Strength and Dimensional Stability of Cement Bonded Board Reinforced with Tomato Stem Particles and Coconut Husk Dust

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The use of coconut husk sawdust and tomato stem particles at varying blending proportion was examined for the production of particle board. Boards of dimensions 350 mm by 350 mm by 6 mm were produced (coconut husk dust, tomato stem particles) at different blending proportion and addition of additive ($CaCl_2$ at different concentrations). The physical properties (water absorption and thickness swelling) and mechanical properties (modulus of rupture (MOR) and modulus of elasticity (MOE)) were investigated. Thickness swelling and water absorption were investigated at 24 and 48 hours. The results showed that boards exhibited mean values of 0.50% to 4.16% and 2.12% to 7.00% respectively of thickness swelling at 24 hours and 48 hours respectively and 13.6% to 25.2% and 17.6% to 29.1% of water absorption at 24 h and 48 h, respectively. The boards also exhibited means of 1.00 N/mm^2 to 5.25 N/mm^2 and 339 N/mm^2 to 3430 N/mm^2 for MOR and MOE respectively. An increase in the tomato particle content caused increase in water absorption and thickness swelling, resulting in the highest water absorption and thickness swelling values. Tomato stem and coconut husk dust can be used to produce cement bonded boards after pre-treatment with hot water and preferably both sieved.

Keywords: Strength; Dimensional stability; Cement-bonded particle board; Tomato stem; Coconut husk; Sawdust

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INTRODUCTION

The traditional use of wood and demand for wood products are increasing in many parts of the world, including Nigeria. Large quantities of waste are generated daily from the agricultural sectors. This waste is not utilized efficiently; it is burnt or allowed to decay in public places in the open air, creating environmental pollution (Owoyemi *et al.* 2010; Olufemi *et al.* 2012; Shehrawat and Sindhu 2012).

Odewumi (2001) commented that the pollution problems created by dumping and burning of agricultural residues is linked with the concern for conservation of future resources such as forest and water. Thus, there is interest in finding utilization outlets for agricultural waste. However, waste generation is closely linked to population, urbanization, and affluence, which is connected with everyday living that cannot be avoided (Odewumi 2001). Managing these crop wastes in a well-planned manner will provide a healthy environment for man and all other living creatures (Olorunnisola 2008).

To find substitutes for conventional wood and maximize the utilization of wood that is already in high demand as a raw material, research has focused on alternatives with similar characteristics to wood (Youngquist *et al.* 1993). A notable area of interest is using agricultural waste in wood-cement composite board manufacture (Ajayi and Badejo 2005; Papadopoulos 2006; Ajayi and Olufemi 2011).

Wood-cement composite board products have many advantages such as no emission of toxic materials during their manufacture, low cost, and ability to cure without applying high temperatures (Lima *et al.* 2011). Panels made from these composites have high versatility in terms of finishes (Matoski 2005). The product can be sawn, nailed, screwed, and glued; it is widely used in flat roofing, prefabricated structures, mobile homes, permanent formwork, cladding, sound barriers, and paving, as they work as structural insulation panels (Karade *et al.* 2010).

In this study, particleboard was produced from the agricultural wastes of tomato stem and coconut husk sawdust with cement as a binder. These products may provide a suitable alternative to low-density sawn timber. They could reduce the demand for wood and wood products for other board production. They are available in large quantities, thereby reducing pressure on forest and ensuring sustainable forest management.

EXPERIMENTAL

Preparation of Tomato Stem Particles

The tomato stems were collected from the Crop Science and Pest (CSP) Farm at The Federal University of Technology, Akure (FUTA). The stems were turned into particles using a hammer mill, treated in hot water to remove contents that hinder the setting and curing of cement, and then dried to aid its adhesion to the binder. The particles were sieved and allowed to pass BS 40 – mesh sieve (425 µm) but retained on BS 60 – mesh (250 µm) sieve to a uniform particle size, which was used for the production of the tomato stem based board. The particles were dried to 12% moisture content in a laboratory environment. The coconut husk was acquired from the dumping ground of the popular coconut farm market at Bolorunduro Ogbese, Akure. The coconut husks were hammer milled, and the dust was sieved using a 2 mm aperture sieve to obtain uniform husk dust sizes. It was then pre-treated using hot water to remove soluble extractives that possibly hinder its binding with cement.

Preparation of particleboard

The material contents comprising tomato stem particles and coconut husk dust were weighed using a blending proportion 0:100, 75:25, 50:50, 25:75, and 100:0 for varying additive concentration (1.5%, 2.5%, and 3.5%). The cement and dusts were weighed into the mixing bowl in an appropriate quantity based on the blending ratio of the materials, mixed thoroughly, and spread into the mould for mat formation. The cold pressing machine was used to densify the materials in the mould; the formed board was removed from the mould and stored inside a conditioned environment. The boards were then cut into experimental sizes.

The board formation process was conducted as follows: collection of raw materials; weighing of the materials; mixing; mat formation; pressing; demoulding; drying; conditioning; and cutting test specimen to size.

Fig. 1. (1) Cleaning tomato stems; (2) pretreatment of coconut husk dust; (3) additive (calcium chloride); (4) milling machine used to reduce tomato stem and husk size; (5) sieving of coconut husk dust after milling; (6) drying of milled tomato stem particles; (7) sample under test; (8) weighing of board contents; (9) board produced

Testing

This study examined the thickness swelling, water absorption, modulus of rupture (MOR), and modulus of elasticity (MOE) of the tomato stems based and coconut husk dust cement particleboard. The cement-based boards were cut into test specimens according to a modified ASTM D 1037 (1998), with specified samples of 50 mm x 50 mm x 6 mm, which was used to conduct the thickness swelling and water absorption, while 195 mm x 50 mm x 6 mm sized samples were used for MOR and MOE determination.

Water Absorption

Water absorption (WA) is the percentage of the increase in weight of board over original weight or initial weight. This test was carried out to determine the dimensional stability of produced boards. Test specimens were soaked in water (at room temperature) for water uptake for 24 h, and the final weight was recorded. The percentage water absorption for the test samples were calculated using Eq. 1,

$$\text{WA (\%)} = \frac{w_{1-w_2}}{W_1} \times \frac{100}{1} \tag{1}$$

where WA is the water absorption (%), W_1 is the initial weight (g), and W_2 is the final weight (g).

Thickness Swelling

The same procedure was used to determine the thickness swelling, using the same samples at the same water soak period. The thickness of the cement-based boards was measured using a veneer caliper before and after water soaking. The thickness swelling was expressed as the percentage of increase in thickness of the cement-based board over the original thickness as expressed below,

$$\text{TS \%} = \frac{T_0 - T_1}{T_1} \times 100 \tag{2}$$

where TS is the thickness swelling (%), T_1 is the thickness of the board after water immersion (mm), and T_0 is the initial thickness of the board (mm).

Strength Properties

The modulus of rupture (MOR) and modulus of elasticity (MOE) were evaluated by subjecting a sample of 195 mm x 50 mm x 6 mm to a force/load on a computer controlled electronic universal testing machine (model WDW-20, Jinan Hensgrand Instrument Co., Ltd., Jinan, China). The samples were supported by metal bearing plates to prevent damage to the beam at the point of contact between specimen and reaction support. The forward movement of the machine leads to gradual increase of load at the middle of the span until failure of the test specimens occurred. At the point of failure, the force exerted on each sample that caused the failure was recorded; thus, MOR and MOE were calculated using Eqs. 3 and 4, respectively,

$$\text{MOR} = \frac{3PL}{2bD^2} \left(\frac{N}{\text{mm}^2}\right) \tag{3}$$

$$\text{MOR} = \frac{PL^3}{4bd^3D} (\text{Nmm}^2) \tag{4}$$

where L is the span of board sample between the machine supports (mm); b is the width of the board sample (mm); d is the thickness of the board sample (mm); P is the ultimate failure load (N); and D is the deflection.

Experimental Design

The experimental design for this study was the Randomized Complete Block Design, the tomato stem particles and coconut husk dust ratio (100:0, 75:25, 50:50, 25:75, 0:100) being the treatment, and the additive concentration $CaCl_2$ representing the block.

Statistical Model

The statistical model was described as follows,

$$Y_{ij} = \mu + T_i + B_i + \varepsilon_{ijk} \quad (5)$$

where Y_{ij} is the Individual Observation, μ is the general mean, T_i is the treatment effect, which is the three different mixing ratio, B_i is the block effect (additive concentration), and ε_{ijk} is the experimental error.

Data Analysis

Microsoft Excel was used for the basic statistical analyses. Descriptive statistic was presented as mean and standard deviation values.

Equipment used

A computer control electronic universal testing machine manufactured by Jinan Hensgrand Instrument Co., Ltd. (Jinan, China) with model number WDW-20 was used for the mechanical properties determination.

RESULTS AND DISCUSSION

Physical Properties

The mean values of water absorption and thickness swelling are represented in Figs. 3 through 6. The mean values of water absorption and thickness swelling at 24 h ranged from 13.62% to 25.16% and 0.5% to 4.16%, respectively, with the lowest value showing the least board weight and thickness as shown in Figs. 3 and 5. The mean values of the water absorption and thickness swelling at 48 h ranged from 17.62% to 29.07%, as shown in Figs. 4 and 6. The weight and thickness of samples increased as the proportion of tomato stem particles increased.

Water Absorption

During the period of immersion in water, the amount of water absorbed by the boards increased as the tomato stem particles increased (Figs. 2 and 3).

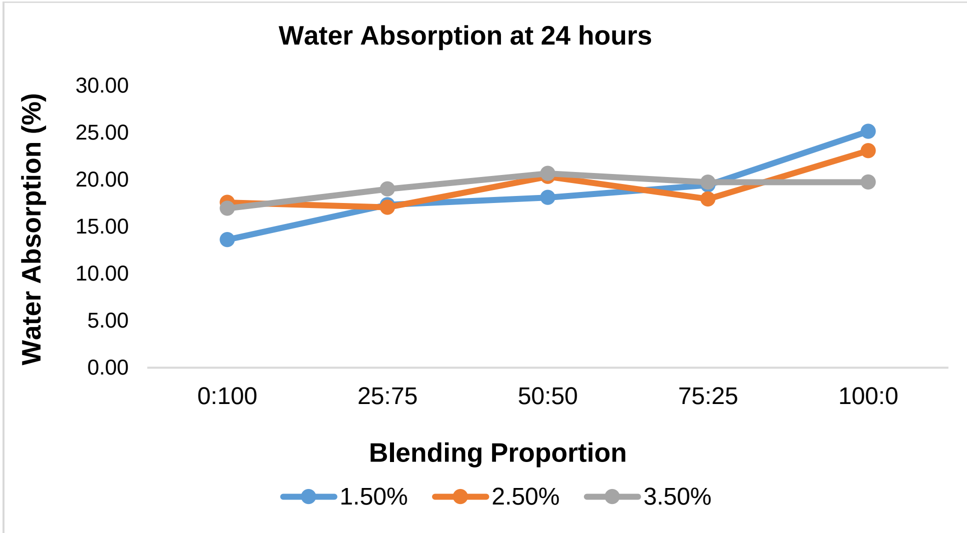

Fig. 2. The effect of variables on water absorption for boards exposed to water for 24 h

The lowest mean values of water absorption of 24 h and 48 h was 13.6% and 25.2%, respectively, which were obtained at the highest tomato stem particle content and highest additive concentration of 3.5%, while the highest mean values at 24 h and 48 h at 25.2% and 29.1%, respectively, were obtained at the lowest tomato stem particle content and lowest additive concentration of 1.5%. This is in accordance with previous research (Ajayi 2002; Nadzri *et al.* 2012), in which the water absorption of cement and coconut husk dust produced boards increased as soaking time increased as a result of the influence of the coconut husk dust.

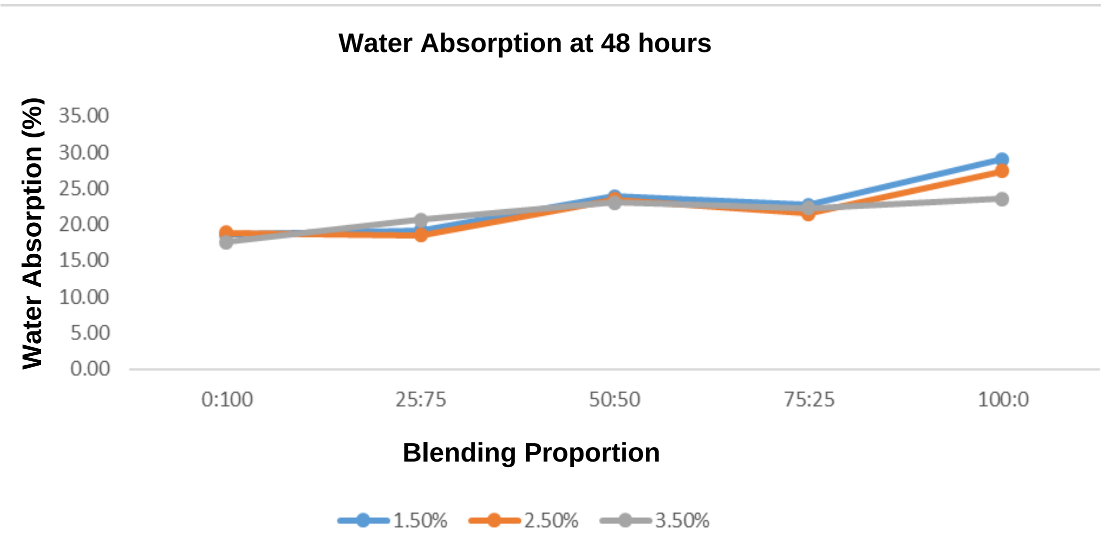

Fig. 3. The effect of variables on water absorption for boards exposed to water for 48 h

An analysis of variance (Table 1) showed that the concentration of $CaCl_2$ and wood blending proportion (BP) had no significant effect on water absorption after 24 h and 48 h of immersion. Boards produced with pure tomato stem particles and cement were the best when water absorption is considered; absorption was reduced as quantity of tomato stem particles reduced.

Table 1. ANOVA Conducted for Water Absorption of Cement Bonded Particleboards

Properties	Period	Source of variance	Sum of Squares	df	Mean Square	F cal.	Sig.
Water absorption	24 h	Blending Proportion (BP)	144.322	4	36.081	10.720	0.000*
		$CaCl_2$	1.557	2	0.779	.231	0.796ns
		MR * $CaCl_2$	62.329	8	7.791	2.315	0.077ns
		Error	50.485	15	3.366		
		Total	258.693	29			
	48 h	Blending Proportion (BP)	262.396	4	65.599	39.516	0.000*
		$CaCl_2$	7.905	2	3.952	2.381	0.126ns
		MR * $CaCl_2$	32.346	8	4.043	2.436	0.065ns
		Error	24.901	15	1.660		
		Total	327.548	29			

ns = not significant, * = significant at 0.05% level of probability.

Thickness Swelling

The mean values of thickness swelling at 24 h ranged from 0.50% to 4.16% with the lowest value showing the least swollen board as shown in Fig. 4. The mean values of the thickness swelling at 48 h ranged from 2.12% to 7.00% (Fig. 5). The thickness swelling decreased as the quantity of tomato stem particles decreased. This result was attributed to high cement content, which makes the cement crystals grow and develop from the cement particles during the hydration process so that they push themselves against the fibre surfaces and penetrate into the available void spaces for anchorage. Therefore, greater amounts of cement result in stronger interlocking between the cement crystals and fibres, resulting in a strong fibre-cement composite product. This result agrees with the findings of Tuico (1994), where boards with higher cement: coconut coir dust ratio absorbed less water than boards with a lower ratio.

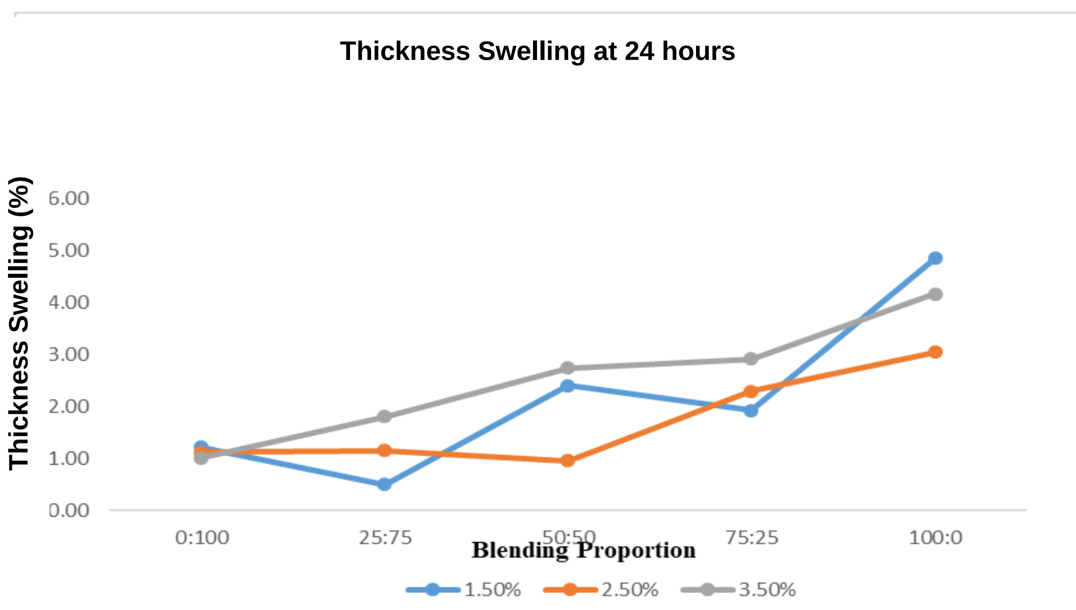

Fig. 4. The effect of variables on thickness swelling for boards exposed to water for 24 h

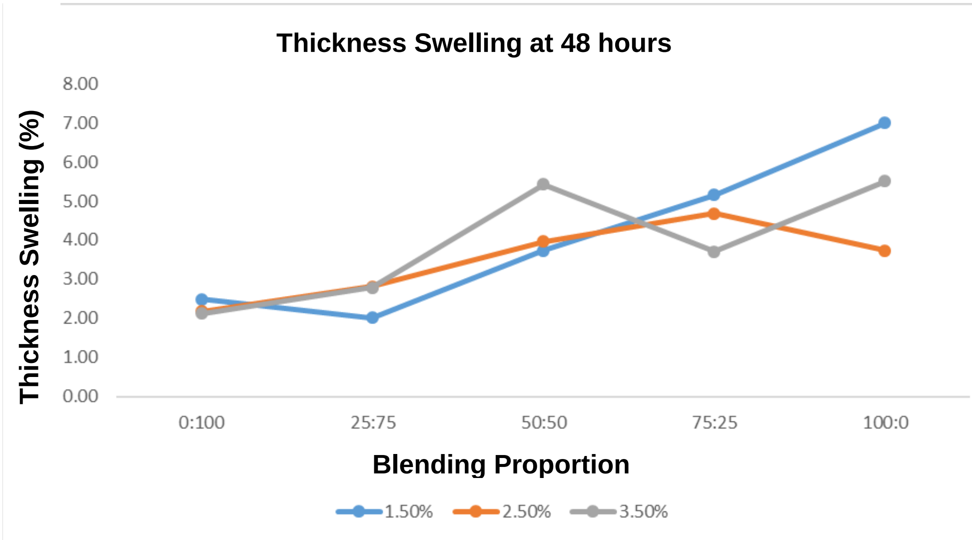

Fig. 5. The effect of variables on thickness swelling for boards exposed to water for 48 h

Another analysis of variance (Table 2) showed that the blending proportion of tomato particle to coconut sawdust, concentration of $CaCl_2$, and their interaction had no significant effect on thickness swelling after 24 h and 48 h immersion in water. The results in Table 2 show that there is no significant different in the effect of different blending proportion, $CaCl_2$ and their interaction on the thickness swelling of boards after 24 h and 48 h of water immersion.

Table 2. ANOVA Conducted for Thickness Swelling of Cement Bonded Particleboards

Properties	Period	Source of variance	Sum of Squares	df	Mean Square	F cal.	Sig.
Thickness Swelling	24 h	Blending Proportion (BP)	33.616	4	8.404	2.525	0.085ns
		$CaCl_2$	3.326	2	1.663	0.500	0.617ns
		MR * $CaCl_2$	6.269	8	0.784	0.235	0.977ns
		Error	49.933	15	3.329		
		Total	93.143	29			
	48 h	Blending Proportion (BP)	44.386	4	11.097	2.978	0.054ns
		$CaCl_2$	1.928	2	0.964	0.259	0.775ns
		MR * $CaCl_2$	15.343	8	1.918	0.515	0.827ns
		Error	55.895	15	3.726		
		Total	117.553	29			

ns = not significant, * = significant at 0.05% level of probability.

Mechanical Properties

Modulus of rupture (MOR)

Figure 6 shows the mean values of MOR obtained for this study, which ranged from 1.00 to 5.25 N/mm^3 for all the blending ratio and additive concentration.

Table 3. ANOVA for Mechanical Properties of Particleboard

Mechanical properties	Source of variance	Sum of Squares	df	Mean Square	F	Sig.
Modulus of elasticity	Blending Proportion (BP)	19648987.918	4	4912246.980	11.628	0.000*
	$CaCl_2$	1881378.399	2	940689.200	2.227	0.142ns
	MR * $CaCl_2$	2411098.252	8	301387.282	0.713	0.677ns
	Error	6336756.921	15	422450.461		
	Total	30278221.491	29			
Modulus of rupture	Blending Proportion (BP)	44.554	4	11.139	24.752	0.000*
	$CaCl_2$	1.390	2	0.695	1.545	0.245ns
	MR * $CaCl_2$	4.422	8	0.553	1.228	0.348ns
	Error	6.750	15	0.450		
	Total	57.117	29			

ns = not significant, * = significant at 0.05% level of probability.

The results of the analysis of variance in Table 3 show that strength properties of the board were greatly influenced by blending ratio. There is significant difference between the blending ratios with board containing pure tomato being the highest, which is in accordance with Yang *et al.* (2004) that boards tend to be brittle when their modulus of rupture value is high and tend to be ductile or flexible when the value is low.

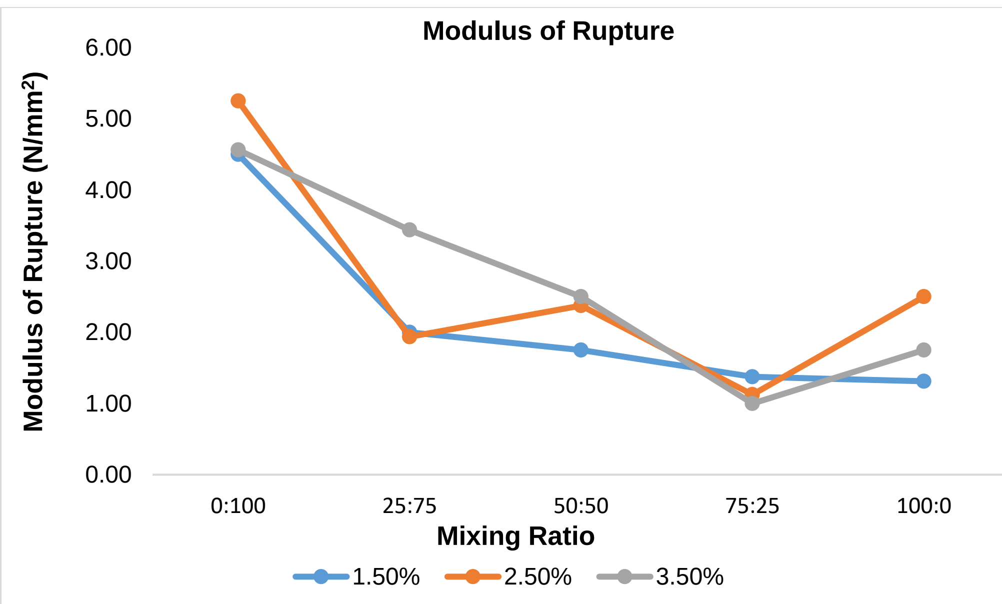

Fig. 6. The effect of variables on MOR of the boards

Modulus of elasticity (MOE)

The average values obtained of modulus of elasticity ranged from 339 N/mm^2 to 3426 N/mm^2, which indicates that the MOE increased as the board density and mixing ratio as presented in Fig. 7. The analysis of variance in Table 3 showed that MOE was significantly affected by the board wood blending proportion at 0.05% level of significance, whereas the effect of additive concentration and the interaction between the blending proportion and additive concentration was not significant.

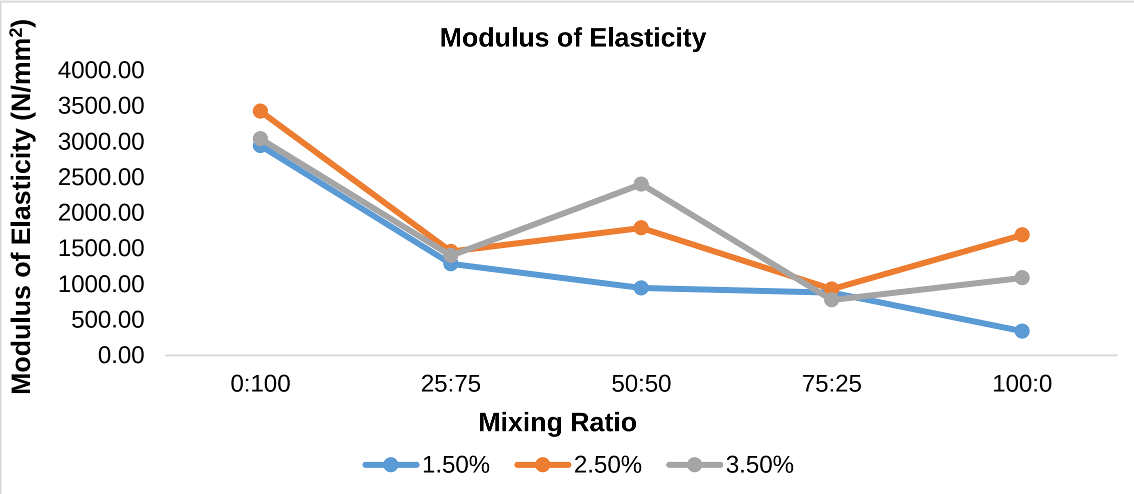

Fig. 7. The effect of variables on MOE of the boards

Recommendations

Tomato stem particles and coconut husk dust are considered as suitable raw materials for production of cement bonded boards, hence it is recommended. However, using tomato stem particles only for board production should be avoided for applications where high strength properties are required.

Furthermore, utilization of agricultural waste such as tomato stem particles and coconut husk in making boards should be encouraged so as to also help mitigate environmental pollution.

CONCLUSIONS

1. Cement bonded boards reinforced with tomato stem particles and coconut husk dust were successful produced.
2. Tomato stem particle content did not contribute significantly to the high strength properties and dimensional stability of the boards produced.
3. The strength and dimensional stability of boards produced from husk dust and cement at 50:50 blending proportion were better than boards produced from cement and tomato stem particles.

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