Civil and Environmental Research
ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online)
Vol.10, No.6, 2018
www.iiste.org

Study on the Bending Strength of Solid and Glue-Laminated Timber from Three Selected Nigerian Timber Species

Ekundayo Olurotimi Olusegun
School of Environmental Technology, Federal University of Technology Akure
P.M.B 704 Akure, Ondo State Nigeria

Alake Olaniyi
School of Environmental Technology, Federal University of Technology Akure
P.M.B 704 Akure, Ondo State Nigeria

Abstract

Structural timber is desirable for lightness, aesthetics and environmental friendliness. However harnessing timber for structural application can be daunting. Over decades, developed societies modified their sawn timber species by way of gluing in the forms of glued laminated beams and columns. In Nigeria, sawn timber is yet to be explored along these lines. This paper therefore assessed the suitability of *Funtumia africana*, *Alstonia congensis* and *Antiaris toxicaria* Nigerian timber species in the production of glue- laminated timber elements using polyvinyl acetate glue. The glueability, physical and mechanical properties of solid and glue-laminated species were assessed and compared. Bending strength and characteristic values of bending strength were determined. Results showed that the timber species were glueable and bending strength across the species was 65.22 N/mm^2 vs 36.44 N/mm^2; 26.15 N/mm^2 vs 25 N/mm^2; 14 N/mm^2 vs 20 N/mm^2 in solid vs glued laminated *Funtumia Africana*, *Alstonia congensis* and *Antiaris toxicaria* beams respectively in edge wise bending. The glued laminated elements across the species developed 55%, 95% and 143% of the solid wood strength. It was shown that the timber species were structurally glueable using polyvinyl acetate glue. The study has shown that the bending strengths of glue-laminated Nigerian timber species were of structural significance given the bending strength of 36.44 N/mm^2, 25 N/mm^2 and 20 N/mm^2 in *Funtumia africana* (Ire), *Alstonia congensis*(Awun) and *Antiaris toxicaria* (Oriro).

Keywords: Glueability, Glued laminated timber, Nigerian timber species, bending strength

1.0 INTRODUCTION

Timber has versatile application in the construction industry, ranging from simple framing in housing projects to large scale construction for commercial ventures. It is a natural and renewable material, having a high strength-to-weight ratio and is easy to work with (Apu, 2003). There are many types of softwoods and hardwoods in the country widely applied in roof fabrication and household furniture as timber lends itself to flexible use. (Abubakar and Nabade, 2013). In developed parts of the world according to Anthony and Joshua (2014), timber is predominantly adopted as load-bearing elements for residential buildings and public spaces. This is due to the material's economy, high speed of erection, dryness of form and reduced on-site activities due to the method of construction as compared to concrete. This therefore engenders reduction in the cost of building production. However, because natural wood has strength-reducing features which occur at growth, engineered wood products such as glulam was developed to improve natural wood beyond its limitation so as to meet the most demanding structural requirements.

2.0 LITERATURE REVIEW

The need for housing ranks among man's utmost need. Rapid population growth and continuous technological advancement globally bears with it increasing demand for housing. The rising spate of construction to meet this demand has rendered the built environment a threat to the natural environment (Blessing, 2013). The construction industry has been reported to be a major consumer of about half of the earth's non- renewable resources making it an unsustainable industry. Contemporary issues like climate change, environmental pollution, greenhouse gas emission, and natural resource depletion have continued to raise ethical issues associated with the current practice of construction globally. It is therefore feared that the earth may not be able to meet the demand of construction and the built environment without recourse to a sustainable and environmentally responsive approach (Willmott, 2010). The Kyoto protocol of 1997 effective from 2005 is an international treaty on the environment, advocating the use of materials and technologies that reduce greenhouse gas emission in manufacturing and recycling (Carballo et.al, 2009). Against this background, material selection has been underscored as a veritable tool to mitigating the impact of construction and the built environment (Blessing, 2013). Adogo & Kolo (2008) have also noted that building material is the single largest input that significantly influences the cost component of the construction industry. Similarly the role of material selection vis-a-vis the neo concepts of sustainability, renewability and biodegradability has been drummed up more than ever before.

Of all the materials popularly used in construction such as timber, steel and concrete, timber has been identified as a construction material with an excellent environmental credential that is unparalleled and able to address the aforementioned challenges (Bradford, 2008). However, because timber is an organic and adaptive material, its value as a construction material has been undermined by other artificial alternatives like steel and concrete.

Aside the anisotropy of the material, several literatures have identified some of the challenges to the extensive use of timber construction in Nigeria. Yomi and Olu (2003) associated the extent of timber utilization to inadequate emphasis on timber in researches carried out by the academia and research institutions. Zziwa *et.al* (2006) has identified insufficiency of test data on both wood and wood composites as factors that affect the reliability of test result in research findings. Mackenzie et al. (2005) and Green et al (2006), adduced the mode of strength assessment as a factor. Methods of Non-destructive testing have been deployed in developed societies for material testing as against the prohibitively costly, material and time wasting destructive method of testing. The widespread sale of unseasoned or poorly seasoned timber in the market also bears record to the lack of quality control in forest products in Nigeria (Yomi and Olu, 2003). Similarly a tour of the local timber market would reveal that there are more timber species than is profiled in the Nigerian Standard Code of Practice (NCP 2, 1973) for the use of timber. It clearly also shows that there is a wide gap between timber utilization and research in Nigeria, and a wide gap between research and product development which, working in tandem has fostered the extensive use of timber in developed countries. According to Adogbo & Kolo (2008), the restriction to the use of timber in Nigeria is not a problem peculiar to timber alone but one that is so for indigenous building materials (IBMs). One of such challenges to the extensive use of timber is the lack of comprehensive standards and "perception" furnished by the inappropriate use of the material.

Similarly, limitations in cross-sectional dimension and span by growth priorities and defects have limited its extensive use for structural purpose. Furthermore, to address span and dimensional limitations, mechanical methods of jointing were developed. The traditional connection methods commonly used in timber construction consist mainly of dowels, bolts, lag screws, split rings, shear plates, nails and spikes. Some of these methods suffer large deformations (Jacob and Barragan, 2007; Kimeng, 2010), splitting in wood, and loss of strength in elevated temperature among other adverse effects. Similarly, being high embodied energy splicing components, they as well detract from the tenets of sustainability desirable in timber construction.

Sequel to these was recourse to wood adhesives which proved to be better alternatives than mechanical joints. Banea and Silver (2009) noted that adhesively-bonded joints are becoming viable alternatives to mechanical joints in engineering applications providing many advantages over conventional mechanical fasteners. Among these advantages are lower structural weights, lower fabrication costs and improved damage tolerance. Wood adhesives offer a sense of seamlessness in spliced timber element, flexibility in architectural forms, and maintenance of high strength-to-weight ratio while offering wood joints of comparable strength to clear wood fiber.

The advent of wood adhesives has led to the development of Engineered Wood Products (EWP) such as glue-laminated timber (glulam), Parallam, Microllam, Cross Laminated Timber (CLT) and Parallel Strand Lumber (PSL). Literature is replete with researches in Europe and the USA showing that their timbers can be glued to take advantage of these important qualities (Kimeng et.al, 2014). The use of foreign timber with natural and synthetic wood adhesives has been established. Species like Southern pine (*Pinus*spp.), Douglas fir (*Pseudotsugamenziesii*)–larch and Norway spruce species with natural and synthetic wood adhesives like Resorcinol Formaldehyde Resins, Melamine Formaldehyde resins and Epoxy Resins in the production of reconstituted wood elements has been reported (Robert and Roland, 1995; Suhaimi et.al, 2004; Wan et.al, 2011). However, the use of Nigerian timber species in the development of reconstituted wood for structural purpose is yet to be extensively researched (Suhaimi et.al, 2004; Kimeng et.al, 2014).

3.0 AIM AND OBJECTIVES

The study therefore aims to determine the suitability of local timber in the production of structural glue-laminated timber.

The objectives of the study were to;

1. Determination of glueability of the species at moisture content below Fiber saturation Point (FSP) i.e. 25%.
2. Determination of the static bending strength using third- point loading.
3. Determination of physical and mechanical properties of solid and glued-laminated elements from *Funtumia africana*, *Alstonia congensis and Antiaris toxicaria* timber species from experimental works and compare the performance of the wood composite and the solid wood using polyvinyl acetate glue.

3.1 MATERIALS AND METHODS

3.1.1 Materials

The materials used in this study are solid or sawn and glue-laminated elements fabricated from timber specimens obtained from the southern part of Nigeria: *Funtumia africana*, *Alstonia congensis and Antiaris toxicaria.*

(a) Funtumia Africana wood is a white or pale yellowish even textured timber. It is used for cheap joinery, furniture and matchstick manufacture. The wood is also reportedly used for carving stools, doors and miscellaneous household requirements. Funtumia Africana is a forest tree situated in rainforests with geographic distribution across Angola, Cameroon, Cote d'Ivoire, Democratic Republic of Congo, Gabon, Kenya, Liberia, Mozambique, Nigeria, Sierra Leone, Tanzania, Togo, Uganda (World Agroforestry Center).

(b) *Alstonia Congensis* is a lightweight wood which occurs from south-western Nigeria to the Central African Republic, eastern and southern DR Congo, and northern Angola. The wood is used for light construction, light carpentry, open boats, molding, furniture, interior joinery, implements, boxes, crates, matches, pencils, sculptures (e.g. masks), and for veneer and plywood (interior). It is locally popular for the production of household implements because of its good working properties and stability. In trade, the wood of *Alstonia Congensis* is not distinguished from that of *Alstonia boonei De Wild* as they have similar properties. The heartwood is creamy white and indistinctly demarcated from the up-to-20cm wide sapwood. The grain is straight, occasionally wavy, texture moderately coarse.

(c) Antiaris Toxicaria is a lightweight wood. There is little difference between the sap and heartwood; it is yellow-white and soft with moderate shrinkage upon seasoning. The wood has good peeling properties making it a good choice for veneer production. The timber is also used in construction of beer canoes. Wood treatment using boron, chromium, arsenic fluoride treated with 5 and 10% BFCA preservative by hot immersion (1, 2 or 3 hours at 60 – 70 ^{0}C) followed by cold immersion for 24 hours is suitable. Rapid conversion and the application of anti-stain chemicals upon felling are essential, as the wood is liable to sap-stain. The wood is easily attacked by termites and the marine-borer (*Limnoriatripunctata)* (Orwaet al. 2009)

(d) Adhesives

Polyvinyl Acetate (PVA) Glue

The advent of adhesives has brought about more efficient use of timber resource. Certain advantages have motivated the preference for adhesive joints over mechanical joints. These include improved joint performance and durability, assembly costs reduction, design flexibility, reduction in finishing operations and aesthetics (Huntsman, 2007).

Adhesives increase the stiffness and strength properties of wood products; as such, load responses in wood composite are superior to sawn lumber. It enables the fabrication of structural elements with control on the matching or location of superior wood fiber against points of higher stresses to optimize the use of forest products. However the effectiveness of the stress transfer from one member to another is a matter of the strength of the polymer chain across the adhesive-bonded joint. The strength of the chain according to Charles & Christopher (2005) depends on the control of factors that influence bond strength during product assembly.

Vinyl acetate is the principal constituent of the PVA emulsion adhesives under the trade name of ***Top Bond*** which is readily usable liquid polymerized with other polymers; white in color and producing dry colorless bond line. It is applied directly at room temperatures and in high-frequency press to produce high dry strength. Its resistance to moisture and elevated temperatures is low.

4.0 METHOD

4.1 EXPERIMENTAL PROCEDURE

The physical properties of the timber species were determined in line with EN 13183-1 (2002) and EN 408 (2003). The mechanical properties were determined in accordance with EN 408 (2003) and ASTM D193 (2000). The characteristic values of the mechanical properties and density of the timber species were determined in accordance with EN 384 (2004). The glue-laminated elements were prepared in line with BS 5268 (2002).

(a) Moisture Content (MC) *and* Density

The species moisture contents (MCs) were determined in accordance with BS 373 (1957) EN 13183-1(2002) and EN 408 (2003). The MC for each slice taken from each test piece for bending strength test was determined by first measuring its initial mass before drying using weighing balance. The test slices were then oven dried at a temperature of 103 ±2^{0}C for 24 hours. The initial and oven-dry mass of each slice were recorded and the MC was then computed from equation 1

$$MC= m_1-m_2/m_2 \qquad (1)$$

Where, m_1, m_2 and MC are the initial mass, oven-dry mass and MC the moisture content of test piece in percentage.

(b) Density

The density of the specimens was determined in accordance with EN 408 (2003) at particular moisture content while the characteristic values of density of species were determined in accordance with EN 384 (2004) from equation 2:

$$^{\rho}{}_{05} = \bar{x} - 1.65\sigma \qquad (2)$$

Where: $\bar{x}$ **is** the mean value σ is the standard deviation and $^{\rho}{}_{05}$ is the characteristic density, in (kg/m^3) respectively.

The 18% MC adjustment for characteristic density of timber in accordance to NCP2 (1973) was computed using equation 3:

$$^{\rho}{}_{\mathbf{k,\,18\%}} = {}^{\rho}{}_{w}\,[1\text{-}(1\text{-}0.5)(U\text{-}18)/100] \qquad (3)$$

Where;

$^{\rho}{}_{w}$ is the density at the time of testing , U is the moisture content at the time of test, $^{\rho}{}_{\mathrm{k},\,\mathbf{18\%}}$ is the characteristic density at 18% MC.

For bending strength tests, the timber species were planned before 160No laminates of 34 mm × 80 mm × 1500 mm each, that is, 40 pieces per specie (of which 20 specimen were solid timber and 20 specimen were glulam elements) were prepared and cut to dimension in the carpentry workshop of Building department, Ahmadu Bello University (ABU), Zaria, Nigeria. For MC and density, averages of 3 readings for each specimen were taken from bending strength test specimen sliced to 34 mm× 50mm×80 mm. Laminates of 20mm each of four laminates were glued using PVA and then clamped with enough pressure to produce thin glue lines between the wood laminates. These were then left to cure for 24hours.

5.0 Mechanical Properties

Bending Strength

Bending strength was defined by the three point bending strength tests as specified by ASTM D193 (2000). A total of 60 specimens, i.e.20 specimens for each of the selected timber specie were produced. Thirty (30) specimens for solid timber and 30 specimens for glue-laminated timber with 4 laminas of 20mm each were tested in the Strength of materials laboratory of the Department of Mechanical Engineering, Ahmadu Bello University, Zaria. Each specimen was tested using the Denison universal testing machine until failure occurred. The failure load in respect of the individual beam was recorded. The bending strength was calculated using equation (4):

$$f_m = 3F_{\max}l\,/2bh^2 \qquad (4)$$

Where f_m is the bending strength (in Newton), $f_{\max}$ is the maximum Load (in Newton), b is the width of cross-section in bending test (mm), h is the depth of cross section in bending test (mm) and l is the length of test specimen between supports (mm).

The characteristic values of strength properties based on the measured MC were computed from equation 5 (Ranta-Maunus et al, in Abubakar and Nabade 2013):

$$f_{\mathrm{mk}} = 1.12 f_{0.5} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where, f_{mk} and f_{05} are the characteristic and 5th-percentile values of bending strength respectively.

According to EN 384 (2004), the sample size to be considered for bending test should have a depth of 150mm. For depths other than 150 mm, the 5-percentile values of bending strength shall be adjusted to 150 mm depth or width by dividing by equation (6).

$$K_h = [(150/h)^{0.2}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Where k_h is the depth adjustment factor and h is the depth adopted for the bending test. A depth of 80 mm was adopted for the test so that h=180mm. (Abubakar & Nabade, 2013).

The adjustment for characteristic values of bending strength from the measured MC to 18% MC in order to suit Nigerian environmental condition (NCP2, 1973) was computed from equation 7:

$$F_{\mathrm{m\,(18\%)}} = f_{\mathrm{measure}}/\ 1 + 0.0295(18 - U) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Where f_m is the characteristic bending strength at 18% MC, u is the measured MC (%) and $f_{m18\%}$ *measured* is the characteristic bending strength at the measured MC (N/mm^2).

According to section 3.1 of EN 384 (2004), the mean Modulus of Elasticity (MOE) is a characteristic value. Therefore, the mean MOE is equivalent to characteristic MOE. The global MOE obtained from three point bending test was computed from equation (8) (ASTM D193, 2000):

$$E_{\mathrm{mg}} = l_3\,(P_2 - P_1)\,/\,48I\,(E_2 - E_1) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

$$E_{\mathrm{m18\%}} = E_{\mathrm{measured}}\,/\,1 + 0.0143(18 - u) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

Where $E_{\mathrm{m18\%}}$ is the characteristic bending MOE at 18% MC, E_{measured} is the characteristic MOE at the measured MC (*N/mm*^{2}) and u is the measured MC (%).

6.0 RESULTS AND DISCUSSION

6.1 MOISTURE CONTENT

The average MC results from the (3) selected timber species are presented in Table 1. The results of Table 1 show the mean, standard deviation and coefficient of variation of MC for solid and glue-laminated *Funtumia africana*, *Alstonia congensis*, and *Antiaris Toxicaria* timber species. The mean values of MC with respect of all the three species were found to fall below the fiber saturation point (FSP). The FSP is usually between 25-30% MC (Nabade, 2012).

6.2 DENSITY

The mean values of density for solid and glulam timber are presented in Tables 2 and 3. The two measures of dispersions show variation from the mean values between the species and between solid and glulam timber. The density values for the glulam elements are higher than that of solid wood. The results of the characteristic densities which are the 5-percentile values are given in Table 3. The current Nigerian timber design code is based on 18% MC, the values were therefore adjusted to the recommended MC relevant for local environmental condition.

The results given in Table 3 show that characteristic density increased due to the adjustment of MC for MC values lower than 18% while it decreased for values higher than 18%.

6.3 Bending Strength

Table 4 presents the average values of bending strength based on the measured MC and MC adjusted to 18%, (NCP2, 1973). Table 4 presents the average values of bending strength based on the measured MC and 18% adjusted MC. Bending strength values were adjusted to the equivalent 18% MC, (NCP2, 1973).

For the characteristic bending strength, EN 384:2003 specifies that for depths other than 150mm 5-percentile, values of bending strength shall be adjusted to depths and width of 150mm.

$K_h = \{(150/h)^{0.2}\}$……………… (10)

K_h is the depth adjustment factor and h is the depth used for testing that is 80mm. Therefore the adjusted depths becomes 180mm. K_h becomes 0.564 by which characteristic bending strength shall be divided (Abubakar and Nabade, 2013).

The adjustment for characteristic values of bending strength from the measured MC to 18% MC in line with local environmental condition (NCP2, 1973) was computed from equation 11:

$f_{m,18\%} = f_{measured} / 1+0.0295(18 - U)$…... (11)

Where f_m,18% is the characteristic bending strength at 18% moisture content, u is the measured moisture content (in %) and f measured is the characteristic bending strength(N/mm^2) at the test moisture content. The 18% MC adjustment for characteristic density of timber specie as required by NCP2 (1973) was computed using equation 12 (Abubakar and Nabade, 2013):

$\rho_{k,18\%} = \rho_w$ [1-(1-0.5)(U-18)/100]……..(12)

ρ_w is the characteristic density at the time of testing, U is the moisture content at the time of test.

According to section 3.1 of EN 384 (2004), for MOE, the mean MOE is also characteristic value. For this reason, mean MOE is equivalent to characteristic MOE as shown in Table 4, the values of MOE was adjusted to 18% moisture content in line with NCP 2 using equation 13

$E_{m,\ 18\%} = E_{measure} / 1+ 0.0143(18 - U$…. (13)

Where $E_{m,\ 18\%}$ is the characteristic MOE at 18% MC, $E_{measure}$ is the characteristic MOE at the measured MC (N/mm^2) and U is the measured MC (%).

Table 5 presents the average values of bending strength, and density adjusted to 18% MC and specimen test dimensions. The bending strength values in Table 4 were adjusted to a reference depth of 150mm as shown in Table 6 using equation (10) in line with EN 384:2003,(Abubakar & Nabade, 2013).

7.0 COMPARATIVE PERFORMANCE OF SAWN AND GLULAM TIMBER BEAMS

Bending strength results were compared between the solid and glulam elements across the species. The bases of comparison are the reference MC of 18% and reference depth of 150mm as applied to test results in table 5. The results of bending strength was compared between sawn and glue laminated beams where it showed that the glue laminated beams developed clear wood strength of 55% in *FA*, 95% in *AC*, and 143% in *AT* before failure occurred.

8.0 FAILURE CHARACTERISTIC

In practice, the understanding of failure modes in timber structures aids in analyzing potential reliability in-service problems with the aim to forestall such occurrences early in the design process (Kenneth, 2002). Identifying potential failure modes and determining their effect on the performance of structural elements helps to identify strategies for failure mitigation. While anticipating every failure mode is not possible, certain failure modes have been identified as those which typically occur in glulam beams. According to Thelandersson & Larsen (2003), these include bending, failure due to tension parallel to grain, shear failure, and failure due to tensile stress perpendicular to grain. Plate 1-6 shows failure patterns of samples tested in this study. These were generally similar across the species.

Bending failure of beams is essentially a combination of actions i.e. compression and tension. Examinations of the failure modes displayed in the Plates in appendix 1 are those typical of the beams in the species studied. It was observed that failure in solid and glulam beams showed difference. Solid beams appeared to be governed more by compression failure (Plates 1, 3 and 5) while those of glulam (Plates 2, 4 and 6) by tension. Tension failure exhibited more brittleness in failure while compression failure exhibited ductility. Findings from this study were therefore in line with those of Thelandersson & Larsen (2003).

9.0 GENERAL FINDINGS

Three timber species were used for this study with polyvinyl acetate glue. After conducting laboratory experiments the findings of the general behavior of the glue- laminated timber joints derived from the study are as follow:

i. The species considered could be glued using PVA
ii. PVC in the trade name Top bond developed glue lines of very high strength.
iii. Glue-laminated elements developed significant solid wood strength using PVA
iv. Failure mode was characterized by failure in wood fiber than in glue line
v. Glulam elements were not always stronger than clear solid wood; this was the case across all the species of study.

10.0 CONCLUSION

Laboratory experiments were conducted on three timber species to determine and compare properties of solid and glue laminated timber beams. From the results obtained the following were the findings;

(i) The timber species were found to be glueable.
(ii) Bending strength properties at MC during test were 65.22 N/mm^2 & 36.44 N/mm^2, 26.15 N/mm^2 & 25 N/mm^2, 14 N/mm^2 and 20 N/mm^2 for solid and glue laminated *Funtumia africana, Alstonia congensis* and *Antiaris toxicaria* in that order.
(iii) Comparatively, the glue-laminated beams developed 55%, 95% and 143% clear wood strength in *Funtumia africana, Alstonia Congensis* and *Antiaris Toxicari*a. Sawn *Funtumia African* showed the highest carrying capacity but developed the lowest clear wood strength in its glulam beam, while *Antiaris toxicaria* yielded the lowest carrying capacity but developed the highest clear wood strength of 143% in glulam beams.
(iv) At 18% MC, the characteristic density of the species classifies them in group N7 of NCP 2, 1973. This is particularly so for *Funtumia African and Antiaris toxicari* which have not been captured in NCP2, 1973.

11.0 RECOMMENDATIONS

(i) Given the results obtained from laboratory experiments, locally glue-laminated timber elements could be further developed for structural application.
(ii) More local timber species contained in NCP 2 could be tested for their suitability for glulam production.

12.0 REFERENCES

Abubakar I and Nabade A. M (2013). Physical and Mechanical Properties of Some Common Nigerian Timber Species Based on Limit State Design Approach**.** *Study of Civil Engineering and Architecture (SCEA),* 2 (4), 90 -97

Adogbo, K.J and Kolo, B.A. (2008). The perception on the use of Indigenous Building materials by professionals in the Nigerian Building Industry. *Environmental Technology and Science journal (ETSJ),* 3 (2), 62-78.

Anthony N.E and Joshua O.O (2014): Appraisal of Timber as Structural Members for Residential Buildings in Nigeria. *International Journal of Engineering & Technology IJET-IJENS* 14 (01), 108 – 112.

Apu, S. S. (2003): Wood Structure and Construction Method for Low-cost Housing. *International Seminar / Workshop on Building Materials for Low-Cost Housing*, September 7-28, Indonesia.

ASTM D193 (2000). “Standard Method of Testing Small Clear Specimens of Timber”, American Society for Testing and Materials.

Banea M.D and Silva L.F.M (2009): Adhesively bonded joints in composite materials Proceeding*s* of the Institution of Mechanical Engineers. *Journal of Materials Design and Application (JMDA),* 223(219), 1 - 18.

Blessing Adegoke (2013): Assessment of criteria for selection of timber as building material for building construction projects within Lagos Metropolis. *Bachelor’s thesis*

Life cycle assessment (2013, March)- retrieved, http://www.bradfordforest.com/Life-cycle-assessment.2010.0.html

Carballo J., Hermoso E and Fernandez J.I (2009): Mechanical Properties of Structural Maritime Pine Sawn Timber from Galicia. *Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA*) 18(2), 152 -158.

CAN/CSA-O122-06 (R2011) - Structural Glued-Laminated Timber

EN 384 (2004). "Structural Timber: Determination of Characteristic values of Mechanical Properties and Density", European Committee for Standardization, CEN, Brussels, Belgium.

EN 408 (2003): "Timber structures – Structural timber and Glued-laminated Timber: Determination of some Physical and Mechanical Properties", *European Committee for Standardization, CEN, Brussels, Belgium.*

EN 1194: Wood constructions- glue laminated timber – Strength classes and determination of characteristic values.

Glos P. (1995): Strength grading STEP lecture A6 Centrum Hout, the Netherlands.

Glue Laminated Timber Association UK (2010): Structural glued laminated timber –Design essentials.

Green, D., Gorman, T., Evans, J., and Murphy, J. (2006). "Mechanical Grading of Round Timber Beams." *J. Mater. Civ. Eng.*, 10.1061/ (ASCE) 0899-1561(2006)18:1(1), 1-10.

Huntsman Advanced Materials (2007): Users Guide to Adhesives
2007 Huntsman Corporation. All rights reserved. www.freemansupply.com

Jacob, J. and Barragan, O.L.G. (2007): Flexural Strengthening of Glued Laminated Timber Beams with Steel and Carbon Fiber Reinforced Polymers (Master's thesis). Retrieved from http://publications.lib.chalmers.se/records/fulltext/40294.

Kenneth C. (2002): Failure Modes and Effects Analysis (FMEA)

Drm Associates Product Development Forum NPD Body of Knowledge FMEA Workshop,PD Toolkit (FMEA Software)

Kimeng, H.T. (2009) Reliability Based Evaluation of Effectiveness of Fasteners and Connection in Timber Trusses. Unpublished Ph.D Dissertation Ahmadu Bello University Zaria Nigeria

Mackenzie R. K. T., Smith R.S. and Fairfield, C.A. (2005): New directions for NDT in forestry. British Institute of non-destructive testing.

NCP 2: (1973): The use of Timber in Construction Nigerian Standard Code of Practice, Nigerian Standard Organization, Federal Ministry of Industry, Lagos Nigeria.

Robert H. and Roland H (1995): Performance of glued laminated Timber beams of European manufacture. *Focus artic Glue Laminated Timber Association UK (2010): Structural glued laminated timber –Design essentials*

Suhaimi A.B, Abdlatif S, Zainab B M(2004): Factors affecting the strength of solid and glued laminated beams

Sven Thelandersson and Hans J. Larsen (2003): Timber Engineering Mechanical performance and modelling of glulam. Pg. 69

Willmott D. (2010): Impacts of Construction and the Built Environment, Briefing note 33 version 1 December 2010.

Wan H, Wan M, Mohd A R, and Zakiah A: Bending strength properties of glued laminated timber from selected Malaysian hardwood timber. *International Journal of Civil & Environmental* (*IJCEE -IJENS*) 11 (04)

World Agroforestry Centre, undated. Agroforestry tree Database. [Internet] World Agroforestry Centre (ICRAF), Nairobi, Kenya. http://www.worldagroforestry.oStojic, D., 1999 Innovation in Design in Timber Structures FACT A UNIVERSITATIC, series. Architecture and Civil Engineering Vol. 2 No 1,pp 77-83.rg/ Sites/Tree DBS/ aft.asp. Accessed January 2005.

Yomi M, Adedeji and Olu O. O (2005): Modern Techniques of Using Timber in Building Structures and Components in Nigeria Department of Architecture, Federal University of Technology, Akure

Yomi O, Margret J, and Opuene O (2002): Acquisition of Technological Capability in Africa: A Case Study of Indigenous Building Materials Firms in Nigeria. ATPS Working Paper Series No. 33

Zziwa, A, Ziraba Y. N. and Mwakali J. A.: Timber use practices in Uganda's building Construction industry: current situation and future prospects. *The Journal of the Institute of Wood Science Vol 19.Wood Technology Society of the Institute of Materials, Minerals and Mining 2009.Department of Civil Engineering, Faculty of Technology, Makerere University, Uganda.*

Table 1: Results of Moisture Content

Timber specie		**Measured Moisture Content (%)**		**Coefficient of Variation**
		Mean	**Standard deviation**	
Funtumia Africana	Sawn	19.13	4.58	0.245
	Glulam	12.11	4.36	0.360
Alstonia congensis	Sawn	10.90	1.38	0.125
	Glulam	10.90	0.774	0.071
AntiarisToxicaria	Sawn	11.47	1.90	0.163
	Glulam	10.82	2.71	0.237

Table 2: Results of Density

Timber species		**Timber density (Kg/m^3)**		**Coefficient of variation**
		Mean	**Standard deviation**	
Funtumia Africana	Solid	433.0	26.20	0.061
	Glulam	450.7	30.30	0.067
Alstonia congensis	Solid	350.5	25.78	0.070
	Glulam	373.5	34.06	0.090
Antiaris toxicaria	Solid	291.5	41.62	0.142
	Glulam	332.0	27.52	0.083

Table 3: Characteristic Bending

Timber species	**Density(Kg/m^3)**		
	Solid		**Glulam**
Funtumia Africana	$P_{k\ @\ measured}$	433.0	450.7
	ρ_k, **18%**	430.0	463.9
AlstoniaCongensis	P_k	350.5	373.5
	ρ_k, **18%**	362.9	386.8
AntiarisToxicara	P_k	291.5	332.0
	ρ_k, **18%**	301.2	343.9

Table 4: Bending Strength at mean Mc from table 1

Characteristic Bending Strength, f_{mk}		***Funtumia africana***	***Alstonia Congensis***	***Antiaris Toxicaria***
Edge-wise (N/mm^2)	Solid	62.15	31.9	15.92
	Glulam	43.3	30.6	22.44
Flatwise (N/mm^2)	Solid	50.12	27.6	20.78
	Glulam	55.95	27.7	19.6
Modulus Of Elasticity In Bending And Compression (N/mm^2)				
Edge wise bending	Solid		2301	34714
	Glulam		1215	34714
Flatwise (N/mm^2)	Solid		3645	47313
	Glulam		7290	40178

Table 5: average values of bending strength and density adjusted to mean mc of 18%

Characteristic properties	***Funtumia Africana***		***Alstonia congensis***		***Antiaris toxicaria***	
Bending Strength	**Solid**	**Glulam**	**Solid**	**Glulam**	**Solid**	**Glulam**
Edge-wise (N/mm^2)	65.22	36.44	26.15	25	14	20
Flat wise (N/mm^2)	56	48	24	23	16.5	16
Density (Kg/m^3)	430	464	363	386	301	344
Modulus of Elasticity in bending and compression (N/mm^2)						
Edge wise bending			2073	1095	32443	32143
Flat wise bending			3344	6688	41869	36525

Table 6: bending strength adjusted to reference depth of 150mm

Characteristic Properties	***Funtumia Africana (FA)***		***Alstonia Congensis (AC)***		***Antiaris Toxicaria (AT)***	
Bending Strength f_{mk},	Sawn	Glulam	Sawn	Glulam	Sawn	Glulam
Edge-wise (N/mm^2)	115	65	46	44	25	35
Flat wise (N/mm^2)	50	43	22	21	15	14

Appendix 1

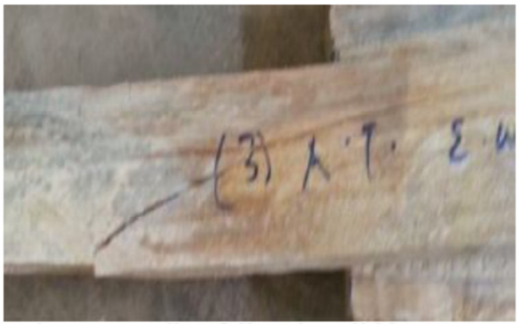

Plate 1: Bending failure in solid beam

Plate 2: Bending failure in glulam

Plate 4: Bending failure in glulam

Plate 3 Bending failure in solid beam

Plate 5: Bending failure in solid beam

Plate 6: Bending failure in glulam