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Characterization of Physical and Mechanical Properties of Branch, Stem and Root Wood of Iroko and Emire Tropical Trees

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Abstract: This study investigated the physical and mechanical properties of branch, stem and root wood of iroko (*Milicia excelsa*) and emire (*Terminalia ivorensis*). The basic density, MOE and MOR were determined in accordance with BS 373:1957. Fifty samples from the wood types of each species were used for each test. The study showed that the root wood of iroko and emire exhibited the highest basic density of 760 and 620 kg/m^3, respectively, while the basic densities of the branch and stem wood of emire (537 kg/m^3) were comparable. The differences in the MOE values among the wood types of iroko and emire were found to be statistically insignificant. The MOR value of the branch wood of emire (73 MPa) was found to be significantly higher than that of the stem wood (71 MPa). However, there was no significant difference between the MOR values of the branch and stem wood of iroko (67 MPa). Basic density of all wood types was found to be a good predictor of MOE in static. With exception of the root wood of emire, significant but low correlations were found for the regression relationships between MOE and MOR. For the emire stem wood, MOE explained about 41% of the variation in the MOR of that wood type. The study concludes that it is possible to substitute the branch and root wood of iroko and emire for stem wood in many applications.

Key words: Basic density, compression parallel to grain, density, modulus of elasticity, modulus of rupture, utilization

INTRODUCTION

The forest situation in Africa poses enormous challenges to its economic development agenda. The total forests area of Africa is 635 million hectares and this accounts for 21.4% of its land area (FAO, 2009). This forest area represents only 16% of the global forest area. Depletion of the Africa's forests is well documented. According to FAO (2009), between 2000 and 2005, 4 million ha of forests were lost annually in Africa. The growing demand for fuelwood and rapid urbanizations coupled with increasing agriculture will exacerbate the forest situation in Africa (FAO, 2009).

The future of the timber industry in Ghana is even gloomier. The total forest area of Ghana stands at 5.5 million ha representing about 24% of the total land area. Over the years, the country's forest area has shrunk substantially. According to FAO (2009), the annual rate of decline of the forest area of Ghana stood at 135,000 ha for the period between 1990 and 2000 and 115,000 ha from 2000 and 2005. Between 1990 and 2005, the forest area of Ghana experienced an annual decline rate of 2%. What is most worrying is the eminent extinction of most of the commercial timber species. In the estimation of the International Institute for Environment and Development (IIED), the supplies of the traditional timber species such as edinam (*Entandrophragma angolensis*), sapele (*Entandrophragma cylindricum*), iroko (*Milicia excelsa*) and emire (*Terminalia ivorensis*) could fall by 50% within five years (Acquah and Whyte, 1998). In the face of the scarcity of timber resource, logging residues have been reported to be relatively high in Ghana. A study conducted by Amoah (2008) in three ecological zones of Ghana indicated that about 25% of merchantable wood in the form of branches and stems was left as residues during logging operations.

On account of decreasing raw material supply and the environmental concerns about the depletion of the tropical forests, industrial utilization of branches and roots has been a subject of interest to researchers and industry. In the estimation of Hilton (2001), branch wood represents 25-30% of the total wood volume. Even though branch wood represents a secondary resource its potential utilization has less been investigated. Increasing the added value of branches indicates finding alternative uses other than firewood or particleboard for wood-based panels (Gurua *et al.*, 2008). The commercial utilization of wood residues in Ghana has been investigated by several researchers (Amoah, 2008; Amoah and Becker, 2009; Okai *et al*., 2004). The utilization of branches and roots

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may depend on their dimensions, physical and mechanical properties. Amoah and Becker (2009) conducted a study on the assessment of logging efficiency at three logging sites in Ghana and found that the Small-End Diameter (SED) of the branch stems and main stem left at the logging sites averaged between 31 and 60 cm while the average length of the residues varied from 3.0 to 8.5 m. The diameter and length of the branch wood of iroko (*Milicia excelsa*) for example, was found to be about 51 cm and 6 m respectively. The dimensions of these residues suggest that they could be used to manufacture a wide range of products, including furniture parts, tongue and groove and door frames.

Branch wood could potentially serve as a substitute for stem wood if its physical and mechanical properties are known and understood (Cionca *et al*., 2006). Knowledge of the mechanical properties of wood allows for better optimization and for minimal use of raw material (Van de Kuilen and Blass, 2005). The study of the mechanical properties of timber species is therefore indispensable if the species are to be selected and used in the various domains of engineering. The knowledge of the mechanical properties of timber species allows for their characterization of their behavior under different applications (Santos and Pinho, 2004).

The physical and mechanical properties of root and branch wood of tropical trees in Ghana have been less investigated. Okai (2004) investigated the physical and mechanical properties of branches and stems of emire (*Terminalia Ivorensis*) and asanfina (*Anigeria robusta*). The author reported that the branches of the two species had higher densities and MORs than their corresponding stems. In this study, the variation in the physical and mechanical properties of branches, stems and roots of two tropical tree species, emire (*Terminalia Ivorensis*) and iroko (*Milicia excelsa*) were investigated. The properties of wood investigated were density at 12%MC, basic density, Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) and compression strength parallel to the grain. The two questions raised in this study were:

- How comparable are the density, MOE and MOR values of branch, stem and root of the same species?
- Since there is a paradigm shift to the use of Non-Destructive Test (NDT) to estimate the mechanical properties of wood (Lei *et al*., 2005), the second question was whether it is possible to predict modules of rupture from modules of elasticity?

MATERIALS AND METHODS

The study was carried out in the Tinte Bepo forest reserve located in the semi-deciduous forest type (latitude 7º5′N and longitude 2º2′W) in the Ashanti Region of Ghana. Data were collected from the reserve in 2009 between the months of March and September. Two hardwood timber species, iroko (*Milicia exlcesa*) and emire (*Terminalia ivorensis*) were selected for the study. The selection of these timber species was based on their high economic value and their eminent extinction (Acquah and Whyte, 1998). Therefore the total utilization of their branch and root wood could reduce their felling rates. Three straight trunk each of iroko and emire and representing the average diameters of the two timber species at breast height were sampled. Straight stem, branch and root pieces were randomly taken from the sampled trees of iroko and emire. The root pieces were obtained by digging a trench profile of 600mm wide and 1200mm deep parallel to the direction of the root (Fig. 1).

Fig. 1: Rootwood of iroko being extracted for the study

Preparation of test samples: The preparations of the test specimen were based on BS 373:1957 ‘Method of Testing Small Clear Specimens of Timber’. Bolts of stem, branch and root wood of iroko and emire were sawn into boards. The boards were then planed and carefully examined for visible defects. The boards from each of the timber species and wood type were given identification numbers. From these boards, test specimens were prepared for the determination of basic density, static bending (Modulus of Elasticity, Modulus of Rupture) and compression parallel to the grain.

Physical and mechanical tests: The tests were carried out at the Structural Testing Laboratory at the Kwame Nkrumah University of Science and Technology (KNUST)-Civil Engineering Department, under the guidance of competent technicians. The Universal Testing Machine was used for the strength tests. Fifty specimens from the wood types of each species were used for each test.

Basic density: The density of the timber species which was determined according to ASTM Standard D 143-52, was based on the volumes of the specimens at the time of the test and their weights when oven-dried. The test specimens were 300 mm in length with a cross-section of 50*50 mm.

Static bending: The strength properties determined from the static bending test were Modulus of Elasticity (MOE) and Modulus of Rupture ((MOR). The test specimens were 300 mm long, with a 20*20 mm cross section as recommended in BS 373 (1957) for clear specimens (Gurua *et al*., 2008; The Princes Risborough Laboratory of the Building Research Establishment, 1974). Fifty specimens were prepared for each set of test variables. The actual specimen dimensions were measured with digital calipers calibrated with a 25-mm ± 0 μm slide. The specimens were stored in a room for three weeks and equilibrated to approximately 12% MC. The actual moisture content was determined after testing by using the moisture meter method and validated by oven-dry method. The mean value for each set of the specimens was recorded. The MOE of the specimens was calculated by the following equation (Pashin and de Zeeuw, 1980):

$$\text{MOE} = \frac{l^3}{4bd^3} x \frac{\Delta w}{\Delta x} \quad (1)$$

where *l* is the length of span (mm), w is the imposed load (N), b width of specimen (mm) and thickness of specimen (mm) and Δx deflection at mid-span. The term Δw / Δx is the gradient of the elastic region of the load-deflection graph. The MOR of the specimens was also calculated by the following equation:

$$\text{MOR} = \frac{3wl}{4bd^3} \quad (2)$$

where w is load at failure.

Compression strength parallel to the grain*:* The compression strength parallel to the grain test was performed according to BS; 373 (1957). 300*50*50 mm specimens were employed and the test was performed on a compression universal machine. As in the case of the static bending test, the specimens were stored in a room for three weeks to allow the moisture content to equilibrate to about 12%. The actual moisture content of the specimens was determined by electrical moisture meter after testing. Specimen dimensions were measured to the nearest 0.001 mm the dimension before the testing. The compression strength parallel to the grain was calculated by the following equation (Pashin and de Zeeuw, 1980):

$$\sigma_{cpl} = \frac{W_{\max}}{F}$$

where σ_{cpl} is the compression strength (MPa), W_{mas} is the maximum load at the break points (N) and F is area of cross-section of a specimen on which force was applied.

Data analysis: The data were analyzed using descriptive statistics, one-Way Analysis of Variance (ANOVA).

RESULTS

Density (at 12% MC) of *Milicia excelsa* (iroko) and *Terminalia ivorensis* (emire) wood types: The statistical summary of the densities of the species is shown in Table 1. Among the wood types of iroko, the root wood had the highest average density (760 kg/m^3), ranging between 694 and 813 kg/m^3. Branch wood had the lowest average density (751 kg/m^3), varying between 694 and 808 kg/m^3. Statistical analysis (One-Way ANOVA) indicated, however, that the differences among the densities of wood types of iroko were not statistically significant (p-value = 0.134) (Table 1). In the case of emire, the root wood had the highest average density of (620 kg/m^3) ranging from 597 to 693 kg/m^3, while the stem wood had the lowest (577 kg/m^3), also varying between 568 and 609 kg/m^3. The average density of the branch wood was 611 kg/m^3, with the minimum and maximum values of 569 and 624 kg/m^3, respectively. The One-Way ANOVA test indicated that the differences among the densities of the wood types of emire were statistically significant at the 5% level (Table 1).

Basic density of *Milicia excelsa* (iroko) and *Terminalia ivorensis* (emire) wood types: Table 1 contains the statistical summary of the basic density values of the wood types of the two timber species. Among the wood types of iroko, the root wood recorded the highest average basic density (712 kg/m^3), while the branch wood recorded the lowest (625 kg/m^3). The basic density of the root wood of iroko ranged from 628 to 743 kg/m^3, while those of the stem and branch wood varied between 625 and 637, 604 and 635 kg/m^3, respectively. The average basic density values of the root, stem and branch wood of iroko were respectively, 94, 85 and 83%, respectively of their corresponding density values at 12% MC. As found for iroko, the root wood of emire had the highest average basic density (601 kg/m^3), varying between 534 and 640 kg/m^3. Both the stem and branch wood types of emire had the average basic density of 534 kg/m^3 and ranged from 496 to 597 kg/m^3. The One-Way ANOVA test showed

Table 1: statistical summary of density at 12% MC and basic density of timber species studied

Species	Statistic	Density (Kg/m^3) at 12% m.c				Basic density (Kg/m^3)			
		Branch	Stem	Root	p-value	Branch	Stem	Root	p-value
Iroko									
	Mean	751	752	760	0.134	625ab	637ac	712bc	0.001
	Standard deviation	22.68	22.76	25.59		7.67	4.62	22.90	
	Coefficient of variation (%)	3.0	3.0	3.4		1.2	0.7	3.2	
	Minimum value	694	696	694		604	625	628	
	Maximum value	808	800	813		635	637	743	
Emire									
	Mean	611ab	577ac	620bc	0.001	537a	537b	601ab	0.001
	Standard deviation	12.19	7.67	13.64		19.03	19.03	23.90	
	Coefficient of variation (%)	2	1.3	2.2		3.5	3.5	4.0	
	Minimum value	569	568	597		496	496	534	
	Maximum value	624	609	693		597	597	640	

Values sharing the same letter are significantly different at 0.05 using Tukey Test Post hoc

Table 2: Experimental results for MOE

Statistic	MOE of iroko wood types (GPa)				MOE of emire wood types (GPa)			
	Branch	Stem	Root	p-value	Branch	Stem	Root	p-value
Iroko	Emire							
Mean	12.9	13.2	12.9	0.612	7.6	7.6	7.7	0.663
Standard deviation	1.27	1.33	1.23		0.56	0.56	0.64	
Coefficient of variation (%)	9.7	10.1	9.5		7.4	7.4	8.3	
Minimum value	11.2	11.2	10.9		5.5	6.05	.6	
Maximum value	15.8	15.8	15.8		9.1	8.8	9.0	

Values sharing the same letter are significantly different at 0.05 using Tukey Test Post hoc

that the difference between the basic density values of the root wood and the stem and branch wood was significant at the 5% probability level (Table 1). The average basic density values of the root, stem and branch wood of emire were respectively, 97, 93 and 88%, respectively of their corresponding density values at 12% MC.

Modulus of Elasticity (MOE): The MOE of the iroko wood types varied from 12.9 to 13.2 GPa, with the stem wood recording the highest (Table 2). The MOE of both the branch and stem wood of iroko ranged between 11.2 to 15.8 GPa, while that of the root wood varied from 10.9 to 15.8 GPa. The average MOE of the branch and root wood was about 98% of the stem wood. The ANOVA test showed that the differences of the MOE among the wood types of iroko were not significant at the 5% level. The MOE of the wood types of emire ranged from 7.6 to 7.7 GPa. The MOE of emire root wood (7.7 GPa) was slightly higher than those of the branch, stem and root wood (7.6 GPa) (Table 2). The MOE values of the branch, stem and root wood ranged from 5.5 to 9.1, 6.0 to 8.8 and 5.6 to 9.0 GPa, respectively. As found in the case of iroko, the One-Way ANOVA test did not show any significant difference among the MOE values of the wood types of emire.

Bending strength (Modulus of rupture): The experimental results of the bending strength (MOR) and compression parallel to the grain of the branch, stem and root wood of iroko and emire are summarized in Table 3.

Among the wood types of iroko, the MOR of the root wood (67 MPa) was higher than those of the branch and stem wood (64 MPa). The MOR of the root wood varied between 57 and 75 MPa, while those of the branch and stem wood ranged from 53 to 71 and 57 and 71 MPa, respectively. The One-Way ANOVA test revealed that the MOR of the root wood of iroko was significantly higher than those of the branch and stem wood (Table 3).

As found for iroko, among the wood types of emire, the root wood had the highest MOR while the stem wood had the lowest. The MOR of the root wood was 74 MPa, varying between 53 and 85 MPa. The MOR of the branch wood averaged 73 MPa, also ranging from 66 to 85 MPa, while that of the stem wood was 71 MPa, varying between 62 and 75 MPa. The One-Way ANOVA test showed that the average MOR values of the root wood and branch wood were significantly higher than that of the stem wood. However, no significant difference was found between those of the root and the branch wood at 5% level of probability (Table 3).

Compression parallel to the grain: The root wood of iroko was found to exhibit the highest average compression strength, while the branch wood exhibited the lowest (Table 3). The average compression strength of the root wood of iroko was 57 MPa, ranging between 40 and 64 MPa, while the stem wood had average compression strength of 46 MPa varies from 42 to 48

Table 3: Experimental results for bending and compression strength of the wood types of iroko and emire

		Bending strength (MOR) Mpa				Compression parallel to the grain (MPa)			
Species	Statistic	Branch	Stem	Root	p-value	Branch	Stem	Root	p-value
Iroko									
	Mean	64a	64b	67ab	0.012	44ab	46ac5	7bc	0.001
	Standard deviation	4.55	4.25	3.90		2.90	0.96	6.22	
	Coefficient of variation (%)	7.1	6.6	5.8		6.5	2.1	10.9	
	Minimum value	53	57	57		27	42	40	
	Maximum value	71	71	75		47	48	64	
Emire									
	Mean	73a	71ab	74b	0.008	47a	46ab	47b	0.008
	Standard deviation	3.95	3.11	5.00		1.98	2.15	1.79	
	Coefficient of variation	5.4	4.4	6.8		4.2	4.7	3.7	
	Minimum value	66	62	53		42	40	47	
	Maximum value	85	75	85		50	48	49	

Values sharing the same letter are significantly different at 0.05 using Tukey Test Post hoc

Table 4: Prediction equations for estimating MOR from MOE

					95% C.I			
Species	Wood type	Regression equation	R^2	r	Upper	Lower	t-test	Sig. (2-tailed)
Emire	Branch	MOR = 3.168MOE+48.8	0.204	0.451	1.349	4.986	3.502	0.001
	Stem	MOR = 3.556MOE+44.4	0.414	0.643	2.328	4.785	5.82	10.001
	Root	MOR = 1.818MOE+60.0	0.054	0.232	-0.397	4.032	1.651	0.105
Iroko	Branch	MOR = 2.094MOE+36.6	0.342	0.584	1.252	2.937	4.999	0.001
	Stem	MOR = 1.58MOE+44.2	0.244	0.494	0.764	2.396	3.896	0.001
	Root	MOR = 1.14MOE+52.2	0.129	0.360	0.281	1.993	2.670	0.001

MPa. The compression strength of the branch wood averaged 44 MPa with the minimum and maximum values of 27 and 47MPa, respectively. The ANOVA test showed that there were significant differences among the compression strength values of the wood types of iroko (Table 3). Among the wood types of emire, the strength values of the root and branch wood were higher than that of the stem wood (Table 3). The compression strength of the root wood averaged 47 MPa and ranged from 47 to 49 MPa, while that of the branch also averaged 47 MPa and varied between 42 and 50 MPa. The stem wood had an average compression strength of 46 MPa, varying between 40 and 48 MPa. The One-Way ANOVA test showed that the differences among the compression strength values of the wood types were significant at the 5%level (Table 3).

Prediction equations for estimating MOR from MOE: The MOE was used to predict the MOR of the wood types of iroko and emire. Table 4 contains the prediction equations. Statistical analysis indicated that, with the exception of emire root, the relationships between MOR and MOE for the rest of the iroko and emire wood types were significant at the 99% confidence level (Table 4), even though the correlations were weak. The r-values ranged from 0.45 to 0.64 for emire wood types and 0.36 to 0.58 for iroko wood types.

DISCUSSION

Density at 12% MC of iroko and emire wood types: Because, in general, strength of wood increases with increasing density (Tsoumis, 1968), the determination of densities of the branch, stem and root wood of the two species investigated in this study was instructive. The average density values of the stem wood of iroko (752 kg/m^3) and emire (577 kg/m^3) found in this study were respectively about 16 and 5% higher than the values reported elsewhere (Timber Expert Development Board, 1994). The density of the stem wood of iroko found in this study was in the range reported by Wu *et al*. (2009). The author reported that a SilveiScan density of iroko was 786 kg/m^3 which is 4.5% higher than the value reported in this study.

The study showed that the root wood of both iroko and emire had higher average density values than their corresponding values for the branch and stem wood. This finding is consistent with the study by Peterson *et al*. (2007). The authors investigated the juvenile wood in the branches and roots of Douglas-fir and reported that the roots had higher density wood than the stem. Higher density of branch wood of emire found in this study corroborated the findings of the previous studies (Fegal, 1941; Kollman and Côté, 1968; Tsoumis, 1968). Okai (2003) investigated the physical and mechanical properties of the branch and stem wood of emire (*Terminalia ivorensis*) and asanfina (*Aningeria robusta*) and reported that for both species, the branch wood has higher densities than the corresponding stem wood. Branch wood exhibits higher density possibly because it is characterized by higher percentage in the volume of fibers (Hakkila, 1989). While the density of branch wood of emire was statistically significantly higher than that of the stem wood, no significant difference was found between the densities of the branch and stem wood of iroko. The difference between stem and branch wood densities appears to vary among species rather unpredictably (Manwiller, 1974; Hakkila, 1989). Gurua *et al*. (2008) found that the densities of the branch wood of beech and maple were higher than the corresponding densities of their stem wood. The authors reported, however, that the stem wood density of Scot pine was higher than that of the branch wood. Higher densities of stem wood than the branch wood of softwoods have been reported in the literature (Brunden, 1964; Philips *et al*., 1976).

Basic density of the wood types of iroko and emire: Basic density is used as a measure of wood quality and a predictor of end-use properties (Lindstrom, 1996). The basic densities of the branch stem and root wood of iroko and emire were therefore compared to allow for their end use potential. Cheng *et al*. (1992) reported that the basic densities of iroko stem wood ranged between 620 and 720 Kg/m^3. In this study the basic density of the stem wood of iroko varied from 625 to 637 Kg/m^3 which were in the range reported by Cheng *et al*. (1992). The basic densities of the root wood of iroko and emire were found to be higher than those of the branch and stem wood and the differences were statistically significant at 5% or higher. The basic densities of the root wood of iroko and emire were found to be higher than that of the branch wood and the difference was statistically significant at the 5% level. The basic densities of the root stem and branch wood of iroko were 94, 84 and 83%, respectively of their corresponding densities at 12%, MC. In the case of emire, the basic densities of the root stem and branch wood were 97, 93 and 88%, respectively of their corresponding density values at 12% MC. This showed that the root wood of both iroko and emire exhibited the lowest decreased in density from 12% MC to oven-dry weight.

Bending strength of the wood types of iroko and emire: The average MOE of iroko wood types found in this study ranged from 12.3 GPa for the branch and root wood to 13.2 GPa for the stem wood. The MOE values for the wood types of emire also varied from 7.6 to 7.7 GPa. The differences in the average MOE values among the wood types of iroko and emire were however found to be statistically insignificant (Table 2). The MOE of the branch wood of iroko was about 98% of that of the iroko stem, while in the case of emire no difference was found between them. The MOE value for the stem wood (13.2 GPa) found in this study is comparable to the value reported by CIRAD (2009) and falls between values obtained by Cheng *et al*. (1992), 9.30-9.40 GPa and the SiliviScan value (16.1 GPa) reported by Wu *et al*. (2009). Contrary to expectation, the higher densities of the root wood of iroko and emire did not translate into higher MOE.

Emire wood types exhibited higher MOR values than the iroko wood types. The MOR values for the branch, stem and root wood of iroko were respectively 88, 90 and 91%, respectively of the corresponding values of the emire wood types. The MOR values obtained in this study for iroko varied from 64 MPa for the branch and stem wood to 67 MPa for the root wood. The MOR for the branch and stem wood of iroko was about 96% of that of the root wood of iroko. In the case of emire, the MOR ranged between 71 MPa for the stem wood and 74 MPa for the root wood. The MOR for the branch wood of emire was found to be 3% higher than that of the stem wood of emire. This difference was found to be statistically significant at the 5% probability level.

Prediction equations for estimating MOR from MOE: The regression relationship between MOE and MOR is important because it represents a non-destructive prediction of MOR of wood based on the known value of MOE which can be obtained without damaging the wood material (Kollman and Côté, 1968; Lei *et al*., 2005). With the exception of root wood of emire, significant but low correlations were found for the regression relationships between MOE and MOR of the other wood types of emire and iroko. For the emire stem wood, MOE explained about 41% of the variation in the MOR of the wood types. The r^2 values reported in this study appear similar to those reported elsewhere for tropical hardwoods (Green and Rosales, 1996).

CONCLUSION

In this study, the potential utilization of branch and root wood of iroko and emire was explored by characterizing their physical and mechanical properties. In general, the root wood of both species exhibited higher density. MOE, MOR and compression parallel to the grain values of root wood were higher than those of the branch and stem wood. The physical and mechanical properties of branch and stem wood of both species appear comparable. The MOE of the wood types of both species increased with increasing wood density at 12% MC. Significant but low correlations were found for the regression relationships between MOE and MOR of the wood types of iroko and emire. The study concludes that it is possible to use branch and root wood of iroko and emire for many engineering and structural applications.

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