THE STRENGTH CHARACTERISTICS OF GLULAM AND BOLT- LAMINATED BEAM

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ABSTRACT

This research presents the strength characteristics of Glulam and Bolted Beam timber specimens. The most common connection method in timber construction is the nail. It is imperative to explore other methods such as glue and bolt in order to avert the disadvantages of nails such as labour intensive and increase in cost. Experimental investigation was carried out on three selected Nigeria timbers; Ceiba Pentandra, Terminalia ivorensis and Tectona grandis. The specimen was prepared in sizes as either glued, bolted or solid connection. Moisture content, density, compression parallel and perpendicular to grain and flexural tests were carried out in the laboratory. The glulam beam specimen; Ceiba Pentandra, Terminalia ivorensis and Tectona grandis showed some positive potentials for application than the bolt-laminated beam connection. It was concluded that bolted connection can be improved by increasing bolt sizes and connection points.

Keywords:*Adhesive; Bolted connection; Flexural strength; Glulam; Strength class.*

1.0 INTRODUCTION

The term *glulam* is an abbreviation for *glue-laminated timber*. It is made up of multiple layers of solid wood bonded together with high-strength adhesive to form a single structural unit. Timbers find wide application in the construction industry due to their versatility spanning from simple framing in housing projects to large scale public facilities. Recent increased interest in the application of glulam as a primary building material in the Canadian construction market has prompted amendments to be made to the building codes of several provinces. This manufacturing process is notably advantageous because it utilizes trees that were previously unusable as building materials due to their small size and/or low mechanical properties. Prior editions of the National Building Code of Canada (NBCC) restricted the use of wood as the primary building system by limiting its application to buildings with a maximum height of four storeys. Starting in 2009, 2013 and 2015, the provinces of British Columbia, Quebec, and Ontario, respectively, made amendments to their provincial building codes facilitating the use of timber as the primary building system for the construction of up to six storeys. The recent version of the Canadian Commission on Building and Fire Codes, 2015 increased the height restriction to include buildings up to six storeys. As mid and high-rise buildings can be expected to undergo loading beyond that which can be carried by sawn timber, this presents an ideal application of large glulam structural components, as they are capable of sustaining considerable straining actions when compared to commercially available sawn Timber. Current technical documentation and guidelines in Canada provide a little supporting framework to design timber beam-to-column connection, especially in the context of moment resistance, a key requirement for buildings expected to resist heavy vertical and horizontal loads. However, the aim of this research is to carry out an experimental analysis of Glulam and bolted laminated beam and the specific objectives includes to:

a) determine the physical properties such as: weight, grade and water absorption properties;
b) determine the strength of glulam beam and bolted laminated beams
c) compare the properties of glulam and bolted connections of the selected timber

2.0 LITERATURE REVIEW

Timber has many important traits. It has a warm texture and beautiful appearance and is often used for inside finishing as well for the main structure. Timber members provide high strength-to-weight ratio and good thermal insulation properties. They can be used compositely with concrete and steel. It is easy to work with and can be produced in a wide range of shapes and sizes. This has helped designers to use timber more efficiently and safely and in more challenging and thrilling applications. Timber as constructional material does not contribute to greenhouse emissions and is a fully renewable and largely recyclable material. Because it is a naturally full-grown material, timber is a complex building material. Its properties are highly variable and are sensitive to environmental and loading conditions. It is a highly anisotropic material with high strength and stiffness parallel to the grain but low properties perpendicular to the grain. These factors should be taken into consideration in the design of timber structures.

2.1 Adhesives

According to the Glue Laminated Timber Association (GLTA, 2010), adhesives must provide bonds of such strength and durability that their integrity is maintained in the assigned Service class throughout the expected life of the structure applicable both for bonding the laminations and for making the finger joints. Ambient temperature and relative humidity affect the timber's moisture content, whilst fluctuations in load and changes in the environment surrounding the structure also influence the durable performance. Banea and Silva, (2009). According to BS-EN 301, type I specification may be used in all Service classes while type II specification shall only be used in Service classes 1 or 2 and not under prolonged exposure to temperatures in excess of 50°C.

2.2 Structural glued laminated timber

According to Abubakar and Nabade, 2013; Apu, 2003 and Batchelar, Mcintosh and Hunt (2003); glued laminated timber has gained wide application and demand because of the standard sizes and availability of glued laminated structural elements such as beams and columns. This trend has made architects and specifies to give preference to glulam over other materials for a wide range of structural application in building. Kingsley and Celestine (2020) reported that glue-laminated timber is fast growing in the Nigerian building industries and offers an additional advantage of virtually unlimited flexibility in shape and size.

Structural glued laminated timber is obtained by gluing up suitably selected and prepared pieces of stress graded wood in straight or curved form with the grain of all pieces running parallel to the longitudinal axis of the member. APA,1996; Jacob and Barragan, 2007; Gruin and Bob, 2003. This technology allows the flexibility in the formation of structural elements with a wide variety of sizes, profiles, and lengths having superior strength, serviceability, and appearance to sawn timber. Structural elements such as beams, columns, floor joist and purlins can be produced as glulam elements. Glued laminated timber beams are manufactured with the strongest laminations on the bottom and top of the beam, where greatest tension and compression stresses occur so as to optimize the use of the material, Wan, Wan, Mohd and Zakiah (2011). Depending on the intended use, glued laminated timber members can be manufactured using single or multiple grades of timber, similarly, any species can be used for glulam timber, provided its mechanical and physical properties are compatible and the species glueable; Zhiyong and Robert, 2007.

3.0 MATERIALS AND METHODS

3.1 Materials

The materials used for this research include timber Araba (Ceiba Pentandra), Idigbo (Terminalia ivorensis) and Teak (Tectona grandis), Top Bond glue, 12mm hexagonal bolts and water.

3.1.1 Araba (Ceiba Pentandra)

Ceiba pentandra is a tropical tree of the order Malvales and the family Malvaceae (previously separated in the family Bombacaceae), native to Mexico, central America and the Caribbean, northern and south America, and (as the variety C. pentandra var. guineesis) to tropical west Africa. Figure 1 shows the sawn sizes of Araba.

3.1.2 Idigbo (Terminalia ivorensis)

Idigbo is derived from West Africa. It is a hardwood that has a strength and stiffness comparable to oak but is far more cost-effective. It features a straight to irregular grain and slightly coarse and uneven texture with a yellowish-brown appearance. Has an excellent resistance to moisture and is fairly resistant against insect attack. Figure 2 shows already sawn Idigbo timber.

Fig. 1: Araba Timber (softwood)

Fig. 2: Idigbo Timber (hardwood)

Province teak (CP teak), as well as Nagpur teak. Tectona Grandis is a large, deciduous tree that occurs in mixed hardwood forests as shown in Figure 3.

3.1.4 Top Bond glue

Commonly used wood adhesive in Nigeria is the "Top bond". It is a white high-quality water-based adhesive. The adhesive used in this research is shown in Figure 4.

Fig. 3:Teak Timber (hardwood)

Fig. 4: Adhesive (Top Bond)

1.5 Hexagonal friction grip bolt

A 12mm hexagonal friction bolt was used for the bolting of the beams. They were obtained from the conventional market in Ado-Ekiti Metropolis.

3.1.6 Experimental design

Table 1 show the dimensions of test specimen in accordance with ASTM D193 and EN 408. A total of 28 specimens were dimensioned in line with ASTM D193 and cut for bending test. Eight (8) specimens each for solid timber, bolt-laminated and glue laminated beams. While a total of 4 specimens were marked for compression the test; two (2) each for compression parallel to grain and compression perpendicular to grain.

Table 1**:** Experimental design

Dimension of test piece	glue laminated beam	bolt-laminated beam	solid beam
1000mm x 25mm x 25mm 1000mm x 50mm x 50mm 1000mm x 75mm x 75mm 1000mm x 100mm x100mm	2 2 2 2	2 2 2 2	2 2 2 2
Total number of samples	8	8	8
180mm x 100mm x 34mm	compression parallel to grain	compression perpendicular to grain	-
	2	2	-

3.2 Methods

3.2.1 Preparation of Specimens

The preparation of the beam specimens begins with gluing and bolting of the different sizes of sawn timber (25-100 mm thick). For the glulam beam, the glue was applied on the surface of each specimen (25 mm thick) and pressed together for proper bonding as shown the Figure 5. Similarly, for the bolt-laminated beam, two holes of diameter 12mm was drilled at each end of the beam as shown in Figure 6. 12mm hexagonal bolts was passed through the drilled holes and fastened with bolts. All the beam specimens were weighed prior to experimentation as shown the Figure 7.

Fig. 5: Glued laminated beams

Fig. 6: Drilling holes for bolt-laminated beams

Fig. 7: Weight measurement of beam specimens

Fig. 8: Furnace set at 103^{0}C for water absorption test

3.2.2 Moisture Content

Moisture content (MC) is the amount of moisture present in the sample and expressed in percentage. It was determined in accordance with EN 13183-1. The moisture content for each timber specimen was obtained by first measuring its initial mass before drying using an electronic weighing balance. The test sample were then oven dried at a temperature of 103 ± 2^{0}C and the percentage of moisture present in each sample was estimated using (1). Figure 8 shows the specimen in an oven

$$.MC = \frac{M_2 - M_1}{M_1} \times 100 \quad (1)$$

Where M_1, M_2 and MC are the dry weight (in kilograms), wet weight (in kilograms) and Moisture content (in percentage) of the test slice respectively.

3.2.3 Density

Density is the amount mass in a certain volume of matter. The weight of each specimen was recorded using the digital weigh balance. The volume of each specimen was also estimated using their sawn dimensions. The densities of all the specimens were determine using (2). These values enable the authors to classify the collected Timber species using the BS 5268.

$$Density\ (\rho) = \frac{mass(m)}{volume(v)} \quad (2)$$

3.2.4 Compression test

The compression parallel and perpendicular to grain was carried out using the electronic 100kN Universal Tensile Machine in accordance with Clause 8 of the BS 373: 1957 specificationas shown in Figures 9 and 10

Fig. 9: Compression parallel to grain

Fig. 10: Compression perpendicular to grain

The tests measure the maximum amount of compressive load a material can bear before fracturing. The test piece was placed in position and metal plate was placed at the top to provide an evenly distribution of the concentrated load. Each specimen was tested to different failure load. The dial gauge was mounted and set to zero to measure the strain produced. The compression was computed using (3).

$$\sigma = \frac{load(N)}{crosssectional\ area(mm^2)} \quad (3)$$

3.2.5 Flexural strength

The flexural strength of a material is defined as its ability to resist deformation under load. The three-point bending strength test as specified by ASTM C293 (2000) was carried out in the Structural Engineering, Afe Babalola University Ado-Ekiti (ABUAD). The center loading point and supports were marked and the orientation of the test specimen were perpendicular to the direction of loading.

The test pieces were stabilized with an initial load, after which the dial gauge was mounted and adjusted to zero to monitor deflection. The specimen was supported at the ends while unrestrained to allow bending action throughout the member and ensure failure due to flexure. The flexural strength was computed using (4) as shown in Figure 11. Where f_m is the flexural strength, $f_{\max}$ is the maximum Load, *b, h are* the width and depth of specimen and *l* is the distance between supports.

$$f_m = \frac{3f_{max}L}{2bh^2} \quad (4)$$

4.0 RESULTS AND DISCUSSION

4.1 Results of Moisture content

Tables 2 and 3 show the comparison in moisture content for the softwood and hardwood specimens. The comparison was made for glue, bolted and solid timber specimen. The solid timber tends to absorb less moisture compared to bolted and glued timber beams.

Fig. 11: Three-point bending test

Table 2: Moisture Content of Softwood specimen

SOFTWOOD												
Properties	**Ceiba Pentandra (glued)**				**Ceiba Pentandra (bolted)**				**Ceiba Pentandra (solid)**			
Thickness (mm)	25	50	75	100	25	50	75	100	25	50	75	100
Initial Mass (kg)	0.2	0.9	2.5	3.9	0.2	0.8	2.0	3.5	0.2	0.85	2.4	3.5
Oven Dry Mass (kg)	0.18	0.80	2.2	3.5	0.18	0.7	1.8	3.1	0.18	0.78	2.1	3.15
Moisture Cont. (%)	11	12.5	13.6	10.8	11	14.3	11	12.9	11	9	14.3	11
Avg. M.C (%)	**11.98**				**12.3**				**11.3**			

Table 3: Moisture Content of Hardwood Specimen

HARDWOOD												
Properties	**Terminalia ivorensis (glued)**				**Terminalia ivorensis (bolted)**				**Tectona grandis (solid)**			
Thickness (mm)	25	50	75	100	25	50	75	100	25	50	75	100
Initial Mass (kg)	0.5	1.5	3.5	5.8	0.4	1.5	3.4	5.9	0.44	1.6	3.5	5.8
Oven Dry Mass (kg)	0.46	1.3	3.2	5.4	0.35	1.3	3.1	5.5	0.37	1.5	3.35	5.5
Moisture Cont. (%)	8.7	15.4	9.4	7.4	16.7	15.3	9.7	7.3	16.2	6.7	4.5	5.5
Avg. M.C (%)	**10.2**				**12.25**				**8.2**			

The average moisture content for 25-100 mm solid, bolted and glued timber is in the range:11.3-12.3% for softwood and 8.2-12.25% for hardwood. The solid timber has the lowest moisture content (8.2%) compared to other beam specimen. The EN 338 pegged the requirements for moisture content at 12% for structural timber classification. The estimated moisture content for all the tested specimen in this research are within this specification.

The estimated moisture content of the softwood and hardwood bolted-connections was 2.6-16.7% higher than that of the glue-laminated beams. This increase may be as a result of the response of the surface area of the beam specimens to temperature and relative humidity of the surrounding.

4.2 Results of Density and Classification

The results of the density test are presented in Tables 4 and 5 respectively. The densities are compared for glued, bolted and solid timber specimen. For the hardwood specimen, the average density of the glue-laminated beams was approximate the same with that of the solid beam specimen while the bolted connections have an average density of 10.4% lower than both glue-laminated and solid beam specimen. On the other hand, the glue-laminate beam specimen (softwood) revealed the least density as shown in Table 5.

Ceiba pentandrea is a coniferous specie (softwood) because its characteristic density fell within thesoftwood density ranging from 540-590 kg/m³ as specified by BS5268 code. Terminalia ivorensis and Tectona grandis are deciduous species (hardwood) because their characteristic densities fell within the hardwood density ranging from 590-1200 kg/m³.

Table 4: Densities and Classification of Terminalia ivorensis (Hardwood)

HARDWOOD												
Properties	**Terminalia ivorensis (glued)**				**Terminalia ivorensis (bolted)**				**Tectona grandis (solid)**			
Thickness (mm)	25	50	75	100	25	50	75	100	25	50	75	100
Mass (kg)	0.5	1.9	3.6	5.9	0.4	1.7	3.4	5.9	0.5	1.5	3.3	8.2
Volume (m³) $\times 10^{-3}$	0.63	2.5	5.6	10	0.63	2.5	5.6	10	0.63	2.5	5.6	10
Density (kg/m³)	800	760	640	590	640	680	604	590	800	600	587	820
Avg. Density (kg/m³)	**697.5**				**628.5**				**701.8**			
BS 5268 Classification	SC5				SC5				SC5			

Table 5:Densities and Classification of Terminalia ivorensis (Softwood)

SOFTWOOD												
Properties	**Ceiba Pentandra (glued)**				**Ceiba Pentandra (bolted)**				**Ceiba Pentandra (solid)**			
Thickness (mm)	25	50	75	100	25	50	75	100	25	50	75	100
Mass (kg)	0.2	0.9	2.5	3.9	0.3	1	2.8	4.7	0.35	1.2	2.9	4.8
Volume (m³) $\times 10^{-3}$	0.63	2.5	5.6	10	0.63	2.5	5.6	10	0.63	2.5	5.6	10
Density (kg/m3)	320	360	444	390	480	400	498	470	560	480	515	480
Avg. Density (kg/m³)	**378.5**				**462**				**508.8**			
BS 5268 Classification	SC1-SC3				SC1-SC3				SC1-SC3			

4.3 Results of Compression parallel and perpendicular to grain

The compression parallel to grain is the maximum crushing strength while compression perpendicular to grain is the specimen's stress at elastic limit. The results of compression parallel and perpendicular to grain for glued and bolted connections (softwood and hardwood) based on 12% moisture content are presented in Figures 12 and 13. The results are based on 12% moisture content (USDA, 1999). The plots revealed an increase in compression parallel and perpendicular to grains when sizes of specimen are increased for both softwood and hardwood (glued connection). For the softwood (glued), the maximum compression parallel to grain was 16.13 N/mm^2 at failure load and 35.4 N/mm^2 for the hardwood. The compression perpendicular to grain are 1.9 N/mm^2 and 13.6 N/mm^2 respectively for softwood and hardwood (glued connection). On the other hand, the bolted connection for hardwood and softwood specimen revealed a range of 12.15 N/mm^2 - 30.1 N/mm^2 for compression parallel to grain and 1.29 – 10.18 N/mm^2 for compression perpendicular to grain.The compression parallel to grain for glued specimen (softwood and hardwood) is 15-24.7% higher than that of the bolted connection of same sizes while the compression perpendicular to grain is about 33.7-47.2% lower than that of the glued connection. The glued specimens performed well in terms of mechanical properties than bolted connection.

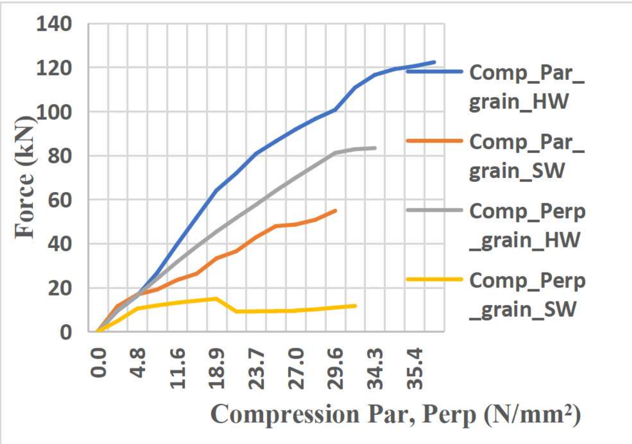

Fig. 12:Compression parallel and perpendicular grains (glued connection)

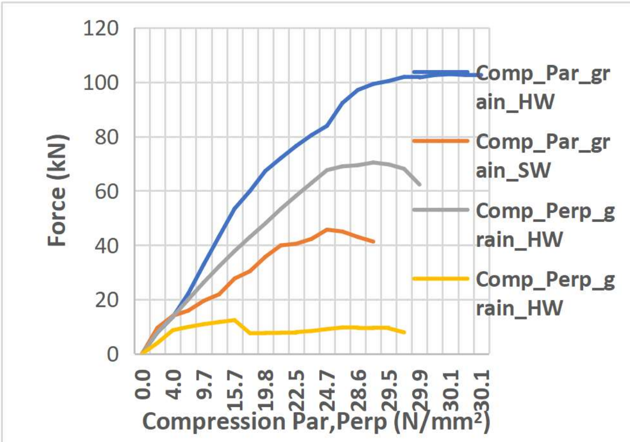

Fig. 13:Compression parallel and perpendicular to to grains (bolted connection)

4.4 Results of Flexural Strength

The flexural strength is also known as the Modulus of Rupture (MoR) or bending strength. It is the maximum stress a material can withstand before it yields and an accepted criterion of strength within the elastic range of the specimens. The Force-Deflection curves in Figures 14 and 15 indicates an increase in deflection with the application of loads. The Force applied increases with increase in deflection until the elastic limit of the specimen was reached. The graphs also revealed that the softwood (glued and bolted) yielded faster on the application of loads than those of the hardwood specimen (glued and bolted).Figures 16, 17 and 18 show the plots of MoR, Force applied and deflection against the various sizes of the specimen. Figure 16 shows that the MoR decreases with an increase in the sizes of beam specimen. The MoR of the solid beam is about 84.5 N/mm^2 for 25 x 25 mm specimen and 29 N/mm^2 for 100 x 100 mm sample size; 10.2-53.8 N/mm^2 for hardwood (glued connection); 8.4-30.7 N/mm^2 for softwood (glued connection); 10.2-25 N/mm^2 for hardwood (bolted connection) and 6.6-15.4 N/mm^2 for softwood (bolted connection). Generally, the solid timber gave higher MoR than all other specimen tested. But, the glued connection is about 53.5% higher than those of the bolted connection (hardwood) and 49.8% for the softwood specimen.

Figure 17 shows an increase in timber sizes causes an increase in the failure load. The solid beam gave a failure load of 24kN; hardwood (glued and bolted), 8.5 kN; softwood (glued), 6.7 kN; and softwood (bolted), 5.5 kN.

Figure 18 also revealed a reduction in specimen's deflection when sizes of timber is increased. The lowest deflection recorded was 17.7 mm for solid beam; 24.1 mm for glue connection and 26.8 mm for bolted connection. The decrease in deflection with larger sizes of beams may be due to the high resistance to applied loads provided by the tested specimen. The potential of glued connection might have arisen due to the perfect bonding emanating from the use of glue adhesive across the length of tested specimen. This will help to prevent excess moisture from the external environment. On the other hand, the bolted connection might have allowed moisture ingress from the surrounding through surfaces that are not bolted.

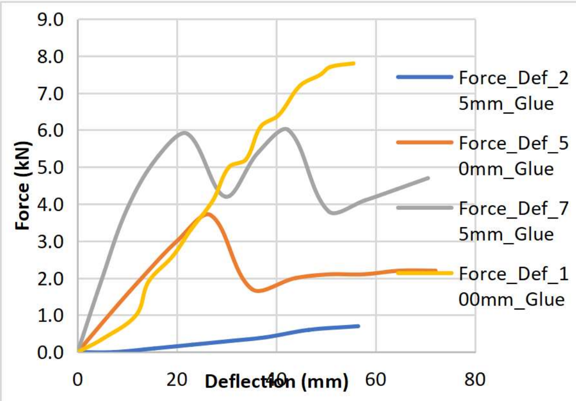

Fig. 14: Force-Deflection Curve (glued connection)

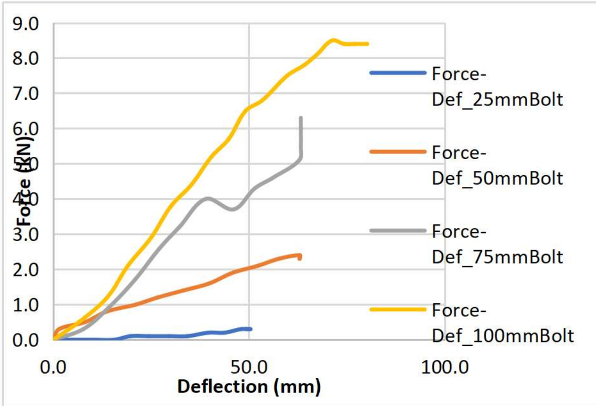

Fig. 15: Force-Deflection Curve(bolted connection)

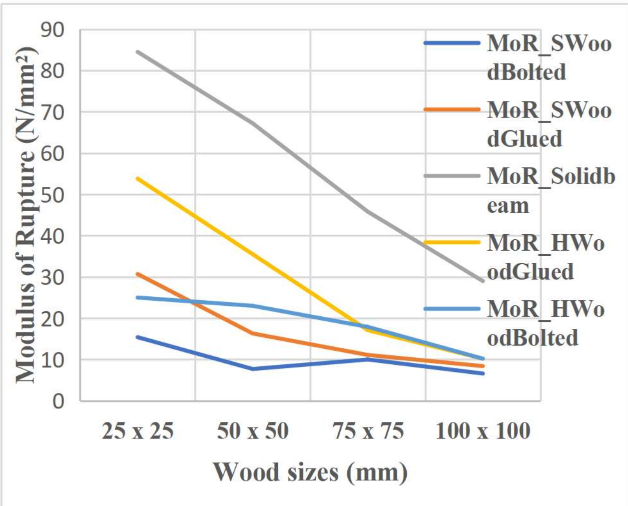

Fig. 16: Modulus of Rupture against wood sizes

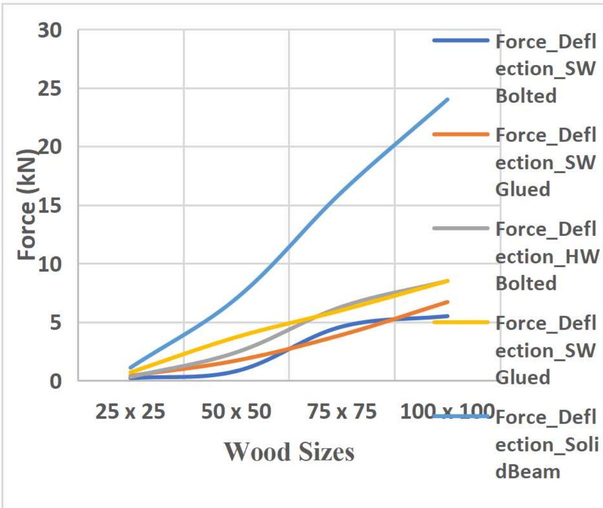

Fig. 17: Applied Force against wood sizes

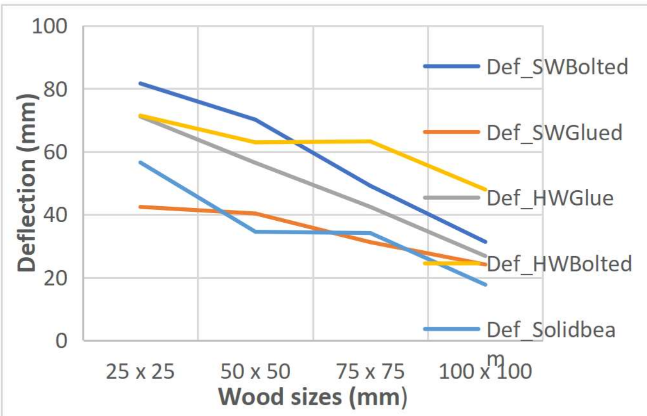

Fig. 18: Deflection of bolted and glued connection against wood sizes

5.0 CONCLUSION

From all the data and results gathered, the following conclusions were drawn:

1) The average moisture content of Ceiba pentandre for both bolted, glued and solid specimen tested are within the specification of USDA, 1999.
2) The density classification following the BS 5268 revealed a strength class of SC1-SC3 for Ceiba pentandre and SC5 for Terminalia ivorensis and Tectona grandis. The SC1-SC4 are purely softwood classes while the higher value of densities (greater than 590 kg/m^3) are classified as hardwood with strength class, SC5 and densities less than 590 kg/m^3 are classified as softwood. Physical properties such as moisture content and density will assist in the careful selection of wood for different application within the building, design and construction industries.
3) The compression parallel and perpendicular to grains for all timber sizes using the glued connection revealed perfect bonding between the connected specimens tested than the bolted connection.
4) Flexural strength test results obtained also supported the results from the compressive strength. The potential of glue connection is revealed in this research. The effects of increasing diameter of bolts and holes on the beam specimen may further be investigated to check resistance to applied load.

6.0 RECOMMENDATIONS

This research shows the positive effect of glue application in joining timber members.Glulam is an innovative laminated timber structural solution that can be used in a wide variety of commercial and residential projects. They are perfect for long span and curved designs and also offers strength without aesthetic compromise.

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