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Performance of IROKO and OMO Cross Laminated Timber in Coastal Environmental Conditions

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Abstract
This study explores the mechanical characteristics and behavior of Cross-Laminated Timber (CLT) panels made from Iroko and Omo wood species in coastal settings. The study focuses on bending strength (Modulus of Rupture), compressive strength, shear strength, and modulus of elasticity before and after exposure to moisture. Results reveal that both Iroko and Omo CLT panels demonstrate robust bending strength, but exposure to moisture led to slight reductions in strength, impacting adhesive bonding and causing delamination. Compressive strength, indicating a material's ability to withstand compression forces, experienced minor decreases after moisture exposure. Notably, Omo CLT exhibited superior bonding, minimizing splitting under compression. Shear strength, representing resistance to internal layer sliding, showed marginal reductions after moisture exposure, with observed rolling shear failure. Modulus of Elasticity values reflected wood stiffness, with Iroko being less prone to deformation compared to Omo. These findings offer practical insights into the structural performance of Iroko and Omo CLT in coastal environments, providing valuable information for engineering applications and sustainable construction practices.

Keywords: *CROSS-LAMINATED TIMBER, MECHANICAL PROPERTIES, COMPRESSIVE STRENGTH, BENDING STRENGTH, MODULUS OF ELASTICITY*

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I. Introduction

The advancement of construction technology, particularly Cross-Laminated Timber (CLT), is reshaping the global construction landscape as a sustainable alternative to traditional building systems (Satheeskumar et al. 2021). This study investigates the challenges and potential improvements of employing CLT in the coastal regions of Nigeria, encompassing Lagos State, Cross River State, Ondo State, and Delta State, where heightened water levels and humidity pose distinct hurdles. Despite Nigeria's adoption of CLT due to its adaptability to diverse climates, environmental factors in coastal areas limit its durability (Olawoki 2021). Ongoing global research explores CLT applications in coastal regions, forming the backdrop for this research focused on scrutinizing CLT utilization in Nigeria's coastal areas, aiming to address existing limitations and offer insights for enhancements.

Coastal environments, characterized by elevated humidity and moisture levels, pose formidable challenges to the long-term viability and resilience of CLT. Investigating the repercussions of prolonged moisture exposure and evaluating the efficacy of moisture-resistant coatings on CLT panels are crucial for enhancing their durability (Kai et al. 2020). In addressing the relocation challenges resulting from flooding-induced evacuation in coastal regions, timber structures, particularly those utilizing CLT, offer a flexible and cost-effective solution (Scalet T. 2015). The disassembly capability of timber structures allows for relocation and reconstruction, mitigating the need for entirely new structures. CLT's application contributes to lightweight construction, preventing structural sinking and reducing material requirements for foundations, promoting both structural integrity and sustainability (Brandner, 2016).

Coastal areas, vulnerable to saltwater exposure and extreme weather events, necessitate additional research to comprehend the potential acceleration of CLT component deterioration under combined effects. This inquiry is pivotal for devising effective strategies to bolster the resilience of CLT structures in challenging coastal conditions.

The research's overarching goal is to scrutinize the performance of CLT panels fabricated from selected timber in Nigeria's coastal regions, focusing on physical and mechanical properties evaluation, suitability assessment, and systematic fabrication process development. Laboratory tests will ascertain tensile, compressive, and flexural strengths, followed by exposure to simulated coastal conditions to monitor dimensional stability and durability. The research seeks to optimize the fabrication process, provide practical recommendations, and advance timber construction practices in Nigeria's coastal context. The study considers two wood species: Iroko, known for its stability and resistance, widely used in construction; and Omo Tree, prized for its durability and resistance to termite infestations, utilized in various woodworking projects.

II. Methodology

Materials Utilized: The construction of the cross-laminated timber board involves the use of two distinct wood species, specifically Iroko (Chlorophora excelsa) and Antiaris toxicaria (Omo) wood. Additionally, laminates, including moisture-curing polyurethane wood adhesive and a common wood adhesive, water, and various timber species are incorporated.

Sourcing: Timber was procured from the Bodija Sawmill in Ibadan North, then seasoned and cut to size at the University of Ibadan wood workshop. The common adhesive was sourced from the general Ogunpa market in Dugbe, Ibadan.

Machines and Equipment Utilized: The process employs a universal testing machine, a meter rule for timber/lumber size measurements, a digital caliper for checking adhesive thickness and test specimen measurements, a cutting machine to achieve standard lumber sizes, a brush for adhesive application to lamella layers, clamps for secure bonding, and markers for specimen and lumber labeling.

Material Tests: To determine the mechanical properties of the wood species, 30 pieces of each timber species underwent various tests, including bending strength, compression strength (both parallel and perpendicular), tensile strength, and shear strength. The objective is to identify the timber species suitable for CLT production in accordance with global production guidelines. Tests are conducted following standard codes: BS 526:2002, ASTM D143-22, and BS 373:1957.

CLT Fabrication Process: The fabrication of the Cross-Laminated Timber (CLT) panel involves a meticulous series of technical steps. Commencing with lumber selection and defect removal, the process includes cutting, adhesive application, panel stacking, and pressing to achieve the desired thickness. The layering procedure is iterated to create three, five, or seven layers. Considerations such as moisture content and temperature are crucial in lumber selection, preventing issues like "wane" to maintain bonding area and reduce stress concentration. Lumber is categorized based on strength directions and moisture content. Additional steps involve planning to prevent oxidation, cutting lumber to length, and applying adhesive to surfaces and edges. Adhesive selection is based on bond strength, flexibility, curing time, and compatibility with CLT. Application methods include brush, roller, spray, or dispensing tools to ensure an even layer. CLT boards are joined immediately after adhesive application, with pressure applied for proper contact. Proper layer arrangement is essential for increased structural strength, positioning each layer perpendicularly. Considering the potential for local production in coastal regions, there is an opportunity to assess timber suitability for CLT production based on engineered properties, mitigating cost and logistical challenges associated with importing CLT.

Mechanical properties of CLT: The mechanical properties evaluation of Cross-Laminated Timber (CLT) involved the production of 3-layer panels using Iroko and Omo lumber with a width of 310 mm, adhering to the specifications outlined in PRG 320. These panels, denoted as CL3/75, had a total thickness of 75 mm and were constructed with 25/25/25 mm layups. Longitudinal laminations employed lumber with a nominal cross-sectional dimension of 75 mm × 25 mm, while transverse laminations utilized lumber with a nominal cross-sectional dimension of 140 mm × 25 mm. Assembly of all CLT panels utilized polyurethane adhesive in an alternate press, with additional edge gluing. The average moisture content of the lumber utilized was 18%, and detailed specifications for both the Iroko and Omo 3-layer panels are discussed.

To assess the bending stiffness and shear properties of the dimensional lumber used in CLT panel construction, three-point bending tests were conducted. The lumber designated for bending had dimensions of 75 mm × 25 mm in width and depth, respectively, and a total length of 900 mm, adhering to the stipulation that it should not exceed 18 times the lumber thickness (875 mm). The distance between the supports for the three-point bending tests was fixed at 750 mm. throughout the tests; a constant displacement loading rate of 5.0 mm/min was applied. The dimensions of the test specimens and the loading setup adhered to the guidelines outlined in BS EN 408.

Shear Strength Assessment: In adherence to the European standard BS EN 408, certified for the determination of stiffness and strength properties of Cross-Laminated Timber (CLT) based on EN 16351, bending tests were systematically conducted. The loading process involved a steady application of force (Figure 1), with the loading head's movement rate limited to not exceed 0.0002 h mm/s. The flexural test evaluated the force required to bend a beam under 3-point loading conditions. Symmetric loading was applied at the center points of the test pieces, inducing bending over a span measuring 5 times the depth. The dimensions of the specimens for the 3-point bending test were precisely 475 mm × 75 mm × 75 mm, representing length, width, and thickness, respectively.

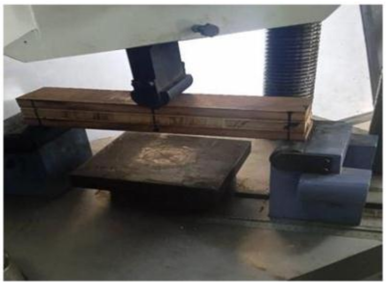

Fig. 1: Shear test arrangement in the Universal testing machine

Compression Parallel to the Grain: The test specimens designed for compression parallel to the grain exhibited dimensions of 375 mm × 75 mm × 75 mm in length, width, and thickness, respectively. These specimens possessed a full cross-section with a length measuring six times (6 × h) the smaller cross-sectional dimension. The end-grain surfaces underwent meticulous preparation to ensure flatness, parallelism to each other, and perpendicularity to the piece's axis. The calculation of Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) relied on measured values obtained from the overall cross-section of the tested samples, adhering to the guidelines outlined in BS EN 408.

To apply compressive loads to these specimen, spherically seated loading or other suitable devices were employed(Figure 2) ensuring concentric loading without inducing bending. The compressive load was applied at a constant rate, with the movement of the loading head not exceeding 0.00005 l mm/s. The maximum load was attained within 300 ± 120 s. The time until failure for each test piece was meticulously recorded, and the average time was subsequently reported.

Fig. 2: compression test arrangement using UTM

III. Results and Discussion

The analysis of the physical properties of Iroko and Omo timber samples yields significant findings as presented in Table 1. The timber's moderate density indicates its suitability for structural applications, striking a balance between strength and weight considerations. The initially high moisture content poses potential challenges to dimensional stability and durability, underscoring the crucial role of meticulous drying processes. Specific gravity values offer insights into the timber's buoyancy and inherent resistance to decay, with Iroko displaying a moderate level of durability. The relatively low bulk density points to a higher proportion of void spaces, influencing the timber's strength, stiffness, and insulating properties. This data set serves as a valuable reference for making informed decisions in the selection and utilization of Iroko and Omo timber, ensuring optimal performance across diverse environmental conditions.

Table 1: Physical Properties of CLT Samples

	Moisture Content (%)	Specific Gravity	Dry Density (kg/m^3)	Bulk Density (kg/m^3)
Iroko	9.21	0.63	566.98	614.60
Omo	12.78	0.41	322.15	411.53

Mechanical Properties of CLT samples

The durability of the CLT samples was tested and the results are presented in Table 2 below:

Table 2: Mechanical properties of Iroko and Omo Timber

	Compressive (N/mm^2)		Sheer Strength (N/mm^2)	Bending Strength (N/mm^2)	Tensile Strength (N/mm^2)	MOE
	Parallel	Perpendicular				
Iroko	39.29	52.93	12.86	96.98	56.19	10061.04
Omo	30.72	26.04	9.04	47.52	28.56	4091.91

Bending Strength (Modulus of Rupture): The Iroko and Omo Cross-Laminated Timber (CLT) panels exhibited commendable bending strength, measuring 21.67 N/mm^2 and 17.87 N/mm^2. This signifys their capacity to withstand bending or flexural stresses without fracture. The bending strength of CLT is influenced by variables such as individual layer thickness, adhesive quality, and layer orientation during production. Notably, the bending strength decreased when panels were exposed to moisture, with reductions of 0.111% and 0.22% for Iroko and Omo, respectively. This reduction also affected the adhesive bonding strength with the timber. The observed failures during the bending strength test manifested as delamination along the glue line for both CLT specimens, both before and after exposure to moisture.

Compressive Strength: Prior to moisture exposure, the Iroko and Omo CLT panels demonstrated an average compressive strength of 278.06 N/mm^2 and 177.61 N/mm^2. Subsequent exposure to moisture resulted in a slight reduction in compressive strength by 0.12% and 0.06%, respectively. Compressive strength assesses a material's ability to withstand forces applied in compression, such as crushing. CLT panels exhibit high compressive strength, making them suitable for load-bearing applications, particularly in vertical elements like columns and walls. Notably, the compressive strength test revealed that the Omo CLT exhibited superior bonding adhesive strength compared to Iroko, as evidenced by the reduced splitting under compressive force.

Shear Strength: The Iroko and Omo CLT panels demonstrated average shear strength of 16.37 N/mm^2 and 8.45 N/mm^2, with a marginal reduction in strength upon exposure to moisture by 0.12% and 0.2%, respectively. Shear strength pertains to a material's resistance to forces causing internal layers to slide relative to each other. CLT's cross-laminated structure imparts excellent shear strength, enhancing its lateral load-carrying capacity and suitability for horizontal elements like floors and roofs. The observed failure during the shear strength test manifested as rolling shear, a specific mode of shear failure where layers or planes of the material slide relative to each other along the direction of the applied force.

Modulus of Elasticity: The Modulus of Elasticity (M.O.E.) values for Iroko and Omo are significant indicators of the respective wood species' stiffness and ability to deform under applied stress. A higher M.O.E., such as the value of 10061.04 for Iroko, suggests greater stiffness and resistance to deformation, indicating that Iroko is less prone to bending or sagging when subjected to external forces. On the other hand, the M.O.E. value of 4091.91 for Omo implies a lower stiffness compared to Iroko, suggesting that Omo is more flexible and may exhibit more significant deformation under applied stress. These M.O.E. values are crucial for assessing the structural performance and suitability of each wood species for specific applications, such as load-bearing elements in construction. Tables 2 and 3 present the mechanical properties of Iroko and Omo CLT before and after exposure in N/mm2.

Table 2: Mechanical properties of Iroko and Omo CLT before exposure in N/mm2

Timber	**Bending**		**Shear**		**Compression**	
	MOR	MOE	Eapp	G	Fmax	Ec,o
Iroko	21.67	3437.12	4069.34	16.37	278.06	3516.44
S.D	3.80	931.83	323.28	22.09	1.03	206.69
Omo	17.87	2579.13	2599.34	177.61	8.45	1708.70
S.D	1.28	288.06	415.06	28.36	0.76	152.36

Table 3: Mechanical properties of Iroko and Omo CLT before exposure in N/mm2

Timber	Bending		Shear		Compression	
	MOR	MOE	Eapp	G	Fmax	Ec,o
Iroko	19.46	2937.12	3769.70	247.13	14.57	3127.64
S.D	3.80	982.83	314.90	21.05	1.53	2.69
Omo	14.65	2150.46	2196.74	147.82	7.94	1613.70
S.D	1.28	267.02	385.88	25.76	0.82	155.60

IV. Conclusion

In conclusion, the study on the “Performance of Iroko and Omo Cross-Laminated Timber (CLT) in Coastal Environmental Conditions" provides valuable insights into the structural behavior of Iroko and Omo CLT panels. The bending strength results highlight the panels' commendable ability to resist flexural stresses, with Iroko exhibiting a higher initial strength than Omo. However, both species experienced a reduction in bending strength when exposed to moisture, emphasizing the influence of environmental conditions on CLT performance. The observed delamination along the glue line underscores the vulnerability of CLT to moisture-induced degradation. The compressive strength findings indicate substantial load-bearing capacity for both Iroko and Omo CLT panels, with Omo exhibiting superior bonding adhesive strength. This strength, coupled with the slight reduction after moisture exposure, signifies the panels' resilience under compressive forces. The study emphasizes the suitability of CLT for vertical load-bearing applications in coastal regions. Shear strength results highlight the exceptional lateral load-carrying capacity of CLT due to its cross-laminated structure, with both Iroko and Omo panels demonstrating notable shear strength. The occurrence of rolling shear failures suggests a specific mode of shear failure when subjected to shear stress. This insight is crucial for understanding potential failure mechanisms in CLT structures. The Modulus of Elasticity (M.O.E.) values further differentiate the stiffness of Iroko and Omo, with Iroko exhibiting higher stiffness and resistance to deformation. Conversely, Omo's lower stiffness implies greater flexibility and potential for deformation under applied stress. These M.O.E. values serve as key indicators for assessing the structural performance and application suitability of each wood species in construction projects. Overall, the study underscores the significance of considering coastal environmental conditions in the design and application of CLT panels. The findings contribute to informed decision-making in the selection of wood species and the design of CLT structures for optimal performance and durability in coastal regions. Based on the outcomes of the investigation into the "Mechanical Properties and Performance of Cross Laminated Timber (CLT) in Coastal Environmental Conditions," several recommendations are proposed. Firstly, it is advisable to employ moisture-resistant adhesives to mitigate the observed reduction in bending strength and adhesive bonding strength when CLT panels are exposed to moisture. Additionally, the application of effective sealants on exposed CLT surfaces is recommended to act as a protective barrier against moisture absorption and prevent dimensional changes. Climate-adapted design principles should be integrated into the fabrication and construction processes, optimizing layer thickness, adhesive quality, and layer orientation to address the specific challenges posed by high humidity and moisture in coastal regions. Careful consideration of wood species selection, balancing stiffness, bonding strength, and flexibility, is crucial to align with project requirements and the coastal climate. Implementing a continuous monitoring system for CLT structures in coastal environments will enable the tracking of mechanical property changes over time, facilitating timely maintenance. Encouraging ongoing research and development efforts, educational outreach, and collaboration among industry professionals can collectively contribute to standardized guidelines and practices for resilient CLT construction in coastal areas.

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