Temperature Effects on Glue Performance and Compressive Strength of Glue Laminated Funtumia Africana

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***Abstract*: The effect of varying temperatures was investigated on the integrity of glue line and compressive strength parallel to grain for glue laminated Funtumia Africana (Ire) timber laminated with polyvinyl acetate glue. The performance of the glue line was investigated over temperatures of 0°C, 30°C, 40 °C, 50°C, 70°C, and 100°C administered to test samples over a period of 4 hours. The strength values were computed at an average moisture content of 5.6%. A mean compressive strength of 34.4 N/mm^2 was recorded at 0°C while a rise to 41.2N/mm^2 was recorded for 30°C. However subsequent decreases in mean compressive strength were recorded with increasing temperature from 30 °C to 100 °C. The highest and least mean compressive strength of 41.2N/mm^2 and 24.4N/mm^2 was recorded at 30 and 100°C respectively. The failure modes were similar over the various temperatures except for a brittle failure of both glue line and timber recorded at 0 °C due to extremely low temperature.**

Key words: Glulam, glue line, compressive strength, polyvinyl acetate glue, temperature variation, failure mode.

I. Introduction

Timber remains one of the earliest natural construction materials. This renewable material finds application for several purposes such as waterfronts, poles, roof carcass, and bridges among other uses. Timber has remained a preferred construction material to Engineers and builders as a result of improved technology, Camille and Kmeid in Ali [1].

Timber as a constructional material has occupied a pride of place among construction materials as it offers a high strength to weight ratio, reusability, low intrinsic energy, environmental compatibility and simplicity of fabrication. In spite of the fact that it is largely superseded by steel, plastics and concrete timber still offers potential for extensive use. Funtumia Africana is a deciduous tree that grows to a height of 25to 30 m with a straight cylindrical trunk and a narrow tree crown widely dispersed in tropical Africa. The tree is of rapid growth, and is an evanescent colonizer of abandoned land. The wood is soft, white, uniform in texture and fine-grained. It is easy to work and is ubiquitously used for carving, stools, bowls, clogs, doors, paddles, and miscellaneous household requirements, (Burkill, [4]). Rapid growth tress of this nature with wide distribution in tropical West Africa grown on sustainably managed forest should not only be considered for future supply need but also to relief the pressure on over exploited valuable timber species. Despite the presence of F.africana species in the market, information on its physical and mechanical properties are not captured in NCP 2 1973. Therefore a shortage of 'valuable species' may have compelled its harvest. According to Zziwa et.al [3] timber species are divided on the binary of 'valuable' and 'less- valuable' which is why Kityo and Plumptre in Zziwa et.al [3] noted that valuable timber species in any natural forest normally constitute about 10% of the total tree biomass. By this figure it is clear that the existence of the valuable species is jeopardized by the growing demand for timber. This study was therefore undertaken to investigate and document the properties of Funtumia Africana so as to spur interest in the specie.

Sequel to the observable trends in global climate change the concept of green building is drummed- up more than ever before. The need to arrest greenhouse gases through processes, technologies and materials that engender environmental safety has taken the front burner. This is particularly demonstrated by the global consciousness to meet the obligations of the Kyoto protocol of 1995 which took effect in 2005 with the mandate to cut carbon emission of industrial processes. Trees are known to fix and immobilize atmospheric CO_2 which in effect makes timber an ecological material, (Carballo.et .al, [11]).

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The interpretation of which for the construction industry particularly in Nigeria would be the use of environmentally friendly building materials. Timber according to Falk [14] has few rival materials with its environmental benefits. Ayedun and Oluwatobi [2] solicited a more robust research effort by the NBRI towards timber as a local building material. This research work is therefore one of such efforts towards developing timber construction.

The nature of products in the construction industry is usually that of component-assembly especially as touching structural timber elements. To this end the monolithic action of joints is pivotal to structural performance. While mechanical connections, such as screws, rivets, pins, dowels and spot welds have shown remarkable performance in timber construction the industry has over time witnessed a shift of the designer's interest to the use of chemical joints. (Huntsman, [10])

The use of adhesives dates far back in time to the pharaohs. The ancient Egyptians attached veneers to furniture with glue as derivatives of natural substances. This has today been superseded by synthetic resins and polymers. Wettability of any given adhesive is a prerequisite to effective bonding. Hence the surfaces must be sufficiently porous to allow penetration of the glue and to fill the gap between surfaces to be bonded. Subsequent solidification of the bond enables the adhered to withstand the stresses of use. The solidification process is achieved by a chemical reaction. This is why a definite chemical affinity must exist between the adhesive and the adhered. This phenomenon is the character of adhesives that produce the strongest bond.

Glued laminated timber is known to be one of the oldest methods of improving the use of timber beyond the limitation of sawn lumber, (Ali et.al, [1]). It is acknowledged to be a high-performance composite material used in construction and offering higher mechanical properties than solid wood (Bourreau et.al, [7]).It is an age long technology whose origin is traced back to Europe at around the turn of the century, in Canada 1952 while in the U.S 1940's.

Glulam can be manufactured from any specie of timber provided the strength and stiffness properties meet code requirements. Extensive studies have been undertaken in glued laminated softwood with limited studies in hardwood species. Since not all timber is glueable due to the difference in porosity of the cells (Manja et.al [13]), one of the objectives of the studies was to provide information on the suitability of F. Africana as a glued laminated element.

Developments in synthetic glues have engendered the extensive use of glulam. However while the mechanical properties of a given timber specie is of interest in determining its performance the properties of the glue to maintain monolithic action of the entire timber element under conditions such as; resistance to temperature variations, climate changes, moisture content variation and microbial attack could further offer advantages to glulam construction over steel or concrete, (Manja et.al, [13]). The requirements for structural adhesives are set out in details in EN 301 [8].

According to Huntsman [10] some of the advantages of glulam includes the extended service life of glulam structures due to the continuity of the glue line such that upon loading, uniformity of stresses distribution over the bonded area is ensured over that achieved with mechanical joints. Glued joints therefore obviate the local stress concentrations of mechanically fastened joints. The continuity of glued joints produces stiffer structure with the possibility of maintaining stiffness – to – weight ratio by reducing the weight of the structures if additional stiffness is not required. The improved appearance adhesive bonding offers is of particular interest to the architect. A nearly seamless appearance of joints eliminating protruding fasteners such as screws or rivets enhances the appearance grade of glued laminated structures.

Development in adhesives bonding allows glulam elements to optimize the use of timber resources such that timber species of dissimilar strength classes can be joined to offer an element of the required strength. The simplicity of adhesive bonding makes assembly procedures simple to achieve with less sophisticated tools and energy which mechanical fasteners would require. This further minimizes the risk operative are exposed to. The evolution of timber joints from mechanical fasteners to adhesives bonding further entrenches the low embodied energy in timber construction.

However certain limitations are associated to the use of glued joints. The behavior of an adhesive under temperature variation and exposure to an aggressive chemical environment depends upon the class of materials from which it is sourced. Adhesives may be sourced from polymers, plastics or synthetic resins. The limitations of that class with temperature determine the behavior of the bond under temperature.

Polyvinyl acetate emulsion adhesives are constituted of vinyl acetate. It is a synthetic polymer, or plastic. Being a thermoplastic, it melts at high temperatures, and resets to an elastic and flexible substance at room temperature. PVAc glue is acid free , easy to use and handle without gloves or other skin protection, and can be cleaned up with water, and does not give off any hazardous fumes, but there is a loss of bond strength on exposure to water. Since not all timber is glueable and no specific glue produces equal strength for all timber species, the main objective of this study is to provide technical information regarding the use of Funtumia Africana and PVAc in laminated wood products and the effect of temperature variation on the compressive strength parallel to grain and failure modes of the glued joints.

II. Materials and Methods

Funtumia Africana timber is readily available in Nigeria and is mostly used for furniture and timber roof trusses. The size of the timber sold in the market is 50x300mm in cross section and 3.6m long. 12 pieces of this timber were bought and those that were clear and free of defects were chosen for the study. The timber pieces were then planed and the thicknesses were reduced to 34mm. The timber pieces were cut to lengths of 34mm x 150mm and 1.8m long for easy transportation to the laboratory where they were seasoned for 3

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weeks. After 3 weeks of seasoning 72 pieces of timber measuring 50mm x50mm x 34mm were cut from the seasoned timber and used to determine the moisture content. An average moisture content of 10.2% and characteristic density of 442kg/m3 was obtained for the tested samples. The next step involved producing the samples that will be used for compression test at varying temperatures. A total of 100 timber pieces were cut into sizes of 20mm x 34mm x 180mm long. Polyvinyl glue was then applied to the surfaces of 5 pieces and they were glued together to form a short column 34mmx100mmx180mm long. A total of 20 short column specimens were produced. A G-clamp was used to hold the specimens in place for 24 hours to enable the curing of the glue. The tightening of the clamp was such that it will not allow for glue to be squeezed out of the laminates without starving the joints of the glue. The specimens were then left for 2 weeks after which they were then subjected to temperature variations of 0^{o}C, 30^{0}C, 40^{o}C, 50^{o}C, 70^{o}C and 100^{o}C. The timber specimens were then tested in compression parallel to the grain as shown in Plate I using a Denison compression testing machine (250ton capacity). The tests were carried out in accordance with BS 5268 [5] and EN408 [9].



Plate I: Compression parallel to grain test set up

III. RESULTS AND DISCUSSION

Table 1.0: Compressive strength results at varied temperatures

Temp 0^{o} C	Ultimate load N	Compressive strength (N/mm^2)	Moisture content (%)	Density (Kg/m^3)
0	117000	34.4	5.1	485
30	140000	41.2	5.7	485
40	133000	39.2	6.8	457
50	127000	37.3	5.3	447
70	93000	27.4	5.6	462
100	83000	24.4	5.5	469

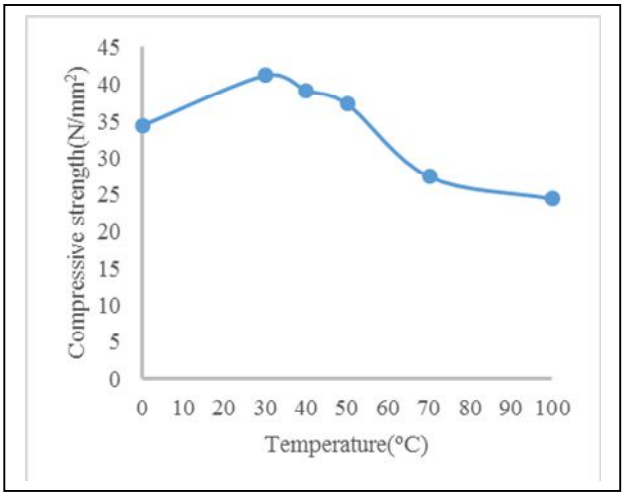


Fig. 2 The effect of Temperature variation on Compressive Strength of glue laminated timber

The moisture content of the oven treated specimens had a mean value of 5.6% and mean density of 467.5kg/m^3. As the temperature increased from 0^{o}C to 30^{o}C, there was an increase in compressive strength after which there was a gradual decrease in strength as the temperature increased to 100^{o}C as shown in plate I. A mean compressive strength of 34.4 N/mm^2 was recorded at 0 ^{o}C while a rise to 41.2N/mm^2 was recorded for 30^{o}C which was the control at an average room temperature as at the time of testing. However subsequent decreases in mean compressive strength were recorded with increasing temperature from 30^{o}C to 100^{o}C which Bednarek, [15] also reported on the compressive strength of Oak and Pine samples. The drop in strength from 30^{o}C to 100^{o}C was 40% while the increase in strength from 0^{o}C to 30^{o}C was 20%.

Timber in many structural applications would be subjected to compressive action both parallel and perpendicular to grain. Similarly, building and civil engineering structures at some points in service life are prone to temperature variations and the resultant fire risk depending on the use of the structure and associated risk. Much research efforts is required to elicit the responses of glue laminated structural elements of various timber species subjected to temperature action with the view to forestall the limit state associated with these temperature effects for safe evacuation of persons and as well the safety of rescue teams. Concrete and steel structures have been extensively investigated in this line. Timber has however not been extensively profiled along this path (Bednarek [15]).

The performance of the glue line was investigated over temperatures of 0^{o}C, 30^{o}C, 40^{o}C, 50^{o}C, 70^{o}C, and 100^{o}C administered to test samples over a period of four hours. At 0oC the failure was crushing in the wood and delamination of the glue line as shown in Plate II, while at 30^{o}C the failure was basically crushing of the timber in all the specimens tested as shown in plate IV without the failure of the glue line which mean the glue maintained its integrity at 30^{o}C. As the temperature increased, failure was both by crushing of the wood and excessive delamination of the glue line as shown in Plates III. Polyvinyl acetate glue is sourced from a

thermoplastic polymer and at 0°C it was observed to assume a glass-like state which may have been responsible for the resultant brittleness in fiber fracture and a glass shattering- like sound while it failed. This meant that the temperature at 0°C being the glass transition temperature was responsible for the decay of polymer in the glue alongside the freezing of pore water in the timber for delamination and general brittle failure to occur.



Plate II: Crushing and delamination of glued specimens at 0 °C



Plate III: Crushing and Delamination of glue specimen at 100 °C

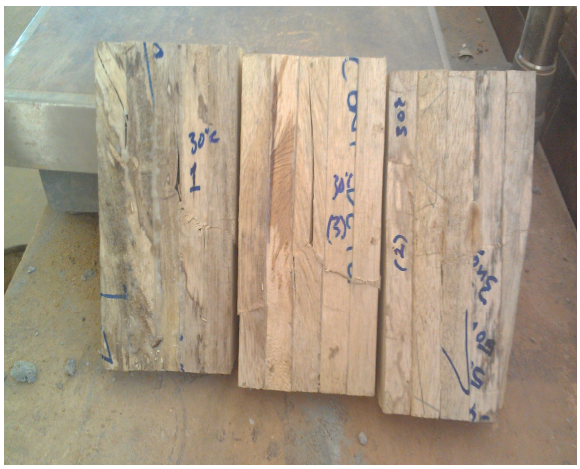


Plate IV: Crushing without delamination of glue specimen at 30 °C

IV. CONCLUSIONS

The results of the study clearly demonstrate that strength reduction in glue laminated timber is temperature dependent and that the performance of the glue was optimal at a temperature of 30°C. Clear delamination at 0°C and 100°C was due to hardening 0°C and softening of the glue line at 100°C. Temperature has a considerable effect on the performance of glue joints. The study shows that while polyvinyl acetate glue could produce glue laminated elements of compressive strength of structural significance their use should however be limited to room temperature where the strength was least affected by temperature. Funtumia Africana is also found to be a glueable timber specie.

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