

MECHANICAL PROPERTIES AND DIMENSIONAL DURABILITY OF CEMENT AND POLYVINYL ACETATE (TOPBOND) BONDED PARTICLEBOARDS PRODUCED FROM *GMELINA ARBOREA* AND *KHAYA IVORENSIS* SAWDUST IN RELATION TO WOOD DENSITY

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Abstract:

This study evaluated the mechanical and physical properties of cement and Topbond (polyvinyl acetate, PVA) bonded particleboards produced from Gmelina arborea Roxb. and Khaya ivorensis A. Chev. sawdust in relation to wood species density and dimensional stability. Boards were produced at a target density of 1000 kg/m³ using three mixing ratios: 80:15:5, 70:25:5 and 60:35:5 (sawdust:binder:CaCl₂) in a 2×2×3 factorial experiment in completely randomized design with three replicates. Modulus of elasticity (MOE), modulus of rupture (MOR), water absorption (WA) and thickness swelling (TS) after 24h and 48h immersion were determined following ASTM D1037 and BS 373 standards. MOE ranged from 1581.34 to 2203.09 N/mm² and MOR from 1.99 to 3.97 N/mm². Cement-bonded boards exhibited significantly higher MOR than Topbond-bonded boards ($p < 0.001$). Gmelina arborea cement recorded the highest MOE (1965.50 N/mm²), while Khaya ivorensis cement recorded the highest MOR (3.41 N/mm²). Sample C (60:35:5) consistently produced optimal mechanical performance (MOE 2133.16 N/mm²; MOR 3.34 N/mm²). WA 24h ranged from 4.83% to 26.58% and TS 24h from 7.70% to 23.59%. Cement-bonded boards showed superior dimensional stability with significantly lower WA and TS ($p < 0.001$). Khaya ivorensis cement Sample C had the lowest TS (7.70% at 24h; 12.65% at 48h). Density of Khaya ivorensis (545-640 kg/m³) contributed to higher MOR, while lower density of Gmelina arborea (450-575 kg/m³) provided higher compaction ratio and comparable MOE. Topbond boards exceeded EN 634-2 limits for exterior use (TS up to 35.89%), indicating poor dimensional stability in humid tropical conditions. Khaya ivorensis cement-bonded board at 60:35:5 ratio is recommended for ceiling, partitioning and semi-exterior applications.

Key words: Gmelina-Khaya particleboard; properties; cement-bonded; topbond; dimensional stability.

INTRODUCTION

The Increase in global demand for wood and wood-based panel products, coupled with deforestation and pressure on natural forests, has necessitated the search for alternative raw materials for particleboard production (Maloney 1993; Olorunnisola 2008). Particleboard is an engineered wood product manufactured from wood particles or other lignocellulosic materials bonded with synthetic or inorganic binders under high heat and pressure (Rowell 2005).

Nigeria is endowed with numerous fast-growing plantation species that are under-utilized for panel products. Two of such species are *Gmelina arborea* Roxb. and *Khaya ivorensis* A. Chev. *Gmelina arborea* is a fast-growing deciduous tree introduced to Nigeria in the 1960s for pulp and paper production (Adeyemi and Ogunsanwo 2011). It has become a major plantation species in southern guinea savanna and rainforest zones, with rotation age of 10-15 years for pulp and 20-30 years for timber (Onyekwelu 2004). *Gmelina* wood density ranges from 242 to 540 kg/m³ at ages 3-15 years and average 380-575 kg/m³ in mature wood (Dvorak 2003; Akachukwu 1990). Its specific gravity is 0.35-0.50g/cm³.

Khaya ivorensis belongs to family Meliaceae, commonly called African mahogany. It is one of the most valuable timbers in international trade. Khaya wood density ranges 450-640 kg/m³, average dried weight 545 kg/m³ and basic density 488 kg/m³ at base of 1.2 m (Olorunnisola 2008). It has high strength: MOE 8.9-10.3 GPa and MOR 77-89 MPa for solid wood.

The properties of particleboard are greatly influenced by wood species density, anatomical structure, chemical composition, particle geometry and type of binder (Moslemi 1989; Badejo 1989). Low-density woods generally produce boards with higher compaction ratios, leading to better bending strength, while high-density woods may result in low compaction and poor inter-particle bonding (Kelly 1977). Binders such as urea-formaldehyde, phenol-formaldehyde, cement and polyvinyl acetate (Topbond) have different compatibility with wood species due to inhibitory extractives (Fuwape and Fabiyi 2003).

OBJECTIVE

The aim of this study is to evaluate properties of cement and Topbond bonded particleboards from *Gmelina arborea* and *Khaya ivorensis* in relation to wood density and. The specific objectives are: (i) to determine mechanical properties (MOE, MOR) and physical properties (WA, TS) of boards; (ii) to assess effect of wood species density on board performance; (iii) to evaluate stability implications for interior and exterior applications; (iv) to recommend optimal species-binder combination.

MATERIALS AND METHODS

Study Area and Sample Collection

The research was conducted at the Forestry Research Institute of Nigeria (FRIN), Jericho Hills, Ibadan, Oyo State, Nigeria. Ibadan is located in South Western Nigeria approximately on Longitude 3°5'-4°36'E and Latitude 7°23'-7°55'N. Sawdust of *Khaya ivorensis* and *Gmelina arborea* was collected from Bodija plank market, Ibadan under supervision to ensure homogeneity. Portland cement and Topbond (PVA) were purchased from Dugbe Market, Ibadan.

Sample Preparation and Pre-treatment

The sawdust was stored in the Reconstituted Wood Products Section of Forest Product Development and Utilization Division, FRIN, at constant room temperature to air dry. It was extracted in hot water at 90°C to reduce concentration of inhibitory sugar compounds, then separately air dried for two weeks to attain moisture content of approximately 12% prior to use.

Board Formation

Sawdust and binder quantities were measured based on mixing ratio by weight. (hardener) (CaCl₂) was 5% of cement weight. Water quantity was determined by relationship developed by Moslemi and Pfister (1987):

$$Wt = 0.35C + (0.30 - M) W \quad (1)$$

where: Wt = weight of water (g), C = cement weight (g), M = moisture content (%), W = wood dry weight (g).

Boards were produced at target density 1000 kg/m³ with three mixing proportions (Table 1). Solution of calcium chloride and water was mixed to uniform matrix. A wooden mat 350 mm x 350 mm was placed on metal caul plate covered with polythene sheet. Plywood plate was used to pre-press mat and covered with another polythene sheet before top metal caul plate. Mat was transferred to cold press and pressed for 24 hours. Boards were stored inside sealed polythene bags for 28 days for post curing, trimmed to avoid edge effect, and stored at 20±2°C and 65% relative humidity for 21 days.

Table 1

Mixing ratios used for particleboard production

Sample	Sawdust (%)	Binder (%)	Additives-hardeners (%)
A	80	15	5
B	70	25	5
C	60	35	5

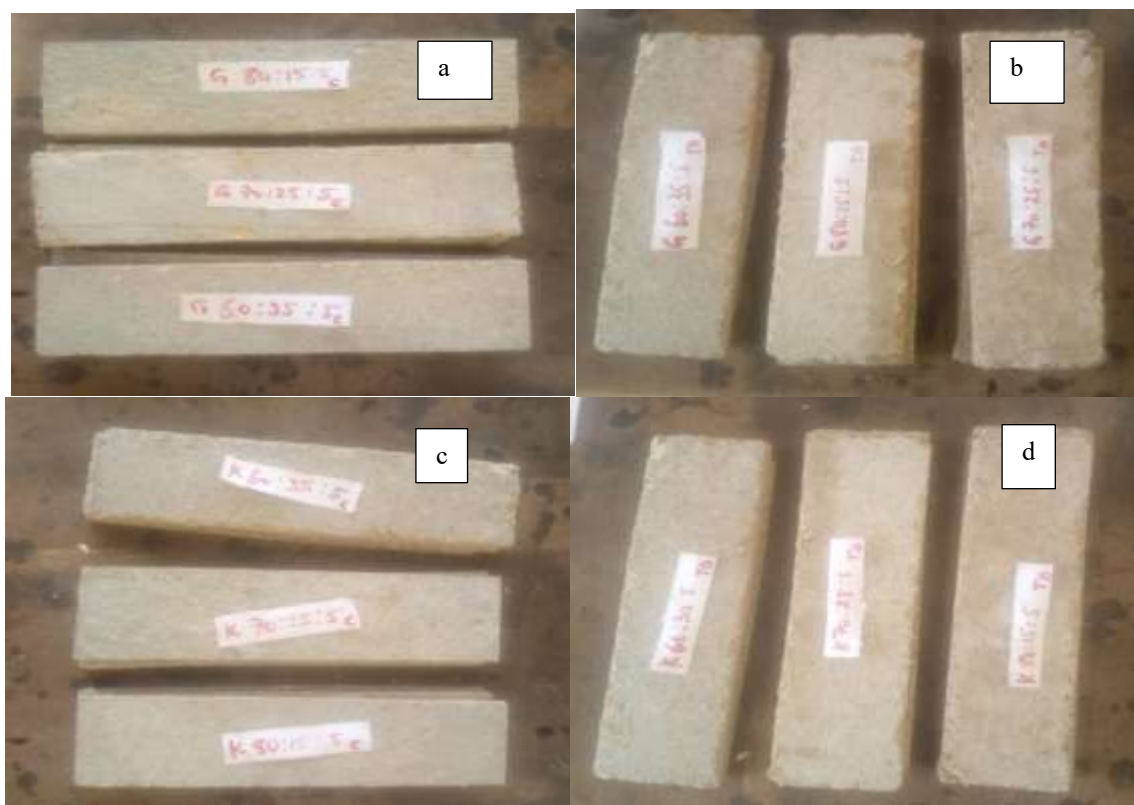


Fig. 1.

a: Sample of *Gmelina arborea* cement bonded particleboard; b: Sample of *Gmelina arborea* Topbond bonded particleboard; c: Sample of *Khaya ivorensis* Cement bonded particleboard; d: Sample of *Khaya ivorensis* Topbond bonded particleboard.

Determination of Physical and Mechanical Properties

Samples 50mm x 50mm x 10mm were used for physical properties tests according to BS 373 (1989). $WA (\%) = (W2 - W1)/W1 \times 100$ (2), $TS (\%) = (T2 - T1)/T1 \times 100$ (3). Mechanical properties tested were MOR and MOE with samples 10mm x 50mm x 195mm according to ASTM D1037 (1978). $MOR = 3PL / 2bd^2$ (4), $MOE = PL^3 / 4bd^3h$ (5), where P = failure load-force (N), L = span (mm), b = width (mm), d = thickness (mm), h = slope from load-deflection graph, Unit Measurement.

Experimental Design and Statistical Analysis

A 2x2x3 factorial experiment in completely randomized design (CRD) was used. Factors were wood species, binder type, mixing ratio with three replicates. Model: $Y_{ijk} = \mu + A_i + B_j + C_k + AB_{ij} + AC_{ik} + BC_{jk} + ABC_{ijk} + E_{ijk}$. ANOVA at 5% probability level and Duncan's Multiple Range Test (DMRT) for mean separation using SPSS version 23.

RESULTS AND DISCUSSION

Mechanical Properties

Mean MOE ranged from 1581.34 to 2203.09 N/mm² (Table 2). Highest MOE (2203.09±96.75N/mm²) was *Khaya ivorensis* cement Sample C, lowest (1581.34±173.77) was *Khaya* Topbond Sample A. MOR ranged 1.99-3.97 N/mm². Cement-bonded boards consistently exhibited higher MOR than Topbond. Highest MOR (3.97±0.04) was *Khaya* cement Sample C, lowest (1.99±0.21) *Gmelina* Topbond Sample A.

Table 2

Mean values for mechanical properties

Board type	Sample	MOE (N/mm ²)	MOR (N/mm ²)
Gmelina Topbond	A	1845.83±85.74	1.99±0.21
Gmelina Topbond	B	1665.81±54.45	2.54±0.29
Gmelina Topbond	C	2170.12±125.81	2.36±0.20
Gmelina Cement	A	2156.45±189.10	3.27±0.14
Gmelina Cement	B	1761.07±12.06	3.10±0.03
Gmelina Cement	C	1978.99±85.82	3.54±0.02

Khaya Topbond	A	1581.34±173.77	2.74±0.44
Khaya Topbond	B	1590.12±328.96	2.25±0.39
Khaya Topbond	C	2180.45±173.24	3.48±0.02
Khaya Cement	A	1840.64±26.57	3.04±0.08
Khaya Cement	B	1676.75±154.05	3.22±0.07
Khaya Cement	C	2203.09±96.75	3.97±0.04

ANOVA (Table 3) revealed board type had no significant effect ($p>0.05$) on MOE ($F=2.282$, $p=0.105$), while sample and interaction (type*sample) had significant effects ($p<0.05$). For MOR, board type, sample and interaction all had highly significant effects ($p<0.001$).

Table 3

ANOVA for MOE and MOR					
Property	Source	Type III SS	Mean Square	F-cal	Sig.
MOE	Board Type	154956.862	51652.287	2.282	0.105 ns
	Sample	1285948.708	642974.354	28.405	0.000*
	Type*Sample	484041.741	80673.624	3.564	0.011*
	Error	543269.316	22636.221		
MOR	Board Type	7.001	2.334	49.621	0.000*
	Sample	2.571	1.286	27.338	0.000*
	BT*BS	1.922	0.320	6.812	0.000*
	Error	1.129	0.047		

DMRT (Table 4) showed Gmelina cement (1965.50 N/mm²) had highest MOE significantly different from Khaya Topbond (1783.96 N/mm²). For MOR, Khaya cement (3.41) and Gmelina cement (3.30) were not significantly different but higher than Topbond. Sample C recorded significantly higher MOE (2133.16) and MOR (3.34) than A and B.

Table 4

DMRT for Mechanical Properties		
Board Type / Sample	MOE	MOR
Khaya Cement	1906.82 ab	3.41 a
Gmelina Cement	1965.50 a	3.30 a
Khaya Topbond	1783.96 b	2.82 b
Gmelina Topbond	1893.92 ab	2.30 c
Sample C	2133.16 a	3.34 a
Sample B	1673.43 c	2.78 b
Sample A	1856.06 b	2.76 b

Physical Properties and Dimensional Stability

WA 24h ranged 4.83-26.58%, WA 48h 5.00-29.56% (Table 5). Highest WA was Khaya Topbond Sample A (26.58±2.97% at 24h; 29.56±2.09% at 48h), lowest Gmelina cement Sample C (4.83±1.28% at 24h) and Khaya cement Sample C (5.00±0.17% at 48h). TS 24h ranged 7.70-23.59%, TS 48h 12.65-35.89%. Cement-bonded boards showed superior dimensional stability, with Khaya cement Sample C lowest TS (7.70±0.12% at 24h; 12.65±0.08% at 48h).

Table 5

Mean values for Physical Properties					
Board type	Sample	WA 24h (%)	WA 48h (%)	TS 24h (%)	TS 48h (%)
Gmelina Topbond	A	10.11±2.42	15.43±5.15	19.87±2.66	35.89±3.74
Gmelina Topbond	B	17.87±0.65	21.23±0.22	23.59±1.40	30.97±9.57
Gmelina Topbond	C	17.15±1.94	18.50±1.94	23.54±3.72	21.74±1.08
Gmelina Cement	A	14.46±3.40	22.19±6.22	20.17±0.62	29.82±0.86
Gmelina Cement	B	11.62±1.95	17.87±4.53	11.50±1.25	14.07±4.01

Gmelina Cement	C	4.83±1.28	5.00±0.16	13.60±1.28	16.89±1.01
Khaya Topbond	A	26.58±2.97	29.56±2.09	21.31±0.83	30.86±0.96
Khaya Topbond	B	18.93±2.60	24.94±2.58	21.31±1.65	32.47±5.65
Khaya Topbond	C	11.17±1.02	14.26±0.87	11.18±0.17	13.98±0.21
Khaya Cement	A	18.21±0.25	28.87±5.58	8.71±0.41	13.26±0.90
Khaya Cement	B	9.12±0.19	12.82±0.13	16.03±0.52	25.03±1.39
Khaya Cement	C	4.93±0.01	5.00±0.17	7.70±0.12	12.65±0.08

ANOVA (Table 6) showed highly significant effects ($p < 0.001$) of board type, sample and interaction on all physical properties.

Table 6

ANOVA for Physical Properties

Property	Source	SS	MS	F-cal	Sig
WA 24h	BT	440.688	146.896	40.166	0.000*
	BS	373.827	186.913	51.108	0.000*
	BT*BS	515.622	85.937	23.498	0.000*
WA 48h	BT	352.470	117.490	10.621	0.000*
	BS	1092.817	546.409	49.396	0.000*
	BT*BS	695.666	115.944	10.482	0.000*
TS 24h	BT	633.476	211.159	83.011	0.000*
	BS	118.089	59.044	23.212	0.000*
	BT*BS	361.163	60.194	23.664	0.000*
TS 48h	BT	846.415	282.138	21.105	0.000*
	BS	857.191	428.595	32.060	0.000*
	BT*BS	797.435	132.906	9.942	0.000*

DMRT (Table 7) for physical properties showed Khaya Cement and Gmelina Cement not significantly different for WA but significantly lower than Topbond. Sample C recorded significantly lowest WA and TS.

Table 7

DMRT for Physical Properties

Board Type / Sample	WA 24h	WA 48h	TS 24h	TS 48h
Khaya Cement	10.75 a	15.56 a	10.81 a	16.98 a
Gmelina Cement	10.30 a	15.02 a	15.09 b	20.26 a
Khaya Topbond	18.89 c	22.92 b	17.94 c	25.77 b
Gmelina Topbond	15.05 b	18.39 a	22.34 d	29.54 c
Sample C	9.52 a	10.69 a	14.01 a	16.32 a
Sample B	14.38 b	19.22 b	18.11 b	25.64 b
Sample A	17.34 c	24.01 c	17.52 b	27.46 b

Density and dimensional stability Discussion

The significantly higher MOR in cement-bonded boards is consistent with cement hydration products creating rigid matrix improving stress transfer (Ajayi 2006; Fuwape and Fabiyi 2003). Non-significant effect of board type on MOE suggests stiffness more influenced by wood species density and particle geometry (Badejo 1989). Superior performance of Sample C attributed to higher density and lower extractive content improving cement compatibility. Khaya cement gave highest MOR due to higher wood density and interlocking grain enhancing mechanical interlock.

Higher density of *Khaya ivorensis* (545-640 kg/m³) contributed to higher MOR (3.41 vs 3.30 N/mm²). This agreed with findings by ((Kelly 1977; Erakhrumen et al. 2008; Papadopoulos 2008) and Izekor et al. 2010) stated that higher density provides more cell wall material per unit volume. However, lower density Gmelina achieved comparable MOE (1965.50 N/mm²) to Khaya cement (1906.82) because lower density species have higher compaction ratio.

WA and TS are critical indicators of dimensional stability. Cement coating reduces accessible hydroxyl groups and seals voids (Papadopoulos et al. 2006; Naghizadeh et al. 2021). Topbond (PVA) susceptible to moisture, leading to bond degradation (Adedeji et al. 2023). WA values 4.83-26.58% within range for wood-cement composites (10-25%) (Erakhrumen et al. 2008) lower than urea-formaldehyde boards >50% (Maloney 1993). Significant interaction confirms species-extractive interaction influences hygroscopic behavior (Olorunnisola 2008).

This findings confirmed that stability is not only biological but dimensional one. Topbond boards TS up to 35.89% (48h) would lead to degradation in humid tropical climates of Ibadan/Lagos, exceeds 8% limit of EN 634-2 for exterior use. Cement boards TS 7.70-13.60% (24h) for Sample C within acceptable limits for protected exterior applications. Alkaline cement protects non-durable Gmelina (Class 4-5) against fungi and termites. Based on EN 312-2 (European Committee for Standardization 2010) MOR should be ≥11 N/mm² for 6-13 mm boards; EN 634-2 minimum MOR 9 N/mm² for structural cement-bonded boards. Values obtained (1.99-3.97) are low for structural but suitable for non-structural uses such as ceiling tiles, partition walls, insulation panels (Aghakhani et al. 2014). Improvement strategies: hot water pre-treatment, CaCl₂ accelerator 3-4%, increase cement-wood ratio (Ogunjobi et al. 2022).

CONCLUSIONS

Cement binder significantly improved modulus of rupture and dimensional stability (lower WA and TS) compared to Topbond binder for both Gmelina arborea and *Khaya ivorensis* particleboards. Sample C (60:35:5) produced best overall performance, indicating within-tree variation and binder content are important. *Khaya ivorensis* cement-bonded board (Sample C) showed optimal balance of mechanical strength (MOR 3.97 N/mm², MOE 2203.09 N/mm²) and low thickness swelling (TS 7.70% at 24h), making it suitable for interior and semi-exposed applications.

1. *Khaya ivorensis* cement-bonded board at 60:35:5 (sawdust: cement: CaCl₂) is recommended for humid environments and semi-exterior applications requiring dimensional stability.
2. Gmelina arborea Topbond boards are suitable only for interior dry-use furniture where light weight and machinability are prioritized.
3. Hot water extraction at 90°C and 3-5% CaCl₂ hardener should be retained to improve cement compatibility.
4. Further work should optimize cement-wood ratio to achieve EN 634-2 requirements, investigate effect of particle size (1-2 mm thickness), board density (1200-1300 kg/m³), and evaluate long-term biological durability.

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