and heavy branches. The leaves are pinnate with 2-4 pairs of leaflets and 6-8 pairs of lateral nerves. It has small flowers that are monoecious formed in

March usually in fours. The fruits are woody capsule usually with 5 valves, flat golden brown with small seeds engulfed by a narrow irregular thin wing.

The tree grows on deep fertile soil and along water bodies.

1.2 Khaya ivorensis

Khaya ivorensis (Dubini) is found in Ghana largely in wet and moist evergreen and moist semi-deciduous lowland rainforests and areas with average annual rainfall of 1600–2500 mm and a dry season of 2–3 months, up to 700 m altitude. It extends from West Africa (Ivory Coast) to Central Africa (Gabon).

The tree is up to 50 m tall and 6 m in girth with long clear bole of 30 m usually straight and cylindrical. The bark has reddish-brown surface and slightly rough. The slash is reddish, scented, thick and bitter. The massive crown is open and rounded and leaves inclined upwards. The evergreen leaves are spirally arranged, pinnate and have between 4-7 pairs of leaflets, 7.5-14 cm long by 2.5- 4.5 cm broad, oblong, abruptly long-acuminate at the apex (the tip very long and conspicuous in seedling and saplings); stalk of leaflets about 4 mm long. The flowers usually with 5 valves are white, formed from September to December and February to May. The fruits are woody capsule which contains narrowly winged seeds.

Khaya ivorensis often occurs along watercourses. It prefers alluvial soils which are moist but well-drained, but it can also be found on slopes on lateritic soils. It occurs either in small groups or singly, for the most part on moist valley sites in dry areas.

Leaves of *Khaya ivorensis*

Slash and bark of *Khaya ivorensis*

1.3 Khaya senegalensis

Khaya senegalensis is found in Senegal through Sudan to Uganda. Locally called *'Kuntunkuri'* is slightly found in Ghana's Dry semi-deciduous forest, Transitional forestand Savanna woodland.

The tree is 35 m tall and 3 m in girth. It has a dense crown with short bole and covered with dark-grey scaly bark. It has a slash color of dark-pink and produces gum. The tree has pinnate leaves with 3-4 pairs of leaflets. The flowers form from January to April. Fruits mature from

December to April with 4 valves and seeds are elongated and winged.Aside water bodies, *Khaya senegalensis* are friendly to low-lying areas.


Leaves of *Khaya senegalensis* Slash and bark of *Khaya senegalensis*

1.4 Khaya grandifoliola

Khaya grandifoliola, among the valuable Africa mahogany locally called *'Kruba'* is found in the dry semi-deciduous forest in Ghana with an average annual rainfall of about 1200–1800 mm and a dry season of 3–5 months. It occurs up to 1400 m altitude. Sometimes it can be found on rocky and hilly parts of moist semi-deciduous forest. The species also extends from Guinea to Angola and Uganda.

Tree height is usually 40 m tall, diameter up to 2 m and buttress 3 m high. The bark is rough and greyish brown with slash being reddish with white streaks, scented and viscous exudate. Leaves are spirally arranged with 3-5 pairs of leaflets sometimes with 12-15 pairs of well-defined nerves. Flowers are unisexual and fruits contain disk-shaped, strongly flattened, narrowly winged all around the margin and brown seeds.

It does well in moist but well-drained soils, and is locally common on alluvial soils in valleys.


Leaves of *Khaya grandifoliola* Slash and bark of *Khaya grandifoliola*

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CHAPTER TWO

Ghana's trade in African mahogany: The trend in a Decade and half

By:

Sarah Pentsil

2.0 Introduction

Mahogany could be classified as one of the most extremely valuable timber species with a high local and export demand dating as far back as the 18th century, due to its excellent aesthetic and physical properties. Within the West and Central African sub-region, records show that four main species of mahogany from the family Meliaceae are present namely: *Khaya anthotheca, Khaya ivorensis, Khaya grandifoliola and Khaya senegalensis. Khaya anthotheca* usually occurs in wet or dry semi-deciduous forest though some are present in the transition zone. Likewise, *Khaya grandifoliola* grows in semi-deciduous forest, primarily in dry areas and within the savanna zone, the species could be found along water courses. On the other hand, *Khaya ivorensis* is most abundant in the evergreen forest whereas *Khaya senegalensis* usually occurs in wet parts of savanna woodland. It is important to state that present studies have also confirmed that mahogany has the potential to grow very well in plantations which could help offset the decline in tree density in the natural forest. (Can we delete this first part because of similarities with chapter One)

Over the years due to similarities in appearance of the Khaya species, they are usually mixed and traded on the global market. On the international scene, mahogany is used for light flooring, ship construction, musical instruments, vehicles bodies, turnery and toys among others. According to TIDD (2015) wood products from Ghana are exported in primary, secondary or tertiary form to major markets in Europe, America, Asia, Oceania, Africa and Middle East.

The most compelling evidence from these records on export trends have continually shown marked decline in volume of wood products exported since 2001 due to illegal harvesting, illegal mining and poor agricultural practices. Opuni-Frimpong (2008) indicated that until the 1950s for example, timber from mahogany was the most dominant species of Ghana' wood product export accounting for over 100,000m^3.

It is equally important to emphasize that though documentation on trade of the species has focused on lumber and its related products, every part of the mahogany tree is of extreme importance in many cultures and has some export potential. Nikiema and Pasternak (2008) noted that in Cameroon whereas the bark is used to treat skin diseases, wounds and depression, the roots are equally useful and could be applied against oedema and amenorrhoea. Again flowers were used to cure syphilis and seed oil rubbed on the skin could cure rheumatism and influenza. The young twigs are also used as chewing sticks and toothbrushes. Similarly, in Tanzania, roots decoctions treat anemia, dysentery and rectal prolapsed whereas in DR Congo, chemical extracts from the leaves are used for making arrow poison (Maroyi 2008).

Locally, mahogany is used for the construction of canoes, furniture, doors, door and window frames, panels etc. The medicinal value of the bark of the tree is known to cure colds, pneumonia, stomach pains, vomiting and gonorrhea. Yet, demand on the export market remains high only for the trunk of the tree. The goal of this study is to assess the export trend, product innovation and quantum of trade of mahogany in Ghana.

2.1 Methodology

The approach to this study was mainly through secondary data that was obtained through literature search and review of socio-economic knowledge on mahogany and collation of data on export trend of mahogany products from Ghana from 2001 to 2015.

2.2 Results/Findings

2.2.1 Comparison of mahogany products in the overall export volume of wood products from Ghana

During the past 15 years (2000-2015) period, the highest volume of export for mahogany was recorded in 2007 i.e. 32,149m^3 (Table 1) whereas the highest export value of €22,054,932.29 was gained in 2005 from a volume of 30,741m^3. The least export volume was in 2001 and by 2012 mahogany alone constituted 6.96% of the overall volume of timber species.

Table 2.1: Percentage of mahogany in the overall export volume

Year	Volume of Mahogany (m^3)	Overall volume of timber species (m^3)	Percentage
2001	14,082	476,500	2.95
2002	17,908	472,427	3.79
2003	18,931	444,388	4.26
2004	26,191	455,180	5.75
2005	30,741	466,155	6.59
2006	31,235	451,608	6.91
2007	32,149	528,570	6.08
2008	29,630	545,915	5.04
2009	19,933	426,221	4.68
2010	21,876	403,254	5.42
2011	19,801	319,843	6.19
2012	17,503	251,346	6.96
2013	16,894	271,772	6.22
2014	17,293	356,036	4.86
2015*	10,832	249,846	4.33

2.2.2 Direction of trade of Ghana's wood products-(Khaya spp. and products)

Up to the present time, Ghana has six major markets for its wood products namely: Europe, Africa, America, Oceania, Middle East and Asia. In terms of product requirement, much of the primary and secondary products such as air dried lumber and plywood are exported to the African and Asian markets whereas demand for tertiary products are higher with regard to Europe and America. Though the global outlook of Ghana's that import wood products from Ghana are very huge, the lead destinations in terms of volume have been indicated on the map (Figure 2. 1).

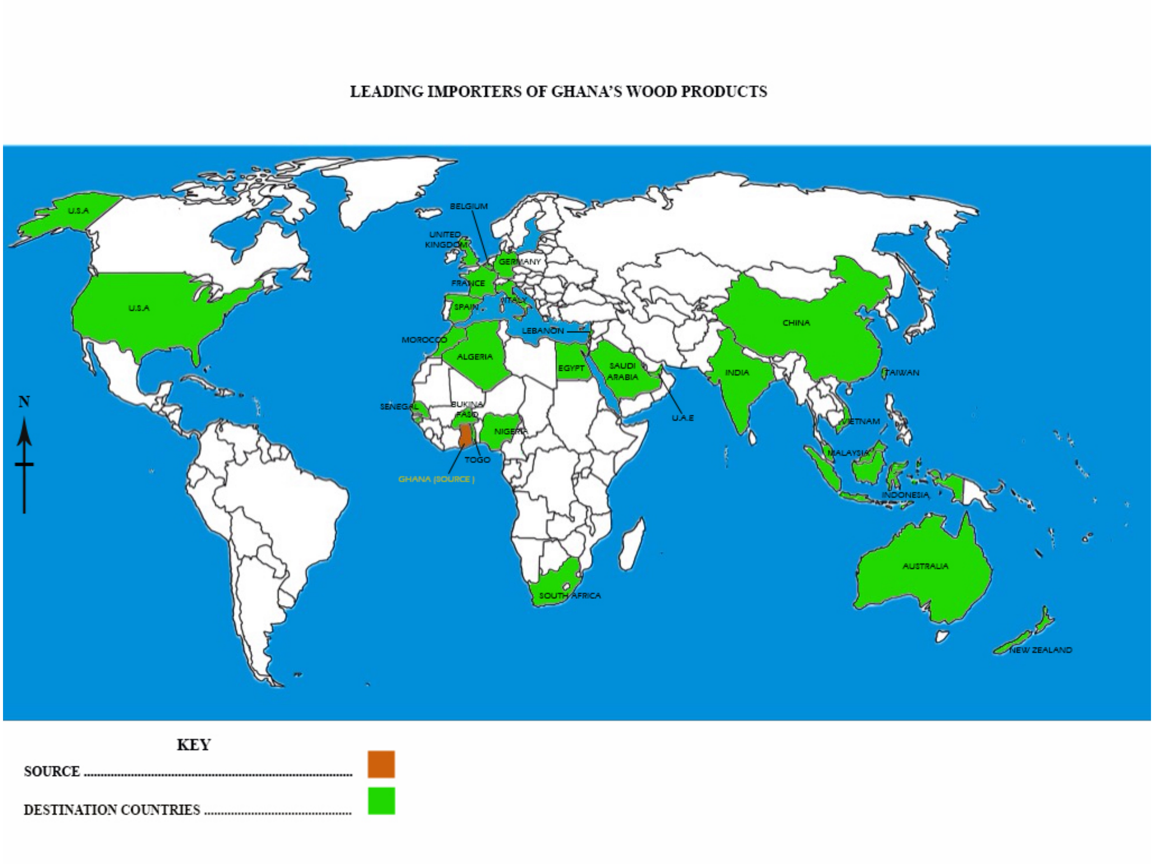

Figure 2.1: Global picture of major destinations for wood products

2.2.3 Demand for Ghana's wood products in Africa

The statistics show that exports from Ghana to other African countries have significantly increased since 2001 through to 2003 which recorded comparatively lower values of 9.77% and 8.78% respectively of the total volume of export. By the close of 2006, trade within the region had grown to a little over a quarter of the overall volume and this increment continued until 2012 when the figure was more than half of the export volume resulting in a decline to major markets in Europe, Asia, Middle East and America.

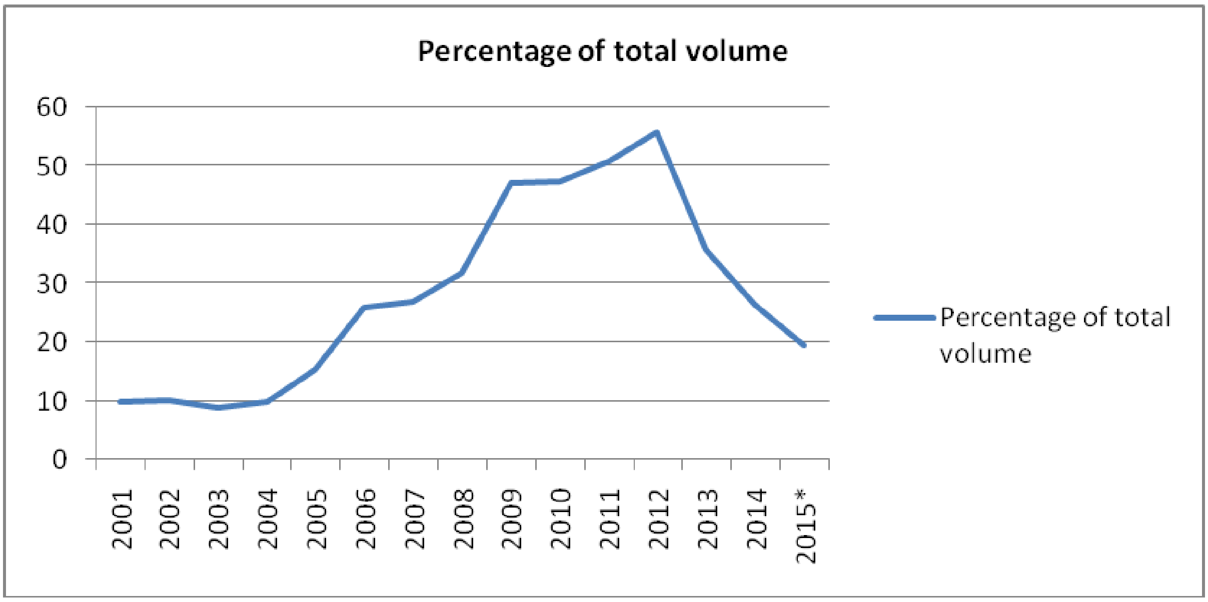

Figure 2.2: Supply of wood products to other African countries

Likewise within the ECOWAS region, the top three destinations for wood products are Nigeria, Senegal and Burkina Faso. Ghana presently appears to be the major supplier of lumber to some wood deficit countries in northern parts of the region as well as its immediate neighbouring countries including Cote D'Ivoire, Togo and Sierra Leone (Figure 3). Aside these leading importers, records show that trade in wood products from Ghana extends to every country within the sub region apart from Mauritania.

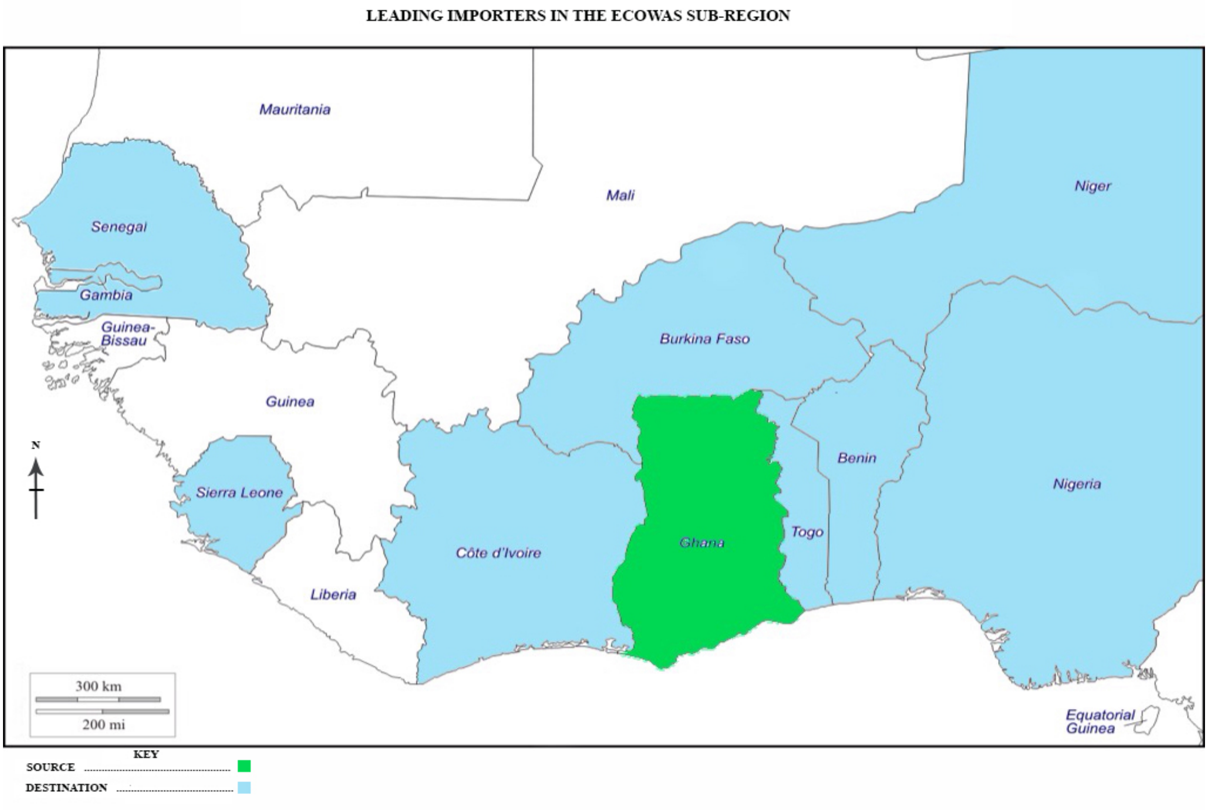

Figure 2.3: Destinations of wood products within the sub-region

The yearly outlook of the overall volume of wood exported during the period under review (2001-2015) is presented in Figure 2.4. From the break down, it is clear that the demand for Ghana's wood products within the ECOWAS sub-region has increased since 2001 just as it had for the whole African continent with 2009 recording the highest volume of trade within the 15year period. In 2003 for example, the total volume of air dried lumber exported was 7,330m^3 out of which 2,591m^3 was imported by Senegal. Likewise in 2004, Senegal was among the largest importers of air dried lumber from Ghana accounting for 1,718m^3 of the total volume of 9,839m^3. By 2006 through to 2010 volumes of wood products to the ECOWAS region continued to increase with air dried lumber and plywood as the leading export products until 2011 when demand for wood products started to decline.

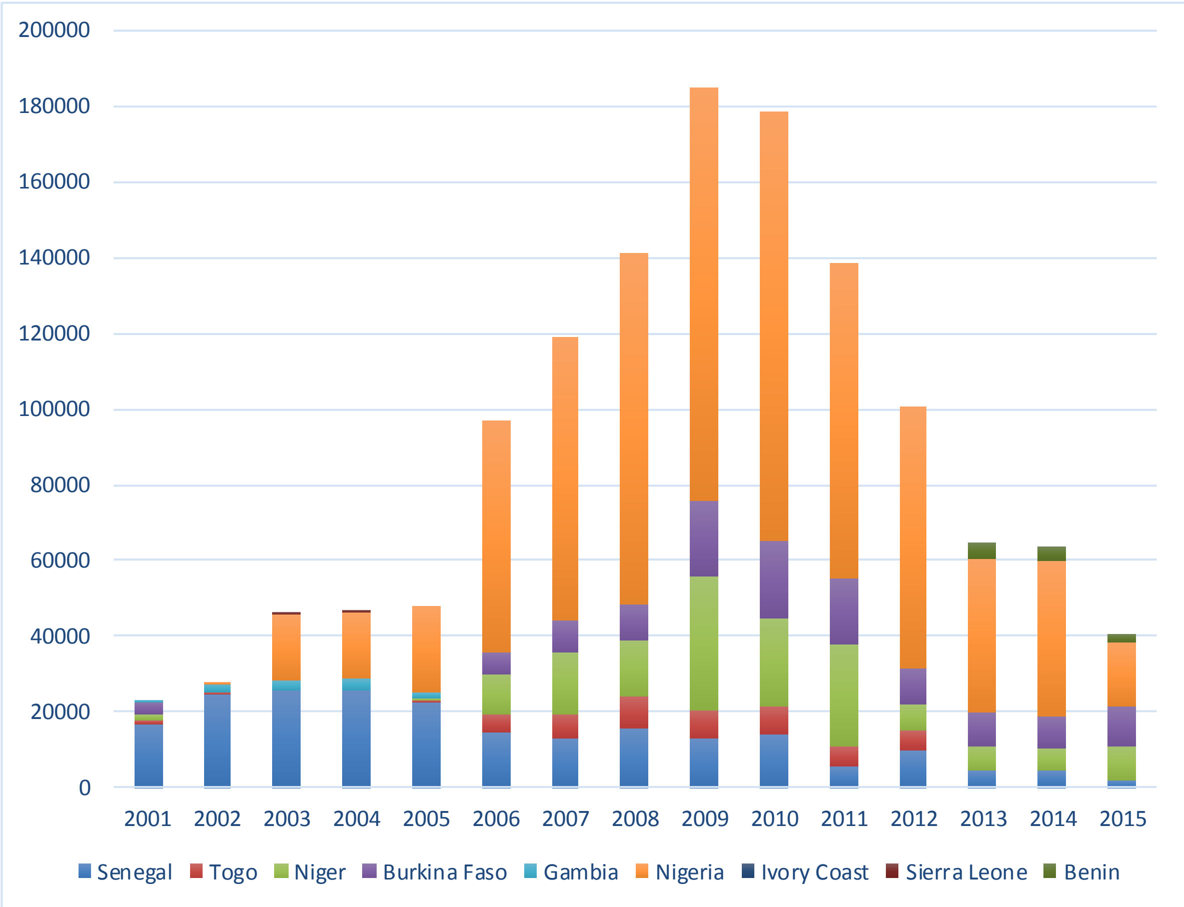

Figure 2.4: Leading importers of wood products in the ECOWAS Region

2.2.3.1 Export performance of secondary and tertiary products from mahogany

The TIDD-Ghana classifies lumber (air and kiln dried), veneers, block boards, plywood (overland) and kindling as secondary products while dowels, flooring, processed lumber moulding, profile boards and furniture parts could be referred to as tertiary products.

2.2.3.2 Volume of air and kiln dried lumber exported

Comparison of volume of air and kiln dried lumber exported during the entire period shows that the market demand for kiln dried lumber is much higher and the country earns more on the export market than air dried lumber which is mostly sold in the ECOWAS region.

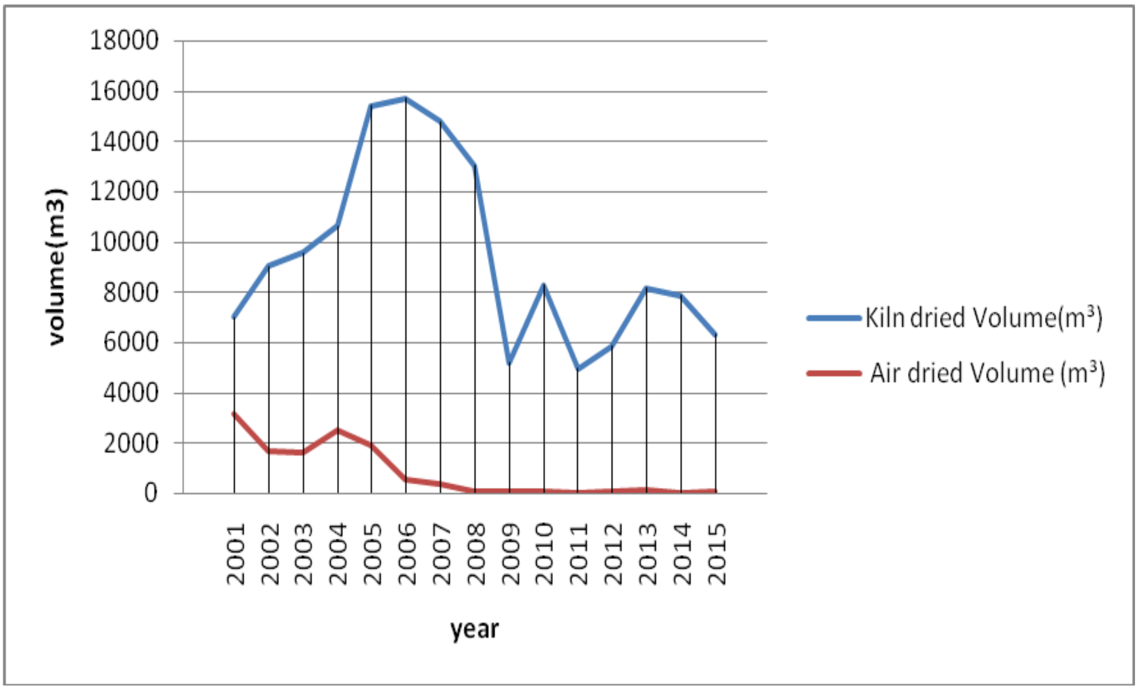

Figure 2.5: Volume of air versus kiln dried lumber exported

Comparison of the value of air dried and kiln dried lumber clearly depicts that the latter is more valuable than the former and continued export of large volumes of kiln dried lumber could result in a huge loss of revenue causes the Ghanaian economy.

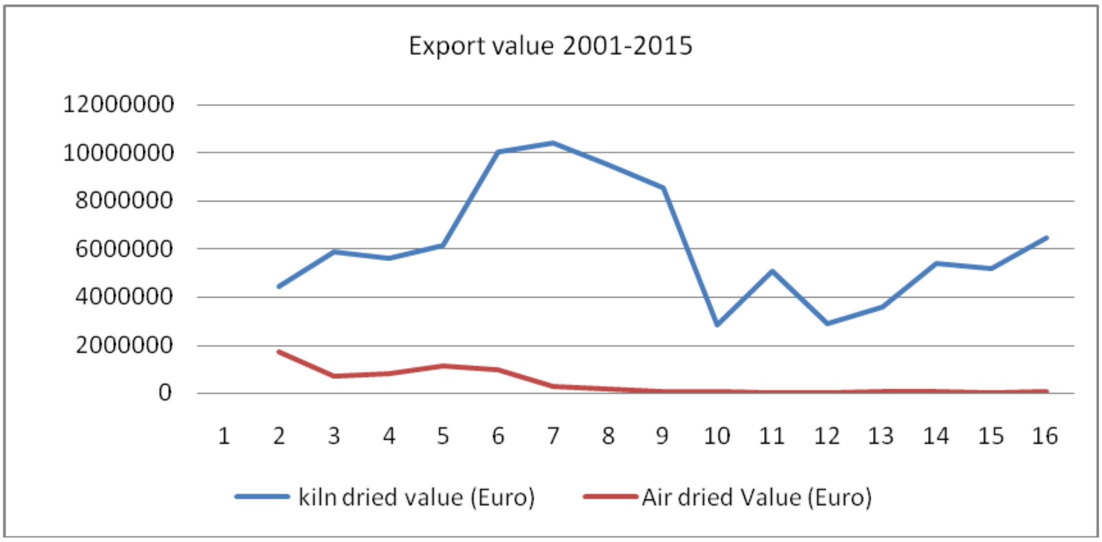

Figure 2.6: Value of air versus kiln dried lumber

2.2.3.3 Trade in veneer products

Four types of veneer were produced for the export market (Figure 7). By and large, sliced veneer accounted for the largest volume of mahogany products exported throughout the period under review and veneer curls were the most priced of the four. In fact in 2014, 2015 for example veneer curls was exported at a price per cubic metre of 11,612 and 13,151 Euros respectively.

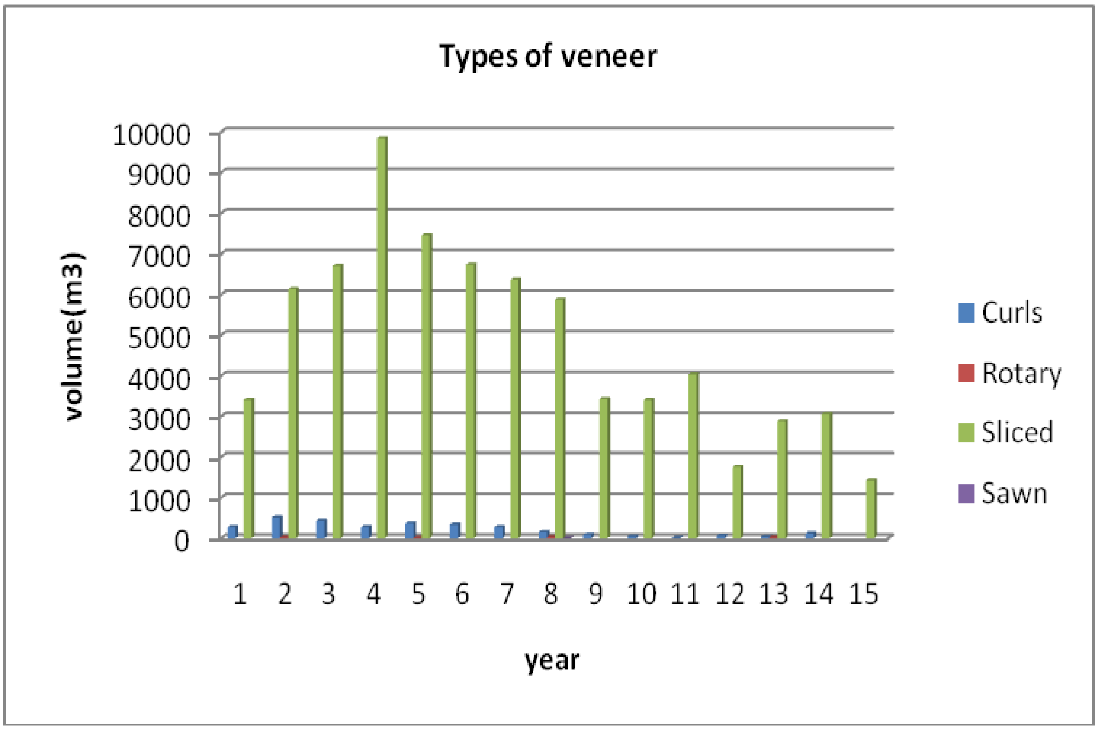

Figure 2.7: Types of veneer produced for export

2.2.3.4 Tertiary products

Profile boards, flooring, furniture parts and processed mouldings were the only tertiary products exported during the period. Ghana's performance in terms of volume of tertiary products produced in comparison to the volume of the overall wood products could only be described as very poor (Figure 8). It is unfortunate that a similar trend persists throughout the sub-region where wood processing is mostly carried out at the secondary level. Ogunwusi and Olife (2012) reports that in Nigeria, for example, low quality of standards even limits the local demand for furniture resulting in high exports of secondary products. Much of the sawmill production primarily focused on producing secondary products which are of relatively lower value. As already stated, Ghana earned its highest ever export value of €22,054,932 from mahogany in 2005 from a volume 30,741m^3. However, the highest volume of mahogany products (32,149m^3) was sold in 2007 at a value of €20,122,681. This disparity in volume and value could be explained by the quantum of tertiary products exported in that year alone (Figure 8). The trend analysis further reveal that 2005 was the only year that recorded the highest volume of export of furniture parts (905m^3) whereas the volume exported in 2007 was 239m^3. It is also equally important to note that in 2013 and 2014, mahogany was only exported as secondary product.

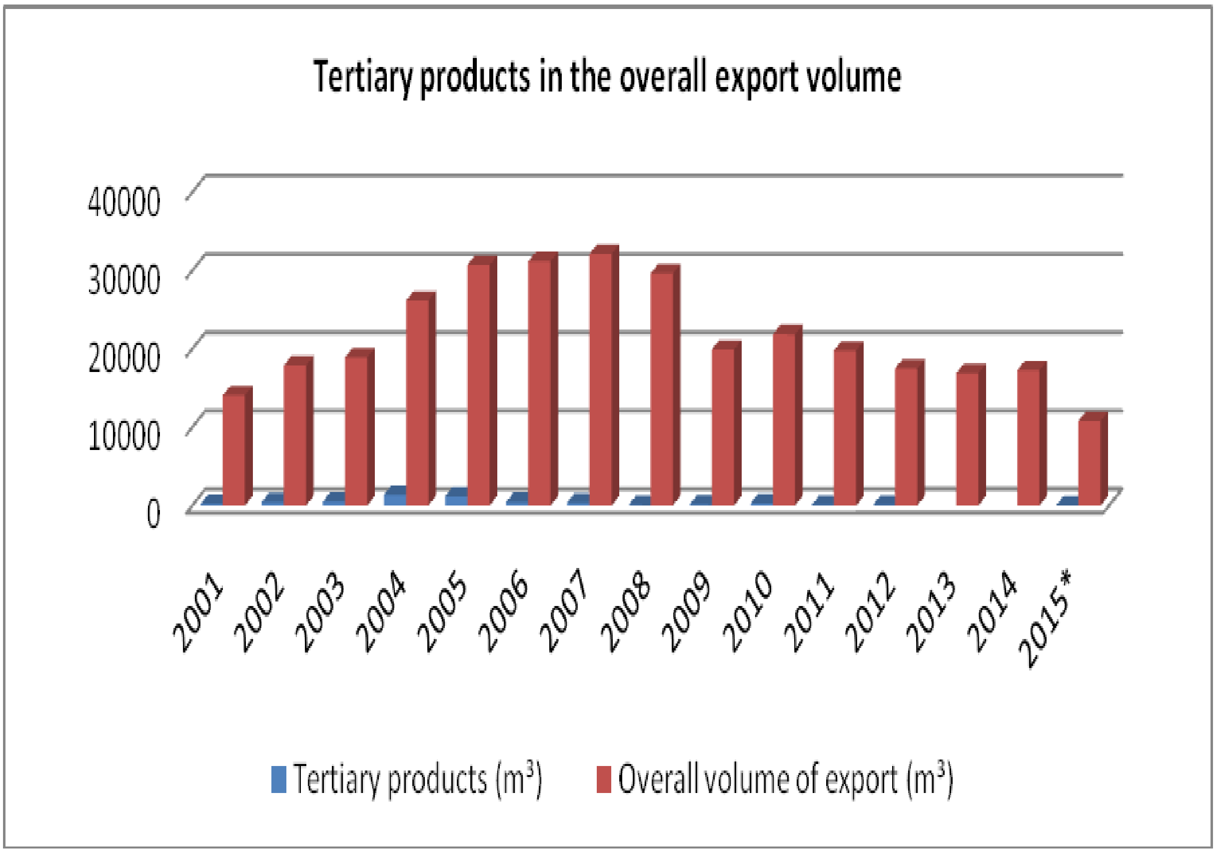

Figure 2.8: Volume of tertiary products exported

An overview of the types of tertiary processing revealed that Ghana exported more of processed mouldings and furniture parts than any other product with profile boards being the least (Figure 9). Indeed years with records of high volumes of tertiary products were also invariably periods that Ghana gained more on the export market.

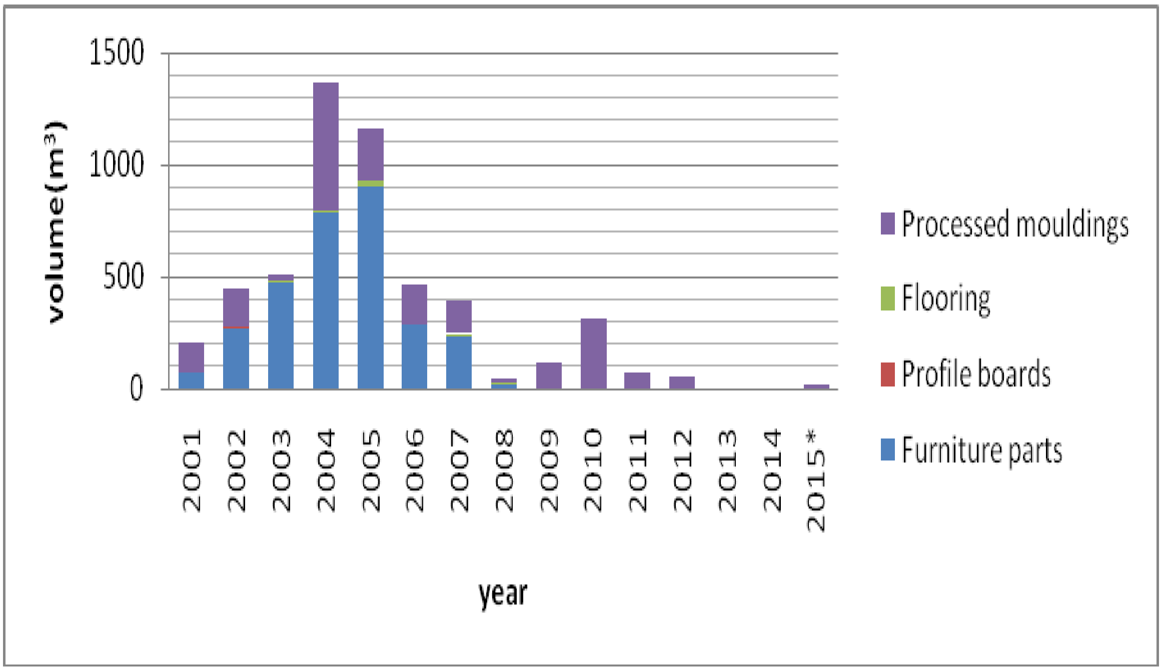

Figure 2.9: Type of tertiary products exported during the period

2.2.3.5 Trend in product innovativeness from mahogany

Ghana continues to export the same products over and over again with very limited attempt to use innovation to produce comparatively new products for export. Powdered barks for example were only exported in 2008 and 2009. Other products that could also be placed in this rare export category include curls board and block boards. In the final analysis, it is striking that cumulatively the total volume of these products exported does not exceed 200 cubic metres.

2.3 Recommendations and Conclusion

Ghana is one of the key suppliers of wood products throughout Africa and at the global stage. It appears wood products are exported to almost all countries in the world but for many areas our dominance is short lived. Our focus has been to meet demand without researching into other products that is on demand by the global market. The country's comparative advantage in the ECOWAS region, for instance, has the potential to improve export earnings more than ever before but there is the need to curtail the huge reliance of our regional neighbors on air dried lumber which is entirely unsustainable in the 21st century. Ghana should clearly aim towards zero export of air dried lumber to earn more.

On the world scene, though our sphere of influence in terms of supply of tropical timber is high nonetheless dominance of traditional secondary products has also limited our market value greatly over the past decade. As at now, no attempt has been made to export wood chips for example like other competitors. There is the need to upscale production of tertiary products for export. The country is likely to earn twice as much from the latter than from secondary products. In addition, there should be some incentive for mills that venture into production of innovative products in the face of high utilities charges and dwindling forest resources among others.

Without a doubt Ghana has a huge market for its wood products. The main challenge however is to ensure sustainable use of our resource base and vigorously work towards restocking degraded areas to increase tree density through plantation development.

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CHAPTER THREE

Machining properties of mahogany: Examining Stemwood and Branchwood

By

Tekpetey Stephen Lartey, Thomas Amaning, Sampson Mensah,

3.0 Introduction

Machining is a stress-failure process, which is conveniently analyzed as an action of a cutting tool on a piece of wood (Dinwoodie, 1980). Machining properties are directly related to the behavior of wood when shaped, bored, turned, sanded or put through any other standard woodworking operation (Davis 1962). For some purposes, the difference between wood in machinability is negligible but for other uses, however, as in furniture and fixtures, the surface quality and facility with which wood can be worked may be the most important of all properties. According to Davis (1962), along with specific gravity and tendency to split and warp, machinability is of first importance to the woodworker. Thus, unless a wood machine is fairly well and with moderate ease, it is not economically suitable for such uses regardless of its other virtues.

There are a number of machining properties including turning, shaping, sanding, planning boring and nail holding capacity. Sanding, which is one of the most important woodworking operations, remains the accepted term for the use of coated abrasives in finishing wood and the machines that perform the job are termed sanders. Several types of sanding machines are available, some of which are highly specialized for turnings, mouldings, contours and edges. The great bulk of sanding, as reported by Davis (1962), is the so-called "flatwork" and the chief machines used for this are the drum sander and belt sander. Several different abrasives are used in sanding wood. The mineral quartz, which is the oldest and best known coated abrasive, has very largely been replaced by garnet and aluminium oxide in the industrial woodworking sector (Davis, 1962). The abrasives in the woodworking trade come in a wide variety of sizes and it is a general practice with a given wood to use the finest grit that will not make scratches visible to the eye. Sanding is done to remove any machining defect or remedy a slight mismatch where different parts of a finished product join to prepare the surface of the wood for the application of finishes. In this study, some machining properties of stemwood and branch wood of plantation grown *Khaya ivorensis* were assessed and compared with natural ones from same ecological zone in Ghana.

3.1 Data collection

The mahogany samples were harvested in the Moist Semi-Deciduous forest Zone of Ghana specifically Amantia. In all about forty (40) pieces of branch wood of *Khaya ivorensis* was collected from Amantia. The pieces were cross-cut into length of 1.59m. The pieces were then transported to FORIG for further processing. Finally, twenty (20) pieces were again selected and transported to Wood Industries Training Centre (WITC). Measurements were taken on every piece (the diameter of the two ends and the length). The branch woods were then converted into lumber using flat and quarter sawing methods with a swivel forester mill into different sizes. Tungsten Carbide Teeth (TCT) saw blade with diameter 43cm was used to convert the branch wood. The sawn lumbers were treated with pyrinex to protect the wood from insect attack. The lumbers were then stacked with stickers under a shed for drying until an average moisture content of 14% was attained.

All operations involved in the sawing, cutting, planning and sanding tests were carried out at the Wood Industries Training Centre (WITC) Akyawkrom, in Kumasi (Ghana), where basic wood working machines were available.

3.1.1 Selection of Sample Material and Sample Size

The air dry samples of selected branch wood of *Khaya ivorensis* at an average moisture content of 14% were used for the tests. Samples were selected from the stacked lumber for the preparation of the test specimens. All the test samples were sound pieces that are free from all splits, beetle holes, cracks and loose knots. About 120 and 125 samples were prepared for the compression and static test with dimensions 2x2x6cm and 2x2x30.5cm respectively. For the sanding test, four grits sizes of sand papers were used for the test. 2.5x10x100cm was the dimension of the samples for the sanding test and the sample size per grit test was 30 for A and B. The selection of the test samples and their preparations were based on ASTMD 143-83 (1994) and ASTMD 1666-87 (1994).

The test specimens, after each of the machining operations were critically examined, evaluated and graded visually with the help of a hand lens. The grading, according to ASTM D1666-87 (1994); were on a numerical scale of 1-5 as follows: Grade 1 – excellent (defect-free); grade 2 – good (slight defects); grade 3 – fair (medium defects); grade 4 – Poor (severe/advanced defects); grade 5 – rejected/Poorest (fiber tear outs and broken corners).

3.1.2 Sanding Test

Surfacer machining type 300x2.10m SCM via Emilia 7747037 Rimini, Mod: P3A, N:AV 170480, Kg≈290 with hand pressure feed and spindle speeds of 2.5m/min 3,600 rpm and a cutting angle of 20° was used to plane one face and one edge for flatness. The 7.5 horse power thicknessing planer machine type 53x84 cm was used to reduce the thickness of the sanding sample pieces. After planing, the chipped sample pieces were labeled group A and the non-chipped wood were labeled group B.

Grits No. 80 and 100 were used to sand the chipped wood (labeled group A) and grits No. 120 and 150 was used to sand the non-chipped wood (labeled group B) using Belt Sanding machine type Wadkin with table size of 90mmx1.83m. The sample species were inspected visually and with the help of a hand lens to detect the scratches on the samples. It was graded on a scale of 5 as an indication of the seriousness of any defect that was found. It was graded in percentages of defects and defect-free sample pieces.

3.1.3 Selection of Sample Material for stemwood of **Khaya ivorensis**

The air dried samples of the stems of *Khaya ivorensis* at an average moisture content of 15% were used for the tests. Random samples of the lumber from the five trees taken from different locations of the stem. (From the butt end, middle and top portions) were taken made from the stacked lumber for the preparation of the test sample. All the samples were clear, free from cracks, splits, loose knots or flaws, beetle holes or deep raisin ducts.

Figure 3.1: materials being planned at FORIG Workshop

3.1.4 Planing of Samples of Mahogany

A sample size of thirty (30) per test per tree was taken from both plantation and natural mahogany. Dimensions of 2*7.5*30cm were used for both the shaping. Three spindle speeds were used for the shaping tests. Ninety (90) samples were prepared for the sanding tests for three grit sizes of sand paper that were used. The dimensions of the samples for the sanding tests were 2.5*10*100cm with sample size per location of tree being 30. The selection of the test samples and their preparation were based on ASTM D 143-83 (1994) and ASTM D 1666-87(1994)

For the stemwood, all the activities involved in planning, shaping and sanding were undertaken at FORIG, Fumesua (Ghana). The test specimen after each machining operation were examined, evaluated and graded visually with the help of a hand lens. The grading according to ASTM D 1666-87 (1994) were on a numerical scale of 1-5 as follows: Grade 1 –

defect free (excellent) ,Grade 2 – Slight defects (good),Grade 3 – Medium defects (fair),Grade 4 – Severe or advanced defects (poor) ,Grade 5 – Fiber tear outs and broken corners (reject or poorest). The defects observed for each machinery test were also recorded.

3.1.5 Shaping Test

In this investigation, a narrow bandsaw (type Wadkin C5) and spindle moulding (type Swdgwick SM4) machines were used. The pattern selected was traced on each of the specimen to be shaped. The selected outline or patterns of cut required varies from right angles to parallel to the grain because woodworking machines and hand tools differ in the way they cut wood at different angles to the grain. The narrow band saw machine and a 19mm saw blade running at speeds 3000rpm 1500rpm per minute respectively was used initially to shape the entire specimen to the desired curved outline. The band saw shaped specimen were fastened one after the other to a jig and fed past the cutters of the spindle molder manually. The three spindle speeds used were 3000rpm, 4500rpm, and 6000rpm. The entire shaped specimen were then examined and graded on a scale of 1-5 on the basis of such defects as raised, chipped, torn, fuzzy and rough-end grain as well as side-grain and end-grain cuts. The most defective place of each sample determined its grade because such a place determines the amount of sanding to be performed to make it commercially acceptable. The percentage of specimens grading good to excellent was also calculated. **Sanding test**

A two knife combined surfacing and thicknessing planer machine of type 610*230mm "D.A.A" was used to plane the sanding test specimens at feed and spindle speeds of 9m/min 5200rpm and a cutting angle of 20". After planning, the specimens were sorted out into chipped and non-chipped groups. After sanding, the specimens were inspected visually with the help of a hand lens for (a) degree of chipped defect on group A samples and (b) fuzz and scratches on group B samples. These were then graded on a scale of 1-5 as an indication of the seriousness of any defects that were present. The percentage of specimens grading excellent (defect free) were determined.

Figure 3.2: Materials being sanded at FORIG Workshop

3.1.6 Machining

For the stemwood of Mahogany samples, the machining operations showed no significant differences between the plantation and natural Mahogany. It was however realized that higher speed cutting produced a better finish in both the plantation and naturally grown Mahogany. According to Goli *et al* 2008, cutting is the splitting of the material along the path described by the cutting edge, and the deflection of the split material. In many cases the inefficiency of the cut is not connected with the tool itself, but surface defects maybe caused by how the wood reacts to the applied forces, species of the wood and the pressure exerted on the tool to the surface of the wood. The surface defects maybe due to the inability of the tool to correctly perform the cut.

From the planning and sanding results, the samples shows that plantation give better planning and sanding qualities in the mahogany samples as shown in Table .. and Table …. This work confirms the findings of Tekpetey *et al*. 2015 on the surface quality of mahogany samples from Ghana using more quantitative techniques. According to the work of Tekpetey *et al*. (2015), the evaluation was made at three different height levels: bottom, middle and top portions of the harvested Mahogany samples. The average roughness (Ra), mean roughness depth (Rz), maximum surface roughness (Rmax), core roughness depth (Rk), reduced peak height (Rpk), reduced valley depth (Rvk), total height of roughness (Rt), and maximum depth of roughness motif (Rx) were estimated on tangential surfaces of the samples after sanding using paper of grit size P150, P180 and P 280(for further details see chapter on Surface quality).

According to Owusu and Ayakwah, (2011), machining quality improves with increasing speed which meant that, shaping quality depends on spindle speed, thus, the higher the speed, the better the surface quality. They also stated there was the possibility that *Khaya* spp can score 100% defect free samples and fuzzing tendencies decreases with grit sizes. Scratches made by belt sander on *Khaya* or mahogany spp. also decreases with increasing grit size. With grit sizes 120 and 150, it was observed that plantation mahogany produced smoother surface than the natural mahogany.

Table 3.1: Results of the stemwood mahogany sanding test

Grits Size	**% Defect free**	**% Defect free**	**Remarks**
	Natural Samples	Plantation Samples	
80	58%	86%	Plantation sample is better
120	53%	56%	Plantation similar to natural
150	67%	79%	Natural plantation better than plantation

From Table 3.1, in the sanding operation with grit size 80, defect free samples increased as the grit sizes were increasing, thus (53%, 58% and 67%) respectively. In the plantation mahogany, the percentage defect free samples when sanded with grit size 80, were higher than when sanded with 120 grit but the figure appreciated when it was sanded with girt size 150 (86%, 56 and 79%)

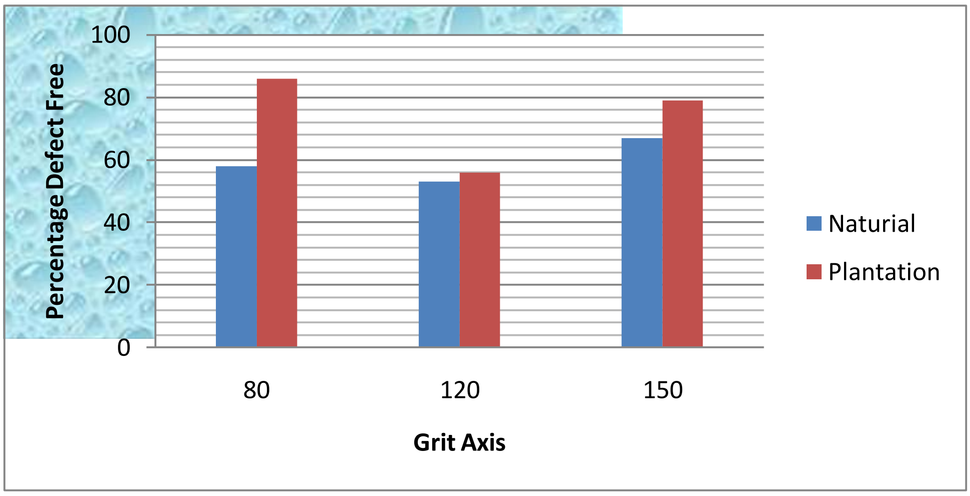

Figure 3.2: mahogany sanding test

In the planning test, the percentage defect free increase as the speed was increasing, thus the higher the speed, the better the finishing as shown in Table 4.2. These results can be shown in fig 4.

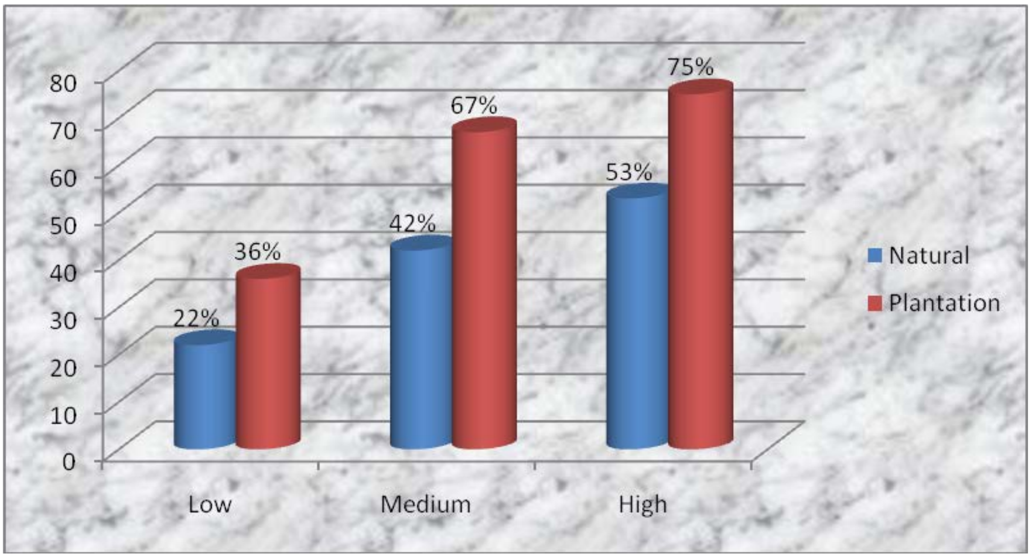

Figure 3.3: Graph of Planing test of Mahogany stemwood

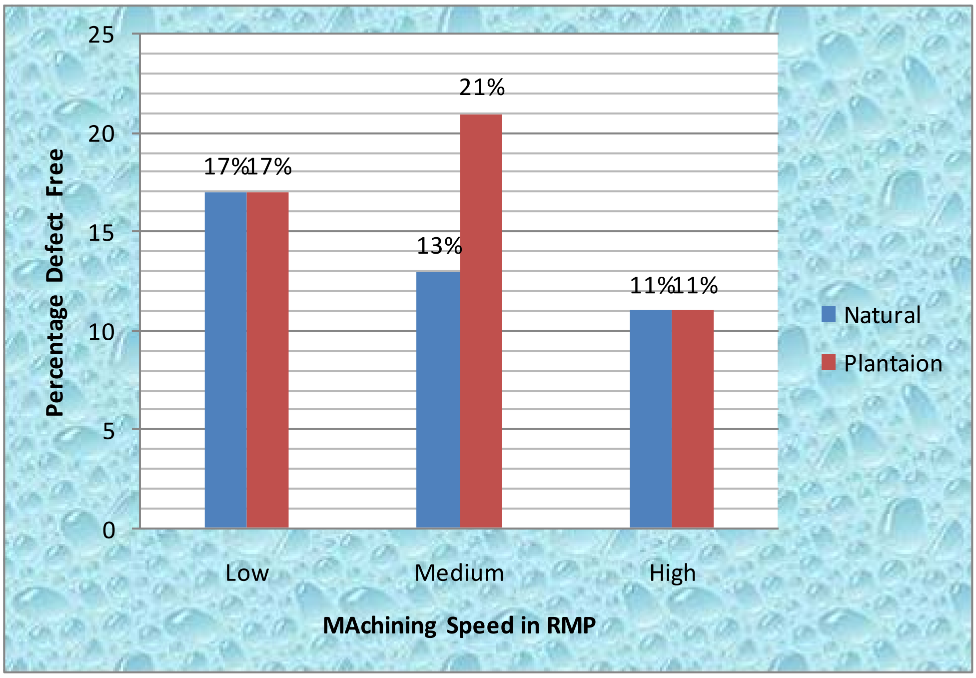

Figure 3.4: Graph of Shaping Test of Mahogany stemwood

Figure 3.5: Sand Paper Grit Size, P 80

Figure 3.6: Sand Paper Grit size, P120

Figure 3.7: Sand Paper Size Grit, P150

3.2 Conclusion

Based on the findings from the test on the machining properties of stemwood and branch wood of *Khaya ivorensis*, it can be concluded that the plantation samples are not inferior in term of sanding, planning and shaping to the natural samples from the sample ecological zones in Ghana. Though the use of visual grading of surfaces by experienced graders at the test site is subjective, the difference in the quality is not wide enough for any visual grading issues. With the advances of more qualitative analysis of wooden surface after machining, better interpretation and results can be obtained.

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CHAPTER FOUR

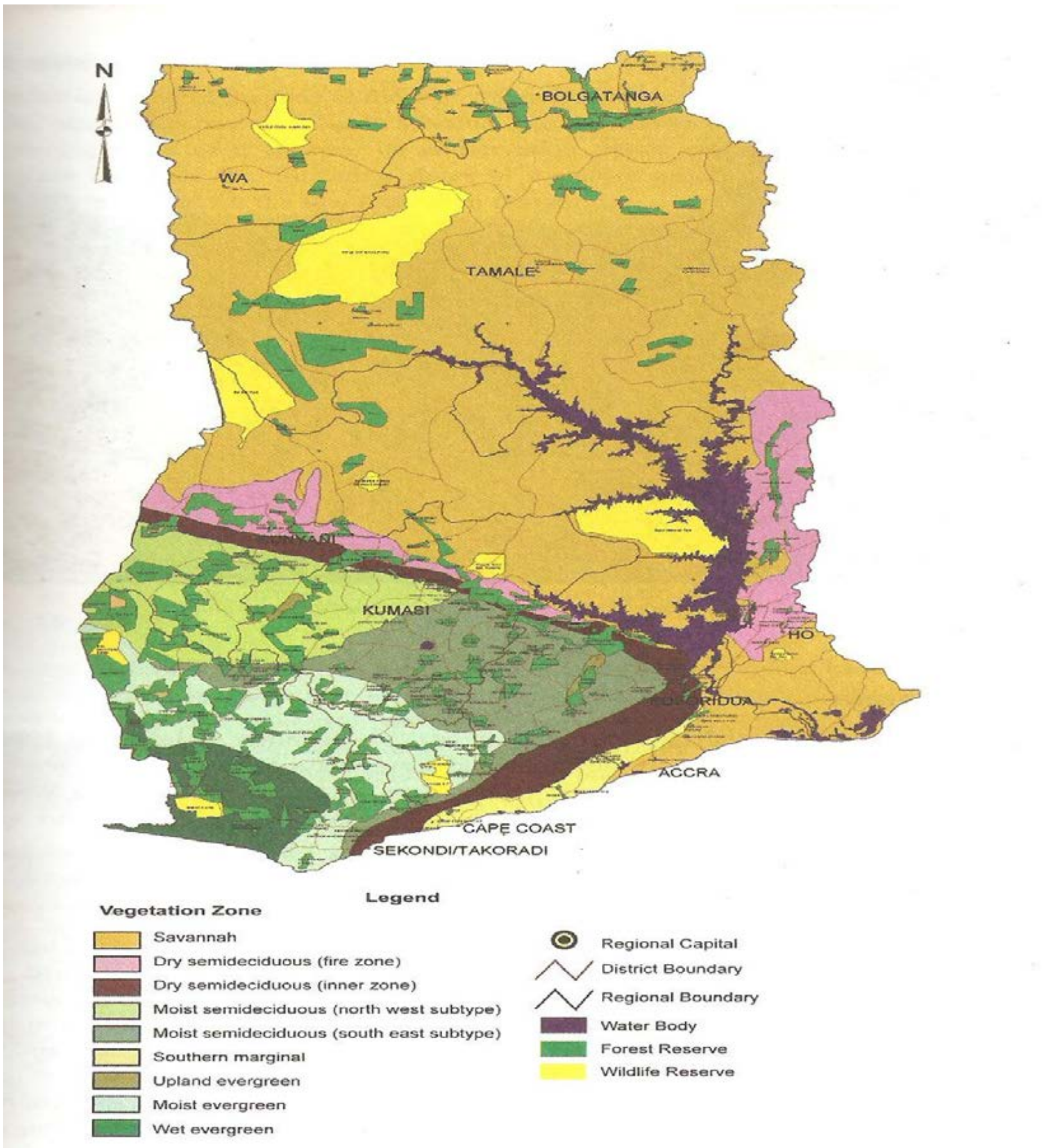
Lumber recovery and slice veneer production from African Mahogany

By:

Sarah Pentsil

4.1 Materials and Methods

Five matured trees of ‘PGM’ and three matured Naturally Grown Mahogany (NGM) were extracted from Amantia in the Pra-Anum Forest Reserve and FORIG plantation for the experiment during the dry season of February, 2012 using Logging machinery from LLL, Kumasi, Ghana.



g. 3.1. Vegetation Map of Ghana (*Source: Cartographic Unit , Forest Commission*)

Figure 4.1: Vegetation map of Ghana

The diameter and length of each tree and logs were measured and recorded using a tape measure. The logs were transported to Log and Lumber Limited, Kumasi for the primary processing. Logs of each tree were further cross-cut using a chain saw into two different length classes (**250- 300 cm**) and (**390 to 435 cm**) based on whether they would processed for **lumber production** or **sliced veneer** production. The logs were then clearly labeled P and N for Plantation and Natural trees respectively and for each log four (4) diameters at the cross cut end of the logs were measured. The tree samples were obtained from Amantia in Pra-Anum Forest Reserve, Ghana.

Figure 4.2: Harvesting of trees at Amantia

Figure 4.3: Inspection of logs at LLL logyard, Kumasi

Figure 4.4: Logs of Mahogany at LLL log yard, Kumasi

Figure 4.5: Cross cutting of logs and removal of disc for at LLL logyard

4.2 Primary Processing of Harvested Trees

A vertical band mill at Logs and Lumber Limited, Kumasi with saw blade thickness of 8 inches and length of 33feet 3inches with gauge of 17'' without tipping was used . The saw blade was swage set for processing. In all about 600 lumber pieces of thickness 35mm and 70 mm were obtained from logs extracted from the five PGM and three NGM. Two readings of lumber thicknesses were taken about 20cm from the both ends of the lumber, length and 2 width of each each lumber from logs were measured using a steel tape for the calculation of the lumber recovery .

Figure 4.6: Vertical band saw for processing

Figure 4.7: Labelling of mahogany lumber

Figure 4.8: Stack of PGM at LLL

4.2.1 Sliced Veneer Production

The logs that were harvested were further sorted for the slice veneer production as described above. (Wood veneer is a thin 0.3 to 6 mm sheet of wood having its grain parallel to the surface). The sheet or layon is peeled from a selected log by using either a lathe or slicer. The selected logs were heated with the following beneficial effects on veneer production. The veneer log is temporally softened making it more plastic, pliable and more readily peeled. The quality and quantity of veneer recovered from heated logs is also greater. Smoother veneer is produced from heated logs thereby decreasing adhesive consumption during gluing. Knife wear and power consumption during peeling are reduced.

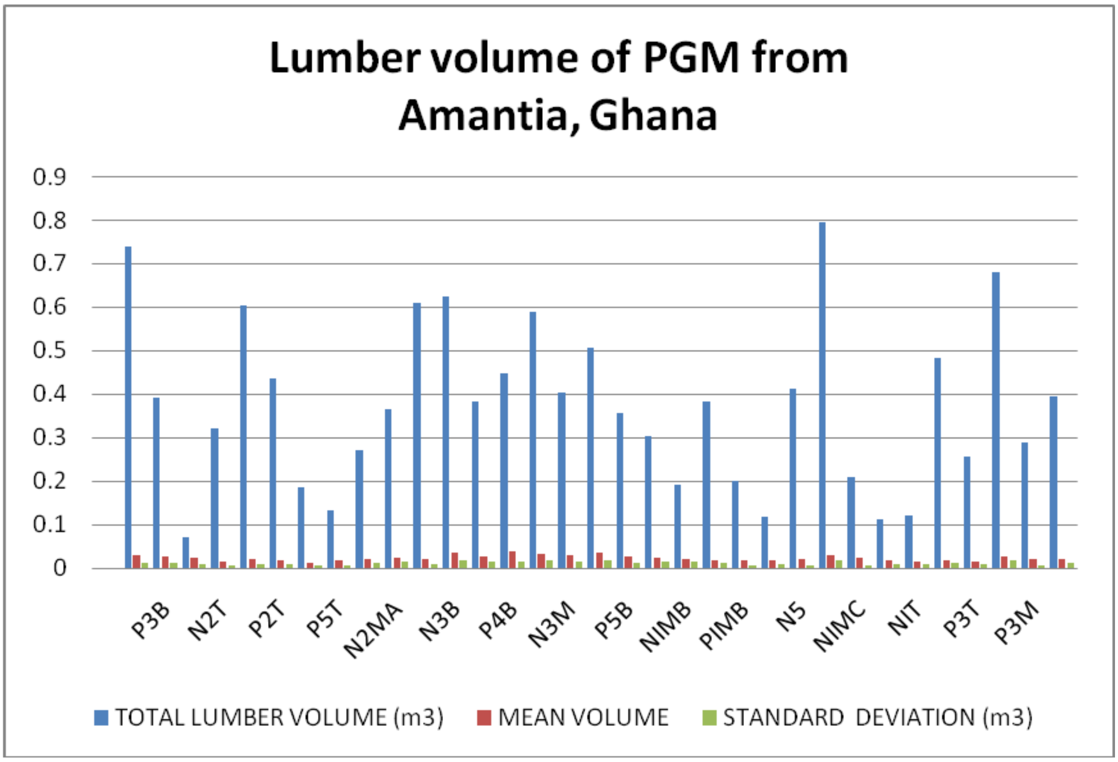
Figure 4.9: Preparation of flitches and heating of logs or veneer production

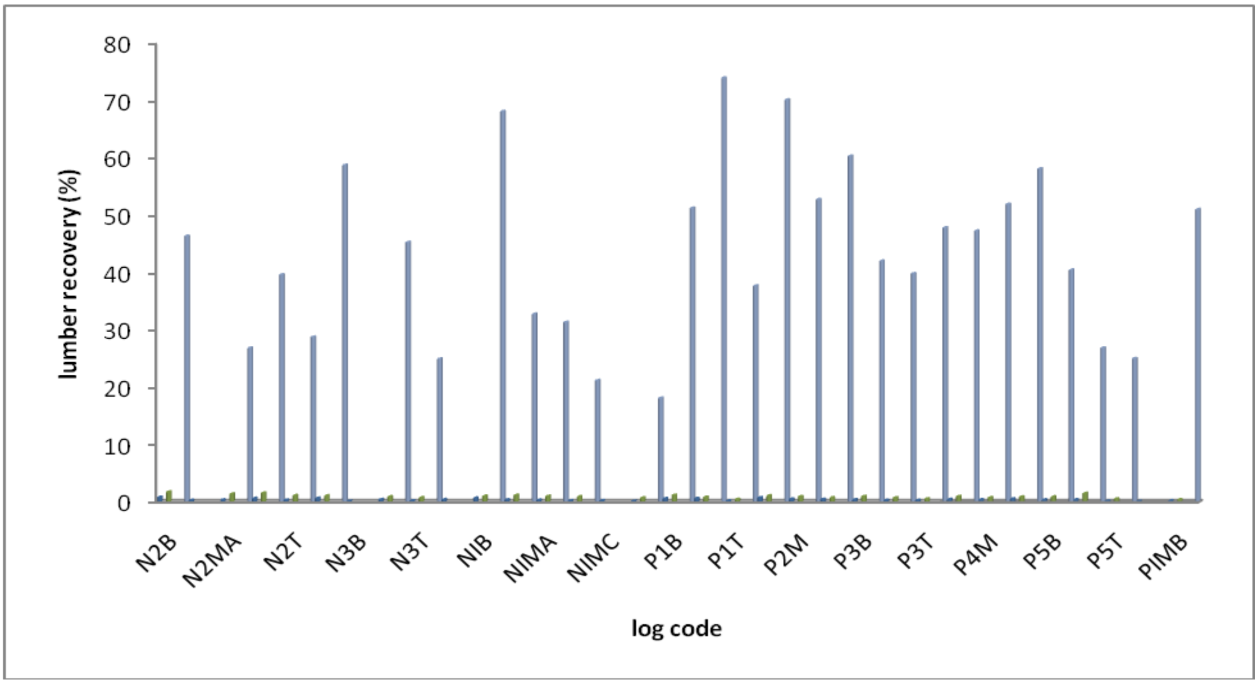
Table 4.1: Dimension of logs selected for sliced veneer production from LLL company

Table : Log dimension used for slice veneer from LLL company, Kumasi (Ghana)					
Log code			diameter		Length(cm)
	DI	D2	D3	D4	
P52	55	58	54	52	436
P2T	64	64	62	62	390
P2M	64	65	62	62	390
P5M	62	62	60	60	390
N2M	75	73	66	65	**390**
P3M	65	67	72	75	458
N1B	68	71	66	66	**385**
N1B	74	76	69	68	**385**

4.3 Results

The results and findings of this study, with logs from plantation and natural forest, are summarized in the three following graphs:





Key:

- N-Natural
- P- Plantation
- B,M,T-Base , middle and Top portion,
- 1,2,3….Number of tree species

The lumber recovery, for the logs collected for the experiment, was below 80 % with majority of the logs below 50% recovery rate. Thee plantation samples as shown by P notes in the above graphs were relatively higher than the natural ones.

Table 4.2: Quality of sliced veneer from Plantation grown mahogany

LOG CODE	**Grades: face, interior, low interior, backing, low backing**			
	interior	low interior	backing	low back
P5B	4	-	6	-
P2T	4	-	5	-
P2M	6	-	6	-
P5M	7	3	5	
N2M	4	1	3	
P3M	5	-	5	
N1B	3	-	2	
N1B	3	-	4	

CHAPTER FIVE

Chemical composition of plantation grown *Khaya ivorensis* mahogany

By

James Korang, and Thomas Amaning

5.0 Introduction

The chemical composition of wood varies from species and affects its utilization. The dry wood is a complex natural polymer that consists of three essential chemical components of cellulose, hemicellulose and lignin with a minor amount of (5-10%) of extraneous material. The extraneous material depends on species, biological variations such as genetic differences within species, and growing conditions. The choice of wood for specific project such as construction, furniture, wood fuel will depend on its property such as strength, colour, and energy which intend are derived from its chemical composition.

Cellulose is the major component and constitutes about 40 to 50% of the dry weight of wood. Itis a high-molecular weight carbohydrate polymer chain of only glucose monomers. The glucose monomers are linked to one another primarily with β(1-4) glycosidic bonds. The fibrous nature of the wood cells is the result of the linear, oriented, crystalline arrangement of their most abundant component, cellulose. Hemicellulose is also a carbohydrate and a branched low-molecular polymer of xylose, arabinose, galactose, mannose, and glucose. Hemicelluloses bind bundles of cellulose fibrils to form micro fibrils, which enhance the stability of the cell wall. Hemicellulose is less complex and its concentration is 25 to 35% (Saha et al). Although the cellulose structure is the same in different species, the hemicelluloses vary considerably among species and especially between hardwoods and softwoods (REF). Hardwood hemicelluloses are generally richer in pentose while softwood hemicelluloses generally contain more hexoses. Lignin acts as the cementing agent that holds the carbohydrate polymers together. It's a three-dimensional phenyl propanol complex polymer unit's of propane (*p*-coumaryl, coniferyl and sinapyl alcohol). The lignin cross-linked to each other with a variety of different chemical bonds. Lignin is the third major component of wood and its concentration ranges from 20 to 35% and confers the hydrophobic properties reflecting the fact that it is based on aromatic rings.

Unlike the lignocellulose, which is the major constituents of wood, extraneous materials are not structural components. Both organic and inorganic extraneous materials are found in wood. The organic component takes the form of extractives, which contribute to such wood properties as color, odor, taste, decay resistance, density, hygroscopicity, and flammability. Extractives include tannins and other polyphenolics, coloring matter, essential oils, fats, resins, waxes, gum starch, and simple metabolic intermediates. This component is termed extractives because it can be removed from wood by extraction with solvents, such as water, alcohol, acetone, benzene, or ether. Extractives may constitute roughly 5% to 10% of the wood substance, depending on such factors as species, growth conditions, and time of year when the tree is cut. The inorganic component of extraneous material generally constitutes 0.2% to 1.0% of the wood substance, although greater values are occasionally reported. Wood extractives vary between wood species, part of the tree, and environmental conditions (Alañón et al. 2011, Zanuncio et al. 2013).

5.1 Objective:

This investigation was initiated to understand the variation in the chemical composition of naturally grown mahogany (NGM) and plantation grown mahogany (PGM).

5.2 Methods and materials

Moisture content was performed according to TAPPI standard method T 264 cm-74 and expressed as percentage weight loss on drying. About 2 g of air-dried sample was weighed and oven dried at 105°C for 5 h to a constant weight. The experiment was done in three replications and an average of the three replicates was taken. The percent loss on drying was then calculated as follows. The total extractives were determined in three successive steps, an extraction with acetone, an extraction with alcohol and a hot water extraction, according to TAPPI standard method T 204 cm-97. The dried samples were ground into powder with Wiley mill in order to pass 40-mesh (425 μm) sieve and retained on 60-mesh (250 μm) sieved. The extraction was performed using soxhlet extractor. After the extractions, the wood samples were air-dried prior to the determination of its chemical components.

Holocellulose content determination followed TAPPI standard method T 203 cm-74 by weighing 2g of extractive free sample in a 250ml conical flask with a small watch glass cover. The sample was then treated with 180ml of distilled water, 8.6g of Sodium acetate, 6.0ml of acetic acid and 6.6g of Sodium chlorite. The sample was covered and place on hot-water bath for 3hrs. The sample was removed and placed in an ice water bath until cold to room temperature. The sample was filtered into a coarse porosity fitted-glass of known weight and wash free of ClO_2 with distilled water. The crucible was oven-dried at 103^oC, cooled in desiccator, and weighed until a constant weight was reached. The percent holocellulose was calculated.

Cellulose content was performed according to TAPPI standard method T 203 cm-74 by weighing 1.5g of the holocellulose into 250ml Erlenmeyer flask with a small watch glass cover. The flask was placed into water bath at 25^oC and adds 100ml of 17.5% NaOH solution with thorough stirring. After 30 mins of stirring, add 100ml of water and continue stirring for another 30mins. The Erlenmeyer flask was removed and filtered with a fritted-glass crucible of known weight. The residue was washed with 25ml of 9.45% NaOH solution and then with 40ml of 10% acetic acid and finally washes free of acid with plenty of water. The residue was oven-dried in an oven at 103^oC, cooled in a desiccator, and weighed until a constant weight was reached.

Lignin content was determined by TAPPI standard method T 222 cm-88 by weighing 1g of extractive-free sample into a conical flask. Add 15mL of cold sulfuric acid (72%) was slowly while stirring and mixed very well. The reaction proceeded for two hours with frequent stirring in a water bath maintained at 18-20^oC. When the two hours had expired, the specimen was transferred by washing it with 560 mL of distilled water into a 1,000 mL flask, diluting the concentration of the sulfuric acid to three percent. A condenser was attached to the flask and placed in a boiling water bath for four hours. The flasks were then removed from the water bath and the insoluble material was allowed to settle. The contents of the flasks were filtered by vacuum suction into a fritted-glass crucible of known weight. The residue was free of acid with 500 mL of hot tap water and then oven-dried at 103^oC. Crucibles were then cooled in a desiccator and weighed until a constant weight was obtained.

5.3 Results and discussion

The extraneous component of the *Khaya spp* wood is reported in Fig. 5.. The moisture content of the natural was 12.2% and that of plantation sample was 11.7%. The cold-water, acetone and alcohol extracts were 8.3%, 2.9% and 1.8% respectively for naturally grown mahogany whilst in plantation grown mahogany sample the cold-water, acetone and alcohol extracts were 11.8%, 9.0%, and 2.7% respectively. The production of extraneous component is affected by environmental factors and also some species produces some chemicals for protection. The significant extraneous component for plantation compared to naturally grown mahogany may be as a result of excessive production of chemicals for protection against attack or repeated attacks by shoot borer. Comparing the durability of the wood against fungi attack could validate this assertion.

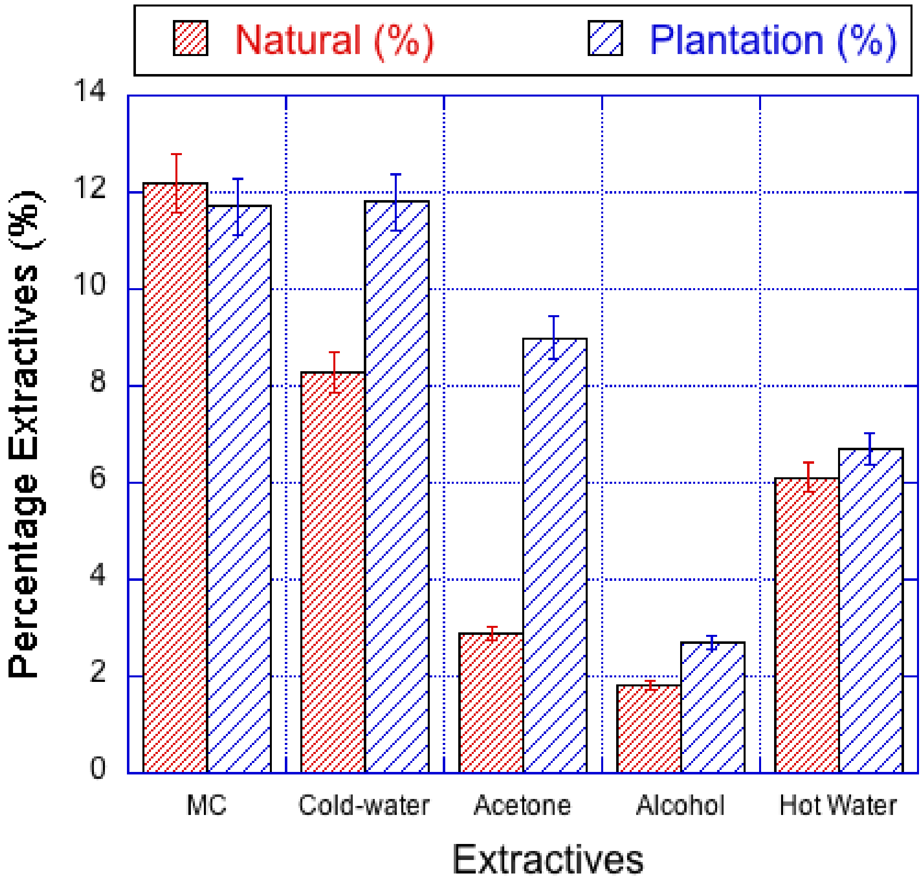


Figure 5.1: The Extraneous material in *Khaya spp.* wood.

The chemical composition of woods affects the mechanical property and its use. In Fig. 2, we report the holocellulose, cellulose, lignin and the total extractives composition for the two samples. The composition of cellulose in hardwood according to literature is between 40-50%, the cellulose composition for both samples were significantly lower with the PGM containing the lowest of 32.2% and that of NGM having 39.2%. The holocellulose, which comprises of both the cellulose and hemicellulose, was 66.4% and 61.4% for the NGM and the PGM respectively. The lignin content NGM was higher 17.3% compared to 15.2% for PGM. The chemical composition i.e cellulose, hemicellulose and lignin content was significantly affected by the higher extraneous component in PGM. The variations in the chemical composition between the two mahogany samples are expected to affect both the mechanical and durability properties of the wood.

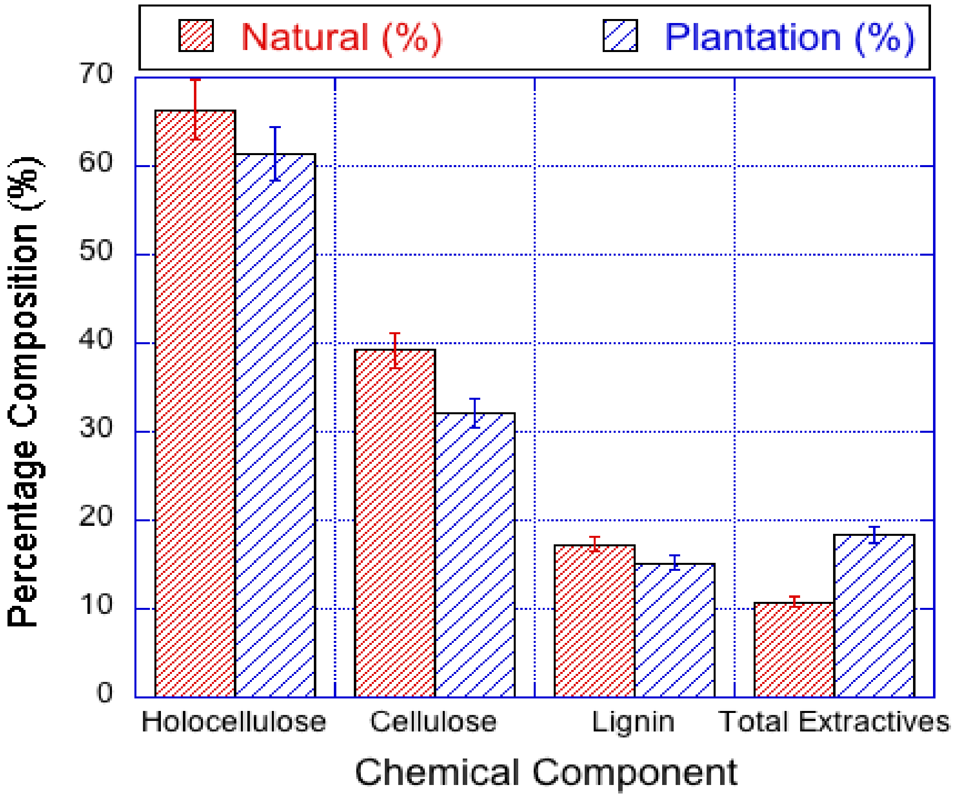


Figure 5.2: The Chemical Composition of *Khaya spp.* wood.

5.4 Conclusion

The properties of a wood are affected by the chemical composition. In this investigation, there were significant variations in the chemical composition between "NGM" and "PGM" wood. The extraneous component is thought to impart natural durability whilst the holocellulose and lignin content will affect mechanical property. It can therefore be concluded that the difference in the chemical composition of "NGM" and "PGM" will have affect the properties of the NGM and PGM wood and hence its utilization.

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CHAPTER SIX

The mechanical properties of plantation grown *Khaya ivorensis* from Ghana

By

Emmanuel Appiah-Kubi PhD

6.0 Introduction

Mahogany (*Khaya species*) is ranked as one of the best-known and most valuable tropical timbers on the international market (ITTO 2004). The wood commands a high price on the market, and is used above all for high quality cabinet work, furniture and expensive interior finishing. Large quantities are also used for boat and ship construction. A high percentage of the wood sold in Europe as 'mahogany' comes from *Khaya ivorensis*. Timber of African mahogany trees is of great value internationally because of its unique working properties. These species are becoming scarcer in the wake of dwindling forest cover in Ghana with illegal logging as the major contributing factor. The over-dependence on few species and localized felling depleted *Khaya ivorensis* in the south western portion of the forest zone of Ghana (Taylor 1960).Sustainable forest management has been made a priority in Ghana, and the government is now actively promoting the use of Lesser-Used-Species (LUS) and plantation grown species to reduce the pressure on the more popular commercial timber species. To ensure continuous supply of *Khaya ivorensis*, plantations have been established.

Most plantation-grown timber species are known to have relatively lower yield and inferior wood quality than naturally grown timber species (Haygreen and Bowyer 1996). In this regard, plantation species may pose special problems, because they do not have a long history of utilization for wood products or have altered properties because of their plantation origins (Simpson 1992).Foli *et al.* (2009) describe *Khaya ivorensis* (Dubini) as a fast growing species, which does well in semi-deciduous and evergreen forest, tending to do better on banks of streams.

Efforts to plant *Khaya ivorensis* have been unsuccessful due to severe mortality resulting from shoot-borer attack. However, there appear to be prospects for plantation establishments with the identification of fast growing, rapid self-pruning tolerant genotypes of *Khaya ivorensis*. Fast growing plantation tropical tree species may reach harvesting girth quicker than naturally grown ones, but may have higher proportion of low quality juvenile wood than mature wood. These defects could significantly reduce the wood quality of fast growing *Khaya ivorensis* plantations in Ghana.

There is very little information on the timber properties of fast-growing species. Therefore, the use of these species has been limited to paper, pulp, and fuel woods, which are less profitable for foresters (Cossalter and Pye-Smith 2003). There is a concern that fast growing species would contain a large volume of juvenile wood bearing unstable properties. This concern is an obstacle for the use of fast-growing species for timber (Kojima *et al*. 2009). Consequently, the resources of fast-growing plantations remain under-utilized so far as construction is concerned.

Zbonak et al. (2010) investigated the wood properties and processing outcomes for plantation grown *Khaya senegalensis* trees from Queensland and Northern Territory in Australia. The trees from Queensland were between the ages of 18 and 20 years and those from the Northern Territory were 14 years old. The investigation of the authors centered on the physical and sawing properties of the trees. The engineering properties were however not established.

The Forestry Research Institute of Ghana has a plantation of *Khaya ivorensis* (Mahogany) located at Amantia in the Moist Semi-deciduous ecological zone of Ghana. The trees were planted in 1968. An assessment of the stands in 2011 revealed that most of them had attained felling diameters of between 70cm – 110cm. The beautiful stands of this 43-year old mahogany plantation made it necessary to assess their wood quality and suitability for utilization compared to the naturally grown ones.

The properties of plantation grown mahogany (*Khaya spp*) have not yet been established and there is little scientific information on the properties of plantation grown mahogany as compared to naturally grown ones. The general concern among major stakeholders in Ghana is whether the matured plantation and grown *Khaya ivorensis* will exhibit similar properties as the naturally grown ones. There is therefore the need to investigate the engineering properties of plantation grown Mahogany (PGM) in order to determine their suitability as a construction material. The objective of the study was to determine the mechanical properties of plantation grown mahogany in order to promote its use.

6.1 Materials and methods

Materials for the study were obtained from the plantation the Forestry Research Institute of Ghana (FORIG) located at the Pra-Anum Forest Reserve, Amantia in the Ashanti Region of Ghana. The *Khaya ivorensis* trees were planted in 1968.Three (3) matured mahogany trees were harvested and transported to Logs and Lumber Limited (LLL), a private sawmill in Kumasi for processing. Three (3) matured naturally grown mahogany tree from the natural forest located at the same forest reserve were also harvested and transported to the same sawmill. The trees from the plantation and the natural forest had the same felling diameters (between 90 - 110 cm dbh).

6.2 Study Area

The Pra-Anum Forest Reserve located at Amantia in the Ashanti Region of Ghana lies in the Oda Forest District. The reserve is between latitude 6º 11’to 6º 20’ North and longitude 1º07’ to 1º16’ West (Figuress 3.1a and 3.1b). The topography of the site is gently undulating within average height of about 190m above sea level. The site is situated within the moist semi-deciduous (South-East) forest type, with a mean annual rainfall of between 1500mm and 1750mm, characterized by a two peak rainy season and a mild harmattan (Hall and Swaine 1981). The soils of Pra-Anum are mainly composed of forest oxysol-ochrosol integrates which are made up of sandy loam and clayey loam compositions respectively which are well drained and very fertile. The district records a maximum temperature of about 30ºC in March and April. The minimum temperature of about 26ºC is recorded in August, the coolest month of the year.

6.3 Primary processing of logs

A vertical band mill at Logs and Lumber Limited, Kumasi with saw blade thickness of 8 inches (0.2 m) and length of 33feet 3 inches (9.975 m) with gauge of 17’’ (0.425 m) without tipping was used. The saw blade was swage set for processing. The logs were processed into lumber on this vertical band mill. In all about 600 lumber pieces of thickness 35mm and 70 mm were obtained from logs extracted. Two readings of lumber thicknesses were taken about 20cm from both ends of the lumber; the length and two widths of each lumber from logs were measured using a steel tape for the calculation of the lumber recovery. Boards for green tests were transported to the wood processing workshop at FORIG for immediate processing into test specimen dimension for the necessary tests. Green specimens were kept in a refrigerator in order to ensure that they remained green. Boards for dry tests were staked for air drying. Test specimens were conditioned in a climate chamber at a temperature of 20^{o}C and 65% relative humidity prior to the tests.

Figure 6.1: Testing of clear samples using Instron testing machine

Figure 6.2: sample of mahogany for mechanical properties test

6.3.1 Bending strength (MOR and MOE)

25mm thick boards were trimmed, planed and cut to 110 mm wide boards. The two sides of the boards got adjusted on the jointer such that the annual growth ring orientation was perpendicular to one surface. Planks measuring25mm x25mm were obtained and planed to 20mmx20mm cross-sections. On the circular saw, the 20 mm x20mm cross-sections were cut to the length of 380mm. Thirty (30) samples each were obtained for different heights of the trees (Top, Middle and Bottom) for each tree. Three (3) trees each were sampled from both Plantation and Natural Mahogany.

The test was carried out on the 100kN Universal Testing Machine (UTM) Zwick/RoellZmart.Pro (Zwick GmbH & Co. KG, Ulm, Germany), situated at the Department of Wood Biology and Wood Products, Georg-August-University of Goettingen, Germany. The testing machine is equipped with a Zwick/RoellVideoXtens Camera System (Zwick GmbH & Co. KG, Germany) to record contact-free elongation of specimens. The software used for analysis was TestXpert II V3.5 (ZwickGmbH& Co. KG, Germany). The test was conducted according to DIN 52186:1978 Standard.The dimensions of the specimens were obtained using Sylvac measuring device (Sylvac Deutschland, Schöneck-Kilianstädten, Germany) and the weight of each specimen was recorded with a Sartorius CP323S scale (Sartorius AG, Göttingen, Germany).

A three-point bending test set-up was installed on the Zwick/RoellZmart.Pro. The UTM was set on position control mode with a speed of between 3 mm/min and 17 mm/min. The load was applied at this rate until the failure of the test specimen. The time frame for the test was 90 $\pm$ 30 seconds. The load and the corresponding deflection at every 0.01N load were recorded by the test machine. The maximum load at failure as well as the load at the limit of proportionality was also recorded. The MOE was measured automatically with the Zwick / Roell VideoXtens Camera System between 50N and 150 N loading.

The modulus of rupture, R, was computed by the equation:

$$R=\frac{3FL}{2bh^2}$$

Where:

- R= modulus of rupture (N/mm^2)
- F = maximum load applied at the mid-point of the sample (N)
- L = span of beam (mm)
- b= breadth of test piece (mm)
- h=depth of the test piece (mm)

6.3.2 Compression Parallel to Grain

The resistance to compression was determined by using parallel to the longitudinal grain method. The sample sizes were cut according to the 2cm standard i.e. 2cm x 2cm x 6cm. Thirty (30) to Forty-five (45) samples were tested per section of each of the trees. The "Instron" Universal Testing Machine with the compression test fixture was used for the test.

The test was conducted in accordance with the BS 373 (1957). The load was applied to the test piece in such a way that the loading plates approached each other at a rate of 3.15×10^{-6} mm/min as shown in Figure 1. The test piece was loaded to failure at the specified rate and the maximum load at failure was recorded automatically by the "Instron" machine. Before the test itself, there were checks to ensure that the rectangular test piece was smooth and parallel and normal to the axis and that the testing machine was of such construction. The plates between which the test piece was placed were parallel to each other and remained so during the whole period of test. These checks were done to make sure accurate results were obtained. The test duration was 90 $\pm$ 30 seconds.

The compressive stress at maximum load is computed as follows:

$$C = \frac{P}{A}$$

where:

- C = Compressive stress at maximum load (N/mm^2)
- P = maximum load in Newton (N)
- A = Cross sectional area of sample (mm^2)

6.3.4 Shear Parallel to Grain Determination

The test was conducted in accordance with the BS 373 (1957). The sample sizes according to the standard were 5 cm x 5 cm x 5 cm. Thirty (30) samples were tested per section of each of the trees. The "Instron" Universal Testing Machine with the shear test fixture was used for the test. The load was applied at a constant rate of crosshead movement of 0.635 mm/min. The direction of shearing was parallel to the longitudinal direction of the grain. The load was applied to the test piece at the test speed until failure occurred. The load at which failure occurred was recorded automatically by the "Instron" machine. The test duration was 90 $\pm$ 30 seconds.
Shear parallel to the grain (ν) is calculated as follows:

$$\nu = \frac{P}{A} \quad (3.7)$$

where

- ν = Shear in N/mm^2
- P = Maximum load in Newton (N)
- A = Area in shear in mm^2

6.3.4 Hardness (Janka Indentation Test)

The test was conducted in accordance with the BS 373 (1957). The specimen dimension for the hardness test was 5 cm x 5cm x 15 cm and was cut radially and tangentially. Thirty (30) samples were tested per section of each of the trees. The "Instron" Universal Testing Machine with the hardness test fixture was used for the test. The fixture is made up of a steel bar with a steel ball at one end, measuring 11.3 $\pm$ 2.5 mm in diameter. The load necessary to force into the test piece, to a depth of 5.6 mm, by the hemispherical end of the steel ball was recorded automatically by the "Instron" machine as the failure load. The determination was made on the radial and the tangential surfaces.

6.3.5 Statistical Analysis

Descriptive statistics was used to summarize the data numerically and graphically. The tools used in displaying the results of the various properties determined include the mean, standard deviation and coefficient of correlation. Data were imported into the statistical software Origin (Version 8.1) for statistical analysis. An ANOVA was used to test for the significant differences in the results within and between trees. The Levene test for the assumption of homogeneity of variances was performed. Tukey ANOVA was used for significant differences between the various groups of specimens. Box plots showing minimum, 1st quartile, mean, 3rd quartile and maximum values were plotted using the Origin 8.1 Pro software. Relationships between properties at different heights were evaluated by using a general linear model (GLM) and Pearson Correlation.

6.3.6 Characteristic strength values

European standard EN 384:2004 which specifies the procedures and equations for determining the characteristic values of mechanical properties and density was used in the determination of the characteristic values. The values determined in accordance with this standard were used to assign grades according to the strength classes of BS EN 338 (DIN EN 384 2004).

6.4 Results and Discussions

6.4.1 Bending strength (MOR and MOE)

Table 1 presents results of specimens under green conditions whilst Table 3 presents results of specimens conditioned to 12% moisture content. Results from Table 3 followed similar trend as Table 2 with plantation mahogany trees obtaining higher strength values than natural mahogany trees. Results from Tables 2 and 3 confirm previous assertions that strength properties increase with decreasing moisture content (Madsen 1976, Gerhards 1982, Hoffmeyer 1995, Forest Products Laboratory 1999). For example, plantation mahogany trees had a mean MOR of 81.47 N/mm^2 at a moisture content of 12% and a mean MOR of 65.48 N/mm^2 at a moisture content of 41.7%. On the other hand, natural mahogany trees had a mean MOR of 73.9 N/mm^2 at a moisture content of 12% and a mean MOR of 50.31 N/mm^2 at a moisture content of 41.71%.

Table 6.1: Results of MOR and MOE for natural and plantation grown mahogany under green conditions

Species	MOR, N/mm^2			MOE, N/mm^2			MC %	Density kg/m^3	Count
	Mean	Std. Dev.	f_{05}	Mean	Std. Dev.	f_{05}	Mean	Mean	
N1B	52.75	6.35	42.27	7410	885	5950	36.95	500.00	35
N1M	49.78	3.85	43.43	7373	613	6362	30.77	480.90	35
N1T	54.55	5.54	45.41	6811	695	5664	54.67	665.97	35
N2B	36.07	8.26	22.44	6244	1109	4414	40.39	565.28	36
N2M	37.86	6.41	27.28	6468	977	4856	43.34	576.04	35
N2T	43.22	15.72	17.28	6593	1668	3841	34.19	598.96	35
N3B	66.66	8.50	52.64	9095	1254	7026	53.14	830.21	35
N3M	61.91	6.85	50.61	8448	1130	6584	38.09	762.50	35
N3T	50.03	11.06	31.78	6800	2243	3099	43.83	773.96	35
P2B	67.73	5.21	59.13	8032	822	6676	47.41	718.40	35
P2M	66.57	5.23	57.94	9311	686	8179	37.09	642.01	35
P2T	70.60	4.37	63.39	9176	459	8419	60.40	780.90	35
P3B	61.55	7.67	48.89	7031	976	5421	37.74	626.04	35
P3M	59.87	8.40	46.01	6776	1068	5014	35.06	554.51	35
P3T	62.60	8.75	48.16	6503	942	4949	56.66	777.43	35
P5B	69.04	8.89	54.37	7841	1146	5950	33.10	722.92	32
P5M	64.48	6.41	53.90	7173	813	5832	32.32	695.49	35
P5T	66.84	7.58	54.33	7121	731	5915	35.55	745.83	33
Mean N	50.31	8.06	37.01	7249	1175	5311	41.71	639.31	316
Mean P	65.48	6.95	54.01	7663	849	6261	41.70	695.95	310

Key:

- N - *Natural tree*;
- P - *plantation tree*;
- B, M, and T *denote bottom, middle and top portions of the trees*;
- Numbers 1, 2, 3, 5 *denote tree numbers*;
- f_{05} *is the characteristic strength value.*

From Table 6.2, the bending strength of the species generally increased along the tree height from bottom to the top. Natural tree N1 for instance had an MOR of 58.82 N/mm^2 at the bottom, 63.61 N/mm^2 at the middle and 76.42 N/mm^2 at the top (Figure 2) with mean densities of 370 kg/m^3, 444 kg/m^{3}and 515 kg/m^{3}respectively.

Likewise, Plantation tree P3 had an MOR of 76.8 N/mm^2 at the bottom, 80.16 N/mm^2 at the middle and 80.45 N/mm^2 at the top (Figure 3) with mean densities of 491 kg/m^3, 518 kg/m^{3}and 554 kg/m^{3}respectively. Density increased along the height of the trees with increasing MOR. This is consistent with previous assertions that density is proportional to strength of wood (Larjavaara and Muller-Landau 2010, O'Connor 2007). One-way ANOVA test revealed significant differences ($p < 0.05$) in the results at different heights of the natural trees. However, results at different heights were not significantly different ($p > 0.05$) in the plantation trees. Plantation trees had higher MOR values and therefore had higher bending strength than the natural trees at all section of the trees. The one-way ANOVA test showed significant differences between the results of the natural and plantation trees at different heights along the tree except at the bottom which showed no significant difference between the two at 5% level of probability.

The results indicate that plantation grown mahogany can therefore be adopted for the same purposes as the natural mahogany trees in construction. Values obtained for both tree types are however less than most heavy construction species such as *Cylicodiscus gabunensis* (Denya) with MOR of 137 N/mm^2, *Nesogordonia papaverifera* (Danta) with MOR of 137 N/mm^2, *Celtis spp* (Esa) with 104 N/mm^2, *Sterculia rhinopetala* (Wawabima) with 127 N/mm^2 and *Albizia ferruginea* (Albizia) with 102 N/mm^2 (Addae-Mensah et al. 1989, Ayarkwa 1998). Plantation mahogany can therefore be used for light to medium structural (construction) works.

Table 6.2: Results of bending strength test (MOR, MOE) of all the trees at 12% moisture content

TREES	MOR, N/mm²				MOE, N/mm²				Density, Kg/m³		
	Mean	Std. Dev	Sig. Diff.	f_{05}	Mean	Std. Dev	Sig. Diff.	f_{05}	Mean	Std. Dev	ρ_{05}
N1B	58.82	2.90	C	54.04	7515	231	a	7133	370.06	9.61	354.20
N1M	63.61	2.42	B	59.62	6661	199	b	6332	444.27	4.93	436.14
N1T	76.42	11.31	A	57.76	7810	827	a	6445	514.6	11.28	495.99
N2B	77.37	7.16	A	65.56	7624	393	b	6957	524.02	39.74	458.45
N2M	68.99	3.27	B	63.59	9638	526	a	8770	448.11	5.45	439.12
N3B	74.92	7.72	C	62.18	8988	840	b	7602	576.16	12.59	555.39
N3M	83.66	6.84	B	72.37	9500	857	b	8086	575.04	18.73	544.14
N3T	88.62	5.93	A	78.84	12193	937	a	10647	620.1	17.96	590.47
P2B	77.61	6.73	B	66.51	8408	980	c	6790	528.29	43.06	457.24
P2M	84.67	3.39	A	79.08	9871	375	b	9251	533.37	56.82	439.62
P2T	82.44	7.28	A	70.43	9225	505	a	8392	511.66	8.23	498.08
P3B	76.8	5.58	A	67.59	8603	555	b	7687	491.35	29.55	442.59
P3M	80.16	5.09	A	71.76	10051	888	a	8585	518.03	34.02	461.90
P3T	80.45	7.78	A	67.61	8718	980	b	7101	553.86	29.24	505.61
P5B	77.53	6.26	B	67.20	9827	679	c	8706	547.98	29.41	499.45
P5M	77.99	8.83	B	63.42	9019	833	b	7644	588.34	30.24	538.44
P5T	96.93	3.78	A	90.69	10516	925	a	8990	586.47	12.9	565.19
NB	70.44	10.37	A	53.33	7864	716	b	6683	489.14	62.17	386.56
PB	71.92	9.8	A	55.75	8856	867	a	7426	567.35	55.23	476.22

NM	71.92	9.8	B	55.75	9127	1237	b	7086	522.54	41.57	453.95
PM	80.87	6.73	A	69.77	9696	882	a	8241	546.58	51.46	461.67
NT	82.79	10.55	B	65.38	11037	2319	a	7211	546.58	51.46	461.67
PT	86.43	9.9	A	70.10	9188	1197	b	7212	550.66	32.44	497.13
Mean N	73.90	11.29	B	55.27	9113	1882	a	6008	509.04	80.22	376.68
Mean P	81.47	8.56	A	67.35	9234	1045	a	7511	539.93	44.17	467.05

Key:

- N - *Natural tree*;
- P - *Plantation tree*;
- B, M, and T *denote bottom, middle and top portions of the trees*;
- Numbers 1, 2, 3, 5 *denote tree numbers*
- *Sig. Diff.: same letters indicate no significant differences ($p < 0.05$), different letters indicate significant differences*
- f_{05} *is the characteristic strength value.*

6.4.2 Compressive strength

Table 6.3: Results of compressive strength of trees in green conditions

Trees	Compressive stress N/mm^2			Mean Test MC %	Density Kg/m^3	Count
	Mean	Std. Dev.	f_{05}			
N1B	23.45	2.73	18.95	36.95	500.00	35
N1M	24.35	2.69	19.91	30.77	480.99	35
N1T	24.15	2.85	19.45	54.67	665.97	35
N2B	18.05	2.56	13.83	40.39	565.28	36
N2M	18.00	2.57	13.76	43.34	576.04	35
N2T	24.74	4.31	17.63	34.19	598.96	35
N3B	30.36	3.66	24.32	53.14	830.21	35
N3M	27.44	3.21	22.14	38.09	762.5	35
N3T	23.11	3.87	16.72	43.83	773.96	35
P2B	30.12	2.33	26.28	47.41	718.4	35
P2T	31.99	1.23	29.96	60.4	780.9	35
P3B	27.58	3.81	21.29	37.74	626.04	35
P3M	27.53	3.28	22.12	35.06	554.51	35
P3T	28.56	3.82	22.26	56.66	777.43	35
P5B	32.61	3.67	26.55	33.1	722.92	32
P5M	28.69	2.71	24.22	32.32	695.49	35
P5T	29.56	3.14	24.38	35.55	745.83	33
Mean N	23.74	3.16	18.52	41.7	639.31	316
Mean P	29.58	2.99	24.63	42.28	702.69	275

Key:

- N - *Natural tree*;
- P - *plantation tree*;
- B, M, and T *denote bottom, middle and top portions of the trees*;
- Numbers 1, 2, 3, 5 *denote tree numbers.*

Table 6.4: Results of compressive strength for all trees at 12% MC

Trees	Compressive stress, N/mm^2			
	Mean	Std. Dev.	f_{05}	Sig. Diff.
N1B	34.51	2.32	30.68	a
N1M	31.94	3.28	26.53	b
N1T	36.16	5.20	27.58	a
N2M	32.20	2.99	27.27	b
N2T	33.47	3.02	28.49	a
P1B	35.64	3.50	29.87	b
P1M	38.95	4.29	31.87	a
P2B	35.45	4.55	27.94	c
P2M	41.70	2.65	37.33	a
P2T	38.93	3.48	33.19	b
P3B	36.13	3.54	30.29	b
P3M	39.04	4.64	31.38	a
P3T	40.61	4.97	32.41	a
NB	34.51	2.32	30.68	b
PB	35.74	3.89	29.32	a
NM	34.24	4.96	26.06	b
PM	39.88	4.14	33.05	a
NT	34.65	4.31	27.54	b
PT	39.78	4.37	32.57	a
Mean N	34.42	4.42	27.13	b
Mean P	38.29	4.55	30.78	a

Key:

- N - *Natural tree*;
- P - *plantation tree*;
- B, M, and T *denote bottom, middle and top portions of the trees*;
- Numbers 1, 2, 3, 5 *denote tree numbers*
- *Sig. Diff.: same letters indicate no significant differences ($p < 0.05$), different letters indicate significant differences*

Results of compressive strength generally increased along the tree height from the bottom to the top of the tree for the dry specimens at 12% MC as shown in Table 5. Plantation trees had higher compressive strength ranging between 35.45 and 41.70 N/mm^2 with overall mean and characteristic strengths of 38.29 N/mm^2 and 30.78 N/mm^2 respectively, whilst the natural trees had values ranging between 31.94 and 36.16 N/mm^2 with an overall mean and characteristic strengths of 34.42 N/mm^2 and 27.13 N/mm^2 respectively. After an ANOVA test at 5% level probability, the difference between the values obtained for plantation and natural trees were found to be significant ($p < 0.05$). Results of the specimens under green condition did not follow the same pattern as in the dry specimens (Table 4). However, plantation trees had higher strength values ranging from 27.53 N/mm^2 to 32.61 N/mm^2 with overall mean and characteristic strengths of 29.58 N/mm^2 and 24.63 N/mm^2 at a moisture content of 42.28% whilst the natural trees had strength values ranging between 18.00N/mm^2 and 30.60 N/mm^2 with overall mean and characteristic strengths of 23.74 N/mm^2 and 18.52 N/mm^2 at a moisture content of 41.7%. According to Shepard and Shottafer (1992), the matured period for all tree properties begin at an age of about 40 years. The plantation trees were harvested at age 43 and may be the reason why its properties are not inferior to the natural stands and even having higher strength values since they had already attained maturity. The use of silvicultural practices in the plantation as well as anatomical features such as fibre length, vessel diameter etc. could contribute to the higher strength values for the plantation trees.

The results from the two tables agree with previous assertions that strength increases with decreasing moisture content and beyond fibre saturation point (FSP), increase in moisture content does not affect strength (Madsen, 1976;Gerhards, 1982; Hoffmeyer, 1995; Forest Products Laboratory, 1999). Results obtained compare with *Chlorophora spp* (Iroko) with compressive strength of 33.8 N/mm^2 and *Terminalia superba* (Ofram) with compressive strength of 32.6 N/mm^2 (Forest Products Laboratory, 1999). However values of both plantation and natural mahogany are less than the values of most heavy construction timbers such as *Milicia excelsa* (Odum) with compressive strength of 52 N/mm^2, *Nesogordonia papaverifera* (Danta) with compressive strength of 65 N/mm^2, *Celtis spp* (Esa) with 60 N/mm^2, *Sterculia rhinopetala* (Wawabima) with 66 N/mm^2 and *Albizia ferruginea* (Albizia) with 59 N/mm^2 (Addae-Mensah et al., 1989; Ayarkwa, 1998; Brunner et al., 2008; Appiah-Kubi et al., 2012).

6.4.3 Shear strength

Table 6: Results of shear strength of the trees at 12% MC

Trees	**Shear strength, N/mm^2**			
	Mean	Std. Dev	f_{05}	Sig. Diff.
N1B	11.73	1.54	9.19	A
N1M	11.32	1.46	8.91	A
N2B	11.40	1.37	9.14	A
N2M	11.05	1.61	8.39	A
N2T	11.29	1.12	9.44	A
N3B	13.26	1.71	10.44	A
N3M	13.73	1.29	11.60	A
P3B	15.23	1.2	13.25	A
P3M	14.18	1.53	11.66	B

P3T	14.14	1.1	12.33	B
P5B	13.21	1.06	11.46	B
P5M	14.33	1.67	11.57	A
P5T	14.89	1.34	12.68	A
NB	11.58	1.46	9.17	B
PB	14.18	1.47	11.75	A
NM	12.53	1.96	9.30	B
PM	14.26	1.6	11.62	A
NT	11.29	1.12	9.44	B
PT	14.52	1.28	12.41	A
Mean N	11.99	1.75	9.10	B
Mean P	14.31	1.45	11.92	A

N - *Natural tree*; P - *plantation tree*; B, M, and T *denote bottom, middle and top portions of the trees*; Numbers 1, 2, 3, 5 *denote tree numbers*

Sig. Diff.: same letters indicate no significant differences ($p < 0.05$), different letters indicate significant differences

Shearing strength was higher in plantation trees compared to the natural trees. Natural trees had strength values ranging between 11.05 and 13.73 N/mm^2 with a mean shear strength of 11.99 N/mm^2 whilst plantation trees had values ranging between 13.21 and 15.23 N/mm^2 with a mean shear strength of 14.31 N/mm^2 (Table 6). Higher shearing strength in plantation may be due to more fibre compressions in plantation trees compared to the natural trees, which is evidenced in the light microscopy. A one-way ANOVA test conducted showed that the results were significantly different between the plantation and the natural trees at 5% level of probability. Significant differences were again observed between the sections of the plantation trees. However results between sections along the tree height among the natural trees were not significantly different ($p < 0.05$).

6.4.4 Hardness

Table 7: Results of Hardness in both tangential and radial direction of the species at 12% MC

Trees	**Tangential**				**Radial**			
	Mean (N)	**Std. Dev**	**f_{05}**	**Sig. Diff.**	**Mean (N)**	**Std. Dev**	**f_{05}**	**Sig. Diff.**
N1B	2.72	0.28	1.81	a	2.33	0.29	1.85	b
N1M	2.52	0.53	1.65	b	3.59	0.67	2.48	a
N2B	2.28	0.43	1.57	b	2.27	0.04	2.21	b
N2M	2.03	0.24	1.63	c	2.09	0.28	1.63	b
N2T	2.87	0.45	2.13	a	2.91	0.42	2.22	a
N3B	3.50	0.43	2.79	a	3.39	0.32	2.86	a
N3M	3.68	0.78	2.39	a	3.57	0.78	2.28	a

P2B	3.59	1.65	0.87	b	3.47	0.73	2.27	a
P2M	4.87	2.98	-0.05	a	3.54	0.59	2.57	a
P3B	3.76	1.08	1.98	b	3.32	0.46	2.56	b
P3M	3.49	0.32	2.96	b	3.31	0.34	2.75	b
P3T	4.36	2.16	0.80	a	3.90	0.32	3.37	a
P5B	3.53	0.48	2.74	b	3.12	0.43	2.41	b
P5M	3.49	0.63	2.45	b	3.29	0.41	2.61	b
P5T	4.34	1.11	2.51	a	4.26	0.81	2.92	a
NB	2.71	0.63	1.67	b	2.64	0.57	1.70	b
PB	3.51	0.70	2.36	a	3.29	0.58	2.33	a
NM	2.71	1.19	0.75	b	3.08	0.92	1.56	b
PM	3.65	0.73	2.45	a	3.37	0.46	2.61	a
NT	2.90	0.43	2.19	b	2.91	0.42	2.22	b
PT	3.89	0.52	3.03	a	4.07	0.63	3.03	a
N	2.73	0.86	1.31	b	2.89	0.76	1.64	b
P	3.65	0.76	2.40	a	3.49	0.63	2.45	a

N - *Natural tree*; P - *plantation tree*; B, M, and T *denote bottom, middle and top portions of the trees*; Numbers 1, 2, 3, 5 *denote tree numbers*

Sig. Diff.: same letters indicate no significant differences ($p < 0.05$), different letters indicate significant differences

Table 7 presents results of the hardness of the trees. Hardness was measured in both the tangential and radial directions of the tree. The mean hardness generally increased along the tree height from bottom to the top in both directions. The plantation trees were found to have higher hardness than the natural trees. The overall mean hardness in the tangential direction of plantation trees was 3.65 N with a standard deviation of 0.76 whilst natural trees had 2.73 N with a standard deviation of 0.86. The plantation trees were found to be therefore harder than the natural trees. This was due the presence of resins in the vessels of the plantation trees.

Tables 8 and 9 present a summary of the strength properties of both plantation and naturally grown mahogany at 12% moisture content and in green state.

6.5 Conclusions

Mechanical properties generally increased along the tree height from bottom to the top of the tree. Plantation trees had higher strength values than the natural trees and the differences in strength values were significant ($p < 0.05$). This agrees with similar findings of Shepard and Shottafer (1992) that wood properties of plantation trees were not inferior to natural stands. According to Shepard and Shottafer (1992), the matured period for all tree properties begin at an age of about 40 years. The plantation trees were harvested at age 43 and may be the reason why its properties are not inferior to the natural stands and even having higher strength values since they had already attained maturity. The use of silvicultural practices in the plantation as well as anatomical features such as fibre length, vessel diameter etc. could contribute to the higher strength values for the plantation trees.

Significant differences in strength values were found between the different sections of the natural trees whilst the plantation trees showed no significant differences between tree sections. This is because the natural trees are left in nature under competition to survive. The natural trees have non-uniform boles and tend to have a lot of variations in its properties at different sections. Plantation trees grow under ideal conditions of care and many silvicultural practices that contribute to uniform boles and hence less variations in properties at different sections of the trees. Results obtained for samples at 12% moisture content had higher strengths than those obtained under green conditions (MC = 41%). This corresponds with previous research that strength of wood increase at lower moisture content. The density of plantation trees was also higher than the natural trees.

Based on the strength properties, both plantation and natural trees belong to the same strength class except in the case of tensile strength, where plantation tree qualified to be in D70 class with a characteristic tensile strength parallel to grain value of 41.66 N/mm^2 while the natural trees belong to the D60 class with a characteristic tensile strength parallel to grain value of 37.39 N/mm^2. Natural trees had a characteristic bending strength value of 62.2 N/mm^2 and a characteristic compressive strength parallel to grain value of 32.1 N/mm^2, all of which belonged to the strength class D60. Plantation trees also had a characteristic bending strength value of 69.44 N/mm^2 and a characteristic compressive strength parallel to grain value of 33.71 N/mm^2 which also belonged to the D60 strength class. Due to the limitation of logistics, few trees at one location could be researched. It is recommended that future research is carried out to prove this trend of findings for mahogany plantations in different locations.

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CHAPTER SEVEN

Variations in decay resistance and its effects on mechanical properties of plantation and naturally grown mahogany in Ghana

By

C. Essien

1.0 Introduction

Wood is a valuable and versatile renewable natural resources with an extremely wide range of uses but it is liable to degradation by physico-mechanical, chemical and most importantly biological agents. According to Zabel and Morrell (1992) decay caused by mushroom fungi is the most prevalent and destructive type of wood deterioration because it can cause rapid structural failure and well over 10% of the annual volume of timber harvested in US is used to replace wood that has been deteriorated in service. Scheffer (1973) added that annual losses of over $1billion in the United State result from only fungal deterioration of untreated or inadequately treated wood. Since decay is the most destructive among wood destroying organisms because considerable damage can be caused while no visible damage to the wood or weight loss is incurred. It really reduces the enviable aesthetic, physical and mechanical properties of wood (Wilcox 1978; Immamura 1993; Kim *et al* 1996; Clausen &Kartal 2003). Highley (1999) stated that by the time 1% weight loss occur, 6 - 50% reduction in toughness is incurred. Curling *et al* (2001) emphasized that 3% reduction in MOR and 6% reduction in maximum compression strength is incurred with no weight loss noticed.

Natural resistance of wood to these degrading agents has been a yard stick for selecting timber species for use. This common practice has resulted in an over-exploitation of the known few durable species in their natural range. Unfortunately, most of the known naturally durable species have extremely long rotational period to attain harvestable size under natural regeneration conditions due to pest and diseases, fire, poor logging practices. These activities alter the physio-climatological environment required for healthy natural regeneration of these species. This long rotational period has necessitated the establishment of plantations of various tropical timbers which African mahogany being one of these priority species. Mahogany (K*haya spp.*) is among the highly ranked, best-known and most valuable tropical timbers on the international market (ITTO, 2004). This species is valued for its decorative figures which in outstanding in the production of veneer, furniture and cabinet. It is also very popular in structural applications due to its superior resistance to bio-deterioration, stiffness and strength. However due to these excellent properties, the global stock of mahogany has evidenced a sharp decline throughout its natural range. In Ghana, this problem has exacerbated in the wake of dwindling forest cover due to pest and disease such as mahogany shoot borer, over exploitation, slower natural regeneration, wild fire, and illegal logging. Beside these setbacks, a demonstrational mahogany plantation was established in the 1970s to study the survival and growths dynamics of *Khaya spp.* in its natural range. The major objective of the study was to identify superior and pest resistant progeny and develop appropriate silvicultural management tools for mahogany plantations. Wood quality traits were not considered in the selection processes hence the wood quality of the mahogany resources from the plantations was not certain. This is as a result of the several utilization challenges posed by juvenile or core wood emanated from plantation origin. The juvenile tend to have high microfibril angle, thin fibular cell walls, high dimensional instability, low density, low stiffness and strength. Lumbers produced from juvenile wood have bow, crook and twist during drying. All these utilization challenges casted though on the quality of mahogany from the plantation origin. Therefore it became apparent that the success of promoting commercial plantation development of mahogany hinges on the wood quality data from similar eco-climatological zones. Hence this study focused on assessing the decay resistance of the plantation grown African mahoganies in comparison to their naturally grown counterpart.

7.1 Materials and methods

Stakes were selected from the bottom (150 cm from the ground), middle (50% height from the bottom) and top (50% height from the middle) portions of the stems. 180 stakes with dimensions 2cm x 2cm x 20cm were used for this assessment comprising 90 stakes each from the naturally grown mahogany (NGM) and plantation grown mahogany (PGM). Out of the 90 stakes, 30 each were selected from the top, middle and bottom portions of each of the NGM and PGM with 30 *Ceiba pentandra* stakes as control. All the samples were conditioned to 12% moisture content. The stakes were planted 50cm between rows and 50cm within rows using complete randomized design (Figures 1&2) at Bobiri Forest Reserve. The samples tested in the graveyard were subjected to types of bio-deterioration agents such as termites, fungi, carpenter ants and wood destroying beetles. Another set of 90 samples were selected for the "termite exclusion test" where the seven samples consisting of three samples each for each type of mahogany and one control sample, were sealed in each wire mesh (20-40μm) to help assess the sole effect of fungi on this species. The samples were then placed on the forest to assess the fungi activities and its effect on the mechanical properties of the samples of Figure (3).The Bobiri Forest Reserve used for this studies is located in the Moist Semi-deciduous South East forest zone and lies between latitudes $6^{o}39'$ and $6^{o}44'$ N; and longitudes $1^{o}15'$ and 1^{o} $23'$ W. The mean annual rainfall is about 1,500 mm with moderate to high relative humidity. The mean annual temperature for the site is about $27^{o}C$ with the annual range of $23^{o}C$ -$35^{o}C$. The site is strictly protected from wildfire which has led to massive populations of several types of macro and micro fauna and flora including termites and fungi (Figures 4-6). However, selection, preparation, installation and assessment of the stakes were done in accordance with the AWPA E – 7 – 07 (2008) and ASTM D 1758 – 06 (2008). The stakes were assessed biweekly for the termite and fungi activity on the stakes for a period of 14 weeks based upon the ASTM D 1758-06 ratings system. The setup was allowed to additional 12 weeks after which the last inspection was undertaken. According to ASTM D 1758-06(2008) and AWPA E – 7 – 07 (2008), termite/ fungi rating system was:

- 10 means sound- 1 to 2 small nibbles permitted;
- 9 means slightly attack-nibbles to 3% of cross section;
- 8 means moderately attacked- penetration 3 to 10% of cross section;
- 7 means moderately to severe attack- penetration 10 to 30% of cross section;
- 6 means severe attack- penetration 30 to 50% of cross section;
- 4 means very severe attack - penetration 50 to 75% of cross section
- 0 means failure
- The stakes meant for the "termite exclusion" were inspected monthly and three sets of the samples were collected for the weight loss and mechanical properties testing after reconditioned to 12% moisture content.

Figure 7.1: Site preparing for graveyard test

Figure 7.2: Samples planted in the graveyard test site with termite mount

Figure 7.3: Termite exclusion test samples on the forest floor

Figure 7.4: Test samples infested with termite

Figure 7.5: Test samples infected with fungi from the graveyard test

Figure 7.6: Test samples infested with termites

7.2 Results and Discussions

7.2.1 Natural Durability Variation between the Plantation and Naturally Grown Mahoganies

The rate of deterioration of wood is a measure of the wood's natural ability to resist bio-deterioration. The deterioration rate samples exposed to termite and fungi activities in the graveyard test is presented on Figure 7. The rate of deterioration increased with increasing exposure period for both mahoganies and the control (Ceiba) sample. The deterioration rate was rapid for the Ceiba (control) samples for the first month and progressing steadily afterwards reaching full failure by the twelfth week while both mahoganies deteriorate slowly but steadily with time (Figure 7). This deterioration as a function time may be due to the stead increase in the population of the bio-deterioration organisms with time. As the population increased their feeding activities increased exponentially until the wood materially is fully consumed as witnessed in the control samples (Figure 7). Alternatively, it may be due to the progressive leaching of the toxic phenolic compounds in the wood samples. However the deterioration was higher for the control sample as compared to the mahogany samples (Figure 7). Both types of mahoganies seem to follow similar trajectories with the plantation samples lying slightly above the natural ones for the first 14 weeks but emerged afterwards (Figure 7). However, the rate was relatively faster for the plantation grown one as compared with the naturally grown one (Figure 2). Respectively, 61% and 59% of the plantation and naturally grown mahoganies samples remained after the twenty-sixth weeks of exposure indicating 39% and 41% respectively were consumed within the period (Figure 7). This indicated both types of mahoganies contained similar phenolic compounds (extractives) which make them unpalatable to the degrading organisms as compared to the control samples. This difference observed in the deterioration rates between the mahoganies may be due the high concentration of toxic phenolic extractive present in the naturally grown types as compared with the plantation grown type. The emergencies of the trajectories of the mahoganies samples may indicate that the phenolic compounds might have leached from the wood with time thereby exposing both types of mahoganies to similar degree of deterioration in the absence of the control samples. Notwithstanding, both mahoganies were rated moderately attacked (Table 1).

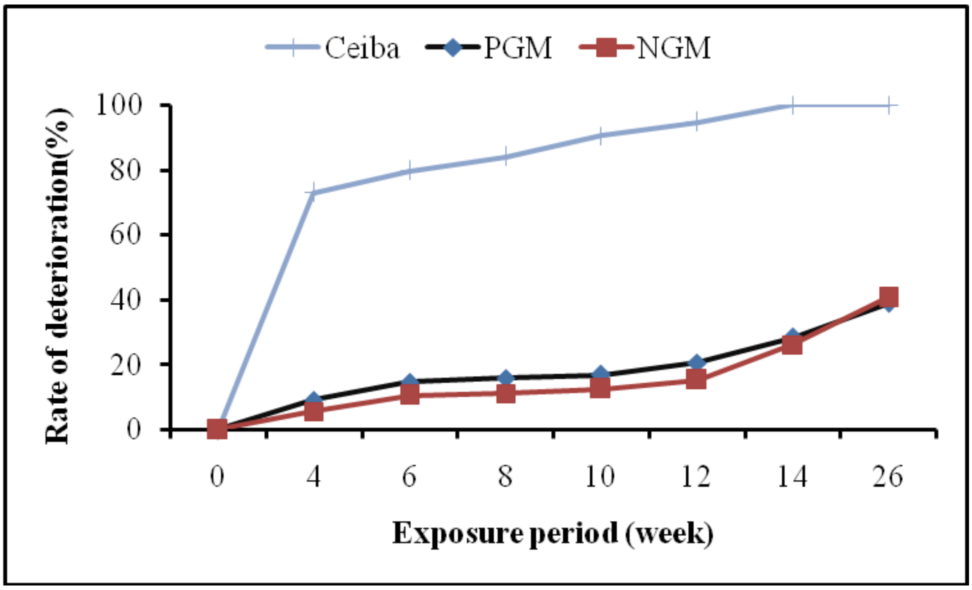

Figure 7.7: Durability variation between plantation and naturally grown mahoganies

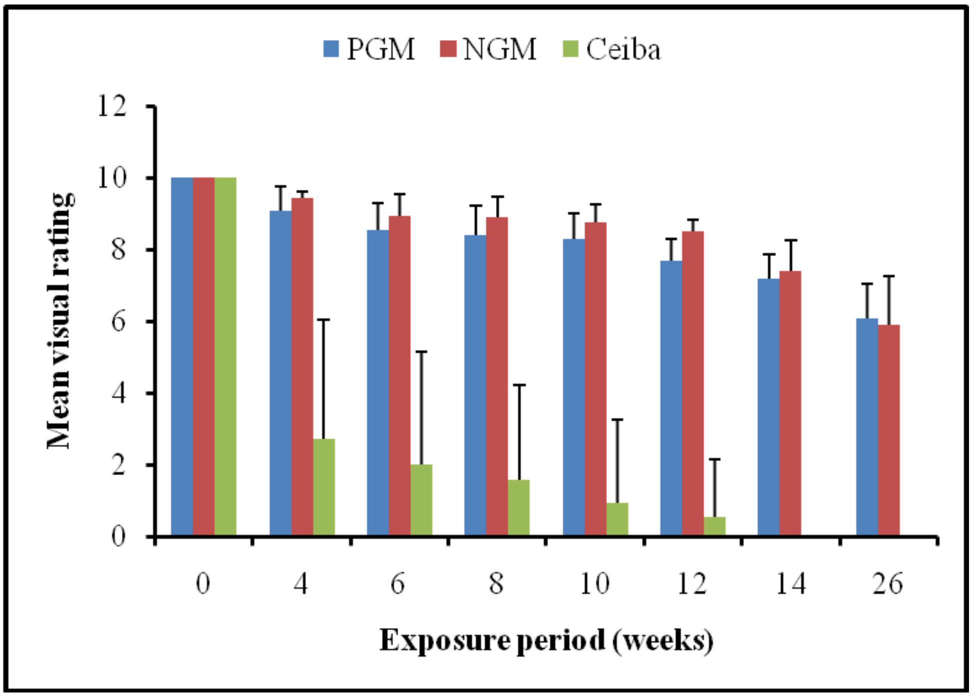

Figure 7.8: Mean visual ratings of the Ceiba, plantation and naturally grown mahoganies for the 26 weeks exposure period.

Table 7.1: Percentage of wood consumed by the organisms within the 26 weeks exposure period

	0week	4weeks	6weeks	8weeks	10weeks	12weeks	14weeks	26weeks
PGM	10	9.1	8.5	8.4	8.3	7.7	7.2	6.1
NGM	10.0	9.4	8.9	8.9	8.8	8.5	7.4	5.9
Ceiba	10.0	2.7	2.0	1.6	0.9	0.5	0.0	0.0

7.2.2 Natural Durability Variation within the Plantation and Naturally Grown Mahoganies

Again, the rate of bio-deterioration varied from the bottom to the top in both types of mahoganies (Figure 8). Generally the top samples were severely consumed by the organisms as compared with the bottom and middle samples (Figure 8). This may be due to the small amount of the phenolic compounds present in the top portions as compared with the other parts of the tree (Essien 2005, Essien 2012). The bottom was less consumed due to the presences of high amounts of the phenolic compounds. After the 26thweek, the top portions of both types of mahoganies were rated as heavily attacked, while the middle and bottom portions were rated as moderate to heavily attack (Table 2). Therefore in application where durability is a critical factor, both the naturally grown mahoganies and the plantation grown mahoganies can be used.

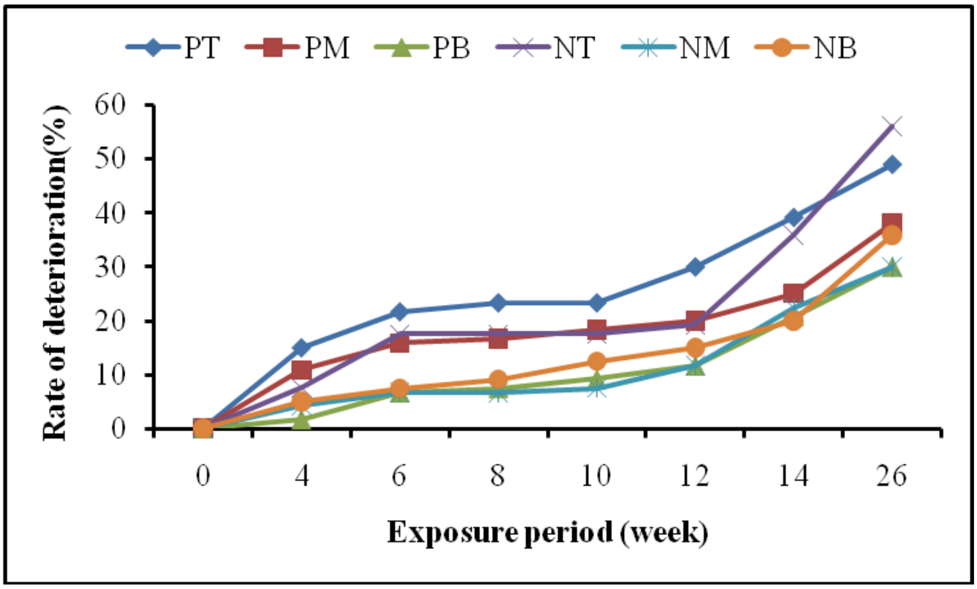

Figure 7.9: Durability variation within plantation and naturally grown mahoganies

Table 2.2: Durability variation within plantation and naturally grown mahoganies assessed over 26 week period

Portions	0 wk	4weeks	6wks	8 wks	10wks	12wks	14wks	26wks
PT	10.0	8.5	7.8	7.7	7.7	7.0	6.7	5.1
PM	10.0	8.9	8.4	8.3	8.2	8.0	7.5	6.2
PB	10.0	9.8	9.3	9.3	9.1	8.1	8.0	7.0
NT	10.0	9.3	8.3	8.3	8.3	8.2	6.4	4.4
NM	10.0	9.6	9.3	9.3	9.3	8.8	7.8	7.0
NB	10.0	9.5	9.3	9.1	8.8	8.3	8.0	6.42
Ceiba	10.0	2.7	2.0	1.6	0.9	0.5	0.0	0.0

7.2.3 Variation in natural resistance to fungi decay

The termite exclusion test was meant to solely screen the mahoganies against wood decaying fungi. The results of the test are presented on figure 10.Over the 26 weeks period, the Ceiba (control) samples lost about 16% of the initial weight of the wood materials while mahoganies lost 2.9% and 2.5% for the plantation and the natural respectively (Figure 10). This percentage loss translates into 0.6% weekly for the control sample, 0.1% weekly and 0.09% weekly for the plantation and naturally grown mahoganies respectively. Both mahoganies were rated as moderately resistant to fungi decay while the control was rated as perishable.

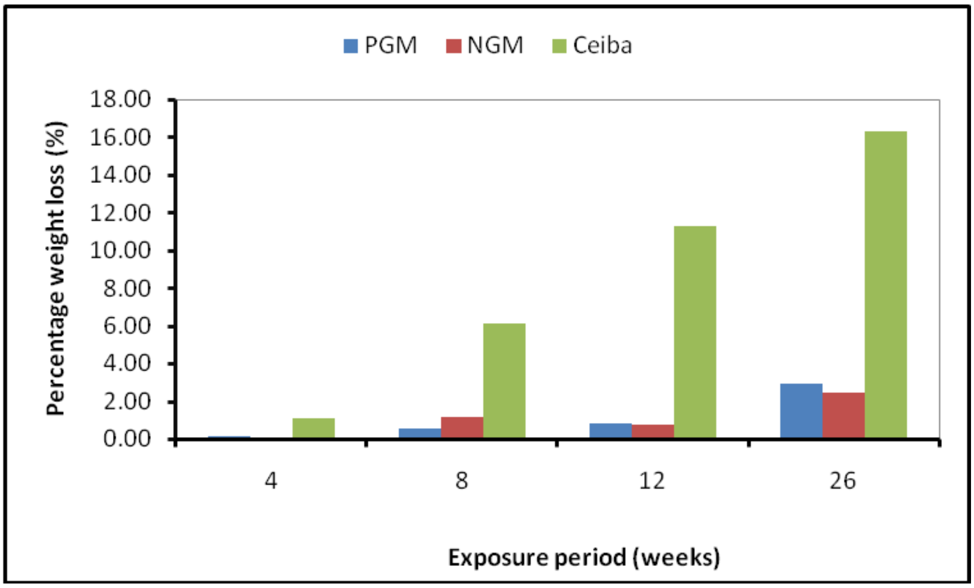

Figure 7.9: Durability variation between plantation and naturally grown mahoganies as compared with control “Ceiba”

7.2.4. Effect of decay fungi on Modulus of Rupture (strength) and Modulus of Elasticity (stiffness) of mahogany

The strength and stiffness of the samples reduced with time of exposure (Figures 10&11). For the plantation grown samples, the stiffness reduced from 7.8GPa to 3.8GPa representing about 49.5% while that of the naturally grown type declined from 6.8 to 4.8GPa representing about 29.3% within the exposure period (Figure 10). These stiffness reductions translated into 2.25% and 1.32% weekly for the plantation and naturally grown types respectively. Also, the strength (modulus of rupture) of the plantation grown samples reduced from 72.8MPa to 46.6 MPa representing 36.3% and 1.64 weekly while that of the naturally grown samples was from 56.6 to48.4MPa representing 14.4% and 0.65 weekly (Figure 11). This indicated that by the time 1% weight loss is observed in the plantation mahogany, stiffness and strength of the wood would have reduced by about 17% and 12% respectively. In the same way, the stiffness and strength would have reduced by 12% and 6% for the naturally grown mahogany. Though the plantation grown type had higher stiffness and strength, it is very susceptible to fungi decay as compared with the naturally grown one (Figure 10 & 11).

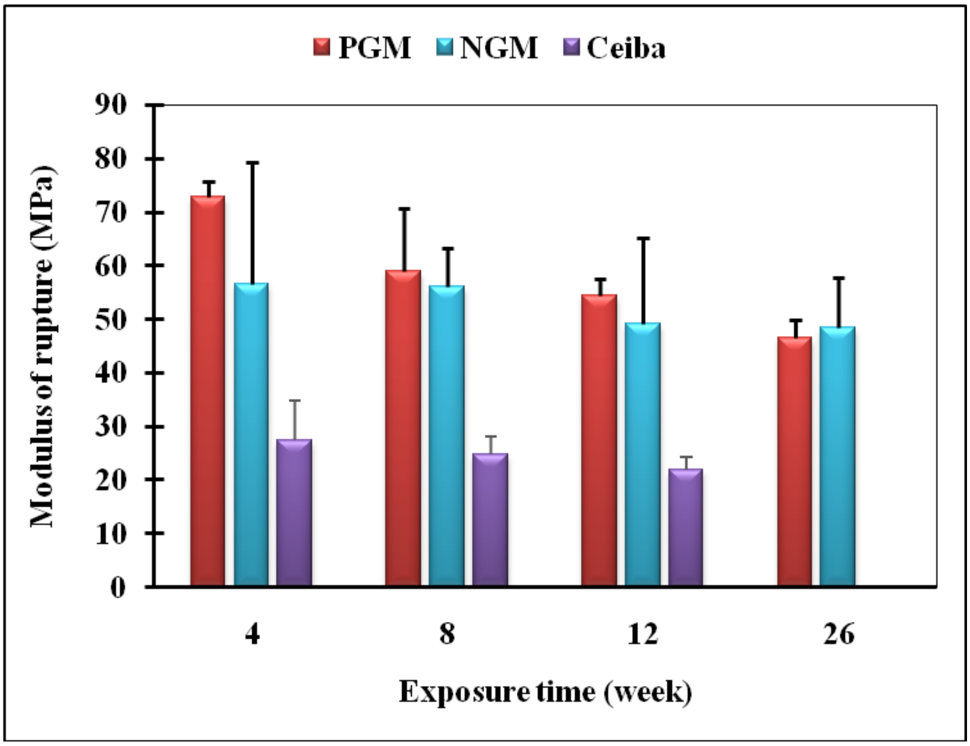

Figure 7.10: Reduction in strength with time of Ceiba, plantation and naturally grown mahoganies

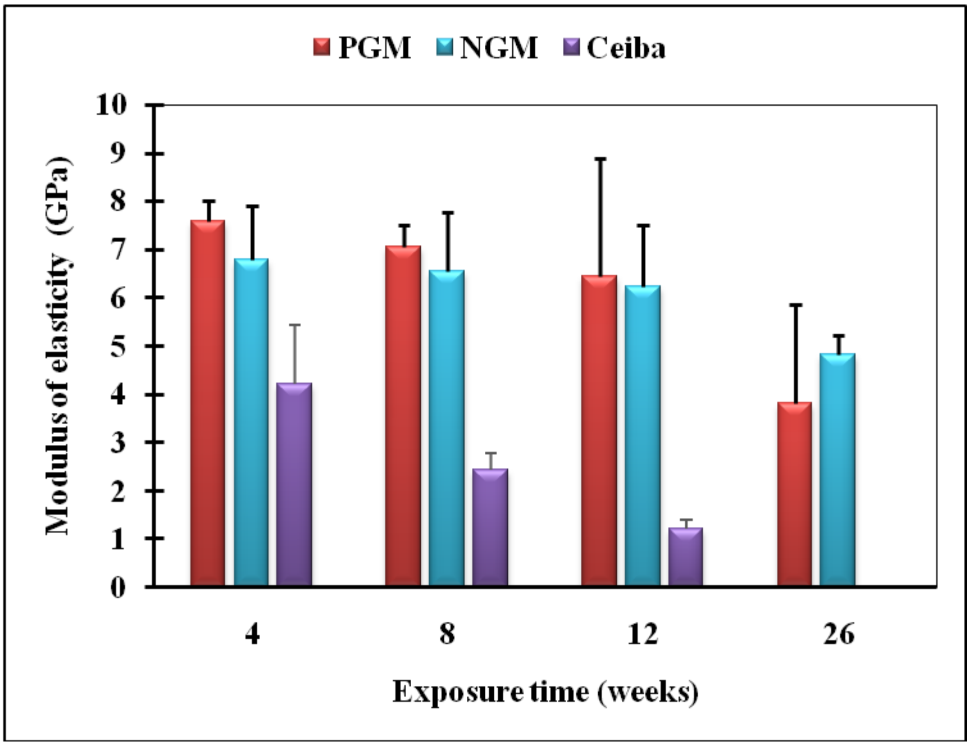

Figure 7.11: Reduction in stiffness with time of Ceiba, plantation and naturally grown mahoganies

7.3 Conclusions

The natural durability varied within the tree with the top being prone to deterioration than the middle and bottom portions. There was no difference in the percentage weight loss between the plantation grown and naturally grown mahoganies.

Though there was no difference in weight loss between the mahoganies, the strength and stiffness reduction was rapid for the plantation grown type as compared with the naturally grown one. The plantation grown mahogany had quality parameters similar or even superior to that of the naturally grown ones hence it can be conveniently used as a replacement of the naturally grown ones.

Both mahoganies were rated as moderately –heavy attached by termites and moderately resistant to fungi decay hence lumber from mahoganies should adequately dry to moisture contents below 20% to reduce its susceptibility to fungi decay. Also in applications where termite infestation is expected, appropriate chemical preservative should applied. This is very essential especially when proper and hygienic storage practices are not observed.

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CHAPTER EIGHT

Surface quality of African mahogany (*Khaya ivorensis*) from Ghana using stylus and deflectometry techniques.

By

Tekpetey, S.L, Adrian Riegel and Dekomien K

8.0 Introduction

Quality evaluation of wooden surface has been described as one of the most difficult issues in wood working research and its mode of assessment has been subject of great interest to researchers and consumers of wood products (Sandak and Negri, 2005; Sinn, 2009). The surfaces of machined wood are a complex heterogeneous polymer composed of cellulose, hemicellulose and lignin and is influenced by several intrinsic factors of the materials morphology of polymers and other physical and chemical properties of wood as well as processing conditions. Properties inherent to wood, such as cell types and arrangement, porosity, density and color variations, make measurement of surface roughness a challenge (Sandak, 2003).This could have been one of the reasons why there are no generally valid correlation to estimate surface roughness parameters as a function of influencing factors. Surface texture of machined surfaces of wood, as revealed by reaction to cutting tools which in turn is determined by size and proportional amounts of cells, especially the vessels, is an important wood quality when decorative and finishing process of tropical wood are concerned.

Many research works have been undertaken on surface quality of solid wood and wood composite in past decades (Lemaster and Beall, 1993; Mitchell and Lemaster, 2002). According to Wengert and Lamb (1994) the planed surface characterization of solid wood is a function of the machining quality. Some other researchers on surface quality were dedicated to relationships between 3D roughness parameters and machining parameters or gluing performance (Hernandez *et al.* 2011; Fellin *et al.*, 2009; Cool and Hernandez ,2011; Ramananantoandro *et al.*, 2014).

Generally, most natural tropical hardwood wood species are brown, cream (white), red or shades of these three colors and are predominately species of medium density though a few are of lower high density (Oteng-Amoako, 2006).These species like *Khaya ivorensis* are commercially used for decorative furniture, boats and boat components, vehicle bodies and decorative veneer for plywood making.

Scarcity of these valuable natural hardwood species and degradation of most tropical forest have led to the establishment of plantation. Worldwide, the managed fast-growing forests have been increasing steadily and are expected to dominate the world's wood supply in some years to come. But, managed resources have been associated with a significant decline in wood quality (Zobel, 1984; Kellogg,1986). These resources are usually characterized by younger age, smaller stem diameter, larger taper, larger knots, higher juvenile wood content and different wood characteristics and processing properties. A combination of these factors of plantation trees could eventually influence the quality of the wood and finally the wood surface. However quality may also be influenced within limits by sawing especially when the head saw is a band saw or a circular saw.

Over the years, various physical phenomena such as mechanical, optical, pneumatic, ultrasonic, electric, or temperature detection approaches have been used as principal components for the measurement of wood surfaces (Shiraishi 1986; Riegel, 1993; Thomas 1999). The appropriateness and applicability of these techniques vary significantly in industrial and laboratory conditions. The techniques most capable of determining surface roughness of materials like metal, plastic and wood in an industrial environment are those that are non-contact, with reproduction of the profile such optical profilometers, microscopes, image analyzers, imaging spectrographs, interferometers, fiber-optic transducers, laser scatters, and optical light-sectioning systems. The contact process of measuring surface roughness like the stylus profilometer provides a more quantitative and hence more objective measure of the surface profile though there are some limitations in the filtering process especially in measuring tropical timber species with large vessel size (porous timber).

The stylus method has been used to determine surface roughness of solid wood in past studies (Hiziroglu and Suchsland, 1993; Mummery, 1993). There are many advantages of using the stylus instrument for measuring the roughness of machined wood surfaces. The production of actual profile of surfaces and the ability to calculate different roughness parameters from the profile using different amplitude filters. This technique has some important limitations such as possible damage of the surface; non-zero tip radius: missing fine irregularities; cone angle of the tip: sliding on the steep fragments of the profile; and relatively slow. In recent years, several attempts have been made to overcome some of these limitations (Fujiwara, 2004; Fujiwara et al. 2001)

Though much work has been done on the several methods of evaluating the surface quality of solid wood and the relationship between these techniques, little information exist on the quantitative assessment of decorative and valuable tropical African timber species and the comparison of the techniques of assessing the surface quality of wood obtained from natural and plantation forest. The objective of this study was to therefore evaluate the surface quality of the machined surfaces of African mahogany from both natural and plantation forest using the stylus profilometer and deflectometry methods.

8.1 Material and methods

Five (5) matured trees of plantation grown mahogany and three (3) naturally grown mahogany (NGM) were extracted from Amantia in the Pra-Anum Forest Reserve, Ghana. The location of the reserve is between latitude 6º 11'to 6º 20' North and longitude 1º 07' to 1º16' west. The site is situated within the Moist Semi-deciduous (South-East) Forest type in Ghana with a mean annual rainfall of between 1500mm and 1750mm.The trees were harvested for the experiment in February, 2012 using logging machinery from Log and Lumber Limited (LLL), Kumasi, Ghana. The logs were transported to LLL, Kumasi for the primary processing where a vertical band mill with saw blade of thickness of 8 inches and length of 33 feet 3inches with gauge of 17'' without tipping was used. The saw blade was swage set for processing.

8.1.1 Sample preparation

Thirty-six samples (36) consisting of eighteen (18 samples) each for plantation grown and natural wood of *Khaya ivorensis* with dimension 230mmx 105mm x 10.5mm were prepared and planed. The samples were then placed in the computer controlled climate chamber at 20º C and relative humidity of 65% for two weeks. According to Kilic *et al.*(2006) no significant difference existed between surface roughness characteristics of tangential and radial machined surfaces of wood samples at a 95% confidence level. The tangential surfaces of the test samples were sanded using wide belt sanding machine using sanding papers of grit sizes of P150, P180 and P280 (aluminium oxide type) sanded at the cutting speed (Vc)= 18m/s and work piece feed speed Vf =(12m/s). Figure 1 shows the sanded samples. These machining parameters were kept constant for sanding of all samples. The sanded samples were then placed in the climate chamber before the measurement for surface profile analysis was made.

Figure 8.1: Sanded mahogany samples

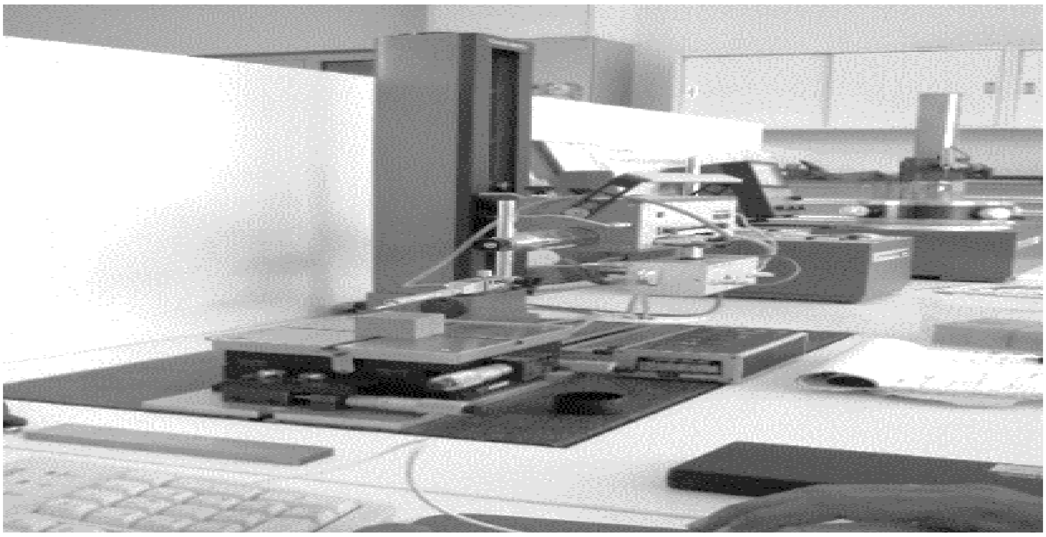

Figure 8.2: Hommelwerke Stylus instrument

8.1.2 Data collection

a) The stylus method

*T*he stylus instrument used in this study was the Hommelwerke type with a tip type of TK300 (figure 2). The measurements were taken with a 48 mm scan length with a Gaussian regression filter - DIN ISO 11562. Each sample of the mahogany was measured 10 times on the tangential surface. The roughness parameters: the average roughness (Ra), mean peak to valley height (Rz), core roughness depth (Rk), reduced peak height (Rpk), reduced valley depth (Rvk), total height of roughness (Rt), maximum surface roughness (Rmax) and maximum depth of roughness motif (Rx) were estimated on tangential surfaces of the wood samples.

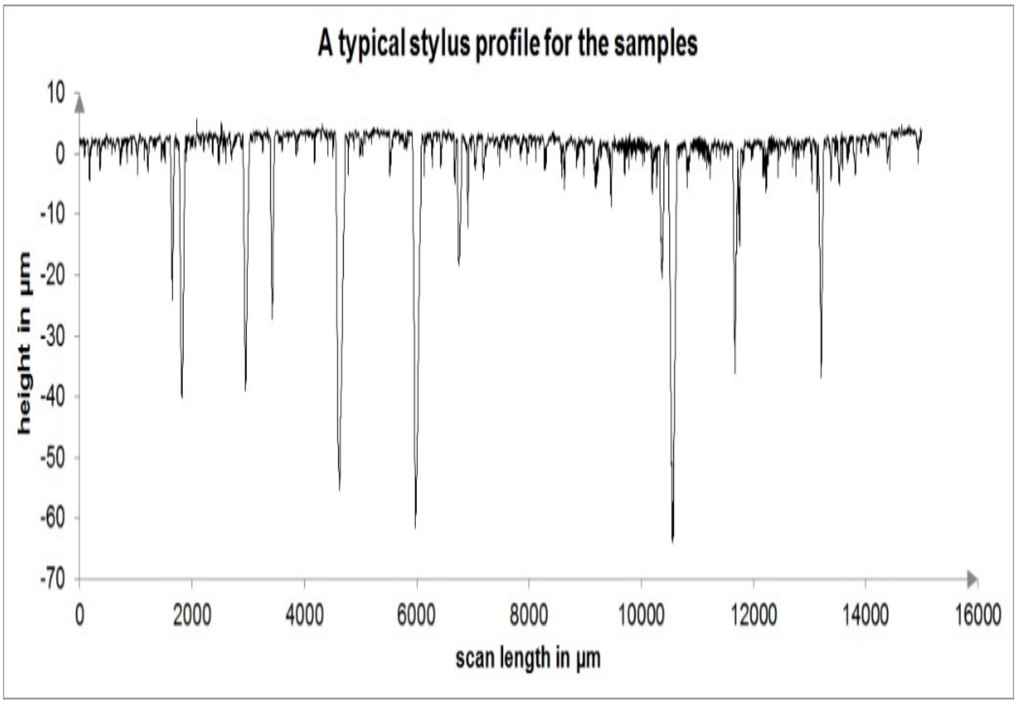

Figure 8.3: A typical profile of the *Khaya ivorensis* species

b) Optimal Deflectometry

The Optimap™ (Figure 4) uses an advanced measuring technique known as 'Phase Stepped Deflectometry' (PSD). It makes fast, objective, full field measurements over large areas requiring no movement over the surface. In this study configuration mode of extra dull, display mode: texture and multiband was used. The device has camera of 1.3 megapixels, image resolution 1296mmx966mm. The measurement area was 95mm X70mm with lateral resolution of 75µm. Texture values were measured at different wavelength (Ta=0,1 – 0,3 mm, Tb=0,3 – 1,0 mm, Tc=1,0 – 3,0 mm, Td=3,0 – 10 mm and Te=10 – 30 mm).

Figure 8.4: Picture of Optimap

8.2 Results and Discussion

8.2.1 Roughness Parameters

Results of mean values for surface roughness parameters of the thirty six (36) sanded samples are presented in Table 1. As shown the plantation samples recorded relatively lower mean roughness values than the natural one at the bottom and middle portions of the stem but higher values at the top portion. This indicates smoother surfaces at the bottom and middle of plantation samples than natural ones. For instance, mean roughness values natural and plantation at the base are Ra (4.815, 3.722); Rq (9.95, 7.465); Rz (80.610, 62.96); Rvk (27.345, 20.273) respectively. At the middle portions, similar trend was recorded for all roughness values measured**.** The top portion, however, showed a different trend for natural and plantation samples for all roughness values except for Rpk values (2.773, 2.468). Statistical analysis of the results revealed that there was no significant difference in the mean roughness parameters of natural and plantation samples at 95% confidence level. For instance, the statistical P-value for roughness parameter Ra and Rvk were 0.9562 and 0.9434 respectively.

Table 8.1: Mean Roughness parameters of plantation grown and natural grown *Khaya ivorensis* from Ghana.

	Khaya Wood species					
	Base		Middle		Top	
	Natural	Plantation	Natural	Plantation	Natural	Plantation
Ra(µm)	4.815	3.722	5.383	3.738	3.945	6.957
	(0,590)	(0,503)	(0,649)	(0,436)	(0,532)	(0,781)
Rq(µm)	9.950	7.465	10.960	7.353	8.012	12.645
	(1,128)	(1,00)	(1,072)	(0,784)	(1,099)	(1,226)
Rz(µm)	80.610	62.960	86.928	61.312	67.973	90.862
	(8,534)	(6,944)	(7,362)	(6,078)	(9,017)	(7,690)
Rmax(µm)	102.827	80.515	110.615	77.230	89.485	112.557
	(12,039)	(11,592)	(11,0831	(9,677)	(12,483)	(11,385)
Rpk(µm)	2.497	2.313	2.775	2.282	2.773	2.468
	(0,275)	(0,209)	(0,266)	(0,256)	(0,378)	(0,396)
Rk(µm)	6.337	5.527	6.880	5.497	6.060	6.292
	(0,276)	(0,256)	(0,325)	(0,255)	(0,286)	(0,286)
Rvk(µm)	27.345	20.273	30.422	20.193	20.743	36.105
	(3,88)	(3,404)	(3,897)	(2,815)	(3,845)	(4,178)

( )- standard deviation

In Figure 6, the result of the surface roughness for natural grown mahogany is shown. In all roughness parameter the top samples were relatively low indicating smoother surface than the other portions. Again, the bottom shows lower values of Ra, Rq, Rz and Rmax than middle portions of naturally grown mahogany. This may be due to the variation in some physical properties of the stem such as density and vessel sizes shown by Rvk values.

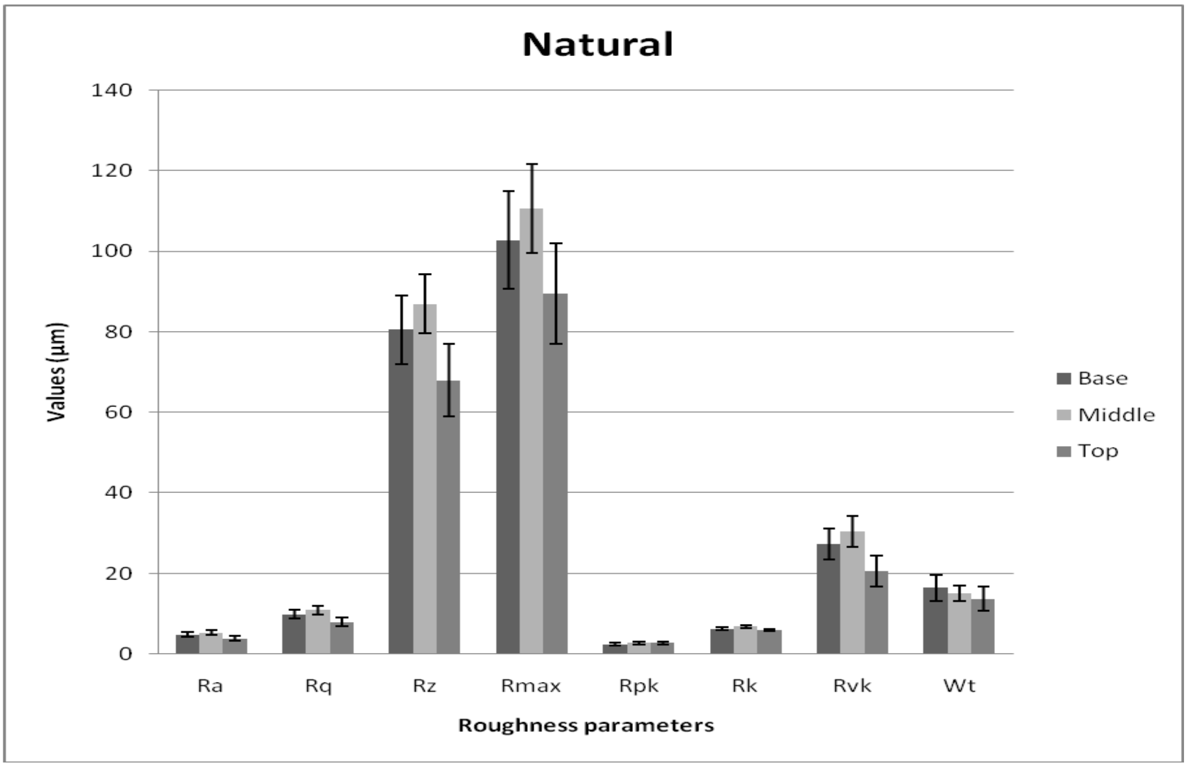

Figure 8.5: Mean roughness parameters of natural *Khaya ivorensis* samples

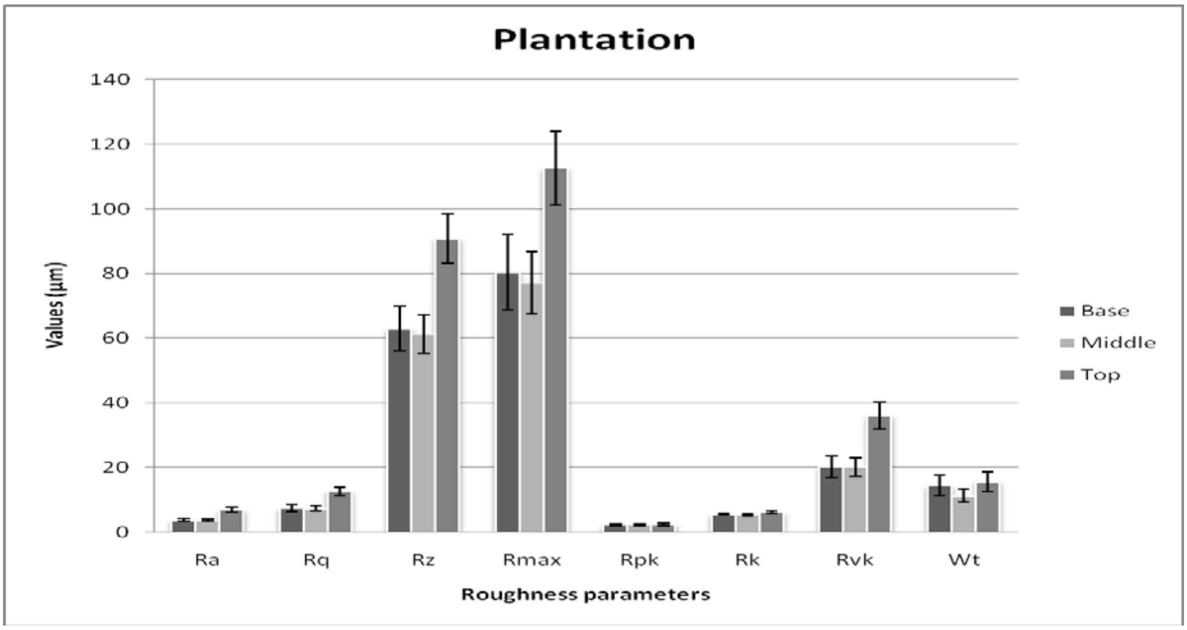

Figure 8.6: Mean roughness parameter of plantation *Khaya ivorensis* sample

Table 8.1 shows statistical P-values for the roughness parameters for the different parts of the samples. All roughness parameters except Rpk varied significantly at different portion of the samples of both natural and plantation samples at 95% confidence level.

8.2.2 Texture Measurement

Tables 8.2 and 8.3 show the texture values in the x direction of the sanded samples of plantation and natural grown mahogany at the different wavelength. No regular trend was recorded for the mean values samples at different height levels in both natural and plantation.

Table 8.2: Texture values for plantation grown mahogany at different wavelength

	Plantation	X-direction				
	T	**Ta**	**Tb**	**Tc**	**Td**	**Te**
Base	15	370	130	120	250	800
	68	240	130	120	240	640
	45	370	120	110	200	420
	73	370	93	100	160	480
	31	300	110	110	210	650
	36	340	120	110	220	660
Ave	*44.6667*	*331.667*	*117.167*	*111.667*	*213.333*	*608.333*
St Dev	*22.3129*	*52.6941*	*14.006*	*7.52773*	*32.0416*	*137.174*
Middle	90	410	85	99	160	440
	97	430	83	100	170	500
	80	400	99	110	170	330
	83	400	97	110	170	380
	97	430	82	99	160	550
	68	370	100	110	180	370
Ave	*85.8333*	*406.667*	*91*	*104.667*	*168.333*	*428.333*
St Dev	*11.1967*	*22.5093*	*8.50882*	*5.85377*	*7.52773*	*84.2417*
Top	25	230	93	100	200	540
	68	340	90	100	210	460
	42	290	100	100	200	490
	37	280	100	100	200	520
	36	240	89	100	190	640
	37	360	100	100	200	550
Ave	*40.8333*	*290*	*95.3333*	*100*	*200*	*533.333*
St Dev	*14.4418*	*52.1536*	*5.27889*	*0*	*7.07107*	*61.8601*

Table 8.3: ANOVA- Texture values for plantation samples

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit.*
Sample	16268.74	2	8134.37	3.844439	0.024997	3.097698
Columns	2907758	5	581551.6	274.851	6.63E-53	2.315689
Interaction	140429.7	10	14042.97	6.636942	1.24E-07	1.937567
Within	190429.2	90	2115.88			
Total	3254885	107				

Table 8.4: ANOVA- Texture values for natural samples

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit.*
Sample	43650.8	2	21825.4	7.76959	0.000771	3.097698
Columns	3095640	5	619128	220.4024	6.8E-49	2.315689
Interaction	54525.54	10	5452.554	1.941046	0.04954	1.937567
Within	252817.2	90	2809.08			
Total	3446634	107				

Table 8.5: Texture values for natural samples in the X direction at different wavelength

	Natural	**X-direction**				
	T	**Ta**	**Tb**	**Tc**	**Td**	**Te**
Middle	73	440	120	120	260	540
	40	310	130	120	290	490
	64	430	120	120	280	670
	62	400	120	110	250	540
	72	430	120	120	260	630
	27	360	130	120	260	610
Ave	*56.3333*	*395*	*123.333*	*118.333*	*266.667*	*580*
St Dev	*18.6619*	*50.892*	*5.16398*	*4.08248*	*15.0555*	*67.5278*
Base	64	360	100	110	160	490
	42	330	110	110	170	530
	34	330	120	110	170	380
	84	390	89	100	170	470
	63	370	110	110	160	470
	66	360	100	110	180	370
Ave	*58.8333*	*356.667*	*104.833*	*108.333*	*168.333*	*451.667*
St Dev	*18.049*	*23.3809*	*10.7781*	*4.08248*	*7.52773*	*63.3772*
Top	40	290	100	100	200	420
	36	390	130	110	210	600
	90	470	120	110	200	690
	75	480	130	120	200	850
	69	340	92	97	190	450
	72	360	92	98	200	410
Ave	*63.6667*	*388.333*	*110.667*	*105.833*	*200*	*570*
St Dev	*21.1912*	*74.6771*	*18.1402*	*9.04249*	*6.32456*	*176.748*

Based on statistical analysis of the results as shown in Table 5 and 6 there is significant variation in the texture values at different height levels. Significant variation also exists in the different height levels of the samples. The results relate to the variation recorded in the roughness parameters recorded in this study. Hendarto *et al*.(2006) proposed a new approach to overcome the shortcoming in measured profile like artificial peak (push up) and provide a more accurate and reliable timber roughness analysis methods.

8.3 Conclusion

Tropical hardwood species like *Khaya ivorensis* species have characteristic that make them suitable for commercial uses. In this work, the evaluation of the machined wooden surface using the stylus profilometer was aimed at estimating differences between the samples of natural and plantation grown wood. Based on the statistical analysis, no significant difference was observed between surface roughness parameters of plantation and natural samples at 95 % confidence level. Further analysis, however indicates that there were significant variation in the roughness parameters within tree species at different height levels measured at 95% confidence level at the three height levels for both natural and plantation samples. In the use of plantation samples for industrial purpose much efforts is needed during the machining to ensure that tropical timber species are well processed for better surface quality. Further work on the filtering process such as the use of robust filtering methods will be necessary to eliminate the effect of artificial peaks that might be related to the use of the Gaussian filters.

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APPENDIX

LUMBER INFORMATION FOR NATURAL AND PLANTATION GROWN MAHOGANY

Code	T/cm	T2/cm	average/cm	Width 1/cm	Width 2/cm	average/cm	Length/cm
*	3.0	3.000	3.000	27.000	27.300	27.150	245.20
*	3.0	3.200	3.100	10.000	12.000	11.000	306.00
N1B	5.9	5.800	5.850	14.800	14.900	14.850	258.50
N1B	6.0	5.800	5.900	18.500	19.000	18.750	258.00
N1B	6.0	6.500	6.250	34.000	34.200	34.100	256.00
N1B	5.6	5.500	5.550	30.000	30.500	30.250	253.00
N1B	6.0	6.000	6.000	18.000	19.000	18.500	262.00
N1B	6.0	6.000	6.000	24.000	25.000	24.500	226.00
N1B	5.5	6.000	5.750	17.000	17.800	17.400	254.00
N1B	3.0	3.000	3.000	20.000	20.000	20.000	257.60
N1B	3.0	3.000	3.000	20.000	18.000	19.000	255.00
N1B	3.0	3.000	3.000	14.500	15.000	14.750	254.00
N1B	3.0	3.000	3.000	13.600	14.000	13.800	255.00
N1B	3.0	3.000	3.000	22.000	20.000	21.000	254.00
N1B	3.0	3.000	3.000	20.000	21.000	20.500	255.00
N1B	3.0	3.000	3.000	14.000	14.700	14.350	254.00
N1B	3.0	3.000	3.000	18.700	19.500	19.100	254.00
N1B	3.0	3.000	3.000	12.500	14.000	13.250	254.00
N1B	3.0	3.000	3.000	12.500	11.000	11.750	254.00
N1B	5.6	5.500	5.550	30.000	30.500	30.250	254.00
N1B	6.0	6.000	6.000	43.000	44.000	43.500	256.00
N1B	5.5	5.600	5.550	44.000	45.500	44.750	256.00
N1B	6.0	16.000	11.000	23.000	23.100	23.050	257.00
N1B	5.3	5.200	5.250	23.000	22.000	22.500	256.00
N1B	5.3	6.000	5.650	24.000	23.500	23.750	254.00
N1B	3.0	3.000	3.000	6.500	5.500	6.000	259.00
N1B	3.0	3.000	3.000	14.500	14.000	14.250	257.00
N1M	3.5	3.400	3.450	24.800	25.000	24.900	256.00
N1M	3.5	3.200	3.350	24.000	25.000	24.500	256.50
N1M	3.2	3.300	3.250	26.000	25.500	25.750	255.00
N1M	3.0	3.000	3.000	25.000	27.000	26.000	165.00
N1M	3.0	3.000	3.000	25.000	25.000	25.000	170.00
N1M	3.0	3.000	3.000	25.000	27.000	26.000	245.00
N1M	3.1	3.000	3.050	14.000	13.000	13.500	245.00
N1M	3.0	3.000	3.000	16.700	14.500	15.600	245.00
N1M	3.0	3.000	3.000	11.000	11.000	11.000	244.50
N1M	3.0	3.000	3.000	11.000	12.500	11.750	245.00
N1M	3.0	3.000	3.000	7.200	9.000	8.100	244.00
N1M	3.0	3.000	3.000	25.000	25.000	25.000	245.00
N1M	3.1	3.000	3.050	13.400	13.000	13.200	245.00

N1M	3.0	3.000	3.000	24.900	25.000	24.950	245.00	
N1M	3.0	3.000	3.000	32.000	30.000	31.000	245.00	
N1M	3.1	3.000	3.050	24.000	22.500	23.250	244.00	
N1M	3.3	3.200	3.250	27.000	25.000	26.000	243.50	
N1M	3.0	3.000	3.000	20.000	20.000	20.000	243.00	
N1M	3.0	3.000	3.000	32.500	32.500	32.500	244.00	
N1MA	3.0	3.300	3.150	25.600	26.000	25.800	256.30	
N1MA	3.5	3.200	3.350	16.300	15.500	15.900	266.50	
N1MA	3.0	3.500	3.250	18.000	16.000	17.000	253.00	
N1MA	3.0	3.000	3.000	25.700	25.800	25.750	261.00	
N1MA	3.5	3.000	3.250	17.000	18.000	17.500	261.00	
N1MA	3.4	3.300	3.350	24.000	24.000	24.000	262.00	
N1MB	3.0	3.300	3.150	9.500	9.600	9.550	252.00	
N1MB	3.5	3.500	3.500	17.000	17.400	17.200	257.50	
N1MB	6.0	6.000	6.000	35.500	37.000	36.250	255.00	
N1MC	3.0	3.000	3.000	19.000	19.200	19.100	245.00	
N1MC	3.0	3.000	3.000	41.000	41.000	41.000	245.50	
N1MC	3.0	3.500	3.250	43.000	43.500	43.250	245.00	
N1MC	3.0	3.100	3.050	29.000	30.500	29.750	244.00	
N1MC	3.0	3.500	3.250	28.000	26.000	27.000	244.00	
N1MC	3.0	3.000	3.000	26.000	26.200	26.100	244.00	
N1MC	3.0	3.000	3.000	43.000	46.000	44.500	244.00	
N1MC	3.0	3.000	3.000	28.000	28.000	28.000	244.00	
N1T	3.0	3.000	3.000	13.200	13.200	13.200	231.00	
N1T	3.0	3.000	3.000	21.500	21.000	21.250	230.50	
N1T	3.0	3.000	3.000	13.300	13.100	13.200	231.50	
N1T	3.0	3.000	3.000	13.200	13.000	13.100	181.00	
N1T	2.5	3.000	2.750	16.000	17.000	16.500	229.00	
N1T	3.0	3.200	3.100	11.500	12.000	11.750	230.00	
N1T	5.8	6.000	5.900	17.000	18.500	17.750	180.00	
N1T	3.0	3.500	3.250	15.000	16.000	15.500	230.00	
N1T	6.0	5.500	5.750	25.000	25.000	25.000	221.00	
N2B	3.5	3.400	3.450	21.500	22.300	21.900	307.00	
N2B	3.1	3.000	3.050	11.000	11.500	11.250	304.00	
N2B	3.5	3.500	3.500	22.500	21.000	21.750	305.00	
N2B	3.0	3.100	3.050	11.100	11.500	11.300	305.00	
N2B	3.3	3.400	3.350	22.000	22.000	22.000	306.00	
N2B	3.3	3.200	3.250	16.000	15.000	15.500	306.00	
N2B	3.5	3.500	3.500	34.000	25.000	29.500	243.00	
N2B	3.4	3.500	3.450	13.000	13.500	13.250	272.30	
N2B	3.5	3.100	3.300	16.000	15.500	15.750	304.00	
N2B	3.5	3.100	3.300	23.000	23.400	23.200	301.00	
N2B	3.5	3.500	3.500	28.000	27.500	27.750	301.00	
N2B	3.5	3.500	3.500	31.500	32.000	31.750	301.00	

N2B	3.5	3.500	3.500	34.000	33.000	33.500	304.00
N2B	3.3	3.400	3.350	23.000	23.000	23.000	305.00
N2B	3.0	3.500	3.250	10.000	10.000	10.000	305.00
N2B	3.1	3.500	3.300	10.000	10.500	10.250	231.00
N2B	3.0	3.000	3.000	22.000	21.000	21.500	308.00
N2B	3.0	3.000	3.000	21.000	15.000	18.000	308.00
N2B	3.2	3.200	3.200	21.000	22.000	21.500	305.00
N2B	6.5	6.000	6.250	13.500	13.000	13.250	302.50
N2B	6.5	6.000	6.250	37.000	36.000	36.500	305.00
N2B	6.0	6.500	6.250	27.000	27.000	27.000	301.50
N2B	6.0	6.000	6.000	30.000	29.000	29.500	305.00
N2B	6.5	7.000	6.750	22.700	22.500	22.600	307.00
N2B	7.0	6.000	6.500	22.700	21.000	21.850	305.50
N2B	6.0	6.100	6.050	27.000	27.000	27.000	301.00
N2B	6.0	6.300	6.150	35.000	34.000	34.500	305.00
N2B	6.0	6.000	6.000	7.500	7.400	7.450	256.00
N2M	3.0	3.000	3.000	17.000	17.100	17.050	250.00
N2M	3.3	3.500	3.400	25.000	23.000	24.000	259.00
N2M	3.5	3.300	3.400	19.500	20.000	19.750	269.50
N2M	7.0	7.000	7.000	31.000	31.300	31.150	243.00
N2M	7.5	7.000	7.250	16.700	17.000	16.850	245.00
N2M	3.4	3.300	3.350	16.100	15.000	15.550	252.00
N2M	3.5	3.500	3.500	15.000	16.100	15.550	252.00
N2M	3.5	3.300	3.400	15.000	16.000	15.500	253.00
N2M	3.4	3.400	3.400	27.900	27.000	27.450	251.00
N2M	3.5	3.500	3.500	25.000	24.500	24.750	252.00
N2M	3.5	3.200	3.350	21.000	20.500	20.750	256.00
N2M	3.3	3.500	3.400	25.600	24.500	25.050	252.00
N2M	3.0	3.000	3.000	15.000	16.000	15.500	251.00
N2MA	6.0	6.000	6.000	32.000	31.500	31.750	249.00
N2MA	3.5	3.400	3.450	19.500	20.000	19.750	251.00
N2MA	3.4	3.500	3.450	13.800	14.000	13.900	250.00
N2MA	3.0	3.400	3.200	21.300	22.000	21.650	251.00
N2MA	3.4	3.100	3.250	21.600	22.000	21.800	253.00
N2MA	3.5	3.500	3.500	11.100	12.100	11.600	252.60
N2MA	3.5	3.300	3.400	17.400	18.000	17.700	251.00
N2MA	3.9	4.000	3.950	34.700	35.000	34.850	252.00
N2MA	6.2	6.000	6.100	26.000	26.000	26.000	252.00
N2MA	6.0	6.000	6.000	32.900	32.000	32.450	252.00
N2MA	3.5	3.400	3.450	17.000	17.100	17.050	269.00
N2MA	4.0	3.500	3.750	15.500	15.000	15.250	269.00
N2MA	3.2	3.400	3.300	15.500	15.000	15.250	249.00
N2MA	3.5	3.400	3.450	15.200	15.500	15.350	249.00
N2MA	6.3	6.000	6.150	32.500	35.500	34.000	250.00

N2MB	3.5	3.500	3.500	17.000	17.000	17.000	269.00
N2MB	3.5	3.500	3.500	17.000	17.000	17.000	268.50
N2MB	3.4	3.400	3.400	23.000	22.000	22.500	269.00
N2MB	3.5	3.400	3.450	14.500	14.300	14.400	269.00
N2MB	3.2	3.500	3.350	16.000	16.200	16.100	269.00
N2MB	3.4	3.000	3.200	22.000	22.100	22.050	269.00
N2MB	3.4	3.400	3.400	29.500	29.000	29.250	259.00
N2MB	3.4	3.500	3.450	22.000	22.000	22.000	269.00
N2MB	3.0	3.400	3.200	21.000	21.000	21.000	269.00
N2MB	3.5	3.300	3.400	18.000	18.000	18.000	269.00
N2MB	3.2	3.400	3.300	18.000	18.400	18.200	269.00
N2MB	3.5	3.300	3.400	18.100	17.700	17.900	251.00
N2MB	3.3	3.200	3.250	17.600	17.800	17.700	248.00
N2MB	3.2	3.100	3.150	42.000	44.500	43.250	270.00
N2MB	3.5	3.300	3.400	33.500	37.500	35.500	269.50
N2MB	3.5	3.500	3.500	24.500	251.000	137.750	269.50
N2MB	3.4	3.400	3.400	26.500	26.500	26.500	217.00
N2MB	3.2	3.000	3.100	18.000	18.000	18.000	271.00
N2MB	3.5	3.500	3.500	25.000	25.400	25.200	269.00
N2MB	3.4	3.200	3.300	22.700	23.400	23.050	266.50
N2MB	3.5	3.300	3.400	23.000	22.500	22.750	255.50
N2MB	3.1	3.200	3.150	30.000	30.000	30.000	268.00
N2MB	3.1	3.400	3.250	25.000	25.000	25.000	259.00
N2MB	3.0	3.200	3.100	10.000	11.000	10.500	269.00
N2MB	3.1	3.300	3.200	21.000	20.500	20.750	263.00
N2MB	3.0	3.400	3.200	16.000	15.000	15.500	268.00
N2MB	3.5	3.300	3.400	21.500	21.000	21.250	269.00
N2MB	3.4	3.400	3.400	13.300	14.000	13.650	268.00
N2MB	3.5	3.500	3.500	25.400	22.500	23.950	268.00
N2MB	3.5	3.400	3.450	36.500	36.000	36.250	250.50
N2T	3.0	3.000	3.000	16.600	16.700	16.650	255.90
N2T	3.1	3.400	3.250	16.500	16.000	16.250	256.00
N2T	3.0	3.200	3.100	15.700	15.700	15.700	256.20
N2T	3.0	3.000	3.000	16.500	16.700	16.600	256.20
N2T	3.0	3.000	3.000	14.300	13.300	13.800	256.00
N2T	3.0	3.100	3.050	14.500	3.500	9.000	256.00
N2T	3.0	3.000	3.000	14.200	13.500	13.850	256.00
N2T	3.0	3.000	3.000	11.100	11.200	11.150	256.20
N2T	2.9	3.000	2.950	21.100	20.500	20.800	255.90
N2T	3.0	3.000	3.000	16.000	16.200	16.100	255.30
N2T	3.0	3.000	3.000	14.200	14.900	14.550	255.90
N2T	3.0	3.000	3.000	14.000	14.100	14.050	255.70
N2T	3.1	3.000	3.050	15.000	14.900	14.950	255.00
N2T	3.0	3.000	3.000	14.000	14.000	14.000	254.20

N2T	3.0	3.000	3.000	13.500	13.000	13.250	255.00
N2T	3.1	3.000	3.050	13.800	13.400	13.600	255.50
N2T	5.9	5.800	5.850	13.000	12.900	12.950	256.50
N2T	5.8	6.000	5.900	17.300	16.900	17.100	256.20
N2T	5.8	5.800	5.800	11.900	12.800	12.350	255.00
N2T	6.0	6.000	6.000	11.300	11.000	11.150	257.00
N2T	6.0	6.000	6.000	16.500	16.400	16.450	256.10
N2T	6.0	6.000	6.000	10.000	9.000	9.500	257.00
N2T	5.8	6.000	5.900	7.700	7.600	7.650	265.00
N3B	7.4	7.500	7.450	42.000	42.000	42.000	245.00
N3B	7.0	7.000	7.000	35.400	35.000	35.200	245.00
N3B	7.0	7.400	7.200	25.000	25.000	25.000	245.00
N3B	7.3	7.300	7.300	23.200	23.000	23.100	245.00
N3B	7.5	7.500	7.500	26.000	27.000	26.500	245.00
N3B	7.1	7.400	7.250	23.000	23.000	23.000	245.00
N3B	7.1	7.400	7.250	18.000	17.900	17.950	245.00
N3B	7.0	7.000	7.000	23.400	23.500	23.450	245.00
N3B	7.0	7.000	7.000	15.500	15.300	15.400	243.00
N3B	7.5	7.500	7.500	33.000	33.000	33.000	245.00
N3B	7.3	7.000	7.150	34.700	34.500	34.600	245.00
N3B	3.0	3.500	3.250	12.000	12.500	12.250	245.00
N3B	3.0	3.000	3.000	9.000	9.000	9.000	245.00
N3B	3.2	3.500	3.350	8.500	9.000	8.750	245.00
N3B	3.5	3.500	3.500	25.000	25.000	25.000	245.00
N3B	3.5	3.500	3.500	28.500	28.700	28.600	245.00
N3B	3.5	3.400	3.450	32.000	32.000	32.000	251.00
N3B	3.4	3.300	3.350	24.000	23.000	23.500	245.00
N3B5	3.5	3.600	3.550	24.000	24.500	24.250	245.00
N3M	7.0	7.300	7.150	33.000	32.500	32.750	190.00
N3M	7.0	7.000	7.000	16.000	16.000	16.000	205.00
N3M	7.0	7.000	7.000	20.500	21.300	20.900	179.00
N3M	6.8	7.000	6.900	35.700	36.000	35.850	245.00
N3M	6.5	6.800	6.650	27.000	26.800	26.900	205.00
N3M	7.2	7.000	7.100	26.000	26.000	26.000	245.10
N3M	7.1	6.900	7.000	20.000	18.000	19.000	245.00
N3M	3.5	3.600	3.550	11.300	9.000	10.150	245.00
N3M	3.5	3.500	3.500	8.500	10.000	9.250	244.50
N3M	5.3	5.700	5.500	13.000	12.500	12.750	254.00
N3M	3.8	3.500	3.650	31.100	31.000	31.050	245.50
N3M	3.5	3.400	3.450	31.300	31.000	31.150	245.00
N3M	3.4	3.500	3.450	19.500	20.000	19.750	245.00
N3M	3.4	3.500	3.450	36.000	36.000	36.000	245.00
N3M	3.0	3.000	3.000	21.000	20.500	20.750	244.00
N3T	3.0	3.100	3.050	14.800	15.400	15.100	251.00

N3T	3.0	3.000	3.000	9.800	9.000	9.400	255.70
N3T	3.0	3.000	3.000	16.500	16.000	16.250	257.00
N3T	3.3	3.000	3.150	13.200	15.000	14.100	256.00
N3T	3.0	3.000	3.000	15.200	11.500	13.350	260.00
N3T	3.0	3.000	3.000	8.100	8.600	8.350	260.00
N3T	3.4	3.000	3.200	21.000	21.000	21.000	257.00
N3T	3.0	3.400	3.200	17.500	18.000	17.750	257.00
N3T	3.0	3.000	3.000	20.000	20.000	20.000	250.90
N3T	3.0	3.000	3.000	23.500	23.000	23.250	254.00
N3T	3.0	3.400	3.200	14.800	15.500	15.150	254.90
N3T	3.0	3.000	3.000	14.000	13.000	13.500	252.50
N3T	3.0	3.000	3.000	14.500	14.000	14.250	254.00
N3T	6.0	5.900	5.950	17.500	18.000	17.750	255.00
N5	3.0	3.000	3.000	18.500	18.000	18.250	253.00
N5	3.0	3.000	3.000	29.000	29.500	29.250	253.30
N5	3.3	3.000	3.150	33.000	32.300	32.650	252.00
N5	3.1	3.200	3.150	33.500	32.800	33.150	253.00
N5	3.0	3.000	3.000	23.100	24.000	23.550	251.00
N5	3.5	3.000	3.250	31.000	32.000	31.500	252.00
N5	3.0	3.200	3.100	29.000	28.000	28.500	254.00
N5	3.0	3.000	3.000	32.000	33.000	32.500	256.00
N5	3.0	3.000	3.000	32.000	32.000	32.000	255.00
N5	3.0	3.000	3.000	22.500	22.000	22.250	254.00
N5	3.0	3.000	3.000	24.000	23.500	23.750	253.00
N5	3.0	3.000	3.000	36.800	36.000	36.400	255.00
N5	3.0	3.000	3.000	27.000	27.500	27.250	254.00
N5	3.0	3.000	3.000	40.000	40.500	40.250	253.00
N5	3.5	3.300	3.400	18.000	18.000	18.000	256.50
N5	3.5	3.500	3.500	15.000	15.000	15.000	256.50
N5	3.4	3.400	3.400	18.500	18.000	18.250	200.00
N5	3.3	3.500	3.400	32.000	31.500	31.750	25
N5	3.3	3.500	3.400	18.500	18.000	18.250	25
N5	3.5	3.400	3.450	17.500	18.000	17.750	17
NIM	6.0	6.000	6.000	37.000	38.000	37.500	25
NIM	3.0	3.000	3.000	24.000	24.000	24.000	25
NIMA	6.0	6.000	6.000	35.500	36.100	35.800	25
NIMA	6.0	6.000	6.000	38.100	37.500	37.800	25
NIMA	3.2	3.500	3.350	15.000	16.000	15.500	25
NIMA	3.5	3.500	3.500	23.000	23.300	23.150	25
NIMA	4.0	3.500	3.750	22.000	22.000	22.000	25
NIMA	3.0	3.000	3.000	25.700	25.000	25.350	20
NIMA	3.5	3.500	3.500	15.000	15.000	15.000	26
NIMB	6.0	6.000	6.000	23.200	23.000	23.100	25
NIMB	3.2	3.400	3.300	26.000	24.000	25.000	25

NIMB	3.4	3.000	3.200	15.000	16.000	15.500	25
NIMB	3.0	3.200	3.100	18.000	17.000	17.500	25
NIMB	3.0	3.500	3.250	19.000	18.000	18.500	17
NIMB	3.0	3.200	3.100	25.000	25.000	25.000	25
NIMC	3.0	3.100	3.050	20.000	21.000	20.500	24
P1B	7.0	7.200	7.100	19.000	19.300	19.150	24
P1B	7.5	6.900	7.200	19.400	19.200	19.300	24
P1B	7.0	6.700	6.850	12.500	12.700	12.600	24
P1B	7.5	7.300	7.400	38.000	38.300	38.150	24
P1B	7.0	7.500	7.250	28.500	28.300	28.400	24
P1B	6.8	6.800	6.800	29.000	28.000	28.500	24
P1B	6.9	6.800	6.850	27.500	26.800	27.150	24
P1B	7.0	6.900	6.950	17.200	17.200	17.200	23
P1B	7.0	6.900	6.950	29.000	30.000	29.500	24
P1B	7.0	6.500	6.750	18.500	18.600	18.550	24
P1B	6.9	7.300	7.100	31.000	31.000	31.000	24
P1B	3.5	3.700	3.600	22.300	22.000	22.150	24
P1B	3.5	3.500	3.500	22.000	21.000	21.500	24
P1B	4.0	4.000	4.000	29.000	30.000	29.500	24
P1B	3.5	3.200	3.350	19.000	18.500	18.750	24
P1B	3.5	3.500	3.500	14.000	15.000	14.500	24
P1B	3.4	3.300	3.350	14.000	15.000	14.500	24
P1B	3.5	3.700	3.600	22.300	22.000	22.150	24
P1M	3.0	3.000	3.000	20.000	20.000	20.000	25
P1M	3.1	3.100	3.100	23.000	22.500	22.750	25
P1M	3.2	2.600	2.900	21.200	22.200	21.700	25
P1M	3.5	3.200	3.350	22.000	22.600	22.300	25
P1M	3.0	3.000	3.000	7.400	7.000	7.200	25
P1M	3.0	3.000	3.000	22.000	22.500	22.250	25
P1M	3.2	3.000	3.100	20.500	21.000	20.750	25
P1M	3.1	3.200	3.150	10.000	11.000	10.500	24
P1M	3.2	3.200	3.200	22.500	22.700	22.600	24
P1M	3.1	3.100	3.100	29.500	29.000	29.250	24
P1M	3.0	3.000	3.000	29.700	29.500	29.600	24
P1M	3.9	3.000	3.450	28.000	28.100	28.050	24
P1M	3.2	3.000	3.100	26.700	27.000	26.850	24
P1M	5.3	6.000	5.650	21.000	20.000	20.500	24
P1M	6.0	6.000	6.000	34.000	33.500	33.750	24
P1M	8.2	6.000	7.100	28.900	28.000	28.450	25
P1M	6.2	6.000	6.100	16.000	16.200	16.100	25
P1M	3.1	3.000	3.050	31.600	30.500	31.050	24
P1M	3.0	3.000	3.000	18.700	18.200	18.450	25
P1M	3.0	3.000	3.000	16.000	15.100	15.550	25
P1M	3.3	3.300	3.300	18.500	28.500	23.500	24

P1M	3.0	3.000	3.000	22.500	22.000	22.250	25
P1M	3.0	3.200	3.100	19.500	19.500	19.500	25
P1M	3.5	3.500	3.500	15.800	15.500	15.650	26
P1M	3.5	3.400	3.450	21.500	21.500	21.500	25
P1M	3.3	3.400	3.350	32.800	32.000	32.400	25
P1M	3.5	3.200	3.350	8.000	7.500	7.750	24
P1M*	3.4	3.500	3.450	16.000	15.800	15.900	17
P1MB	6.0	6.000	6.000	23.000	22.500	22.750	24
P1MB	6.0	6.000	6.000	21.500	23.000	22.250	25
P1MB	5.9	6.000	5.950	19.000	19.500	19.250	25
P1MB	6.0	6.000	6.000	21.000	22.000	21.500	25
P1MB	6.0	6.000	6.000	21.300	20.000	20.650	25
P1MB	3.0	3.500	3.250	16.000	15.000	15.500	25
P1MB	4.0	3.200	3.600	26.000	27.000	26.500	25
P1MB	3.5	3.500	3.500	26.000	27.500	26.750	25
P1MB	3.4	3.500	3.450	26.000	27.000	26.500	25
P1MB	3.0	4.000	3.500	24.000	22.000	23.000	25
P1MB	3.0	3.500	3.250	11.000	121.500	66.250	25
P1MB	3.5	3.500	3.500	18.500	19.000	18.750	25
P1MB	3.4	3.500	3.450	25.000	26.000	25.500	26
P1MB	3.0	3.300	3.150	22.500	23.000	22.750	25
P1MB	3.5	3.500	3.500	14.500	15.000	14.750	25
P1MB	4.0	3.500	3.750	17.000	16.000	16.500	25
P1T	6.0	6.000	6.000	13.500	14.000	13.750	25
P1T	6.0	6.000	6.000	11.100	11.500	11.300	25
P1T	6.0	6.000	6.000	22.000	21.200	21.600	25
P2B	3.0	3.000	3.000	17.500	17.000	17.250	25
P2B	3.0	3.000	3.000	16.500	15.000	15.750	25
P2B	4.0	3.000	3.500	10.300	10.000	10.150	25
P2B	3.2	3.100	3.150	31.900	31.000	31.450	25
P2B	3.0	3.500	3.250	32.500	31.900	32.200	25
P2B	3.0	3.100	3.050	29.900	28.900	29.400	25
P2B	3.0	3.000	3.000	22.600	21.000	21.800	25
P2B	3.0	3.000	3.000	22.500	22.100	22.300	25
P2B	3.5	3.500	3.500	33.400	34.000	33.700	25
P2B	3.5	3.500	3.500	37.000	36.000	36.500	25
P2B	3.5	3.400	3.450	38.500	39.000	38.750	25
P2B	6.0	6.000	6.000	36.000	35.800	35.900	25
P2B	6.0	6.000	6.000	30.000	29.500	29.750	25
P2B	3.5	3.500	3.500	37.000	36.000	36.500	25
P2B	3.4	3.000	3.200	32.500	32.000	32.250	25
P2B	3.4	3.000	3.200	25.000	26.000	25.500	25
P2B	3.5	3.300	3.400	26.000	25.000	25.500	25
P2B	3.5	3.300	3.400	22.000	21.000	21.500	25

P2B	3.4	3.300	3.350	27.300	28.000	27.650	25
P2B	6.0	6.200	6.100	24.000	23.000	23.500	25
P2B	6.0	6.000	6.000	21.500	23.000	22.250	25
P2B	6.0	6.000	6.000	29.000	29.000	29.000	25
P2B	6.0	6.000	6.000	32.500	31.000	31.750	25
P2B	6.0	6.100	6.050	32.500	32.000	32.250	25
P2B	6.0	7.500	6.750	23.500	24.000	23.750	17
P2B	3.5	3.400	3.450	20.000	21.000	20.500	25
P2M	3.0	3.000	3.000	19.500	21.800	20.650	25
P2M	3.0	3.000	3.000	22.000	19.000	20.500	25
P2M	3.0	3.100	3.050	17.000	16.000	16.500	25
P2M	3.0	3.000	3.000	15.000	16.000	15.500	25
P2M	3.0	3.000	3.000	15.000	14.500	14.750	15
P2M	3.5	3.000	3.250	12.900	13.000	12.950	25
P2M	3.0	3.000	3.000	15.000	16.000	15.500	25
P2M	3.0	3.000	3.000	9.000	8.000	8.500	25
P2M	3.0	3.000	3.000	17.600	14.000	15.800	25
P2M	3.0	3.000	3.000	17.000	16.000	16.500	25
P2M	3.4	3.000	3.200	26.000	26.000	26.000	25
P2M	3.0	3.400	3.200	20.700	21.500	21.100	25
P2M	3.0	3.000	3.000	16.000	16.000	16.000	25
P2M	3.0	3.000	3.000	12.000	13.000	12.500	25
P2M	3.0	3.000	3.000	28.500	26.000	27.250	25
P2M	3.2	3.300	3.250	19.500	20.000	19.750	25
P2M	3.0	3.000	3.000	29.000	28.500	28.750	24
P2M	3.0	3.000	3.000	31.900	31.500	31.700	25
P2M	3.0	3.000	3.000	32.500	31.900	32.200	25
P2M	3.0	3.000	3.000	34.900	34.200	34.550	25
P2M	3.0	3.200	3.100	22.500	32.000	27.250	25
P2M	3.0	3.000	3.000	30.000	28.500	29.250	25
P2M	5.6	5.800	5.700	39.500	40.000	39.750	25
P2M	5.7	6.000	5.850	27.000	26.900	26.950	25
P2M	5.8	6.000	5.900	21.000	23.000	22.000	25
P2T	6.0	6.000	6.000	36.000	36.100	36.050	25
P2T	6.0	6.000	6.000	10.200	29.500	19.850	25
P2T	3.0	3.000	3.000	18.000	18.000	18.000	25
P2T	3.0	3.300	3.150	18.200	18.000	18.100	25
P2T	3.1	3.200	3.150	18.000	18.100	18.050	26
P2T	3.1	3.000	3.050	15.000	15.500	15.250	25
P2T	3.0	3.000	3.000	25.600	25.600	25.600	25
P2T	3.1	3.100	3.100	18.000	20.500	19.250	25
P2T	3.0	3.000	3.000	14.000	13.500	13.750	16
P2T	3.1	3.000	3.050	16.000	16.000	16.000	25
P2T	3.0	3.000	3.000	32.000	32.000	32.000	25

P2T	3.0	3.000	3.000	18.000	17.500	17.750	26
P2T	3.0	3.200	3.100	26.000	26.500	26.250	25
P2T	3.0	3.100	3.050	25.500	26.000	25.750	25
P2T	3.0	3.200	3.100	28.500	28.000	28.250	25
P2T	3.1	3.000	3.050	15.000	14.900	14.950	26
P2T	3.0	3.100	3.050	22.000	22.100	22.050	25
P2T	3.0	3.000	3.000	18.500	18.500	18.500	25
P2T	3.0	3.000	3.000	30.000	30.000	30.000	25
P2T	3.1	3.200	3.150	30.000	30.500	30.250	25
P2T	3.0	3.000	3.000	33.000	30.000	31.500	25
P2T #	3.1	3.200	3.150	23.000	19.000	21.000	25
P2T #	3.0	3.200	3.100	15.200	12.400	13.800	25
P3B	3.0	3.000	3.000	14.000	16.500	15.250	25
P3B	3.0	3.500	3.250	29.000	28.000	28.500	25
P3B	3.0	2.900	2.950	29.000	26.000	27.500	25
P3B	3.0	3.000	3.000	28.700	27.600	28.150	25
P3B	3.0	3.000	3.000	15.000	15.200	15.100	25
P3B	3.1	3.100	3.100	20.500	19.600	20.050	25
P3B	3.0	3.400	3.200	24.700	24.000	24.350	25
P3B	3.3	3.100	3.200	24.500	24.000	24.250	25
P3B	5.7	5.900	5.800	27.200	27.200	27.200	25
P3B	6.0	6.000	6.000	19.600	19.900	19.750	25
P3B	6.0	6.000	6.000	21.100	21.800	21.450	25
P3B	5.8	6.000	5.900	27.600	27.900	27.750	25
P3B	6.0	6.000	6.000	35.600	36.500	36.050	25
P3B	3.0	3.000	3.000	35.000	36.500	35.750	25
P3B	3.5	3.000	3.250	20.000	20.000	20.000	25
P3M	3.0	3.000	3.000	20.500	22.000	21.250	25
P3M	3.0	3.300	3.150	28.000	28.200	28.100	25
P3M	3.0	3.000	3.000	25.700	27.300	26.500	25
P3M	3.0	3.000	3.000	24.600	25.500	25.050	25
P3M	3.6	4.000	3.800	19.500	18.500	19.000	25
P3M	3.2	3.300	3.250	24.500	24.500	24.500	25
P3M	3.0	3.000	3.000	21.500	17.500	19.500	25
P3M	3.0	3.000	3.000	25.600	25.400	25.500	25
P3M	3.4	3.400	3.400	23.900	24.000	23.950	25
P3M	3.0	3.000	3.000	26.000	27.000	26.500	25
P3M	3.5	3.500	3.500	18.000	17.000	17.500	25
P3M	4.0	3.500	3.750	13.000	11.000	12.000	33
P3M	3.0	3.000	3.000	25.000	26.500	25.750	25
P3M	6.0	6.000	6.000	20.000	20.000	20.000	25
P3M	6.0	6.000	6.000	23.500	22.000	22.750	25
P3T	3.0	3.000	3.000	21.000	21.400	21.200	25
P3T	3.0	3.000	3.000	15.800	14.500	15.150	25

P3T	3.0	3.000	3.000	15.000	15.000	15.000	170.00
P3T	3.2	3.000	3.100	17.900	15.900	16.900	258.00
P3T	5.8	5.800	5.800	23.000	22.000	22.500	253.40
P3T	6.0	5.800	5.900	24.000	23.000	23.500	210.00
P3T	3.4	3.300	3.350	18.000	17.300	17.650	256.00
P3T	3.0	3.000	3.000	16.000	17.500	16.750	236.00
P3T	3.0	3.000	3.000	11.000	9.500	10.250	256.00
P3T	3.0	3.000	3.000	18.500	17.000	17.750	256.00
P3T	3.1	3.200	3.150	15.000	16.000	15.500	256.00
P3T	3.0	3.200	3.100	17.400	17.000	17.200	255.00
P3T	3.0	3.200	3.100	15.500	13.500	14.500	254.50
P3T	3.0	3.000	3.000	17.000	14.500	15.750	256.00
P3T	5.0	5.800	5.400	12.000	11.000	11.500	253.00
P3T	5.8	5.500	5.650	21.500	21.400	21.450	253.00
P4B	7.0	7.000	7.000	14.000	13.500	13.750	245.00
P4B	7.0	7.000	7.000	13.500	13.000	13.250	245.00
P4B	7.0	7.000	7.000	28.000	27.000	27.500	245.50
P4B	7.0	7.000	7.000	34.000	35.000	34.500	245.00
P4B	7.0	7.000	7.000	21.500	21.000	21.250	245.50
P4B	7.0	7.000	7.000	14.000	14.400	14.200	245.00
P4B	7.0	7.000	7.000	29.000	28.700	28.850	245.50
P4B	7.0	6.900	6.950	14.800	15.000	14.900	244.90
P4B	7.0	6.900	6.950	14.800	15.000	14.900	244.90
P4B	7.0	6.800	6.900	32.700	33.000	32.850	245.20
P4B	7.0	6.800	6.900	33.000	33.000	33.000	245.00
P4B	3.0	3.500	3.250	23.500	23.000	23.250	245.00
P4B	3.3	3.300	3.300	26.000	26.000	26.000	245.00
P4M	7.0	7.000	7.000	25.000	25.700	25.350	245.00
P4M	7.0	7.200	7.100	11.900	13.000	12.450	245.00
P4M	7.0	7.000	7.000	23.000	22.200	22.600	245.00
P4M	7.0	7.200	7.100	23.400	23.000	23.200	244.90
P4M	7.4	7.200	7.300	15.000	15.800	15.400	244.80
P4M	7.0	7.500	7.250	14.000	13.800	13.900	245.00
P4M	7.0	7.000	7.000	36.700	36.500	36.600	245.00
P4M	3.5	3.400	3.450	14.700	16.000	15.350	245.00
P4M	4.8	3.500	4.150	20.000	20.500	20.250	245.00
P4M	3.5	3.500	3.500	18.000	17.000	17.500	245.00
P4M	3.4	3.500	3.450	22.300	21.000	21.650	246.00
P4M	3.5	3.000	3.250	28.000	27.000	27.500	246.00
P4M	4.0	3.000	3.500	13.000	13.500	13.250	245.00
P4M	3.0	3.500	3.250	26.000	25.700	25.850	245.00
P4T	7.0	6.800	6.900	25.500	26.000	25.750	365.00
P4T	7.2	7.000	7.100	16.500	16.000	16.250	365.00
P4T	7.0	7.000	7.000	21.300	20.000	20.650	366.00

P4T	7.0	7.000	7.000	30.000	30.000	30.000	366.00
P4T	6.9	7.000	6.950	18.000	16.000	17.000	360.00
P4T	6.0	6.000	6.000	17.000	15.500	16.250	253.00
P4T	6.0	6.000	6.000	25.000	25.000	25.000	252.00
P4T	3.5	3.500	3.500	16.500	19.000	17.750	251.00
P4T	3.0	3.200	3.100	11.000	12.000	11.500	251.00
P4T	3.5	3.500	3.500	14.000	14.500	14.250	365.00
P4T	3.5	3.500	3.500	21.000	22.000	21.500	265.00
P4T	3.5	3.500	3.500	20.000	20.000	20.000	366.00
P4T	3.5	3.000	3.250	23.000	21.000	22.000	365.50
P4T	3.0	4.000	3.500	22.000	23.000	22.500	366.00
P4T	3.5	3.000	3.250	16.000	16.600	16.300	366.00
P5B	6.0	6.000	6.000	31.000	30.000	30.500	260.00
P5B	6.0	6.000	6.000	36.400	37.000	36.700	264.00
P5B	6.0	6.000	6.000	25.000	24.000	24.500	262.50
P5B	6.0	6.000	6.000	18.000	18.000	18.000	258.00
P5B	3.3	3.500	3.400	23.000	22.800	22.900	255.90
P5B	3.3	3.500	3.400	26.000	24.000	25.000	262.30
P5B	3.3	3.500	3.400	24.700	26.000	25.350	262.00
P5B	3.5	3.200	3.350	18.200	18.000	18.100	254.80
P5B	3.5	3.500	3.500	19.000	19.000	19.000	261.50
P5B	3.4	3.500	3.450	20.500	19.800	20.150	262.00
P5B	3.5	3.500	3.500	26.500	27.000	26.750	262.00
P5B	3.5	3.100	3.300	24.000	25.000	24.500	261.00
P5B	3.5	3.500	3.500	22.500	22.000	22.250	263.00
P5M	3.0	3.500	3.250	13.500	13.000	13.250	336.00
P5M	3.0	3.000	3.000	11.000	12.500	11.750	334.00
P5M	3.0	3.000	3.000	16.000	16.800	16.400	253.00
P5M	3.0	3.000	3.000	12.000	13.500	12.750	337.00
P5M	3.0	3.000	3.000	26.000	26.000	26.000	336.00
P5M	3.0	3.000	3.000	22.500	22.000	22.250	335.00
P5M	3.4	3.500	3.450	22.500	18.000	20.250	335.00
P5M	3.2	3.000	3.100	17.000	16.500	16.750	270.00
P5M	3.0	3.000	3.000	12.000	10.000	11.000	336.00
P5M	3.0	3.500	3.250	12.500	12.000	12.250	339.00
P5M	3.0	3.400	3.200	15.500	14.000	14.750	360.00
P5M	3.0	3.000	3.000	16.500	16.000	16.250	340.00
P5M	3.5	3.000	3.250	16.000	15.000	15.500	340.00
P5M	5.3	5.500	5.400	20.000	21.000	20.500	373.00
P5M	6.0	6.000	6.000	27.000	27.600	27.300	340.00
P5M	5.5	5.000	5.250	17.500	17.000	17.250	339.00
P5M	6.0	5.800	5.900	29.000	28.000	28.500	254.00
P5M	3.0	3.000	3.000	16.000	14.000	15.000	255.00
P5T	3.1	3.100	3.100	28.200	28.500	28.350	264.00

P5T	5.8	5.800	5.800	21.200	21.500	21.350	263.00
P5T	3.0	3.100	3.050	26.000	26.000	26.000	264.00
P5T	3.0	3.300	3.150	19.000	20.700	19.850	264.00
P5T	3.0	3.000	3.000	17.000	17.000	17.000	263.00
P5T	3.0	3.000	3.000	17.500	16.000	16.750	264.00
P5T	3.1	3.000	3.050	17.500	16.500	17.000	254.00
P5T	5.0	5.500	5.250	27.000	27.000	27.000	338.00
PBR	3.0	3.000	3.000	22.000	22.000	22.000	185.00
PBR	5.5	5.700	5.600	19.500	21.000	20.250	268.00
PBR	6.0	6.000	6.000	19.000	18.500	18.750	265.00
PBR*	3.0	3.000	3.000	22.000	21.500	21.750	241.00
PBR*	3.0	3.000	3.000	22.000	22.000	22.000	185.00
PBR*	3.0	3.000	3.000	22.000	21.500	21.750	205.00
PIM	6.0	6.000	6.000	18.000	18.000	18.000	249.00
PIM	3.0	3.200	3.100	26.000	25.000	25.500	254.00