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STATIC BENDING AND MOISTURE RESPONSE OF CEMENT-BONDED PARTICLEBOARD PRODUCED AT DIFFERENT LEVELS OF PERCENT CHEMICAL ADDITIVE CONTENT IN BOARD.

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ABSTRACT

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A study was carried out to determine the optima level of percent additive concentration for wood cement board production from mixed tropical hardwoods species. Eight hardwood species used for the study are: Triplochiton scleroxylon K. Schum (Obeche). Terminalia ivorensis A. Chev. (Idigbo) Terminalia superba Eng. & Diets (Afara) Brachystegia nigerica Hoyle & A.P.D. Jones (Okwen) Khaya ivorensis A. Chev. (Lagos Mahogany) Nesogordonia papavertfeni A. Chev. (Dantu - Oro) Tectona grandis Linn. F. (Teak) Gmelina arborea Roxb. (Gmelina). The experimental boards were made at five chemical additive content levels of 1.00%; 1.50%; 2.00%; 2.50% and 3.00% based on dry weight of cement in board, and three cement/wood mixing ratio levels of 2.25: 1.0, 2.50: 1.0 and 2.75:1.0. The experimental design is a two-factor factorial experiment, a combination of which manifested in 15 treatment combinations. The mean Moduli of Rupture and Elasticity (MOR and MOE) obtained for each of the 15 treatment combinations in this experiment ranged from 3.28 to 10.46 N/mm² while MOE values ranged from 2200 to 4010 N/mm². The mean percent water absorption (WA) values ranged from 24.66 to 46.37% while the thickness swelling (TS) ranged from 0.98 to 3.62%. Statistical analysis showed chemical additive concentration and wood/cement ratio were found significant at 1% level of probability on the flexural and moisture properties Stronger, stiffer and more dimensionally stable boards were produced at increasing levels of these two production variables. Also percent chemical additive content in board of 3.0% (Based on dry cement weight in board) performed best.

Keywords: static bending, moisture response, chemical additive, cement bonded particle board additive concentration

INTRODUCTION

In order to ensure proper setting of cement and consequently improve the strength characteristics of manufactured wood-cement boards, pre-treatments of wood prior to use have been adopted. This exercise has increased the range of wood species used for board production and the four major pre-treatment practices today are, mild seasoning of the wood raw materials, biological approach, hot water pre-treatment and chemical pre-treatment (Badejo, 1988). The biological approach first proposed by Davis (1966) involves the treatment of wood with blue stain fungus *(Ceratocystlis pilifera)*. Blue stain fungus attacks the sugar portion of the wood and sugar is one of the wood chemical substances identified as highly inhibitory to cement setting (Biblis and Lo 1968). Following this biological treatment therefore, such wood species are expected to become more suitable for board manufacture. Attack by certain fungi on wood earmarked for wood-cement board production has also been noted to be beneficial. Raczkowski *et al* (1983) reported that Pine woods which exhibit brown stain caused by fungus Cytospora pini can be used for board production. Badejo (1984) reported that *Melia azadirachta* wood samples deteriorated by blue stain caused by fungus *Botryodiplodia theobromae* Pat. were suitable for board production.

Pre-treatment with hot water appears to be one of the simplest methods for laboratory research and commercial scale production of wood-cement boards from inhibitory wood raw materials. Water soluble chemical substances such as sugars, carbohydrates, hydrolysable tannins and oils present in wood which tend to inhibit proper setting of cement when mixed with it are extracted from the wood into the hot water. By applying warm water, Simatupang (1974) reported that board production became feasible from 15 tropical hardwoods which had otherwise been reported unsuitable. Kavvouras (1987) demonstrated the superiority of hot water extraction over four other pre-treatment methods. In his study, flakeboards made from a mixture of Oak and Pine extracted for 2 hours with hot water at temperature of 50°C were stronger and more resistant to moisture uptake when tested that those made from 2% sodium silicate, 0.25% and 0.50% sodium hydroxide extraction for periods ranging from 90 to 120 minutes. The extraction was to remove hemicelluloses which are inhibitory to setting of cement; thereby ensuring adequate compatibility of the wood raw materials with cement.

Application of chemical additives in wood-cement board production is quite distinct from that of hot water. The hot water is applied to facilitate extraction of chemical substances which inhibit setting of cement from the wood raw materials. The chemical additive on the other hand, acts as accelerators to speed up the setting process. They can be applied with or without the hot water application. Chemical pre-treatment is probably the most widely used among the pre-treatment practices adopted for laboratory research and commercial scale production of wood-cement boards. The chemical additives presently used include Calcium chloride, Magnesium chloride, Sodium silicate, Potassium silicate, Calcium formiate and Calcium acetate (Chittenden *et al.*, 1975, Simatupang *et al.* 1978). The early German board producers seemed to prefer Sodium silicate because of its efficiency and in some cases Calcium chloride because of ready availability. Further investigations have showed that the use of high concentrations of Calcium chloride gives rise to blooming on the surfaces of the boards while the use of Sodium silicate resulted in the production of brittle boards (Sudin and Ong 1983, Chittenden *et al* 1975). Shukla *et al* (1981) further reported that boards made with Calcium chloride as additive showed greater weight increases during swelling tests, a phenomenon they attributed to the probable hygroscopicity of the chemical. It was suggested that boards meant for use in wet areas and humid locations should not contain Calcium chloride (Shukla *et al*, 1981). Other chemical additives which have been tried for board production are the chlorides of Zinc, Iron and Aluminium (Zhengtian and Moslemi 1985) as well as Ferric sulphate (Krekel 1972). Other forms of chemical pre-treatments include use of bitumen to coat the particles of such unsuitable wood species prior to blending with cement (Kawamura *et al* 1979); use of oil liquid paraffin (Yamagishi *et al.*, 1980), and use of esters of phosphoric acid-ethyl phosphate or propyl phosphate (Yamagishi *et al.*, 1982).

Chemical additives are used at varying concentration levels based on the dry cement weight in the board. Biblis and Lo (1968) reported that use of 1 % concentration of Calcium chloride is adequate to bring about a significant reduction in the setting time of cement binder. Christensen and Lyncis (1949) earlier reported that 1 to 3% of Calcium chloride would be required to neutralise the effect of 0.1% sugar concentration on setting time of cement. Investigating the hydration characteristics of *Larix occidentals* Nutt. (Western Larch), Zhengtian and Moslemi (1985) applied the chlorides of Zinc, Iron and Aluminium at concentration levels of 5.0 to 6.5% to bring about an increase in the maximum hydration temperature of wood-cement-water mixtures above 60^{0}C as well as reduction in the time required to reach this temperature level. Generally, chemical additives are reportedly used at most favourable concentration levels of 1 % to 5% (Namioka et al 1976) out of which a range of 0.5% to 3.0% is indicated to effectively contribute to the accelerating process of setting of the cement binder. The study is therefore carried out to determine the optima level of percent additive concentration for wood cement board production.

MATERIALS AND METHODS

Eight hardwood species used for the study are: *Triplochiton scleroxylon K. Schum* (Obeche), *Terminalia ivorensis A. Chev.* (Idigbo) *Terminalia superba Eng. & Diets* (Afara) *Brachystegia nigerica Hoyle & A.P.D. Jones* (Okwen) *Khaya ivorensis A. Chev.* (Lagos Mahogany) *Nesogordonia papavertfeni* A. *Chev.* (Dantu - Oro) *Tectona grandis Linn. F.* (Teak) *Gmelina arborea Roxb.* (Gmelina). Wood wastes of the above species were collected from sawmills which operate around Ibadan in Oyo state Nigeria. As gathered from the sawmillers, log supply to the mills originates within the same ecological zone. In view of this therefore, differences in the chemical composition of the wood species arising from environmental differences in tree growth were ignored. The coarse sawdust collected from sawmills were pooled together according to species type. The pile from each species was screened through 6mm mesh but retained on 2mm mesh to remove fine particles. The coarse sawdust particles were spread out in open air for four weeks in order to allow for gradual degradation of starches and sugars present in them that could impede setting of the cement binder. After seasoning, 25 kg by weight from the sawdust pile of each of the eight hardwood species was weighed out. These were mixed together to provide the 200 kg of sawdust particles used as mixed species for board production. The air seasoned particles were then subjected to hot water pre-treated and drained. The treated particles were thereafter put in a sieve to allow for 20 minutes dripping of the water. They were later air seasoned for two weeks to a moisture content of about 12%, bagged and stored until needed.

Experimental designs and procedures

The experimental boards were made at five chemical additive content levels of 1.00%; 1.50%; 2.00%; 2.50% and 3.00% based on dry weight of cement in board, and three cement/wood mixing ratio levels of 2.25: 1.0, 2.50: 1.0 and 2.75:1.0. The experimental design is a two-factor factorial experiment, a combination of which manifested in 15 treatment combinations. The model for this type of experimental arrangement (Hicks 1973) is given as:

$$Yijk - M + Ai + Bj + Abij + Ek(ij) \qquad (1)$$

Where:

A and B represent the two factors of chemical additive content and mixing ratio respectively.

Yijk = *individual observation.*

M = *general mean.*

Ai = *Effect of factor A*

Bj = *Effect of a factor B*

ABij = *Effect of a two-way interaction between factors a and B*
Ek(ij) = *Random error within cell.*
i = *Level of factor A (1, 2, 3, 4 and 5).*
j = *Level of factor B(1, 2 and 3)*
k = *Number of observations per cell.*

Each test panel was 6mm thick and 3-layered comprising of 4mm thick flake-cement core layers and 2mm thick sawdust-cement face layers (1 mm on each side of the core). All boards were made with nominal 1200 kg/m^3 board density and cement/water ratio of 0.60. The quantities of sawdust and flake particles needed to make a panel were separately measured and put inside separate plastic bowls. To each material was added the needed quantity of water in which has been dissolved, the required quantity of chemical additive (Aluminum chloride). Thorough manual mixing was done until a well blended wood particle - chemical additive solution -cement mix, free of cement lumps, was formed.

The mats formed were passed into a cold hydraulic press and tamped to the required thickness of 6mm with aid of a wooden stopper which was provided around the four sides of the mats. A pressing pressure of 2.23 N/mm^2 was applied for a period of 24 hours. Replicate panels were produced in order to provide adequate test specimens for the experiment. Following the expiration of the 24-hour pressing cycle, the panels were removed from the press, stripped off the caul plates and kept inside polythene bags for 48 hours. They were thereafter trimmed and cut into test specimen sizes in accordance with the ASTM standard D1937 - 78. The bending strength test was carried out on a Tensometer machine while the water soak tests were done following prolonged immersion in cold water for 144 hours at room temperature. The prolonged soaking was considered essential in view of the Tropical climatic weather conditions of the country and the proposed use of the 6mm thick panels for ceiling.

RESULTS AND DISCUSSIONS

Moduli of rupture and elasticity

The mean Moduli of Rupture and Elasticity (MOR and MOE) obtained for each of the 15 treatment combinations used in this experiment are as summarized in Table 1. MOR values ranged from 3.28 to 10.46 N/mm2 while MOE values ranged from 2200 to 4010 N/mm^2. The results obtained for some of the treatments are very favourable and compare well to previous studies reported in literature. For example, the mean MOR values of (146 N/mm^2, 9.51 N/mm^2, 8.89 N/mm^2, 8.88 N/mm^2, 7.42 N/mm^2, 7.13 N/mm^2 and 6.52 N/mm- obtained for 7 out of the 15 treatment combinations which applied in the experiment compare favourably to mean value of 11.3mm^2 (Dinwoodie 1978); range value of 8.8 to 12.7 N/mm^2; (Bison-Werke 1981); range value of 5.22 to 11.12 N/mm^2 (Badejo 1988); and range value of 4 to 15 N/mm^2 (Fuwape 1995). In a similar manner, the MOE range values of 2920 to 4010 N/mm^2 obtained in 10 out of the 15 experimental treatment combinations used in this particular experiment compare favourably to mean values of 2940 N/mm^2 and range value of 1149 to 3297 N/mm^2 reported by Bison-Werke (1981) and Fuwape (1995) respectively.

Shown in Table 2 is the factorial analysis of variance carried out to test the effects of the chemical additive concentration on strength (MOR) and stiffness (MOE) of the experimental boards. The concentration levels at which the Aluminum chloride, used as chemical additive, was incorporated into the experimental boards were found significant at 1% level of probability on MOR and MOE. Cement/wood mixing ratio, which indicates the cement binder content in board, was similarly found significant at 1% level of probability on MOR and MOE of the boards. The two-way interaction between these two variables was not significant. At each of the three mixing ratios of 2.25:1.0, 2.50:1.0 and 3.00:1.0 of cement to wood applied in this study, MOR and MOE of the test panels increased as the content of me chemical additive in board was steadily raised from 1.0% to 3.0%. This means that stronger and stiffer experimental cement-bonded particle boards (CPB) were produced from mixed sawdust and flake particles of the eight Nigerian hardwood species as the content of the chemical additive in board increased. Percent chemical additive content in board at level of 3.0% manifested in the production of strongest and stiffest CPB from mixed particles of the eight Nigerian hardwood species.

Applying Newman-Keuls test (Hicks 1973), the mean MOR value of 8.56 N/mm^2 obtained at the additive content level of 3.0% was significantly different at 0.05 level from the mean values of 4.79 N/mm^2 and 5.66 N/mm^2 obtained at the levels of 1.0% and 1.5% respectively. However, the general improvement observed between the additive content levels of 2.0% and 3.0% notwithstanding, comparison of result data by the Newman-Keuls test showed that the mean MOR value of 8.56 N/mm^2 obtained at the content level of 3.0% was not significantly different at 5% level of probability from the mean values of 6.65 N/mm^2 and 7.37 N/mm^2 obtained at the levels of 2.0% and 2.5% respectively. Comparing the means from the MOE data, the chemical additive content level of 3.0% manifested in the production of cement-bonded particleboard panels which were significantly stiffer at 0.05 levels than those obtained at any of the rest four levels of 1.0%, 1.5%, 2.0% and 2.50%.

The influence of cement/wood mixing ratio on MOR and MOE of the test panels is similar to that of percent chemical additive content in board. The higher the cement binder contents in board, the stronger and stiffer the experimental panels. The MOR and MOE mean values of 8.56 *N/mm²* and 3560 N/mm² obtained at the highest cement binder content as indicated by the mixing ratio level of 2.75 :1.0 were significant different at 5% level of probability from those produced at the lower levels of 2.25 : 1.0 and 2.5: 1.0. The increasing favourable influence of percent chemical additive content in board at increasing levels on MOR appear to be in conformity with previously published studies on cement-bonded particleboard production from tropical hardwoods (Badejo 1989). Similarly, increased strength and stiffness obtained for the panels at increasing cement binder content level (as indicated by mixing ratio) conforms to published results on cement-bonded Particleboard (Prestemon 1976, Xla 1982, Oyagade Oyagade et al. 1995, Omole and Badejo 1999, Omole and Adetogun 2010.)

The regression analysis performed on the test data, showing the correlation of the MOR and MOE with the significant variable inputs - percent chemical additive content in board and mixing ratio were listed in Table 3. From the results obtained, percent chemical additive cement/wood mixing ratio were highly correlated with MOR and MOE of the experimental panels. Percent chemical additive content in board was positively correlated with MOR and MOE. In line with Statistical practice (Wonnacott and Wonnacott 1972), multiple regressions of MOR and MOE on percent chemical additive content in board and cement/wood mixing ratio were computed, the multiple regression equations obtained with their corresponding correlation coefficient R values are;

(i) $Y_1 = 15.669 + 7.524X_1 + 1.693X_2$ .... (2)

$R = 0.989$ (MOR)

(ii) $Y_2 = 2539.330 + 1980X_1 + 328.66X_2$ .... (3)

$R = 0.993$ (MOE)

Where Y_1 and Y_2 represent the dependent variables, MOR and MOE; while X_1 and X2 represent the independent variables of cement/wood mixing ratio and percent chemical additive content in board respectively. For the two cases of MOR and MOE, the multiple regressions performed were highly significant at 1% level of probability (Table 3).

The correlation between percent chemical additive content in board and MOR as well as MOE was found to be weak (correlation coefficient, R values of 0.608 and 0.495). The coefficient of determination, R^2 values of 0.370 and 0.245 were obtained from the simple regression equations which relate it to MOR and MOE. These R^2 values imply in effect that only 37.0% and 24.5% of the total variations of these two static bending properties are explained by the percent chemical additive content in board. These proportional values are too low for any meaningful prediction of MOR and MOE from this independent variable; and suggest that other vital sources of variable inputs need to be explored. Cement/wood mixing ratio is however well correlated with MOR and MOE (correlation coefficient, R values of 0.780 and 0.861 respectively) with R^2 values of 0.609 and 0.742 respectively. It means therefore that as much as 60.9% and 74.2% of the total variations of MOR and MOE are explained by cement/wood mixing ratio; while 39.1% and 25.8% respectively are still due to other vital sources.Qwer56

As already indicated, the multiple regression equations which relate the combined effect of the two independent variables (additive concentration and mixing ratio) on MOR and MOE gave R^2 values of 0.978 and 0.987 respectively; meaning that as high as 97.8% and 98.7% of the total variations of MOR and MOE are jointly explained by the two production variables; while cement/wood mixing ratio contributed highly and significantly to these values.

Water absorption and thickness swelling

The mean percent water absorption (WA) and thickness swelling (TS) is as listed in Table 1 for each of the 15 treatment combinations. WA values ranged from 24.66 to 46.37% while values for TS ranged from 0.98 to 3.62%. In both cases, measurements were made following 14; hours soak in cold water. The WA range values recorded for this experiment compared favourably with figures of 28.08 to 77%, 18.50 to 39.85% and 32.95 to 46.00% reported by Prestemon (1976) and Badejo (1986) and (1988) respectively on cement-bonded particleboards production from mixed particles of different wood raw materials. Similarly, the TS range values of 0.98 to 3.62% obtained compared favourably with figures of 1.2 to 1.8%, 0.67 to 3.60%, 0.50 to 1.50%, 3.4 to 26.2% and mean value of 0.75% piously reported by Bison-Werke (1981), Prestemon Denisov *et al.*, (1985), Fuwape (1992) and Dinwoodie (1978).

The factorial analysis of variance carried out to test the effects of the treatment variables on WA and TS of the test panels is presented in Table 2. Both variables were found significant at 1% level of probability on the tested properties. The two-way interaction between these two variables was not significant. The mean WA and TS values declined with increase in the concentration of Aluminum chloride and cement binder con tent the in board. It therefore means that the ability of the experimental boards to take up moisture under the prolonged soak in water decreased with increase in the percent chemical additive content and cement/wood mixing ratio levels resulting in the production of more dimensionally stable CPB on exposure to water.. These findings tend to follow previously published research investigations on cement-bonded particleboards (Namioka *et al.*, 1972 and 1976; Prestemon 1976; Badejo 1989).

Applying Newman-fouls test (Hicks 1973), the mean WA value of 31.73% obtained at the percent chemical additive content in board level of 3.0% was significantly superior at 5% level of probability to the mean values of 38.43% and 37.13% obtained at the concentration levels of 1.0% and 1.5% respectively. Although use of percent chemical additive content in board at increased levels generally led to manifestation of improved dimensional stability, the mean WA values of 31.73% obtained at the concentration level of 3% was however found to be insignificant at 5% level of probability from the mean values of 34.03% and 35.83% obtained at the lower levels of 2.5% and 2.0% respectively. Comparing the means from the TS data, the mean value of 1.57% obtained at the chemical additive concentration level of 3.0% was found significantly lower than the mean value of 2.31% obtained at the lowest level of 1.0% but insignificantly different to the mean values of 2.12%, 1.93% and 1.77% obtained at the concentration levels of 1.5%, 2.0% and 2.5% respectively.

The mean WA value of 28.41% produced at the highest cement/wood mixing ratio level of 2.75: 1.0 was significantly lower at 5% level of probability than the mean values of 34.84% and 43.04% obtained at the mixing ratio levels of 2.50: 1.0 and 2.25: 1.0 respectively. Similarly, the value obtained at the cement/wood mixing ratio level of 2.50:1.0 was significantly lower than that obtained at the cement/wood ratio level of 2.25: 1.0 and this trend was also experienced for TS. In general, the results of this experiment showed that the lowest mean WA and TS values of 24.66% and 0.98% respectively originated from experimental panels made at the highest percent chemical additive content in board level of 3.0% and cement/wood mixing ratio level of 2.75:1.0.

The regression analysis performed on the test data showed that the percent chemical additive content in board was negatively correlated with the two dependent variables of WA and TS and the relationships were linear. Similarly, cement/wood mixing ratio was negatively and linearly correlated with WA and TS.

The multiple regression equations which relate WA and TS to the two production variables used in this experiment, with their corresponding correlation coefficient, R values are shown below:

(i) $Y = 115.009 - 29.264X_1 - 3.177X_2$ (4)

$R = 0.996$(WA).

(ii) $Y = 12.935 - 4.104X_1 - 0.366X_2$ (5)

$R = 0.941$(TS)

Where Y represents the dependent variables, WA and TS; while X1 and X_2 represent the independent variables of cement/wood mixing ratio and percent additive content in board respectively. For the two cases of WA and TS, the multiple regressions performed were highly significant at 1% level of probability (Table 3).

Similar to the situation observed for MOR and MOE, there was a strong correlation between cement/wood mixing ratio and WA as well as with TS (correlation coefficient, R values of 0.933 and 0.899 respectively). Coefficient of determination, R^2 values of 0.870 and 0.809 were given by the regression equations which relate cement/wood mixing ratio alone with WA and TS respectively. This implies that as much as 87.0% and 80.9% of the total variations of WA and TS respectively were explained by cement/wood mixing ratio. There were however very weak correlations between percent chemical additive content in board and WA as well as with TS (correlation coefficients, R values of 0.351 and 0.217 respectively). Coefficient of determination, R^2 values of 0.123 and 0.077 were given by the simple regression equations which relate chemical additive concentration with WA and TS respectively. From these results, cement/wood mixing ratio was strongly correlated with correlated with WA and TS while percent chemical additive content in board was a weak predictor of these two moisture response properties. The low R^2 values obtained from the regression equations which relate percent chemical additive content in board to WA and TS implies that there are other sources of vital variable inputs which need to be explored. This is confirmed from the high R^2 values of 0.993 and 0.886 obtained from the multiple regression equation which relate both percent chemical additive content in board and cement/wood mixing ratio to WA and TS; which implies that 99.3% and 88.6% of these dependent variables respectively were jointly explained by the two production variables. To these high values, the cement/wood mixing ratio contributed more significantly. Furthermore, the R^2 values obtained from these multiple regression equations showed that W A could be more accurately predicted from the combined pair of percent chemical additive content in board and cement/wood mixing ratio than TS.

Generally, the noticeable improvements in the static bending (MOR and MOE) and moisture response (WA and TS) properties of the test panels with increase in the concentration of the chemical applied as additive is very much expected. Application of chemical additive by itself is a pre-treatment method made of to ensure compatibility between wood and cement and serves as cement setting accelerators. It therefore showed that at increased concentration level, the degree of conformability and inter-participle contact between the sawdust particles, the flake particles and the sawdust - flake particles were improved. The increasing positive influence of percent chemical additive content in board on properties of the test panels follow previously published studies on cement-bonded particleboards. It is noted that for MOR, WA and TS results, the mean values obtained at the concentration level of 3.0% was not statistically significant at 0.05 level from the values obtained at the lower level of 2.5%. §or MOE property however, the concentration level of 3.0% was significantly different from the level of 2.5%. It is therefore concluded that percent chemical additive content in board and board density significantly influenced the MOR, MOE, WA and TS of the experimental cement-bonded particleboards. Stronger, stiffer and more dimensionally stable boards were produced at increasing levels of these two production variables. Also percent chemical additive content in board of 3.0% (Based on dry cement weight in board) performed best.

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Table 1: Mean values of MOR, MOE, and water response of cement-bonded particleboard produced at different levels of percent chemical additive content in board.

Treatment combinations of Chemical additive content in wood	Cement/ wood ratio	MOR(N/mm^2)	MOE (N/mm^2)	WA (%)	TS (%)
1.0	2.25:1.0	3.28	2200	46.37	3.62
1.5	2.25:1,0	4.20	24.80	44.97	3.41
2.0	2.25:1.0	4.77	25.40	43.65	3.20
2.5	2.25:1.0	5.47	27.20	41.20	2.95
3.0	2.25:1.0	6.35	29.30	39.02	2.71
1.0	2.50:1.0	4.56	28.10	37.53	2.03
1.5	2.50:1.0	5.44	29.20	36.32	1.76
2.0	2.50:1-0	6.29	30.50	35.01	1.49
2.5	2.50:1.0	7.13	31.70	33.84	1.32
3.0	2.50:1.0	8.88	37.50	31.52	1.03
1.0	2.75:10	6 52	32.40	31.40	1.29
1.5	2.75:1.0	7.42	33.50	30.11	1.20
2.0	2.75: 1.0	8.8?	35.70	28.84	1.11
2.5	2.75:1.0	9.51	36.50	27.04	1.05
3.0	2.75:1.0	10.46	40.10	24.66	0.98

Table 2: ANOVA on effect of percentage chemical additive on the tested board properties

Sources of variation	Degree of freedom	Mean squares values (MS) MOR	MOE	WA	TS
Additive concentration (AC)	4	21.55**	Q§3**	0.88**	1.00**
Mixing ratio (MR)	2	72.17**	4,90**	10.81**	23.63**
ACxMR	8	0.24	0.03	0.02	0.09
Error	45	6.20	0.21	0.22	0.26

Table 3: Regression analyses showing correlation of board properties with percent chemical additive content in board

Sources of variation	Degree of freedom	Mean square values (MS) MOR	MOE	I WA	TS
Regression	2	28.44**	1.63E+06**	305.48**	5.77**
Residual	12	0.10	3440.0	0.38	0.12

**Significant at 1% level of probability

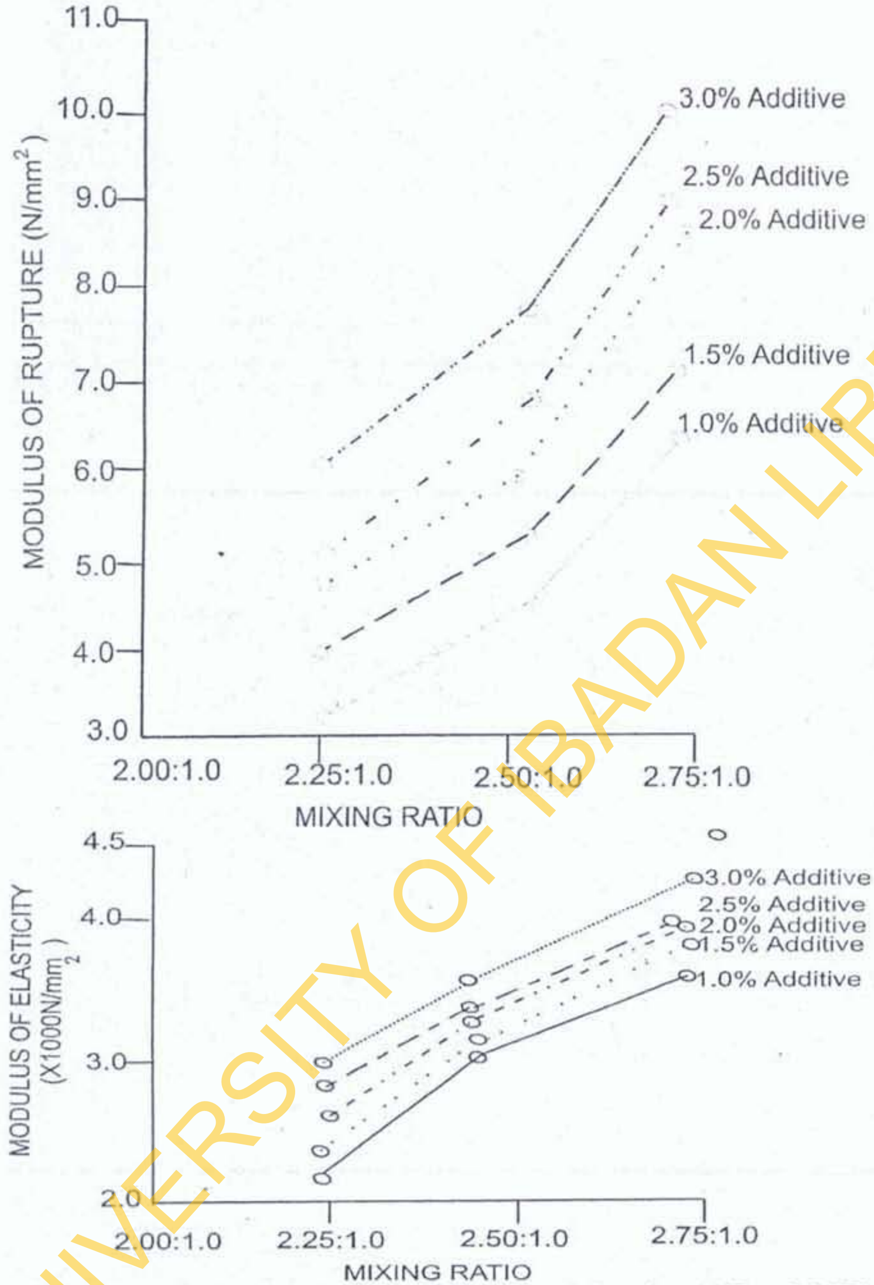

Fig. 1 Influence of percent chemical additive content in board on MOR and MOE of cement bounded particle boards made from mixed particles of the eight Nigerian hardwood species.

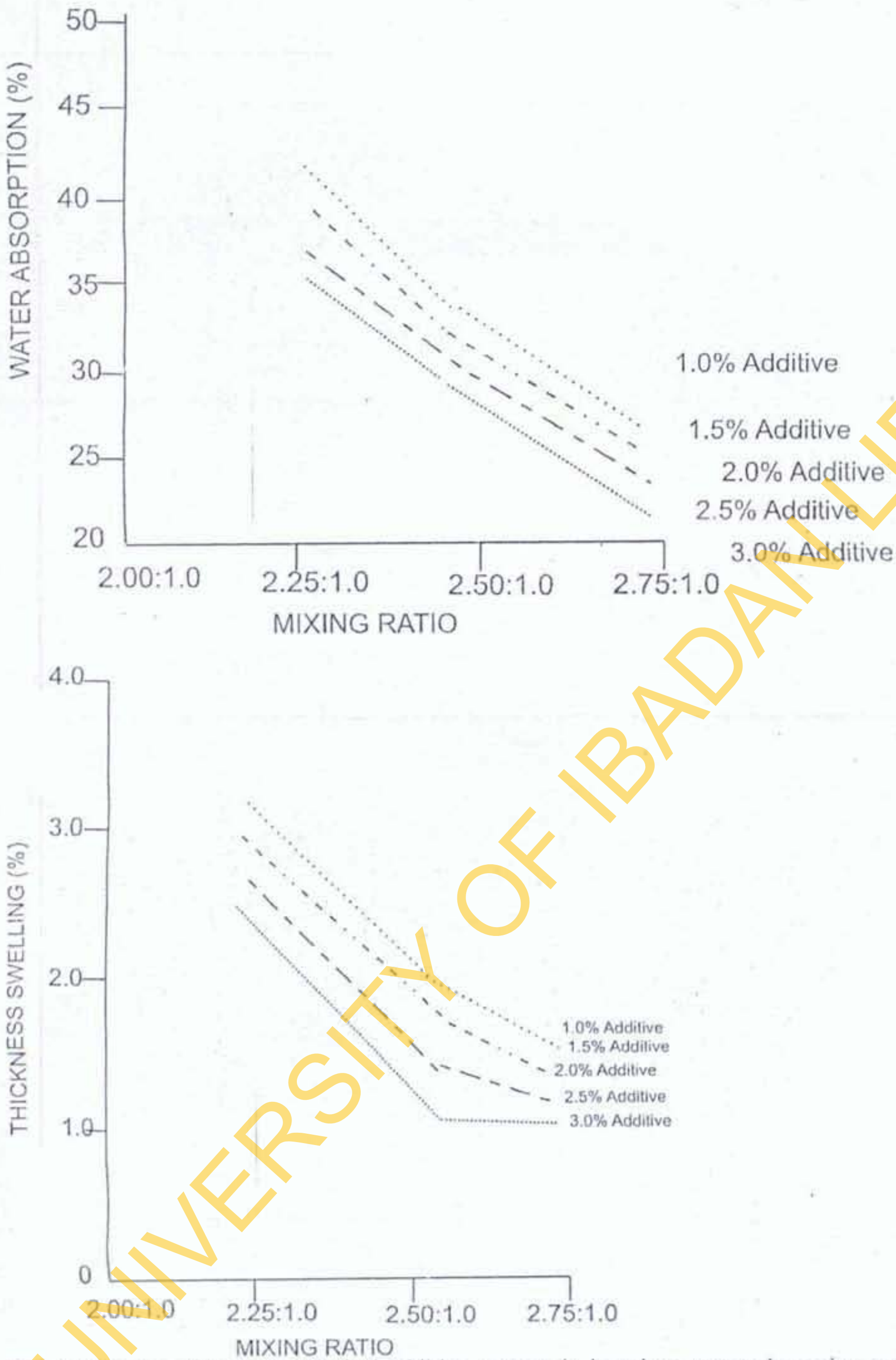

Fig. 2 Influence of percent chemical additive content in board on water absorption and thickness swelling of cement bonded particle boards made from mixed particles of the eight Nigerian hardwood species.

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