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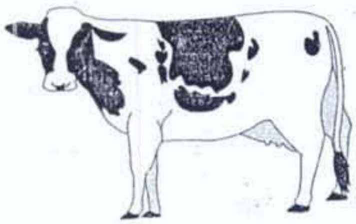

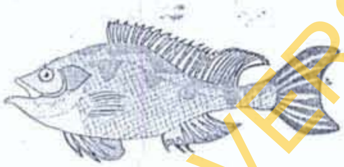

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SORPTION AND BENDING PROPERTIES OF WOOD CEMENT PANELS PRODUCED FROM MIXED NIGERIAN HARDWOODS AT VARYING WATER/CEMENT RATIOS

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ABSTRACT

The study was carried out to investigate the influence of water/cement ratio on the moisture response and mechanical properties of wood cement panels fabricated with mixed hardwood species. The experimental boards so produced were subjected to modulus of rupture (MOR), modulus of elasticity (MOE), water absorption (WA), thickness swelling (TS) and linear expansion (LE) tests. Data collected were subjected to statistical analysis using ANOVA and multiple linear regressions.

MOR and MOE ranged from 4.94 N/mm^2 to 11.63 N/mm^2 and 2340 N/mm^2 to 4880 N/mm^2 respectively. Strength (MOR) and stiffness (MOE) of the boards increased as water/cement ratio was raised from 0.50 to 0.60. Within these ranges, more dimensionally stable cement-bonded particleboards were obtained. As water/cement ratio was however raised from 0.60 to 0.65, weaker and inferior boards were produced. The results of the multiple regression analysis showed that water/cement ratio (WCR), cement/wood mixing ratio (MR) and board density (BD) were positively correlated with MOR and MOE. Water absorption (WA), thickness swelling (TS) tests ranged from 16.27 to 48.82% and 0.49 to 2.30% respectively. Statistical analysis of the results showed that the process variables WCR, BD and MR were significant at 1% level of probability on WA and TS. Moiture uptake and swelling of the panel decreased as water/cement ratio was raised from 0.50 to 0.60. Inferior panels were produced when water/cement ratio was increase beyond 0.60. Therefore 0.60 was considered uptimum level for board fabrication in this study.

Key words: *wood cement panels, bending properties, sorption properties, mixed hardwoods, water/cement ratio*

INTRODUCTION

Mixing ratio is an important variable in wood-cement board production as resin content is to resin-bonded particleboard. Only limited literature are found indicating the influence of mixing ratio at varying levels on properties of cement-bonded particleboard (Namioka *ct al.* 1972; Prestemon 1976; Xia 1982; Badejo 1987, Oyagade 1990). The reported research of Dinwoodie (1978) and lida *et al* (1983) only made use of this production variable at a specified level. Using mixed wood particles of *Picea jezoensis* and *Abies saccharlensis*, Namioka *et al* (1972) studied the influence of cement/wood mixing ratio within the range of 1.5 to 2.5 on properties of cement-bonded particleboards and reported that static bending strength decreased with increase use of mixing ratio (a measure of cement binder content in board). Thickness swelling of the boards however decreased with increase use of cement/wood mixing ratio. This indicates improved board dimensional stability with increase in panel's cement binder content. Prestemon (1976) showed that increased use of cement/wood mixing ratio manifested in improved properties of the panels in relation to static bending strength and stiffness; compression parallel to surface; tensile strength perpendicular to surface; and nail withdrawal resistance. Similarly, panels made with increased use of cement binder content were the most dimensionally stable. Badejo (1987) investigated the influence of cement/wood mixing ratio at eleven levels equispaced between 2.0: 1.0 and 3.0 : 1.0 of cement to wood on cement-bonded particlcboards fabricated from four tropical hardwoods - *Mitragyna cillata, Triplochiton scleroxylon, Terminalia superba* and *Ceiba pcntandra.* The findings of the study showed that strength and stiffness of the experimental panels appeared to be associated with the densities of the wood species used. The mixing ratio range of 2.0: 1.0 to 2.4:1.0 produced the most favourable results. On the other hand however, thickness swelling decreased with increased use of cement/wood mixing ratio for each of the hardwood species. Oyagade (1990) investigated the effect of cement/wood ratio at levels of 1.55: 1.0, 2.33: 1.0 and 3.10 : 1.0 on the relationship between cement-bonded particleboard densities and bending properties using wood samples *of Picea abies* (Norway spruce). At constant board density, decrease in bending properties with increase in cement/wood ratio was observed.

Fuwape (1995) reported on the influence of cement-wood ratio on strength properties of cement-bonded particleboards from Spruce at levels of 70/30, 60/40, 50/50 and 40/60. The results indicated that MOR and MOE as well as internal bond (IB) decreased with decrease in cement/wood ratio. However, within above similar range of cement/wood mixing ratio, Fuwape (1992) had earlier reported that thickness swelling and water absorption increased with decrease in cement/wood ratio applied for cement-bonded particleboard production from Sitka spruce.

Water-cement ratio

Water is required for homogenous mixing of the cement binder with the wood particles. Similar to what operates with concrete, the strength of wood-wool boards has been reported to vary with the amount of water added (Yamagashi *et al* 1980; Yamagashi *et al.* 1981). The optimum water-cement ratios decrease with increasing density of the boards and increase slightly as the sizes of wood particles become smaller. For the highly compressed boards such as cement-bonded particleboards, a water-cement ratio of 0.40 of the cement weight in the board is generally used to estimate the quantity of water applied when using woods of specific weights of 0.43 (Simatupang et *al* 1978). Experimenting with water/cement ratios of 0.50, 0.55 and 0.60, Yamagishi *et al* (1981) reported the ratio level of 0.55 as the optimum required for the manufacture of cement-bonded particleboards from wood flakes of Larch within board specific gravity levels of 1.05 to 1.08. Xia (1982) indicated in his study that an optimum water-cement ratio of 0.65 is required to manufacture 3-layered oriented cement-bonded particleboards from the wood raw materials used. Oyagade (1988) investigated the influence of cement-water ratio at four levels of 0.45, 0.55, 0.65 and 0.75 on properties of cement-bonded particleboards made from *Picea abies* (Norway spruce) and reported that the level 0.65 produced the most favourable results. Although studies have been undertaken to assess the effect the effects of water/cement ratio on static bending and moisture response properties of the cement-bonded particleboards, however, very limited investigation have been directed at establishing the uptimum level at which water can the applied to produce high quality particleboard especially from mixed tropical hardwood species. The study is therefore iniatiated to assess the sorption and static bending properties of the boards produced at varying water/cement ratio with a view to determining the uptimum level at which the production variable can be applied.

MATERIALS AND METHODS

The eight hardwood species used for the study are: *Triplochiton scleroxylon* K. Schum (Obeche). *Terminalia ivorensis* A. Chev. (Idigbo) *Terminalia superba* Eng. & Diels (Afara), *Brachystegia nigerica* Hoyle & A.P.D. Jones (Okwen), *Khaya ivorensis* A. Chev. (Lagos Mahogany), *Nesogordonia papaverifera* A. Chev. (Danta - Oro) *Tectona grandis* Linn. F. (Teak), *Gmelina arborea* Roxb. (Gmelina).

Wood wastes of the above selected species were collected from sawmills which operate around Ibadan in Oyo state. The wood wastes collected from sawmills were pooled together according the species type and screened with the aid of wire mesh to remove too fine particles and barks for the lot. The screened particles were subsequently spread out on plywood moulds and air dried for 28 days to allow for gradual disintegration of the starches and other sugar in the wood that can slow down the setting of cement binder. The air-dried particles were later properly bagged and kept in the laboratory prior to hot water pre-treatment. Hot water pre-treatment of the particle for board production was carried our in accordance with procedure developed by Simatupang 1974 and modified by Badejo 1999.

Experimental designs and procedures;

Three process variables were employed in the fabrication of the 6mm thick experimental panels. These are water/cement ratio by weight at four levels (0.50, 0.55, 0.60 and 0.65), two board density levels of 1100 and 1200kg/m³ and cement/wood mixing ratios at two levels of 2.25: 1.0 and 2.75: 1.0. The combination of the above production inputs is a three factors factorial experiment which manifested in 16 treatment combinations. For each of the 16 treatment combinations which were involved in this factorial experiment (2 x 2 x 4), four replicate panels were made in order to provide adequate test specimens for the experiment.

RESULTS AND DISCUSSIONS

Moduli of rupture and elasticity;

The compiled averages of the Moduli of rupture and elasticity (MOR and MOE) test results for each of the 16 experimental treatments are summarised in Table 1. As shown in the table, MOR and MOE ranged from 4.94 N/mm² to 11.63 N/mm² and 2340 N/mm² to 4880 N/mm² respectively. These range values, as obtained for this study, compared favourably with MOR range values of 3.28 N/mm² to 10.46 N/mm² and 4.23 N/mm² to 11.92 N/mm¹ as well as MOE range values of 2200 N/mm² to 4010 N/mm² and 1950 N/mm² to 4140 N/mm² reported in literature (Dinwoodie 1978, Bison-Werke 1981, Badejo 1999 and Badejo *et al* 2011,).

Factorial analysis of variance of the results in table 2 shows that the levels at which the water/cement ratio and the other two variables used along with it (cement/wood mixing ratio and board density) had significant effects at 1% level of probability on MOR. These production variables produced similar effects on MOE except for board density which had significant effect on this dependent variable at 5% level of probability. No two-way or three-way significant interactions were found between and among these three production variables on MOR and MOE. These findings are graphically depicted in figures 1 and 2. At each of the two mixing ratio levels of 2.25:1.0 and 2.75:1.0 applied in this experiment, MOR and MOE of the test panels increased as the water/cement ratio was raised from 0.55 to 0.60. This means that application of water/cement ratio between the levels of 0.50 and 0.60 manifested in the production of stronger and stiffer cement-bonded particleboards from mixed particles of the eight hardwood species. Raising the water/cement ratio of the experimental panels beyond the level of 0.60 to 0.65 however led to production of panels with weaker strength when tested. The trend of influence of the water/cement ratio on MOR and MOE of the panels at each of the board density level used in the experiment is similar to that of the cement/wood mixing ratio. At each of the two board density levels of 1100 and 1200 kg/m^3, strength (MOR) and stiffness (MOE) of the test panels increased as water/cement ratio was raised from 0.55 to 0.60 beyond which a decrease was observed at the highest level of 0.65.

The results of the Newman-Keuls test carried out to determine the significant differences in treatment means revealed that the mean MOR value of 8.71 N/mm^2 obtained at the water/cement ratio of 0.60 was significantly higher at 5% level than the mean values of 7.83 N/mm^2 and 6.95 N/mm^2 obtained at lower levels of 0.55 and 0.50 respectively. It was also significantly superior at 5% level than mean MOR value of 7.17 N/mm^2 obtained at the highest water/cement ratio level of 0.65. The cement-bonded particleboards made at the highest ratio of 0.65 is so inferior that the mean MOR of 7.17 N/mm^2 obtained at this level was found to be insignificantly different from the mean of 6.95 N/mm^2 obtained at the lowest ratio of 0.50. Furthermore, the mean MOR values of 9.50N/mm^2 and 8.11 N/mm^2 obtained at the higher cement/wood mixing ratio level of 2.75:1.0 board density level of 1200 kg/in^3 were significantly higher at 5% from the mean MOR values 5.83 N/mm^2 and 7.22 N/mm^2 obtained at the lower levels of 2.25: 1.0 and 1100 kg/m^3 respectively. The trend of comparism of the treatment means for MOE is exactly similar to that of MOR.

The results of the regression analysis to determine relationship between the significant factors and MOR and MOE as listed in table 3 showed that water/cement ratio, cement/wood mixing ratio and board density were positively correlated with MOR and MOE. The multiple regression equations which relate MOR and MOE to the three production variables applied in this experiment, with their corresponding correlation coefficient, R values are indicated presented in table 5.

The coefficient of determination, R^2 values obtained from the step-wise regression analysis are summarised in Table 4. Results showed that water/cement ratio and board density were weakly correlated with MOR from computed correlation coefficient, R values of 0.089 and 0.221 respectively. The simple regression equations which relate water/cement ratio and board density to MOR gave very low coefficient of determination, R^2 values of 0.008 and 0.049 respectively; meaning that only 0.8% and 4.9% of the total variations of MOR can only be explained by these two production variables.

The pair of water/cement ratio and board density also gave low R^2 values of 0.057 on MOR that is, explaining only 5.7% of its total variations. On the other hand, high correlation coefficient, R value of 0.901 was given by the simple regression equation which relates mixing ratio with MOR. As shown in Table 4, the coefficient of determination, R^2 value obtained implies in effect that about 81.2% of the total variations of MOR were explained by cement/wood ing ratio. The pairs of mixing ratio and water ratio as well as mixing ratio and board density respectively accounted for 82.0% and 86.1% of the total variations of MOR for which mixing contributed significantly in each case. Cement/wood ratio, on the other hand, was well correlated with MOE based on correlation coefficient, R value of 0.863 obtained from the simple regression equation which relates it to this static bending property.

From this finding, water/cement ratio and board density were weak predictors of MOR and MOE while cement/wood mixing ratio was a strong predictor of these two dependent variables as carried out in this experiment.

Water absorption and thickness swelling

As summarized in table 1, the compiled mean values for the WA and TS ranged from 16.27 to 48.82% and 0.49 to 2.30% respectively. These range values, as obtained for this particular study, compared favourably with the range values reported in the work of Oyagade (1990), Fuwape and Oyagade (1993) and Badejo (1988 and 1999).

Statistical analysis of the result showed that water/cement, cement/wood mixing ratio and board density were significant at 1% level of probability on WA and TS. No significant interaction was found between and among the three production variables used in this study. Moisture uptake and swelling of the panels decreased as the water/cement ratio was raised fro 0.50 to 0.60. Increasing the water/cement ratio beyond this level to 0.65 manifested in production of inferior panels which produced increased WA and TS values when tested. This trend of behavior was observed at each of the cement/wood mixing ratio levels of 2.25:1.0 and 2.75:1.0 applied in the study. Again, panels made with increased cement binder content at the cement/wood mixing ratio level of 2.75:1.0 were more dimensionally stable as they produced lower WA and TS values when tested than those panels made at lower cement/wood mixing ratio level of 2.25:1.0. As shown in figure 4, board density influenced water absorption and thickness swelling of the experimental panels in a similar manner as that observed for cement/wood mixing ratio. At each of the water/cement ratio levels of 0.50, 0.55, 0.60

and 0.65 applied in the experiment, WA and TS values obtained at the board density level of 1200kg/m^3 were lower than those given at the level of 1100kg/m^3. Board density however has a more decided effect on thickness swelling than water absorption of the experimental panels when judged from the wider gap that exists between the two board density curves illustrated in figure 4.

Newman-Keuls tests which analysed the significant differences between the treatment means for the process variables shows that the mean WA of 34.16% obtained at cement/water ratio of 0.60 was significantly lower at 5% and therefore superior with respect to dimensional stability to mean values of 39.17%, 40.08% and 45.70% obtained at the other levels of 0.65, 0.55 and 0.50 respectively. Similarly, the mean value of 37.93% (WA) obtained from panels fabricated at increased cement binder of 2.75:1.0 was significantly lower (an indication of improved dimensional stability) at 5% than the mean WA value of 41.62% obtained at the lower ratio cement/wood mixing level of 2.25:1.0. This trend was also observed at different nominal board densities. Absence of significant differences between the mean of 0.76% obtained at the cement/water ratio level of 0.60 and mean values of 1.01% and 1.11% obtained at the levels of 0.65 and 0.55 respectively notwithstanding, results showed that thickness swelling values consistently decreased as the water/cement ratio was raised from 0.50 to 0.60

The results of the regression analysis show that the three independent variables applied in the experiment were negatively and linearly correlated with WA and TS. The multiple regression equations which relate WA and TS to the three production variables, with their corresponding values of correlation efficients, R are as indicated in table 6.

The regression performed on TS was significant at 1% level of probability. On the other hand, the regression performed on WA at 1% level of probability is not significant (Table 4). The simple regression equation which relates each of the three production variables with WA gave correlation coefficient, R values of 0.228, 0.114 and 0.400 respectively. For these low values, they were weakly correlated with the moisture response property. The low coefficient of determination, R^2 values of 0.052, 0.013 nd 0.160 obtained from the three simple regression equations suggested that WA cannot be predicted from water/cement ratio, cement/wood mixing ratio or board density alone as each accounted only for 5.2%, 1.3% and 16.0% respectively of total variations of WA.

The combined pairs of water/cement ratio and board density as well as cement/wood ratio and board density gave R^2 values of 0.721 and 0.678 respectively. This implies that each of these combined pairs explained up to 72.1% and 67.8% of the total variations noted in TS. Unlike its influence on WA, water/cement ratio, cement/wood mixing ratio, and board density are well correlated with TS in a multiple regression equation which relate them to this moisture response property (correlation coefficient value of 0.913 was obtained).

The test data listed in Table 1 generally revealed an increased improvement in board properties at increased level of use of water/cement ratio. The inferior boards obtained at the lower water/cement ratio levels of 0.50 and 0.55 could be attributed to insufficient water needed to promote adequate blending and uniform coating of the cement binder on the wood particles (both sawdust and flakes). At the water/cement ratio level of 0.55, more water was available to achieve this desired objective than at the level of 0.50; and at 0.60 levels, more water was again available to thoroughly coat the cement-wood particles mix than at the level of 0.55. In effect therefore^ increasing MOR and MOE as well as decreasing WA and TS values were observed as water/cement ratio increased from 0.50 level to 0.60. As the water/cement ratio was raised from 0.60 to 0.65 levels however, inferior panels which exhibit lower strength, stiffness and moisture response values when tested were obtained. What was observed to have happened at the water/cement ratio level of 0.65 was not that of insufficient water to coat the cement-wood particle mixes but availability of excess water. With too much water in the mixes, the volumes of the blended materials-cement, sawdust/flake particles, water and chemical additive were noted to shrink considerably. As a result of this shrinkage, the thicknesses of the mattresses, which used to be 1.5 to 2 times the nominal thickness of the boards to be made, prior to pressing, was found to have reduced considerably. This observed phenomenon led to insufficient consolidation on the mattresses during pressing and consequently production of weak and porous boards which gave low MOR and MOE as well as high WA and TS values when tested. In essence therefore, the study has clearly demonstrated that insufficient water in a cement-wood particle mix would entail production of low quality cement-bonded particleboards while addition of excess water to the mix would similarly produce weak experimental boards.

The noticeable decrease in MOR and MOE values; as well as increase in WA and TS values as the water/cement ratio was raised from 0.60 to 0.65 may be further attributed to the strength of the hydrated cement which bonds together the sawdust particles, the flake particles and the sawdust/flake particles. Water/cement ratio has been indicated to have a dominating influence on strength of cement paste (Lea 1970, Soroka 1979). Increases in water/cement ratio decreased cement paste strength. This generally happened when the added water is more than necessary and consequently, weaker hardened cement paste is obtained. Although Oyagade's (1988) study on influence of water/cement ratio on properties of cement-bonded particleboard focussed on use of a temperate wood species (Norway Spruce), similar trend of result was however observed. Experimenting with four water/cement ratio levels of 0.45, 0.55, 0.65 and 0.75, he (Oyagade 1988) reported that the level of 0.65 produced the most favourable results. Thickness swelling values were found to decrease as water/cement ratio was raised from 0.65 to 0.75. Based on the findings obtained in this study, the water/cement ratio of 0.60 seemed to be the optimum level necessary to produce cement-bonded particleboards in mixed particles of the eight hardwood species.

Use of water/cement ratio at increasing levels between 0.50 and 0.60 manifested in the production of stronger, stiffer and more dimensionally stable cement-bonded paniclebaords. Increasing the water/cement ratio beyond the level of 0.60 to 0.65 produced weaker and inferior boards which gave lower MOR and MOE values as well as higher WA and TS values when tested.

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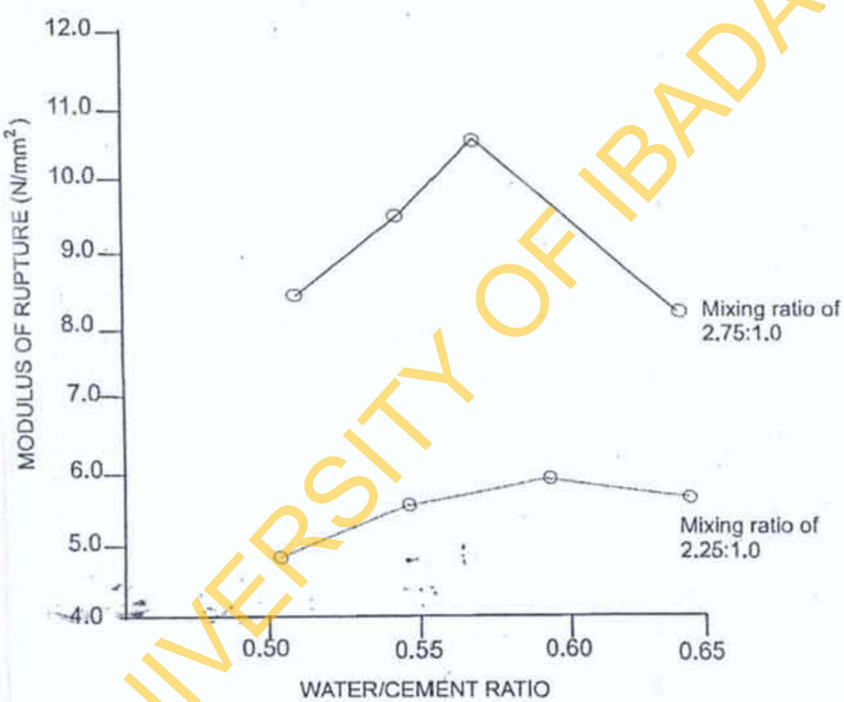


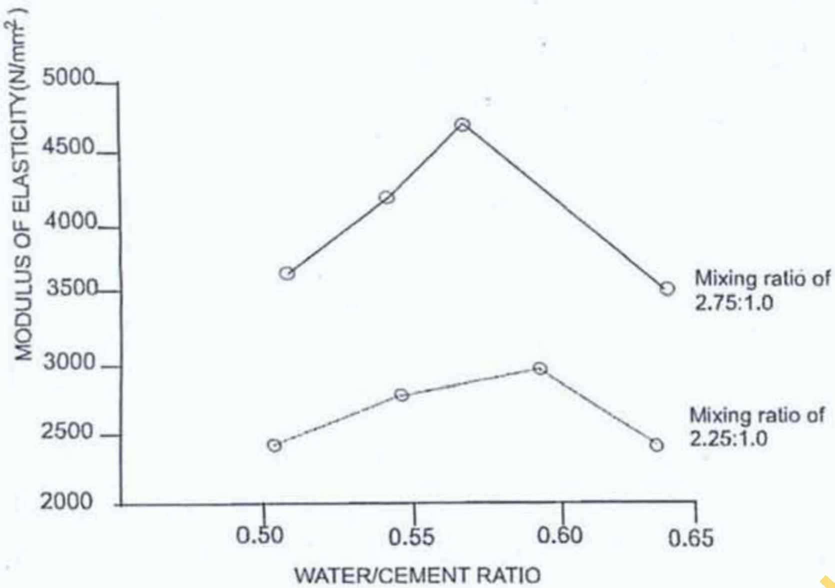
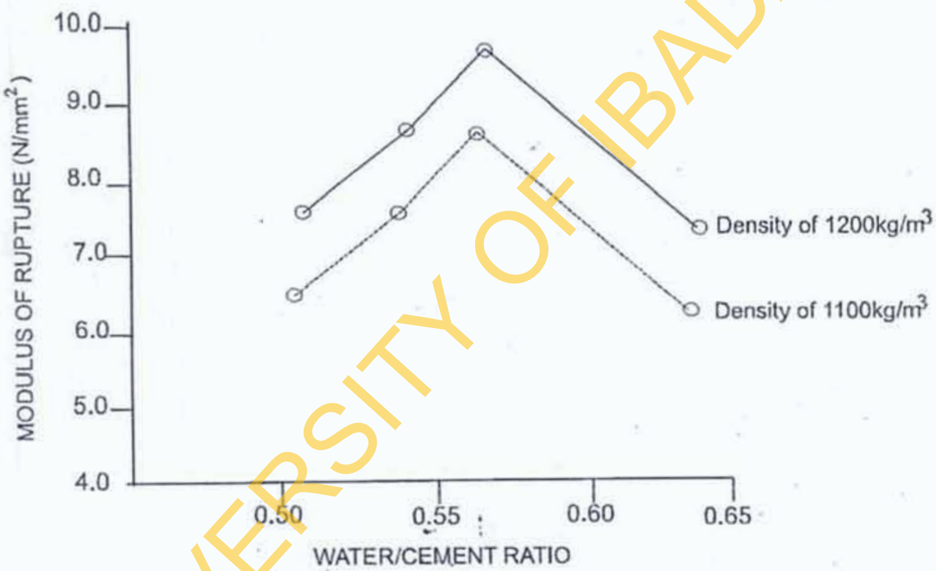


Figure 1: Influence of water/cement ratio and mixing ratio on Modulus of Rupture and Elasticity of cement-bonded particle boards made from mixed particles of the eight Nigerian hardwood species.



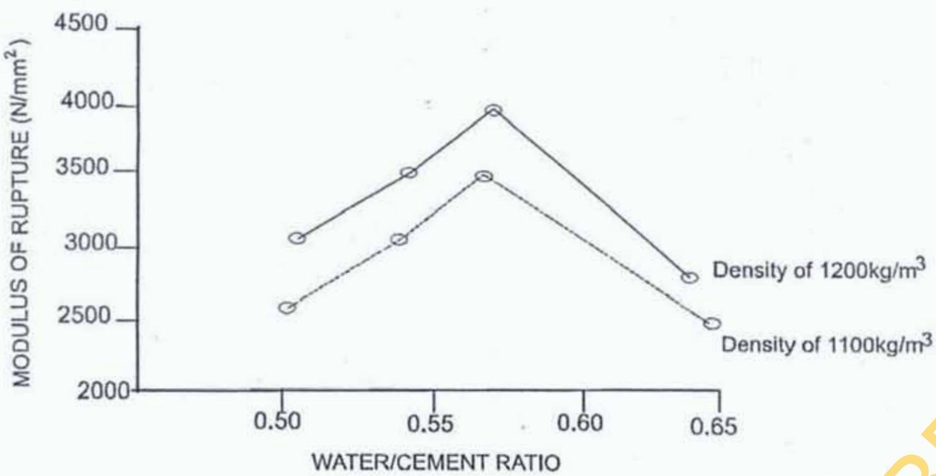
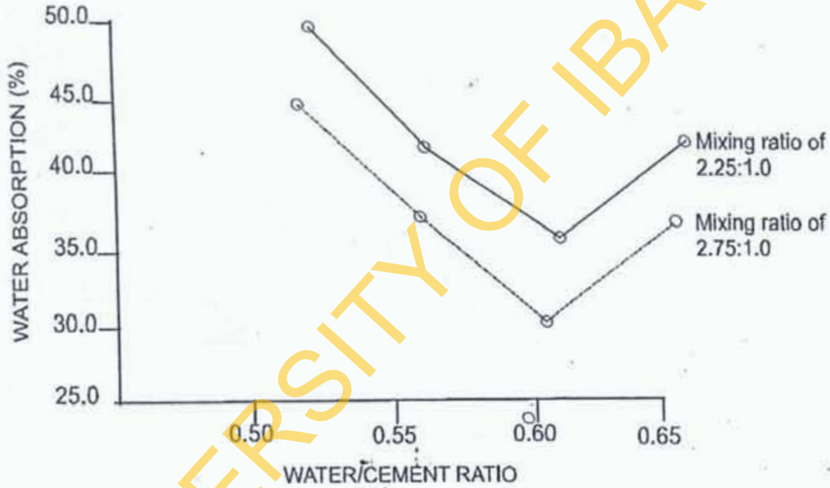


Figure 2: Influence of water/cement ratio and board density on MOE of cement-bonded particle boards made from mixed particles of the eight Nigerian hardwood species.



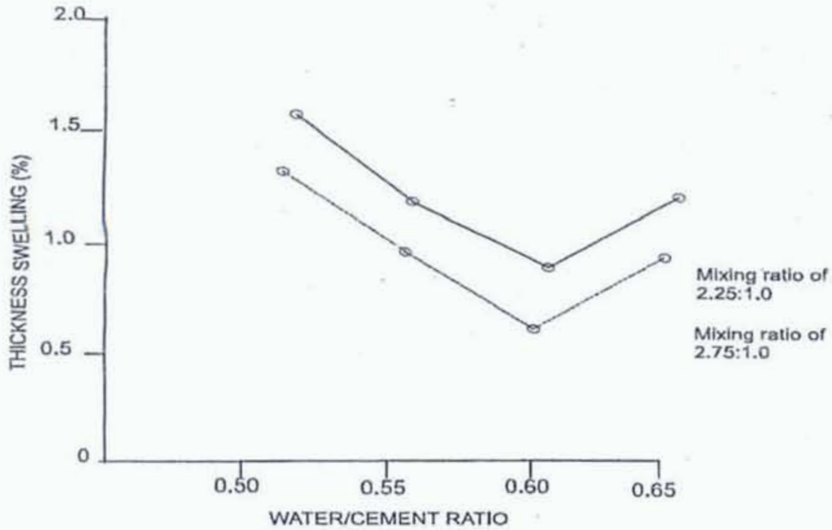
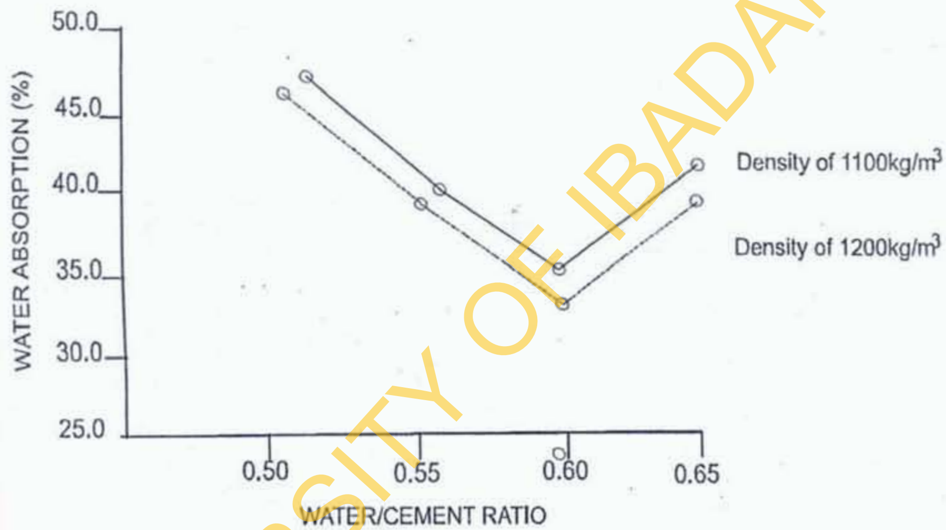


Figure 3: Influence of water/cement ratio and cement mixing ratio on WA and TS of the experimental particleboards.



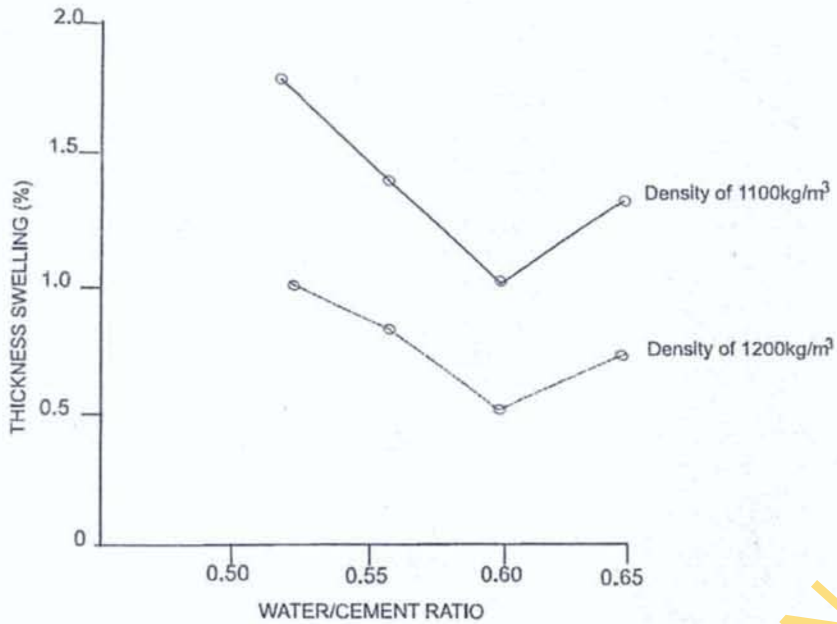


Figure 4: Influences of water/cement ratio and board density on WA and TS of the experimental cement-bonded particleboards.

Table 1: Mean values of physical and mechanical properties of the panels produced at different water/cement ratio levels.

Treatment combinations			MOR (N/mm^2)	MOE (N/mm^2)	WA (%)	TS (%)
W/C	C/W	BD (kg/m3)				
0.50	2.25:1.0	1100	4.94	2340	48.82	2.30
0.50	2.25:1.0	1200	5.63	2600	47.38	1.16
0.55	2.25:1.0	1100	5.55	2650	42.47	1.64
0.55	2.25:1.0	1200	6.47	2940	41.22	0.83
0.60	2.25:1.0	1100	5.89	2990	35.95	1.17
0.60	2.25:1.0	1200	6.88	3320	34.87	0.59
0.65	2.25:1.0	1100	5.21	2480	41.75	1.60
0.65	2.25:1.0	1200	6.09	2710	40.53	0.75
0.50	2.75:1.0	1100	8.32	3570	44.34	1.65
0.50	2.75:1.0	1200	8.89	3820	42.26	0.79
0.55	2.75:1.0	1100	9.17	3970	39.24	1.28
0.55	2.75:1.0	1200	10.14	4320	37.40	0.70
0.60	2.75:1.0	1100	10.45	4490	33.75	0.86
0.60	2.75 :1.0	1200	11.63	4880	32.10	0.40
0.65	2.75:1.0	1100	8.23	3540	38.11	1.20
0.65	2.75:1.0	1200	9.16	3840	36.27	0.49

Mean values based on 4 samples for each treatment combination, assessed after 144 hours soak in water.

Table 2: Factorial ANOVA results of the effect of the process variables of the board properties

Source of Variations	Degrees of freedom	Mean Square Values (MS)			
		MOR	MOE	WA	TS
Mixing Ratio (MR)	1	215.06	26.73	2.2053	1.78
Water/Cememt Ratio (WCR)	3	10.06	2.41	3.5688	1.43
Board Density (BD)	1	12.70	1.51	0.3783	8.97
MR X CWR	3	1.98	0.15	0.0349	0.06
MR x BD	1	0.01	0.01	0.0109	0.06
CWR x BD	3	0.15	0.007	0.0008	0.16
MR x CWR x BD	3	0.017	0.0013	0.0007	0.006
Error	48	1.34	0.360	0.0516	0.24

Table 3: Regression analysis of the significant factors and board properties

Source of Variation	Degress of freedom	Mean Square Values(MS)			
		MOR	MOE	WA	TS
Regression	3	19.09**	2.38 + 06**	29.74^{NS}	1.10**
Residual	12	0.72	0.15E + 06	25.60	0.06

** Significant at 1% level of probability, NS Not significant

Table 4: Stepwise regression analysis relating process variables with the tested board properties.

SN	Factors of Production	Coefficient of Determination R^2			
		MOR	MOE	WA	TS
1	Water/Cement ratio (CWR)	0.008	0.010	0.052	0.155
2	Cement/Wood ratio (MR)	0.812	0.744	0.013	0.112
3	Board Density (BD)	0.049	0.042	0.160	0.566
4	CWR x MR	0.820	0.754	0.065	0.267
5	CWR x BD	0.057	0.052	0.212	0.721
6	MR x BD	0.861	0.786	0.173	0.678
7	CWR x BD x MR	0.869	0.796	0.225	0.833

Table 5: Multiple regression equations which relate MOR and MOE to the three production variables

Independent Variables	Depedent Variables	Equations	R values
WCR, BD & MR	MOR	$Y_1 = -22.8 + 3.16X_1 + 7.32X_2 + 0.00899X_3$	0.932
	MOE	$Y_2 = 7375 + 1350X_1 + 2585X_2 + 3.08X_3$	0.892

Y_1 and Y_2 = MOR and MOE respectively; X_1, X_2 and X_3 = independent (process) variables of WCR, MR and BD

Table 6: Multiple regression equations which relate WA and TS to the three production variables

Independent Variables	Depedent Variables	Equations	R values
WCR, BD & MR	WA	$Y_1 = 102 - 20.03X_1 + 2.26X_2 + 0.0399X_3$	0.474
	TS	$Y_2 = 13.4 - 3.51X_1 - 0.667X_2 - 0.00749X_3$	0.913

Y_1 and Y_2 = WA and TS respectively; X_1, X_2 and X_3 = independent (process) variables of WCR, MR and BD