Journal of Tropical Forest Science 22(4): 389–396 (2010)

DIMENSIONAL STABILITY OF NINE TROPICAL HARDWOODS FROM CAMEROON

SR Shukla* & DP Kamdem**

Laboratory of Wood Science and Technology, Department of Forestry, 126 Natural Resources Building, Michigan State University, East Lansing MI 48824, USA

Received September 2009

SHUKLA SR & KAMDEM DP. 2010. Dimensional stability of nine tropical hardwoods from Cameroon. This study investigated the rate of swelling and dimensional stability of nine tropical hardwood species from Cameroon, namely, ayous (*Triplochiton scleroxylon*), bilinga (*Nauclea diderrichii*), bubinga (*Guibourtia tessmannii*), iroko (*Chlorophora excelsa*), makore (*Mimusops heckelii*), moabi (*Baillonella toxisperma*), movingui (*Distemonanthus benthamianus*), teak (*Tectona grandis*) and zingana (*Microberlinia brazzavillensis*). Continuous swelling of wood specimens immersed in water at room temperature for up to a maximum of 48 hours were monitored using linear voltage displacement transducers (LVDTs). The amount of water uptake as function of immersion duration was measured and correlated with wood porosity. Among the species used in this study, teak showed the lowest swelling rate, therefore, the more dimensionally stable property. Ayous, iroko and movingui were relatively more dimensionally stable than bubinga, makore and moabi. The swelling rate in the tangential direction was much higher than the radial. Bubinga, bilinga and zingana exhibited higher radial swelling rates compared with iroko, teak and makore. Similarly, higher tangential swelling rates were obtained for bubinga and movingui in comparison with teak, makore and moabi. The calculated ratios of the tangential to radial swelling rates also known as the anisotropy of the species used in this study were within the normal range and in agreement with published data. In conclusion, dimensional stability of some tropical species can be estimated with a 48-hour swelling test. Long-term and field data are needed to confirm the validity of this test.

Keywords: Swelling, swelling rate, tropical woods, density, anisotropy, porosity

SHUKLA SR & KAMDEM DP. 2010. Kestabilan dimensi sembilan kayu keras tropika dari Cameroon. Kajian ini menyelidiki kadar pembengkakan dan kestabilan dimensi sembilan spesies kayu keras tropika dari Cameroon iaitu ayous (*Triplochiton scleroxylon*), bilinga (*Nauclea diderrichii*), bubinga (*Guibourtia tessmannii*), iroko (*Chlorophora excelsa*), makore (*Mimusops heckelii*), moabi (*Baillonella toxisperma*), movingui (*Distemonanthus benthamianus*), jati (*Tectona grandis*) dan zingana (*Microberlinia brazzavillensis*). Pembengkakan berterusan spesimen kayu yang direndam dalam air pada suhu bilik selama maksimum 48 jam dipantau menggunakan transduser pembezaan voltan linear (LVDT). Jumlah pengambilan air sebagai fungsi tempoh rendaman disukat dan dikorelasikan dengan keronggaan kayu. Antara spesies yang diguna dalam kajian ini, kayu jati menunjukkan kadar pembengkakan yang paling rendah. Ini menjadikannya spesies yang mempunyai dimensi paling stabil. Ayous, iroko dan movingui lebih stabil secara relatif berbanding bubinga, makore dan moabi. Kadar pembengkakan tangen lebih tinggi daripada arah jejari. Bubinga, bilinga dan zingana mempamerkan kadar pembengkakan jejari yang lebih tinggi berbanding iroko, jati dan makore. Kadar pembengkakan tangen yang lebih tinggi juga didapati untuk bubinga dan movingui berbanding jati, makore dan moabi. Nisbah pembengkakan tangen kepada pembengkakan jejari yang juga dinamai anistropi spesies adalah dalam julat normal dan selari dengan data yang sudah terbit. Sebagai kesimpulan, kestabilan dimensi sesetengah spesies tropika dapat dianggar menggunakan ujian pembengkakan 48 jam. Data jangka panjang serta data lapangan diperlukan untuk mengesahkan kesahihan ujian ini.

INTRODUCTION

Tropical forests contain numerous wood species but just a few are known and used to manufacture valuable products due to lack of comprehensive information on their properties. More than 300 wood species have been identified in Cameroon forests but only one quarter are actually commercially used to manufacture wood products or trade on the international wood market (Nzokou *et al.* 2005). Ayous (*Triplochiton scleroxylon*), sapele (*Entandrophragma

---

*Present address: Institute of Wood Science and Technology, Malleswaram, Bangalore, 560003, India
**Author for correspondence. E-mail: kamdem@msu.edu*

cylindricum), African mahogany (*Khaya ivorensis*), iroko (*Chlorophora excelsa*) and frake (*Terminalia superba*) are among the major commercial species which contribute to more than one half of the total harvested volume in Cameroon (Nzokou *et al.* 2005). Other species labelled 'secondary or lesser-known species' are mostly used for low value products in rural areas as firewood and temporary farm constructions.

Information on the physical properties including dimensional stability and shrinkage/swelling behaviour of wood is paramount to maximise the value added on wood products. Information on the swelling behaviour of wood is routinely obtained by studying the dimensional changes of wood when exposed to different relative humidities and temperatures and in contact with water and other liquids (Mantanis *et al.* 1994). The dimensional stability of wood varies with species, density, direction of measurement, relative humidity, temperature, chemical composition in terms of lignin, microfibril angle, type and amount of extractives (Mantanis *et al.* 1994, Hernandez 2007). Swelling and shrinkage are often used to define or classify the relative dimensional stability of wood.

Several methods have been used to estimate wood swelling of tropical species. Dimensions measured using a micrometer at different complete equilibrium moisture contents (EMCs) and at oven-dry condition have been used to compute the swelling of nine hardwoods from Peru (Hernandez 2007). Considerable variation in weathering performance and dimensional stability of 10 tropical hardwoods from Bolivia was reported by Williams *et al.* (2001). The samples were exposed to different relative humidity levels at 27 °C and dimensional changes were measured in radial, tangential and longitudinal directions. Mantanis *et al.* (1994) used a computer interfaced linear variable displacement transformers to study the rate and maximum swelling of several North American wood species. Not much information is available in the literature on the application of this technique for studying the swelling characteristics of tropical wood species from Cameroon except maximum radial and tangential shrinkage (or swelling) values from green to oven-dry condition (Chudnoff 1980).

The use of wood is restricted due to its swelling and shrinkage at different relative humidities and temperatures. With the large number of tropical species available, the objective of this study was to develop a rapid, robust, simple and reproducible method to estimate the dimensional stability of tropical species. The swelling profile along with the amount of water uptake during immersion in water may be good indices of dimensional stability. The swelling profile and water uptake of tropical wood specimens were monitored from 10% EMC to apparent saturation with water at room temperature. The use of several species will help in the understanding of the effects of species, wood extractive, density and porosity on water uptake and swelling profile.

MATERIALS AND METHODS

Wood samples

Kiln-dried, defect-free heartwood of nine tropical wood species, namely, ayous (*T. scleroxylon*), bilinga (*Nauclea diderrichii*), bubinga (*Guibourtia tessmannii*), iroko (*C. excelsa*), makore (*Mimusops heckelii*), moabi (*Baillonella toxisperma*), movingui (*Distemonanthus benthamianus*), teak (*Tectona grandis*) and zingana (*Microberlinia brazzavillensis*) were selected from a sawmill located in Cameroon and shipped to Michigan, USA for this study. Samples measuring 22 (radial) × 25 (tangential) × 70 mm (longitudinal) were machined and used for the swelling test. For every test, six replicates per species were conditioned prior to testing by storing them in a room set at 21 °C and 65% relative humidity until constant weight was achieved (within 1% variation). EMCs of conditioned samples were calculated using the oven-dry method. The approximate void volume was computed using in equation 1 (Bowyer *et al.* 2007):

$$P(\%) = (1 - d/1500) \times 100 \quad (1)$$

where P is the percentage of void volume or porosity and d, the oven-dry specific gravity of wood. The constant 1500 is the oven-dry specific gravity of lignocellulosic cell wall.

Swelling test

Tangential and radial swelling profiles were continuously collected during the 48-hour immersion. One specimen for either tangential or radial swelling was placed in a 500-ml beaker and in contact with calibrated linear variable displacement transducers (LVDTs) connected to a computer through a data logger. Distilled water at 22 ± 3 °C was then filled slowly until complete immersion of the specimen. Dimensional changes in the radial or tangential direction of the specimen immersed in water were continuously recorded with LVDTs with an accuracy of ± 2.5 µm. Dimensional changes of the specimens immersed in water was recorded as the upward movement of the LVDTs initially after every one second interval up to two hours and subsequently at every one minute interval. A predetermined calibration factor was used to convert the electrical signal generated in the LVDTs during swelling to the amount of change in the dimension of the specimen. The tangential or radial swelling was then computed from the following equation:

$$S\,(\%) = \frac{T_2 - T_1}{T_1} \times 100 \qquad (2)$$

where S is the swelling in percentage of the initial dimension, T_2, the dimension at any given time during water immersion condition and T_1 is the initial tangential or radial dimension of the specimen before immersion. The weights and dimensions of samples were measured before and after the completion of the swelling test. During swelling test, the per cent of water uptake by wood specimens was computed using equation 3.

$$WA\,(\%) = \frac{W_2 - W_1}{W_1} \times 100 \qquad (3)$$

where W_1 and W_2 are weights of each specimen before and after the swelling test respectively.

Swelling rate

Radial and tangential swelling percentages versus duration of samples immersed in water were fitted in a non-linear regression model proposed by Hosli and Mannion (1991) as described in equation 4.

$$\text{Swelling} = K - \left[K \times \exp(-L \times \text{time}^{M})\right] \qquad (4)$$

where K, L and M are the fitting parameters of the model. Parameter K is the maximum percentage of possible swelling of wood immersed in water. Information on the K value for different species or different chemically, mechanically, physically, biologically modified wood may be used to predict the dimensional stability. Constant L is the speed or the rate of swelling and a low value of L corresponds to a slow dimensional change or slow swelling. M is related to the shape of the curve of swelling versus time and, to some extent, describes the variability of the swelling phenomenon. Non-linear regression curve fitting was performed using PeakFit version 4.12 for Windows software from Systat Software (San Jose, California) for goodness of fit and to compute values of K, L and M of the different wood species used in this study. Two swelling rates were obtained, one for short-term immersion of 1 hour duration or less and another for long-term immersion of 40 to 48 hours. Data of short- and long-term swelling were fitted in a linear equation to calculate the short- and long-term swelling rates for each wood species.

RESULTS AND DISCUSSION

Average values of the density at the initial EMC and the swellings in the tangential and radial directions of the nine tropical wood species from 10% to saturation after 48-hour immersion are listed in Table 1. There is about 10% difference in average EMC values of tropical wood species in this study compared with temperate wood species (Bowyer *et al.* 2007). Ayous, a diffuse porous, was the least dense species with a mean density of 448 kg m^{-3} while moabi had the greatest density with a value of 950 kg m^{-3}. Density values obtained in this study are comparable with published data (Richter & Dallwitz 2000).

The swelling of samples from 12% EMC to almost water saturation during the 48 hours of water immersion varied from 2.4 to 4.8% in the tangential direction and 1.2 to 4.2% in the radial direction in function of the species. Low swelling value was an indication of low dimensional instability during water uptake from 10% EMC to water saturation. Values reported in the literature are higher than the data listed in Table 2; this may be due to the fact that shrinkage and/or swelling values of tropical species available in the open literature are often reported as values from green to oven-dry or vice versa, while this paper reports the value from 10% EMC to water saturation state, i.e. close to green. The swelling values in the radial direction for all species were lower than in the tangential direction. The lowest values of the radial and tangential swelling of teak clearly confirm its good dimensional stability.

The average percentage of water uptake during the immersion period of 48 hours at room temperature varied from 29 to 70% (Table 1). The form, dimensions and the 48-hour immersion facilitated water uptake close to the fibre saturation point (30%) as described by Anonymous (2007). Dimensional changes were null to negligible at moisture contents above the fibre saturation point.

The highest value of water uptake at 70% was obtained by ayous and bubinga followed by movingui and iroko at 62 at 58% respectively. Chemical composition, type and amount of extractives, proportion of heartwood to sapwood, presence and quantity of rays and vessels, proportion of earlywood to latewood, and presence of crystals, tyloses and oils in the intercellular structures of wood are parameters that may influence the amount of water uptake in wood. The amount of water uptake may also depend on the percentage of void volumes or porosity which is related to the intercellular spaces and cell cavities. The percentages of void volume in function of the percentages of water absorbed during 48 hours immersion are represented in Figure 1. A linear regression with $r^2 = 0.82$ was obtained by plotting amounts of water uptake (y) versus the percentage of void (x) as expressed in the linear equation below:

$$y = 1.14\,x - 13.26 \tag{5}$$

This study confirms that wood species with a higher percentage of voids absorb greater amount of water as suggested by Mantanis *et al.* (1994).

Time-dependent radial and tangential swelling profiles of tropical woods in water at room temperature are shown in Figures 2 and 3 respectively. A small induction period of 1 to 2 min which was attributed to sample size was observed and similar to previous observation by Mantanis *et al.* (1994). Induction time is the minimum time required for movement of water along fibre direction through the lumen as well as the initial diffusion into the cell wall of wood fibres. The swelling curves were divided into three major zones, namely, an initial zone from 0 to 1 hour corresponding to initial wetting with a high rate of swelling as evidenced by the slope of the curve, a curvilinear middle zone from 1 to about 40 hours with some levelling off of the swelling rate and finally a plateau with low swelling rates beyond 40 hours.

The initial and final swelling regimes were used to compute the short- and long-term swelling rates. Swelling data in the radial and tangential directions were used to fit an experimental model of wood swelling developed by Hosli and Mannion (1991) and described in equation 4. Constants K, L and M for radial and tangential swelling were obtained using this equation and are listed in Table 2.

Table 1 Average values of equilibrium moisture content (EMC), density, water absorption, and radial and tangential swellings

Species	EMC (%)	Density (kg m^{-3})	WA (%)	Swelling (%)	
				Radial	Tangential
Ayous (*T. scleroxylon*)	11.0 ± 0.8	448 ± 10	70 ± 5	2.05 ± 0.13	3.42 ± 0.59
Bilinga (*N. diderrichii*)	11.2 ± 1.2	800 ± 20	41 ± 4	3.52 ± 0.25	3.83 ± 0.56
Bubinga (*G. tessmannii*)	10.5 ± 1.5	790 ± 35	70 ± 5	4.20 ± 0.19	4.79 ± 0.42
Iroko (*C. excelsa*)	11.0 ± 0.8	580 ± 20	58 ± 6	2.20 ± 0.20	3.25 ± 0.39
Makore (*M. heckelii*)	10.4 ± 1.2	860 ± 30	36 ± 6	3.69 ± 0.39	4.57 ± 0.22
Moabi (*B. toxisperma*)	12.2 ± 0.6	950 ± 20	29 ± 4	1.76 ± 0.50	3.30 ± 0.66
Movingui (*D. benthamianus*)	10.6 ± 1.5	630 ± 15	62 ± 5	2.22 ± 0.33	3.40 ± 0.42
Teak (*T. grandis*)	10.5 ± 0.5	600 ± 20	43 ± 4	1.20 ± 0.19	2.39 ± 0.38
Zingana (*M. brazzavillensis*)	10.8 ± 1.4	690 ± 15	45 ± 7	1.64 ± 0.26	3.04 ± 0.51

WA = water absorption after 48 hours

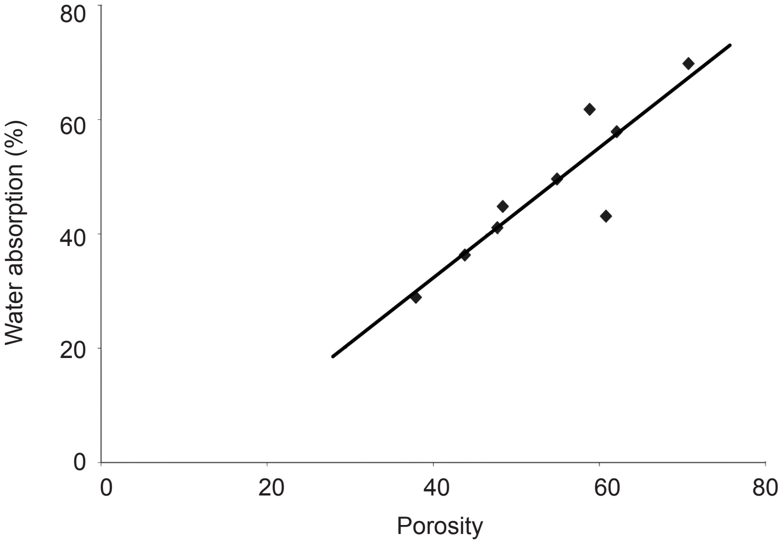

Figure 1 Relation between water absorption and wood porosity of nine tropical woods

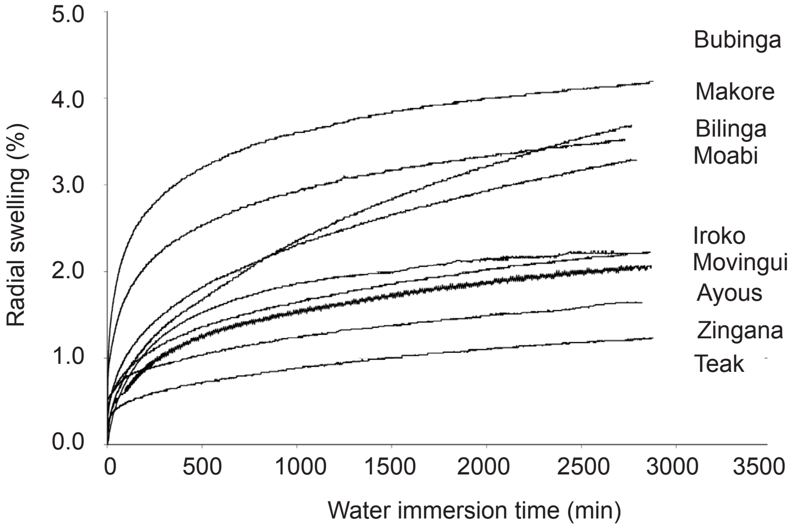

Figure 2 Radial swelling profiles of tropical woods immerged in water

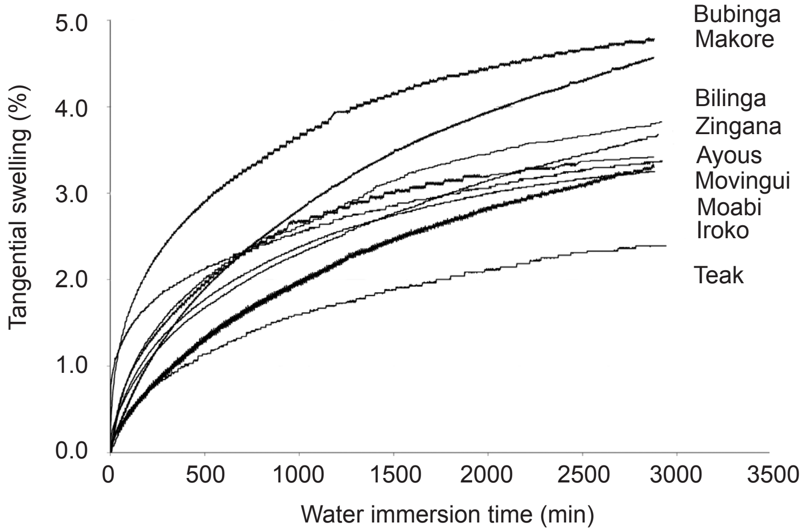

Figure 3 Tangential swelling profiles of tropical woods immerged in water

Table 2 Fitting parameters (K, L, M) of swelling equation (4)

Species	Total swelling (%) (K value)		Swelling rate (L value)		Shape variability (M value)		Anisotropy T/R ratio
	Radial	Tangential	Radial	Tangential	Radial	Tangential	
Ayous	3.14	3.90	0.032	0.013	0.44	0.64	1.24
Bilinga	4.23	4.89	0.076	0.012	0.40	0.61	1.16
Bubinga	4.78	5.67	0.110	0.029	0.37	0.52	1.19
Iroko	2.66	3.87	0.030	0.010	0.53	0.66	1.45
Makore	5.73	6.18	0.010	0.004	0.58	0.74	1.08
Moabi	5.09	5.78	0.030	0.004	0.44	0.69	1.14
Movingui	3.41	4.53	0.040	0.035	0.41	0.46	1.33
Teak	2.22	3.03	0.046	0.007	0.35	0.67	1.36
Zingana	3.37	5.63	0.070	0.008	0.28	0.60	1.67

All K values in the radial direction were lower than values in the tangential directions for all species, confirming that swelling in the latter direction was higher than in the former. Teak was the most dimensional stable with the lowest K values of 2.22% in the radial and 3.03% in the tangential directions. Species with higher K values were less stable compared with teak; these included bubinga, moabi and makore (Table 2). In the same manner, lower K values will rank the species (ayous, iroko and movingui) as dimensionally stable, similar to teak.

The L parameter from the fitting model is related to the rate of swelling. L values in the radial direction were generally higher than in the tangential direction (Table 2). This suggests that the swelling rate in the tangential is lower than in the radial direction (Anonymous 2007). Bubinga, bilinga and zingana had higher radial swelling rates compared with makore, iroko and ayous. Similarly, bubinga and movingui had higher rates of tangential swelling compared with the rest of the species tested.

Experimental swelling curve in function of time indicated that for short-term tangential and radial swellings, bubinga and movingui had the highest swelling rates while teak, makore and moabi exhibited the lowest. Highest radial and tangential swelling rates between 40 and 48 hours of immersion period were obtained by makore and moabi as illustrated in Figures 2 and 3. Although parameter M determines the variability of the shape of swelling time curves, it does not have any physical significance as reported by Hosli & Mannion 1991. Further work needs to be done to elucidate the role of M in this model.

The T/R ratio was calculated from the swelling values in the tangential and radial directions (Table 2). This ratio is used to express the degree or level of anisotropy of a species which is influenced by wood species, wood structure in terms of diffuse porous or ring porous, chemical composition mainly the percentage and distribution of lignin in the cell wall, thickness of the wood cell wall in the radial and tangential directions, proportion of latewood to earlywood and microfibril angles. T/R ratios of less than 1.6 are considered favourable, between 1.6 and 2.0 as normal and if greater than 2.0, unfavourable (Noack *et al.* 1973, Patrick & Minford 1991). In this study, T/R ratios of all nine hardwoods varied from 1.1 to 1.7, i.e. within favourable to normal range (Table 2). Total radial, tangential and overall radial plus tangential swelling values of nine tropical wood species were plotted against their density (Figure 4). Linear regression lines expressed as in equation 6 were correlated between radial and tangential swelling separately and also both radial and tangential swellings and wood density.

$$Y_1 = ax_1 + b \tag{6}$$

where Y_1 represents the swelling and x_1 is the mean density of wood species. Values of fitting parameters 'a' and 'b' are presented in Table 3. A positive but weak linear regression with r^2 of 0.56 was obtained between the values of radial swelling and density, suggesting that radial swelling increased with density. However, no linear relation was found between

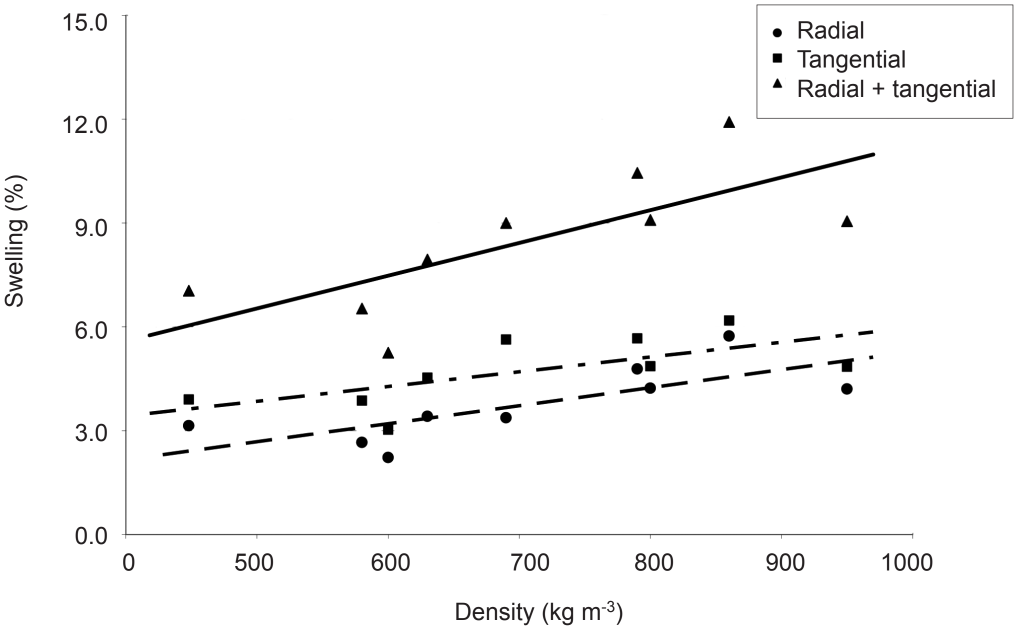

Figure 4 Radial, tangential and overall radial plus tangential swelling versus density of woods

Table 3 Values of fitting parameters for equation (6) between swelling and density

Swelling (%)	Linear fitting parameters		
	a	b	r^2
Radial	0.005	0.078	0.56
Tangential	0.004	1.720	0.44
Radial plus tangential	0.010	1.800	0.54

the tangential and the combination of radial and tangential values of swelling and density. This may be due to interlocked and deviated grains often present in tropical species. Similar radial and tangential swelling/shrinkage relationships with the wood density as shown in equation 6 were also reported in spruce wood (*Picea abies*) (Gryc *et al.* 2007). A linear relation was reported between density and radial and tangential shrinkages in plantation grown *Tecomella undulata* (Shukla *et al.* 2003).

CONCLUSIONS

Dimensional stability of nine tropical hardwoods from Cameroon varying in density from 450 to 950 kg m^{-3} was evaluated using water immersion for 48 hours. Continuous swelling measurement technique using LVDTs was applied successfully to record the information on dimensional changes and the water uptake during immersion. The amount of water absorbed was related to wood porosity. High porosity woods absorbed high amounts of water in comparison with low porosity woods. Time-dependent radial and tangential swellings fitted a non-linear profile with three parameters K, L and M. Teak exhibited the lowest K values for maximum swelling in radial and tangential directions. The highest K values were obtained for bilinga, bubinga, makore, moabi and zingana, confirming their low dimensional stability. Ayous, iroko and movingui had intermediate K values which helped in classifying these species as relatively stable in comparison with teak. T/R ratios or anisotropy of these species were within favourable to the normal range. A comparison of swelling rates suggested that wood swelled faster in radial than in tangential directions. Bubinga, bilinga and zingana showed higher radial swelling rates compared with makore, iroko and ayous. Similarly, high rates of tangential swelling were shown by bubinga and movingui compared with makore, moabi and teak. No strong linear relationship was observed between overall radial and tangential swelling and density values of the tropical hardwoods. A 48-hour swelling can be used as described in this study to rank tropical species in terms of dimensional stability.

ACKNOWLEDGEMENT

The authors thankfully acknowledge the financial support from USDA-CSREES Eastern Hardwood Utilization programme in the Department of Forestry, Michigan State University, East Lansing, Michigan.

REFERENCES

Anonymous. 1957. *Shrinking and Swelling of Wood in Use.* Research Report No 736. USDA Forest Service, Washington DC. Available at http://www.fpl.fs.fed.us/documnts/fplr/fplr736.pdf.

Anonymous. 2007. *The Encyclopedia of Wood.* Skyhorse Publishing Inc, Washington DC.

Bowyer JL, Shmulsky R & Haygreen JG. 2007. *Forest Products and Wood Science: An Introduction.* Fifth edition. Blackwell Publishing, Ames.

Chudnoff M. 1980. *Tropical Timbers of the World.* USDA Forest Service, Washington DC. Available at http://www2.fpl.fs.fed.us/publications/chud_total.pdf.

Gryc V, Vavrčík H & Horáček P. 2007. Variability in swelling of spruce (*Picea abies* [L.] Karst.) wood with the presence of compression wood. *Journal of Forest Science* 53: 243–252.

Hernandez RE. 2007. Swelling properties of hardwoods as affected by their extraneous substances, wood density and interlocked grain. *Wood and Fiber Science* 39: 146–158.

Hosli JP & Mannion K. 1991. A practical method to evaluate the dimensional stability of wood and wood products. *Forest Products Journal* 41: 40–44.

Mantanis GI, Young RA & Rowell RM. 1994. Swelling of wood. Part I: swelling in water. *Wood Science and Technology* 28: 119–134.

Noack D, Schwab E & Bartz A. 1973. Characteristics for a judgment of the sorption and swelling behavior of wood. *Wood Science and Technology* 7: 218–236.

Nzokou P, Wehner K & Kamdem DP. 2005. Natural durability of eight tropical hardwoods from Cameroon. *Journal of Tropical Forest Science* 17: 416–427.

Patrick RL & Minford JD. 1991. *Treatise on Adhesion and Adhesives.* Volume 7. CRC Press, Boca Raton.

Richter HG & Dallwitz MJ. 2000. Commercial timbers: descriptions, illustrations, identification, and information retrieval. http://biodiversity.uno.edu/delta/ (assessed 4 May 2000)

Shukla SR, Sharma SK & Rao RV. 2003. Specific gravity and shrinkage behavior of eight-year-old plantation grown *Tecomella undulata. Journal of Tropical Forest Products* 9: 35–44.

Stamm AJ. 1964. *Wood and Cellulose Science.* Ronald Press, New York.

Williams RS, Miller R & Gangstad J. 2001. Characteristics of ten tropical hardwoods from certified forests in Bolivia. Part I. Weathering characteristics and dimensional change. *Wood and Fiber Science* 33: 618–626.