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Development and Performance Evaluation of an Improved Vibrating Table for Wood-Cement Board Production

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ABSTRACT

Wood-cement board properties and performances are affected by the existence of air bubbles, void-spaces, and weak-spots within the board and segregation of components. The present study was designed to improve the performance of the existing vibrating table. A double-mould, manually and electrically operated vibrating table with complete uniform uniaxial vibration of the top plate was designed and fabricated. The major parts include; unbalanced eccentric assembly, stand frame, top plate as platform, springs, air cushion suspension system, and electric rotor. The vibrating table with an eccentricity assembly of mass 1.64kg operating at amplitude of 0.4mm and frequency of 1500 rpm produced two tiles at once with at an average production rate of 102 Roman-tiles per hour. The performance evaluation showed that non-porous, homogenous and well consolidated boards were produced at faster rate with enhanced properties that compared favourably with the conventional boards.

Key words: Wood-cement boards, Vibrating table, Machine design, Double-mould, Unbalanced eccentric assembly

INTRODUCTION

Composite materials are materials made from two or more constituent materials, the reinforcing phase and the matrix phase, with significantly different physical or chemical properties, that when combined, produce a material with characteristic different from the individual components. The reinforcement unit supports structural load while proving strength and rigidity and the matrix unit, serves as a binding unit for the components of the composites. Cement-bonded wood-fibre reinforced composite is a composite material manufactured throughout the world from specially graded aggregately chipped wood (especially wood wastes) and Portland cement. The composites are used to produce panels, bricks tiles and other products used in the construction companies [1-5]. The world is currently turning to wood-cement composite, this is due to the basic engineering properties of crack resistance, ductility and energy absorption that it possesses over unreinforced concrete [6]. These properties ensure long and trouble-free service life to many of the infrastructure constructions that enhance the quality of life of the users. Wood-fibre cement composites are now used in a host of applications including sidings, shingles, soffits, flooring (as ceramic tiles backboards), skirting, pipes and architectural columns [7]. Furthermore, the successful substitution of asbestos, for its poisonous contents and negative effects on health, with wood fibres in cement-bonded composites has led to increased research and awareness of the wood-fibre cement composites [8].

The abundance and availability of natural fibres in many parts of the world has made natural fibre cement composite an important part in the development of the world economy, providing such advantages as energy savings, conservation of the nation's scarce resources and reduction in environmental pollution. Their resulting high weather resistance and low sound transmission properties combined with the ability to accept a wide range of surface treatment makes these products highly attractive for a wide variety of application such as partitions, internal and external walls, roof elements e.tc. However, this innovative technology has been lagging behind in research resourcefulness in some developing countries such as Nigeria, due to low level of technological development. Hence there is the need to provide an avenue for researchers to carry out reasonable research in wood fibre-cement composite production techniques. Wood-cement board production is fraught by the presence of air bubbles, void-spaces, weak-spots and segregation of the various

ingredients of the composite which can adversely affect the properties and characteristics of the hardened tiles. The problems can be curtailed by proper placing, forming, consolidating and compacting of the slurry.
The present study was carried out to improve the existing vibrating table by making it double-mould which increases the production rates, electrically and manually operated, complete base vibration of the top plate to ensure non-porous, homogenous and well consolidated boards are produced with enhanced properties.

METHODOLOGY

Design of the Vibrating Machine

The design of the machine was adapted from literatures [9-11] and text books [12-13] for appropriate design principles and parameters. The design analyses were carried out based on materials availability, design requirements and performance specifications. These are detailed below.

Design of the Vibrating Machine Components

Table Top

Since the mass of a standard size Romans roof tile is about 4.5kg. And the objective is to produce two tiles at once. Moulds were designed to accommodate 10kg of tile. Hence a square piece of dimensions were selected based on the volume-mass-density relation;
Mass of Table-top (Mt) = 31.44kg.
Mass of the eccentricity assembly (Me) = 1.64kg.
Mass of the roofing tiles (Mr) = 10kg.
Using density of mild steel = 7860kg/m^3 [12].
Consider the Table-top as a beam (mild steel)
Length =100cm = 1m

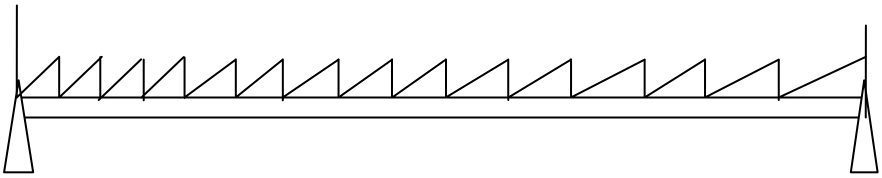

Fig. 1 Loading behavior of top plate of machine with Reactions R_1 and R_2

Total load on the beam = (mass of table-top + mass of the eccentricity assembly + mass of roofing tiles).
Total load on beam (roof tiles) = 43.08kg = 422.184N = 0.422KN.
Taking a factor of safety of 2, to prevent effect of possible overload, and from Figure 1 according to Khurmi and Gupta [13] equation (1) was derived;

$$load(W) = 0.422 \times 2 = 0.844KN.$$

$$R1 = R2 = \frac{WL}{2} \quad (1)$$

Where W = total load on the beam.
L= length of the beam
R = reaction at the ends.
R1 = R2 = $\frac{0.448 \times 1}{2}$ = 0.224kN
Moment of inertia

$$M_1 = M_2 = M_{max}(neg) = -\frac{WL^2}{12} \quad (2)$$

$$M_x = \frac{-0.844 \times 1^2}{12} = -0.070333KNm^2$$

$$M_{max} = \frac{WL^2}{24} = \frac{0.844 \times 1^2}{24} = 3.52 \times 10^{-02}KNm^2$$

Bending moment

$$\Delta_x = \frac{WL^4}{384EI} \quad (3)$$

$$I = \frac{bd^3}{12} \quad (4)$$

Where E = Young Modulus of Elasticity (GN/m^2), E = 200GN/m^2
I = Moment of inertia (m^4)
b = breath (m)
d = depth (m)
b = 0.8m, d = 0.003m

$$I = \frac{0.8 \times 0.003^3}{12} = 1.8 \times 10^{-9}m^4$$

$\Delta_x = \frac{0.844\times 1^4}{384\times 200\times 10^9 \times 1.8\times 10^{-9}}$ = 6.11 x 10^{-6} KNm^2

Shaft

The radial load on the shaft = weight of the crome. Since the shaft is supported by two bearing. Choosing a factor of safety of two;
Bearing 1kg each
Mass attachment on shaft = 0.5kg
Mass of shaft 0.75kg
Mass of Pulley =0.3kg
Fr = 18.5 × 9.81 = 181.5× $2 = 363N$
Axial load on shaft Fa = weight of threaded shaft, flat bar for roller lifting and roller which is 18.5 + 4.5 + 2.5 = 25.5 $\times 9.81 = 250.2N$.
Choosing bearing designated as 6004 in RHP catalogue the static load Co = 1000.
Conversion from pounds to Newtons;
Co = 1000× $4.448 = 4448N$

$$\frac{Fa}{Co} = \frac{250.2}{4448} = 0.06$$

The equivalent load factor 1.02
Therefore, equivalent load

$$P = e\ (Fa + Fr) \qquad (5)$$

P = 1.02 (250.2 + 363)
P = 625.5N≈ 0.63kN
Dynamic load capacity C from the RHP catalogue
C = 1620× $4.448 = 7205.8N \approx 7.2kN$
Expected life of bearing L =$(\frac{7.2}{0.63})^3 \times 10^6$ revolutions
Since the roller press is a free roll, the effect on bearing will not be much, therefore L = 1496.3× 10^6 revolution is safe.

Column Design

Using equal iron pipe (700mm, Outer Diameter, d_o = 50mm, Inner diameter, d_i = 30mm)
Area =$\pi \frac{d_o^2 - d_i^2}{4}$ = 1256.8mm^2

Moment of inertia (I)

$$I = \pi d^4/64 \qquad (6)$$

I = $3.142\frac{(do-di)^4}{64} = 3.142 \times \frac{160000}{64} = 7855mm^4$
Radius of gyration, R = $\sqrt{\frac{I}{A}}$, = $\sqrt{\frac{7855}{1256.8}} = 2.5mm$

Belt Design

Length (L) of belt, from Khurmi and Gupta [13]

$$L = 2C + \frac{\pi}{2}(D1 + D2) + \frac{(D2-D1)^2}{4C} \qquad (7)$$

Where L = length of the belt
C = centre distance between the larger pulley and the smaller one
D1 = diameter of driver (i.e smaller pulley)
D2 = diameter of driven (i.e larger pulley)
L = $2\times 0.28 + \frac{\pi}{2}(0.07 + 0.11) + \frac{(0.11-0.07)^2}{4\times 0.28} = 0.8444m$
L =844mm, therefore a belt of Length 0.9m (90cm) was selected.

Belt Contact Angle

$$\mathrm{Sin}\alpha = R2 - R1/C \qquad (8)$$

=75 -25/280 = 50/280
α= $10.2866^0 = 10.3^0$.

Angle of Lap

$\theta = 180 - 2\alpha$= 180 – 2(10.3) = 159.4^0
= 159.4× $\frac{\pi}{180} rad = 2.782rad$

Groove Angle of the Pulley
$2\beta = 34^0$, $\beta = 17^0$

Belt Tension
From Khurmi and Gupta [13]

$$\log_e(\frac{T1}{T2}) = \mu\theta \quad (9)$$

Simplifying we have;

$$\frac{T1}{T2} = e^{\mu\theta} \quad (10)$$

Where T1 = tension in belt on tight side, T2= tension in belt on slack side θ = Contact angle in rad and μ = coefficient of friction between belt and pulley

$1.30 \log(\left(\frac{T1}{T2}\right) = 0.3 \times 2.782$
T1/T2 = 2.306
T1 = 2.306T2

Power Transmitted By Open Belt

$$P = (T1\text{-}T2)\ V \quad (11)$$

Where V = velocity of driving pulley [13]
$V=\frac{\pi D2N1}{60} = \frac{\pi\times 0.07\times 180}{60} = 0.6598m/s$
2 = (T1-T2)0.6598
T1-T2= 2/0.6598 =3.031

$$T1 = T2 + 3.031 \quad (12)$$

Substituting T1 = 2.306T2 intoequation (12)
2.306T2-T2 = 3.031
1.306T2 = 3.031
T2 = 2.3209N T1 =5.35N

Resultant Torque
Tr = (T1-T2)R where R=radius of bigger pulley
Tr = (5.35 – 2.32)0.105 = 0.318Nm

Eccentricity Assembly
The eccentricity, as shown in Figure 2, is to allow for the amplitudes of vibration to remain within the specification of 0.3 and 0.4mm for all mould sizes. The primary eccentricity options were considered.
The eccentricity assembly consists of the followings:

1. Input shaft
2. Housing
3. Bearings
4. Eccentricity mass
5. Pulley.

The amplitude of the vibration (X_0) is given as:

$$\frac{X_0}{e}\frac{M}{m} = \frac{r^2}{\sqrt{(1-r^2)^2+(2\zeta r)^2}} \quad (13)$$

$$X_0 = \frac{(me\,r^2)/M}{\sqrt{(1-r^2)^2+(2\zeta r)^2}} \quad (14)$$

$$x = X_0 \sin(\Omega t - \phi) \quad (15)$$

$$\omega = \sqrt{\frac{k}{M}} \quad (16)$$

$$\varsigma = \frac{c}{2\sqrt{kM}} \quad (17)$$

$$r = \frac{\Omega}{\omega} \quad (18)$$

$$tan\phi = \frac{2\zeta\omega\Omega}{\omega^2-\Omega^2} = \frac{2\varsigma r}{1-r^2} \quad (19)$$

Nomenclatures
M – Total mass of the table-top including unbalanced mass (kg)
m – unbalanced mass (kg)
e – eccentricity of the unbalance distance from the mid-diameter of the input shaft(mm)
ω - angular velocity of rotation of unbalanced mass (rad/s)
k- spring stiffness of the support (N/m)

c- damping coefficient (N-s/m)
r-frequency ratio
X_0−amplitude of vibration (mm)

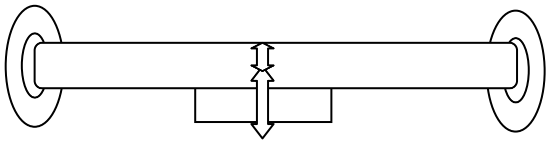

Fig. 2: Eccentricity Assembly

Calculations involved in determining the coefficient of eccentricity.
With M = 54.3kg, m = 1.64kg, e = 40mm = 0.04m, r = 0.9, and $\zeta = 0.15$

$$X_0 = \frac{1.64\times(0.9)^2\times0.04/39}{\sqrt{(1-0.9^2)+(2\times0.15\times0.9)^2}} = 0.0019m.$$

Design Considerations and Parameters

The evaluation of the necessary design parameters, such as the strength and size of materials of construction was done and considered in selecting various machine parts in order to avoid failure due to excessive yielding and failure during the life cycle of the machine. The machine components and their corresponding estimated masses are as presented in Table 1.

Table -1 The Vibration Machine Components and masses

S/No	Element	Mass (kg)	Weight (n)
1	Moulds (2)	4	39.2
2	Top plate	31	303.8
3	Rubber platform	2.0	19.6
4	Stopper	0.03	0.3
5	Iron pipe for column (4) (9.5kg each)	38	372.4
6	Iron pipe for beam (6) (1.7kg each)	10.2	99.8
7	Electric rotor and its support (iron flat bars 0.3kg each)	3.65	35.8
8	Iron pipe for column bracing (2) (2.8kg each)	5.6	54.5
9	Iron pipe for middle bracing	3.0	29.4
10	Bearing rod, the load and bearing case	3.5	34.3
11	Battery setter	1.2	11.8
	TOTAL	102.2	1000.9

Construction and Assembly

The construction/fabrication of the machine was done at the Faculty of Technology University of Ibadan technical workshop and took into consideration the designed and known parameters. The fabrication of the machine undertook some machining operation which include; marking out, cutting, beating, welding, grinding, sharpening, drilling and boring processes.

i. **The top plate:** The top plate was constructed from steel plate of thickness 11mm and suitably braced and fixed so that there is no significant variation in the vibration characteristics. The length of the table top was taken as 100cm and the breath was recorded as 80cm. it was design to be able to vibrate 2 moulds of cement tiles at once at 22.86N.
ii. **The base frame:** The frame was built with one-inch metal pipes (mild steel) and half-inch iron pipes. The four supporting stands were made by cutting four lengths of the one-inch metal pipes, 700mm long, acting as a vertical stands while six lengths of half-inch metal pipes (550mm) were used as beam running along the length of the table top. Three other lengths of the half-inch mild steel pipes were cut into lengths of 530mm and 555mm, act as horizontal brace stands to prevent deflection. Two iron flat bars of lengths 240mm were used as a hanger to hold an electric rotor in position. All joints were affected by arc welding using gauge 12 electrodes.
iii. **Eccentric assembly:** The assembly which consists of the input shaft, housing, bearing eccentric mass and pulleys is attached to the motor shaft at one end and fixed to top plate which is also used to hold the samples.
iv. **The bearings:** The bearings of the mechanical vibrators were strong enough to withstand wide variation of loads and full force required to accelerate the optimally loaded table to maximum frequency, and conforms to international standards.
v. **The springs:** the stiffness of the springs on which the vibrating table was mounted was designed to make the natural frequency of the spring-supported system very low compared with the frequency of vibration.

The exploded diagram and the bird's eye view of the double mould Vibrating machine are show in Figures 3 and 4 respectively, while the assembled table with values indicating the dimensions is as shown in Figure 5.

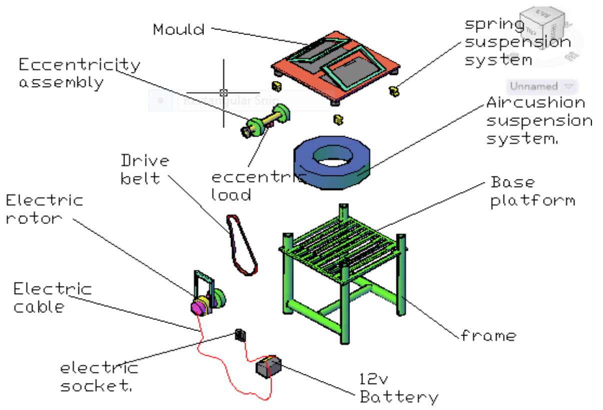

Fig. 3 Exploded diagram of the double mould Vibrating machine

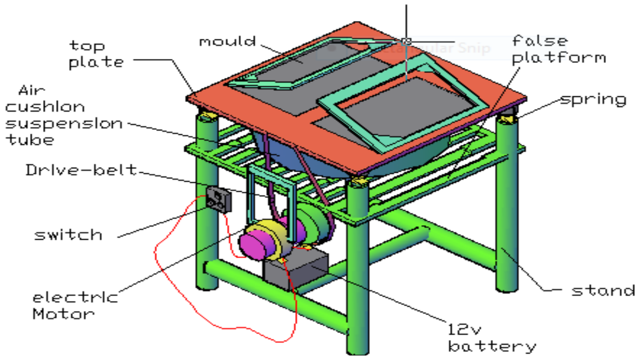

Fig. 4 Assembly Drawing of the Vibrating Machine

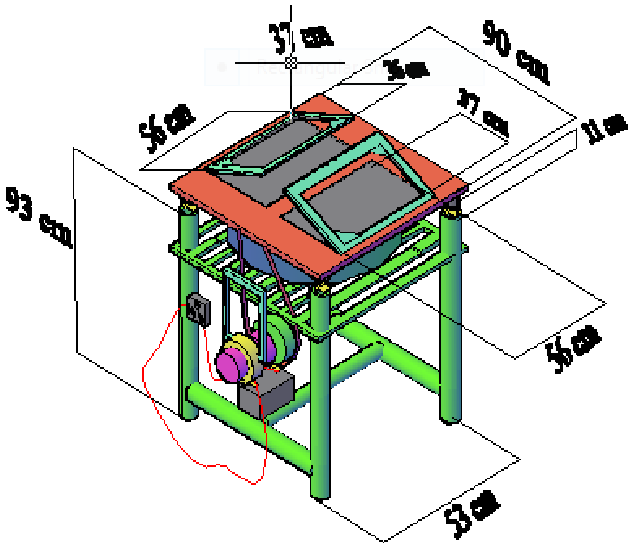

Fig 5 Assembled vibrating table parts with dimensions

Performance Evaluation

The performance of the vibrating table was evaluated by producing oil palm empty fruit bunch fibre cement-bond composite tiles as shown in Figures 8 and 9. This was done by dry mixing the fibres, cement, and sand in a plastic container until a homogenous mixture was achieved. An estimated quantity of potable water was added and the entire contents were mixed until an acceptable level of homogeneity was achieved. The slurry was poured on a plastic sheet in two flat moulds of 50cm by 30cm by 0.6cm on the table vibrator (Figure 8) and spread to cover the entire area and leveled (Figure 9). The top plate was then vibrated for about 60seconds. After which it was moist cured first for a period of 24h and later for a total of 28 days. Three replicates of each of the property tests were carried out. The cement/sand ratio was 1:3 for the specimen and the fibre content was 10% by mass of cement.

Specimen Test and Procedure

Water Absorption (WA) Tests

The water absorption tests were conducted according to ASTM C642-06 [14]. The percentage of WA for these specimens were determined using Eqn. (20)

$$\%\ \text{Water absorption} = \frac{Wet\ weight - Dry\ weight}{Dry\ weight}\ X\ 100 \qquad (20)$$

Porosity Tests

The Porosity tests were conducted according to ASTM7063/D7063M-11 [15].
The percentage of porosity for these specimens were determined using Eqn. (21)

$$\%\ \text{Porosity} = \frac{Wu - Wk}{Wu - Wa}\ \text{x}\ 100 \qquad (21)$$

Where: Wu = mass of specimen in air
Wk = mass of dry specimen
Wa = mass of specimen under water

Flexural Strength

The mechanical properties comprising Modulus of rupture (MOR), and Modulus of elasticity were determined using an OKH-600 digital display universal testing machine in accordance with ASTM D1037 [15].

RESULTS AND DISCUSSION

A double mould capacity vibrating machine was designed and fabricated using locally sourced materials. Figures 6 and 7 showed the exploded views of the machine's parts and the completely assembled vibrating machine.

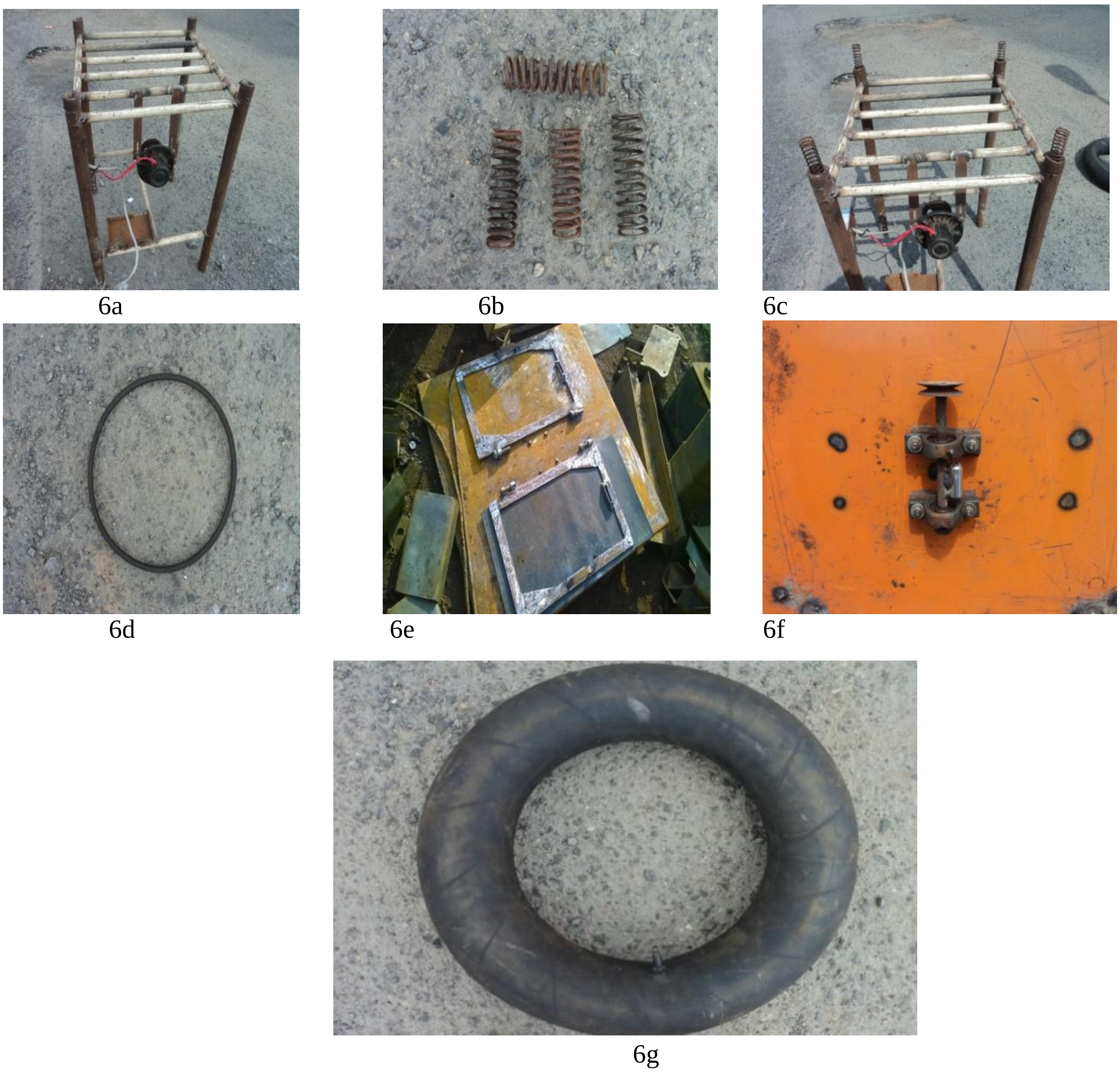

Fig. 6a–6g Exploded parts of the two-Mould Vibrating Machine (a) Skeletal Frame, (b) Springs (c) Drive system (Motor) (d) Drive-belt (e) Top plate (f) Eccentric assembly (g) Air-Cushion tube

Fig. 7 The Developed Vibrating Machine

Discussion of the Test Results

Table 2 revealed the sorption properties (WA, TS and Porosity) and mechanical properties of the boards produced. The percentage reduction in WA, TS and porosity are 15.2, 1.7 and 12.1% respectively compared with the un-vibrated tiles. This showed that proper vibration of cement slurry reduced porosity, so as the pores reduced, the sorption properties are enhanced this corroborates the findings of Farhana *et al* [17]. The mechanical properties, MOR and MOE, values increased by 1.7 and 1.1% respectively and compared favourably with the values reported in literatures [18-19].

The vibrating machine helps in consolidating the concrete composite thereby increasing its mechanical properties. The composite slurry poured and placed in the moulds contains as much as 20% entrapped air. The amount varied with mix type and slump, form size and shape, the amount of reinforcing fibre, and the concrete placement method. At a constant water-cement ratio, each percent of air present in the slurry, decreases compressive strength by about 3% to 5%. Vibration consolidates concrete in two stages, first by consolidate and compact the concrete particles, then by removing the entrapped air and weak spots thereby improved the bond strength and decreases concrete permeability. The machine creates pressure waves that rearrange aggregate particles, reducing friction between them. Thus, large voids (honeycomb) disappeared. The machine was used to produce samples of cement-concrete tiles to ascertain its performance. The leveling of the slurry in the moulds of the vibrating machine is as shown in Figure 8 and 9.

Fig. 8 Operation of the Machine

Fig 9: Consolidated cement boards ready for curing

Table -2 Properties of OPEFB Fibre-Cement Composite at 10% Fibre Content

Properties	Change after 28 Days of Curing %)	Remark
WA (%)	15.2	Decreased
TS (%)	1.7	Decreased
Porosity (%)	12.1	Decreased
MOR (MPa)	1.7	Increased
MOE (GPa)	1.1	Increased

Advantages of the Improved Vibrating Machine

- Enhanced the board properties
- Increased the rate of boards production
- Lower cost and smaller size
- Made from available local materials
- Less noise is generated

CONCLUSION AND RECOMMENDATION

A double-mould, electrically-operated cement composite roof tile vibrating machine capable of handling a load of 100N at amplitudeof 0.4mm and a frequency of 1500rpmwas developed in line with basic engineering principles. Its output capacity averaged about 102 Roman-tiles per hour. The machine performed satisfactorily byincreasing the rate of production, enhancing compaction and eliminating voids resulting in boards with improved properties that compared favourably with the conventional boards

However, it is recommended that the integrity of the cement composite mixture be ascertained.

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