SUITABILITY OF USING PLANTATION-GROWN *NAUCLEA DIDERRICHII* MERILL POLES FOR ELECTRICITY AND TELECOMMUNICATION OVERHEAD SUPPORT LINES IN GHANA – PART 1: SAPWOOD WIDTH AND DIMENSION TABLE

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ABSTRACT

One hundred and seventy poles of plantation-grown Kusia (Nauclea diderrichii Merill) of lengths 7 to 15 m were extracted from the Pra-Anum Forest Reserve in Ghana. The cross-wise top and butt outer diameters and sapwood widths of the poles were measured, and their circumference taper and sapwood proportions determined. Small 'clear' defect-free specimens (obtained from 4 trees of length 14-15 m) were used in determining the basic density of the species as well as the modulus of rupture (MOR) and modulus of elasticity (MOE) of the wood species by the 3-point loading system on an 'Instron' Test Machine. The circumference taper averaged 31.7 mm/m. The minimum sapwood width (23.6-55.2 mm) increases with pole length. The mean sapwood width and percentage volume averaged 37.5 mm and 31.1% respectively. Basic density averaged 607 kg/m^3. 'Green' MOR averaged 93.3 N/mm^2, the 5th percentile 'characteristic' MOR was 73.50 N/mm^2, and the derived designated fibre stress was 82.9 N/mm^2. Using the fibre stress and the taper derived, the required dimension table for Kusia utility poles were determined. The dimensions and taper of Kusia render it particularly suitable for use as 10-15 m long poles for high voltage electric transmission and distribution support lines.

Keywords: **Sapwood width, circumference taper, modulus of rupture, fibre stress, dimension table.**

INTRODUCTION

In 1990 the Ghana National Electrification Scheme was instituted. It is aimed at extending the reach of electricity to all parts of the country over a 30-year period from 1990 to 2020. For this scheme alone, at least 50,000 treated poles are required annually. Additional poles are also needed as replacements and reinforcements for the existing systems. Treated poles are currently being manufactured locally from teak (*Tectona grandis*) trees that are mainly obtained from plantations of the Forest Service Division (FSD) of the Forestry Commission. It is becoming difficult to obtain these pole trees from the FSD plantations. This is especially so for poles longer than 9 m which are used for high tension or high voltage distribution and transmission. 10 m to 12 m poles are required for transmission of power to the district capitals, self-help electrification, and system reinforcement and replacements. Mining companies also usually require poles of length 12 to 16 m for power transmission.

Currently, 10 m to 12 m long poles are being imported to augment the quantities produced in the country (Ministry of Energy, Personal Communication). There is therefore the need to look beyond teak for additional local wood species, which could be used as distribution and transmission poles. Apart from teak, the only other local wood species that has been assessed (Ofori, 2001) and has been found suitable for use as poles for electric support lines is Afina (*Strombosia glaucescens*). Indeed major wood poles treaters in the country have started using Afina.

The requirements for a wood species to be considered for overhead transmission and/or distribution poles include: abundance, straight form, adequate weight and good strength, adequate natural durability and/or amenability to treatment (BSI, 1984; Aaron and Oakley, 1985; Wolfe and Moody, 1994; Wolfe, 1999).

Material evaluation begins with an assessment of availability. Abundance or availability reflects the economic feasibility of procuring poles of the required size. Poles used to support electric utility distribution and transmission lines range in length from 6 to 38 m and from about 130 to 760 mm in diameter (or 410 to 2390 mm in circumference) at 1.8 m from the butt (Wolfe, 1999).

Form or physical appearance refers to natural growth properties or visual characteristics, such as cross-sectional dimensions, straightness and presence of surface characteristics such as knots and spiral grain (Wolfe & Moody, 1994). Most structural applications of poles require timbers that are relatively straight and free of large knots. Standards for poles have been written with the assumption that a tree has a round cross section with a circumference that decreases linearly with height. Actual measurements of tree shape indicate that taper is rarely linear and often varies with location along the height of the tree. Average taper values for the more popular pole species in Europe and USA are provided in the European Standard EN 12479: 2002 (CEN, 2002a) and the ANSI 05.1 standard (ANSI, 1997). Straightness of poles is determined by two form properties: sweep (a measure of bow or gradual deviation from a straight line joining the ends of the pole) and crook (an abrupt change in direction of the centroidal axis). Limits on these two properties are specified in ANSI 05.1 (ANSI, 1997).

Weight affects shipping and handling costs and is a function of volume, moisture content, and wood density. An accurate estimate of volume of a round pole would require numerous measurements of the circumference and shape along the length, because poles commonly exhibit neither a uniform linear taper nor a perfectly round shape. If the volume is known, the preservative weight can be approximated by multiplying volume by the recommended preservative retention.

Regardless of the application, any structural member must be strong enough to resist imposed loads with a reasonable factor of safety. Most poles are used as structural members in support structures for distribution and transmission lines. For this application, poles may be designed as single-member or guyed cantilevers or as structural members of a more complex structure. Specifications for wood poles used in single pole structures have been published by ANSI in Standard 05.1 (ANSI, 1997).

The ANSI 05.1 standard gives values for fibre stress in bending for species commonly used as transmission or distribution poles. These values represent the near-ultimate fibre stress for poles used as cantilever beams. For most species, these values are based partly on full-sized pole tests (and include adjustments for moisture content and pretreatment conditioning), and on strength of small clear test samples. In the latter instance,

allowable stresses are derived by adjusting small clear values for effects of growth characteristics, conditioning, shape, and load conditions as discussed in applicable standards.

Durability is directly related to expected service life and is a function of natural decay and termite resistance and treatability. Treatability depends on penetration and distribution of preservative and adequate retention of preservative. Preservative can usually only be absorbed by sapwood. Wood species with a high proportion of treatable sapwood are desirable since they ensure good penetration and retention of preservative.

Kusia (*Nauclea diderrichii* Merill) is a Ghanaian lesser-used wood species (Upton and Attah (2003)). It is regionally distributed from West Africa to Central Africa (ATIBT, 1990). The species is fairly distributed in the Wet and Moist Evergreen, Moist Semi-Deciduous and Dry Semi-Deciduous ecological zones of Ghana (Hall and Swaine, 1981). In the production areas, the mean stem number per km^2 in the diameter classes 5-9 cm, 10-29 cm and 30-49 cm are 18, 14 and 3 respectively; while the corresponding basal areas are 0.06, 0.36 and 0.42 m^2/km^2 (Ghartey, 1989). Stems in the diameter classes 10-29 cm and 30-49 cm may be suitable for use as electric support lines (Wolfe, 1999).

Kusia has a good tree form. The bole is cylindrical and slim, with no buttresses and has a height of 24-30 m, and diameter of up to 1.5 m (G.T.M.B., 1969; Bolza and Keating, 1972; BRE, 1975).

The 25-50 cm whitish, pale, yellow, pink or grey sapwood is clearly demarcated from the yellow to pale or orange yellow heartwood (G. T. M. B., 1969; Bolza and Keating, 1972; BRE, 1975; ATIBT, 1990). The sapwood is liable to attack by lyctus or powder-post beetles (Bolza and Keating, 1972; BRE, 1975; ATIBT, 1990). The heartwood

is variously described as moderately resistant (BRE, 1975) or resistant (Bolza and Keating, 1972) or very resistant to termites (G. T. M. B., 1969), and resistant to *Anobium* and marine borers (Bolza and Keating, 1972) or very resistant to marine borers (G. T. M. B., 1969). The heartwood is naturally durable (ATIBT, 1990) or very durable (BRE, 1975). The sapwood is permeable, and the heartwood is moderately resistant to treatment (Bolza and Keating, 1972; BRE, 1975; ATIBT, 1990).

The grain is described as usually interlocked or irregular (G. T. M. B., 1969; Bolza and Keating, 1972; BRE, 1975), or slightly/occasionally interlocked to highly/frequently interlocked (ATIBT, 1990). It has a rather slow drying rate, splitting and checking may occur, and serious distortion sometimes develops (BRE, 1975; ATIBT, 1990).

Kusia varies with site with regard to density and strength, but generally heavy; and the density of material from Ghana is 730-800 kg/m^3 (Bolza and Keating, 1972). The green weight of the wood is 1000-1100 kg/m^3 (ATIBT, 1990). The density of African Kusia at 12-15% moisture content is 740-1120 kg/m^3 (G. T. M. B., 1969; BRE, 1975; ATIBT, 1990). The wood is exceptionally strong and it is superior in strength to most hardwoods of equal relative density. It is stronger, in most strength properties, than the English oak, yellow birch, and teak (G. T. M. B., 1969). The range of published mean numerical strength values for defect-free timber of African Kusia at moisture content of 12% (G. T. M. B., 1969; Bolza and Keating, 1972; BRE, 1975; ATIBT, 1990; Green *et al.*, 1999) are as follows: modulus of rupture (79-134 N/mm^2), modulus of elasticity (10,700-16,300 N/mm^2), maximum shear parallel to grain (11.7-16.7 N/mm^2), compression parallel to grain (46.2-71.7 N/mm^2). Values at green moisture content are as follows: modulus of rupture (51.7-

86.1 N/mm^2), modulus of elasticity (9,100-14,200 N/mm^2), maximum shear parallel to grain (6.54-11.0 N/mm^2), and compression parallel to grain (25.8-43.4 N/mm^2). These values are generally from Africa. There have not been any specific reported strength values for material from Ghana. There is the need to obtain strength values for Ghanaian Kusia which could subsequently be used to derive a dimension table for the species to enable its use for electric support lines.

Possible end uses as a heavy structural timber in the round form after preservative treatment could be for poles and piles (BRE, 1975; ATIBT, 1990).

The former Ghana Post and Telecom (P&T) used to use treated wooden poles for telegraph and telephone services since 1961 to mid nineties. The present day Ghana Telecom (GT) continues to use treated wooden poles for its telephone line services, but like the former P&T, it does not attempt to differentiate each batch of poles into species. The species used had predominantly been Afina (*Strombosia glaucescens* var lucida*)*, Obaa *(Xylopia quintasii),* Duabankye (*Dialium aubrevillei* Pelgr*)*, Kusibiri (*Diospyros sanza-minika* A. Chev), Esa (*Celtis mildbraedii Engl*), and Baku (*Minusops heckelii)* (Ghana Telecom, Personal Communication). There is the need to differentiate the batches of poles into species to enable species characterisation. Apart from Afina, the dimensions of the poles used and parameters such as sapwood width, pole species taper, preservative penetration and retention achievable have not been established to find out the suitability of the species for use as poles for electric support lines. These parameters for Afina have now been established and reported by Ofori (2001); there is the need to establish these parameters for other species.

Kusia plantation plots have been established in at least two research plots of the Forestry Research Institute of Ghana (formerly Forest Products Research Institute) since 1972-1975. The plots have been successful, and the trees have grown into sizes that could be considered as probably suitable for wood poles production.

In the study reported here, the following were determined: the taper, the minimum and average sapwood width, sapwood volume of the trees, and static strength in bending of small clear defect-free specimens. From the latter, the mean fibre stress was derived. The circumference taper and fibre stress were used to determine the required dimensions of Kusia for use as utility poles.

MATERIALS AND METHODS

Pole Source

As part of a routine thinning exercise of plantation-grown Kusia at the Forestry Research Institute of Ghana's research station at the Pra-Anum Forest Reserve at Amantia [6° 12' - 6° 19' N; and 1° 9' - 1° 17' W] in the moist semi-deciduous forest zone of Ashanti Region of Ghana, the thinnings were sold to Dupaul Wood Treatment Company Limited.

Pole Dimensions Measured

One hundred and seventy (170) trees of plantation-grown Kusia of lengths 7 to 15 m were used for this study. The cross-wise top and butt outer diameters and cross-wise sapwood widths at the top and butt of the poles were measured.

Increment corings were also taken within 300 mm above and 300 mm below the 3 m mark from the butt by means of a 5 mm diameter calibrated increment borer. The sapwood portions were clearly distinguished from the heartwood portions; and the sapwood widths were measured.

Volume estimates were based on the assumption that the pole is shaped as the frustum of a cone. The volume was determined as the product of average cross-sectional area and length. Estimates of average cross-sectional area were obtained by taking the average of the butt and top diameters to estimate the area (AWPA Standard F3, 1996).

Bending Strength Test Procedure

Four of the poles of lengths 14 m and 15 m (which had butt diameters of about 30-35 cm) were used for determining the bending strength. The poles were cross-cut into logs of 2 to 3 m lengths and were converted on a horizontal bandmill ('Woodmizer') to 25 mm thick boards. Matched boards were divided into two. One lot was earmarked as 'green' test boards, and the other lot for drying.

Boards for the 'dry' test samples were dipped in a chlorpyrifos insecticide (- tradename 'Dursban') to prevent insect damage during drying. The boards were then stacked for air-drying under shed. After these boards were fully air-dried, test specimens for the 'dry' test samples were prepared and conditioned to about 12% moisture content.

Both the 'green' and dry test specimens were prepared as 20 mm x 20 mm x 300 mm clear defect-free specimens, and were tested for their static bending strength (i.e. modulus of rupture and modulus of elasticity) using the 3-point loading system based on the British Standard BS 373 (BSI, 1957) on an 'Instron' Test Machine. Their moisture content and basic density were also determined according to the British Standard BS 373 (BSI, 1957).

RESULTS AND DISUSSION

Top and Butt Diameters, Diameter and Circumference Taper

Table 1 shows the minimum and maximum green poles dimensions that were measured, and the mean top and butt diameters that were derived. The diameter taper (which is the difference in diameters of the butt and top divided by the pole length) and circumference taper for each pole were derived from the top and butt outer diameters. The diameter and circumference tapers of the poles within the various pole lengths that were derived are also indicated in Table 1. The mean diameter taper averaged 10.1 mm/m (and ranged from 6.9 to 14.5 mm/m), and were well within the range of 6 to 16 mm/m indicated in the European Standard En 12479: 2002 (CEN, 2002a). The mean circumference taper ranged from 28.3 to 35.8 mm/m and averaged 31.7 mm/m. Circumference taper for American wood pole species of 17 to 37 mm/m have been reported in ANSI-05.1 (ANSI, 1997). The pole taper determined, was generally small. Poles with a greater taper have smaller top circumference.

Sapwood Width and Sapwood Volume

The mean sapwood widths at pole mid-length and 3 m from butt, as well as the sapwood volume and proportions of sapwood in poles are shown in Table 2. The mean sapwood width at pole mid-length ranged from 30.3 to 53.1 mm, and averaged 37.0 mm, while the mean sapwood width at 3 m from butt ranged from 30.9 to 52.9 mm, and averaged 37.5 mm.

Table 1: Top and butt diameters, diameter and circumference taper of plantation-grown Kusia poles

Pole Length m	No. of Samples	Top Diameter mm			Butt Diameter mm			Diameter Taper mm/m			Circumference Taper mm/m			
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Std. Dev.
7	2	136	141	138	203	210	207	9.6	10.1	9.8	25.7	31.7	30.9	1.1
8	36	123	154	138	195	239	218	8.2	13.3	10.6	25.7	41.6	33.4	5.2
9	38	143	156	150	230	242	237	9.1	11.7	10.5	28.6	36.7	33.0	2.7
10	35	130	208	168	229	302	264	6.9	14.3	9.9	21.7	44.8	31.2	6.6
11	29	151	207	179	265	322	289	8.9	14.1	10.7	27.9	44.4	33.5	5.8
12	20	162	200	180	263	306	290	7.9	9.9	9.1	30.2	31.0	28.7	2.0
13	6	162	200	190	286	361	329	9.6	14.5	11.4	30.2	45.6	35.8	5.7
14	2	198	212	205	355	380	368	10.9	11.1	11.0	34.2	35.0	34.6	0.6
15	2	175	199	187	305	332	319	8.6	9.4	9.0	27.0	29.5	28.3	1.8
All Samples	170	123	212	167	195	380	271	6.9	14.5	10.1	21.7	45.6	31.7	6.7

Table 2: Sapwood width and sapwood volume in plantation-grown Kusia poles

| Pole Length m	No. of Samples	Mid-Length Sapwood Width mm			Sapwood Width 3m from Butt mm			Sapwood Volume in Pole %			Sapwood Volume in Pole m³		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
7	2	32.9	35.5	34.1	33.5	35.4	34.5	34.7	36.8	35.7	0.0561	0.0598	0.0579
8	36	23.3	35.0	30.3	23.6	35.6	30.9	27.1	35.5	31.3	0.0421	0.0736	0.0608
9	38	26.0	36.3	33.5	26.6	36.8	34.2	25.6	34.4	31.8	0.0648	0.0884	0.0829
10	35	29.1	50.0	36.6	30.8	50.4	37.4	24.1	41.2	31.5	0.0772	0.1489	0.1129
11	29	35.0	49.6	40.3	33.9	50.4	41.1	25.3	37.4	31.7	0.1229	0.1824	0.1481
12	20	31.3	48.5	37.8	30.4	48.6	38.4	24.0	40.0	29.8	0.1219	0.1829	0.1518
13	6	32.1	52.4	41.2	31.5	31.5	40.4	23.1	35.9	29.6	0.1611	0.2534	0.1976
14	2	50.8	55.4	53.1	50.6	55.2	52.9	30.6	36.3	33.5	0.3007	0.3108	0.3057
15	2	42.3	42.4	42.3	44.4	44.4	44.4	29.4	32.4	30.9	0.2166	0.2424	0.2295
All Samples	170	23.3	55.4	37.0	23.6	55.2	37.5	23.1	41.2	31.1	0.0421	0.3108	0.1307
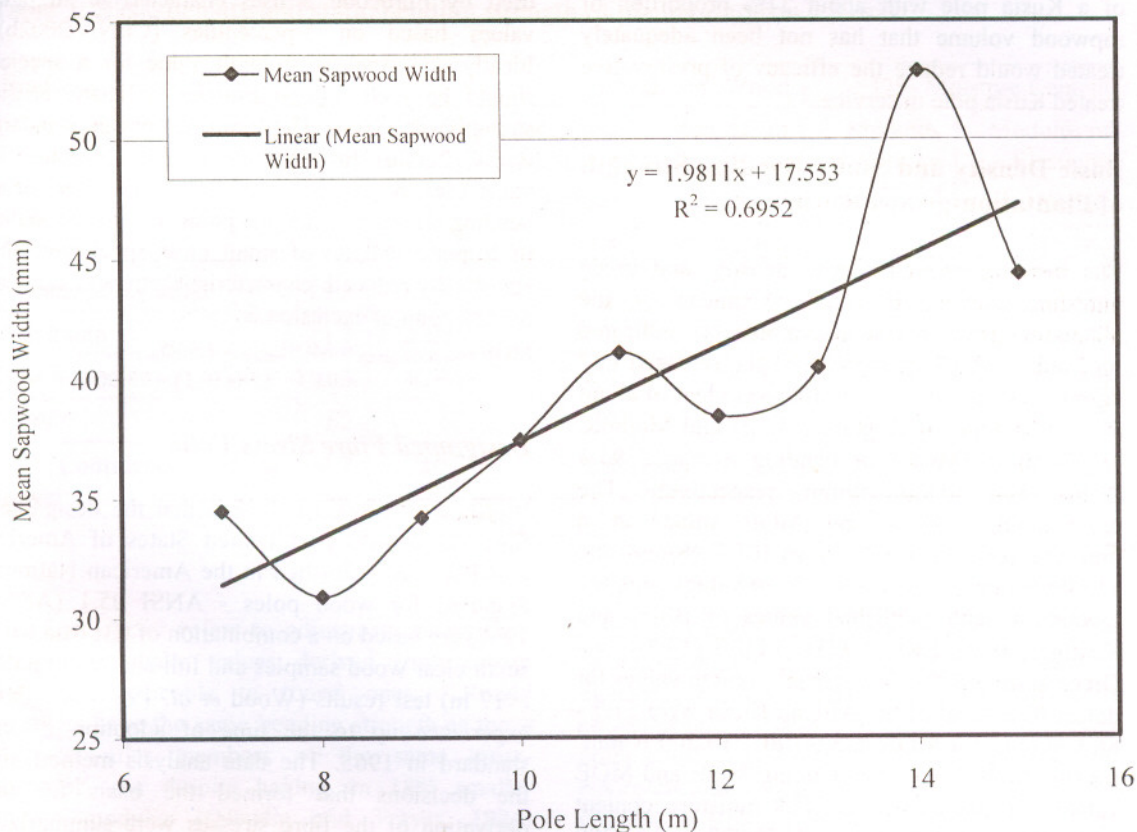
Figure 1: Mean sapwood width at 3m from butt at various pole lengths

Figure 1 shows the variation of mean sapwood width at 3 m from butt with pole length. The mean sapwood width (y) of the poles appears to increase with pole length (x). A linear regression equation of $y = 1.9811x + 17.553$ and an R^2 of 69.5% was established. The minimum sapwood width recorded was 23.3 mm, while the minimum mean sapwood width for the different pole lengths was 30.9 mm. It is thus recommended that the minimum sapwood width taken at the thinnest section of a Kusia pole be limited to 25 mm.

The mean proportion of sapwood in the Kusia poles ranged from 29.6 to 35.7%, and averaged 31.1%. Since the sapwood of Kusia is susceptible to lyctus, not durable to wood decay fungi, and not immune to termites and other insect attack, but is fairly permeable to treatment (Bolza and Keating, 1972), it is recommended that full sapwood penetration is achieved during treatment. Since the minimum sapwood width is 23.3 mm, penetration of 25 mm or 85% of sapwood whichever is greater must be realized. If this were not achieved, the risk

of a Kusia pole with about 31% proportion of sapwood volume that has not been adequately treated would reduce the efficacy of preservative treated Kusia pole in service.

Basic Density and Static Bending Strength of Plantation-grown Kusia

The bending strength, basic density, and green moisture content of clear specimens of the plantation-grown Kusia determined are indicated in Table 3. Basic density of Kusia averaged 607 kg m^{-3}. The 'green' (i.e. moisture content of about 56 %) Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) in bending averaged 93.3 N/mm^2 and 10,955 N/mm^2 respectively. The corresponding MOR and MOE values at a moisture content of 12% were 105.7 N/mm^2 and 11,300 N/mm^2 respectively. These values compare favourably with published values of Bolza and Keating (1972), BRE (1975), ATIBT (1990), and Green *et al.* (1999). The 'green' strength values for defect-free wood of the African Kusia were 51.7 - 86.1 N/mm^2 for MOR and 9,100 – 14,200 N/mm^2 for the MOE. The corresponding MOR and MOE values for the timber at 12% moisture content were 79 – 134 N/mm^2 and 10,700 – 16, 300 N/mm^2 respectively.

Variability of wood / Characteristic Strength Value

The strength property of any given wood species is known to vary widely. The strength property is normally distributed, with mean f_{mean} and standard deviation σ_{n-1} (Sunley, 1968; Ocloo, 1985; CEN, 2002b). Unlike structural timber which has Eurocode 5 as an international design standard, there is no international design standard for poles. Whilst many of the current design methods for poles use strength properties that are mean values from test data, the partial coefficient design philosophy

used by Eurocode 5 uses characteristic strength values based on 5-percentiles (CEN, 2002b). Ideally, the weakest strength value for a species should be used, but in practice a 'characteristic strength' is given. The draft European standard (CEN, 2002b) for determining the characteristic value uses the 5% point of exclusion for the mean bending strength of the test poles. For the Modulus of Rupture (MOR) of small clear specimens, the statistically reduced 'characteristic' strength value at the 5% point of exclusion is:

$$MOR_{P5\% \text{ when green}} = MOR_{mean} - 1.96\sigma_{n-1}$$
$$= 93.3 - 1.96(10.1) = 73.50 \text{ N/mm}^2.$$

Designated Fibre Stress Value

Wolfe *et al* (2001) indicated that the designated fibre stress values of United States of America wood species published in the American National Standard for wood poles - ANSI 05.1 (ANSI, 1997) are based on a combination of test data from small clear wood samples and full-size small poles (<17 m) test results (Wood *et al*, 1960) and field experience up to the time of adoption of the standard in 1965. The data analysis method and the decisions that formed the basis for the derivation of the fibre stresses were summarized by Wood & Markwardt (1965). Adjustment factors covering load sharing, moisture content, and conditioning effects that were not considered in the testing phase were adopted by consensus (Wolfe *et al*, 2001). The factors summarized by Wood and Markwardt (1965) include geometric form, moisture content, pre-treatment conditioning, size classification, and load sharing.

Table 3: Basic density and static bending strength of plantation-grown Kusia

Statistic				'Green' Wood	12% Moisture Content	
	Moisture Content	Basic Density	Modulus of Rupture	Modulus of Elasticity	Modulus of Rupture	Modulus of Elasticity
	%	kg/m^3	N/mm^2	N/mm^2	N/mm^2	N/mm^2
Mean	56.0	606.5	93.3	10,955	105.7	11,300
Standard Deviation	18.5	39.2	10.1	1,349	20.8	1,793
Minimum	24.2	522.1	69.8	8,397	58.2	8,143
Maximum	110.3	679.1	118.0	14,180	141.5	16,200
Count	62	62	59	59	52	52
95% Confidence Level	4.7	10.0	2.6	352	5.8	499

The form factor refers to adjustment of bending strength to make values derived from square members applicable to round ones. Round members have the same bending strength as those of rectangular members of the same cross-sectional area despite having an 18% smaller section modulus ((Newlin and Trayer, 1924) quoted by Wolfe *et al*, 2001). This indicates that when the standard stress equation (bending moment divided by section modulus) is used, the round section exhibits higher stress at failure; i.e. a round beam will sustain a bending moment which is 18% greater than is computed from its section modulus, when using the MOR derived from tests of square or rectangular beams ((Wilson and Draw, 1953) quoted by Coetzee, 1978). However, the ANSI 05.1 adopted an 8% increase for the change from small clear bending strength to full-size pole strength (Wolfe *et al*, 2001).

Wood and Markwardt (1965) recommended 10% increase to the green modulus of rupture values for poles dried in service (in the USA), however, the ANSI 05.1 committee adopted a 16% increase for drying on the premise that the moisture content of in-service poles will rarely exceed 20% at 1.2m above ground. (The moisture content of in-service poles could well be lower than the 20% for the environmental conditions in Ghana, and the 16% increase in strength due to drying would thus be probably higher).

Pre-treatment conditioning improves the treatability of poles; however conditioning that involves high temperature have detrimental effects on wood strength. ANSI 05.1 recommended a 10% reduction in strength for kiln drying below 79 °C, and no reduction for air drying (Wood and Markwardt, 1965).

Fibre stress determinations could also be carried out using standard test methods of static tests of wood poles (based upon the cantilever method) such as the European Standard En 12509 (CEN, 2001) or ASTM Standard D1036-99 (ASTM, 1999). In the absence of facilities for undertaking these tests, the

MOR data on small clear specimens were used. A mean MOR value of 93.3 N/mm^2 (with a standard deviation of 10.1 N/mm^2) is being used. To obtain the fibre stress to be used for pole classification and dimensions, adjustment factors covering change from small clear bending strength to full-size pole strength, moisture content change due to drying of in-service poles, and pre-treatment conditioning effects are being made on the 'characteristic' MOR strength value of 73.50 N/mm^2.

The adjustment factors we used were the factors adopted in the ANSI 05.1 standard (ANSI, 1997). These were an 8% increase for the change from small clear bending strength to full-size pole strength, a 16% increase for drying of in-service poles, and a 10% reduction in strength for kiln drying below 79°C.

Thus the designated fibre stress value that may be used for plantation-grown Kusia is calculated as:

Fibre stress
= 'Characteristic' MOR x 1.08 x 1.16 x 0.90 N/mm^2
= 73.50 x 1.08 x 1.16 x 0.90 N/mm^2 = 82.9 N/mm^2.

Dimensions of Kusia Poles

The ANSI 05.1 pole classification system based on pole load capacity was adopted (ANSI, 1997). The system treats all poles that meet a set of acceptance criteria as a single grade in which strength varies only with species.

Poles are classified only by the size needed to meet preset load capacity requirements for the target pole class. The fibre stress values approximate average pole strength, not the design values. These are used to determine pole class sizes for each species. Minimum circumferences at 1.8 m from the butt are derived so that a given class pole will have the required groundline bending moment capacity, regardless of species. Designated loads for each pole class, when applied perpendicular to the pole

length (L), 60 cm from the top will give a groundline bending moment of approximately 0.9L. Dividing the bending moment by the fibre stress gives the required section modulus.

For a given horizontal load and fibre stress, a minimum circumference at groundline is calculated using standard engineering formulae. The minimum pole circumference at 1.8 m from butt is calculated from the formula:

$F = 32 \, \pi^2 Pa/C^3$, or $C^3 = 32 \, \pi^2 Pa/F$,

where,

F = maximum fibre stress at groundline (N/mm^2),

P = load at failure (kN),

a = distance from groundline to point of load (mm), and

C = circumference at point of break (cm).

This circumference is then translated to a location 1.8 m from the butt using average circumference tapers per metre of length, for the species in question, between the groundline and the 1.8 m location from the butt. The mean circumference taper used was the value of 31.7 mm/m obtained from the taper calculations above. The top circumference is used as the basis for the design of utility hardware. In making the calculations it is assumed that the pole is used as a simple cantilever and that the maximum fibre stress in the pole subjected to the bending moment applied will occur at the assumed groundline location.

Table 4: Wood pole dimension table of plantation-grown Kusia (Based on a fibre stress of 82.9 N/mm^2 and circumference taper of 31.7 mm/m)

Class of Pole		1	2	3	4	5	6	7
Minimum Circumference at Top (mm)		510	485	455	430	405	380	355
Length of Pole (m)	Groundline distance from Butt * (m)	Minimum Circumference at 1.8m from Butt (mm)						
7	1.2	715	670	620	575	530	490	455
8	1.5	755	710	660	615	565	525	485
9	1.5	800	750	695	645	595	550	510
10	1.8	835	780	730	675	625	580	535
11	1.8	870	815	760	705	650	600	560
12	1.8	900	845	785	730	675	625	580
13	2.0	930	875	815	760	700	650	
14	2.0	960	900	840	780	720	670	
15	2.1	990	930	865	805	745		
16	2.2	1015	955	885	825	765		
17	2.3	1040	975	910	850	785		
18	2.4	1065	1000	930	870	800		

* The figures in this column are intended for use only when a definition of groundline is necessary in order to apply requirements relating to scars, straightness, etc.

Dimension Table for Kusia

The horizontal loads used for separating the classes are as follows (ANSI, 1997):

Pole class	1	2	3	4	5	6	7
Horizontal load (kN)	20.0	16.5	13.3	10.7	8.4	6.7	5.3
(kg)	2043	1680	1362	1090	863	681	545
Minimum top circumference (mm)	510	485	455	430	405	380	355.

The dimension table of Kusia poles based on a fibre stress of 82.9 N/ mm^2, a mean circumference taper of 31.7 mm/m, the horizontal loads above used for separating the classes, and the standard engineering formula ($C^3 = 32 \pi^2 Pa/F$) is indicated in Table 4.

The pole top circumference varies by increments of 25 mm, and the pole circumference 1.8 m from the butt varies by increments ranging from 25 to 100 mm.

The true circumference class is determined as follows: 'Measure the circumference at 1.8 m from the butt. This dimension will determine the true class of the pole, provided that its top (measured at the minimum length point) is large enough. Otherwise, the circumference at the top will determine the true class provided that the circumference at 1.8 m from the butt does not exceed the specified minimum by more than 125 mm or 20%, whichever is greater' (ANSI, 1997).

The minimum circumference at 1.8 m from the butt ranged from 705 mm (for 7m poles) to 1050 mm (for 18 m poles). These are well within the range of 410 to 2390 mm values indicated by Wolfe (1999) as being the circumferences for 6 to 38 m long poles used to support electric utility distribution and transmission lines. Their equivalent diameters of 224 mm and 334 mm are within the stem diameter classes 10-29 cm with 14 stems/km^2 and 30-49 cm with 3 stems/km^2 respectively of natural forest Kusia stems in the production areas in Ghana's forest reserves (Ghartey, 1989).

In a subsequent study (Ofori *et al*, 2008b), the treatability of the sapwood by the full cell vacuum-pressure impregnation method using a copper-chrome-arsenate preservative would be determined by measuring the depth of penetration and analysis of the retention of preservative oxides components by X-ray fluorescence spectroscopy. The minimum sapwood width, the sapwood penetration that may be achievable during treatment and an assay zone that could be used in the retention analysis would be recommended.

CONCLUSIONS

- Rapid extraction and prophylactic treatment of plantation-grown Kusia poles during drying and storage is necessary because the sapwood is susceptible to lyctus. Serious end splits occur during air-drying.

- The mean sapwood width at 3 m from the butt averaged 37 mm. The minimum pole sapwood width (23-48 mm) increases with pole length. About 31% of the Kusia pole volume is sapwood.

- The mean circumference taper which was derived from the top and butt outer diameters averaged 31.7 mm/m.

- The basic density of plantation-grown Kusia poles averaged 607 +/- 39 kg/m^3.

- The 'green' modulus of rupture for small clear specimens of plantation-grown Kusia was 93.3 N/mm^2, and after making allowances for the effects of the variability of wood, the green 'characteristic' MOR obtained was 73.50 N/mm^2. Adjustment factors made on the 'characteristic' MOR to cover change from small clear bending strength to full-size pole strength, moisture content change due to drying of in-service poles, and pre-treatment conditioning effects lead to a designated fibre stress value of 86.6 N/mm^2.

- Based on a fibre stress of 82.9 N/mm^2, the mean circumference taper of 31.7 mm/m, pre-determined horizontal loads used for separating the classes, and the standard engineering formula, the dimension table of plantation-grown Kusia poles was established.

- The dimensions and strength properties of plantation-grown Kusia render it suitable for use as poles for electric support lines. It is particularly suited for use as high voltage transmission and distribution poles.

ACKNOWLEDGEMENT

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