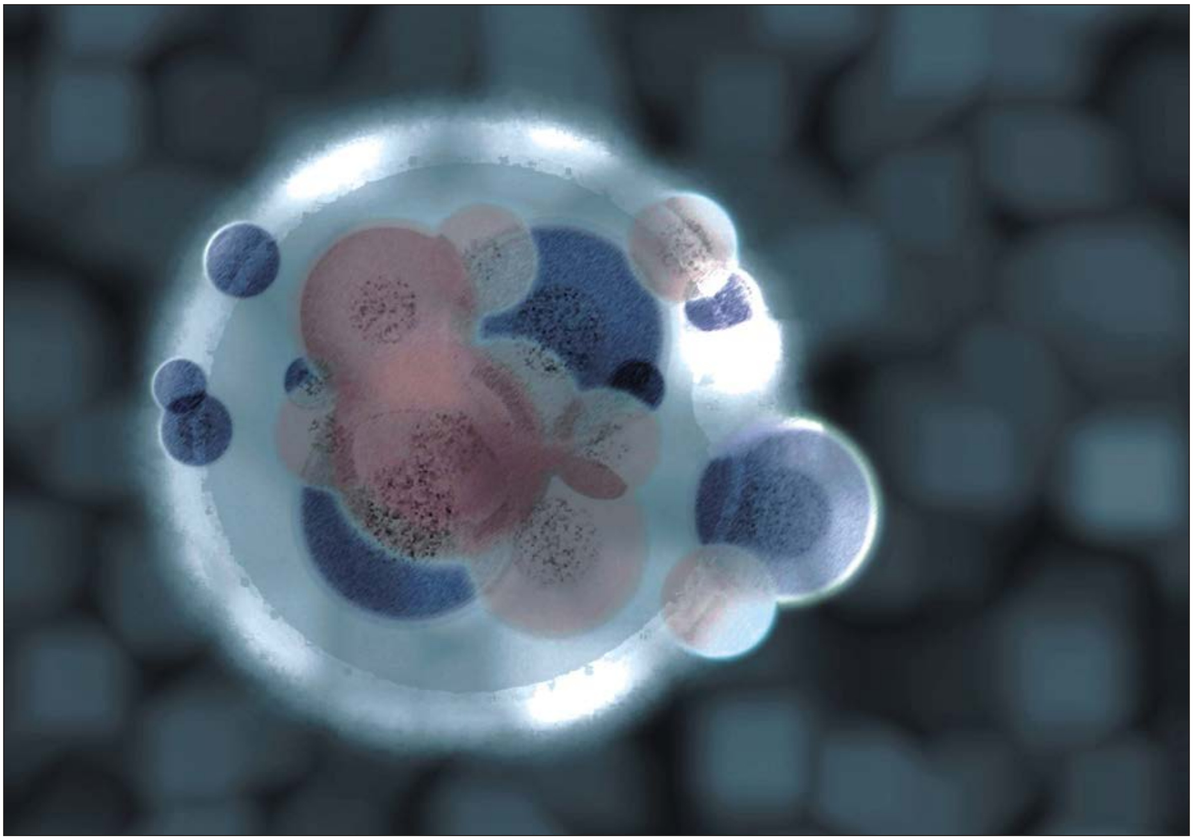

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Eccentricity Effect on Bamboo's Flexural Properties

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Abstract: Bamboo stem's cross sectional area is never a perfect circle, but almost ellipse. Each ellipse shape has a unique value of eccentricity (e) as parameter to denote its circularity. A perfect circle has a zero value of eccentricity. Conventional calculation for bamboo flexural properties as designated by ISO 22157-1:2004 resulted an overestimated or underestimated value compared to the actual value because of the perfect circle cross sectional assumption. Inappropriate geometrical assumption of cross sectional area derived inaccurate value of moment of inertia hereafter affected to the measured flexural properties. Thirty six bamboo stems from 4 species namely Ampel (*Bambusa vulgaris* Schrad.), Tali (*Gigantochloa apus* (Bl.Ex Schult.f) Kurz), Gombong (*Gigantochloa verticillata* (Willd.) Munro) and Mayan (*Gigantochloa robusta* Kurz.) were harvested and it was found that the eccentricity (e) value of bamboo stem could vary from 0.000 to 0.508. This paper studied the effect of eccentricity to the flexural properties of bamboo and aimed to create the strength ratio (C_e) between actual elliptical shape and assumed perfect circle shape. It was reported that the conventional calculation arise an under estimate result if the major axis arranged horizontally, while overestimate result will be get if the major axis arranged vertically. So the modulus of rupture (S_R) which is calculated by conventional calculation should be adjusted by the strength ratio of eccentricity (C_e) in order to define more precise value. This study result the exact relationship between C_e value and eccentricity for both conditions. For simplicity, the graphical sketches were made too.

Key words: Bamboo, cross sectional area, eccentricity, flexural properties, moment of inertia, strength ratio

INTRODUCTION

Bamboo is natural product which traditionally has become the rural community's main choice for many purposes in South East Asia villages because it is cheap and easy to find in their neighborhood; some bamboo species are used for building material (pillars, walls, roof and floor), e.g., *Bambusa bambos* (L.) Voss, *B. blumeana* (J.A. and J.H. Schulthes), *B. tulda* Roxb, *B. vulgaris*, *Dendrocalamus asper*, *Gigantochloa apus* (J.A. and J.H. Schultes) Kurz, *G. atter* (Hassk.) Kurz, *G. levis* (Blanco) Merrill, *G. pseudoarundinaa* (Steudel) Widjaja, *G. robusta* Kurz and *G. scortechinii* Gamble (Dransfield and Widjaja, 1995). People commonly build their bamboo houses based on the traditional experiences without any engineering calculations. Since the demand for green and sustainable construction arises and spreads globally (Tam *et al*., 2004; Lam *et al*., 2011; Kamar *et al*., 2010), recently bamboo construction attracts the engineer's attention because of its artistic, high performance, natural resources sustainability and environmentally friendly (Chele *et al*., 2012; Yu *et al*., 2003; Chung and Yu, 2002; De Flander and Rovers, 2009). Many researcher reported the advantages of bamboo for environment (Bahtiar *et al*., 2012; Van der Lugt *et al*., 2006, 2012), its properties compared to another materials (Hamid *et al*., 2012; Verma *et al*., 2012; Sakaray *et al*., 2012; Jiang *et al*., 2012; Yu *et al*., 2008; Huang *et al*., 2012; Li and Shen, 2011) and its sustainability (Vogtlander *et al*., 2010; Nath *et al*., 2012).

As natural product, bamboo stem properties are influenced by many factors during its growth period, e.g., genetic and habitat condition (Kleinhenz and Midmore, 2001). These factors create the variability in size and physical shape, so every stem could have varied diameter size, taper and eccentricity (Nugroho and Bahtiar, 2012). Nugroho and Bahtiar (2012) conducted some researches of bamboo taper effect on its flexural properties. It was reported that the taper value didn't affect to flexural properties on center point bending test, but the previous study on third point loading bending test showed that taper played significantly to its flexural properties. So the bamboo modulus of rupture (S_R) should be adjusted by its taper strength ratio (C_t) when it was defined by third point loading bending test. Conventional method to measure the S_R of bamboo stem as designated in ISO 22157-1:2004 based on third point loading bending test resulted under estimate values than the actual ones because of no-taper assumption. Adjusting the resulted testing value with the corresponding strength ratio will result more precise

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value. Beside taper effect, the eccentricity on bamboo stem will affected to its flexural properties which will be studied in this paper.

Bamboo stem commonly assumed as hollow cylinder shape (Sharmaa *et al*., 2013; Wegst, 2011; Inoue *et al*., 2011; Schulgasser and Witztum, 1992). In fact, a perfect circle of natural product (including bamboo stems) may never be found. The cross sectional area of bamboo stems are naturally more similar to ellipse than circle. There are always maximum and minimum diameters on every pieces of cross sectional area. Some standards (e.g., ISO 22157-1:2004) designated the average value of diameter as standard value to calculate the bamboo mechanical properties. This unapropriate geometrical assumption created an over or under estimate value compared to the actual properties because the inaccurate value of moment of inertia of plane area. Moment of inertia is directly related to the beam stress and strain (Nash, 1998) which is became the basic equation to calculate the flexural properties of beam. An overestimate mechanical properties of material could become dangerous in structural planning because the building could collapse since the overload condition, while the under estimate value created non-efficient building. A precise value of each material mechanical properties play important role in building construction planning. So it is important to study the effect of eccentricity on bamboo mechanical properties in order to plan the bamboo construction more reliable.

Eccentricity term is commonly used in physical and planetary science (Olson and Deguen, 2012; Correia *et al*., 2011). Eccentricity is the parameter to measure the circularity of ellipse shape. The eccentricity value for a perfect circle is 0 (zero), while the value becomes higher for the thinner ellipse shape. This study aimed to derived the exact mathematical relationship between eccentricity value and its effect on the bamboo stems flexural properties which determined by its strength ratio (C_e). Then this mathematical relationship was applied for eccentricity range value which was obtained from survey and harvested bamboo stems. Finally, this study resulted strength ratio formulae which could be applied as adjustment factor to gain more precise value of bamboo flexural properties.

MATERIALS AND METHODS

Survey on bamboo eccentricity: First, a survey was conducted on 5 bamboo shops in Bogor, West Java-Indonesia to measure the dimensional properties of available bamboos. We choose 20-40 bamboo stems on every shop randomly. At the same time we harvested 36 bamboo stems from 4 species in Arboretum Bamboo-Bogor Agricultural University: 9 stems from each species, then measuring its dimensional properties.

Strength ratio of eccentricity (C_e) derivation: Eccentricity effect on bamboo's flexural properties defined by deriving it theoretically based on beam's maximum stress concept. The ratio of maximum stress on ellipse (actual) and circle (assumed) cross sectional shape is denoted as strength ratio of eccentricity (C_e). The exact relationship between eccentricity (e) and its strength ratio (C_e) derived mathematically.

C_e value range for bamboo: The C_e value for overal range of bamboo stems eccentricity could be justified by substituting the range of eccentricity value which resulted from survey and harvested stems into the obtained mathematical equation.

RESULTS AND DISCUSSION

Survey on bamboo eccentricity: A survey was conducted in 5 bamboo shops in Bogor. The basal and top diameters of 162 bamboo Tali (*Gigantochloa apus* (Bl.Ex Schult.f) Kurz) stems which have 50-110 cm length were measured. The maximum diameter was defined as major axis and minimum diameter was the minor axis. The result was shown in Table 1. The basal eccentricity varied from 0.00 to 0.47 and the top varied from 0.00 to 0.51. Then 36 bamboo stems from 4 species, namely: Ampel (*Bambusa vulgaris* Schrad.), Tali (*Gigantochloa apus* (Bl.Ex Schult.f) Kurz), Gombong (*Gigantochloa verticillata* (Willd.) Munro) and Mayan (*Gigantochloa robusta* Kurz.), were harvested: 9 stems from each species. The measurement found that the bamboo cross sectional shape could vary from perfect circle into ellipse. Zero eccentricity which means a perfect circle shape

Table 1: Dimensional properties of tali stems

	Basal				Top				
	d (cm)	a (cm)	b (cm)	e	d (cm)	a (cm)	b (cm)	e	Taper
Min.	3.33	3.38	3.28	0.00	3.21	3.28	3.14	0.0000	0.00000
Max.	7.40	7.50	7.30	0.47	7.17	7.23	7.10	0.5100	0.01360
Average	5.12	5.19	5.05	0.21	4.84	4.90	4.78	0.1926	0.00439
St. Dev	0.96	0.97	0.95	0.10	0.96	0.97	0.95	0.1000	0.00330
Covariance	18.69	18.74	18.73	49.51	19.75	19.76	19.82	52.3500	75.11000

d: Average diameter, a: Major axis (maximum diameter), b: Minor axis (minimum diameter), e: Eccentricity, N = 162

Table 2: Eccentricity of bamboo stems

Species	n	a (cm)	b (cm)	e
Tali	9	7.32-9.940	7.26-9.810	0.000-0.338
Ampel	9	5.73-8.600	4.94-8.120	0.000-0.508
Gombong	9	6.30-11.24	5.85-11.24	0.021-0.438
Mayan	9	7.05-9.890	6.32-9.780	0.126-0.498
Overall				0.000-0.508

N = 4, a: Major axis, b: Minor axis, e: Eccentricity

found in Tali and Ampel, but it was not found in Gombong and Mayan. As seen on Table 2, the overall eccentricity for 36 measured bamboo stems was 0.000-0.508. It was similar with the survey result on the shops. This condition proved that most of bamboo cross sectional plane was more similar to ellipse than circle shape. Meanwhile some researchers assumed the circle cross sectional area of bamboo stem in order to make more simple calculation for their study (Sharmaa *et al*., 2013; Wegst, 2011; Inoue *et al*., 2011). In their study, the diameter was defined as average of maximum diameter (major axis) and minimum diameter (minor axis). Since there is exact relationship between geometrical shape and beam's stress and strain (Nash, 1998), bending test with perfect circle cross sectional area assumption may result unprecise value of bamboo's flexural properties. In order to minimize the difference of assumed and actual value, a strength ratio should be applied (Nugroho and Bahtiar, 2012). Kretschmann (2010) defined: "the strength ratio is the hypothetical ratio of the strength of a piece of lumber with visible strength-reducing growth characteristics to its strength if those characteristics were absent". On this study, strength ratio was defined as the hypothetical ratio of strength of a piece of bamboo stem with ellipse cross sectional shape compared to its strength if ideal circle shape applied.

Strength ratio of eccentricity (C_e) derivation: Bamboo stem's cross sectional area is commonly assumed as a perfect circle, while its actual shape is almost ellipse (Fig. 1). Ellipse shape has major (a) and minor (b) axis which are the longest and shortest diameters, respectively (Bressoud, 1991). In order to calculate more simply, in some studies the circle diameter (d) which calculated as average of maximum and minimum diameter of ellipse shape is commonly chosen as the standard value (Sharmaa *et al*., 2013; Wegst, 2011; Inoue *et al*., 2011). So the mathematical relationship between a, b and d usually be defined as Eq. 1:

$$d = \frac{a+b}{2} \quad (1)$$

The strength ratio of eccentricity (C_e) denoted as the ratio of maximum stress in actual ellipse shape (σ_e) and the assumed cylindrical shape (σ_c) (Eq. 2):

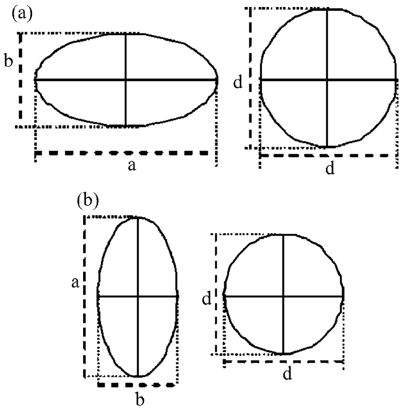

Fig. 1(a-b): Sketch of assumed cylindrical shape compared to the actual ellipse shape which the major axis coincides with (a) Absis and (b) Ordinate

$$C_e = \frac{\sigma_e}{\sigma_c} \quad (2)$$

Since the bending stress is known as Eq. 3 (Nash, 1998), so the eccentricity strength ratio could be define as Equation 4 because the maximum length from centroid (c) for circle is a half diameter (d/2) while for the ellipse is a half minor axis (b/2):

$$\sigma = \frac{Mc}{I} \quad (3)$$

$$C_e = \frac{bI_c}{dI_e} \quad (4)$$

Substituting Eq. 1 into 4 it becomes:

$$C_e = \frac{2bI_c}{(a+b)I_e} \quad (5)$$

Since the moment of inertia for circle (I_c) and ellipse (I_e) shape are denoted by Eq. 6 (Nash, 1998) and Eq. 7 (Symonds *et al*., 1996), respectively, Eq. 5 could be solved become Eq. 8:

$$I_c = \frac{\pi}{64} d^4 \quad (6)$$

$$I_e = \frac{\pi}{64} ab^3 \quad (7)$$

$$C_e = \frac{(a+b)^3}{8ab^2} \quad (8)$$

Eccentricity is the ratio of the distance of any point on a conic section (ellipse, parabola, hyperbola or circle)

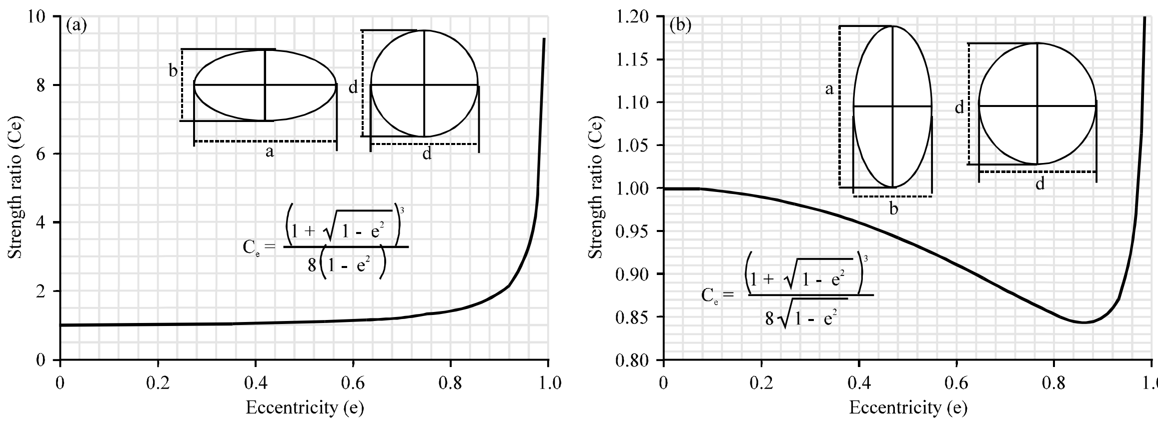

Fig. 2(a-b): Strength ratio of ellipse bamboo when major axis arranged (a) Horizontally and (b) Vertically during bending test

from a focus to its distance from the corresponding direction. This ratio is describing the shape of a conic section and the value is constant for any particular conic section (Jennings, 1994). By this definition, eccentricity (e) is defined as Eq. 9, so ratio of minor axis (b) to major axis (a) of ellipse could be defined as Eq. 10:

$$e = \sqrt{1 - \left(\frac{b}{a}\right)^2} \tag{9}$$

$$\frac{b}{a} = \sqrt{1 - e^2} \tag{10}$$

Substituting Eq. 10 into 8, we get the exact relationship between eccentricity with its strength ratio as seen in Eq. 11 and the graphical sketch is shown in Fig. 2a:

$$C_e = \frac{\left(1 + \sqrt{1 - e^2}\right)^3}{8\left(1 - e^2\right)} \tag{11}$$

As seen on Fig. 2a, strength ratio value for a perfect circle shape is 1 (one), while for ellipse shape is always higher than 1 (one). It is proved that the perfect circle assumption on conventional bending test resulted an under estimate flexural properties value when the major axis (a) configured horizontally during testing. Equation 11 and Fig. 2a are suitable for major axis (a) arranged coincided with horizontal axis (absis) (Fig. 1a). Different result will arise when the testing conducted with major axis (a) configured vertically as shown in Fig. 1b. If the major axis (a) arranged coincided with vertical axis (ordinate), the C_e value could be derived by similar way become Eq. 12 and the graphical sketch is shown in Fig. 2b:

$$C_e = \frac{\left(1 + \sqrt{1 - e^2}\right)^3}{8\sqrt{\left(1 - e^2\right)}} \tag{12}$$

Figure 2b showed that the strength ratio commonly lower than 1 (one). This condition proved that the conventional flexural properties are over estimate compared to the actual value if the major axis (a) configured horizontally during the bending test.

Strength ratio of eccentricity (C_e) value range for bamboo: As mentioned before, during the survey it was found that most of bamboo stems cross sectional plane varied from perfect circle into ellipse. Most of them were ellipse. Applying Eq. 11 for bamboo in bending test which its major axis arranged horizontally, the strength ratio value was 1.000-1.087. The detail strength ratio for all 4 species was shown in Table 3. So the conventional bamboo's flexural properties value which calculated within circle shape of bamboo stem assumption could make 0-8.7% under estimate value. The under estimate flexural properties value will made the oversize structural component. The building will be stronger but more expensive. Meanwhile, Table 3 also showed the strength ratio for bamboo in bending test when its major axis arranged vertically. The values were gained by applying Eq. 12. For overall eccentricity range the strength ratio value was 1.000-0.935. It means perfect circle shape assumption on bamboo bending test caused 0-6.5% over estimated value compared to the actual modulus of rupture (S_R) which tested by vertically arranged major axis ellipse shape configuration. This condition could be dangerous because it leads the engineer to design smaller size structural component than the demand. In extreme condition, the building could be collapse before estimated maximum load applied.

Table 3: Strength ratio of eccentricity for bamboo species

Species	Eccentricity (e)	Strength ratio (C_e) (major axis) Horizontal	Vertical
Tali	0.000-0.338	1.000-1.032	1.000-0.971
Ampel	0.000-0.508	1.000-1.087	1.000-0.936
Gombong	0.021-0.438	1.000-1.059	1.000-0.952
Mayan	0.126-0.498	1.004-1.082	0.996-0.938
Overall	0.000-0.508	1.000-1.087	1.000-0.935

N = 4

CONCLUSION

Cross sectional shape of bamboo stems could vary from perfect circle into ellipse. The eccentricity which denoted the circularity of the shape affected to the measurement of bamboo stem's flexural properties. The relationship between eccentricity and its strength ratio was determined by mathematical equation and it was proved that circle assumption on bending test lead under estimate value if the major axis arranged horizontally on test configuration and lead over estimate value if the major axis arranged vertically. The measured modulus of rupture (S_R) could be 0-8.7% lower or 0-6.5% higher than the actual value.

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REFERENCES

Bahtiar, E.T., N. Nugroho, A. Carolina and A.C. Maulana, 2012. Measuring carbondioxide sink of betung Bamboo (*Dendrocalamus asper* (Schult f.) Backer ex Heyne) by Sinusoidal curve fitting on its daily photosynthesis light response. J. Agric. Sci. Technol., 206: 780-788.

Bressoud, D.M., 1991. Second Year Calculus: From Celestial Mechanics to Special Relativity. Springer, Germany.

Chele, E.S., M.C. Ricardo, P.M. Anac and M.R. Teresad, 2012. Bamboo, from traditional crafts to contemporary design and architecture. Proc. Soc. Behav. Sci., 51: 777-781.

Chung, K.F. and W.K. Yu, 2002. Mechanical properties of structural bamboo for bamboo scaffoldings. Eng. Struct., 24: 429-442.

Correia, A.C.M., G. Boue and J. Laskar, 2011. Pumping the eccentricity of exoplanet by tidal effect. Astrophys. J. Lett., 744: 1-5.

De Flander, K. and R. Rovers, 2009. One laminated bamboo-frame house per hectare per year. Constr. Build. Mater., 23: 210-218.

Dransfield, S. and E.A. Widjaja, 1995. Plant Resources of South-East Asia No. 7: Bamboos. Backhuys Publishers, Leiden, Netherlands, Pages: 189.

Hamid, N.H., O. Sulaiman, A. Mohammad and N.A. Ludin, 2012. The decay resistance and hyphae penetration of bamboo *Gigantochloa scortechinii* decayed by white and brown rot fungi. Int. J. For. Res., 2012: 1-5.

Huang, D.S., A.P. Zhou, H.T. Li, Y. Su and G. Chen, 2012. Experimental study on the tensile properties of bamboo related to its distribution of vascular bundles. Key Eng. Mater., 517: 112-117.

Inoue, A., S. Sakamoto, H. Sugaa and F. Kitahara, 2011. Estimation of culm volume for bamboo, *Phyllostachys bambusoides*, by two-way volume equation. Biomass Bioenergy, 35: 2666-2673.

Jennings, G., 1994. Modern Geometry with Applications. Springer, Germany.

Jiang, Z., F. Chen, G. Wang, X. Liu, S.Q. Shi and H.T. Cheng, 2012. The circumferential mechanical properties of bamboo with uniaxial and biaxial compression tests. Bioresources, 7: 4806-4816.

Kamar, K.A.M., Z.A. Hamid, M.K. Ghani, C. Egbu and M. Arif, 2010. Collaboration initiative on green construction and sustainability through Industrialized Buildings Systems (IBS) in the Malaysian construction industry. Int. J. Sustainable Constr. Eng. Technol., 1: 119-127.

Kleinhenz V. and D.J. Midmore, 2001. Aspects of bamboo agronomy. Adv. Agron., 74: 99-153.

Kretschmann, D.E., 2010. Stress grades and design properties for lumber, round timber and ties. General Technical Report FPL-GTR-190 National, Chapter 7, Forest Products Laboratory, USDA Forest Service, USA. http://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr190/chapter_07.pdf

Lam, P.T.I., E.H.W. Chan, C.K. Chau, C.S. Poon and K.P. Chun, 2011. Environmental management system vs green specifications: How do they complement each other in the construction industry?. J. Environ. Manage., 92: 788-795.

Li, H. and S. Shen, 2011. The mechanical properties of bamboo and vascular bundles. J. Mater. Res., 26: 2749-2756.

Nash, W.A., 1998. Schaum's Outline for Theory and Problems of Strength of Materials. McGraw-Hill, USA.

Nath, A.J., D.C. Franklin, M.J. Lawes, M.C. Das and A.K. Das, 2012. Impact of culm harvest on seed production in a Monocarpic Bamboo. Biotropica, 44: 699-704.

Nugroho, N. and E.T. Bahtiar, 2012. Bamboo taper effect on center point bending test. J. Phys. Sci. Appl., 2: 386-391.

Olson, P. and R. Deguen, 2012. Eccentricity of the geomagnetic dipole caused by lopsided inner core growth. Nat. Geosci., 5: 565-569.

Sakaray, H.N.V., V.K. Togati and I.V.R. Reddy, 2012. Investigation on properties of bamboo as reinforcing material in concrete. Inter. J. Engin. Res. Appli., 2: 077-083.

Schulgasser, K. and A. Witztum, 1992. On the strength, stiffness and stability of tubular plant stems and leaves. J. Theor. Biol., 155: 497-510.

Sharmaa, B., K.A. Harriesa and K. Ghavamib, 2013. Methods of determining transverse mechanical properties of full-culm bamboo. Constr. Build. Mater., 38: 627-637.

Symonds, J., J.P. Vidosic, H.V. Hawkins and D.D. Dodge, 1996. Strength of Materials. In: Marks Standard Handbook for Mechanical Engineers, Avalone, E.A. and T. Baumeister (Eds.). 10th Edn., McGraw-Hill, USA.

Tam, C.M., V.W.Y. Tam and W.S. Tsui, 2004. Green construction assessment for environmental management in the construction industry of Hong Kong. Int. J. Project Manage., 22: 563-571.

Van der Lugt, P., A.A.J.F van den Dobbelstee and J.J.A Janssen, 2006. An environmental, economic and practical assessment of bamboo as a building material for supporting structures. Constr. Build Mater., 20: 648-656.

Van der Lugt, P., J.G. Vogtlander, J.H. van der Vegte and J.C. Brezet, 2012. Life cycle assessment and carbon sequestration: The environmental impact of industrial Bamboo products. Proceedings of the 9th World Bamboo Congress, April 10, 2012, Antwerp, Belgium, pp: 73-85.

Verma, C.S.. V.M. Chariar and R. Purohit, 2012. Tensile strength analysis of bamboo and layered laminate bamboo composites. Inter J. Engin. Res. Appli., 2: 1253-1264.

Vogtlander, J., P. van der Lugt and H. Brezet, 2010. The sustainability of bamboo products for local and Western European applications: LCAs and land-use. J. Cleaner Prod., 18: 1260-1269.

Wegst U.G.K, 2011. Bending efficiency through property gradients in bamboo, palm and wood-based composites. J. Mech. Behav. Biomed. Mater., 4: 744-755.

Yu, H.Q., Z.H. Jiang, C.Y. Hse and T.F. Shupe, 2008. Selected physical and mechanical properties of moso bamboo (*Phyllostachys pubescens*). J. Trop. For. Sci., 20: 258-263.

Yu, W.K., K.F. Chung and S.L. Chan, 2003. Column buckling of structural bamboo. Eng. Struct., 25: 755-768.