STEAM BENDING QUALITIES OF EIGHT TIMBER SPECIES OF GHANA

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ABSTRACT

*Steam bending qualities of eight lesser used timber species of Ghana have been studied and compared with the quality of Mahogany (**Khaya spp**), a fast diminishing noble species, with the view to providing information for the furniture and glulam industries. Wood samples collected from three ecological forest zones of Ghana were steamed in an improvised steam chamber and bent on a prepared jig to a curvature of 660mm. Danta (**Nesogordonia papaverifera**) was identified to have the best steam bending quality followed by Yorke (**Broussonetia papyrifera**), Rubberwood (**Hevea brasiliensis**), Cedrela (**Cedrela odorata**), Eucalyptus (**Eucalyptus tereticornis**), Emire (**Terminalia ivorensis**), Cocowood (**Cocos nucifera**) and Borassus palm (**Borassus aethiopum**) in that order. The good steam bending performance of Danta and Yorke was attributed to their straight wood grains and fine-texture, and the poor steam bending qualities of Cocowood and Borassus palm was attributed to their fibrous wood grains, and the interlocked grains of Borassus palm. Yorke and Cedrela had good steam bending qualities despite their brittle wood fibres and their low porosity. There was no clear relationship between wood density and steam bending qualities of the eight species. Wood density however seems to affect the ease of bending the wood after steaming. Due to Mahogany's superior steam bending qualities, it was placed in a proposed quality Class I category with excellent steam bending quality, whilst Danta, Yorke, Rubberwood, Cedrela and Eucalyptus were placed in Class II category with good steam bending qualities. Emire, Cocowood and Borassus Palm were, however, placed in Class III category with poor steam bending qualities. Danta, Yorke, Rubberwood, Cedrela and Eucalyptus may be recommended for steam bending in the furniture and glulam industries.*

Keywords: Steam bending properties, lesser-used species, furniture, glulam

INTRODUCTION

Wood bending is an ancient craft that is of key importance to many industries today, especially in those that manufacture portal frames, glue-laminated beams, furniture, boats and ships, agricultural implements, tool handles and sporting goods. Products with slight curve such as back post or back rail of a dining room chair and other parts of furniture may be either sawed or bent (Ayarkwa, 2009). Of the several methods commonly used to produce curved parts from wood, bending is the most economical, most productive of members of high strength, and perhaps the cheapest (Tsoumis, 1991; Davis, 1962; Peck, 1957). Wood is normally straight and unbending, but all types of wood can be bent to some extent (Smith, 2004). Wood bending involves the stretching of fibers 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 (Tsuomis, 1991). Wood is usually plasticized by steaming at atmospheric pressure, soaking in hot or boiling water or microwave heating of moist wood (Ramakrishnan, 2000; Kollman and Cote, 1968). The purpose of all plasticizing treatments is to soften wood sufficiently to enable it to take the compressive deformation necessary to make the curve. Hot wood is more plastic than cold wood, and wet wood is more plastic than dry wood (Ramakrishnan, 2000; Tsuomis, 1991; Peck, 1957). A combination of heat and moisture is therefore most effective in softening wood. When wood is steamed, it results in softening of the natural polymers which behave like thermoplastic resins, but this requires a large amount of uninterrupted heat, and a free flow of steam to do this (Smith, 2004). While in the moist hot condition, wood can be bent to desired shapes. When it is again dried, holding it in the bent shape, the wood regains it stiffness and strength and the bent shape becomes permanent. This is the principle of steam bending of wood (Smith, 2004; Ramakrishnan, 2000).

Wood is made up of long tube-like cells of cellulose connected end to end forming long fibers running the length of the tree. Additional fibers run across the grain, tying everything together. Except for the outermost cambium, the heartwood is dead, serving the plant for structural support and water storage and transport. Each year a new layer of fibers is added under the bark, its thickness determined by growing conditions and stress - more moisture which gives a thicker ring, and more stress which gives a thicker ring on the stressed side. Over time, the inner layers may fill with resins, forming heartwood, which is usually denser, and more rigid. The newer, outer layers, sapwood, are still relatively flexible and wet. Heating wood turns the inherent water to steam which dissolves some of the bonds between fibers allowing them to realign, reforming the bonds when they cool. Steam bending is the process of weakening, stretching and reforming wood fibers to the desired shape (Smith, 2004; Kidder, 2001; Ramakrishnan, 2000). Steam bending is employed in bending several hardwoods in wood processing industries (Ayarkwa, 2000).

Many variables are involved in steam bending such as the size of the material, its moisture content, the amount of steaming, the radius of the bend required, and other details connected with the type of equipment used (Smith, 2004; Ramakrishnan, 2000; Davis, 1962). Wood may be steamed for a period not less than 30-40 min for 25 mm thick samples (Kollman and Cote, 1968) or for about 15 min/cm thickness (Ramakrishnan, 2000). A moisture content of 20 to 25% is required for wood plasticization, and at lower moisture content wood may be steamed for about 30 min/cm thickness (Ramakrishnan, 2000). Wood plasticized as above can be compressed as much as 25-30% parallel to the grain, but it can be stretched only 1 to 2%. This means that during bending most of the deformation of the wood must be compression to avoid rapture of the wood (Ayarkwa, 2009; Ramakrishnan, 2000). After steaming, wood may be bent on prepared forms of desired curvature (Smith, 2004; Ramakrishnan, 2000; Tsuomis, 1991).

The selection of species of wood to use in a manufactured product containing a bent member of slight to moderate curvature is largely governed by suitability and availability of the species for the product. However, if the curvature is to be severe, the species of wood must be selected primarily for its bending quality (Peck, 1957). The bending quality also varies not only among different species but also within the same species (Smith, 2004; Ramakrishnan, 2000; Peck, 1957). It is common knowledge that every thin strip of wood can easily be bent with the hands to a quite sharp curvature. In making baskets and other products, thin veneers are bent by hand and held in place by weaving them together or attaching them to other parts. Such bending is done without treating the wood. In bending thick pieces of solid wood, however, softening with steam or hot water or plasticizing with chemicals is essential.

Wood to be steam bent should be of good quality, without defects at least at the points where high stress develops 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 are recommended for bending (Smith, 2004; Ramakrishnan, 2000; Tsoumis, 1991). Heartwood is also preferred in situations exposed to the weather (Tsoumis, 1991). Other factors such as age, width of growth increments, wood structures, relative amount of resin and other extractives in wood, soil characteristics and differences in genetic constitution of different wood species also have influence on the bending qualities of wood (Tsoumis, 1991, Kollman and Cote, 1968). Bent parts have the advantage of being more economical in material utilization and also of being stronger because of less cross grains than sawed part. Thus, wood bending is environmentally friendly as it reduces wood waste (Ayarkwa, 2009). Excessive bending of a wooden sample 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 (i.e. brittle tension) (ASTM, 1994a).

The practice of steaming or soaking wood in boiling water for short periods to improve its pliability for bending to sharp curvature is reported to have no major damaging effect on its subsequent properties (Tsuomis, 1991). In glulam construction, cold bending is usually done as the high moisture of the wood after steaming may hinder gluing. Gluing steam bent wood or steam bending straight laminated members may, however, be done (Tsuomis, 1991). In northeast Japan, steam bending is used by the old communities in making traditional snowshoes known as "kanjiki". Their method of bending the wood is to place the material directly on the pot, put a cover on it, and after steaming it for a while, just press it to the desired shape (Katsuragi, 2002).

In general hardwoods are more amenable to bending than softwoods, and some hardwoods are particularly suitable for bending. Investigations at the Forest Research Institute (FRI), Dehra Dun, have shown that out of 30 species studied only a few species such as *Morus spp.* (mulberry), *Lagerstroemia spp.* (Benteak), *Ulmus spp.* (Elm), *Dalbergia latifolia* (Rosewood) and *Acacia arabica* (Babul) could be successfully bent to sharp curvature (Ramakrishnan, 2000). Among plantation species also, Rubberwood and Eucalyptus are reported to be amenable to steam bending (Ramakrishnan, 2000). In Ghana, steam bending properties of six selected lesser-used species have been studied (Ayarkwa, 2000). The results showed that only Celtis had good steam bending qualities, and Denya, Essia, Ceiba, Awiemfosamina and Kyenkyen had poor qualities.

Ghana's annual allowable cut of timber of about 2.0 million m^3 is considered woefully inadequate to support the expanding timber and construction industries. It is also undeniable the fact that the preferred traditional timber species are scarce, and wood users are looking for other species to serve their purpose. The need to utilize more lesser-used species, plantation grown species, and non-timber trees has been expressed (Ministry of Lands and Forestry, MLF, 1996). This study was therefore undertaken to provide information on steam bending qualities of selected species which are of potential benefits to the furniture and glulam industries.

MATERIALS AND METHODS

Material Collection and Preparation

Wood samples of four of the eight selected species for the study - Emire (*Terminalia ivorensis*), Danta (*Nesogordonia papaverifera*), Yorke (*Broussonatia papyrifera*) and Cedrela (*Cedrela odorata*) as well as Mahogany (*Khaya spp)* used as control species, were collected from three ecological forest zones of Ghana - Pra-Anum Forest Reserve in the Moist Semi-deciduous zone (South-East type), Asenanyo Forest Reserve in the Moist Semi-deciduous zone (North-West Forest type) and Afram Headwaters Forest Reserve in the Dry Semi-deciduous zone (Fire Zone Forest type). Samples of Eucalyptus (*Eucalyptus tereticornis*) were collected from Pra-Anum, Afram Headwaters Forest Reserves and the Mesewam research plot of the Forestry Research Institute of Ghana (CSIR-FORIG). Rubberwood (*Hevea brasiliensis*) was collected from plantations at the Kwame Nkrumah University of Science and Technology (KNUST) and Kwamo in the Moist Semi-Deciduous Forest zone and at the Ghana Rubber Estates Limited (GREL) in the Wet Evergreen Forest zone. Cocowood (*Cocos nucifera*) was collected from plantations at Ankobra in the Wet Evergreen Forest zone, KNUST and Kwamo. Borassus palm (*Borassus aethiopum*) was collected from Abofour, Proso and Sekyedumasi all in the transitional forest belt which is the habitat of the species. Test samples of the species were taken from three trees of each species from each site. The trees of Danta, Emire and Mahogany were of average diameter of 60cm, those of Yorke, Cedrela, Rubberwood and Eucalyptus of average diameter of 40cm, and those of Borassus palm and Cocowood of average diameter of 30cm. These were considered adequate exploitable sizes of the species.

Three logs of 2.5m length were cut from each tree, and two beams each of 50mm x 250mm x 2000mm dimensions were sawn along radial direction of each log. All the beams were air dried to average moisture content of 18%. Test specimens were prepared from clear, straight-grained wood samples. From each of the 54 beams of each species, six steam bending specimens of 15mm x15mm x 500mm dimensions were prepared (Figure 1). In all, 324 specimens of each species were prepared for the steam bending tests in accordance with the procedure used by Tsoumis (1991) and Kollman and Cote (1962). The test specimens of Mahogany were used as control since its bending properties are already well documented (Ayarkwa and Owusu, 2000; Farmer, 1972; Irvine, 1961).

Figure1: Test specimens of 15mm x 15mm x 500mm dimensions

The Jig (Pegged Form) and Steam Chamber

A 19mm thick plywood board and wooden dowels were used to prepare the jig for the steam bending tests (Figure 2). Holes were drilled along curvatures of 660 mm drawn on the board, and dowels of 12 mm x 12 mm x 50mm were inserted into the holes.

Figure 2: Jig for the steam bending tests

A steel barrel was improvised and used as a steam chamber. The barrel was cut open at the top to create a lid by welding the cut cover with hinges to the barrel (Figure 3a). Mild steel rods were welded across the inner circumference of the barrel at 440 mm from the bottom to act as a platform for the wood specimens (Figure 3b). The steam chamber was set up as shown in (Fig. 3c), filled with water to a designated 280 mm minimum level and heated to 100^{o}C.

Test specimens of each species were then put onto the platform in the pre-heated steam chamber in batches and allowed to steam for 30 minutes (Kollman and Cote, 1968). On removal from the steam chamber using an improvised wood clipper, specimens were hand bent, whilst hot, to a radius of 660mm on the pegged form (Figure 4) and then given time to set (Ayarkwa, 2000; Davis, 1962). A sash clamp was used to aid bending of very stiff specimens.

(a) (b) (c)

Figure 3: Improvised steam chamber

Figure 4: Steam bent specimens on pegged form

Quantity of failed specimens and the types of failure in each specimen were recorded for each species. The bending time for each specimen was also recorded using a stop-watch. The density of each test specimen was determined from the mass and volume of the specimens in accordance with ASTM D 2395-93 (ASTM, 94b). The moisture content of each test specimen was also determined from a small specimens cut near the failed part in accordance with ASTM D 2395-93 (ASTM, 94b).

Method of Data Analysis

Percentage of unbroken specimens was calculated for each species, and the most predominant failure type in each species recorded. Steam bending properties of all the species were assessed based on percentage of unbroken specimens in each

-species. The species were then classified into three proposed quality classes (Ayarkwa, 2000) as follows:

Class I (superior 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.

The average bending time for each species was also calculated to give an indication of the ease of bending.

RESULTS AND DISCUSSIONS

The results of the steam bending tests are presented in Table 1 showing average wood densities, percentages of unbroken specimens and predominant failure types. Comparative steam bending qualities of the nine wood species studied are also presented in Figure 5.

The results show a wide difference between Mahogany's superior steam bending quality, with 96% unbroken specimens, and the other eight species studied. Whereas Danta, Yorke, Rubberwood, Cedrela and Eucaplyptus had unbroken specimens ranging from 56% to 68%, Emire and Cocowood had 24% and 4% unbroken specimens respectively. In the case of Borassus palm, however, all the specimens tested were broken.

Figure 5 shows that among the wood species studied, Mahogany possessed the best steam bending qualities, followed by Danta, Yorke, Rubberwood, Cedrela, Eucalyptus and Emire in decreasing order. Cocowood and Borassus palm, however, have poor steam bending qualities. The poor steam bending quality of Borassus palm may be attributed to its interlocked and fibrous wood grains(Ayarkwa,1997).

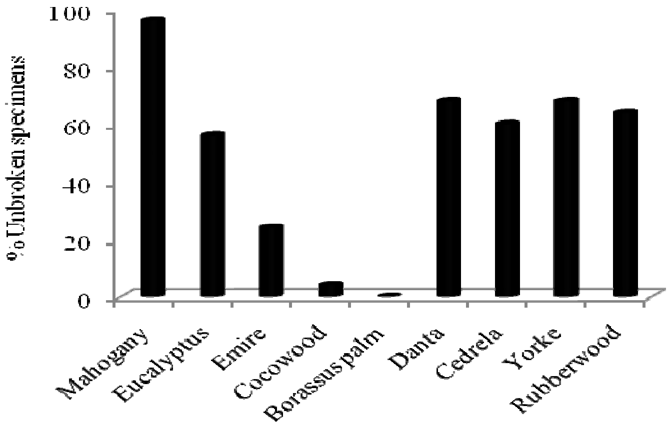

Figure 5: Comparative steam bending performance of nine species

This is confirmed by the fact that splintering tension was the most predominant type of failure in Borassus palm (Table 1 and Figure 6). Cocowood's weakness under steam bending may be due to the brittleness of the wood's fibrous grains and its high porosity (Ramakrishnan, 2003). Steaming might have weakened the fibres of Cocowood and made them too pliable for bending.

The rather unimpressive steam bending performance of Emire may be attributed to its medium coarse texture, and the predominant cross grained tension failure (Table 1 and Figure 6) may be due to the somewhat interlocked or irregular grains (Timber Export Development Board, TEDB, 1994; Farmer, 1972).

Table 1: Steam bending qualities of nine timber species

Species	Average Density (kg/m^3)	No. of broken specimens	% unbroken specimens	Predominant failure type
Mahogany (*Khaya spp.*)	674	13	96	Cross grain tension
Eucalyptus (*Eucalyptus tereticornis*)	1114	143	56	Cross grain tension
Emire (*Terminalia ivorensis*)	623	246	24	Cross grain tension
Cocowood (*Cocos nucifera*)	903	311	4	Cross grain tension
Borassus Palm(*Borassus aethiopum*)	1216	324	0	Splintering tension
Danta (*Nesogordonia papaverifera*)	807	104	68	Cross grain tension
Cedrela(*Cedrela odorata*)	442	130	60	Brittle tension
Yorke (*Broussonetia papyrifera*)	507	104	68	Brittle tension
Rubberwood(*Hevea brasiliensis*)	821	117	64	Brittle tension


Figure 6a: Cross grained tension failure in Emire


Figure 6b: Brittle tension failure in Rubberwood


Figure 6c: Splintering tension failure in Borassus palm

The poor steam bending qualities of Emire may also be attributed to a likely reduction in the amounts of resins and extractives in the wood (TEDB, 1994) caused by the steaming process (Tsoumis, 1991). The relatively good steam bending performance of Danta, Rubberwood and Eucalyptus may be attributed to their fine to medium texture and shallowly interlocked to straight grains (Ramakrishnan, 2000b; TEDB, 1994; Farmer, 1972). The shallowly interlocked grains of Danta and Eucalyptus might have accounted for their cross grain tension failure. Although Yorke and Cedrela have brittle wood grains (Ramakrishnan, 2000b), they exhibited good steam bending properties which might be due to their even texture and straight grains. The most common failure type in steam bending of Yorke and Cedrela was identified as brittle tension (Table 1).

The results show no clear relationship between wood density and percentage unbroken specimens (Table 1). Borassus palm had the highest density but exhibited the lowest steam bending quality with all specimens breaking during the test. Mahogany (density of 674 kg/m^3) and Cedrela (density of 442 kg/m^3) had better steam bending qualities than the extremely high density Borassus palm (density of 1216 kg/m^3) and Eucalyptus (density of 1114 kg/m^3).

This result differs from the assertion of Tsuomis (1991), Kollman and Cote (1968) and Davis (1962) that wood density affects the performance in bending of timber and that high density timbers perform better than low density ones. The result, however, agrees with Peck (1957) who reported that there is no good correlation between wood density and wood bending quality.

The results (Table 2) seem to show that between the extremely high density species and the medium density species, there exist a direct relationship between wood density and the time taken to bend each wood specimen (i.e. ease of bending). Wood specimens of the extremely high density Borassus palm and Eucalyptus took longer times to bend, compared with Yorke and Cedrela which have comparatively lower densities. For example bending Borassus palm (density of 1216 kg/m^3) took about two-and-a-half times the time taken to bend Yorke (density of 507 kg/m^3).

Table 2: Wood density versus average bending times

Species	Average density (kg/m^3)	Average bending time (sec.)
Mahogany (*Khaya spp.*)	674	0.43
Eucalyptus (*Eucalyptus tereticornis*)	1114	1.13
Emire (*Terminalia ivorensis*)	623	0.51
Cocowood (*Cocos nucifera*)	903	0.50
Borassus palm (*Borassus aethiopum*)	1216	1.30
Danta (*Nesogordonia papaverifera*)	807	0.45
Cedrela (*Cedrela odorata*)	442	0.43
Yorke (*Broussonetia papyrifera*)	507	0.49
Rubberwood (*Hevea brasiliensis*)	821	0.54

However, within the high and moderate density species, the direct relationship between density and time taken to bend specimens does not seem to exist. For example, Danta (density of 807 kg/m^3) and Mahogany (density of 674 kg/m^3) could be bent in a shorter time than Yorke and Emire (density of 623 kg/m^3). Thus density alone cannot explain the ease of bending the specimens of different species after steaming (Ramakrishnan, 2000; Peck, 1957).

The control species Mahogany clearly proved to be a superior species in steam bending, based on percentage unbroken specimens, and could be placed in the proposed quality Class I category with excellent bending quality (Table 3). Danta, Yorke, Rubberwood, Eucalyptus and Cedrela, however, could be placed in the proposed Class II category with good steam bending qualities, whilst Emire, Cocowood and Borassus palm could be placed in the Class III category with poor steam bending qualities. Figure 7 shows specimens of some of the species after steam bending.

Table 3: Steam bending quality classes for nine timber species

QUALITY CLASSES	SPECIES
CLASS I	Mahogany
CLASS II	Danta, Yorke, Rubberwood, Eucalyptus and Cedrela
CLASS III	Emire, Cocowood and Borassus palm

Figure 7a: Danta after steam bending

Figure 7b: Rubberwood after steam bending

Figure 7c: Emire after steam bending

CONCLUSIONS AND RECOMMENDATONS

The species studied have been found to differ in steam bending properties. The control species Mahogany has the best steam bending qualities followed by Danta, Yorke, Rubberwood, Cedrela, Eucalyptus and Emire in decreasing order. Cocowood and Borassus palm have the poorest steam bending qualities. Due to Mahogany's superior steam bending qualities, it is placed under the proposed quality Class I species. Danta, Cedrela, Eucalyptus, Rubberwood and Yorke, which have good steam bending qualities, are grouped under the proposed quality Class II species. Cocowood and Borassus palm are graded as Class III species with poor steam bending qualities. The results show that high wood density does not necessarily indicate high steam bending quality. There is also no clear relationship between wood density and ease of bending steamed wood.

Danta, Cedrela, Eucalyptus, Rubberwood and Yorke may be recommended for steam bending in the furniture and glulam industries. However, for glulam products the gluing properties of the individual species should firstly be considered. Cocowood and Borassus palm are not recommended for steam bending.

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