Forests and Forest Products Journal 4:43-52

Physical and Mechanical Properties of Cement-Bonded Particleboards Produced at Different Water Pre-Treatment Temperatures and Cement/Wood Mixing Ratios

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Abstract

The influences of water pre-treatment temperature and cement/wood mixing ratios on static and moisture response properties of cement-bonded particleboards produced from mixed Nigerian hardwood species were assessed in this study. The process variables for board fabrication were pre-treatment temperature (5 levels) and wood/ cement mixing ratios (5 levels) resulting in 25 treatment combinations in a factorial experiment. The examined properties are modulus of rupture (MOR), modulus of elasticity (MOE), water absorption (WA), thickness swelling (TS) and linear expansion (LE) properties of the experimental cement-bonded particleboards. Data collected were analysed using a combination of ANOVA and multiple linear regression models. Mean MOR and MOE ranged from 4.02 to 12.74 N/mm^2 and 2040 to 4060N/mm^2 respectively, while (WA), (TS) and (LE) ranged from 27.13 to 43.97%, 0.51 to 3.50% and 0.14 to 0.72% respectively. Strength (MOR) and stifness (MOE) of the boards increased as water pre-treatment temperature were raised from 35°C to 80°C. As water pre-treatment temperature was raised from 80°C to 95°C, weaker and inferior boards were produced. Water pre-treatment temperature was weakly correlated with MOR, MOE, WA, TS and LE. On the other hand, cement/wood mixing ratio was well correlated with these board properties. The study thus demonstrated that there is optimum water pre-treatment temperature range (65^{o}C-80^{o}C) within which high quality boards can be produced in the selected species; and beyond which board quality will be impaired.

Introduction

The preference of cement bonded particleboard in house construction is attributed to its overriding properties such as resistance against insect and fungus attack, excellent insulation against sound and heat, considerable low moisture uptake values and reduced swelling thereby ensuring dimensional stability under varying humidity and temperature changes.(Dinwoodie and Paxton 1983 Badejo 1999, Omole and Badejo 1999 and Omole and Adetogun 2010). In spite of all its good attributes, the drawback to wood-cement board production lies in the wood raw materials used. Boards cannot easily be made from every wood, most especially the hardwood species. Board production is usually affected by wood species (Kawouras 1987, Iddi et al 1992, Hawkes and Cox 1992). The unsuitability of such wood species is attributed to the soluble sugars and wood extractives, mostly phenolic compounds which are present in them (Zhengtian and Moslemi 1985, Miller 1987). Hardwood species are generally less preferred for board manufacturing than softwood species.

The emphasis of researchers on the inhibitory effect of chemical substances of wood on setting of cement has strengthened the caution generally exercised on board manufacture from hardwood species (Yamagishi et .al 1982). For this similar reason, cement-bonded particleboard is generally not made from mixed hardwood species. There is need to improve the knowledge and understanding of cement-bonded particleboard manufacture from mixed hardwood species in particular because, the influences of production process variables on properties of cement-bonded particleboards from mixed tropical hardwood species have not been well established. Where reported research studies exist, the findings obtained are sometimes conflicting and in most cases, such studies were based on use of temperate wood species.

Of particular significance is the use of hot water pre-treatment which has been reported as the simplest method adopted for ensuring wood-cement board production from unsuitable species. The method has been noted to improve the degree of compatibility between wood and cement (Simatupang *et al*., 1978, Moslem *et al*., 1983, Badejo 1989). The water soluble inhibitory substances such as sugars, carbohydrates, hydrolysable tannins and oils are extracted from the wood into the hot water during the extraction process. However, the effect of the hot water pre-treatment temperature on properties of cement-bonded particleboards manufactured from mixed tropical hardwoods has not been established. There are limited literatures on the effect of water pre-treatment temperature on properties of cement-bonded particleboards made from mixed hardwood species. This indicates that there is a probable optimum level at which board properties are maximised. It is also expected that there is an optimum level at which hot water can safely be applied without drastically impairing the strength of the wood particles being treated and consequently, the strength properties of panels made from them. Furthermore, environmental differences in tree growth may also manifest in differences in chemical composition of wood species from one locality to the other. Extractive contents may therefore vary in quantities, if not in composition, for different wood species. Thus, kinds of chemical substances and their concentration levels may differ among and between species. The optimum temperature of water needed to extract chemical substances which inhibit cement setting from wood may therefore differ from species to species.

The objective of the study is therefore to determine the effects of water pre-treatment temperature and cement/wood mixing ratio on static bending properties and moisture stability of the boards.

Materials and Methods

Wood waste of *Triplochiton scleroxylon* K. Schum (Obeche), *Terminalia ivorensls* 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) and *Gmelina arborea* Roxb. (Gmelina) were collected from sawmills and pooled together according to species type. The particles were spread out and air dried for four weeks in order to allow for gradual degradation of starches and sugar present in the wood that could impede setting of cement binder in accordance with the recommendation of Bison (1981). Within this duration of time, it is presumed that adequate degradation would have been effected. After seasoning, 25kg by weight from the sawdust pile of each of the eight hardwood species was weighed out and mixed together to provide the 200kg sawdust particles used as mixed species for board fabrication.

Hot water pre-treatment of the sawdust and flake particles

For the pre-treatment procedure, boiling water was poured into an aluminium pot and was diluted with cold water to bring it to any of the five pre-determined temperatures of 35oC, 50oC, 65°C, 80oC or 95°C. The particles allotted to a particular temperature were soaked in hot water, turned gently for 10 minutes and thereafter left to stay in the hot water for further 30 minutes. After the expiration of the 40 minutes soak period, the hot water changed colour and became darkish brown. The coloured water was drained off and the particles washed with fresh hot water at same temperature level for another 10 minutes. The fresh hot water was again drained off in order to wash off extracted chemical substances which may be contained on the surfaces of the the particles, cold water soaking was later effected for another 10 minutes duration. The treated particles were thereafter put in a sieve to allow for 20 minutes dripping of the water. The soaking, draining and dripping processes were carried out to facilitate adequate removal of all traces of inhibitory chemical substances which have already been washed out of the wood particles. The treated particles were later air seasoned to a moisture content of about 12%, before being used for board fabrication.

For board production, only two variables were investigated which are water pre-treatment temperature at five levels, viz: 35°C, 50°C, 65°C, 80°C and 95°C; and cement/wood mixing ratio also at five levels of 2.00 : 1.0; 2.25 : 1.0; 2.50 :1,0; 2.75 : 1.0 and 3.00 :1.0. The experimental arrangement is a 5 x 5 factorial experiment, a combination of which manifested in 25 treatment combinations. The design for the experiment is a split-plot factorial with four replications.

Each experimental panel was trimmed before cutting into test samples to completely remove edge effect which could significantly affect the tested properties of the panels. Thereafter , four test specimens, were obtained from each panel for the static bending tests and moisture response assessment. Each test sample measuring 50mm wide and 94mm long was loaded to failure on a Hounsfield Tensometer testing machine while the MOR and MOE of specimens were determined in accordance to ASTM Standard No D-1037 of 1978. The MOR and MOE values for each replicate panel were taken as the mean for the four test specimens.

Also four test specimens each measuring 152mm by 152mm in size were obtained from each replicate panel for moisture response determination. The moisture response properties assessment made from the test specimens are water absorption (WA), thichness swelling (TS), and linear expansion (LE). These properties were however assessed following prolonged soak in cold water for 144 hours in accordance with the recommendations of Badejo (1999).

Results and Discussions

Moduli of Rupture and Elasticity

The mean values of the static and moisture response properties of the fabricated boards are as listed in Table 1. The MOR and MOE ranged from 4.02 to 12.74 N/mm^2 and 2040 to 4060N/mm^2 respectively. The recorded mean MOR and MOE values obtained in this study conform favourably with those reported by Oyagade *et al* (1995), Badejo (1999), Omole and Badejo (1999). The mean minimum and maximum MOR values obtained in the test were 4.02 N/mm^2 and 12.74N/mm^2 respectively. Also, the mean minimum and maximum MOE values obtained were 2040 N/mm^2 4060 N/mm^2 respectively. Table 2 shows that water pre-treament temperature and cement/wood mixing ratio were had significant effects at 1% level of probability on MOR and MOE of the test panels. The two-way interaction between these two production variables was also significant at the same level of probability. From the statistical analysis, it is pertinent to note that strength and stiffness of the experimental boards increased between the water pre-treatment temperatures of 35°C and 80°C; beyond which there was a significant decline in the MOR (strength) and MOE (stiffness) values. High quality cement-bonded particleboards were produced as cement/wood mixing ratio (an indicator of cement binder content in board) increased steadily from 2.00:1.00 to 3.00:1.0.

Table 1: Mean values of the properties of the fabricated boards

Treatment Combination		Assessed Board Properties				
WPT	CMR	MOR (N/mm2)	MOE (N/mm2)	WA (%)	TS (%)	LE (%)
35	2.00:1.0	4.02	2040	43.97	3.50	0.72
35	2.25:1.0	4.95	2230	39.92	2.61	0.67
35	2.50:1.0	5.78	2350	37.71	1.61	0.53
35	2.75:1.0	6.90	2520	33.99	1.26	0.49
35	3.00:1.0	7.25	3140	31.24	0.79	0.29
50	2.00:1.0	4.28	2160	43.59	2.74	0.69
50	2.25:1.0	5.98	2330	39.49	0.90	0.62
50	2.50:1.0	7.37	2550	37.23	0.27	0.40
50	2.75:1.0	8.30	2630	33.37	0.10	0.37
50	3.00:1.0	9.81	3320	30.85	0.69	0.24
65	2.00:1.0	4.59	2510	40.15	0.76	0.53
65	2.25:1.0	6.77	2680	37.08	0.23	0.44
65	2.50:1.0	7.94	2890	35.55	0.86	0.36
65	2.75:1.0	9.60	3320	32.23	0.76	0.32
65	3.00:1.0	11.70	3830	28.98	0.59	0.21
80	2.00:1.0	5.73	2660	35.51	1.17	0.46
80	2.25:1.0	7.85	2750	33.13	0.82	0.35
80	2.50:1.0	9.28	3070	30.39	0.70	0.30
80	2.75:1.0	10.90	3430	28.80	0.67	0.25
80	3.00:1.0	12.74	4060	27.13	0.51	0.14
95	2.00:1.0	4.57	2340	41.14	1.78	0.48
95	2.25:1.0	6.56	2610	37.86	1.28	0.40
95	2.50:1.0	7.87	2850	35.68	0.90	0.34
95	2.75:1.0	9.56	3270	31.51	0.85	0.28
95	3.00:1.0	11.33	3720	28.80	0.65	0.17

Table 2: Analysis of variance (ANOVA) for comparing the MOR and MOE of the boards produced at different levels of water pretreatment temparatures and cement/wood mixing ratio

Source of variation	Df	MOR		MOE	
		SS	MS	SS	MS
Replicates (R)	3	2.396	0.799	2.69	0.897
Water Pre-treatment Temp. (WPT)	4	135.973	33.993**	7.707	1.927**
R x WPT1	12	0.003	25 x 10-5	0.00006	5 x 10-6
Cement/wood mixing ratio (CWR)	4	420.995	105.249**	19.995	4.999**
R x CWR	12	0.004	33.0 x 10-5	0.00134	11 x 10-5
WPT x CWR	16	21.854	1.366**	0.477	0.0298
R x WPT x CWR2	48	2.057	0.043	0.0973	0.0020

Df = degree of freedom; SS = sum of squares: MS = Mean square
1. whole plot error; 2. Split plot error; ** significant at 1% level of probability

Cement-bonded particle boards produced from mixed sawdust and flake particles of the eight hardwoods at the pre-treatment temperature of 800C had significantly higher MOR and M0E values than those made from mixed particles pre-treated with hot water at temperature levels of 35°C, 50°C, 65°C and 95°C. The highest MOR and MOE values of 12.74 N/mm2 and 4060 N/mm2 respectively obtained in the study originated from panels fabricated at the water pre-treatment temperature level of 80°C and cement/wood mixing ratio level of 3.00 : 1.0. These figures were significantly different at 5% level of probability from the values of 11.70 N/mm2 (MOR) and 3830 N/mm2 (MOE) obtained at the temperature level of 65°C and mixing ratio of 3.00:1.0; as well as the values of 11.33 N/mm2 (MOR) and 3720 N/mm2 (MOE) obtained at the temperature level of 95°C and mixing ratio of 3.00: 1.0. The good performance of the temperature level of 80°C could be attributed to better extractive solubility at this level.

The noticeable improvement in board properties with respect to MOR and MOE of the experiment particle board bfrom 350C to 800C may be attributed to improved degree of compartibility of the wood species with cement. This study has however demonstrated that the quality of cement-bonded particleboards in this study is influenced by the temperature level at which the particles were pre-treated with hot water prior to use. The observed improvement in the strength and stiffness of the test boards as pre-treatment temperature was raised from 35°C, through 50°C and 65°C, to 80°C therefore testifies to the following facts: (i) that the degree of removal of inhibitory chemical substances present in the eight hardwood species seemed to be dependent upon the hotness of water used during the extraction process, (ii) and that these inhibitory chemical substances appeared, to be hot water soluble.

Based on these reasons, board quality improvement, resulting from application of hot water at increased temperature level, may therefore be expected. This noticeable improvement notwithstanding, it was however observed that there was an apparent decrease in strength and stiffness of the experimental panels as the water pre-treatment temperature was raised from 80°C to 950C. This may possibly be attributed to excessive softening of the sawdust and flake particles used for board formation during the hot water soaking exercise carried out to effect the extraction process.

Table 3: Simple regression equations which relate the bending properties of the boards with the process variables.

Independent Variables	Depedent Variables	Equations	R values
Water pre-treatment temperature	MOR	$Y_1 = 4.83 + 0.0437X_1$	0.385
	MOE	$Y_2 = 2157 =10.7X_1$	0.425
Wood/cement mixing ratio	MOR	$Y_1 = -682 + 5.79X_2$	0.850
	MOE	$Y_2 = -208 + 1223X_2$	0.814

Y_1 and Y_2 = MOR and MOE respectively; X_1 = water pre-treatment temperature.
X_2 = cement/wood mixing ratio

The low coefficients of determination, R2 values of 0.148 and 0.181 given in the equation above which related MOR and MOE to water pre-treatment temparature means that only 14.8% and 18.1% of the total variations in MOR and MOE respectively were explained by the water pre-treatment temperature. This suggests that other vital sources of variable inputs need to be explored. Unlike what was observed in the case of water pre-treatment temperature however, high coefficient of determination R2 values of 0.723 and 0.662 were given by the simple regression equations which relate MOR and MOE with cement/wood mixing ratio respectively. This means in effect that as much as 72.3% and 66.2% of the total variations of MOR and MOE respectively were explained by the cement/wood mixing ratio. This indicates the importance of cement/wood mixing ratio in determining these static bending properties. Furthermore, while water pre-treatment temperature appears to be a weakly correlated with MOR and MOE, cement/wood mixing ratio appears to be strong predictor of these board properties. In spite of the high correlation coefficient, R values obtained from the simple regression equations which relate MOR and MOE with cement/wood mixing ratio. Multiple regressions of MOR and MOE on water pre-treatment temperature and cement/wood mixing ratio were computed and the results are as presented on Table 4.

Table 4: Multiple regression equations which relate the bending properties of the boards with the process variables.

Independent Variables	Depedent Variables	Equations	R values
X_1,X_2	MOR	$Y_1 = -9.67 + 0.0437X_1 + 5.80X_2$	0.933
	MOE	$Y_2 = -9.01+10.7X_1 + 1223X_2$	0.918

Y_1 and Y_2 = MOR and MOE respectively; X_1 = water pre-treatment temperature.
X_2 = cement/wood mixing ratio

From the regression equations, water pre-treatment temperature has positive relationship with MOR and MOE when cement/wood mixing ratio is held constant; while mixing ratio does have positive relations to MOR and MOE when temperature is held constant. These regression equations were significant at 1% level of probability (Table 3).

Water absorption, thickness swelling and linear expansion

From the compiled averages on Table 1, (WA), (TS) and (LE) ranged from 27.13 to 43.97%, 0.51 to 3.50% and 0.14 to 0.72% respectively. WA assessments were made following prolonged soak of the test specimens in cold water for 144 hours. The mean WA and TS and LE obtained in this experiment conform quite favourably to those obtained in the previous investigations by Badejo (1986), Oyagade (1988) Fuwape (1992) and Badejo et al 2011.

Table 5: Analysis of variance (ANOVA) for comparing the moisture response properties of the wood cement boards Produced.

Source of Variation	Df	Sum of Squares.			Mean Squares.		
		WA	TS	LE	WA	TS	LE
Replicates (R)	3	2.8221	2.12831	0.1898	0.9407	0.7094	0.0633
Water Pre-treatment Temp. (WPT)	4	5.0696	17.3539	0.7823	1.2674**	4.3385**	0.1956**
R x WPT1	12	0.00032	0.2388	0.0093	27 x 10-6	0.0199	0.0008
Cement/wood mixing ratio (CWR)	4	16.2547	29.3794	1.6285	4.0637**	7.3449**	0.4071**
R x CWR	12	0.00024	0.4172	0.0202	0.00002	0.0348	0.0017
WPT x CWR	16	0.41060	7.3613	0.1004	0.02566**	0.4601**	0.0063**
R x WPT x CWR2	48	0.00097	0.1216	0.0021	20 x 10-6	0.0025	4 x 10-5

Table 6: Regression analysis showing correlation of board properties with water pre-treatment temperature and cement/wood mixing ratio.

Source of Variation	Degree of freedom	Mean Squares (MS) values MOR	MOE	WA	TS	LE
Regression	2	63.28**	2.98×10^{6}**	2.3085**	5.025**	0.2792**
Residual	22	0.855	5.03×10^{4}	3.71	0.161	0.0027

** Significant at 1% level of probability

The results of 5 x 5 split-plot analysis of variance as presented in Table 5 show that, water pre-treatment temperature, cement/wood mixing ratio and the interaction between these two production variables had significant effects at 1% level of probability on WA, TS and LE. The resistance of the experimental boards to moisture uptake, swelling in water and dimensional stability improved remarkably as water pre-treatment temperature increased from 35°C to 80°C but increasing the temperature beyond the level of 80°C to 950C manifested in production of low quality boards which gave higher WA, TS and LE values. Also, water absorption, thickness swelling and linear expansion consistently decreased as cement/wood mixing ratio increased steadily from 2.00: 1.0 to 3.00: 1.0. These observed trends are graphically depicted in Figure 3. Cement-bonded particleboards produced from mixed sawdust and flake particles of the eight hardwoods at the pre-treatment temperature of 80°C were significantly lower in WA and TS than those made at the temperature levels of 35°C, 50°C, 65°C and 95°C.

The simple regression equations which relate WA, TS and LE to the water pre- treatment temperature, with their corresponding correlation coefficient, R values are presented in Table 7.

Table 7: Simple regression equations which relate the bending properties of the boards with the process variables.

Independent Variables	Depedent Variables	Equations	R values
Water pre-treatment temperature	WA	$Y_1 = 39.6 - 0.0710X_1$	0.322
	TS	$Y_2 = 2.36 - 0.0166X_1$	0.477
	LE	$Y_3 = 0.652 - 0.00384X_1$	0.519
Wood/cement mixing ratio	WA	$Y_1 = 0.63.5 – 11.4 X_2$	0.863
	TS	$Y_2 = 5.01 – 1.49X_2$	0.715
	LE	$Y_3 = 1.29 – 0.354X_2$	0.797

Y_1, Y_2 and Y_3 =WA, TS and LE respectively; X_1 = water pre-treatment temperature.
X_2 = cement/wood mixing ratio

The negative coefficient of X1 in each of the three regression equations implies that increased temperature decreased WA, TS and LE. This conforms to the trend of results obtained in the study. Low coefficients of determination, R2 values of 0.104, 0.228 and 0.269 were observed in the simple regression equations. This means in effect that only 10.4%, 22.8% and 26.9% of the total variations of WA, TS and LE respectively were explained by fitting the regressions. This suggests that other vital sources of variable inputs need to be explored. Also, the simple regression equations which relate WA, TS and LE with cement/wood mixing ratios gave negative coefficients of X2 in each of the three regression equations which implies that increased mixing ratio decreased WA, TS and LE. Unlike what was obtained for water pre-treatment temperature, high coefficients of determination, R2 values of 0.745,0.511 and 0.636 were given by the above simple regression equations. This means in effect that as much as 74.5%, 51.1% and 63.6% of the total variations of WA, TS and LE respectively were explained by fitting the regressions. This indicates the importance of cement/wood mixing ratio in determining these moisture response properties. Furthermore, water pre-treatment temperature, from the low R values obtained, is weakly correlated with WA, TS and LE; while cement/wood mixing ratio is a good predictor of these board properties. The regression relationships which relate the three board properties to these two independent variables are illustrated in igure 3. The degree of porosity in the boards was reduced due to inceased cement binder content and the ability of such less porous boards to resist moisture uptake is therefore greatly increased.

The high coefficient of determination, R2 values obtained from the simple regression equations which relate WA, TS and LE to cement/wood mixing ratio still indicate that 25.5%, 48.9% and 36.4% of these three moisture response properties respectively are still due to other vital sources of variable inputs. In view of this therefore, multiple regressions of WA, TS and LE on water pre-treatment temperature and cement/wood mixing ratio were computed. The multiple regression equations obtained with their corresponding correlation coefficient R values are as presented in table 7.

Table 7: Multiple regression equations which relate the bending properties of the boards with the process variables.

Independent Variables	Depedent Variables	Equations	R values
X_1,X_2	WA	$Y_1 = 68.1- 0.0710X_1- 11.4 X_2$	0.922
	TS	$Y_2 = 6.09 - 0.0166X_1-1.49X_2$	0.860
	LE	$Y_3 =1.54- 0.00384X_1 - 0.354X_2$	0.951

Y_1, Y_2 and Y_3 =WA, TS and LE respectively; X_1 = water pre-treatment temperature.
X_2 = cement/wood mixing ratio

As reflected in Table 3, these multiple regressions were significant at 1% level of probability. From these regression equations, it means that water pre-treatment temperature does have positive relations to WA, TS and LE when cement/wood mixing ratio is held constatnt; while mixing ratio does not have positive relation to these moisture response properties when temparature is held constant.

Conclusion and Recommendations

The effects of the water pre-treatment temperature and cement-wood mixing ratio were highly significant on static bending and moisture response properties of the experimental boards. Use of water pre-treatment temperature at increasing levels between 35°C and 80°C manifested in the production of stronger, stiffer and more dimensionally stable cement- bonded particleboards.

The study has demonstrated that there is an optimum pre-treatment temperature range within which high quality boards can be produced; and beyond which board quality will be impaired. From work carried out in this study, this optimum appeared to lie between 65°C and 80°C.

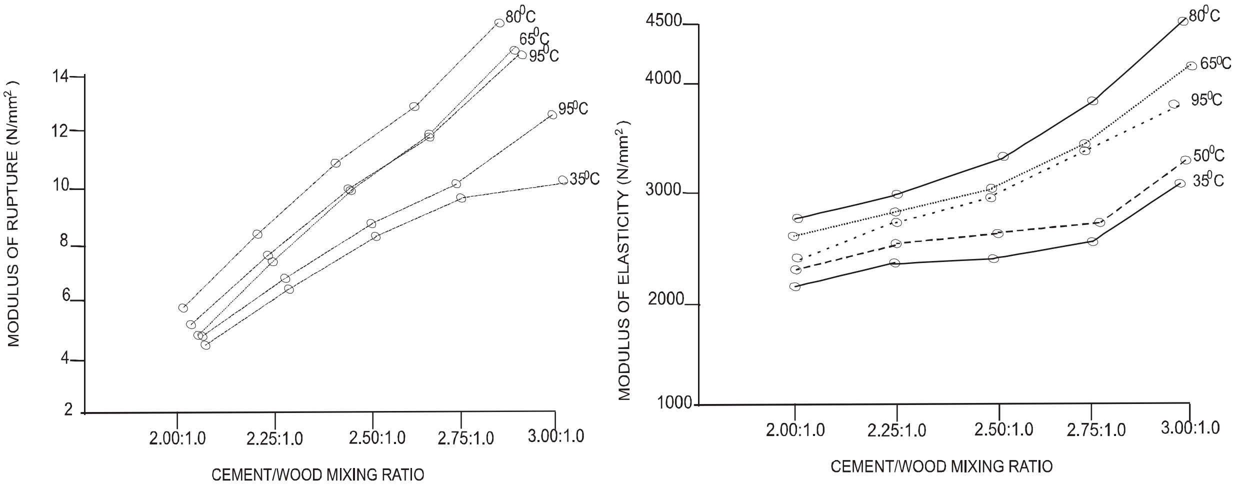


Figure 1: Influences of cement/wood mixing ratio at each water Pre-treatment temperature level on MOR and MOE.

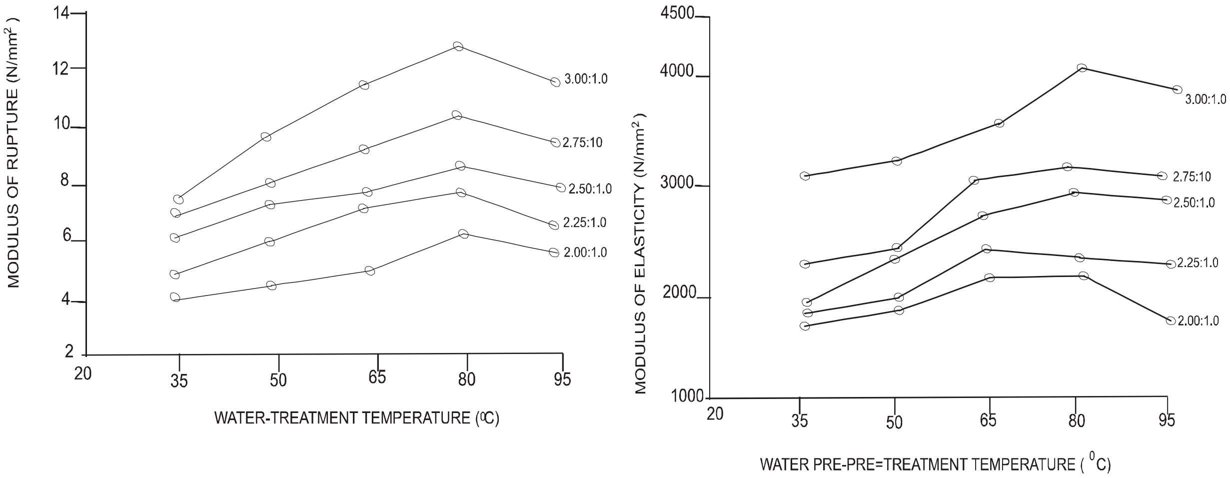
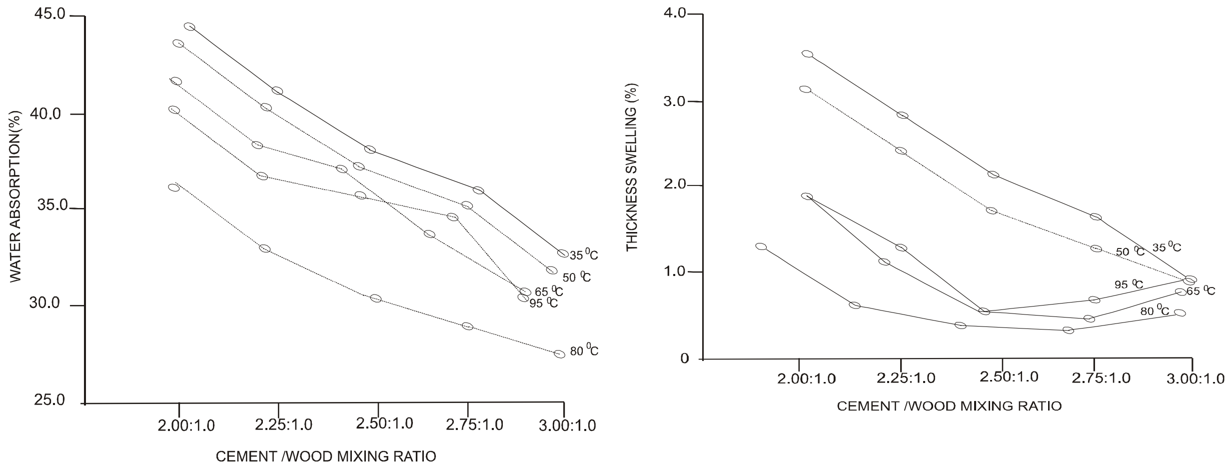


Figure 2: Influence of water pre-treatment temperature at each cement/wood mixing ratio on MOR and MOE of the boards produced



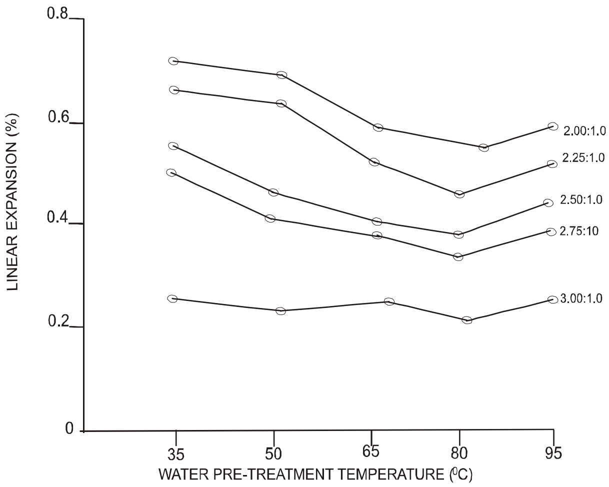


Figure 3: Influence of cement/wood mixing ratio at each water pre-treatment temperature level, on WA, TS and LE of experimental boards

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