COLD AND STEAM BENDING PROPERTIES OF SOME LESSER-USED SPECIES OF GHANA

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ABSTRACT

*The cold and steam bending properties of six selected lesser-used timber species of Ghana have been studied, with a view to providing technical data for the furniture and glulam industries. Differences between timber species and thicknesses of bending lamella have been found to be statistically significant in cold bending of the six species (P=0.05). Denya (*Cylicodiscus gabunensis*) has been found to have superior cold bending qualities for all thicknesses studied, followed by Essia (*Petersianthus macrocarpus*), Ceiba (*Ceiba pentandra*), Awiemfosamina (*Albizia ferruginea*) and Kyenkyen (*Antiaris toxicaria*) in order of decreasing performance. Although in 9 mm thickness, Celtis (*Celtis mildbraedii*) is next to Denya, its performance in 12 and 25 mm thickness is very low. Thickness factors derived indicate that thickness effect is severe in all the species, with Celtis and Ceiba showing the most severe effects. High density species also seem superior in cold bending properties to low density species. For steam bending, however, Celtis has best qualities, followed by Kyenkyen, Awiemfosamina, Denya, Essia and Ceiba in decreasing order. Whereas Ceiba's weakness under steam bending may be attributed to its brittle wood fibres and high porosity, Celtis' superior quality may be due to its fine texture, low porosity and straight grains. Density does not seem to influence steam bending qualities of the six species. Apart from Kyenkyen and Awiemfosamina, all the species studied may be recommended for cold bending, and only Celtis for steam bending in the furniture and glulam industries.*

***Keywords**: Cold and steam bending, Lesser-used species, Furniture, Glulam*

INTRODUCTION

The Ghana timber industry has depended on some few primary timber species for a very long time. Export statistics for wood in 1996 indicate that three species alone, Odum (*Milicia excelsa*), Wawa (*Triplochiton scleroxylon*) and Mahogany (*Khaya* spp.) comprised about 66 % of total exports of air-dried lumber. In the same year, Wawa, Koto (*Pterygota macrocarpus*) and Odum also comprised about 94 % of total exports of kiln-dried lumber (Forest Products Inspection Bureau, 1996). In Ghana's tropical rainforest, however, the logger has a vast array of over 420 different tree species to choose from (Ministry of Lands and Forestry, 1996; Ghartey, 1989; Hall & Swaine, 1981), yet only about 64 species are presently commercially exploited, out of which only a few species are dominant. The rest, the so-called lesser-used species (LUS) are not well exploited.

The over-dependence on only few primary species, besides indicating inefficient utilization of timber resources, has several undesirable consequences such as the imminent extinction of those species from the tropical rainforest (Ministry of Lands and Forestry, 1996; Ghana Forestry Department, 1994). Greater utilization of the LUS is expected not only to increase the output volume and value production per unit forest area, but also to reduce the level of disturbance occurring in the tropical rain forest resulting from the over-utilization of the few primary species. Utilization of the LUS will also result in sustainable management of the tropical rain forests (Ministry of Lands and Forestry, 1996).

Several attempts at marketing the LUS both locally and on the world timber market have been made in recent years; however, only little success has been achieved. It is certain though, that as the preferred traditional species become more scarce, wood users will begin to look more closely at a larger range of species. Utilization of the LUS, however, depends on the availability of reliable information on their properties and areas of application.

The versatility of wood for various purposes such as furniture, construction, and sporting goods sometimes requires it to be bent to various forms. Bent wooden chair parts and tennis rackets are common examples of the rather extreme bends in the furniture and sporting goods fields, whilst the laminated portal frame is another example in construction. Products with slight curves, like the back post or back rail of a dining room chair and other parts of furniture, may be either sawed or bent. However, such bent parts have the advantage of being more economical in material utilization and also of being stronger because of less cross grains than sawed parts (Tsoumis, 1991; Davis, 1962). Thus, bending is environmentally friendly as it reduces wood waste.

Wood bending involves the stretching of fibres of the wood specimen on the outer face of the bend and compressing those on the inner face by amounts required by the nature of the bend. Wood may either be cold or steam bent. However, bending solid wood to produce curved members, is usually done after steaming or other treatment of wood such as exposure to ammonia or urea if no gluing is done simultaneously. This way, the properties of the various woods are considerably improved (Tsoumis, 1991). Wood is usually plasticized by steaming or boiling at atmospheric pressure for a period not less than 30-40 min for 25 mm thick samples, since wood fibres are difficult to stretch in tension during cold bending (Kollman & Cote, 1968). Steaming is usually applied to air-dried wood (with moisture content of about 15 %) and the wood is bent on prepared forms of desired curvature (Tsoumis, 1991).

Steam bending is employed in bending several hardwoods in the timber processing industries. According to Davis (1962), many variables are involved in steam bending, such as the size of the material, its moisture content, the amount of steaming, radius of the bend required, and other details connected with the type of equipment used. Tsoumis (1991) reported that the practice of steaming or soaking wood in boiling water for short periods to improve its pliability for bending to sharp curvature has, in itself, only had minor damaging effect on its subsequent properties. In glulam construction, however, cold bending is usually done as the high moisture of the wood after steaming will hinder gluing. Gluing steam bent wood or steam bending straight laminated members may also be done (Tsoumis, 1991).

According to Tsoumis (1991), wood to be steam bent should be of good quality, without defects at least at the points where high stress develop during bending. Wood defects like irregular fibres, knots, checks, fractures, pitch pockets or ingrown bark will facilitate fracture during bending. Therefore clear, straight-grained wood is recommended for bending (Tsoumis, 1991; Kollman & Cote, 1968). Heartwood is also preferred in situations exposed to the weather (Tsoumis, 1991). Other factors such as age, width of growth increments, wood structure, relative amount of resin and other extractives in wood, soil characteristics and differences in genetic constitution of different wood species also have some influence on the bending qualities of wood (Tsoumis, 1991; Kollman & Cote, 1968).

Wood density also affects the performance in bending of timber and that high density timbers perform better than low density ones (Tsoumis, 1991; Kollman & Cote, 1968; Davis, 1962).

According to Tsoumis (1991), as the thickness of the bending lamella increases, its bending performance apparently decreases. This assertion is based on Weibull's statistical strength theory which states that there is a greater probability that a region of low strength will occur in a member of large volume than a member of small volume. Bohannan (1966) also assumed these regions of low strength to influence the performance of a bending member.

Excessive loading of a wooden beam is expected to cause a characteristic failure which may be classified, according to how it develops and the appearance of the broken surfaces, as cross grain tension, splintering tension and brashness (brittle tension), in accordance with ASTM D 143-94.

The cold and steam bending properties of many of the lesser-used species presently being promoted as substitutes for the over-used timber species in Ghana are, however, unknown. Bending properties are known to differ from species to species and the extent to which wood of a particular species can be bent into curved form depends on the species' peculiar characteristics (Tsoumis, 1991; Kollman & Cote, 1968).

The paper presents the results of a study undertaken to provide data on the cold and steam bending properties of the selected species for potential users in the furniture and glulam industries.

MATERIALS AND METHODS

Material Collection and Preparation

Wood samples for the study were collected from three ecological forest zones of Ghana — Moist Semi-deciduous (South-East type), Moist Semi-deciduous (North-West Forest type) and Dry Semi-deciduous (Fire Zone Forest type). Test samples were taken from three logs of each of the species from each ecological zone. The logs were of average diameter of 90 cm.

From each log six beams, each of 50 mm × 300 mm × 3000 mm dimensions, were sawn along the radial direction (Fig. 1) for the cold and steam bending tests. All the beams were kiln-dried to average moisture content of 12 %. Test specimens were prepared from clear, straight-grained wood samples cut along the length of each beam (Fig. 1). From each of the 54 beams of each species, three cold bending specimens of length 750 mm and width 75 mm were prepared for each of three thicknesses, 9, 12 and 25 mm, representing the usual lamella thicknesses used in the furniture and glulam timber industries (Tsoumis, 1991). Six steam bending specimens of 15 mm × 15 mm × 500 mm dimensions were also prepared from the same beam used for the cold bending. For cold bending, 486 specimens of each species were prepared for the three thicknesses, and 324 specimens for steam bending, in accordance with Tsoumis (1991), Kollman & Cote (1968) and Davis (1962). The six species studied were Denya (*Cylicodiscus gabunensis*), Kyenkyen (*Antiaris toxicaria*), Essia (*Petersianthus macrocarpus*), Celtis (*Celtis mildbraedii*), Awiemfosamina (*Albizia ferruginea*), and Ceiba (*Ceiba pentandra*).

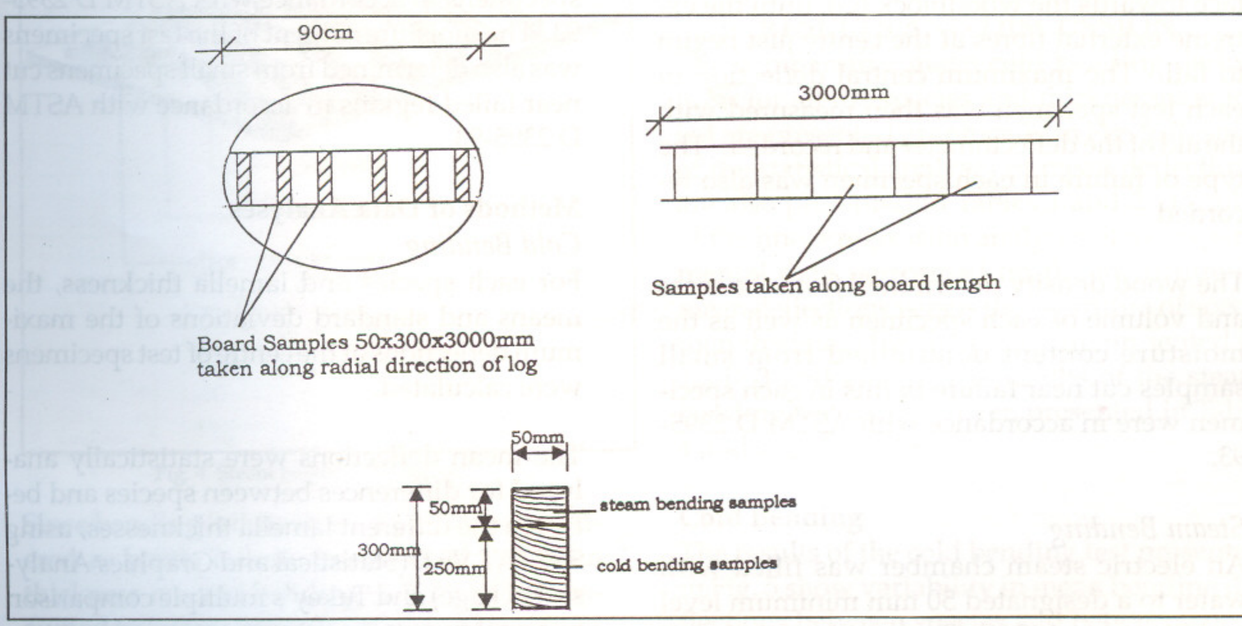


Fig. 1. Specimen cutting principle.

Testing Methods

Cold Bending

A simple jig was fabricated and used for the cold bending test (Fig. 2). This comprised of a plywood base (B) of 740 mm x 400 mm x 25 mm dimensions, an attached wooden block (G) of 70 mm x 45 mm x 740 mm dimensions, two adjustable wooden blocks (F) used as supports, and a steel deflectometer (E). Pressure was applied by a T-shaped steel section bar clamp (C), fitted with threaded steel bar (I) and an adjustable shoe (J).

The test specimen (D) was placed with its ends projecting 50 mm beyond each support (F) and wedged at the supports to keep it clear of (B) during bending. The clamp (C) was then set over the specimen and supported on a wooden block (A) and a piece of timber (H), so that the weight of the clamp could be kept off the specimen. With the clamp set, the adjustable shoe (J) was placed at the marked centre of the specimen. A hardwood bearing was placed between the shoe of the clamp and the specimen such that the surface in contact with the specimen was curved in a direction along the length of the specimen. This is to prevent the edges of the shoe from crushing into the fibres of the test piece when pressure was applied. By tightening the clamp, the test specimen was bent at its centre, with the convex face towards the woodblock (G), until the extreme external fibres at the centre just begun to fail. The maximum central deflection in each test specimen was then measured with the aid of the deflectometer and recorded. The type of failure in each specimen was also recorded.

The wood density determined from the mass and volume of each specimen as well as the moisture content determined from small samples cut near failure points in each specimen were in accordance with ASTM D 2395-93.

Steam Bending

An electric steam chamber was filled with water to a designated 50 mm minimum level and heated to 100 ^{0}C. Test specimens of each species were then put into the pre-heated

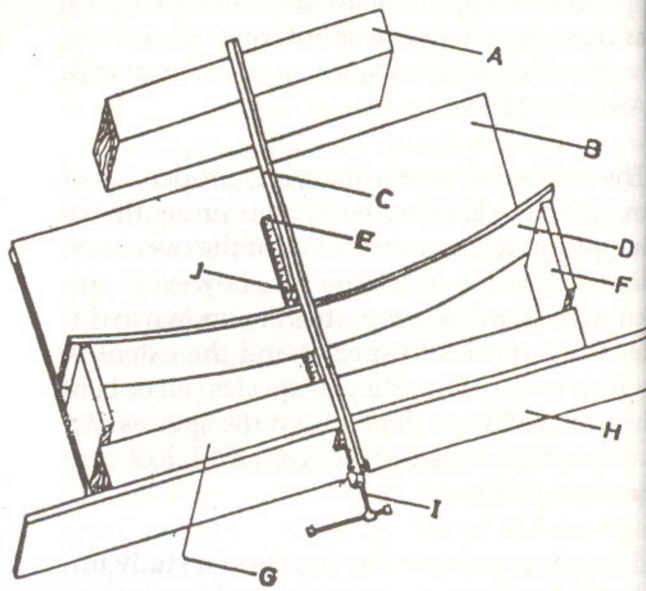


Fig. 2. Schematic diagram of cold bending test set up.

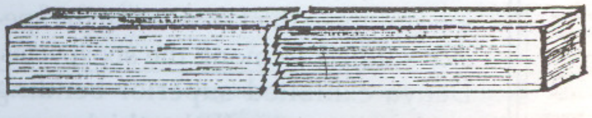
steam chamber in batches and allowed to steam for 60 min. On removal from the steam chamber, specimens were hand bent, whilst hot, to a radius of 660 mm on a pegged form (Fig. 4) and then given time to set (Davis, 1962). The quantity of failed specimens and the types of failure (Fig. 3) were recorded in each species. The density of each test specimen was determined from the mass and volume of the specimens in accordance with ASTM D 2395-93. The moisture content of the test specimens was also determined from small specimens cut near failed regions in accordance with ASTM D 2395-93.

Methods of Data Analyses

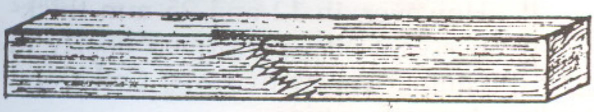
Cold Bending

For each species and lamella thickness, the means and standard deviations of the maximum deflections at the centre of test specimens were calculated.

The mean deflections were statistically analyzed for differences between species and between the different lamella thicknesses, using SYSTAT V5.0 (Statistical and Graphics Analysis Package) and Tukey's multiple comparison test package.



(a) Brittle (brashness) tension failure



(b) Splintering tension failure

(c) Cross grain tension failure

Fig. 3. Failure types under steam bending test.

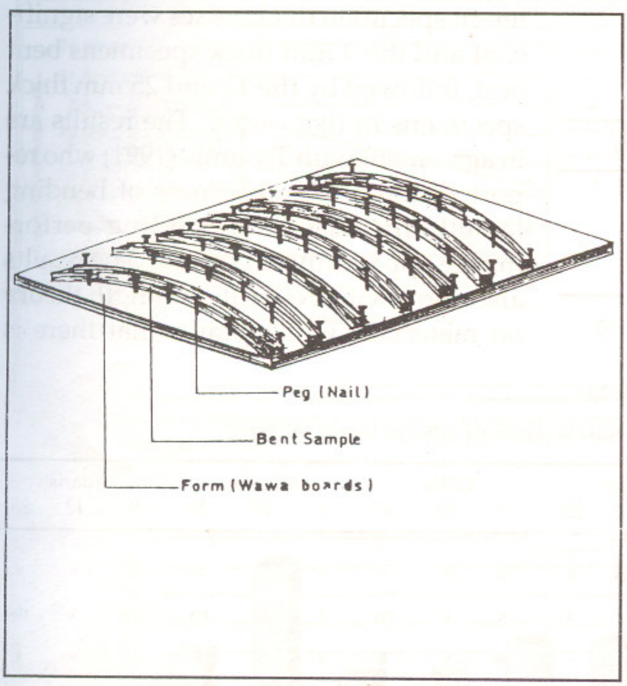


Fig. 4. Steam bending test set up.

Since bending failure in wood may be considered as brittle failure, the effect of specimen thickness on cold bending deflection was assumed to follow Weibull's statistical theory of the strength of material. Thickness effect was then quantified using the slope method (Madsen, 1992; Beaulieu *et al.*, 1997). By this method, the slope (disregarding the negative sign) of a straight line obtained by linear regression of the logarithm of mean deflection versus logarithm of thickness data points is a direct measure of the thickness effect (factor expressed in decimal). The slope of the linear regression is directly proportional to the severity of the thickess effect. Co-efficients of correlation obtained were used to verify the goodness of fit of the linear regression lines.

Steam Bending

Percentages of unbroken specimens were calculated for all the species and the most prevalent failure type assessed. The steam bending properties of the species were assessed based on the percentage of unbroken specimens in each species.

The species were then classified into the following three proposed quality classes:

Class I (excellent quality species) - having more than 85 % unbroken specimens.
Class II (good quality species) - having 50 to 85 % unbroken specimens.
Class III (poor quality species) - having below 50 % unbroken specimens.

RESULTS AND DISCUSSION

The comparative mean cold bending deflections for all the species and thicknesses studied are presented graphically in Fig. 5. Results of the statistical analyses of mean deflections are also presented in Tables 1 and 2. Results of the linear regression analyses of the experimental data performed on the logarithm of mean deflections versus the logarithm of specimen thickness for all species are presented in Table 3 and Fig. 6. The results of the steam bending test are, however, presented in Table 4 and Fig. 7.

Cold Bending

The results of the cold bending test presented in Fig. 5 show variability in mean bending deflections between species and between specimen thicknesses. The results showed a reduc-

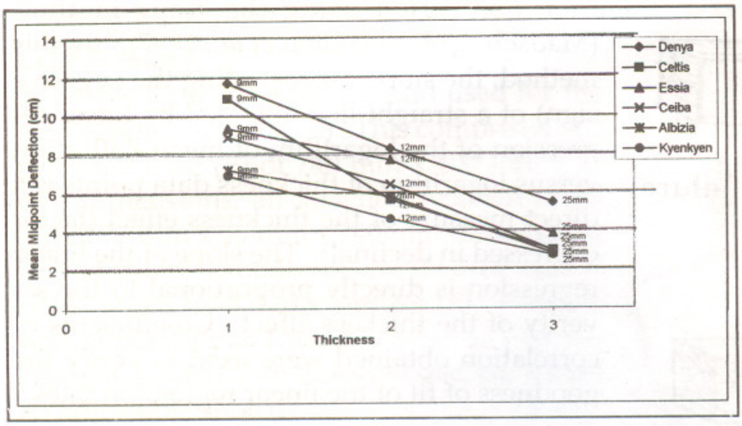


Fig. 5. Comparative cold bending performance of species for different lamella thickness.

tion of mean deflection with increasing specimen thickness for all the species studied. Among the six species, Denya exhibited superior bending performance in all the thicknesses studied. In 9 mm thickness, Denya was followed by Celtis, Essia, Ceiba, Awiemfosamina and Kyenkyen, in order of decreasing performance. However, in 12 and 25 mm thicknesses, Celtis performed poorly in comparison with Essia, Ceiba and Awiemfosamina.

The results of the analysis of variance (ANOVA) and the Tukey's multiple comparison test (Tables 1 and 2) showed that wood species and specimen thickness are significant factors in cold bending (P=0.05). Thus, the differences in mean bending deflections obtained between the different specimen thicknesses were significant and the 9 mm thick specimens bent best, followed by the 12 and 25 mm thick specimens in that order. The results are in agreement with Tsoumis (1991) who reported that as the thickness of bending lamella increases, its bending performance apparently decreases. The results also agree with Weibull's strength theory on materials, which states that there is

TABLE 1

Two-way analysis of variance showing degree of freedom, sum of squares, mean squares, F-value and probability factor for mean deflections in species and lamella thickness

Source of variation	*Sum of squares*	*Degree of freedom*	*Mean square*	*F-Value*	*Prob. factor*
Species	79.48	5	15.90	93.53	<0.001
Thickness	292.56	2	146.28	860.47	<0.001
Species/thickness	21.71	10	2.17	12.76	<0.001
Error	492.66	2898	0.17	-	-
Total	886.41	2915	-	-	

Probability factor of <0.001 indicates statistical significance at $p<0.05$

TABLE 2(a)

Tukey's multiple comparison for mean deflections in three lamellae thicknesses

Lamella thickness (mm)	*9 mm*	*12 mm*	*25 mm*
9	1.000	-	-
12	<0.001	1.000	-
25	<0.001	<0.001	1.000

Probability factor of <0.001 indicates statistical significance at $p<0.05$

TABLE 2(b)

Tukey's multiple comparison for mean deflections in species for different lamella thickness

Timber species	*Denya*			*Celtis*			*Essia*			*Ceiba*			Albizia			Antiaris		
	9	12	25	9	12	25	9	12	25	9	12	25	9	12	25	9	12	25
Denya	-	-	-	s	s	s	s	ns	s	s	s	s	s	S	s	s	s	s
Celtis	-	-	-	-	-	-	s	s	s	s	s	ns	s	S	ns	s	s	ns
Essia	-	-	-	-	-	-	-	-	-	ns	s	s	s	S	s	s	s	s
Ceiba	-	-	-	-	-	-	-	-	-	-	-	-	s	ns	ns	s	s	ns
Albizia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	ns	s	ns
Antiaris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Lamella thickness is in mm
'. s' denotes 'significant difference at p= 0.05 (i.e. probability factor of less than 0.001)'
'ns' denotes 'no significant difference at p= 0.05 (i.e. probability factor of more than 0.001)'

TABLE 3

Results of linear regression analyses of logarithm of mean deflection versus logarithm of lamella thickness

Species	*Regression equations*	*Thickness factors*	*Co-efficient of correlation*
Denya	d = 2.71 - 0.70x	0.70	0.99
Celtis	d = 3.11 - 1.19x	1.19	0.97
Essia	d = 2.82 - 0.88x	0.88	0.99
Ceiba	d = 2.97 - 1.07x	1.07	0.99
Awiemfosamina	d = 2.76 - 0.93x	0.93	0.99
Kyenkyen	d = 2.65 - 0.88x	0.88	0.99

TABLE 4

Results of steam bending

Species	*Density*	*No. of broken specimens*	*% unbroken specimens*	*Common failure types*
Denya	995	181	44	Cross grain tension
Celtis	740	78	76	Cross grain tension
Essia	844	207	36	Splintering tension
Ceiba	278	207	36	Brittle tension
Awiemfosamina	700	168	48	Brittle tension
Kyenkyen	525	168	48	Brittle tension

Densities were determined at moisture content of about 12 %.

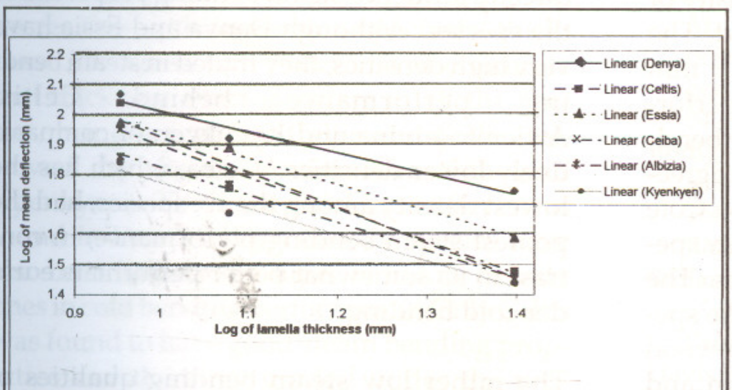


Fig. 6. Regression of logarithm of mean deflection versus logarithm of lamella thickness for six species.

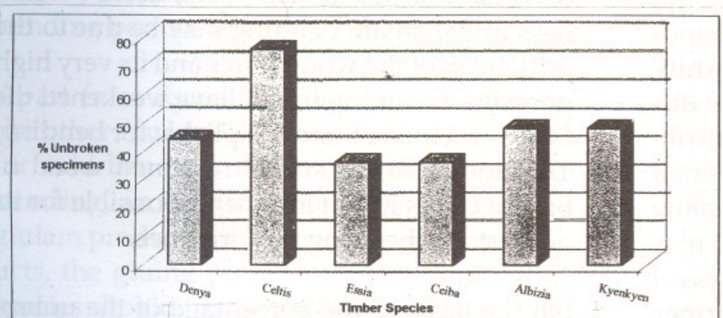


Fig. 7. Comparative steam bending performance of species.

greater probability that a region of low strength will occur in a member of large volume than that of small volume. The analysis showed that for the 9 mm thick specimens, there were significant differences between mean bending deflections of any two of the species studied, except between Essia and Ceiba, and between Awiemfosamina and Kyenkyen. For the 12 mm thick specimens, there were significant differences between any two of the species, except between Denya and Essia, and between Ceiba and Awiemfosamina. In the case of the 25 mm thick specimens, however, the only significant differences were between Denya and all the other species, and also between Essia and all the other species. The significance of the differences between species as regards cold bending deflections is in agreement with the literature (Tsoumis, 1991; Kollman & Cote, 1968). The literature states that bending properties differ from species to species and that the extent to which wood of a particular species bends into curved form depends on the species' peculiar characteristics.

Thickness factors (Table 3) obtained from the linear regression were high for all the species. These factors indicate that thickness effect is very significant in all the species studied. The results indicated severest thickness effect in Celtis (factor of 1.19) and Ceiba (factor of 1.07), followed by Awiemfosamina (factor of 0.93) and both Essia and Kyenkyen (with the same thickness factor of 0.88). Among the species studied, Denya exhibited the least effect of thickness (factor of 0.70). Fig. 5 shows that although Celtis exhibited very high cold bending performance in 9 mm thickness, its performance in 12 and 25 mm thicknesses was very poor. The results thus indicate that the reduction of bending deflection with increasing lamella thickness is species dependent. Co-efficients of correlation obtained from the linear regression also indicated a very good fit of the regression lines to the experimental data (r > 0.97) in all species. This also confirms that the slope method can be used in assessing the severity of thickness effect in bending members (Madsen, 1992; Beaulieu *et al.*, 1997).

The trend of the results further seems to indicate a reduction of cold bending performance with reducing wood density. Almost all the higher density species performed better than the lower density ones. However, the rather high mean cold bending performance of Ceiba, of a very low density of 278 kg/m^3, shows a deviation from this general observation and indicates that density alone cannot explain the bending performance of the different timber species. Within the higher density species, no systematic order was shown with regard to species performance in cold bending with decreasing wood density since, on the basis of density, Essia (density of 844 kg/m^3) should have performed better than Celtis (density of 740 kg/m^3) for all the thicknesses studied. The results, however, showed that for the 9 mm thick lamella, Celtis was superior in performance to Essia. The generally superior bending properties of the denser species is in agreement with Tsoumis (1991) and Kollman & Cote (1968). According to them, higher density species bend better than lower density ones. The variation in cold bending qualities of the species may be attributed to differences in wood structure, the relative amount of resin and other extractives present in the wood, and also to differences in genetic constitution of the different wood species (Tsoumis, 1991).

With regard to failure types under cold bending (Fig. 3), Essia and Awiemfosamina exhibited splintering tension failure in all the different thicknesses studied. This may be attributed to the interlocked nature of the wood grains of the two species. Ceiba failed mainly in compression and brittle tension, which may be due to its low density and the brittleness of the wood grains (Bodig & Jayne, 1982; Farmer, 1972). Celtis and Denya, however, exhibited cross-grain tension failure which might also be due to the presence of cross and interlocked grain (Addae-Mensah & Ayarkwa, 1996; Bodig & Jayne, 1982; Farmer, 1972). Kyenkyen is the only species which failed in brittle tension, possibly due to the brittleness of the wood (Addae-Mensah & Ayarkwa, 1996; Farmer, 1972). Thus, due to its brittle tension failure, Kyenkyen is unsuitable for bent parts in furniture and glulam products.

Steam Bending

The results of the steam bending (Table 4 and Fig. 7) indicate a wide difference between Celtis' high performance and the low performance of all the other species. Whereas in Celtis about 70 % of specimens were unbroken under steam bending, Aweimfosamina and Kyenkyen had 48 %, Denya 44 %, whilst Essia and Ceiba had only 38 % unbroken specimens.

In contrast to the results of the cold bending test, the trend of the steam bending test results seems to indicate that wood density does not directly influence steam bending properties of the species. Although Denya and Essia have very high densities, they trailed in steam bending performance behind Celtis, Awiemfosamina and Kyenkyen of comparatively lower densities. Ceiba, which has the lowest density among the six species, had the poorest steam bending performance, in contrast to its somewhat better performance under cold bending.

The rather low steam bending qualities of Denya and Essia may be attributed to a likely reduction in the amounts of resins and extractives in the wood caused by the steaming process (Tsoumis, 1991). However, Ceiba's weakness under steam bending may be due to the brittleness of the wood fibres and its very high porosity. Steaming might have weakened the fibres and made them too pliable for bending. The fine-textured, straight-grained wood fibres of Celtis might also be responsible for its good steam bending performance.

On the basis of the percentage of the unbroken specimens, Celtis may be placed under the proposed Class II Species having good steam bending qualities. All the other five species may, however, be categorized as Class III Species with poor steam bending qualities.

Brittle tension was the most common failure mode in Awiemfosamina, Kyenkyen and Ceiba under steam bending, which makes them unacceptable for steam-bent products. However, Essia, Celtis and Denya which failed mainly in cross-grain tension, are acceptable for bent products. The steaming might have made the wood fibres of Awiemfosamina more brittle, in contrast to its splintering tension failure under cold bending.

CONCLUSION AND RECOMMENDATIONS

The six species have been found to differ significantly in cold bending properties. Denya has the best cold bending properties followed by Celtis, Essia and Ceiba, with Awiemfosamina and Kyenkyen having the poorest properties. Bending lamella thickness has also been found to be statistically significant, with regard to cold bending performance, decreasing with increasing specimen thickness. Thickness factors derived also indicate that thickness effect is severe in all the species, being severest in Celtis and Ceiba, followed by Essia, Awiemfosamina and Kyenkyen. The least thickness effect was found in Denya. High density species have also been found to be superior to low density ones in cold bending performance. Only Celtis was found to have good steam bending properties and therefore graded under the proposed quality Class II species. All the other species were graded as Class III species, with poor steam bending properties. High wood density does not seem to indicate high steam bending performance in all the species.

Apart from Kyenkyen and Awiemfosamina, the other four species may be recommended for cold bending, and only Celtis for steam bending, in manufacturing furniture and glulam products. However, for glulam products, the gluing properties of the individual species should first be duly considered. Cold bending of Celtis and Ceiba are, however, only recommended in small lamella thicknesses. Ceiba should also be carefully and gently bent due to its low density, to avoid brittle tension failure.

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