MATHEMATICAL MODEL FOR PREDICTING SPECIFIC GRAVITY ACROSS A STEM OF *CALAMUS MANAN*

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WAN TARMEZE, W. A. 1994. Mathematical model for predicting specific gravity across a stem of *Calamus manan*. The specific gravity of rotan manau, *Calamus manan*, was found to increase exponentially from the center of the stem towards the periphery. A mathematical model was developed to predict the specific gravity of a layer in the cross-section of the cane. The model was used to study the effect of peeling on the specific gravity of the rattan.

Keywords: *Calamus manan* - total specific gravity - position across the stem - peeling

WAN TARMEZE, W. A. 1994. Model matematik untuk ramalan graviti tentu merentangi keratan lintang *Calamus manan*. Graviti tentu rotan manau, *Calamus manan*, didapati bertambah secara eksponen dari tengah keratan lintang hingga ke lapisan luar rotan. Sebuah model matematik telah dibangunkan untuk meramal graviti tentu sesuatu lapisan di dalam keratan lintang rotan. Model tersebut telah digunakan untuk mengkaji kesan pengupasan ke atas graviti tentu rotan.

Introduction

Rattan, a spiny climbing plant of the subfamily Calamoideae (Dransfield & Uhl 1986) has become an important source for the global "multi-million dollar" cane furniture industries. Yet, compared to wood, the properties of rattan are still far from being fully understood. The past unscientific exploitation (i.e. without proper technical knowledge) of this material has been blamed for the depletion (Renuka *et al.* 1987) of some popular species. The lack of knowledge has also caused some species to be left unexploited (Dransfield 1979, Abd. Latif 1991).

One of the most important properties of rattan is the specific gravity or density because it influences other properties and end uses. While a number of studies (e.g. Sekhar & Rawat 1965, Hadikusumo 1988, Haron *et al.* 1989, Abd. Latif & Siti Norralakmam 1992) have been done on the variation of the properties between species, age or portion of the culms, very little has been done on the variation across the rattan stems. Bhat (1991) carried out some work on this subject, but only qualitatively.

In this present work, a method was proposed to measure specific gravity of layers across a stem of *Calamus manan* (rotan manau). A mathematical model to predict the specific gravity values was developed.

Material and methods

A boiled and unpeeled manau (*C. manan*) pole was randomly selected from a local supplier. The pole was cut into nine 150 mm length (L_T) samples. The initial or total radius (R_T) of each sample was measured (average value of 10 readings) using a digital caliper and its oven-dried weight (W_O) was then measured to the nearest tenth of a milligram (Table 1). The total specific gravity (SG_T) of the sample was then calculated using the formula below.

$$SG_T = W_O/\text{Volume}$$
$$= W_O/\pi L_T R_T^2$$

Table 1. Radius and specific gravity of the unpeeled samples

Sample	Radius, R_T (mm)	Oven-dry weight, W_O (g)	Specific gravity, SG_T
A	16.8	81.9	0.619
B	16.9	83.4	0.617
C	17.2	80.0	0.588
D	17.2	81.2	0.585
E	17.6	83.1	0.570
F	17.5	80.8	0.560
G	17.6	82.5	0.564
H	17.7	82.9	0.558
I	17.6	80.7	0.553

Specific gravity across the rattan

A layer of about 1.50 mm thickness with a length of 50 ± 0.75 mm (L) from each sample (Figure 1) was carefully removed on a turning lathe machine. After oven-drying, the weight of the sample and the radius of portion B were measured. The specific gravity of the removed layer (SG_L) was calculated using the procedure as described below:

$$SG_L = W_L/V_L \quad \text{.......................} (1)$$

where W_L = oven-dried weight of the removed layer,

V_L = volume of the removed layer.

The oven-dried weight of the removed layer was the difference between the initial weight (W_I) and the final weight (W_F), i.e. the weight after the layer removal.

$$\therefore \quad W_L = W_I - W_F$$

The volume of the removed layer was obtained from the equation below:

$$V_L = \pi L(R_I^2 - R_F^2)$$

where

R_I = Initial radius of portion B,

R_F = Final radius (after a layer removal).

$$\therefore \quad SG_L = W_I - W_F / \pi L(R_I^2 - R_F^2)$$

The process was repeated for the next layer removal until the final radius of portion B was about 5 ± 1.00 mm. The specific gravity of the remaining portion B was then measured.

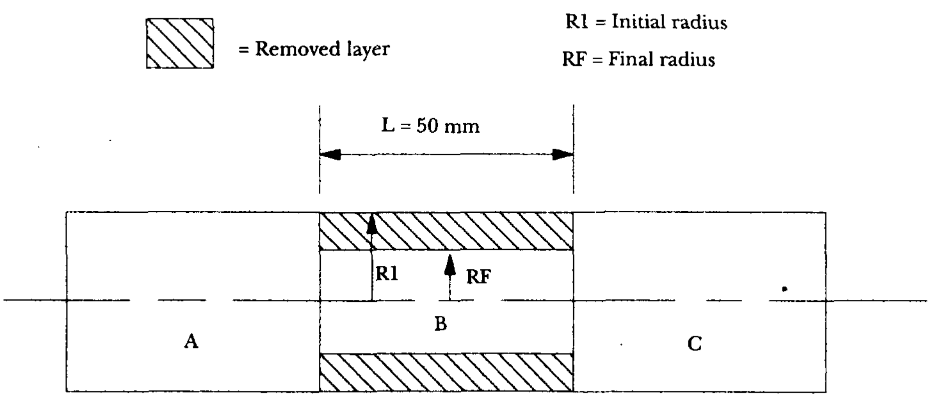

Figure 1. Sample used in the layer removing process

Results and discussion

Variation pattern of the specific gravity

A typical variation pattern of specific gravity across the rattan samples is shown in Table 2 and Figure 2. The relationships are represented by the exponential equation below:

$$SG_P = Ae^{BR_P}; r^2 = 0.83 \text{ to } 0.91 \quad \text{.............................} \quad (2)$$

where

SG_P = specific gravity at a given position across the rattan,
A, B = constants,
R_P = position across the rattan,
r^2 = coefficient of determination.

Table 2. Specific gravity across the stem of *C. manan*

Layer		Sample A	B	C	D	E	F	G	H	I
1	Rp	2.43	2.28	2.42	2.62	2.54	2.69	2.74	2.73	2.75
	SG	0.332	0.351	0.319	0.347	0.334	0.320	0.334	0.285	0.352
2	Rp	5.53	5.34	5.53	6.04	5.90	6.04	6.28	6.36	6.32
	SG	0.394	0.367	0.351	0.351	0.360	0.388	0.390	0.370	0.363
3	Rp	6.97	6.83	7.03	7.54	7.67	7.58	7.81	7.97	7.95
	SG	0.428	0.389	0.375	0.438	0.402	0.428	0.407	0.394	0.447
4	Rp	8.40	8.32	8.59	8.92	8.93	9.06	9.40	9.38	9.49
	SG	0.446	0.416	0.466	0.460	0.450	0.449	0.437	0.408	0.462
5	Rp	9.78	9.89	10.1	10.4	10.4	10.5	10.9	10.8	10.8
	SG	0.558	0.515	0.492	0.479	0.491	0.492	0.469	0.487	0.507
6	Rp	11.3	11.4	11.8	11.9	12.0	12.2	12.5	12.2	12.2
	SG	0.564	0.532	0.504	0.529	0.543	0.536	0.532	0.498	0.534
7	Rp	12.9	13.0	13.3	13.5	13.5	13.7	14.0	13.8	13.6
	SG	0.575	0.542	0.521	0.534	0.571	0.552	0.543	0.543	0.550
8	Rp	14.4	14.6	14.9	14.9	15.2	15.2	15.4	15.4	15.3
	SG	0.675	0.761	0.733	0.762	0.667	0.658	0.668	0.658	0.641
9	Rp	16.0	16.2	16.4	16.3	16.8	16.7	16.9	17.0	16.9
	SG	1.142	1.178	1.094	1.018	1.090	1.022	1.005	0.992	0.985

Notes: Rp = Position across the stem, i.e. a point taken at the middle of the layer;
SG = Specific gravity.

Equation (2) was further developed to include the total specific gravity (SG_T) and total radius (R_T) of the unpeeled rattan as variables of the specific gravity at a given position across the rattan. The product of positional radius (R_P) divided by total radius (R_T) was regressed with the product of positional specific gravity (SG_P) divided by total specific gravity (SG_T) of the samples and the result is shown below:

$$SG_P = 0.418(SG_T)e^{1.246(RP/RT)} \; ; \; r^2 = 0.85 \quad \text{.......................} \quad (3)$$

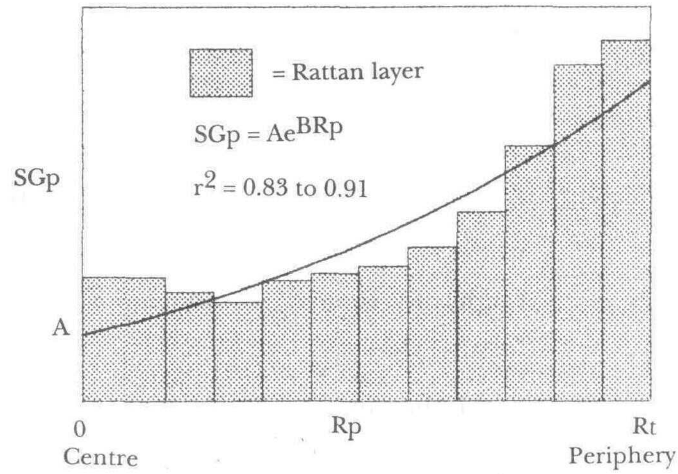

Figure 2. Typical variation pattern of the specific gravity across the stem of *Calamus manan*

Specific gravity of a layer: a mathematical model

A mathematical model was developed based on Equation (3) to predict the specific gravity of a layer (e.g. R_1 to R_2 in Figure 3) in the rattan cross-section. It would help in determining, for instance, the specific gravity of a peeled rattan and rattan cores.

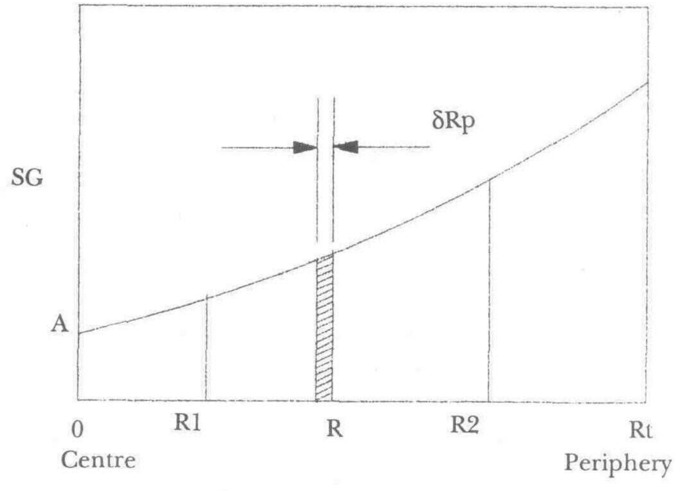

Figure 3. Element δRp to be summed during the integration

Equation (3) could be simplified as,

$$SG_P = Ae^{BR_P} \quad \ldots\ldots\ldots\ldots \quad (4)$$

where

$$A = 0.418(SG_T) \text{ and } B = 1.246/R_T.$$

The specific gravity of a layer from R_1 to R_2 (SG_{R1R2}) could be calculated using the formula below:

$$SG_{R1R2} = \text{Weight of } R_1R_2 \text{ layer / Volume of } R_1R_2 \text{ layer}$$
$$= W_{R1R2} / V_{R1R2} \quad \ldots\ldots\ldots \quad (5)$$

But, the weight of R_1R_2 layer is the summation of elements $SG_P\delta R_P$ with a length (L) rotating about SG-axis (Figure 3). Thus,

$$W_{R1R2} = \lim_{\delta Rp \to 0} \sum_{Rp=R1}^{R2} 2\pi R_P L SG_P \delta R_P = 2\pi L \int_{R1}^{R2} R_P SG_P dR_P$$

and the volume of R_1R_2 layer is

$$V_{R1R2} = \pi L(R_2^2 - R_1^2)$$

Therefore, Equation (5) becomes

$$SG_{R1R2} = (2/(R_2^2 - R_1^2)) \int_{R2}^{R1} R_P SG_P dR_P$$

Substituting the value for SG_P [Equation (4)] gives

$$SG_{R1R2} = (2/(R_2^2 - R_1^2)) \int_{R2}^{R1} R_P Ae^{BR_P} dR_P \quad \ldots\ldots\ldots \quad (6)$$

Application: the effect of peeling on specific gravity

Peeling of manau and other large-diameter canes is a common process in the industry. It is done mainly for the following reasons: to obtain uniform diametrical shapes and sizes, and to remove the defective skins. Most of the rattan processors agreed that peeling does reduce the rattan density and thus their strength. However, nobody could tell exactly the maximum allowable peeling so that the strength reduction is acceptable. The lack of knowledge has often led the processors to over-peel the rattan where in some cases, the rattan is peeled down to half of its original diameter.

Using the mathematical model developed in this study, the effect of peeling on the specific gravity of rattan could be predicted. To calculate the specific gravity of a solid cylindrical rattan, the R_1R_2 layer in Equation (6) should start from the center. This means that R_1 is equal to zero and R_2 is the peeled radius. Thus, Equation (6) could be further simplified as

$$SG_{R2} = \frac{2}{R_2^{\,2}} \int_0^{R2} R_P A e^{BR_P} dR_P$$

$$= \frac{2}{R_2^{\,2}} \left[(AR_2 e^{BR_2}/B) - (Ae^{BR_2}/B^2) + (A/B^2) \right]$$

$$= \frac{2}{R_2^{\,2}} \frac{A}{B^2} (BR_2 e^{BR_2} - e^{BR_2} + 1) \quad \text{.......................................} \quad (7)$$

Example

Equation 7 can be used to determine the specific gravity of, say, Sample D with an unpeeled diameter size of 34.4 mm, and total specific gravity value of 0.585 (Table 1) if it is peeled by 5, 10, 20, 30 and 50% of its original diameter.

Answer:

From Equation 4, $A = 0.418SG_T$ and $B = 1.246/R_T$. For Sample D, $SG_T = 0.585$ and $R_T = 17.2$ mm. Thus,

$$A = 0.245 \text{ and } B = 0.072$$

For 5 % peeling, $R_2 = 0.95R_T = 16.3$ mm. By substituting A, B and R_2 values in Equation (7),

$$SG_{5\%} = 0.557$$

The calculations are repeated for the rest of peeling percentages and the results are shown in Table 3.The results would suggest that below 10% peeling, the percentage of specific gravity reduction was almost equal to that of peeling.

Table 3. Predicted values of the specific gravity of a peeled rattan

Peeling %	R_2	SG	SG reduction %
5	16.3	0.557	4.7
10	15.5	0.534	8.7
20	13.8	0.488	16.6
30	12.0	0.446	23.7
50	8.6	0.374	36.1

Conclusion

The specific gravity across the stem of rattan increases exponentially from the centre towards the periphery. The specific gravity of any layer in the rattan cross-section could be predicted using the mathematical model developed. The model provides some insight of the effect of peeling on the rattan specific gravity.

Although the model might only be valid for the tested rattan pole, the methods introduced in this study could be directly applied to other rattans.

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