UNIVERSITY OF EDUCATION, WINNEBA

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MAXIDITE AMANKWAAH MINKAH

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MAXIDITE AMANKWAAH MINKAH

(8131780009)

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JULY, 2016

DECLARATION

STUDENT DECLARATION

I, Maxidite Amankwaah Minkah, declare that this Thesis, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE:…………………………………………………

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SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of Thesis as laid down by the University of Education, Winneba.

NAME OF SUPERVISOR:……………………………………………..........

SIGNATURE:……………………………………………………………

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ABSTRACT

Utilisation of lesser known species (LKS) or lesser used species (LUS) has become a necessity in the face of dwindling prime timber species. This study therefore contributes to utilization of LUS by investigating and determining Machining Characteristics of *Gmelina arborea* grown in Ghana. Four trees were obtained from *G. arborea* plantations in two different locations: Daboase in the Western region and Abofour in the Ashanti region of Ghana. Each tree was sawn into three sections; top, middle and butt. Planing, turning, shaping and sanding tests were conducted on each of the sections. For the planing test, a constant cutting angle of 30° was employed in combination with feed speeds 6m/min, 9m/min and14m/min. Turning test employed spindle speeds of 1000rpm, 1850rpm and 2500rpm.Shaping test was conducted using three different spindle speeds of 4500rpm, 6000rpm and 10000rpm.The sanding test employed three different grit sizes, P80, P100 and P120. Results show that the least feed speed of 6m/min was found to produce the highest rates of acceptable grades for wood specimens from both locations. The spindle speed recording the highest rate of acceptable grades for Daboase wood samples was 1850rpm but 2500rpm for wood samples from Abofour. It was also observed that, 10000rpm produced highest rates of acceptable grades for shaping wood samples from both locations. For wood samples from Daboase, grit size of P100 produced the highest rate of acceptable grades. However, Abofour wood samples produced highest percentage of acceptable grade at grit size P120.The good machining characteristics of *Gmelina arborea*as indicated by this study makes it recommendable for the furniture industry.

CHAPTER ONE

INTRODUCTION

1.1 Justification

Gmelina arborea, an exotic species from the Indo-Burma region of south-east Asia, is a potential source of raw material for the wood industry (Nwoboshi, 1994). It is a deciduous tree 12-30m high and 60-100cm in diameter. *Gmelina arborea* is a fast growing tree which grows in different localities and prefers moist fertile valleys with 750-450mm rainfall. It does not thrive on ill drained soil and remains stunted on dry sandy or poor soils (Wikipedia). With medium density and strength properties, *Gmelina arborea* provides timber for light construction and packing (Akachukwu, 1990). According to Iyamabo (1990), it is similar to and serves the same purpose as Wawa(*Triplochitonscleroxylon*). *Gmelina arborea* wood is suitable for plywood, particle board manufacture, mining prop wood, and telecommunication transmission poles and fuel wood (Akachukwu, 1990).

In Ghana, over 5,000 hectares of *Gmelina arborea* have been established, 2,000 hectares of this number was cultivated by the Subri Industrial Plantations Limited (SIPL) situated at Daboase near Sekondi-Takoradi (Nwobosi, 1994). The Daboase *Gmelina arborea* plantation was to serve as a wood resource base for a proposed paper processing factory in Ghana. However, there were changes in developments leading to the non-establishment of the factory. It was later realized that, the *Gmelina arborea* could be used as timber resource for various applications (F. W Owusu, personal communication, 2006). In spite of this it is not so common on the local timber market due to lack of scientific information on the machining properties of this species. This information would serve as a point of reference whenever it should be used for the various applications like furniture, tool handles and plywood.

1.2 Problem statement

Ghana's high forest zone covered about one-third by area of the country, which is about 8.3 million hectares. The forests are endowed with about 680 trees species among which 126 grow to timber size (Hall & Swaine, 1981). The Food and Agricultural Organization (2006) reported that, Ghana's forest cover in 2005 was estimated at 5.5 million hectares. This implies that about half of the forest is lost. The decline is to a considerable extent due to highly selective exploitation of the prime timber species. These declining species could be replaced with lesser-used species (LUS).

Addae-Mensah and Ayarkwa(1998) studied some machining qualities of selected lesser used timber species in Ghana. In this study, it was concluded that, the high density species have better boring, turning and shaping qualities than the low-density species. The result of the study also indicated that, most of the lesser-used species investigated have promising boring, turning and shaping characteristics to justify their utilization in the furniture and wood working industries. Sofuoglu and Kurtoglu (2013) also reported on some machining properties of 4 wood species grown in Turkey. This work revealed that, sessile oak (*Quercuspetraea*) had an excellent performance for all machining processes. Black poplar (*Populusnigra L.*) yielded the lowest results for the sanding test. Determining the machining characteristics of *Gmelina arborea* is therefore important for making informed decisions on the potential uses of the timber for furniture.

1.3 Aims and objectives of the Study

The aim of this study is to determine the machining characteristics of *Gmelina arborea*. Specifically, the study seeks to determine:

i) Planing characteristics of *Gmelina arborea*

ii) Turning characteristics of *Gmelina arborea*

iii) Shaping characteristics of *Gmelina arborea*

iv) Sanding characteristics of *Gmelina arborea*

1.4 Limitations of the study

- In the turning test, cutting tools used by the Lathe turner did not have the same level of sharpness throughout the experiment. Since the turning process was manually done, it resulted in Lathe turner exerting varying pressure on the mounted test specimens when using the cutting tools.
- Shaping test witnessed varying feed speed/rate and contact pressure of test specimens against cutter blades since the test was conducted manually.
- In the sanding test, the Belt sander operator inadvertently applied varying pressure on the test specimens against the revolving sand paper. Also it was noticed that, there existed variations in the length of time the each sample was made to contact the revolving sand paper.

1.5 Significance of study

This work would serve as a reference document for wood workers and timber industry stakeholders in assessing the suitability *of Gmelina arborea*for furniture and other uses. It would also inform policy makers on the viability of establishing *Gmelina arborea* plantations as a means of augmenting the country’s timber supply in order to reduce the extinction rate of prime timber species.

CHAPTER TWO

LITERATURE REVIEW

Machining properties of wood relates to the behaviour of wood when planed, shaped, turned or put through any other standard wood working operation. Wood in general is easy to cut, shape and fasten unlike metal. In furniture and fixtures, the smoothness and ease with which wood can be worked may be the most important properties. Unless wood machines fairly well and with moderate ease, it is not economically suitable for such uses as furniture regardless of other virtues (Davis, 1962).

Machining is a stress-failure process. It is convenient to analyze machining as the action of cutting tool on a piece of wood work piece with the cutting action that takes place referred to as chip formation, where a portion of the wood called chip is separated from condition of the wood, and the motion of the tool relative to the orientation of the structure of the wood (Hoadley, 1980). By hand or machine power, force is transmitted to the wood by means of cutting tool. The orientation and direction of the force are controlled by the design and by hand of the wood worker. The tool has pertinent geometry and wood has pertinent physical and mechanical properties. The direction of motion and configuration of the tool determine the way the stress develops and is resisted by the wood and therefore the manner of failure or "cutting" that occurs. Two important concepts are hereby observed. One is the idea of sharpness in which the cutting area (A) of the tool will cause stress (P/A) greater than the strength of the wood. The second factor is the condition and properties of the wood, its density, hardness, moisture content, temperature and defects. Depending on one's objective, machining can broadly be classified as:

i) Severing: Making two or more pieces from one. For example, splitting firewood or band sawing rough parts from a plank or cant.

ii) Shaping: Imparting a specific shape to the work piece, in some cases, a flat-planed surface, in others some specific contours.

iii) Surfacing: Creating a surface of prescribed quality for example sanding a surface, planing etc. In some cases, two or even all three of the above are involved concurrently in a woodworking process (Hoadley, 1980).

According to Herbert et al (1984), the lower the density of wood, the easier the wood could be cut with a tool. Dinwoodie (1980) confirmed and indicated that, as the density of wood increases, the blunting time of cutting tools decreases. According to Kollman and Cote (1968), surface quality of wood becomes better of when the wood species is dense, hard and dry. Dinwoodie (1980) also state that, the quality of wood cut is highly dependent on the grain direction and mechanics involved in the chip breakage. Cutting along the grain is said to be more efficient and results in better finish in a quality than cutting against the grain. According to Davis (1938), the rate of feeding specimens during machining is quite independent of species and is chosen in relation to the type of knife and rotation speed of the cutter block, so that the smoothness of the cut is suitable for the end use of the piece. Extremely low feed speeds may actually result in tearing instead of cutting, producing poor finish. Generally low feed speeds are reported to produce better finish during machining than high speeds (Davis, 1938).

2.1.1 Machining Principles

Machining of wood can be grouped under two basic types of machining principles: Orthogonal cutting and peripheral milling (Hoadley, 1980). In orthogonal cutting, the tool edge is more or less perpendicular to its direction of motion and the cut is in a plane parallel to the original surface of the work piece with the removal of continuous chip. An example is the action of hand planer on a piece of wood. Two factors describe the process orthogonal cutting. These are:

i) The angle between the cutting edge of the knife and the cellular grain direction.

ii) The angle between the direction of the cut and grain direction. Based on the two factors, there are three orthogonal cutting processes. These are:

a) 90-0- This is where the cutting edge is perpendicular to the grain of the wood and the edge is parallel to the tool motion.

b) 0-90- Where the cutting angle is parallel to the grain of the wood and the edge is perpendicular to the tool motion.

c) 90-90- Where the cutting angle and the tool motion are perpendicular to the grain of the wood (Hoadley, 1980).

Kollman and Cote (1984), defined peripheral milling as a type in which single chips of wood are formed and removed by the intermittent engagement of knives carried on the periphery of a rotating cutter block with the work piece. The cutting action is modified by the path of each cutting edge which by combined revolution of the cutter head along the surface of the work piece follows a trochoidal path. Each cutting edge takes a curve chip from the work piece (Hoadley, 1980).

2.1.2 Common machining defects

Defects such as raised grain, torn grain, chip grain and chip marks are common in planing of wood (Williston, 1988). Raised grain is an uneven surface of a piece of wood resulting from the hard higher latewood being raised above but still adhering to the soft lower density early wood or raised grain can also be said to be roughened conditions of the surface but not torn loose from it (Hoadley, 1980). Fuzzy grain occurs when small particles, groups of small particles or fibers do not shave clearly in machining but stands up on the general level of the surface. This is normally caused by dull knives, partially dried lumber or improper cutting angle. Chip grain is barely visible surface irregularity caused when particles are chipped or broken off below the line of cut. Torn grain is a type of severe chipped grain that usually occurs around knots or portions of sharp irregular grain direction (location where grain angle abruptly changes, dives or is short) (Williston, 1988). Chip marks are shallow dents in the surface caused by shavings that have clung to the knives instead of passing off in the exhaust as intended. Doubts as to whether a given defect consists of chipped grain or chip marks can easily be resolved by applying a few drops of water and waiting a few minutes. Chipped grain (which consist of dents where the wood is somewhat compressed) will swell as they absorb water and become less conspicuous (Davis, 1962).

2.1.3 Chip formation

Formation and movement of chips during machining is of great importance to the whole process; the stress on the knife or blade as well as the surface quality (Kollman& Cote, 1984). Koch (1964) studying peripheral milling described three distinct types of chips. Franz (1958) confirmed the occurrence of these three basic chip types when milling wood parallel to the grain. He goes on to classify them as follows;

Type I: Formed when cutting conditions are such that the wood splits ahead of the tool by cleavage until failure in bending as a cantilever beam occurs. Failure is usually due to tension perpendicular to the grain.

Type II: Occurs when wood failure in the chips is along a line extending from the cutting edge to work surface. The face of the knife produces more forward compression than upward lifting. Failure occurs as diagonal plane of shear right at the cutting edge.

Type III: Occurs at every small cutting angle when force is transmitted mainly as compression parallel to the grain resulting in shear failures in the wood ahead of the cutting edge.

2.2.0 Planing

Planing has been defined as the peripheral milling of wood to smooth one or more surfaces of the work piece and to bring it to a prescribed thickness (Kollman& Cote, 1984). The two most important factors of planning according to Kollman and Cote (1984) are feed speed and cutting angle. Feed speed is the steady rate at which a piece of wood is introduced into a wood processing machine (ASTM D, 1984). Cutting angle is the angle between the face of the knife and the radial passing through the centre of the rotating cutter heads, or is the angle between the face of the knife and the line perpendicular to the direction of the plane (Hoadley, 1980). The basic requirement of a machining process is quite simply to produce as efficiently as possible, wood of the required dimension, having a quality surface that commensurate with the intended use (Herbert et al, 1984).

2.2.1 Types of planing machines

Regardless of the size of the enterprise, some form of planer is used in virtually every wood working establishment. To satisfy the diverse requirements of the industry, many designs have been evolved. According to Koch (1964), some important types are discussed in the following section.

i) **Single surfacer**

This machine is designed to smooth one side of a work piece and simultaneously reduce it to a predetermined thickness. A schematic design is shown in Fig. 2.1.

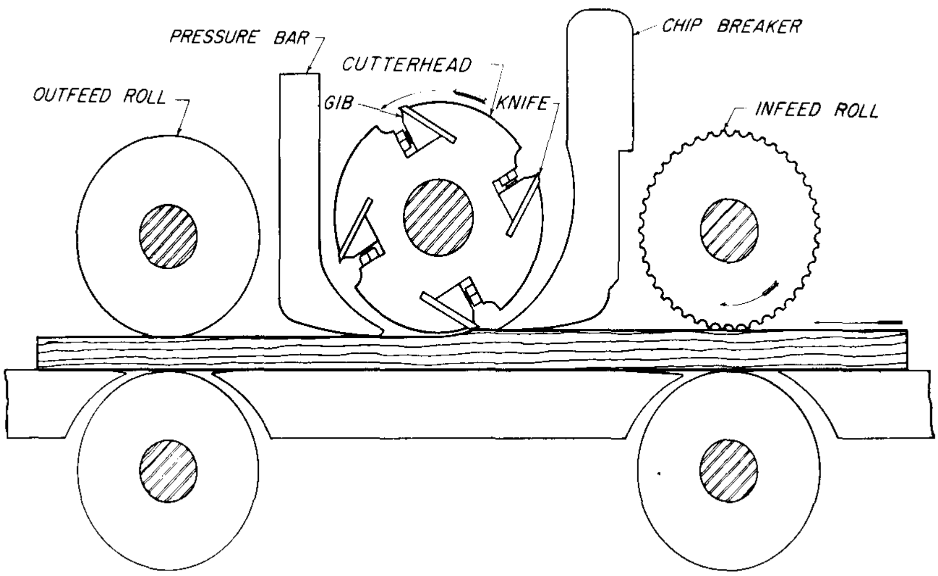


Fig. 2.1 Mode of operation of a planer.

It consists of power feed rolls, chip beaker, cutterhead, pressure bar and a lower platen. When a board enters the planer, it first passes between the two infeed rolls. The upper infeed is adjusted to a point where it holds the wood firmly enough to feed it through the machine without leaving visible corrugation marks on the finished work.

Knives are mounted on the cutter head and the knife action includes splitting as well as cutting. As the knife approaches the end of its cut, the direction of cut becomes slightly up and fine splits often develop just ahead of the knife edge. The function of the chip breaker is to minimize the length of these splits and thus reduce the occurrence of chipped grain on the planed surface. With this objective, the chip breaker is set as close to the cutter head as practical and adjusted to hold the board firmly against the platen without any vibration. The pressure bar is on the exit side of the cutter head. Its function is to prevent any spring up of either end of the board when it leaves the cutter head. This is accomplished by adjusting the pressure bar to hold the board firmly on the table until it reaches the out feed rolls (Davis, 1962)

ii) Double surfacer

This machine has all the basic elements of the single surfacer but in addition to that, it has a second cutter head fixed below the bed. The purpose of a double surface is to smooth both sides of the work piece and simultaneously reduce it to predetermined thickness (Koch, 1964)

iii) Planer and matcher

A planer and a matcher is defined as a double surface that is further equipped with two opposed side heads that can simultaneously machine the two sides of the work piece as the flock flows through the machine. The machine is also equipped with two additional horizontal cutter heads, termed Profile heads. These are capable of machining a pattern or profile on the bottom of the work piece before it leaves the machine (Koch, 1964).

2.2.2 Factors Affecting Surface Quality in Planing

According to Davis (1962), the most important factors that affect the surface quality of planed samples are moisture content, density of the wood, feed rate, cutter head speed, number of knives on the cutter head, cutting angle and depth of cut.

2.2.2.1 Effect of moisture content

According to Kollman and Cote (1984), test results for pine and beechwood remain nearly independent of the moisture content as long as the value lies below the fibre saturation point. If however the moisture content is increased beyond this point, the roughness of the chipped surface is increased. Davis (1962) also stated that, different species were affected in different degrees by the moisture content factor, but in general the best results were obtained at 6 percent moisture content and the poorest results at 20 percent moisture content. With chipped grain, fuzzy grain and raised grain, results at 6 percent or 12 percent moisture content differed little, either one being much better than at 20 percent. Chip marks on the other hand were much less prevalent at 20 percent than any lower moisture content.

2.2.2.2 Effect of density of wood

Koch (1964) stated that, the incidence of defective surfaces increases somewhat with increase in density. Farmer (1972) stated that, some lower density timbers give a wooly surface when planed with the normal 30˚ cutting angle and this is noted against the relevant species.

2.2.2.3 Effect of depth of cut

This is the depth to which the cutting knives enter the wood. Weinig (1986) referred to depth of cut as peak- to- valley height. According to him, this depends upon the pitch and the diameter D, of the cutting circle of the tool. Weinig (1986) calculated the depth of cut from the formula:

$$t = \frac{S_Z^2}{4D}$$

Where Sz is the pitch and D is the diameter of the cutting circle. He stated that good surface finish is a peak- to- valley height in the region of approximately 0.005mm. Tjernlund (1984) noted in his paper on machining Nordic whitewood that best results will be achieved where the depth of the final cut is not less than 1mm and not more than about 2mm. Excessive stock removal (more than 2mm) causes torn grain or pick-up in the timber and also requires more power from the planer (Lavery*et al*, 1995). Trials carried out on fast sitka spruce have indicated that a depth of cut lower than 2mm would result in surfaces that do not produce a tolerable finish (Moloney, 1989).

2.2.2.4 Effect of cutting angle

According to Farmer (1972), the cutting angle is determined by species being planed and the three angles used are 15˚, 20˚ and 30˚. The largest angle is suitable for most species but when interlocked grain is present a reduced angle of 20˚ or even 15˚ may be necessary to avoid picking up of the surface. Davis (1962) stated that, species like oak are not much affected and plane well through a wide range of angles. Hackberry and Willow, on the other hand, may yield three or four times as many defect free samples at the optimum cutting angle as at the poorest one.

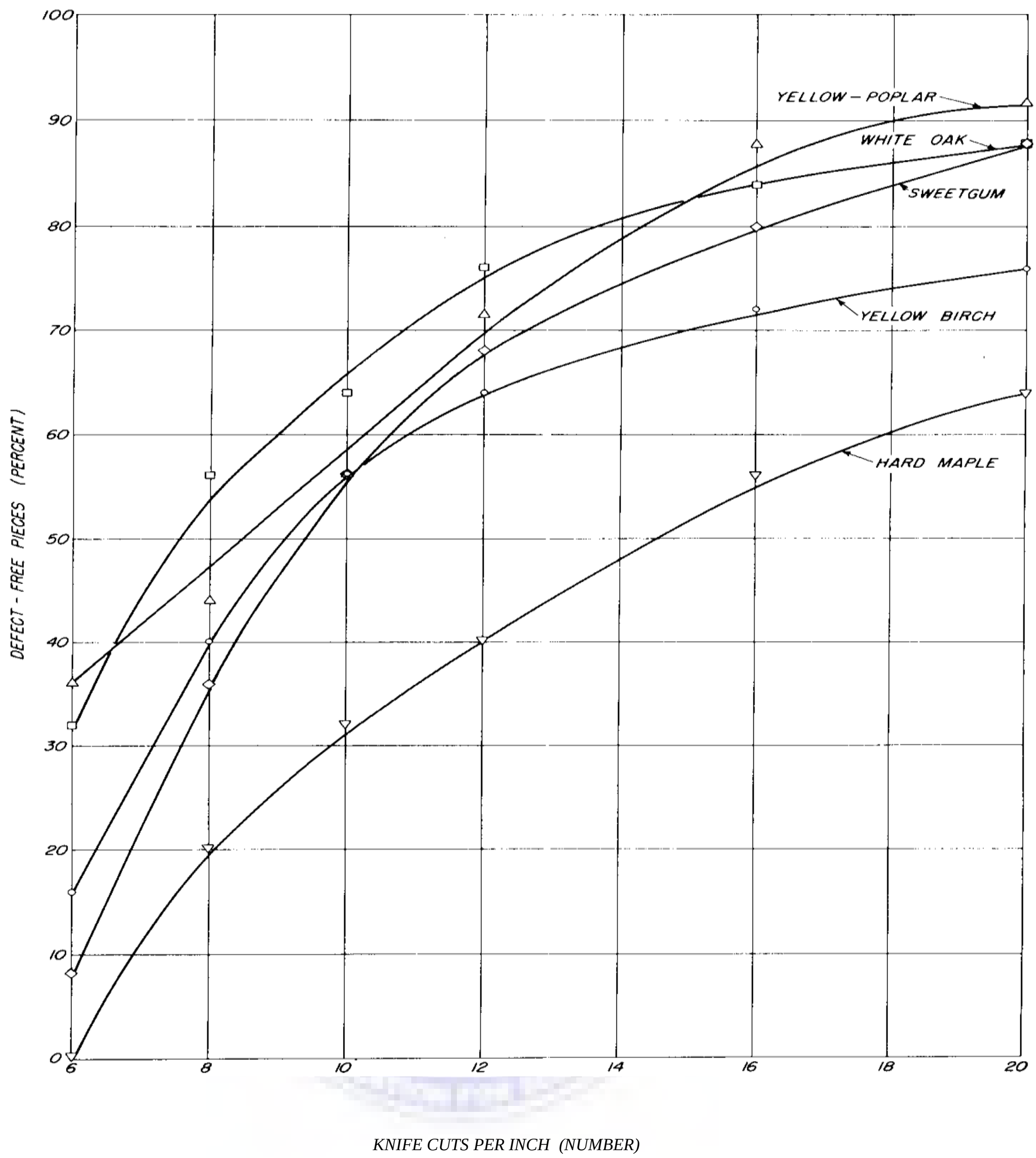
Since it is not practical to change knife angles every few hours with a change of species, Davis (1962) suggested that, a cutting angle that experience and observation have shown to be best suited to a given set of needs should be adopted. He stated that, as a rule, this is 20˚ if the species are hardwoods or largely so and 30˚ if soft woods are the chief raw material. Although angles smaller than 20˚ give good results in some species, they are barely used, because the power required is high and the dulling rate is rapid.

2.2.2.5 Effect of feed rate, cutter head speed and number of knife cuts per centimetre

Koch (1964) pointed out that the quality of planning varies inversely with the square of the feed rate when the cutter head speed, cutting circle diameter and number of knives in the cutterhead remains constant. According to Lavery et al (1995), low feed speeds produced both good and poor quality finishes depending on other combinations of factors. Work conducted by Davis (1962) proved that the number of knife cuts per centimetre is the chief factor affecting quality of work. He gave a formula for the number of knife cuts per centimetre as

$$\text{Knife cuts per cm} = \frac{rpm\ of\ cutterhead\ x\ number\ of\ knives\ in\ head}{feed\ rate\ in\ metres\ per\ \min x\ 100}$$

Considerable variation in degree to which different species are affected was shown in the work done by Davis (1962) as seen in Fig. 2.2.



SOURCE: DAVIS (1964)

Fig. 2.2. Effect of number of knife marks per inch upon quality of finish

2.2.3 Rotating Cutter Head and Its Limitations

The rotating cutter head can be as short as 10cm and as long as 122cm depending on the width of stock to be handled and can even be longer in special applications. The cutter head diameter depends on the number of knives to be fitted and ranges from a minimum of 7.6cm to a maximum of 30.5cm. Cutter heads may carry only one knife (with a balancing knife blank) or as many as 20 knives (Koch, 1964).

The number of knives is limited by the mechanical difficulty of fitting them within a given cutting circle. The cutting circle is also limited by space considerations and secondly by the centrifugal forces involved at cutter head speeds. The cutter head rpm is limited by the present inability to point multiple knife heads at speeds much above 3600rpm. This probably results from excessive and varying knife deflections at high speed.

Cutters generally may be low carbon alloyed steel, high speed steel, tungsten carbide (either solid, tipped or faced). It has been stated earlier, that when a cutter strikes the wood during it circular path it will leave a mark. Theoretically, as the number of cutters is increased in a block, the surface will cut more easily (small chips) and the distance between cutter mark peaks (pitch) will be closer, resulting in a finer/ smoother finish. This should also allow for a greater feed speed than a block with fewer cutters.

However, these factors will only be achieved if each cutter knife traces precisely the same cutting circle. In practice, many multi- cutter blocks very often have one knife doing all of the cutting due to uneven honing/grinding. Some machines have tracking or ‘jointing’ mechanisms fitted so that final grinding can be done while the cutters are in the revolving block. Even where this has been done any wear in machine spindle bearings may affect the cutting circle balance and variations may occur when the pressure of wood as it is being machined causes movement in the block/spindle bearings which may not have been present when the tracking/jointing process was taking place. It does not mean that the desirability of all cutters in the block leaving their mark on the wood should be abandoned. Further, even attempt should be directed towards achieving a common cutters circle for each cutter. Even in a situation of one cutter leaving its mark (known as one knife finishing) the pitch may be varied to give a satisfactory finish through the adjustment of the variables of feed speed, number of cutters set to an identifiable circle, and the revolutions/min of the cutter block. Using the cutter mark mode of grading surface finish, in general terms, finishes of 8-12 marks per inch or 200-300 marks/mm are acceptable for non-joinery purposes and that which is external and painted whereas interior painted work requires approximately 18 marks and hardwood joinery and furniture accepting clear / glazed finishes will require up to 24 marks prior to final preparatory process (Clayton, 1974; Sherlock, 1973).

It is clear that the cutter care and setting are important aspect of achieving desired surface finish. The cutting edge must be sharp and maintained so as long as possible throughout machining runs. The harder steels and tungsten carbides will retain this edge for longer periods than others. A sharp edge will result in the most economic use of power per unit length of machined wood. A clearance angle is required at all times and generally varies from 10˚- 15˚. If this angle is not present local compression of fibres will occur and this will result in uneven surface finish as it tends to rise later. Therefore it is important during final honing of the edges that the formation of a ‘land’ is avoided i.e. a second and flatter bevel behind the edge. Research has shown that where the land exceeds 0.15mm, surface finish will be affected because local to the ‘land’ no clearance angle exists.

2.2.3.1 Cutter knife geometry

i) Cutting angle or front rake angle

This refers to the angle created between the rake of the cutter knife and centre axis of the cutter block. The rake angle will vary relative to the properties of the timber being machined e.g. softwood or hardwood and the variability within these categories, because of wide area of usage the range extends in the case of softwoods from 27˚-35˚ and in the case of hardwoods from 15˚-25˚.

ii) Bevel angle or lip angle

The bevel angle is that which is formed to give the cutting edge on the knife and extends from cutting face via cutter thickness to back face. The bevel angle should be a minimum of 35˚ and preferably be greater; otherwise the support for the cutting edge may be insufficient to provide durability against damage relative to the machinability of the particular timber (Tjerulund, 1984).

iii) Clearance angle

This angle is formed by the line (tangential to the cutter block) of the timber being processed and the bevel angle of the cutting knife as it strikes. The size of the clearance angle will not affect the machining result to any noticeable degree. However, for obvious reasons it must be present, as indirectly it has a bearing on the life of the cutter edge, because for a particular cutting angle it will determine the bevel angle. A common and satisfactory clearance angle is 10˚-15˚(Tjerulund, 1984).

2.2.4 Tool wear

The sharpness or lack of sharpness (dulling) of the cutter/ knife edge is a significant factor on the surface quality of the finished work piece and the related efficiency of the cutting action of chip removal and the consumption of electrical power associated with same. The cutting edge is defined by Voskrensenkii (1955) as follows: "The edge is geometrically the transitional curved surface which connects the surfaces of the leading and the trailing faces of the tool".

In practice the work falls on the edge or cutting edge of the knife or cutter. Test results have shown that the cutting force proper (serving or separation action) as distinct from the formation factor (i.e. the breaking up or deformation of the chip following initial cutting action), is independent of chip thickness but is largely dependent on knife sharpness (Kivimaa, 1950).This unit is inevitable as the area surface of the cutting edge penetrating the wood per width of the unit area will continue to increase with the rounding or dulling of the edge. Voskrensenkii (1955), based on the theory of Prof. M.A. Deskovol, claims that the dulling process follows the initial fracture of the cutting edge. This is due to stress in the section caused by resistance to the bending of the tool to the resistance of the wood against the cutting action. The model used to prove this fracturing is that of a cantilever beam with a triangular contour having a load with a concentrated force of finite magnitude acting at the very end of the beam at the vertex of the triangle. Such loading is impossible as finitely great stresses will develop at the end. Failure will result a fractional distance back from the point or edge. Fracturing of this scale (which is finite) will not occur again as the new edge tends to round with subsequent wear and thickness offers sufficient resistance to fracture.

It is considered practically impossible to achieve a value of cutting factor, associated with the knife edge, which will be the equivalent of zero. Research has shown that in a comparison of three different cutter materials namely; low alloyed carbon steel, high speed steel and tungsten carbide, it was found that a higher initial degree of sharpness of the first two was greater than that for tungsten carbide (Kivimaa, 1950). It was also shown that initial sharpness was short lived and dependent on the species being planed, ranging from 150m to 300m of linear work. After that point the term “work sharp” is used to define the cutter edge condition. The ‘work sharp’ condition deteriorates much more slowly depending on the wood species and the cutter material. While tungsten carbide has a lower initial degree of sharpness, its ‘work sharp’ quality is far superior to that of other materials in dealing with the most abrasive of woods e.g. teak, (Kivimaa, 1950).

In dulling tests carried out by Kivimaa, (1950) on birch wood over a linear travel of 2000m using cutter knife materials namely, low alloyed carbon steel, high speed steel, and tungsten carbide, the following edge conditions were observed as shown in Fig. 2.3.

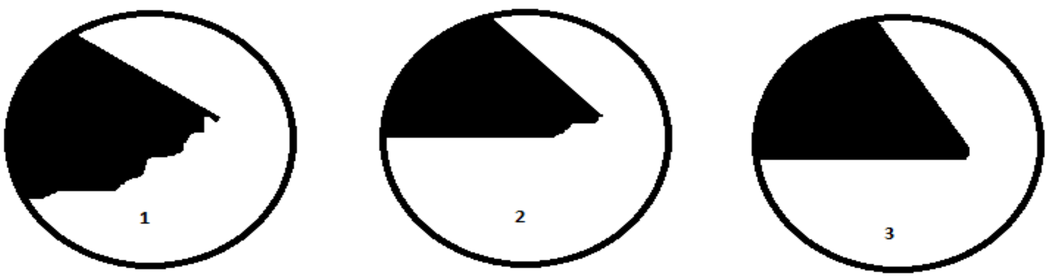


Fig. 2.3. Cross section of cutting edge (1) low alloyed carbon steel, (2) high speed steel and (3) tungsten carbide. Magnification 300x.

Source: Kivimaa, (1950)

The sharpness which can be achieved on a cutter edge is very much dependent on the fineness of structure of the cutter material. The retention of the cutter edge sharpness for longer periods depends on the basic properties of the raw material. The third factor is concerned with the wood species and inherent elements such as moisture content, specific gravity, hardness and frequency of knots and presence of extractives i.e. silica. A further consideration is the sharpening/grinding process/honing process by which the edge is prepared. Overheating may result in affecting the temper of the material. Kivimaa, (1956) found evidence of a tendency for carbon steel cutter knife to overheat during regrinding unless extreme care was taken. It is possible that the heat generated during the planing process may result in accelerated wear in a situation where some overheating affecting temper has already taken place during the grinding process (but which is not immediately visible to the human eye). However, it is also possible that a knife, even where considered to be faultless initially, when it has become excessively dull, can result in a situation during working, whereby the heat generated exceeds its thermal resistance. The "burning" which occurs can clearly be seen in the area around the edge as patches of discolouration. It is rare for the discolouration to include the whole edge area. If the clearance angle is insufficient, local heat may build up during planing and affect the temper with a resultant loss of hardness. Overheating during the planing process is generally associated with processing hardwoods such as teak (very abrasive due to presence of silica) and not common with softwoods.

A ground edge sharpness without honing or jointing will tend to leave a burr on an edge with minute defects or gaps which will contribute to an acceleration of the dulling process. Such minute flaws may provide initial locations for corrosive action in high moisture content processing.

Research by Hillis & McKenzie, (1964) and McKenzie & McCombe (1968) has shown that corrosion may significantly accelerate cutter edge wear when processing green wood. The wet wood provides an acidic environment for accelerating the cutter wear by corrosion. Experiments with a veneer cutter showed a highly significant reduction of wear by applying a potential (electric) to the knife. It follows that the wear of the cutter in wood processing is electrochemical. It also, as stated earlier, requires more power to machine wet wood. Generally, cutters wear increases as the moisture content of the wood increases.

2.3 Turning

The wood lathe is the common machine used in wood turning. It is one of the oldest types of power equipment used to fashion wooden objects. The lathe machine and its basic parts are shown in Fig. 2.4.

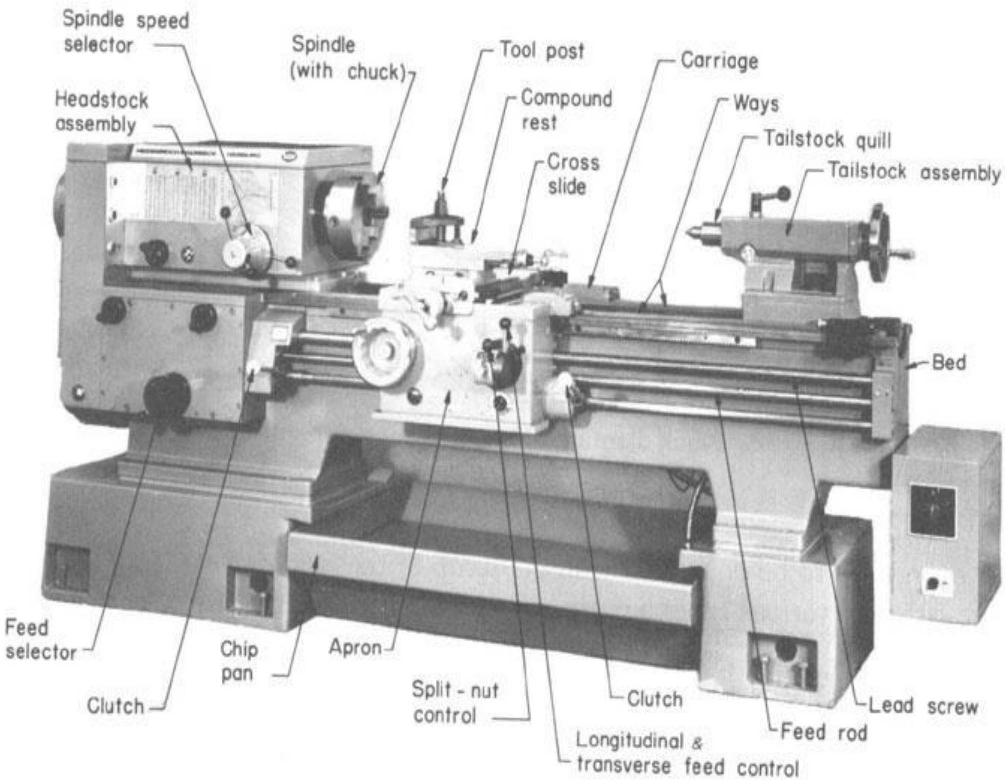


Fig. 2.4 A 12-inch variable speed wood turning lathe

2.3.1 Major machine types and their applications.

i) Tool-point type

This family of designs is characterized by a cutting arrangement in which the work piece revolves between centres at a speed in order of 2000 to 6000rpm and the rigid narrow tool is presented at the desired angle (Koch, 1964). A hand lathe is the simplest configuration of this type. The tool in this case is a hand chisel. Primary tool motion is transverse i.e. parallel to the axis of work piece rotation. A secondary motion involves crossfed, i.e. a motion that brings the tool point closer or further away from the axis of the work piece rotation in such a manner that the work piece diameter is decreased or increased.

Koch (1964) observed that, if the spindle speed is 3600rpm and work piece diameter is 5.4cm then the cutting velocity is approximately 609.6m/min. It is evident that by combining transverse and cross motion of the tool, any desired profile that is round in cross section can be generated with this type of lathe.

ii) Long knife type

The finishing cut on a lathe of this type is produced by the action of a milled-to-pattern knife having the same length as the work piece. The formed, long knife is presented to the rotating log. Almost all the designs require that the blank work piece, in the form of a rough square, be first turned to dowel shape and then continued to approximately 0.05cm oversize before the long knife takes its finishing cut.

iii) Peripheral milling type

In contrast with the machine designs discussed in the foregoing paragraphs, wherein one or more tool points or wide knives are guided against a rapidly rotating work piece, the peripheral milling type relies on a multi-knife, rapidly rotating cutter head brought into cutting action with the slowly rotating work piece. The axis of rotation of the work piece, and the distance between them can be adjusted to bring the cutter head and work piece into contact (Koch, 1964).

iv) Chucking type

This design is distinguished by the fact that the knives revolve around the non-rotating work piece. Factors to be considered in turning tests are as below:

2.3.2 Factors Affecting the Quality of Turned Surfaces

Kollman and Cote (1984) stated that, in the evaluation and application of most turned wood articles, the quality of the surface is of the utmost importance e.g. bobbins, tool handles, sporting goods and furniture parts etc. According to Kollman and Cote (1984), the roughness decreases with increasing cutting speed. The roughness perpendicular to the grain increases in a parabolic manner with the feed speed. Davis (1962) evaluated the machinability of a number of hardwoods in the area of turning. He used a milled-to-pattern knife presented to the work piece in a manner similar to that employed on a back knife lathe. Knife angle and feed speed were not specified. Tests made at four spindle speeds ranging from 950 to 3300 rpm showed that the higher spindle speeds gave better results. Six of the seventy poorest turning woods namely aspen, gumbo-limbo, cotton wood, basswood, willow and buckeys were the lightest wood species tested; but no consistent relationship between the relative density of wood and its turning qualities was established. Davis (1962) work revealed that the species tested turned equally well at 6 and 12 percent moisture contents. As moisture content was increased to 20 percent the quality of the turning decreased markedly. From the same work conducted by Davis (1962), no relationship was observed between number of annual growth rings per centimetre and turning quality.

2.4 Shaping

Shaping is chiefly done in the furniture industry. The commonest is the cutting of patterns on some curved edge like that of a round table. There are power-feed automatic shapers, but the most common type is the spindle moulders (Addae-Mensah & Ayarkwa, 1998). Furniture shapes comes in many forms. A Band saw is used to saw the shape before being shaped using the Spindle moulders. Sometimes Jigs are prepared before producing various shapes. Shaping machine, which is chiefly used in the furniture industry, are used for straight-line cuts as in mouldings, but its distinctive use is to cut a pattern on some curved edge, like that of a round table top (Owusu & Ayarkwa, 2011). Davis (1962) reports that the most common type of power-feed automatic shapers is the spindle shaping machine, which may have either one or two vertical spindles on which one-piece cutters held in collars are mounted. Spindle shapers are typically hand –feed machines, although power-feed attachments are available on the market. Cutter head speed has little influence between 3,600 rpm and 7,200 rpm but if trade opinion is right, it would be significant between 7,200 rpm and 15,000 rpm (Davis, 1962).

2.5 Sanding

The oldest and best-known coated abrasive is the familiar “sand-paper”, in which the mineral is quartz. In industrial woodworking, at least, quartz has now been very largely replaced by garnet and aluminum oxide. In spite of this change, “sanding” remains the accepted term for the use of coated abrasives in finishing wood, and the machines that do the job are termed “sander” (Davis, 1962). Sanding is sometimes done to remedy a slight mismatch where different parts of a finished product join, such as the vertical and horizontal members in a solid door or the sides and front of a drawer. Sanding which is one of the more 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 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 wood working 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 application of finishes. Furniture, fixtures, cabinets, millwork and many minor hardwood products are sanded in the course of manufacturing. Several types of sanding machines are available, some of which are highly specialized for turnings, mouldings, contours and edges. The great bulk of sanding however is mostly done using the hand type and belt sander, which is an electrically powered machine. Several different abrasives are used in sanding wood. These are known as “grits” in the wood working trade and it comes in many sizes that are course, fine, grit one, grit two and so on. All are of crystalline structure and smoothen the wood by the cutting action of their innumerable sharp corners and edges. Under the microscope, the sander dust produced by machine sanding is seen to consist largely of relatively long narrow shreds (Davis, 1962). The smoothness of a sanded material depends mainly on the size, shape and quality of the particles of grit and on the speed of sander and work piece (Kollman & Cote, 1968)

2.4 The *Gmelina arborea* plant

2.4.1 Description

It is a deciduous tree 12-30m high and 60-100 cm in diameter. The bark is light gray-yellow, smooth, thin, somewhat corking, becoming brown and rough: twigs are stout, often slightly 4-angled. Leaves are opposite, broadly ovate, 10-20 cm long, 7-13 cm wide, base with 2-4 glands beneath, acuminate, entire, with 3 or 5 main veins from near the base and 2-5 pairs of side veins, underneath velvety with yellow brown hairs. Petiole is 5-12 cm long, and hairy. Cymes paniculate at ends of twigs, 15-30 cm long, branched, densely hairy. The flowers are many, short stalked, nodding, 4 cm long, densely hairy. Calyx is bell shaped, 5mm long, 5-toothed; corolla is bright orange-yellow or brownish-yellow, with short narrow tube, 2- lipped; stamens are 4 in 2 pairs inserted near base of tube. Pistil is with elliptical 4-celled ovary having 1 ovule in each cell. Stigma is often slightly 2-4-forked. Drupes are ovate or pyriform, 2-2.5 cm long, smooth, becoming orange-yellow, pulpy, with large egg-shaped stone, having 1-4 cells. Seeds produced are usually 1-4 (Little, 1983).

2.4.2 Distribution

Gmelina is native to tropical moist forest from India, Burma, and Sri Lanka to southern china. It is widely introduced in Brazil, Gambia, Honduras, Ivory Coast, Malaysia, Malawi, Nigeria, Panama, Philippines, and Sierra Leone (Duke, 1983). In

Ghana, over 5,000 hectares have been established, out of which 2,000 hectares was by the Subri Industrial Plantations Limited, Daboase near Sekondi-Takoradi (Nwoboshi, 1994).

2.4.3 Ecology

Gmelina grows well in the range of Tropical Very Dry to Wet through Subtropical Very Dry to Wet Forest Life Zones. It is also reported or estimated to tolerate annual precipitation of 7 to 45 dm (NAS, 1980a), annual temperature of 20 to 26˚C, and pH of 6 to 8. It can also tolerate a 6-7 month dry season and grows on many soils, acidic laterites to calcareous loams, doing poorly on thin poor soils with hardpan, dry sands, or heavily leached acidic soils, well-drained basic alluviums (Duke,1983)

2.4.4 Cultivation.

According to Duke (1983), seeds retain their viability for only 12 months and will benefit from soaking if rain or irrigation is not expected. Direct seeding is cheap but tubed seedlings are also outplanted, sometimes intercropped with beans, cashew, corn, peanuts and tobacco. For fuel wood, spacing at 2 x 2 m is recommended, but wider spacing for timber plantations. For the first year or so, weeding is necessary, but the canopy is soon dense, like litter layer, quickly arresting the weed growth.

2.4.5 Energy

Destructive distillation of the wood yields 31.8% charcoal, 47.1% total distillate, 37.1% pyroligneous acid, 10.0% tar, 2.4% pitch, and losses, 4.47% acids, 3.42% esters, 2.38% acetone, and 1.28% methanol on a dry weight basis. The non-condensable gases (1.88 ft^3/Ib) contains 59% CO_2, 31.75% CO, 4.5% methane, 4.15% H, and 0.6% unsaturated hydrocarbons. Many of these have energetic potential (C.S.I.R., 1948-1976). Reynolds and Lawson (1978) concluded that the heating value of Gmelina wood was less than that from the local eucalyptus. Although the calorific values of the samples studied were almost identical (4.53 mcal/kg and 4.54 mcal/kg respectively), the DM contents were 45 and 56%. The fresh weight of Gmelina firewood brought in cubic-meter lots was significantly correlated with the butt size. The NAS (1980a) suggests 4.8mcal/kg for the sapwood, specific gravity of 0.42-0.64. The charcoal burns well, without smoke, leaving a lot of ash. The wealth of India (C.S.I.R., 1948-1976) puts the calorific value at 4.763 mcal (8.547 BTU) with silica free ash of 1.54%. In a 10-year old Philippine stand, the above ground biomass was 127 MT/ha, leaf biomass was 1.4 MT, leaf litter ca 5.2 MT, constituting ca 62% of the total litter. Annual productivity was 18 MT/ha. Annual stem increment was about 10 MT/ha or 30 M^3/ha, little influenced by the age of the stand over the first 15 years (Kawahara et al, 1981). Akachuku's data (1981) show annual yields of 20-50m^3/ha/yr but he cites other studies on poor sandy soil yielding only 7, on laterites only 18; on the best of savanna sites 25, on rainforest sites 31-36, on Malaysia sites 28-38 and on philipine sites 36sm^3. MAI in 7-year trees was 32m^3 (15MT) to 47m^3 (23MT)/ha (Akachuku, 1981).

2.4.6 Biotic Factors

Cattle may eat the foliage and bark; seeds and foliage are consumed avidly by rabbits and deer. In Latin America, the leaves are gathered by the leaf-cutter ants. In India, other insects may defoliate the plant. Calopepla may defoliate, while the borers, Diahamnus and Alicide, may damage trees. The "machete disease", *Ceratocystisfimbriata*, is sometimes severe in moister climates. *Poriarhizomorpha* may cause stem and root diseases in wet situations with heavy soils. Browne (1968) lists the following as affecting *Gmelinaarborea*; (Fungi) *Armillariamellea, Cercosporaranjita, Fomesroseus, Polyporusbaudni,* *Poriarhizomorpha,Sclerotiniarolfsii, Trametesstraminea.* (Angiospermae) *Tapinanthus sp.* (Mollusca) *Limicolaria aurora*. (Myriapoda) *Odontopyge sp*. (Coleoptera) *Alcidodesludificator, Apionangulicolle, A.armipes, Apophylliachloroptera, A. sulcata, Calopeplaleayana, Dihammuscervinus, Empecamentacalabarica, Lagriavillosa, Lixuscamerunus, L. spinimanus, Macrocomacandens, podagricadilecta, Priopterapunctipennis, Xyleborus fornicates*. (Hemiptera)*Agaeuspavimentatus,Anoplocnemistristator, Chunrocerusniveosparus, Dysdercussuperstitiosus, Tingisbeesoni,Triozafletcheri*. (Isoptera) *Coptotermescurvignathus, C. niger, Macrotermes goliath.* (Lepidoptera) *Acrocercopstelestis, Endoclitaundulifer, Eupterote geminate, E. undata, Evergestisaureolalis, Gonodontisclelia, Indarbelaquadrinotata, Metanastriahyrtaca, Phostriacaniusalis, Psilogrammamenephron, Sahyadrassusmalabaricus, Selepaceltis, Xyleutes ceramic.* (Orthoptera) *Heteropternisthoracica, Kraussariaangulifera, Phaneroptera nana*, *Phymateusviridipes, Zonoceruselegans*. (Mammalia) *Axis axis, Strepsicerosstrepsiceros, Sylvicarpagrimmia, Thryonomysswinderianus, Tragelaphusscriptus*. (Duke, 1983).

2.4 Uses

The wood is one of the best timbers of the tropics, useful for particle board, plywood core stock, pit props, matches, and saw timber for light construction, furniture, general carpentry, and packaging. Also used in carriages, carvings, musical instruments, and ornamental work. Graveyard tests indicate that the untreated timber may last 15 years in contact with the soil. With pulping properties superior to most hardwood pulps, Gmelina has been planted by millions, e.g. in the Rio Jari region of Brazil to feed a 750 MT/day kraft pulp mill. In Gambia there are dual purpose plantings, for firewood and for honey. It is often planted as an ornamental avenue shade tree. The wood makes a fairly good charcoal (Duke, 1983). According to Little (1983), the leaves are harvested for fodder for animals and silkworms; the bittersweet fruits were once consumed by humans.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 Project Site

The research was conducted at the Timber Engineering Wood Workshop of the CSIR - Forestry Research Institute of Ghana (FORIG). This is because the workshop is well equipped with the required machines and equipment necessary for a variety of machining operations that are necessary in commercial manufacturing practice. CSIR - FORIG had the required personnel to aid and assist in carrying out the various operations and also had a well-stocked library for making references.

3.1.2 Equipment for the study

- Chain saw machine- this was used for felling the *Gmelina arborea* trees and cross-cutting the logs into lengths of about 2.5m.
- Wood mizer- was used to mill the 2.5mlogs into lumber of thickness of about 2.6cm.
- Rip saw machine- for ripping the lumber into required sample sizes.
- Planer machine- used in planing the test samples.
- Tape measure - for taking measurements.
- Nose mask- for protecting nose during machining.
- Indelible pencil- for coding the test samples.
- Goggles- used for the protection of the eyes during rip sawing and machining.
- Moisture meter- for taking moisture content readings of the boards.
- Electronic callipers- for taking accurate measurements of samples.
- Wheel barrow- for the movement of test materials from one machine to another.
- Lathe machine- used for turning the test samples.

- Spindle moulding machine- for conducting the shaping test.
- Wood boring machine- for conducting wood boring test.
- Belt sander- for performing sanding quality test.
- Electric oven – for oven drying wood specimens

3.1.4 Material selection

Four trees were obtained from *Gmelina arborea* plantations owned by Plantation Socfinaf Ghana Limited (PSGL), formerly Subri Industrial Plantations (SIPL). The plantation is situated in Daboase, the capital of the Mpohor / Wassa east district in the Western region of Ghana and was established in 1977. Daboase lies in 5° 7' 60" North and 1° 39' 0" West in DMS (Degrees, Minutes, Seconds). It is about 27km from the Western Regional Capital, Sekondi - Takoradi and lies in the Wet Evergreen Forest Zone with average annual rainfall of 1500mm. Trees obtained from Daboase had a diameter range of 41.5cm – 56.7cm at breast height. Soils from this location are classified as Nta – Ofin series. Gleyic Arenosol (nta series) consist of yellowish brown, brown or light grey, imperfectly to somewhat poorly drained coarse sand or loamy coarse sands developed in transported hill wash material on gentle lower slopes of 2-5%. They have slow internal drainage, slow run-off, rapid permeability and very low water holding capacity. Ofin series (Stagni-Dysteric Gleysol); are grey to light brownish grey, poorly to very poorly drained alluvial coarse sands or stratified sands and clays developed within nearly flat but narrow valley bottoms along streams. They have slow internal drainage, very slow run-off, very rapid permeability and very low water holding capacity (Senayah, 1996; Adjei-Gyapong & Asiamah, 2002).

The second group of four *Gmelina arborea* trees was cut from CSIR – FORIG research plot at Abofour which is situated in Offinso in the Ashanti Region of Ghana and was established in 1975. Its geographical coordinates are 7° 8' 0" North and 1° 45' 0"

West. It is about 60km from Kumasi, the capital of the Ashanti Region of Ghana and lies in the Semi deciduous rainforest zone with average annual rainfall of 1400mm. Trees obtained from Abofour had a diameter range of 42.0cm – 62.5.0cm at breast height.Soils from this location are classified as Kumasi series (Upland soils) and referred to as Orthi- Ferric Acrisol. These are soils developed over cape coast granites. They are red in colour, well drained (Kumasi series) and yellowish-red to moderately well drained (Asuansi series, quartz gravelly with ironstone, concretionary, sandy to gritty clay loams found on summits upper and middle slopes (3-10%) (Adu, 1992).

3.1.5 Material Preparation

Trees from plantation in each zone were crosscut into three sections: top, middle and butt using a chainsaw machine. Each section measured 2.5m and was labelled accordingly. The resulting *Gmelina arborea* logs were conveyed to the CSIR-FORIG at Fomesua for further processing. A narrow bandsaw wood mizer was used to saw each of the logs into pieces of boards of thickness 2.6cm. The boards were stacked at a drying shed for air drying. The moisture content of the lumber pieces was measured randomly at regular intervals of every fourteen days. Three moisture readings were taken from each of the randomly selected lumber (the two ends and middle). This was done with the aid of a moisture meter until low moisture content was attained. The dried samples were then rip-sawn into dimensions in accordance with ASTM D 1666-64 (1976) for the planing, turning, shaping and sanding tests. The material collection and preparation process is shown in Figure 3.1-3.5 .

Figure 3.1 Picture of scenery of Abofour Gmelina plantation.

Figure 3.2 Picture of Chainsaw operator crosscutting a tree into three logs each of length 2.5m.

Figure 3.3 Picture of labelled 2.5m logs loaded onto a mini truck.

Figure 3.4 Picture of logs being sawn into boards.

Figure 3.5 Picture of stacked boards from Daboase and Abofour under a shed to be air dried.

3.2 Methods

3.2.1Determination of oven dry density

Fifteen *Gmelina arborea* specimens of dimension 20mm x 20mm x20mm were sawn out from each section of *Gmelina arborea* logs obtained from Daboase and Abofour using AGS Wadkin cross cutting machine. Specimens were then left in a Genlab electric oven at 104°Cfor 4 days. Mass of each oven dry specimens was determined by use of an electronic balance model WT10002N of precision 0.01_{g} as $M_{(g)}$. Average oven dry mass for each section $M_{av(g)}$were determined. Dimension of oven dry specimens were determined using an electronic venier calliper. The oven dry volume ($V_{(cm^3)}$) for each specimen was determined and average oven dry volume $V_{av(cm^3)}$ for specimens from each section determined. The average oven dry density $D_{av(kgm^{-3})}$ for each section was determined from the relation;

$$D_{av(kgm^{-3})} = \frac{M_{av(g)} \text{ x } 1000}{V_{av(cm^3)}}$$

3.3.2 Determination of moisture content at test

Fifteen *Gmelina arborea* specimens of dimension 20mm x 20mm x 20mm were sawn out from each section of *Gmelina arborea* logs obtained from Daboase and Abofour by means of AGS Wadkin cross cutting machine. The initial mass M_w of each specimen was determined using an electronic balance model WT10002N of precision, 0.01g. Weighed specimens were then oven dried for 104°C for 4 days. Mass M_o of each oven dried specimens was determined using an electronic balance. The average initial and oven dry masses i.e. M_{wav} and M_{oav} respectively were determined for each section. Average moisture content for each section M_{tav} was determined from the relation;

$$M_{tav} = \frac{M_{wav} - M_{oav}}{M_{oav}} \times 100\%$$

Moisture content and oven dry density of *Gmelina arborea* were determined in accordance with BS 373.

3.2.3 Planing quality test

A two knife-combined surfacing and thicknessing wood planer machine type 610 x 230mm "D.A.A" was used in this study. The dimension of the samples was20mm x 100mm x 900mm. The prepared samples were grouped according the section of the tree and location from which they were obtained. Different operations and adjustments of the planer speeds were used to determine the planing characteristics of *Gmelina arborea*. Three feed speeds (F1= 6m/min, F2= 9m/min and F3= 14m/min) were employed in this study, each coupled with a cutting angle C of 30˚. This resulted in three operational activities as shown below. Fifteen specimens from each tree section passed through each planer operation as illustrated below:

1. CF1 = 15
2. CF2 = 15
3. CF3 = 15

Total number of samples used for each location are = 15 x 3 x 3 =135

For each operation, 15 selected specimens were made to pass through the planer machine of which 2.0mm thickness of wood shavings (chippings) were removed from samples using a single surface and planing machine. This operation was repeated for the other face of the sample. Specimens were labelled for easy identification as it comes out of the planer machine. These were visually evaluated and graded on a scale of 1 – 5(Figure 3.7). The percentage excellent and good specimens for each tree section were then estimated. The planing process is illustrated in Figure 3.6 and 3.7.

Fig.3.6 A Picture of wood workers sawing boards into required sample sizes using the cross cut machine

Figure 3.7 A picture of wood specimen being planed.

Figure 3.8 A Picture showing visual grading of planed specimen.

3.2.4 Turning quality test

A Mini MaxT124 lathe machine was used for this part of the study. Dimension of the test specimen measured 20mm x 20mm x 125mm. The wood lathe machine employed had a maximum spindle speed of 2500rpm. In all 135wood specimens were prepared from logs extracted from each location. This comprises 45specimens each from the top, middle and butt. The study was conducted using three turning speeds of 2500rpm, 1850rpm and 1000rpm. Fifteen specimens from each of the sections were turned using each of the spindle speeds. Test specimen were visually graded and evaluated on a scale of 1 – 5. The percentage of excellent - good of the specimens were estimated for each tree section. The overall turning properties of the two locations were then compared. Images below show the steps involved in the turning test. Various steps in the turning test is shown in Figure 3.9 – 3.11.

Figure 3.9 A Picture of specimen prepared for turning test of required dimension of 20mm x 20mm x 125mm.

Figure 3.10 A Picture of a sample being turned on the lathe machine.

Figure 3.11 A Picture of turned specimens.

3.2.5 Shaping quality test

The study was conducted using a spindle moulder (type SwdgwickSM4, Figure 3.14) and a narrow band saw machine. Test specimens were prepared to the following dimensions20mm x 75mm x 300mm. A jig was used to make the outlines of the shape to be cut on the specimen (Figure 3.13). In all this suitable tolerance was ensured. The shape marked out on each of the samples was sawn out using a narrow bandsaw machine. Thereafter, the shaped specimen, were fastened to a jig and fed past the cutters of the spindle moulder manually. For each location, 135specimens were prepared, with 45 specimens from each tree section, 15 replicates were made for each of the three sections. Spindle speeds of 4500rpm, 6000rpm and 10000rpm were used in this study. After shaping, each sample was graded on the basis of defects such as raised, fuzzy and chipped grain and rough–end grain and the results were recorded. This was done on a scale of 1 – 5. The shaping properties were determined based on estimated percentage excellent to good specimens. Shaping properties of the tree sections were compared along with that of the two ecological zones under consideration. Specimens of reading for grading are as indicated in Figure 3.16.

Figure 3.12 A Picture of specimens used for the shaping test.

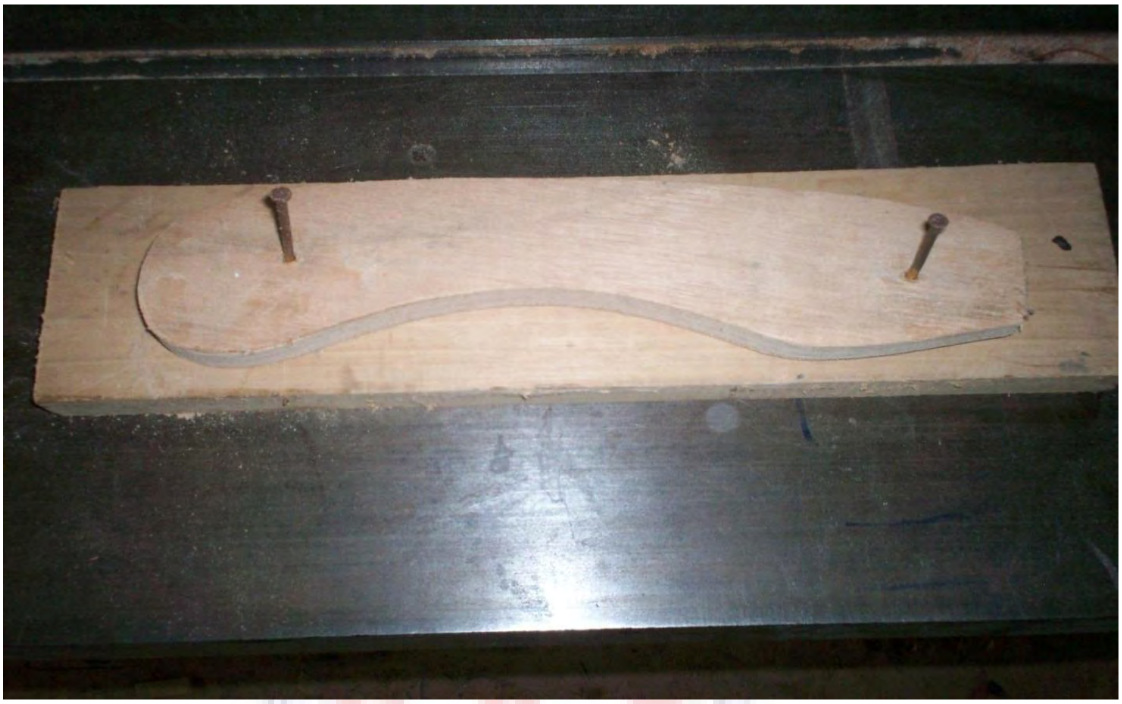


Figure 3.13 A Picture showing jig placed on a shaping sample.

Figure 3.14APicture showing Spindle moulder used for the shaping test.

Figure 3.15 A picture showing technician performing actual shaping operation using a Spindle moulder.

Figure 3.16 A Picture showing shaped specimen ready for grading.

3.2.6 Sanding quality test

The machine employed for this test was a ttLasIII belt sander (Figure 3.18). Dimension of the test specimens was 20mm x 100mm x900mm.Three grit sizes of sand paper namely,P80, P100, P120 were employed in this test. Test was conducted on each tree section and this was replicated fifteen times. For each location a total of 135 specimens were used, 45 from each tree section. Sanded specimens were then visually graded as shown in Figure 3.20 on a scale of 1 - 5. Scratching and fuzzing were the defects looked out for. Percentage excellent specimens were estimated for each tree section and ecological zone. These were then compared.

Figure 3.17 Picture showing planed specimens to be used for sanding test.

Figure 3.18 A Picture showing ttLasIII belt sander used for the sanding test.

Figure 3.19 A Picture of sanded specimens for the two locations with identification marks for easy identification.

Figure 3.20 A Picture of specimen being visually graded.

3.2.7 Grading of specimens

The test specimens, after each of the machining operations, were examined, evaluated and graded visually. The grading, according to ASTM D 1666 – 64(1976), were on a numerical scale of 1 -5 as follows: Grade 1 – excellent (defect free); grade 2; - good – minimal defects, which can easily be rectified by sanding; grade 3 – fair – minimal defects which cannot be easily be removed by sanding; grade 4 – poor – high degree of defects which can be removed with difficulty; grade 5 – reject/ poorest (fiber tear outs and broken corners).

Table 3.1 Quality grades used in determining overall performance for each machining test (ASTM – D 1666)

Machining test	Performance criteria
Planing	Grades 1and 2 (Excellent – Good)
Shaping	Grades 1and 2 (Excellent – Good)
Turning	Grades 1and 2 (Excellent – Good)
Sanding	Grade 1 (Excellent)

Table 3.1 shows quality grades of *Gmelina arborea* specimens used in determining overall performance for each machining test according ASTM – D 1666, 1978. For planing, shaping and turning tests, the machining characteristics were based on percentage of grades 1 and 2(excellent and good) specimens. However, sanding test performance was based on percentage of grade 1 (excellent) specimens.

3.2.8 Data Analysis

After visual examination and grading, resulting data of the machining tests (planing, turning, shaping and sanding) were transformed using log transformation to convert the data into a continuous data before using ANOVA. SAS version 9 statistical program was used in performing the analysis.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

Unless wood machines fairly well and with moderate ease, it will not be economically suitable for uses like furniture making, roofing, as well as all works that wood could be suitably used for Davis, (1962). Wood, in contrast to man-made fabricated materials, is not a homogenous material, but a multifaceted and heterogeneous biological material. Thus, an understanding of it properties will provide possibilities for improving product quality, increasing production efficiency, or otherwise improving the machining processes(Murat, Salim and Erol, 2005).Wood machining could be considered as a performance criterion indicated after planing, shaping, turning, mortising, boring, and sanding. Generally, the machining properties of wood relate to its behaviour when planed, shaped, turned, or put through any other standard woodworking operation. In this section of the thesis the results of a study conducted to determine the planing, shaping, turning and sanding characteristics of *Gmelina arborea* is presented.

4.2 Density of *Gmelina arborea*

Table 4.1 indicates the density of *Gmelina arborea* harvested from a plantation owned by Plantations Socfinaf Ghana Limited at Daboase in the western region of Ghana. Other samples were obtained from a plantation owned by the Forestry Research Institute of Ghana of the CSIR at Abofour situated in the Ashanti Region of Ghana. The average density of *Gmelina arborea* obtained from Daboase plantation was of 515 kg/m^3 with a range of 413kg/m^3– 599kg/m^3. However, average density of *Gmelina arborea* obtained from Abofour was 455 kg/m^3 and it ranged from390kg/m^3

– 500 kg/m^3. The *Gmelina aborea* obtained from the two sites indicate that *Gmelina arborea* is a medium density species. Generally, studies have indicated that high-density species have better boring, turning and shaping qualities than the low-density species (Addae-Mensah &Ayarkwa, 1998). Although the samples obtained from Daboase and Abofour were of the same species, the average density of samples obtained from Daboase was higher than that of Abofour. The difference in the density of *Gmelina arborea* obtained from the areas could be due to difference in climatic as well as differences in soil types of the two regions.

Table 4.1 Average density of tree sections

Location	Tree section	Replicates	Density (kg/m^3)	Standard deviation	Range (kg/m^3)
Daboase	Top	15	537	39	479 – 599
	Middle	15	432	35	413 – 557
	Butt	15	577	18	536 – 599
Abofour	Top	15	471	14	448 – 500
	Middle	15	483	13	458 – 501
	Butt	15	412	17	390 – 439

4.3 Moisture Content of *Gmelina arborea*

Wood moisture content has a great influence on wood machining. Davis (1964) indicated that the physical properties of wood such as moisture content and density affect it machining properties. Davis (1962) also stated that, in general best machining results were obtained at 6% moisture content and the poorest results at 20% moisture content.

Table 4.2 Average moisture content of tree sections

Location	Tree section	Replicates	Moisture content (%)	Standard deviation	Range (%)
Daboase	Top	15	11.41	0.237	11.08 – 11.88
	Middle	15	13.05	0.584	11.20 – 13.51
	Butt	15	11.50	0.256	10.80 – 11.82
Abofour	Top	15	13.80	0.481	13.09 – 14.41
	Middle	15	13.20	0.293	12.74 – 13.64
	Butt	15	13.14	0.300	12.54 – 13.64

In a study conducted on "Machining and related characteristics of United States Hardwoods" Davis (1964) concluded that different roughness were obtained for American hardwoods depending on the species and moisture content under study and that best result was obtained for moisture content 6% while poorer results was obtained for moisture content 20%. Pinheiro,deSampaioAlves, SimõesAmaral, (2015) also observed that the surface roughness of wood increases with increased moisture content. Table 4.2 indicates the moisture content of *Gmelina arborea* used for the study at test. The moisture content of *Gmelina arborea* obtained from Daboase plantation has an average value of 11.99% with a range of 10.80%– 13.51%. Additionally, the average moisture content of *Gmelina arborea* obtained from Abofour was 13.38% and has a range of 12.54% – 14.41%.

4.4 Planing characteristics of *Gmelina arborea*

Planing is the removal of thin, uniform strips from a piece of wood, creating a smooth, level surface as a result of removal of "high spots". Planed surface characteristics of solid wood is a function of machining quality, which is directly related to knife marks per cm and not by cutter head speed alone (Murat, Salim and Erol, 2005). Comparisons of planing properties are based on the percentage grade 1 and 2 (excellent and good) samples obtained after planing test. Each of the three feed speeds (6m/min, 9m/min and 14m/min) was evaluated separately. Table 4.4a provides a summary of percentage grades of planed specimens of *Gmelina arborea* extracted from Daboase. The highest rate of acceptable grade for the top section (66.7%) was recorded at 6m/min. Feed speed 14m/min produced the least rate of acceptable grade (33.3%). Similarly the middle section showed 93.3% of acceptable rate being the highest at 6m/min and the least of 20.0% at 14m/min. Also the butt section recorded highest rate of acceptable grade (86.6%) at 6m/min and 14m/min recording the least (30.0%). In all the middle section recorded the highest rate of acceptable grade of planed specimens (93.3%) at 6m/min and the least acceptable rate specimens (20.0%) at 14m/min. Feed speed 6m/min recorded the highest acceptable rate of planed specimen for the top (66.7%), middle (93.3%) and butt (86.6%).

Table 4.3a: Grade (%) of planed specimens of *Gmelina arborea*

Location	**Tree Section**	**Surface Grades**	**Feed speed**		
			6m/min	**9m/min**	**14m/min**
Daboase	Top	Grade 1	36.7	26.7	-
		Grade 2	30.0	20.0	33.3
		Grade 3	33.3	53.3	46.7
		Grade 4	-	-	20.0
		Grade 5	-	-	-
		Grades 1&2	66.7	46.7	33.3
	Middle	Grade 1	63.3	16.7	-
		Grade 2	30.0	43.3	20.0
		Grade 3	6.7	40.0	80.0
		Grade 4	-	-	-
		Grade 5	-	-	-
		Grades 1&2	93.3	60.0	20.0
	Butt	Grade 1	73.3	26.7	20.0
		Grade 2	13.3	33.3	10.0
		Grade 3	13.4	36.7	70.0
		Grade 4	-	3.3	-
		Grade 5	-	-	-
		Grades 1&2	86.6	60.0	30.0

Legend: Cutting angle of cutting knife = 30°

Table 4.3b shows a summary of percentage grades of planed specimens of *Gmelina arborea* extracted from Abofour. The highest rate of acceptable grade for the top section (100.0%) was recorded at 6m/min. Feed speed 14m/min recorded the least rate of acceptable grade of 76.6%. The middle section recorded the same order with the highest rate of acceptable grades (96.7%) recorded at 6m/min and the least rate (60.0%) at 14m/min. The butt however showed a different order of performance with 6m/min recording the highest rate of acceptable grades (96.6%) but 9m/min providing the least rate (53.3%). Feed speed of 6m/min recorded the highest rate of acceptable grades of planed specimens for the top (100.0%), middle (96.7%) and butt (96.6%). Comparing the results from the two separate locations, it could be found that, for every tree section at each feed speed specimens from Abofour showed higher rates of acceptable grades with the exception of the butt section at 9m/min. Feed speed 6m/min consistently produced the highest rate of acceptable grades for every tree section from Daboase and Abofour. Generally, rate of acceptable quality grades decreases with increasing feed speed. This observation is consistent with Davis (1938), which reports that, low feed speeds generally produce better surface quality during machining than high feed speeds. Abdullah, Chia and Samad (2008), indicates the most important parameter in wood machining process as feed speed and recommends smaller feed speed to be used. The most common defects encountered were fuzzy grain and chip marks.

Table 4.3b: Grade (%) of planed specimens of *Gmelina arborea*

Location	**Tree section**	**Surface grades**	**Feed speed**		
			6m/min	**9m/min**	**14m/min**
Abofour	Top	Grade 1	50.0	10.0	3.3
		Grade 2	50.0	80.0	73.3
		Grade 3	-	10.0	23.3
		Grade 4	-	-	-
		Grade 5	-	-	-
		Grades 1&2	100.0	90.0	76.6
	Middle	Grade 1	60.0	16.7	13.3
		Grade 2	36.7	66.6	46.7
		Grade 3	3.3	16.7	40.0
		Grade 4	-	-	-
		Grade 5	-	-	-
		Grades 1&2	96.7	83.3	60.0
	Butt	Grade 1	23.3	20.0	33.3
		Grade 2	73.3	33.3	26.7
		Grade 3	3.4	46.7	40.0
		Grade 4	-	-	-
		Grade 5	-	-	-
		Grades 1&2	96.6	53.3	60.0

Legend: Cutting angle of cutting knife = 30°

Table 4.3c shows the analysis of variance (ANOVA) of the effect of zone, tree section and feed speed on the surface quality of planed specimens. At 5% level of significance, zone and feed speed each has significant effect on the quality of planed surface. Zone and tree section interaction and zone and feed speed interaction have significant effect on the surface quality of planed specimens. The multiple coefficient value for the ANOVA model was 0.3150. Thus it could be deduced that, zone, tree section, feed speed and their interactions explained about 31.50% of variability in the surface quality of planed specimens.

Table 4.3c ANOVA of effect of location, tree section and feed speed on surface quality of planed specimens

Source	DF	ANOVA SS	Mean Square	F - Ratio	p-value
Location	1	7.3500	7.3500	15.44	0.0001*
Tree section	2	1.2704	0.6352	1.33	0.2644†
Feed speed	2	68.9600	34.4796	72.41	0.0001*
Location x TS	2	5.4111	2.7056	5.68	0.0036*
Location x FS	2	6.8111	3.4056	7.15	0.0009*
TS x FS	4	4.2852	1.0713	2.25	0.0627†
Loc x TS x FS	4	1.8778	0.4694	0.99	0.4148†
Error	493	234.7574	0.4762		

*Statistically significant at 0.05 level of significance; †Not statistically significant at 0.05 level of significance

Legend: TS = Tree section

FS = Feed speed

4.4 Turning characteristics of *Gmelina arborea*

Turning is the art or process of fashioning wooden pieces into various forms and shapes by means of a lathe. In the evaluation and application of most turned wood, the quality of the surface is of the ultimate importance. Examples, bobbins, tools handles, sporting goods and furniture parts (Kollman and Cote, 1984). They also asserted that "the surface roughness decreases with increasing cutting speed and the roughness perpendicular to the grain increases in parabolic manner with the feed speed". Table 4.5a shows the results of turning test of *Gmelina arborea*. Comparisons of the turning properties are based on percentages of grades 1 and 2 (excellent and good) samples as acceptable grades. Three different spindle speeds (1000rpm, 1850rpm and 2500rpm) were used. The top section recorded equal rate of acceptable grades (66.7%) at 1000rpm and 1850rpm with 2500rpm producing the least (60.0%). For the middle section spindle speed 1850rpm produced the highest rate of acceptable grades (80.0%) while 1000rpmrecorded the least (40.0%). The butt section similarly produced highest rate of acceptable grade for the butt (60.0%) at 1850rpm with 2500rpm recording the least (40.0%). Spindle speed 1850rpm cumulatively recorded the highest rate of acceptable grades for all three sections. Between 1000rpm and 1850rpm, it can be stated that, 'surface roughness decreases with increasing spindle speeds. This observation confirms Kollman and Cote (1984). However between 1850rpmand2500rpm, there is a general reduction in the rate of acceptable grades contrasting Kollman and Cote (1984), which reports that, surface roughness of wood decreases with increasing spindle speed.

Table 4.4a: Grade (%) of turned specimens of *Gmelina arborea*

Location	**Tree section**	**Surface grades**	**Spindle speed**		
			1000rpm	**1850rpm**	**2500rpm**
Daboase	Top	Grade 1	-	-	-
		Grade 2	66.7	66.7	60.0
		Grade 3	33.3	33.3	40.0
		Grade 4	-	-	-
		Grade 5	-	-	-
		Grades 1&2	66.7	66.7	60.0
	Midlle	Grade 1	-	-	-
		Grade 2	40.0	80.0	60.0
		Grade 3	60.0	20.0	40.0
		Grade 4	-	-	-
		Grade 5	-	-	-
		Grades 1&2	40.0	80.0	60.0
	Butt	Grade 1	-	-	-
		Grade 2	53.3	60.0	40.0
		Grade 3	46.7	40.0	60.0
		Grade 4	-	-	-
		Grade 5	-	-	-
		Grades 1&2	53.3	60.0	40.0

Table 4.4b gives a summary of the turning test on *Gmelina arborea* samples from Abofour. Comparisons of the turning properties are based on percentages of grades 1 and 2 samples (excellent and good) specimens as acceptable grades. Three different

spindle speeds (1000rpm, 1850rpm and 2500rpm) were used. For the top section, spindle speed 2500rpm recorded the highest rate of acceptable grades (80.0%) with 1000rpm recording the least (20.0%). The middle section also produced highest rate of acceptable grades (80.0%) at 2500rpm and the least (66.7%) at 1000rpm. Similar trend was recorded for the butt section at 2500rpm and 1000rpm as 80.0% and 60.0% respectively. Spindle speed 2500rpm was found to produce highest rates of acceptable grades for all three sections. This wholly confirms Kollman and Cote (1984). Comparing the two locations, *Gmelina arborea* specimens from Daboase recorded the highest rates of acceptable grades at 1850rpm while specimens obtained from Abofour produced highest rate at 2500rpm. Abofour specimens generally performed better in the turning test than those obtained from Daboase. The commonest defects were fuzzy grain, and roughness.

Table 4.4b: Grade (%) of turned specimens of *Gmelina arborea*

Location	**Tree section**	**Surface grades**	**Spindle speed**		
			1000rpm	**1850rpm**	**2500rpm**
Abofour	Top	Grade 1	-	-	33.3
		Grade 2	20.0	40.0	46.7
		Grade 3	80.0	46.7	20.0
		Grade 4	-	13.3	-
		Grade 5	-	-	-
		Grades 1&2	20.0	40.0	80.0
	Middle	Grade 1	-	-	-
		Grade 2	66.7	73.3	80.0
		Grade 3	33.3	26.7	20.0
		Grade 4	-	-	-
		Grade 5	-	-	-
		Grades 1&2	66.7	73.3	80.0
	Butt	Grade 1	-	-	-
		Grade 2	60.0	66.7	80.0
		Grade 3	40.0	33.3	20.0
		Grade 4	-	-	-
		Grade 5	-	-	-
		Grades 1&2	60.0	66.7	80.0

Table 4.4c shows the analysis of variance (ANOVA) of the quality of turned specimens indicates that at 5% level of significance, spindle speed, zone and spindle speed interaction, tree section and spindle speed interaction, zone and tree section and spindle speed interactions have significant effects on the surface quality of turned specimens. The multiple coefficient of determination value was 0.226. Thus it could be deduced that, zone, tree section and spindle speed and their interactions explained about 26.6% of the variability in the surface quality of turned specimens.

Table 4.4c ANOVA of effect of location, tree section and spindle on surface quality on turned specimens

Source	DF	ANOVA SS	Mean Square	F - Ratio	p –value
Location	1	0.0930	0.0930	2.28	0.1326†
Tree section	2	0.0304	0.0152	0.37	0.6900†
Spindle speed	2	0.4195	0.2097	5.14	0.0065*
Location x TS	2	0.0777	0.0389	0.95	0.3876†
Location x SS	2	0.6582	0.3291	8.06	0.0004*
TS x SS	4	0.5401	0.1350	3.31	0.0116*
Loc x TS x SS	4	0.5376	0.1344	3.29	0.0119*
Error	238	9.7189	0.0408		

*Statistically significant at 0.05 level of significance; †Not statistically significant at 0.05 level of significance

Legend: TS = Tree section

SS = Spindle speed

4.4 Shaping characteristics of *Gmelina arborea*

In furniture industry, shaping is cheaply done and the commonest is the cutting of patterns on some curved edge like that of a round table. A band saw is mostly used to saw the shape before being shaped using the spindle moulders. There are other power-speed automatic shapers but the most common type is the spindle moulders (Addae-

Mensah and Ayarkwa, 1998). Davis (1962) reported that cutter head speed has significant influence between 3600 rpm and 7200rpm but if trade opinion is right, it would be significant between 7200rpm and 15000rpm.Comparisons of the shaping properties are based on percentage grades 1 and 2 specimens (excellent and good) specimens as acceptable rate. Each of the three spindle speeds (4500rpm, 6000rpm and 10000rpm) was evaluated separately for the various tree sections. Table 4.5a shows the results of shaping test of specimens of *Gmelina arborea* obtained from Daboase. The top section recorded the highest rate of acceptable grades (46.7%) at 6000rpm and 10000rpm. Spindle speed 4500rpm showed no acceptable grades of specimens. Highest rate of acceptable grade (66.7%) was recorded for the middle section at 10000rpm with the least record at 4500rpm. The butt section at 10000rpm produced the highest rate of acceptable grades (46.7%) with 4500rpm recording no acceptable grade. The highest rate of acceptable grades was recorded for the middle section at spindle speed 10000rpm (66.7%). The experiment suggests that surface roughness decreases with increasing spindle speed. This observation was confirmed by Davis (1962), indicating that spindle speeds between 7200rpm and 1500rpm produce significant levels of acceptable grades.

Table 4.5a: Grade (%) of shaped specimens of *Gmelina arborea*

Location	**Tree section**	**Surface grades**	**Spindle speed**		
			4500rpm	**6000rpm**	**10000rpm**
Daboase	Top	Grade 1	-	6.7	-
		Grade 2	-	40.0	46.7
		Grade 3	93.3	53.3	53.3
		Grade 4	6.7	-	-
		Grade 5	-	-	-
		Grades 1&2	-	46.7	46.7
	Middle	Grade 1	-	-	-
		Grade 2	6.7	20.0	66.7
		Grade 3	80.0	80.0	33.3
		Grade 4	13.3	-	-
		Grade 5	-	-	-
		Grades 1&2	6.7	20.0	66.7
	Butt	Grade 1	-	-	6.7
		Grade 2	-	20.0	40.0
		Grade 3	86.7	80.0	53.3
		Grade 4	13.3	-	-
		Grade 5	-	-	-
		Grades 1&2	-	20.0	46.7

Table 4.5b provides a summary of the shaping test for *Gmelina arborea* specimens obtained from Abofour. The top section recorded highest value of acceptable grades (100.0%) at 10000rpm and the least (13.3%) at 4500rpm. Same order of acceptable grade performance was recorded by the middle section, with 10000rpm producing the highest (80.0%) and 4500rpm the lowest (13.3%). The butt section produced the highest rate of acceptable grade (93.3%) at 6000rpm and least rate (40.0%) at 4500rpm. Spindle speed 10000rpm recorded the highest acceptable grades rate for the top (100.0%) and middle sections (80.0%) but 6000rpm producing highest rate for the butt (93.3%). The experiment suggests to a large extent that surface roughness decreases with increasing spindle speed (Abdullah, Chia and Samad, 2008).For the two locations, specimens obtained from Abofour generally performed better in terms

of resulting rate of acceptable grades for each spindle speed. The most common defect encountered was raised grain.

Table 4.5b: Grade (%) of shaped specimens of *Gmelina arborea*

Location	Tree section	Surface grades	Spindle speed		
			4500rpm	6000rpm	10000rpm
Abofour	Top	Grade 1	-	33.3	26.7
		Grade 2	13.3	20.0	73.3
		Grade 3	86.7	46.7	-
		Grade 4	-	-	-
		Grade 5	-	-	-
		Grades 1&2	13.3	53.3	100.0
	Middle	Grade 1	-	20.0	20.0
		Grade 2	13.3	46.7	60.0
		Grade 3	80.0	33.3	20.0
		Grade 4	6.7	-	-
		Grade 5	-	-	-
		Grades 1&2	13.3	66.7	80.0
	Butt	Grade 1	13.3	26.7	20.0
		Grade 2	26.7	66.6	60.0
		Grade 3	60.0	6.7	20.0
		Grade 4	-	-	-
		Grade 5	-	-	-
		Grades 1&2	40.0	93.3	80.0

Table 4.5c shows the analysis of variance (ANOVA) of the surface quality of shaped specimens indicates at 5% level of significance that zone and spindle speed each has significant effect on the surface quality. The multiple coefficient of determination value was 0.3930. This indicates that, zone, tree section, and spindle speed and their interactions explained about 39.30% of variability in the surface quality of shaped specimens.

Table 4.5c ANOVA of effect of location, tree section and spindle speed on surface quality of shaped specimens

Source	DF	ANOVA SS	Mean Square	F – Ratio	p-value
Location	1	3.8142	3.8142	52.50	0.0001*
Tree section	2	0.1217	0.0608	0.84	0.4340†
Spindle speed	2	0.7708	2.3854	32.83	0.0001*
Location x TS	2	0.2321	0.1161	1.60	0.2045†
Location x SS	2	0.4260	0.2130	2.93	0.0552†
TS x SS	4	0.1975	0.0494	0.68	0.6067†
Loc x TS x SS	4	0.4397	0.1099	1.51	0.1991†
Error	238	17.2911	0.0727		

*Statistically significant at 0.05 level of significance; †Not statistically significant at 0.05 level of significance

Legend: TS = Tree section

SS = Spindle speed

4.4 Sanding characteristics of *Gmelina arborea*

The oldest and best-known coated abrasive is the familiar "sand-paper" in which the mineral is quartz. Sanding is done to remedy a slight mismatch where different part of a finished product joins such as the vertical and horizontal members in a solid door or the sides and front of a drawer (Davis, 1962**).**Table 4.6a shows the percentage grades of sanded specimens of *Gmelina arborea* obtained from Daboase. Three different grit sizes (P80, P100 and P120) were used. According to the sanding properties, the various sections showed different performances. Comparisons of sanding properties are based on grade 1 (excellent) specimens as acceptable grades. The top section recorded the highest rate of acceptable grades (50.0%) at P80 with the least rate (36.7%) at grit size P120. Middle section produced a different order of performance with P100 showing the highest rate of acceptable grades (86.7%) while P120 recorded the least rate (36.7%). P100 showed the highest rate of acceptable grade (63.3%) for the butt with the least (33.3%) at P120. Cumulatively, P100 recorded the highest rate of acceptable grades.

Table 4.6a: Grade (%) of sanded specimens of *Gmelina arborea*

Location	**Tree section**	**Surface grades**	**Grit size**		
			P80	**P100**	**P120**
Daboase	Top	Grade 1	50.0	43.3	36.7
		Grade 2	50.0	53.3	60.0
		Grade 3	-	3.4	3.3
		Grade 4	-	-	-
		Grade 5	-	-	-
	Middle	Grade 1	40.0	86.7	36.7
		Grade 2	50.0	13.3	63.3
		Grade 3	10.0	-	-
		Grade 4	-	-	-
		Grade 5	-	-	-
	Butt	Grade 1	60.0	63.3	33.3
		Grade 2	40.0	33.3	56.7
		Grade 3	-	3.4	10.0
		Grade 4	-	-	-
		Grade 5	-	-	-

Table 4.6b provides a summary of the percentage grades of sanded specimens of *Gmelina arborea* obtained from Abofour for sanding test. Three different grit sizes (P80, P100 and P120) were used. Comparisons of the sanding properties are based on grade 1 (excellent) specimens as acceptable grades. P80 recorded the highest rate of acceptable grades (60.0%) for the top section with P100 showing the least (13.3%). The middle section records highest rates (73.3%) forP80 and P120 while P100 showed highest performance rate (66.7%) at P120 and least rate of acceptable grades at P80. P120 proves to provide the highest rate of acceptable grades cumulatively. Very minimal grade 3 specimens were encountered with some sections recording no

grade 3 specimens. The most common defects encountered were fuzzing and scratching.

Table 4.6b: Grade (%) of sanded specimens of *Gmelina arborea*

Location	Tree Section	Surface grades	Grit size		
			P80	P100	P120
Abofour	Top	Grade 1	60.0	13.3	53.3
		Grade 2	40.0	60.0	46.7
		Grade 3	-	26.7	-
		Grade 4	-	-	-
		Grade 5	-	-	-
	Middle	Grade 1	73.3	43.3	73.3
		Grade 2	23.4	50.0	26.7
		Grade 3	3.3	6.7	-
		Grade 4	-	-	-
		Grade 5	-	-	-
	Butt	Grade 1	3.3	40.0	66.7
		Grade 2	63.3	50.0	33.3
		Grade 3	33.4	10.0	-
		Grade 4	-	-	-
		Grade 5	-	-	-

Table 4.6c shows the analysis of variance (ANOVA) of the surface quality of sanded specimens of *Gmelin aarborea* indicates at 5% level of significance that tree section, zone and tree section interaction, zone and grit size interaction and their interactions have significant effect on the surface quality of sanded specimens. The multiple coefficient of determination was 0.2274. This indicates that zone, tree section and grit size and their interactions explained about 22.74% of the variability in the surface quality of sanded specimens.

Table 4.6c ANOVA of effect of location, tree section and grit size on surface quality of sanded specimens

Source	DF	ANOVA SS	Mean Square	F - Ratio	p-value
Location	1	0.8963	0.8963	3..09	0.0794†
Tree section	2	4.5481	2.2741	7.84	0.0004*
Grit size	2	0.7259	0.3630	1.25	0.2871†
Location x TS	2	2.5037	1.2519	4.31	0.0139†
Location x GS	2	13.7926	6.8963	23.77	0.0001*
TS x GS	4	9.5296	2.3824	8.21	0.0001*
Loc x TS x GS	4	12.5741	3.1435	10.83	0.0001*
Error	522	151.4667	0.2902		

*Statistically significant at 0.05 level of significance; †Not statistically significant at 0.05 level of significance

Legend: TS = Tree section

GS = Grit size

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From this study, it could be stated that *Gmelina arborea* has very good machining characteristics. Feed speed 6m/min was found to be most suitable for planing *Gmelina arborea* specimens at 30° cutting angle. For turning test, spindle speeds 1850rpm and 2500rpm could produce the highest rate of acceptable grades for Daboase and Abofour respectively. The shaping test confirmed spindle speed 10000rpm as producing the highest performance for *Gmelina arborea* specimens. Sand paper of grit sizes P100 and P120 could be most suitable for sanding *Gmelina arborea* specimens from Daboase and Abofour respectively. In all four machining tests, *Gmelina arborea* specimens obtained from Abofour (Ashanti region) performed better than specimens obtained from Daboase (Western region).*Gmelina arborea* can be usedin place of some popular over utilized timber species on the timber market in Ghana and elsewhere. This would reduce pressure on the timber industry key prime wood species, slow down the extinction rate of key timber species, keep the timber industry in business and contribute to an increase in the government's net revenue.

5.2 Recommendations

Since *Gmelina arborea* has very good machining characteristics, it is recommended that further studies be conducted on its mechanical properties and other related areas in order to promote its utilization.

The good machining qualities of *Gmelina arborea* make it recommendable to the furniture industry. It is also recommended that Ashanti region should be chosen for future establishment of *Gmelina arborea* plantation.

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