MACHINING CHARACTERISTICS OF *KHAYA SENEGALENSIS* AND *ANOGEISUS LEIOCARPUS*

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ABSTRACT

Khaya senegalensis *(Kuntunkuri) and* ***Anogeisus leiocarpus*** *(Kane) have been found to be in abundance in the Savannah Zone of Ghana where other Ghanaian primary species are scarcely available. In contribution to the promotion of these species, the turning, shaping, boring and sanding properties were studied. The results have shown that* ***Khaya*** *has a better turning, shaping, boring and sanding properties than Kane. Spindle and feed speeds were found to have significant effect on the two wood species at P ≤ 0.05. The higher the spindle speed, the better the turning and shaping qualities of the species. Spindle speeds of 2,800 rpm and 6,000 rpm used for turning and shaping tests respectively, generated Grade I quality samples for* ***Khaya*** *and Kane. Spindle speeds of 900 rpm and 1,400 rpm combined effectively with feed speeds of 0.9mm/mim, 1.5mm/min, 2.4mm/min and 3.9mm/min to produce Grade I bored holes in the two species while combinations of 2.4mm/min, 3.9mm/min and 300 rpm; 1.5mm/min, 2.4mm/min, 3.9mm/min and 600 rpm and 0.9mm/min, 1.5mm/min and 2,200 rpm achieved Grade I of bored holes for the species. The amount off-size in the bored boles was higher in* ***Khaya*** *than in Kane and the off-size increased with increasing spindle speed. The average variation from size of bored holes in* ***Khaya*** *and Kane with the six spindle speeds (300, 600, 900, 1,400, 2,200 and 2,900 rpm) was 0.3567 mm and 0.3233 mm respectively. Grit sizes of 40 and 60 sanded off any chipped/torn grain defects that were observed on* ***Khaya*** *while grit 40 eliminated the same effect on Kane. The relative freedom from fuzzing in Kane was higher than in* ***Khaya*** *when grits 100, 120 and 150 were used but the relative resistance to scratching with the same grits was evaluated to be higher in* ***Khaya*** *than in Kane. Therefore for effective preparation of the wood species for the application of finishes, grit sizes higher than 150 are recommended. The good machining qualities of* ***Khaya*** *coupled with its aesthetic Mahogany-like colour make it recommendable to the furniture industry while Kane is recommended to the construction industry where quality is not of prime importance. The species should therefore be grown in plantations establishment, especially in the savannah zone where they are reported to grow well to support the proposed industry.*

Keywords: Machining, turning, shaping, boring, sanding

INTRODUCTION

The fast decline in size and productivity of the Ghanaian forest has been a concern to many governmental and non-governmental organisations and even some individuals in the country. This is because the demand and utilization of forest resources cut across the nooks and crannies of the country for various purposes. The main threats to biodiversity in Ghana are increased incidence of annual bushfires, increased forest resource exploitation and clearing of forests for agriculture

(Hawthorne, 1994).

According to the Forestry Department (1987), the total savannah woodland in Ghana covers an area of 156,281 sq Km, which consists of forest reserves (8,806 sq Km), unreserved woodlands (72,008)sq Km) and grasslands, farm lands, etc (75,467 sq. Km). Even at that moment, according to Iyamabo, (1990), the savannah area was lacking in wood supply. In much the same way, about 32% of the forest resources is degraded (MLF, 1996). Even though figures are not available for areas outside the forest reserves for substantiation, it is believed that it may be higher than 50%. Moreover, the capacities of the existing sawmills in Ghana (excluding illegal chain saw operation) have been found to exceed the annual allowable cut (AAC) from the forest (Nsenkyire, 1996). Therefore to arrest this unfortunate situation, it is recommended that more of the species in the forest that are underutilized, lesser-used timber species (LUS) / lesser-known timber species (LKS) be promoted. But in the Savannah Zone, many of the LUS are burnt or otherwise wasted after logging in the reserved forests and conversion of forest lands into agricultural use in the off-reserve areas.

Consequently, the International Tropical Timber Organisation (ITTO) and governments of some tropical countries have designed programmes to ensure greater utilization of lesser-used timber species (LUS). According to Agyemang *et al* (2003), the ITTO within the last few years has sponsored over 25 LUS-related projects, funding for which has totaled over $5 million. These projects were aimed at preventing the creaming of the few traditional high value species, catering for increasing local demand and ensuring sustained production and supply of timber.

The exploitation of the many valuable timber species from the forest has been supporting the economy of Ghana considerably. For instance, Agyemang *et al.* (2003) stated that timber exports earned Dm 354.3 million and Dm 287.3 million in 1994 and 1995 respectively. Again in 1996 and 1997, the processing sector earned for the country Dm 222.1 million and Dm 280 million from the export of wood products, which represents an increase of about 26.1% in terms of value. This accounted for 18% of exports and 5-6% of the total Gross domestic products (GDP).

The timber industry, according to Agyemang *et al.* (2003) employs about 70,000 people in the formal sector (that is logging firms, processing mills and public institutions). Several thousands of self-employed artisans are also engaged in the manufacture of furniture, doors and other constructional items for the housing industry.

The rationale for the promotion of LUS/LKS is based on the fact that the timber industry is highly dependent on a few timber species which has resulted in a reduction in the raw material base and an increase in the cost of sawmilling operations. To increase the cost of efficiency of harvesting and processing LUS, Ghana has adopted a strategy of promoting and marketing LUS as substitutes for primary species based on similarity of characteristics and end-use categorization.

The volume of LUS has increased steadily since 1997 from 4,107m^3 to 5,810m^3 in 1999 representing 0.975 to 1.47% of the total trade respectively. In terms of value, LUS contribution increased within the same period from US $1.3 million to US $2.8 million (Agyemang *et al.* (2003).

Currently, some of the uses of LUS/LKS in Ghana are for furniture and cabinets, veneer, heavy construction, poles, woodcraft, musical instruments, packaging, baseball and softball bats, tool handles, bobbins and spools, picker sticks. Even though a vast number of lesser-used, but potentially useful, timber species exist in the tropical forests, only a few species continue to be exploited. This is because the properties and uses of the LUS/LKS are not known to wood users. Specifications that are of interest to the industry are sawing and machining efficiencies and end-use categorization of the LUS/LKS.

The introduction of more LUS/LKS on the market will increase the resource base and make a lot more raw materials available to the timber industry while taking some of the pressure off the primary species. However, successful expansion of the timber industry through increased LUS/LKS utilization will depend on adequate knowledge of their machining properties.

Machining is a stress-failure process, which is conveniently analysed as an action of a cutting tool on a piece of wood (Dinwoodie, 1980). Machining properties are directly related to the behaviour 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.

Surface quality depends on the wood species and becomes better for denser, harder and drier wood (Kollman and Cote, 1968). Herbert *et al.* (1984) have reported that the lower the density of a wood, the easier the wood is cut with a tool. Dinwoodie (1980) has also stated that blunting time of cutting tools decreases with increasing density of wood. The quality of cut surface depends on the grain direction and that cutting along the grain is more efficient and results in better finish quality than cutting against the grain. The speed with which samples are fed during machining is quite independent of species and it is chosen with respect to the type of cutter and the rotational speed of the cutter block, so that the smoothness of the cut is suitable for the end-use of the piece (Davis, 1938). Extremely low feed speeds may actually result in tearing of fibres instead of cutting, thereby producing poor finish but generally low feed speeds produce a better finish during machining than higher speeds. According to Dinwoodie (1980) and Hoadley (1980), cutting with the grain results in more efficient and better quality surface finish than cutting against the grain. Irregular grains also affect wood surface quality, particularly interlocked grain in tropical hardwoods (Hoadley, 1980). The presence of resins and gums is reported to stick to tools or cutters which result in overheating thereby changing the normal working temperature (Dinwoodie, 1980)

The Savannah woodlands abound in many tree species most of which have the potential of being raised in plantations *Khaya senegalensis* and *Anogeisus leiocarpus*, which are among the recommended species for such catchment management, can be exploited to provide sawn timber for construction and other national needs. However, there is no information on their properties to justify their utilization for specific purposes.

The objective of the study was to establish the turning, shaping, boring and sanding properties of two selected Savannah wood species (*Khaya senegalensis*; Kuntunkuri and *Anogeisus leiocarpus*; Kane), which are categorised under LUS/LKS respectively, for their most convenient promotion.

Lathes, the oldest type of woodworking machine with which a wide range of variety of turned products are made, are manufactured in several distinct types that ranges from specialized automatic machines capable of making several hundred turnings per hour to the familiar manual training hand lathe (Davis 1962). Even though turnings were not very common practice in the woodworking sector, a number of high-quality products, which include tool and implement handles, sporting goods, furniture, spools and bobbins, toy parts and certain types of woodenware, are produced from lathe work. Tools for woodturning, which are grouped into three major styles and cuttings are long and strong, standard and small standard (Sainsbury, 1980). Most of the common features of turning include a bead, cove and fillet together with cuts at several different angles with the grain, therefore the sharpness of details and smoothness of surface are taken into account. According to Sainsbury (1980), the speed of a lathe is related to the size of timber being turned which increases with decreasing size of timber but very slow speeds can be dangerous. He added that slower speeds produce poor surfaces. The density of timber, its grain formation and whether it has an oil or resin content also have a bearing on the speed and that a speed equal to that of the motor, that is, 1,425rpm, is found most suitable for majority of jobs mounted between centres (Sainsbury, 1980).

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. 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. Cutterhead 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).

There are many types of wood drills and boring machines, often highly specialized for a particular job on a mass production basis. The use of dowels, screws, spindles and rungs calls for boring in order to manufacture furniture and other wood products. Davis (1962) has stated that the two major industrial woodworking electric power machines are the single-spindle, hand-feed and automatic multiple-spindle machines that bore several holes of predetermined depth and angle at the same time. The quality of bored holes either adds to or detracts from the general utility of any species and that a smoothly cut, accurately sized hole is necessary for the best glue joint.

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 specialised 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.

Wood Characteristics

Khaya and Anogeisus, which are said to grow very well in the fringing forests, are very common in the drier parts of Ghana especially in the Northern, Ashanti, Brong Ahafo and Volta regions. According to Irvine (1961) and Farmer (1972), Khaya grows to an average diameter of 60cm at breast height (dbh) and an average height of 30m. Anogeisus, on the other hand, grows to an average diameter (dbh) and height of 50cm and 20m respectively. *Khaya senegalensis* is a heavy timber resembling *Khaya gradifoliola* more closely than *Khaya ivorensis* or *Khaya anthotheca* (Farmer, 1972). The heartwood of *Khaya senegalensis*, which is pink-brown, darkens to deep red-brown with a purplish tinge, darker in colour than ordinary commercial Mahogany. The sapwood is slightly paler and browner than the heartwood and not very distinct from it. The wood, which is popularly called Savannah Mahogany, has interlocked grain. According to Oteng-Amoako (2002), the heartwood of Anogeisus which is dark-brown is well demarcated from the yellowish-grey sapwood and the texture is fine.

MATERIALS AND METHODS

Collection of Test Samples

Three trees each of Khaya and Kane were collected from Kintampo in the Savannah zone of Ghana. Each of the trees were felled and cross-cut into logs of length 2.5m of which 9 and 12 logs were obtained for Khaya and Kane respectively. The logs were then transported to FORIG for further processing. They were then sawn into lumber using quarter- and flat-sawing methods with a horizontal mobile band mill. The sawn lumber were stacked under a shed for drying until an average moisture content of 15% was attained.

Selection of Sample Material and Sample Size

The air dry samples of Khaya and Kane at an average moisture content of 15% were used for the tests. Random samples of the lumber (from the three trees of each species) were made from the stacked lumber for the preparation of the test specimens. All the test samples were free from cracks, splits, loose knots or flaws, beetle holes or deep resin ducts. With a sample size of 50 per test per species, a total of 200 samples of dimensions 2 x 2 x 12.5 cm were prepared for the turning tests to be performed with four different spindle speeds. A total of 1, 350 samples per species of dimensions 2 x 7.5 x 30 cm were also prepared for both shaping and boring tests. For each species the sample size per test was 50. As three spindle speeds were used for the shaping test, four feed speeds and six spindle speeds were also selected for the boring test. With the sanding test, about 400 samples for each species were prepared for the six grit sizes of sandpapers that were used. The dimensions of the samples for the sanding test were 2.5 x 10 x 100 cm and the sample size per grit test was also 50. The selection of the test samples, and their preparations were based on ASTM D 143-83 (1994) and ASTM D 1666-87 (1994).

Methods

All the activities involved in turning, shaping, boring and sanding were undertaken at FORIG, Fumesua, where basic wood working machines were available. The test specimens, after each of the machining operations, 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 – excellent (defect-free); grade 2 – good (slight defects); grade 3 – fair (medium defects); grade 4 – poor (severe/advanced defects); grade 5 – reject/

poorest (fiber tear outs and broken corners). The defects observed for each machining test were also recorded.

Turning Test

Wadkin lathe machine (model RS 500) and woodturning tool set of six pieces were used to turn the test specimens, 50 per species per spindle speed at a time. The selected turning patterns were such that cuts were made along the grain, across the grain and diagonal to the grain and the turning speeds used were 240 rpm, 600 rpm, 1,250 rpm and 2,800 rpm. Afterwards, the turned specimens were examined and graded on a scale of 1-5 by taking into consideration the smoothness and sharpness of the surfaces. The poorest point in a turning was the controlling factor, because that point governs the amount of sanding necessary to make it commercially acceptable. To facilitate comparisons, the percentages of specimens grading fair to excellent were calculated.

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/pattern 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 3,000 rpm and 1,500 m/min respectively was used to initially shape all the specimens to the desired curved outline. The bandsaw- shaped specimens, one after the other, were fastened to a jig and fed past the cutters of the spindle moulder manually. The three spindle speeds used were 3,000rpm, 4,500rpm and 6,000rpm. All the shaped specimens were then examined and graded (on a scale of 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 percentages of specimens grading good to excellent were also calculated.

Boring Test

The machine for the boring test was a vertical single-spindle drilling type employing both manual and automatic feeding. This was chosen on account of the strength and rigidity of the head, column and table. These factors ensured that there was little deflection of the head in relation to the table even under the high force experienced. Any large displacements would have had an adverse effect on the accuracy of the hole in a vertical plane, the shape and size of the hole. A motor driven mechanism, which was part of the engine arrangement of the machine, was used to provide a constant downward rate of feed to the spindle quill. Four feed speeds (0.9, 1.5, 2.4 and 3.9 mm/min) and six spindle speeds (300, 600, 900, 1,400, 2,200 and 2900 rpm) were combined through permutation for the boring activities. A selection of commercial types of machine boring bits was made and a 28mm size, single-twist, solid-centre, brad pointed type was chosen for the boring tests. This was kept in first-class cutting condition by polishing the flutes and with frequent sharpening of the cutting edges. The size of the bit was large enough for the bored holes to be well examined. During boring, each of the test specimens was firmly held in a machine vice and four holes were bored through into a *Ceiba pentandra* backing to prevent splintering on the exist side making 200 holes for each test condition. After boring, the holes were examined for crushing, tearouts, fuzziness and general smoothness of cut for each test condition and graded on a scale of 1-5. The percentages of specimens grading good to excellent were calculated. To determine the accuracy of the sizes of the bored holes, they were measured with an electronic caliper (that measured to the nearest 0.001mm) both perpendicular and parallel to the grain immediately after the holes were bored. The difference in average measurements in the two directions and the size of the bit used for each test condition was determined as the amount of off-size in the holes bored.

Sanding Test

A two knife combined surfacing and thicknessing planer machine of type 610 x 230 mm "D.A.A." was used to plane the sanding test specimens at feed and spindle speeds of 9 m/min 5,200 rpm and a cutting angle of 20^0. After planing, the specimens were sorted out into chipped and non-chipped groups. The chipped specimens (labeled group A) were sanded with grits 40, 60 and 80 while the non-chipped ones (labeled group B) were sanded with grits 100, 120 and 150 using a belt sander (a 3-phase model CL300 type). After sanding, the specimens were inspected visually and with the help of a hand lens for: a) the 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 5 as an indication of the seriousness of any defects that were present. The percentages of specimens grading excellent (defect-free) were determined.

RESULTS AND DISCUSSION

The various percentage scores of the machining operations that were undertaken have been presented graphically in Figures 1-13. The results of the relative turning, shaping boring and sanding qualities for Khaya and Kane have been presented in Tables1-3. There were also ratings obtained by averaging grades of the test samples for the various machining operations. The lower the rating or the nearer a rating approaches 1.0, the fewer the defects and the better the machining quality. In order to generally grade each species in terms of its machinability, a rating range of 1.0-5.0 have been grouped into three under the following categories:

Grade I – species with high machining quality (1.0-2.0)

Grade II – species with medium machining quality (2.1-4.0), and

Grade III – species with low machining quality (4.1-5.0).

The basic densities of Khaya and Kane were calculated to be 661 Kg/m^3 and 750 Kg/m^3 at 16% moisture content. The dulling effect on cutting tools was observed to be more frequent with Kane. Therefore the rate of sharpening of tools with Kane was higher than with Khaya. This fact is in agreement with earlier studies by Dinwoodie (1980) that as density increases the blunting time of cutting tools decreases and that the presence of hard deposits in wood has pronounced dulling effect on cutting edges.

Comparative Turning Quality

The statistical analysis performed using Chi-square test at $P \leq 0.05$ showed statistical differences between the four spindle speeds (240; 600; 1,250; 2,800 rpm). The relative turning quality of the wood species tested, as shown in Figure 1 is based on the percentages of the samples graded fair to excellent. The average ratings of the turning results and the category of grade (asterisked) are also presented in Table 1. The results of the percentage turning quality of each of the species for the four spindle speeds indicated that the turning quality increases with increasing spindle speed. A speed of 2,800 rpm recorded the highest percentages of fair to excellent samples for the two species while 240 rpm recorded the lowest (Figure. 1). The ratings, which is an indication of the turning quality (as it approaches 1.0), decreases from a speed of 240 rpm towards 2,800 rpm (Table 1). This confirms the findings by Sainsbury (1980) that slower turning speeds produce poor surfaces. With all the four speed (Figure 1), Khaya recorded higher percentages than Kane. For instance, Khaya at spindle speeds of 600 rpm and 2,800 rpm scored 42% (Grade III) and 88% (Grade I) respectively but Kane scored 22% (Grade III) and 76% (Grade II) in the same order. The results in Table 1 also show that Khaya with a rating ranging between 1.3 and 4.4 has better surface quality at all the operating conditions than Kane with a rating range of 2.1 and 4.5. From the basic densities calculated, Kane is denser than Khaya hence the finding is not in agreement with Kollman and Cote (1968) who reported that surface quality becomes better for denser and harder wood species. The major machining defect observed on Khaya was fuzzy grain while Kane experienced some fibre tearouts and broken corners.

Table 1: Turning and shaping quantities based on rating

	Degree of turning quality				Degree of shaping quality		
Species	240 rpm	600 rpm	1,250 rpm	2,800 rpm	3,000 rpm	4,500 rpm	6,000 rpm
Khaya	4.4	3.1	2.4	1.3	2.9	2.2	1.5
	III*	II*	II*	I*	II*	II*	I*
Kane	4.5	3.5	2.7	2.1	3.2	2.6	2.0
	III*	II*	II*	II*	II*	II*	I*

Rating: the nearer it approaches 1.0 the better the quality
Grade I = High Machining Quality(1.0-2.0); Grade II = Medium Machining Quality(2.1-4.0); Grade III = Low Machining Quality(4.1-5.0)

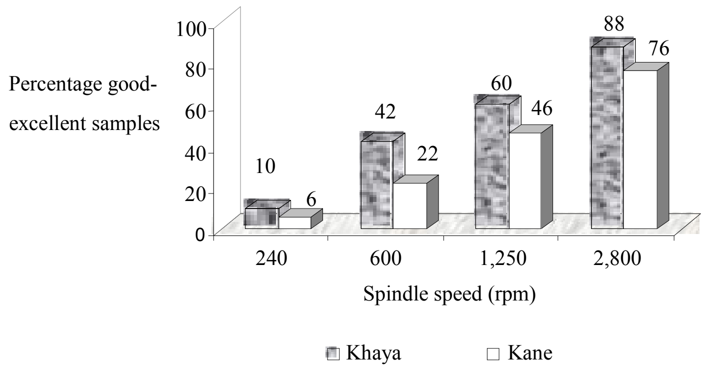

Figure 1: Relative turning qualities of Khaya and Kane

Comparative Shaping Quality

Figure 2 is the relative shaping quality of the species, which was based on the percentages of test samples that were graded good to excellent. The average ratings of the shaping results and the category of grade (asterisked) are also presented in Table 1. There were statistical differences between the three spindle speeds (3,000; 4,500; 6,000 rpm) at $P \leq 0.05$. The percentage of good to excellent samples of each of the two species, Figure 2, increased from a spindle speed of 3,000 rpm to 6,000 rpm. Also in Table 1, the machining quality is observed to improve towards the highest speed of 6,000 rpm. These show that shaping quality depends on spindle speed and that the higher the speed the better the surface quality. The percentage good to excellent samples of Khaya was greater than that of Kane at each of the three speeds. For example, at a speed of 6,000 rpm, Khaya and Kane scored 84% and 68% of samples respectively. The surface quality in terms of their ratings was also better for Khaya. As Kane was graded medium shaping quality (Grade II) with the three speeds, Khaya was categorized under high shaping quality (Grade I) with speed 6,000 rpm and medium shaping quality (Grade II) with speeds of 3,000 rpm and 4,500 rpm (Table 1). Cuts that were made in both diagonal and parallel to the grain of the wood species were consistently and noticeably better than that perpendicular to the grain which confirms the assertion made by Dinwoodie (1980) and Hoadley, (1980). The defects observed on the test samples of the two species at the various directions of cut were surface roughness, fuzzy grain, chipped/torn grain and raised grain. These were more pronounced on the Kane species than Khaya.

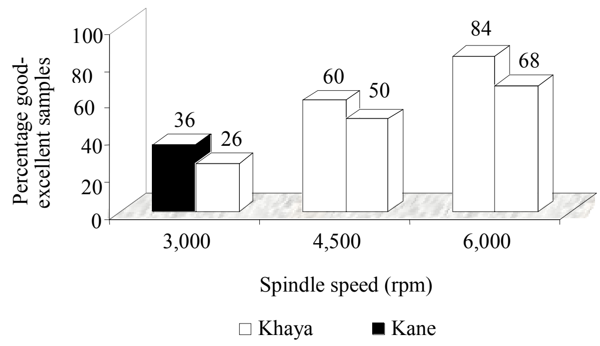

Figure 2: Relative shaping qualities of Khaya and Kane

Comparative Boring Quality

There were also statistical differences at $P \leq 0.05$ between the six spindle speeds (300; 600; 900; 1,400; 2,200; 2,900 rpm) and the four feed speeds (0.9; 1.5; 2.4; 3.9 mm/min) that were used for the boring tests at $P \leq 0.05$. The results of the relative boring qualities of the species based on the percentages of the bored holes graded good to excellent are shown in Figures 3-8. Again, as Figure 9 indicates the variation from size of bored holes in Khaya and Kane and Figure 10 shows the relative smoothness of cut in relation to the spindle speed. The average ratings, which is an indication of the degree of the machining defects, are also presented in Table 2. The percentage good to excellent bored holes with spindle speeds of 300 rpm, 600 rpm, 900 rpm and 1,400 rpm are as shown in figures 3-6 and the rating quality shown in Table 2, increases with increasing feed speed but the trend reverses with the spindle speeds of 2,200 rpm and 2,900 rpm (Figures 7and 8). This is because there were too much fibre crushing and tearouts with spindle speeds of 2,200 rpm and 2,900 rpm as the feed speed increased from 0.9 mm/min to 3.9 mm/min than was observed with the comparatively lower spindle speeds (300 rpm – 1,400 rpm). This finding is partially in agreement with the statement reported by Davis (1962) that low speeds generally produce better surface quality than high speeds.

The percentage of good to excellent bored holes (sum of the 4 feed speeds results for each spindle speed) is higher with the spindle speed of 1,400 rpm and the lowest percentage was scored with a spindle speed of 2,900 rpm for all the species (Fig.10). It was also observed that at a feed speed of 0.9 mm/min, most of the defective bored holes were due to fibre charring especially with spindle speeds of 300 rpm and 600 rpm and was prominent with Kane. This might be due to the heat generated by the inefficient cutting action, which caused the extreme tip of the drilling bit to lose its temper. Again, as asserted by Dinwoodie (1980), the presence of resins and gums that stick to tools or cutters result in overheating and hence change the normal working temperature. Khaya at all feed and spindle speeds recorded higher percentages of good to excellent bored holes than Kane as shown in Figures 3-9. The rating results also indicate that Khaya has a better boring quality than Kane at all the speeds. The best combination of speeds for the production of high quality bored holes (1.0-2.0) in Khaya and Kane are shown asterisked (*) in Table 2. Out of the 24 combinations of feed and spindle speeds, 15 produced Grade I holes for Khaya as against 11 for Kane.

On the variation from the sizes of the bored holes, there were no significant differences (using the Chi-test square) at $P \leq 0.05$ between the four feed speeds and the six spindle speeds. Figure 9 shows the average variation from size of bored holes (amount off-size) recorded for each of the six spindle speeds. The amount off-size, from Figure 9, increases with increasing spindle speed for Khaya, with a basic density of 661 Kg/m^3, as each of the spindle speeds, recorded a higher amount of off-size than Kane of basic density of 750 Kg/m^3. Some of the wood samples of, especially, Kane had their bored holes averaged slightly smaller than the size of the drill bit used. This might be due to the recovery of fibres that were flattened, bent or compressed during boring and then partially recovered their original position. However, oversize holes were much more common than those undersize. Measurements of the bored holes were consistently larger across the grain than parallel to it.

Table 2: Machining (rating) quality of bored holes at different speeds

Speed m/min	300 rpm		600 rpm		900 rpm		1,400 rpm		2,200 rpm		2,900 rpm	
	Khaya	Kane	Khaya	Kane	Khaya	Kane	Khaya	Kane	Khaya	Kane	Khaya	Kane
0.9	2.8	3.3	2.2	2.4	1.9 *	2.1	1.7 *	1.8 *	1.7 *	2.1	2.1	2.4
1.5	2.2	2.6	1.9 *	2.2	1.7 *	1.9 *	1.4 *	1.6 *	1.9 *	2.3	2.4	2.7
2.4	1.9 *	2.2	1.7 *	1.9 *	1.5 *	1.6 *	1.2 *	1.4 *	2.4	2.6	2.9	3.3
3.9	1.7 *	1.8 *	1.5 *	1.6 *	1.2 *	1.4 *	1.1*	1.3 *	2.6	3.1	3.4	3.8

Rating: the nearer it approaches 1.0 the better the quality
Grade I = High Machining Quality(1.0-2.0); Grade II = Medium Machining Quality(2.1-4.0); Grade III = Low Machining Quality(4.1-5.0)

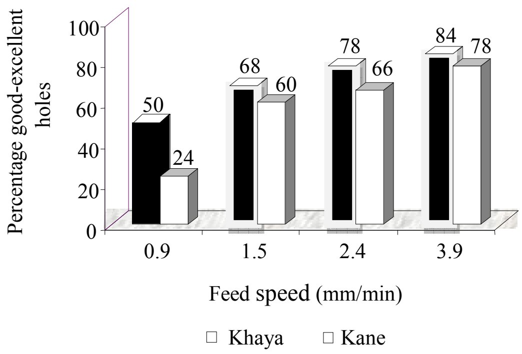

Figure 3: Relative boring qualities of bored holes with 300 rpm

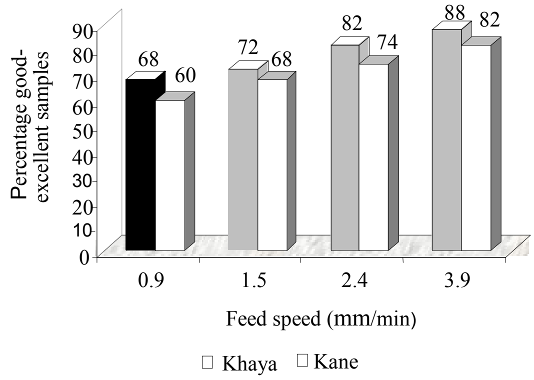

Figure 4: Relative boring qualities of bored holes with 600 rpm

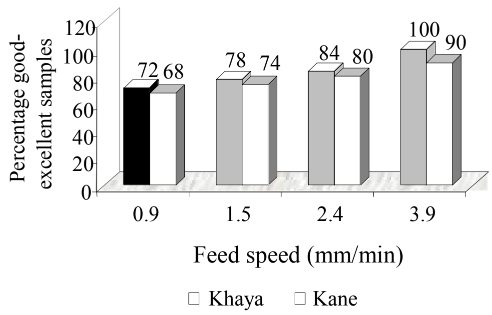

Figure 5: Relative boring qualities of bored holes with 900 rpm

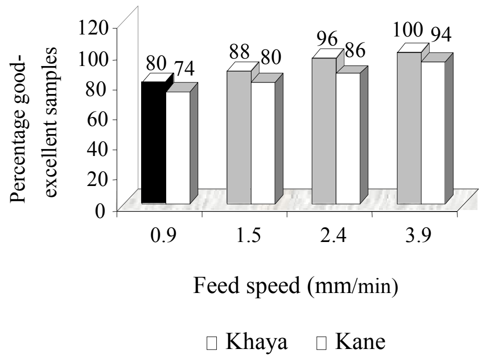

Figure 6: Relative boring qualities of bored holes with 1,400 rpm

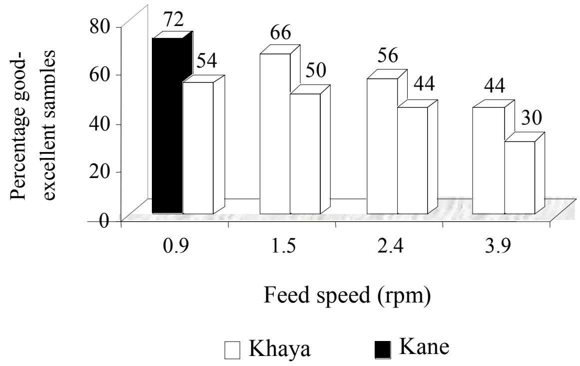

Figure 7: Relative boring qualities of bored holes with 2,200 rpm

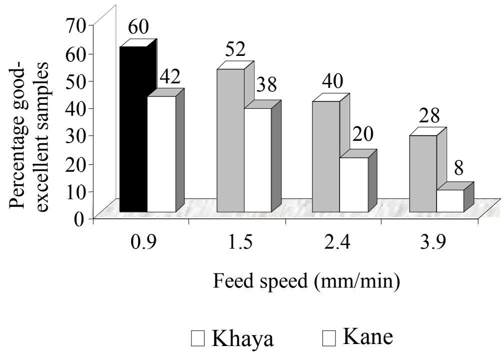

Figure 8: Relative boring qualities of bored holes with 2,900 rpm

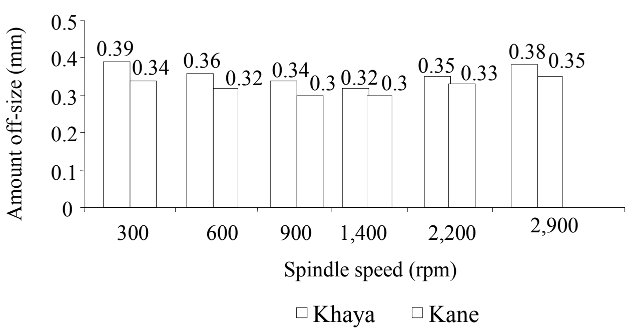

Figure 9: Variation from size of bored holes in Khaya and Kane

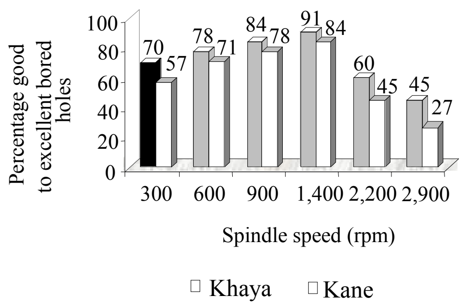

Figure 10: Relative smoothness of cut in relation to spindle speed

Comparative Sanding Quality

Figures 11–13 show the chipping/tearing, fuzzing and scratching tendencies of Khaya and Kane with six grits of sandpapers. With the use of grits 40, 60 and 80 for the elimination of chipped/ torn grain defect, which was generated on the wood species after planing, was observed to be easier with grit 40 (coarsest) followed by grit 60 (coarser) and lastly grit 80 (coarse). From Figure 11, the percentage defect-free (excellent) samples decrease with increasing grit size. Khaya scored 100% defect-free samples with grits 40 and 60 while Kane recorded 100% and 68% with the same grits. From the rating results, as shown in Table 3, the two species sanded with the three grits are categorized under high sanding quality species (Grade I).

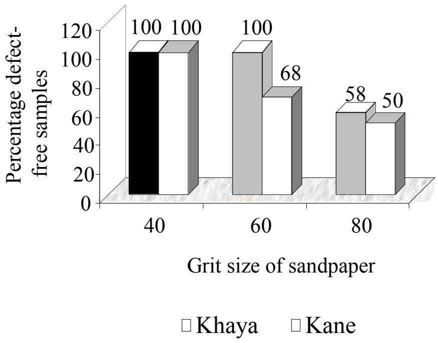

Figure 11: Relative freedom from chipping in Khaya and Kane after sanding

The fuzzing tendencies with grits 100, 120 and 150 as shown in Figure 12, indicates that increasing grit size minimises the degree of fuzz generation on the wood samples and that grit 150, the finest grit, recorded the highest percentages of defect-free samples for Kane (100%) and Khaya (96%). The three grits with a rating score range of 1.0 and 1.3 (Table 3- fuzzing tendency) for the species shows that the species have high sanding quality (Grade I).

The scratches made by the belt sander on the wood samples were observed to be straight lines and these were pronounced with the grits (100, 120 and 150) used. Figure 13, which shows the percentage scratch-free samples, indicates that the higher (finer) the grit size the minimal the degree of scratches that were observed on the surfaces of the wood samples. For instance, with grits 150 & 100, Khaya and Kane recorded 82% & 34% and 70% and 18% scratch-free samples respectively. Since Davis (1962) has reported that coarse-textured species show less scratches than fine–textured species when they are sanded under the same conditions, it is suspected that the grain texture of Kane may not be the same as that of Khaya. From the rating results (Table 3 – scratching tendency), the sanding quality ranges between 1.4 and 2.3, which indicates that in preparing the surfaces of the two wood species for the application of finishes, more finer grits than 150 should be used in order to prevent scratch formation.

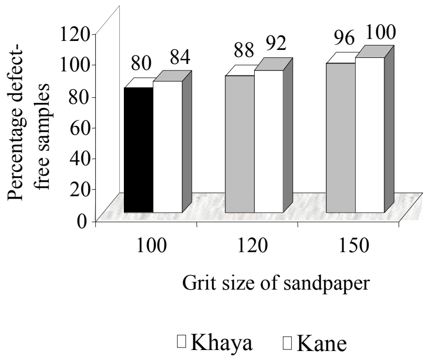

Figure 12: Relative freedom from fuzzing in Khaya and Kane after sanding

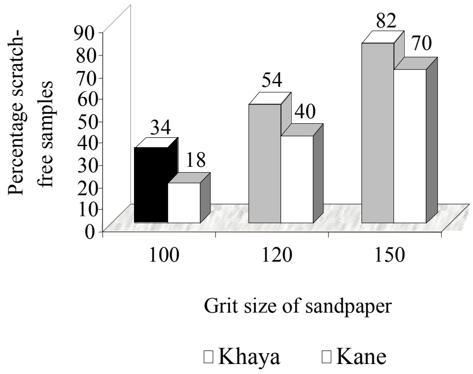

Figure 13: Relative resistance to scratching of Khaya and Kane after sanding

Table 3: Sanding quality of Khaya and Kane

Species	Chipping tendency			Fuzzing tendency			Scratching tendency		
	Grit 40	Grit 60	Grit 80	Grit 100	Grit 120	Grit 150	Grit 100	Grit 120	Grit 150
Khaya	1.0	1.0	1.3	1.3	1.2	1.0	2.0	1.8	1.4
Kane	1.0	1.2	1.7	1.2	1.1	1.0	2.3	2.0	1.6

Rating: the nearer it approaches 1.0 the better the quality
Grade I = High Machining Quality (1.0-2.0);
Grade II = Medium Machining Quality (2.1-4.0);
Grade III = Low Machining Quality (4.1-5.0)

CONCLUSION

A rating obtained by averaging grades of test samples has been established and that the lower the rating the better the machining quality. The results have shown that Khaya has better machining qualities than Kane even though their basic densities at 16% moisture content are 661Kg/m^3 and 750Kg/m^3 respectively. Spindle speeds of 2,800 rpm and 6,000 rpm generated high turning and shaping qualities (grade I) respectively for the two species.

Both species were observed to char in boring at feed and spindle speeds of 0.9 mm/min and 300/600 rpm while fibre crushing and tearouts occurred at speeds of 0.9 mm/min and 2,200/2,900 rpm and that fibre charring was more prominent in the bored holes of Kane than Khaya. Within the range of 0.9 mm/min & 3.9 mm/min feed speeds and 300 rpm & 2,900 rpm spindle speeds that were used in the boring test, 15 and 11 of the combinations of the speeds produced grade I samples for Khaya and Kane respectively. The amount of off-size to the bored holes of Khaya were consistently and slightly higher than that of Kane but the bored holes in both species were found to be consistently larger across the grain than parallel to the grain.

The sanding results indicated that grits 40, 60 and 80 scored grade I (high sanding quality) for each of the species. Again, the species were graded I with grits 100, 120 and 150 for the fuzzing tendencies. The relative resistance to scratching has shown that with each of the grits 100, 120 and 150, Khaya scored only grade I while Kane scored grade I with grits 120 and 150.

The high machining quality that has been exhibited by Khaya amidst its reddish-brown colour justifies its utilization, especially in the furniture industry. Again, it has a high potential of replacing the Mahogany species. Kane, on the other hand, could be used in the construction industry where surface quality is not of prime importance.

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