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# INVESTIGATION OF THE COMPRESSIVE AND TENSILE STRENGTH OF BAMBOO AS REPLACEMENT FOR STEEL IN LOW COST BUILDING

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## Abstract

Nigerian large numbers of population are living in rural areas. These people are working at small scales to fulfill their livelihood and most of them are living in small houses. In such conditions, low cost housing could be the best option and usage of bamboo as constructional material can play a key role to achieve the goal. Several researchers are working towards the economical and eco friendly or green construction. To give attention in this regard, an experimental study was performed using bamboo as replacement of structural steel. In this research, with the help of experimental investigations, the mechanical properties of bamboo has been presented in terms of compressive and tensile strength.

**Keywords:** Bamboo, Compressive, Tensile strength, Replacement and Investigation

## *Introduction*

Bamboo is a renewable resource that is versatile and characterized by its high strength and low weight, as well as its ability to be readily worked using simple tools. It is generally acknowledged to be one of the most important non-timber forest resources due to the tremendous socio-economic benefits derived from

bamboo-based products. With over a 1000 species and classified in roughly 90 genera which grow in diverse climates throughout the world. Most bamboo is harvested from the wild with only about 50 to 100 of the useful species domesticated and cultivated for commercial use around the world (Paglione, 2003). Bamboo is also considered to be the fastest growing woody plant in the world with an approximate growth height of 7.5 to 40cm a day as stated by Wong (1995), with the world record being in Japan with an approximate growth of 1.2m in a day. Bamboo is a woody plant which grows about three times faster than most other species. The use of bamboo is expected to remain strong and perhaps increase, especially in areas where there is shortage of timber supply (Grosser and Liese 1971). Commercially significant species of bamboo usually mature in four or five years, after which continuous harvests are possible every subsequent year, for up to 120 years in some species and indefinitely in others. Bamboo cultivation and harvesting serve as a source of livelihood for millions of rural inhabitant in many developing countries. Several species of bamboo grow in sub-Saharan Africa, most notably Nigeria, but their uses have been limited to constructing traditional houses, irrigation systems, handcrafts, fuel and food, scaffolding in buildings.

Steel over the years have be extensively used as constructional material, specifically pertaining to reinforced concrete structures and steel structures. Commercially, the high cost of steel is very alarming for building construction and it's maintenance, corrosion also its carbon emissions significantly makes it eco-unfriendly which draws my attention towards bamboo. Bamboo is a plant with a great range of applications in the landscape, either as a living plants or building material and finished products from harvested bamboo. It has been used extensively as a building material in regions where it normally occurs. It's ability to absorb Carbon makes it significantly eco-friendly to the environment. Nevertheless, bamboo was found to provides a high tensile strength of about 440N/$m^2$ which actually depends on the species, cultivation area and the cross sectional are Naznin and Chetiya (2015).

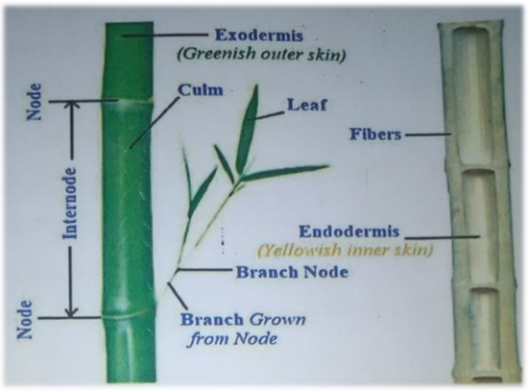



**Figure 1. ANATOMY OF BAMBOO**
**Source: Google search**

## AIMS AND OBJECTIVES OF STUDY

- To investigate the properties of bamboo as a building material.
- To study the compressive and tensile strength of bamboo as replacement for steel.
- To study the challenges of bamboo as a material for low-cost building construction.
- To propose recommendations that will enhance the use of bamboo as a building material for construction in low-cost building in Nigeria.

## AVAILABILITY OF BAMBOO IN NIGERIA

Bamboo is a building material that is readily available in Nigeria but has not been properly utilized as established by various researchers (American Bamboo Society, 2002; Anon, 1987 and Cleaver, 1993). The report of Rasw materials Research and Development Council (RMRDC), (2004) described bamboo as a widely available and distributed material for building construction in the Southern and Middle belt regions of Nigeria. According to the report, the distribution of bamboo in Nigeria is associated with the ecological conditions of the rainforest areas having the most abundant rainfall. The distribution pattern indicates that bamboo is particularly adapted to the rainforest belt of Nigeria where it is found in abundance due to high mean annual rainfall and length of the rainy season. According to Aribisala (1993), the Southern parts of Nigeria has the highest mean annual rainfall, which is more than 1000mm as compared to the North-Central zone which has a mean annual rainfall of between 600-1000mm.

## PROPERTIES OF BAMBOO

- **TENSILE STRENGTH**

  Bamboo has strength properties which are excellent, particularly with regards to the tensile strength (Wakchaure & Kute, 2012; Moroz et al., 2014). Most strength properties of bamboo depend on the species and the climatic condition in which they grow (Sekhar and Gulati, 1973). The strength of bamboo varies along with the height of culm. The compressive strength of bamboo increases

with its height while bending strength has an opposite trend (Liese, 1986; Espiloy, 1994; Kabir et al., 1991, 1993). An increase in the strength of bamboo is believed to occur between 3 to 4 years, and after that decreases (Espiloy, 1994). The outer zone of bamboo has a highly elastic vascular bundle, which also have high tensile strength while the fibre of bamboo run axially, making it more resistant to tension than compression. The high tensile strength of this bamboo fibres is usually higher than that of steel but has a disadvantage of not being possible to construct connections that can transfer this tensile strength.

- **COMPRESSIVE STRENGTH**

  Bamboo with slimmer tubes has a higher compressive strength value than bamboos with larger tubes as regard to their cross-section. Bamboo with slimmer tubes possesses better material properties because larger tubes of bamboo usually have a disadvantage of having a minor part of the outer skin that is highly resistant to tension. Hence, compressive strength is affected by the portion of lignin inside the culms and the large portion of cellulose influences buckling and the tensile strength because it represents the building substance of the bamboo fabrics.

- **FIRE RESISTANCE**

  Bamboo has an excellent fire resistivity due to the high content of silicate acid it possesses. Bamboo which is filled up with water can usually withstand a temperature of 400$^{o}$C while the water cooks inside. It also possesses high moisture content, which is influenced by the age, species as well as the season of harvesting. Although unlike timber, bamboo starts shrinking above the fibre saturation point, the use of Ecology Diversity Synergy technology has remedied this weakness, as EDS treated bamboo is as durable as solid timber for building construction (UNIDO, 2009).

**USES OF BAMBOO AS A BUILDING MATERIAL**

Sakaray et al. (2012) and Salzer et al. (2016) has ascribed the use of bamboo for building construction to be diverse, but presently, only a part of temporary structures or buildings in rural and urban areas utilize the use of bamboo for construction in Nigeria. This use does not exploit the full potential of bamboo as a sustainable building material. Hence, other significant uses of bamboo that can be explored in the building construction industry include;

- **FOUNDATION**

The use of bamboo has been limited for the foundation purpose mainly because bamboo deteriorates and decay quickly when in contact with the damp ground. However, despite this disadvantage of deterioration, the use of bamboos for foundation or supporting posts in buildings is possible when treated with some effective preservatives and built on raised platforms. The different construction processes of bamboo foundations include:

(i) Bamboo in direct contact with the ground. Bamboos are placed on either the ground surface or buried to the ground. Bamboo with nodes that are closely spaced having large diameters and thick sections are used to achieve the best strength and stability. In the absence of this, smaller sections of bamboos can be tied together and preservatives applied to reduce the process of deterioration that usually occurs between 6 to 24 months.

(ii) Bamboo on concrete footings or rocks: The stiffest and largest sections of bamboos are used for bearings and are placed on footings of either rock or preformed concrete without direct contact with the ground.

(iii) Composite bamboo / concrete columns: A bamboo with a post that is integral and durable is achievable through the use of a concrete extension to the bamboo by using a plastic tube with the same diameter of the bamboo.

(iv) Bamboo piles: Bamboo piles are used to reduce settlements of building and sterilize soft soils. This is done through the use of bamboo poles that are split into sections and treated by filling them with coconut coir strands wrapped with jute and tied with wire. Sandy materials are used to cover the area after installation of the piles.

- **FLOORS**

Bamboo can be used as a building material for flooring due to its wear and tear resistance as well as the resilience properties it possesses. The floor covering is done using bamboo boards, mats, etc. employing wire to the frame. The various construction processes of bamboo flooring include:

(i) Small bamboo columns: Bamboo culms are directly tied and nailed together.

(ii) Split bamboo: Bamboo culms are spitted into strips of several centimeters wide along their length

(iii) Flattened bamboo: They are produced by splitting bamboo culms and removing the diaphragms, then rolling and flattening the bamboo culms so that the resulting board is laid and fixed by nailing or typing them across the joists. After that, they are screened with cement mortar to make it easy to clean.

- **WALLS AND PARTITIONS**

The most common use of bamboo for building construction is for the walls and partitions. Bamboo as a building element is used for columns and beams, which generally constitute the structural framework. They are used to carry the self-weight of building and the imposed loads exerted by the building occupants. An infill between framing members is necessary to protect the wall against rain, wind and also to offer privacy. The infill in-wall aims to provide in-plane bracing and ensure the overall stability of the overall structure when subjected to horizontal forces.

- **DOORS AND WINDOWS**

Bamboo is also used for doors and windows in buildings. The use of bamboo frames usually replaces the conventional timber frames often used for doors. Bamboo mat shutters are then fixed to the bamboo frame to serve as the door when hinged to the wall. Also, small bamboo frame can be used to serve as windows when hinged to the top of a wall.

- **SCAFFOLDING**

The use of bamboo as for scaffolding has been in existence for centuries in Asian countries like China and Hong Kong and, despite competition with many metal-scaffolding systems, it remains one of the most preferred systems (Fu, 1993). Also, due to the low construction cost of bamboo and its high adaptability, it can be constructed any layout to follow various irregular architectural features of a building within a relatively short period (Chung et al. 2003). They are used in construction sites in Nigeria to provide temporary access, working platforms for site workers and supervisory staff, and to prevent construction debris from falling onto passers-by. They are either used as single Layered Bamboo Scaffolds (SLBS) for light work or a Double Layered

Bamboo Scaffolds (DLBS) for heavy work. Therefore for bamboo scaffolding like any other, scaffolding must be laterally stable and must possess integrity.

- **TRUSSES**

  One prominent use of bamboo for building construction is the fabrication of roof trusses. Bamboo has a high strength/weight ratio, which makes it an excellent material for roof framing. Achieving any span of truss is possible with bamboo because of its lightweight property alongside its strength and stiffness. The use of bamboo for trusses also results in considerable savings due to the non-use of heavy lifting equipment.

- **ROOFING**

  The roof of buildings serves as protection against weather of varying conditions including sun, rain and wind, and also functions as a shelter for the usable space underneath the roof canopy. The roof should be able to withstand the tremendous forces generated by wind and roof coverings. This makes bamboo a suitable roofing material because of its lightweight and durability. The structure of the bamboo roof can be made of bamboo trusses, rafters and purlins.

## REVIEW OF RELATED LITERATURE

Ahmad et al. (2014) observed that the strength of concrete cubes with fibre doesn't show much improvement up to 28 days but surprisingly strength become double in 50 days testing. Modulus of elasticity of concrete increases with the increase of bamboo fibre. The flexural strength of bamboo reinforced beam increases as high as nearly doubled, so bamboo reinforced beam can be used in low cost buildings. Bamboo fibre can be used as replacement with concrete which can save the expensive concrete, 10,000$cm^3$ and per 1$m^3$ of concrete.

## MATERIALS AND METHODS

### DETERMINATION OF MOISTURE CONTENT

The principle of weighing the loss in mass of the test piece on drying to constant mass was adopted to determine the moisture content in which the calculation of the loss in mass as a percentage of the mass of the test piece after drying was carried out. The apparatus used were weighing balance, electric oven and desiccators. The test was

conducted in an environment of 23ºC temperature and 60% relative humidity. Six culm test pieces were used; measurement was observed and used for the practical.

(i) 2 pieces of Top (T) culm
(ii) 2 pieces of Middle (M) culm
(iii) 2 pieces of Bottom (B) culm

**STEPS FOLLOWED TO DETERMINE MOISTURE CONTENT OF THE SAMPLE**

(i) All culm was weighed to an accuracy of 0.01g and then dried in an oven at a temperature of 103 ± 23ºC.
(ii) The mass was recorded at regular intervals of two hours.
(iii) Care was taken to prevent increase in moisture content between removal from the oven and subsequent determinations of the weight by putting the specimen inside a dessicator when out of oven.
(iv) The drying was considered complete when the difference between the successive determinations of the weight did not exceed 0.01g.

**DETERMINATION OF THE COMPRESSIVE STRENGTH**

The compressive strength of bamboo was evaluated using the specimen made parallel to the fibre direction. Test technique was used for the evaluation of the compressive strength properties. The specimens were tested on a universal testing machine of capacity 2000KN with a loading rate of 0.9mm/min. the apparatus used were universal testing machine, vernier caliper and hacksaw.

**STEPS FOLLOWED TO DETERMINE COMPRESSIVE STRENGTH**

- The test specimens were cut from the top (T), middle (M) and bottom (B) locations of bamboo using a hacksaw and the dimensions of the specimens were measured accurately by a vernier caliper
- The top marked specimen which represented the upper location of the culm was placed parallel to the fibre direction on the compressive plate of the Universal Testing Machine and the specimen was placed so that the centre of the moveable head of the Universal Testing Machine was vertically above the centre of the cross section of the specimen.

- A small load not more than 1KN was initially applied to set the specimen, a continuous load was then applied to cause the moveable head of the Universal Testing Machine to travel at a constant rate until failure occurred.
- The ultimate compressive strength was calculated using the data from the failure load and cross sectional area of the specimens.

**PROCEDURE FOR DETERMINATION OF THE TENSILE STRENGTH**

The apparatus used were universal testing machine, vernier caliper, hacksaw, surface planer and hand file.

**STEPS FOLLOWED TO DETERMINE TENSILE STRENGTH**

- The tensile test specimens (Bamboo scrimbers) were prepared to shape with the use of file and surface planer.
- The cross sectional dimensions of the gauge portion (length of exposed portion) of different dimensions of the culm was cut, measured and recorded. Specimen culm were cut as respect to bar sizes of steel and result was taken.
- The specimen was placed in the lower grip of the moveable cross-head of the Universal Tensile Machine and the moveable cross-head was operated to move downward so as to fix the lower portion of the specimen to the lower grip on the table of the universal testing machine.
- Load was applied continuously at rate of 0.01mm/sec until failure occurred.

The same applies to steel, different diameters 12mm, 16mm, 25mm were cut and placed in the universal machine until failure and were recorded accordingly.

## RESULTS AND DISCUSSION



**Figure 2: BAMBOO SAMPLE USED**

**Table 1 showing physical characteristics of bamboo sample**

| Culm specimen location | Wall thickness T (mm) | Diameter D (mm) | Length L (mm) | Mass M (g) |
|---|---|---|---|---|
| **Top** | 5.30 | 45.20 | 286 | 216.05 |
| **Middle** | 6.48 | 73.52 | 301 | 496.64 |
| **Bottom** | 9.84 | 77.01 | 307 | 858.32 |

The average length of the culm was considered which is 298mm fr determination of compressive and tensile of the bamboo.

**ULTIMATE COMPRESSIVE STRENGTH TEST FOR BAMBOO**

The specimens were tested on a universal testing machine of capacity 100KN with a loading rate of 0.9mm/min



**Figure 3: S.O.N ENUGU UNIVERSAL COMPRESSIVE MACHINE SET FOR BAMBOO COMPRESSION**

**Table 2 showing result of compressive strength of Bamboo**

| Location of culm | Area of culm ($mm^2$) | Maximum load (KN) | Ultimate compressive strength ($N/mm^2$) |
|---|---|---|---|
| **Top** | 354.24 | 32(1.18) | 106.59 |
| **Middle** | 715.36 | 48(1.18) | 79.18 |
| **Bottom** | 1114.27 | 98(1.18) | 103.78 |
| **Average** | ..... | | **96.52** |

The area was determined using Equation A constant k = 1.18 was used to get the final result of maximum load at failure of the specimen.

**Table 3 showing result of tensile strength of Bamboo**

| **Bamboo** | **12mm** | **16mm** | **25mm** |
|---|---|---|---|
| **Max Tensile force (KN)** | 3.16 | 10.43 | 16.54 |

| | | | |
|---|---|---|---|
| **Tensile strength (N/mm$^2$)** | 28.94 | 66.75 | 89.92 |
| **Yield stress (N/mm)** | 0.00 | 47.32 | 49.12 |
| **Elongation (%)** | 0.00 | 6.12 | 8.47 |

The average tensile strength was calculated from Equation for top, middle and bottom culm was taken to get the value in Table above. It was observed that the more the diameter increases the higher the tensile strength of the bamboo.

**Table 4 summary result of tensile strength of steel**

| Bar size | Yield | | Ultimate | | Elongation (%) | Weight (kg) |
|---|---|---|---|---|---|---|
| | Loan (KN) | Stress (N/mm$^2$) | Load (KN) | Stress (N/mm$^2$) | | |
| 12mm A | 40.59 | 358.85 | 57.98 | 512.64 | 11.64 | |
| IGS B | 40.79 | 360.65 | 58.27 | 515.21 | 11.9 | |
| Average | 40.69 | 359.75 | 58.13 | 513.93 | 11.77 | 0.25 |
| 16mm A | 60.40 | 300.36 | 86.29 | 429.09 | 15.00 | |
| Eurotherm B | 57.15 | 284.18 | 81.64 | 405.97 | 8.01 | |
| C | 57.65 | 286.69 | 82.36 | 409.55 | 10.00 | |
| Average | 58.40 | 290.41 | 83.43 | 414.87 | 11 | 0.40 |
| 25mm A | 199.34 | 406.06 | 284.78 | 580.12 | 10.12 | |
| KAM B | 194.54 | 396.30 | 277.92 | 566.14 | 9.22 | |
| C | 193.54 | 394.25 | 276.48 | 563.21 | 10.62 | |
| Average | 195.81 | 398.88 | 279.73 | 569.82 | 9.99 | 1.30 |

**STANDARD: NIS 117:2004 YEILD ≥ 420 N/mm$^2$**

The average tensile was calculated from equation for all samples A, B and C in the above table.

## CONCLUSION

Several samples of bamboo and steel were tested and analyzed to examine their Tensile Properties. This test was carried out on high yield and mild yield steel including bamboo. Tensile test was carried out on 12mm, 16mm and 25mm high yield steel bars. Bamboo also was prepared to about equivalent dimension having cross-sectional area of 10mm x 298mm, 12mm x 298mm, 16mm x 298mm and 25mm x

298mm. The tensile test result indicates that bamboo unlike steel has a very poor tensile property and undergoes brittle failure when loaded. This is a huge disadvantages of using bamboo as a structural member in building construction.

## RECOMMENDATION

In the course of the research, we observed that bamboo has some major demerits which include its poor tensile strength, deterioration by insect attack and aging; therefore we recommend that bamboo should be treated with strong pesticides.

Due to bamboo poor tensile strength, the research concludes that due to the minimal breaking force (FB) of bamboo, it cannot be employed as a main structural member in buildings and other heavy engineering works but can be used for partition walls, ceiling, roofs and other areas of lightweight engineering construction that is not heavy load bearing.

## REFERENCE


Adom et.al "A Comparative Study of Bamboo Reinforced concrete Beams using Different Stirrups Material used for Rural Construction" International Journal of Civil and Structural Engineering.

Aribsala 1993, Atul agarwal and Damodar maity "Experimental investigation on behavior of bamboo reinforced concrete members" 16th International Conference on Composite Structures (ICCS 16). Porto 2011.

ASTM. 1999. Standard Hardness Test Methods for Evaluating PROPERTIES OF Wood-based Fiber and Particle Panel Materials. Annual book standards of the American Society for Testing Materials (ASTM), West Conshohocken, PA, USA, ASTM D1037-99, Section 47-53, pp. 151-2

Bhadari, V.B. 2001. Introduction to Machine Design. McGraw-Hill, New Delhi, India, pp. 78-90. Grosser, D.; and Liese, W. 1971. On the anatomy of Asian bamboos, with special reference to their vascular bundles. Wood Science and Technology 5 (4): 290-312

Dr. Patel Pratima et.al "Performance Evaluation of Bamboo as Reinforcement in Design of Construction Element" International Refreed Journal of Engineering and Science, Volume 2, Issue 4, April 2013.

F. Falade and T. A. I. Akeju (2002). "Structural Design and Economy of Bamboo Reinforced Concrete Beams', Proc. Fifth International Conference on Structural Engineering Analysis and Modeling, (SEAM

Farhana Naznin et.al "A Study on Bamboo Reinforced Concrete Beams" International Journal of Science and Applied Information Technology, Vol.4, No.3, Pages: 49-53 (2015)

Ghavami, K. "Bamboo as Reinforcement in Structural Concrete Elements", Cement & Concrete Composite. Vol. 27, pp 637-649, 2005.

H.M.A Mahzuz et.al "Performance Evaluation of Bamboo with Mortar and Concrete" Journal of Engineering and Technology Research, Vol.3

I.K.Khan "Performance of Bamboo Reinforced Concrete Beam" International Journal of Science Engineering and Technology, Vol-3, No-3, 2014

James Kariuki et.al "Flexural Strength of Laminated Bamboo Beams" International Journal of Advances in Engineering and Technology, Nov 2014.

Jikar.K.Sevalia et.al "Study on Bamboo as Reinforcement in Cement Concrete" International Journal of Engineering Research and Applications, Vol.3, Issue 2, March-April 2013. [5] 6] (12), November 2011

Lo, Cuo, Leung, 2004, "The Effect of Fiber Density on Strength Capacity of Bamboo", Materials Letter, 58, pp 25952598.
Mohmod, A.L.; and Mustafa, M.T. 1993. Variation in anatomical properties of three Malaysian bamboos from natural stands. Journal of Trophical Forest Science 5 (1): 90-6.
Markos Alito (2005), Bamboo Reinforcement As Structural Material For the Construction of low-cost Houses in Ethiopia, Addis Ababa University
M. M. Rahman, M. H. Rashid, M. A. Hossain, M. T. Hasan and M. K. Hasan (2011), Performance Evaluation of Bamboo Reinforced Concrete Beam, International Journal of Engineering & Technology IJET-IJENS Vol: 11 No: 04
RMRDC 1996. Report on the techno-economic survey of the multi-disciplinary task force on pulp, paper products, printing and publishing sector. Raw Material Research and Development Council (RMRDC), Lagos, Nigeria, pp. 1-32
Rahman M. M., Rashid M. H., Hossain M. A., Hasan M. T. and Hasan M. K., Performance Evaluation of Bamboo Reinforced Concrete Beam, International Journal of Engineering & Technology IJET_IJENS 2011,, Vol. 11 No. 04. [5] Concrete floors on grounds," Portland Cement Association Concrete Information, ST-51
Musbau Ajibade Salau, Ismail Adegbite and Efe Ewaen Ikponmwosa "Characteristics Strength of Concrete Column Reinforced with Bamboo Strips" Journal of Sustainable Development Vol. 5, No. 1; January 2012. [15] CBRC (2009) Utilization of Bamboo Book 2
Ogunbiyi et.al "Comparative Analysis of Tensile Strength of Bamboo and Reinforcement Steel Bars as Structural Member in Building Construction" International Journal of Scientific Technology and Research, Volume 4, Issue 11, November 2015.
Ogunsile B.O.; and Uwajeh, C.F. 2009. Evaluation of the pulp and paper potentials of a Nigerian grown Bambusa vulgaris. World Applied Sciences Journal 6(4): 536-41
Paglione 2003, Premkumar. V, Vasuki. V "Study on Mechanical Strength of Bamboo Reinforced Concrete Beams" International Journal of Science Engineering and Technology, Volume 2, Issue – 3, July – 2014.
Sani Haruna, M. Lakshmipathy "Ductility Behaviour of Bamboo Reinforced Coconut Shell Concrete Beams" International Journal of Scientific Engineering and Research, 2014.
TahminaTasnim Nagar and Md. Motiur Rahman " Strengthening of RCC Beams using Bamboo Sticks" International Journal of Advanced Science and Technology, Vol(79), 2015.
V. Ashwin et.al "Experimental Investigation of Bamboo Reinforced Concrete Columns" International Journal of Engineering Research, Vol-3, Issue-3, 2015.
Wong, K.M. 1995. The Bamboos of Peninsular Malaysia. Forest Research Institute Malaysia (FIRM), in collaboration with Forest Research Centre, Forestry Department, Sabah, Malaysia.