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Timber species from Afram arm of the Volta Lake in Ghana: Planing and sanding properties

Francis Wilson Owusu*, Felix Boakye and Godwin Zorve

CSIR, Forestry Research Institute of Ghana (FORIG), Kumasi-Ashanti, Ghana.

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Volumes of timber logs (dead trees) in the Volta Lake in Ghana, that had become a dead trap for water transportation, were being extracted for utilization to increase the timber resource base. Unfortunately, their properties were not known for efficient promotion and utilization. The influence and relative significance of machine surface planing and sanding parameters in the production of good quality timber surface finish on four underwater timber species from the Volta Lake were investigated. The preparation of test specimens, testing, evaluation and grading of the tests specimens were conducted according to ASTM-D 143, 1666-87 and DIN 4768. A cutting depth of 2 mm was made constant. Wood specimens were planed and sanded at 12% moisture content and the surface qualities obtained were visually graded. Surface quality performance increased with decreasing rake angle and feed speed. Low rake angle of 15° with 6 m/min and 9 m/min feed speeds resulted in a high planing quality. The degree of magnitude of the chipped/torn grain defects decreased with decreasing rake angle and feed speed. Grit sizes of sand paper had significant effect on the surface quality of the four species. The chipped/torn grain defects observed were eliminated from all the wood species with grit size 40. High surface sanding quality was registered for all the species with grit 150.

Key words: Feed speed, planing quality, rake angle, sanding quality, surface quality.

INTRODUCTION

The flooding of the Volta Lake in Ghana after its creation in 1965 submerged thousands of hardwood trees (Figure 1), which have been posing danger to water transportation, but at the same time could be useful as timber when harvested. As Ghana's timber resource base is dwindling, there is the need to find alternative resources to feed the timber industry, hence attention being turned to the large volumes of timber under the Volta Lake. However, like the lesser-used and lesser-known timber species, the underwater species need to be promoted to enhance their utilization, but it is not known whether their properties remain the same as the species from the natural forest. It is therefore necessary to establish their properties, which include machining, for their efficient promotion. The study was to determine the planing and sanding characteristics of four timber species harvested from the Volta Lake and recommend some potential uses. Some of the timber logs that had been

*Corresponding author. E-mail: fwowusu3@yahoo.com. Tel: 233-277400036.

Figure 1. Some hardwood trees in the Volta Lake.
Source: Field (2007).

harvested and identified as *Manilkara multinervis* (Berekankum), *Erythrophyleum guinense* (Potrodom), *Diospyros mespiliformis* (Savannah Ebony) and *Cylicodiscus gabunensis* (Denya / Okan) with their scientific and local names respectively, were used for the study.

The results from the study will facilitate the promotion of the new timber resource, thereby making more timber logs available for processing and utilization by the timber industry and revive some of the timber companies that are at the point of collapse. This will lead to reduction of the rate of accident on the Volta Lake, generation of employment which will enhance the livelihood of the local communities around the Volta Lake, save the Ghanaian forests from total depletion in the near future and increase in the country's annual revenue through export of timber products.

One of the most important advantages of wood is its easy machinability in contrast to metal and plastic products (Sofuoğlu and Kurtoğlu, 2014). Karpat and Özel (2007) have indicated that for manufacturers to remain competitive on both local and international markets, they must increase their productivity while maintaining, if not improving, product quality. Any surface defects due to an improper machining process will also reduce the quality of the final product, resulting in an increase in the cost of the manufactured unit (Malkoçoğlu and Özdemir, 2006).

In the machining operations, production rate, cost, and product quality are three incompatible objectives (Cus and Zuperl, 2006). They continue that as the machining industry welcomes the introduction of new materials and cutting tools, it finds itself undergoing a rapid development which is giving rise to processes of highly complex and non-linear phenomena.

Ambrogio et al. (2008) and Tamizharasan et al. (2006) have stated that surface quality in machining is an essential consumer requirement because of its impact on product performance. Also the characteristics of machined surfaces that significantly influence its physical properties have been pointed out by Basheer et al. (2008). Sogutlu and Togay (2011) have also stated that surface roughness is an important factor in the quality of the internal and external decorative elements produced from wood. Chang and Lu (2006) and Oktem et al. (2006) have indicated that surface roughness plays an important role in determining the quality of a machined product.

Surface roughness has been defined by Benardos and Vosniakos (2003) as the superimposition of deviations from a nominal surface from the third to the sixth order where the orders of deviation are defined by international standards, DIN 4760 (1982). Correa et al. (2009) have also defined surface roughness as the functional behavior of a part. Roughness is a measure of the fine irregularities on a surface. The shape and dimensions of the irregularities on a surface determine surface quality of a product. According to Hiziroglu and Kosonkorn (2006) the surface roughness of a wood panel plays an important role since any surface irregularities may show through thin overlays reducing the final quality of the wood panel. Roughness is thus an indicator of process performance and must be controlled within suitable limits for particular machining operations and that the factors leading to roughness formation are complex (Pal and Chakraborty, 2005). Benardos and Vosniakos (2002) and Tan et al. (2012) have declared that statistically significant in roughness formation are the absolute values of cutting parameters such as depth of cut, feed speed, and components of cutting force.

Various techniques, according to Gurau et al. (2005); Hendarto et al. (2005) and Sandak and Tanaka (2005) that have been used to determine surface roughness include optical, pneumatic, electrical, ultrasonic, photographic and stylus methods. It has also been found by Sieminski and Skarzynska (1989) that the stylus-type profilometer was suitable within the tested methods for the measurement of the surface roughness of wood.

Surface roughness is influenced by the rays, pore sizes, knots and reaction wood (Taylor et al., 1999). Skaljic et al. (2009) have also reported that physical and mechanical properties and anatomical structure of wood affect the surface roughness. As the number of blades increases, the surface roughness values decrease, and as the feed rate increases, the surface roughness also increases (Ors and Baykan, 1999; Roger and Cool, 2008).

In planing, the different cutting angles and number of cutters had different effects on surface quality in terms of wood species (Ratnasingam and Scholz, 2007; Malkoçoğlu and Özdemir, 2006). For good machining quality, the cutters used in the machining of the material should be sharpened and machinery should be maintained and stablized (Sofuoğlu and Kurtoğlu, 2014).

In general, better machining performance is obtained with decreasing feed speed (Skaljic et al., 2009). Moreover, increasing feed speed has been reported to cause strong machining defects (Malkoçoðlu, 2007). Farrokhpayam et al. (2010) have also stated that small differences between the different levels of the feed rate affect surface quality and that the slowest feed rate of 8 m min $^{-1}$ gives the best results, with progressively poorer work as fastest feed speed is used. Fujiwara et al. (2001) have confirmed in various studies that if variables such as the feed rate are not selected correctly, then the desired surface quality will not be obtained. Sogutlu and Togay (2011) have reported that when the Oriental beech (*Fagus orientalis* Lipsky) and Scotch pine (*Pinus silvestris* L.) wood specimens were prepared by planing, the surface roughness was less in the tangential cut as compared to the radial cut. Furthermore, the surface roughness was less in planing with 4 blades as compared to planing with 2 blades. Best surface quality could be achieved where the depth of the final cut is from 1 to 2 mm and that excess stock removal of more than 2 mm will cause chipped/torn grain or pickup defects (Tjernlund, 1984).

In planing and sanding, the degree of surface roughness is dependent on the properties of the raw material and production processes (Hendarto et al., 2005; Nemli et al., 2005, 2007). A study by Nemli et al. (2007) shows that grit sizes, feed speed of panels and the feed power of the heads of the sander are the main considerations for a successful sanding operation. Also a report by Beaty (1983) and NPA (1993) indicate that sanding equipment, coated abrasive belt specifications, production scheduling and correct machine setup are the main considerations for successful sanding operation. Sanding is the most common and most influential operation for achieving surface quality during the phase of surface preparation (Skaljic et al., 2009). There is the need to recognize and understand the key factors and variables that affect selection of sanding system, sanding equipment, sanding quality and the ultimate performance of the finished product.

The study sought to investigate the effect of the process parameters that exert significant influence on the surface quality of Savanna Ebony, Berekankum, Denya/Okan and Potrodom (extracted from the Volta Lake in Ghana) after planing and sanding operations. Specifically, the effects of the rake/hook angles, spindle speeds, feed speeds and grit sizes of sand paper on wood planing and sanding qualities were investigated.

MATERIALS AND METHODS

Collection of samples

Four (4) timber species used for the study were *Manilkara multinervis* (Berekankum), *Erythrophyleum guinense* (Potrodom), *Diospyros mespiliformis* (Savannah Ebony) and *Cylicodiscus gabunensis* (Denya / Okan) in their scientific and local names respectively. These were the timber species that had been harvested from the Volta Lake by Clark Sustainable Resource Development (CSRD) at the time of the study. According to their utilization status, *M. multinervis* was a lesser-known timber species while the remaining three were lesser-used timber species (Oteng-Amoako, 2006). Using through and through sawing pattern, the logs were milled into lumber at Forestry Research Institute of Ghana (FORIG) under the Council for Scientific and Industrial Research (CSIR), Fumesua near Kumasi in the Ashanti region. The lumber pieces obtained from each timber species were stacked for air drying.

Preparation of tests specimens

ASTM D 143-94, ASTM D 1666-87 (ASTM, 2004; 2007) and DIN 4768 with some required adjustments were used to prepare the planing and sanding tests specimens. Some lumber boards of 25 mm thickness were taken from the stacked lumber, kiln dried to 10% moisture content for the preparation of 300 specimens of dimensions 25 × 100 × 900 mm. They were then conditioned to 12% equilibrium moisture content at 27°C and 65% relative humidity

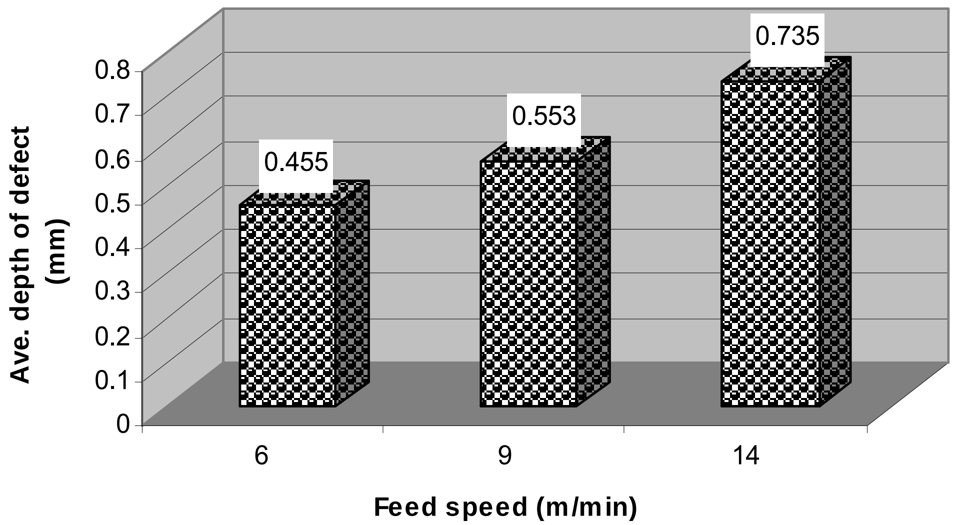

Figure 2. Average depth of chipped/torn grain defect with two cutting angles.

for ten days before the planing test.

Planing test

Planing was done using a combined surfacing and thicknessing machine of type 610 mm × 230 mm 'D.A.A' at a spindle speed of 5,200 rpm. A cutter head with a pair of planer knives were used. The selected feed speeds and rake/hook angles were 6 m/min, 9 m/min and 14m/min and 15° and 20° respectively. With six planing operations, 25 test specimens per operation were made to pass through the planer until all the operations were completed before they were graded in accordance with ASTM D 1666-87. A constant depth of cut of 2 mm per face of two for each specimen was set.

Grading

The specimens were then examined visually, with the aid of a hand lens, evaluated and classified, according to ASTM D 1666-87, on the basis of five quality grades [grade 1 = Excellent or defect-free; grade 2 = good; grade 3 = fair; grade 4 = poor and grade 5 = rejected or very poor. (Grades 2-5 were dependent on the degree of the defect observed)]. Percentage defect-free specimens was calculated for each rake angle and feed speed, as shown in Table 1. The depth of each chipped/torn grain (which is a machining defect), observed on the surfaces of the specimens, was measured and the average for each operation (a rake angle and feed speed) estimated (Table 2).

Sanding test

Sanding operation was undertaken with a vertical belt sander of model CL300. Five grit sizes of sand paper, P40, P60, P100, P120 and P150 were used. The grits were with open-coat paper-backed aluminum oxide sandpapers coated with anti-static zinc stearate. Sanding was carried out along the grain. The defective specimens (chipped/torn grain) were selected from the planed specimens and sanded with grit sizes 40 and 60 to assess the possible elimination of the defect. The specimens without the defects were sanded with grits 100, 120 and 150 for the assessment of the final surface quality for the application of finishes. The degree of scratches observed on all the specimens per species with grits 100, 120 and 150 were noted. The same grading procedure as stated above was used to grade the specimens and the percentage defect-free specimens (grade 1) were estimated for both sanding activities per species (Tables 3 and 4).

RESULTS AND DISCUSSION

Planing properties

The results on planing properties were based on clear specimens (ASTM D 143-94 and 1666-87, 1994). To identify the best planing performance, each planing condition was examined separately. Table 1 shows the percentage defect-free specimens with respect to feed speeds and or rake/hook angles for the four timber species. Analysis of variance (ANOVA) was used to test for the significant differences among the three feed speeds, two rake angles and the species. At P = 0.05, the significant differences in planing quality existed among the different feed speeds. The percentage defect-free specimens increased with decreasing feed speed. This means that the lower the feed speed the better the surface quality. This was consistent with all the timber species as feed speed changed from 6 m/min to 14 m/min (Table 1). This is also reflected in Table 2 and Figure 2 where the average depth of chipped/torn grain generated after planing decreased with decreasing feed speed. Therefore the best surface quality was generated with a feed speed of 6 m/min (72-100%) followed by 9 m/min (68-92%) and then 14 m/min (44-72%). Figure 3 shows the average percentage defect-free specimens for

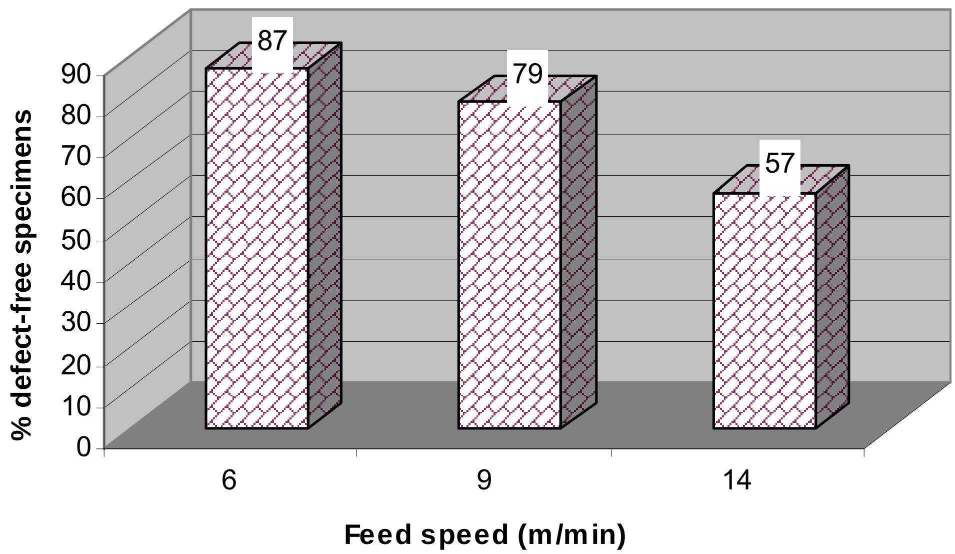

Figure 3. Average percentage defect-free specimens for two rake angles.

the two rake angles. The trend is in agreement with Ors and Baykan (1999) and Roger and Cool (2008) whose reports indicate that as the feed speed increases, the surface roughness also increases. It also confirms the statement by Fujiwara (2001) that if variables such as feed speed are not selected correctly, the desired surface quality will not be obtained. Results of the average percentage defect-free specimens indicate that feed speeds 6, 9 and 14 m/min could be rated as high, medium and low surface quality respectively

The surface quality of all the timber species was affected by the rake angle, as shown in Table 1. The results indicate that the percentage defect-free specimens increased with decreasing rake angle and that 15° rake angle recorded higher percentages than with 20°. The average percentages of defect-free specimens estimated for 15 and 20° rake angles are 81% (high surface quality) and 67% (medium surface quality) respectively. This implies that surface quality was higher with the lower rake angle of 15° than with 20°. The results showed significant differences between the rake angles at P=0.05. A similar trend/pattern has been recorded by Fortin (2001) that "the proportion of defect-free pieces increased as the rake angle decreased from 20 to 15°" and therefore has proposed a rake angle of 15° for planing White spruce wood from plantation forests. Gilmore and Barefoot (1974) have also proposed 15° rake angle for planing some tropical wood species from South America. From Table 2, as the rake angle decreased from 20 to 15° (for each feed speed) the depth of the chipped/torn grain defect also decreased in magnitude. For example, the average depth of the defect at 15° hook angle varied from 0.49 mm (for Ebony) to 0.56 mm (for Potrodom) while that at 20° also varied from 0.57 mm (for Ebony) to 0.65 mm (for Potrodom). The minimum and maximum average magnitudes of the depth of the defect at 15 and 20° with the three feed speeds were estimated to be 0.36-0.73 and 0.44-0.8 mm respectively. On the average 0.6 mm maximum depth was estimated for every species. Therefore the average magnitude of the defect for the three feed speeds was lower with 15° rake angle than 20° as shown in Figure 4.

Generally the planing results have shown that feed speed and rake angle are among the major factors that control wood failure during planing as have been recorded by Sogutlu and Togay (2011) and Fortin (2001). Hence feed speeds of 6, 9 and 14 m/min with a rake angle of 15° will be more appropriate for the planing of the selected timber species.

Comparing species in terms of surface quality, the average percentage defect-free specimens for all the conditions ranged between 67% (for Berekankum) and 80% (for Savanna Ebony). At 95% confidence interval, there was no significant difference between the surface quality of Denya/Okan and Potrodom which recorded an average of 74 and 75% defect-free specimens respectively. This means that the two timber species may have some common anatomical characteristics; hence planing them with the same machine setting will generate equal surface planing quality. According to Oteng-Amoako (2006), Denya and Potrodom are both coarse textured species and therefore confirms the findings of Tailor et al. (1999) that surface roughness is also influenced by rays and pore sizes. Figure 5 shows grade 1 planed specimens of Ebony, Denya, Berekankum and Potrodom. Introducing performance rate classification whereby 80-100% = high surface quality; 60-9%= medium surface quality; 40-59% = low surface quality and below 40% = poor surface quality, Savanna Ebony, on the average, recorded a high surface quality while the

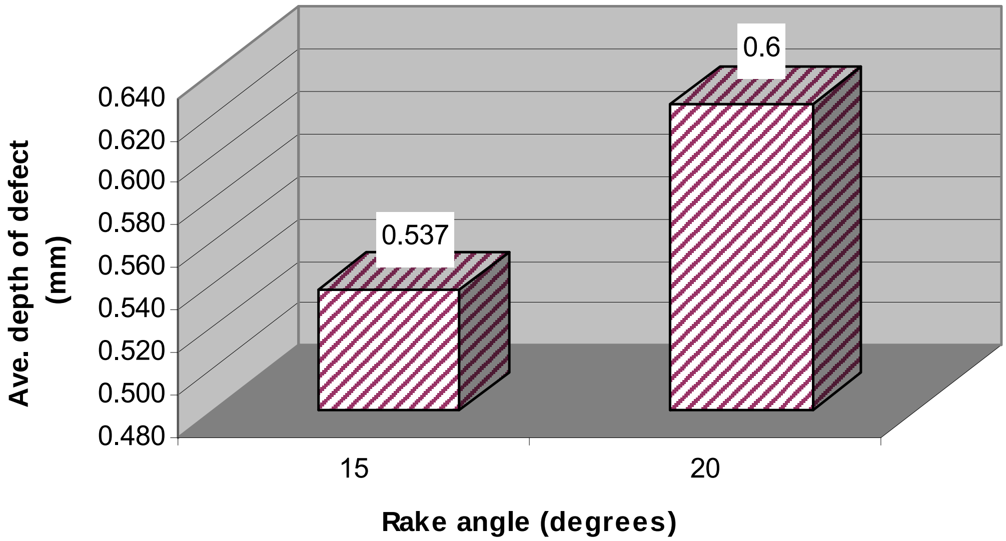

Figure 4. Average depth of chipped/torn grain defect with three feed speeds.

Figure 5. Grade 1 specimens of the four timber species.

three other species attained medium surface quality (Table 1). The average percentage surface quality for all the species with the planing tests conditions was estimated to be 74.2%, which from the machining rating introduced, could be classified as medium surface quality for every species. A report by Farmer (1972) shows that a rake angle of 10° is required for satisfactory planing of Denya (from the natural forest) when it is quarter-sawn, but the feed speed(s) and the percentage defect-free specimens were not specified. Denya (from underwater) with an average score of 75% defect-free specimens (medium surface quality rating) may be equivalent in

Table 1. Percentage defect-free specimens at two hook angles with three feed speeds

Species	Percentage defect-free specimens						
	6 m/min		9 m/min		14 m/min		Average on species basis
	15°	20°	15°	20°	15°	20°	
Berekankum *(Manilkara multinervis)*	84	72	76	68	60	44	*67.3*
Potrodom (*Erythrophyleum guinense)*	92	84	88	68	64	48	*74.0*
Savannah Ebony (*Diospyros mespiliformis)*	100	88	92	76	72	52	*80.0*
Denya / Okan (*Cylicodiscus gabunensis)*	92	84	88	72	64	52	*75.3*
Average % per species	*92*	*82*	*86*	*71*	*65*	*49*	*74.2*

Table 2. Average depth of chipped/torn grain machining defect generated on each species with the planing conditions studied.

Species	Magnitude of defect in millimeters (depth)						
	6 m/min		9 m/min		14 m/min		Average on species basis
	15°	20°	15°	20°	15°	20°	
Berekankum *(M. multinervis)*	0.42	0.50	0.50	0.62	0.71	0.78	0.6
Potrodom (*E. guinense)*	0.43	0.52	0.52	0.65	0.73	0.79	0.6
Savannah Ebony (*D. mespiliformis)*	0.36	0.44	0.47	0.55	0.65	0.72	0.5
Denya / Okan (*C. gabunensis)*	0.44	0.53	0.51	0.60	0.70	0.80	0.6
Average % per species	0.41	0.50	0.50	0.61	0.70	0.77	0.6

Table 3. Percentage defect-free specimen after sanding to remove defects with two different grit sizes.

Species	Percentage defect-free specimen	
	Grit size P60	Grit size P40
Berekankum (*M. multinervis*)	80	100
Potrodom (*E. guinense)*	80	100
Savannah Ebony (*D. mespiliformis)*	100	100
Denya / Okan (*C. gabunensis)*	80	100

Table 4. Scratching tendencies of specimen after sanding with three different grit sizes.

Species	Percentage scratching tendency		
	Grit size P100	Grit size P120	Grit size P150
Berekankum (*M. multinervis*)	56	72	80
Potrodom (*E. guinense)*	60	76	88
Savannah Ebony (*D. mespiliformis)*	48	60	80
Denya / Okan (*C. gabunensis)*	60	80	92

planing quality to that from the natural forest.

Sanding properties

Table 3 shows the percentage defect-free sanded specimens when sand paper of grit sizes 60 and 40 were used in that order. At P = 0.05, there were significant differences between grit sizes of sand papers used. With the chipped/torn grain defects that were generated after planing, grit size 60 was able to remove them from Savanna Ebony, hence scoring 100%; while Berekankum, Potrodom and Denya with 80% defect-free specimens, still had some degree of the defects on the surfaces of some of the specimens. Using sandpaper with grit size 40, the entire chipped/torn grain defects were eliminated from the wood specimens. This implies that sand paper with grit size 40 is capable of eliminating any chipped/torn grain defect from the wood members of the four timber species before further sanding could be under taken for the application of finishes. It was therefore established that the various degree of magnitude of the defect that was eliminated with grit 60 were comparatively shallower and did not affect the thickness of the specimens involved. Such shallower defect was classified by the study as chipped grain while torn grain was referred to that defect which reduced the thickness of the wood specimens above 1.5 mm. Such a reduction could affect the service life of a dimensioned wood member that is put in service (for instance, in production of furniture or roofing). According to Owusu et al. (2011), the sanding quality of Denya (from the natural forest) with grit P60 at 12% moisture content was rated as high, which is comparable to the results obtained in this study.

Grit sizes of 100, 120 and 150 were used to finally prepare the surfaces of the specimens for the application of finishes. This means that scratches formation on wood surfaces was possible at different degrees and hence has to be brought to the barest minimum. The degree of scratches generated on the wood surfaces was observed to decrease with increasing grit size and that the degree of scratches was minimal with grit size 150 than 120 and 100. Therefore higher grit size (in this case, 150) of sand paper is recommended for better finishing in order to effectively add value to tertiary wood products. This shows that grit sizes of sand paper affect surface quality and hence supports the research findings observed by Nemli et al. (2007). The scratches per grit size were observed to be prevalent on Savanna Ebony followed by Berekankum, Potrodom and Denya/Okan. This could be attributed to the texture of the species, and that scratches were obvious on fine textured species than course textured. Therefore the statement by Hendarto *et al.,* (2005); Nemli *et al*., (2007) and Nemli *et al.,* (2005) that the degree of roughness during sanding, as machining activity, is dependent on the properties of the raw material and the production processes is confirmed. It also supports the earlier finding by Owusu et al. (2011) that "the finer the texture of the species, the more pronounced the scratching tendency". The result on the scratching tendency of Denya (from underwater) with grit P120 is equivalent to Denya (from natural forest) at 12% moisture content (Owusu et al., 2011).

Potential uses of the species

Based on the results achieved, the following potential uses are proposed for the four timber species extracted from the Volta Lake: Berekankum *(M. multinervis)*: Furniture products and could be used in replace of African Mahogany. Savannah Ebony (*D.mespiliformis*): Furniture products and walking sticks and could be a good substitute for *M. altissima*. Potrodom (*E. guinense) and* Denya / Okan (*Cylicodiscus gabunensis)*: Interior carpentry and walking sticks

Conclusions

The study has revealed that the four timber species harvested from the Volta Lake have good planing and sanding performances. The surface planing quality increased with decreasing rake angle and feed speed. The best planing condition obtained was 15° rake angle with feed speeds of 6m/min and 9 m/min. The machining defects observed were chipped and torn grain. The average range of magnitudes of the defect in terms of depth with 6, 9 and 14 m/min feed speeds for the four species at 15 and 20° rake angles were 0.36-0.73 and 0.44-0.80 mm respectively. Shallower defect was classified by the study as chipped grain while torn grain was referred to that defect which reduced the thickness of the wood specimens above 1.5 mm. Consistently, Savanna Ebony performed better in all the planing operations.

Sand paper with grit size 40 was capable of eliminating any chipped/torn grain defect from the wood specimens of the four timber species. The degree of scratches generated on the wood surfaces decreased with increasing grit size and that was minimal with grit size 150 than 120 and 100. Therefore higher grit size (in this case, 150) is recommended for final sanding to achieve better finishing in order to effectively add value to tertiary wood products. Scratches were obvious on fine textured species than course textured.

The results obtained for Denya/Okan are comparable (if not better) to that from the literature, which come from the natural forest. Since the machining performance of Potrodom (*Erythrophyleum guinense)*, Berekankum *(Manilkara multinervis)* and Savanna Ebony (*Diospyros mespiliformis*) are equivalent to Denya/Okan (*Cylicodiscus gabunensis)*, it implies that their machining properties could also be comparable with those from the natural forest.

RECOMMENDATIONS

The results indicate that the four species from the Volta Lake recorded, at least, medium machining surface quality, hence a higher potential for processing and utilization. Wood users should therefore patronize them when seen on the timber market.

Conflict of Interest

The authors have not declared any conflict of interest.

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