The Analysis of Bending Stiffness and Strength of Glue Laminated Nigerian Timber

Kingsley Kenchukwu Okafor and Celestine Akaolisa Ezeagu

Abstract—An analysis into the flexural strength of solid and laminated timber specimens under working conditions was conducted. Five hardwoods and five softwoods were investigated, namely: Mansonia, Mahogany, Orji, Ukpi, Ufi mmanu, White Afara, Owen, Melina, Akpu and Ubia. The dimensions of the wood specimens are 100mm×50mm×20mm. The wood samples were tested for flexural strength using a Universal Testing Tensile Machine. The results obtained shows that Owen has the highest ultimate wood strength of 46.806N/mm² for the softwood glulam. Ukpi has the highest wood strength of 73.375N/mm² for the hardwood glulam, and highest MOE at 2412.93N/mm². Akpu recorded the weakest sample with bending strength values for glulam at 11.929 N/mm². Comparisons of strength were made to their respective solid timbers. Failure modes were analyzed. The study therefore demonstrates that the timber species used can be engineered to load bearing glulam structural elements using polyurethane adhesive glue without severe loss of strength.

Index Terms—Flexural Strength, Glulam, Polyurethane Adhesive (PUR), Timber.

I. INTRODUCTION

Structural glued laminated timber (glulam) of which my research is interested in is an engineered stress rated product that consists of two or more layers of lumber i.e. (lamination) glued together with the grains running lengthwise [6]. Laminated timber is usually planed all round and is available in various finishes and pressure impregnated. Laminated timber is used for load-bearing structure in both the horizontal and vertical directions, which are either left visible, or clad. In addition to buildings, laminated timber is used in load bearing bridge construction too.

These laminated timbers were developed to improve the use of natural timber beyond its natural limitations. According to [2], glulam has remained the most resource efficient approach to wood building products. When it comes to optimizing products from a carefully managed timber resource, glue laminated wood can be built of defective wood without losing its strength properties as repeated by [7].

Bending stiffness (K) is the resistance of a member against bending deformation. It is a function of elastic modulus E, the area of moment of inertia I of the beam cross-section along the axis of interest, length of the beam and beam boundary condition. The load bearing capacity of glulam under bending is highly related to the material properties and the tensile capacity of the timber boards used. The glulam timber has more uniform mechanical properties mainly due to the intent of minimizing the influence or defects in timber (e.g. nodes, cracks misalignment of fibers) with the production process [9]. Thus this research major goal is to analyze and investigate the bending stiffness of glulam timber when it is loaded.

II. LITERATURE REVIEW

According to [4], Glulam is probably the fastest growing structural material in Britain. Germany and Italy cumulatively accounted for around 60% of the Europe market revenue owing to glulam high acceptance. There has been a tremendous surge of demand for glulam as it is the evolution of wood as a low cost and sustainable alternative to steel and concrete. As documented in an article by [5], glulam offers the additional advantage of virtually unlimited flexibility in shape and size. Straight beams can be designed and manufactured with horizontal laminations (load applied perpendicular to the wide face of laminations) or vertical laminations (load applied parallel to the wide face of the laminations).

A. Reviews on Flexural Strength of Glulam

Flexural strength as discussed by [1], is commonly known as modulus of rupture and it is “defined as the bending stress in a flexural member at the failure load and is computed assuming an elastic stress distribution”. Alternatively, bending stiffness can be defined as the elastic modulus or breaking point of an element as a result of load applied either transversely or longitudinal. The transverse bending test is most frequently employed, in which a rod specimen having either a circular or rectangular across section is bent until fracture using a three-point flexural test technique. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress. Flexural rigidity is the stiffness of a material when subject to bending also defined as the force couple required to bend a rigid structure to a unit curvature. In other words, Flexural strength of a material can be defined as the maximum stress at the outermost fiber on either the compression or tension side of the specimen in bending. Flexural modulus is calculated from the slope of the stress vs. strain deflection curve. In a conventional test, flexural strength is expressed as:

\[ 3LP/2b^2 \]  

(1)

As shown above, P is the load applied to a sample of test, length L, width b, and thickness d.

Unlike a compression test or tensile test, a flexure test
does not measure fundamental material properties. When a specimen is placed under flexural loading all three fundamental stresses are present, tensile, compressive and shear stresses.

B. A Review on the Bending Stiffness of Nigerian Timber Species as Glulam Elements

As documented by [8]. Their paper assesses the suitability of Funtumia africana, Alstonia congensis and Antiaris toxicaria Nigerian timber species in the production of glue-laminated timber elements using adhesive (polyvinyl acetate glue) otherwise known locally as top bond. “The glue ability, physical and mechanical properties of solid and glue-laminated species were assessed and compared. Bending strength and characteristic values of bending strength were determined. His results showed that the timber species were glue able and the bending strength across the species were: Funtumia Africana solid and glue laminated beams at 65.22 N/mm² and 36.44 N/mm²; Alstonia congensis solid and glulam beams at 26.15 N/mm² and 25 N/mm²; and Antiaris toxicaria beams at 14 N/mm² and 20 N/mm² 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 glue able 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/mm², 25 N/mm² and 20 N/mm² in Funtumia africana (Ire), Alstonia congensis (Awun) and Antiaris toxicaria (Oriro)”. It also goes to show that the kind of adhesive used for experiments should be put into consideration as regards when the load is applied to the members. The stronger the adhesives in grade the better the glulam in resisting load, thus making it a better structural element. The Bending strength was defined by the ratio of the maximum load over the area of bending. This is to facilitate lamination and improve wood-adhesive bonding. It also helps to minimize raised natural frequency tools, or visual grading.

C. Establishment of Knowledge Gaps

- It is seen from various researchers’ opinions that the use of glulam as a better structural element over timber is slightly inconclusive. This is because a lot of factors contribute to its strength such as the type of wood used to manufacture the laminates, the moisture content, knots and defects if any, amongst many other factors in consideration.
- Glue used for manufacture is of great importance, because some kinds of glue have higher rated joint strength when compared to others such as comparison of polyvinyl acetate to polyurethane adhesives.

III. RESEARCH METHODOLOGY

A. Material Preparation

A total of eighty (80) specimens were dimensioned, of which the glulam samples had dimensions of 100mm x 50mm x 20mm and the solid timber samples were dimensions of 100mm x 50mm x 20mm as well cut for static bending test. Forty (40) of the samples were glue laminated timber in the ratio of twenty 20 hardwood timber species to twenty (20) softwood timber species (four laminas of 10mm each). The remaining forty (40) samples were of solid timber, of which twenty (20) samples were made of hardwood species and the other twenty (20) samples were softwood species. The samples and dimensions are summarized in the table below.

B. Materials

| TABLE I: LISTS OF TIMBER SPECIES AND THEIR CLASSIFICATIONS |
|------------------------------------------------------------|
| BOTANICAL NAMES | CLASSIFICATION | OTHER NAMES |
|-----------------|----------------|-------------|
| Terminalia superba | Softwood | White afara |
| Mitragyna spp | Softwood | Owen |
| Mansonia altissima | Softwood | Mansonia |
| Gmelina arborea | Softwood | Melina |
| Banbax bonoponense | Softwood | Akpu |
| Swietenia macrophylla | Hardwood | Mahogany |
| Chlorophoro exelsa | Hardwood | Orji |
| Manilkara bidentata | Hardwood | Ukpi |
| Uapaca guineensis | Hardwood | Ubua |
| Ateiza spp | Hardwood | Uli mmanu |

C. Fabrication of Glulam Samples

The processes involved in this section are in compliance with the fabrication methods adopted by many researchers in producing glulam. Brief summary of the processes are as follows:

1. Drying: Feed stocks are dried to within a range of moisture contents specified by adhesive suppliers. These can be air-dried or artificially dried to reduce the moisture content to between 8% and 15% as suggested by the adhesive producer.

2. Strength grading: Air-dried timbers are sent for strength grading. Only the structural grade timbers will be considered for fabrication of structural Glulam. Grading can be done by means of non-destructive tools such as machine stress grader, natural frequency tools, or visual grading.

3. Planning: Timbers are sent for planning to improve surface smoothness and uniformity of dimension. This is to facilitate lamination and improve wood-adhesive bonding. It also helps to minimize raised grain, warping or cupping occurrence.

4. Glue spreading: Appropriate adhesive mixed are prepared and applied on the surface of the timbers by either one or both of the following adhesive applicators. Tools used in my work were a glue spreader. Both sides of the lamella surface can be concurrently spread with adhesive using the glue spreader at a recommended spread ratio. Freshly
planned wood surface would make better and stronger glue joints and the timber should be exposed for a limited amount of time between the planing, glue spreading and lamination process so as to minimize surface contamination, occurrence of raised grain, warping or cupping. It is best that gluing is done right after planing process. Thus, it is recommended to ensure that the glue spreader be placed near the planer to facilitate working both machines in tandem.

5. Clamping: After glue spreading, the glue spread laminations are transferred to the cramping or clamping station. Cramping or clamping is the process where the lamellae of the glulam member are clench using clamping jigs, screws and bolts.

6. Post curing: This is also known as conditioning period. The bonded members are left for curing for several days depending on the requirement of the type of adhesive being used. In the case of PUR, it is a very strong and fast moisture curing adhesives hence samples were left for just 24 hours before removing from clamp.

7. Finishing: Trimming off the excessive adhesives and planning the edges to a smooth surface finish.

D. Methodology

Bending Strength Test: The static bending test was performed by loading third point in line with [3]. The specimen was measured and weighed. The center loading point and supports were marked, such that the orientation of the test species ensured perpendicularity to the direction of loading. The test pieces were then stabilized with an initial load, after which the dial gauge is mounted and adjusted to zero to monitor deflection. The test piece was supported at the ends while unrestrained to allow bending action throughout the member and ensure failure due to flexure. The speed of the machine was set to load the test piece and allow adequate monitoring of the dial gauge. Readings on the dial gauge was then taken at intervals within the elastic limit before failure.

E. Apparatus

The apparatus used in this test included a M500-25CT universal testometric testing machine which carries load as much as 2500kgf, test speed running at the rate of 50,000mm/min, a dial gauge deflector, computerized diagnosis of samples after running the test, calibrated steel roller beam supports, metal plate and a steel roller loading device.

IV. TEST RESULTS

| SPECIMEN | SAMPLE | MOE (N/mm²) | MOR | SPECIMEN |
|----------|--------|-------------|-----|----------|
| Akpu     | GLULAM | 2365.408    | 23.282 | 2744.4  |
|          | SOLID  | 1563.001    | 42.369 | 3542.8  |
| Masonia  | GLULAM | 1566.989    | 50.10  | 5477.7  |
|          | SOLID  | 1499.955    | 36.699 | 3555.9  |
| Oku      | GLULAM | 508.165     | 59.909 | 6085.6  |
|          | SOLID  | 17970.524   | 227.472| 4310.8  |
| Ubi      | GLULAM | 1763.723    | 18.879 | 2002.1  |
|          | SOLID  | 1741.52     | 52.978 | 5378.3  |
| Ufi mmanu| GLULAM | 2412.93     | 73.375 | 8821.6  |
|          | SOLID  | 2971.019    | 93.021 | 10409.5 |

From the graph above it can be deduced that the softwood Owen has the highest bending strength amongst the five softwoods, falling in a descending order of Masonia, White afala, Melina, and the least as Akpu. The White afala had an abrupt fall in strength the moment it reached the bending strength at peak. Failure occurred thereafter.
From the graph above Ukpi is the strongest wood sample amongst the five wood samples. The other woods fall in a descending in the order of Ubia, Orji, Mahogany, and the least Ufi mmanu.

From the graph above Ubia is the strongest wood sample amongst the five solid wood samples. The other woods fall in a descending in the order of Ukpi, Ufi mmanu, Mahogany, and the least Orji.

A. Failure Modes

The failure modes of the glulam and solid timber samples loaded flat wise showed similar failure characteristics in the ten species Failure was initiated at the outer bottom fiber which was propagated upwards perpendicular to the grain. Some of the glulam however failed along the glue lines.

B. Discussions

From the graphs and tables shown above a lot can be deduced from them. Table 4.1 shows that the softwood glue laminated Owen have the highest load resistant characteristics and highest bending modulus (MOE) when it undergoes deflection due to ultimate loads resistance at peak. Owen being softwood with such a high load resistance further justifies that the softness or hardness of wood is not a measure of strength but rather a mere distinction of physical qualities. Melina however is the strongest softwood solid sample amongst the solid specimens. The sample with the least resistance to load before deflection occurs is Akpu, the highest load resistant in the hardwood specimens are Ukpi which of course has the highest MOE as shown in Table 4.2 and the least amongst the hardwood species is Ufi mmanu. The glulam samples have varying bending strengths both softwood and hardwood, of which hardwood Ukpi has the highest bending strength characteristic and softwood Akpu with the least bending strength.

The solid samples are quite comparable to the glulam but it is seen from the data also that they have better strength and stiffness properties to the glulam samples of same dimensions. Ubia has comparable clear hardwood strength to Ukpi as shown in Table 4.2. From the experiment done in the lab it was deduced that solid Ubia had an excessively high value compared to other wood specimens both for the MOE property and bending strength property. This could be as a result of the natural wood physical qualities for the specimen as it is a very hardwood and Akpu is an all-round weak element. The graphs pictorially display the irregular deflection pattern of the glue-laminated and solid specimens. The irregular curves may be as a result of few reasons which may include the progressive splitting of the extreme tension fibers.

V. Conclusion

1. The said species are glue able using polyurethane adhesives.
2. The strength of glulam was not always higher than solid wood however the strength of glulam elements was of structural significance with Ukpi offering the highest bending strength of 73.375 N/mm², and 11.929 N/mm² for the weaker samples (Akpu).
3. Solid and glulam beams were thus flexible in flat wise bending with varying MOE.
4. The flexural strengths of all the glue laminated samples reduced very significantly compared to the solid timbers
5. The high percentage reduction in load resistance (force at peak) may be due to inconsistencies in the glued areas.
6. Knots and some wood defects across the wood samples affect the glue ability of the wood sample and also the strength characteristics of affected wood species.
7. The strength and stiffness properties of the glulam samples could be improved by increasing the span and depth of the timber.

Consequent upon the results discussed above, it was concluded that the timber species used is an elastic material. The fact that they depicted deflections that are within the safe limits means that the ten timber species tested in this study have been judged to be good as structural members. However, care is to be taken when considering what type of structural application, the timber is used for. Testing of timber specimens is also necessary as it was also evident that most of the solid timbers were more durable in withstandning load than glue-laminated timbers based on their flexural strength characteristics. Both hardwood and softwood species were found to be good for construction with structural timber.

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DOI: [http://dx.doi.org/10.24018/ejers.2020.5.2.1699](http://dx.doi.org/10.24018/ejers.2020.5.2.1699)
1. Outstanding Youth Role model award presented by National Association of Anambra State Students University of Benin Chapter presented at Akin Deko Auditorium University of Benin 2010.

2. Role Model Award for Catholic youths presented by Catholic Youth Organization of Nigeria St. Maria Gorettis Catholic Church Umuona Parish in 2011.

3. Presidential Service Award for Service to Humanity presented by Nigerian Universities Engineering Students Association Nnamdi Azikiwe University Awka in 2014

4. Meritorious Diamond Award for National Development in recognition of contribution to the socio economic development of Nigeria through Engineering by Corporate and Media Africa Communications Ltd at National Merits House Abuja in 2014.

5. Pillar of the Nation Building Award to a Distinguish Academic presented by Strategic Institute for Natural Resources and Human Development at Office of the head of service board room Anambra State in 2015.

6. West Africa Quintessential Meritorious Award presented by Ehi Gong Media Communications and Maracas International News magazine Ghana in 2015.

7. Nigeria Merit Gold Award for Transparency and Accountability presented by TEAM Magazine at National Merit House Abuja in 2015.

Family life and Religious background: Engr. Dr. C. A. Ezeagu is happily married to Lady Colette Nwanneka Ezeagu and has received numerous awards namely:

1. Outstanding Youth Role model award presented by National Association of Anambra State Students University of Benin Chapter presented at Akin Deko Auditorium University of Benin 2010.

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Family life and Religious background: Engr. Dr. C. A. Ezeagu is happily married to Lady Colette Nwanneka Ezeagu and so far the marriage is 20 years old. In 1992, he obtained a Masters degree (M.Eng) in Civil Engineering with basis in Civil Structures from university of Benin and in 2008; he obtained a doctorate degree (PhD) in Structural Engineering from University of Benin.

Through this means he has solved numerous Civil/Structural Engineering problems and has been a consultant to many local, multinational, Oil and Communication companies. As academician, he has taught at the following university, Igbinedion University Okada, University of Benin and presently at Nnamdi Azikiwe University, Awka. He has co-author two books, published over 40 articles in learned journals and over 20 articles in conference proceedings and 15 technical articles. He has attended many local and international conferences in Engineering, Management and Humanities. He has spent over 17 years researching on collapse building, material failures and material properties.

Engr. Dr. C. A. Ezeagu is a community leader. He has been the acting Secretary, Umuona Local Government Area, Anambra State from 2006-2007. He is a Traditional title holder of Nze na Ozo. (Nze Ezeoma).

DOI: http://dx.doi.org/10.24018/ejers.2020.5.2.1699