

## Design and Production Specifications of Machine for Wood Cement Composite Boards Production

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### ABSTRACT

Manual method of producing wood cement composites (WCCs) is time consuming, labour intensive and leads to inconsistent products. This paper reports the design and production specifications for a machine capable of automating the critical processes of mixing, blending, vibrating and compacting involved in WCC production for rural usage at a cottage level. It is a semi-continuous manually operated machine, made up of two broad units: the mixer and the former (conveyor cum press). The mixer is hand powered by a lever 500mm long at an average speed of 35rpm and has a capacity of 0.1514m<sup>3</sup>. The former is made up of rollers interconnected with chain drives and a freely rotating press roll. It is powered by a manually operated pulley system at an average speed of 4rpm. The mixer can save up to 52% of the total time required to achieve homogenous mix while the former can also reduce time required for board formation by 50%. The machine has an overall capacity of producing 30 Nos. of 12.5mm × 570mm × 570mm boards.

**Keywords:** wood-cement composite production, methods of WCC production.

### INTRODUCTION

In view of finding an alternative material to complement wood in different structural applications, wood and other non-woody fibres have been incorporated into cement matrices to manufacture various construction materials. The ability to be moulded into any shape and form to meet specific end use and excellent resistance to freeze-thaw, fire, water, rot, termites, insects, fungi attacks, excellent dimensional stability, machinability, simplicity in the production process and possibility of total utilization of different lignocellulosics and agricultural residues (Olorunnisola 2007, Ajayi *et al.* 2008) make wood-cement composites a highly sought-after construction material. To further unravel the strengths and weaknesses of wood-cement composites as potential substitutes for wood in different structural uses, a great deal of research is being expanded in the area of their production.

Production method can affect the properties of the final composite product. Peled and Mobasher (2003) reported that even when keeping the same matrix and fibres, changing the process could significantly affect the properties of the composite. Manual methods of WCC production are usually time consuming, labour intensive and lead to inconsistent products as a result of variations in production conditions.

Commercial wood-cement composite production in Nigeria employs a batch process where the dosing of raw materials, blending and distribution of blended material in the moulds, stripping and stacking of the moulds all have to be done manually. These invariably cause non-uniformity in the production conditions; leading to variations in the properties of the final products, even when made with the same formulation or ratio.

As reported by Gregor *et al.* (2005), successful production of fibre reinforced composites hinge on proper fibre dispersion as well as workability of the mortar. Over the years, a number of machines for fibre-cement composite production have been developed with varying degree of automation. These include the Hatschek machine, the extrusion machine, the Fourdrinier machine and the pour-on technique. However, the technology behind the development of these machines requires a great deal of capital investment. Development of a semi-continuous production machine that can automate the critical processes of fibre dispersion and composite compaction at a cottage level is an important step at addressing problems associated with the manual method of WCC production. To this purpose, a number of machines have been constructed to help in the development of various wood-cement products at cottage level. These include vibrating table (Omoniyi, 2009) and ceiling board making machine (Balogun, 2010). These two are stand alones that could only serve a purpose in batch processes.

Though they both helped to produce composites of acceptable strength properties, their mode of operation is labour intensive and time consuming. Most of the component parts of this designed machine would be directly and constantly in contact with an alkaline substance (cement paste) which can lead to serious corrosion damage. Therefore to prevent this, a careful selection of locally available materials that are not readily affected in an alkaline environment was used. This is aimed at keeping down the cost of production as much as possible without compromising the functional performance of the machine. Also, the calculated geometry of each component was not compromised to avoid frequent repair which could lead to inevitable failure of the machine. To make its operation ergonomically comfortable, the space requirement is such that the machine could be installed in a 12' by 10' room

This work present the design and development specifications of a suitable machine that could automate the critical processes (mixing, blending, vibrating and compacting) involved in the production of wood-cement composites for rural use.

### MATERIALS AND METHOD

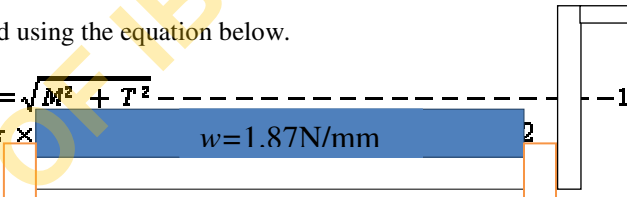
#### The Mixer

The mixer is composed of a cylindrical mixing chamber (Plate 1) made of 3mm thick mild steel plate; 25mm diameter rotating shaft (Plate 2), mixing bars (Plate 2); and stands at a height of 1200mm. The chamber houses the rotating shaft which can be used manually by a lever or powered by a 2hp electric motor and the mixing rods are mounted on it. The lever which is used to operate the rotating shaft is shown in Fig. 1 below.

Figure 1: Manual lever for the rotating shaft

The diameter of the shaft was calculated using the equation below.

$$T_e = \frac{\pi}{16} \times \tau \times d^3$$

$$T_e = \sqrt{M^2 + T^2}$$


Where,

$T_e$  = Equivalent twisting moment in Nmm;  $M$  = the maximum bending moment Nmm;  $T$  = Torque Nmm;  $\tau$  = permissible shear stress of mild steel  $N/mm^2$  and  $d$  = diameter of shaft.  $L=700m$

The thickness of the mixing bars was calculated using the following relations:

$$M = Z \times \sigma_b \text{ in } Nmm \text{ --- 3}$$

$$Z = \frac{b \times t^2}{6} \text{ --- 4}$$

Where,

$M$  = maximum bending moment  $Nmm$ ;  $Z$  = section modulus of the bar;  $\sigma_b$  = permissible bending stress of mild steel in  $N/mm^2$ ;  $b$  = width of the bars in  $mm$  and  $t$  = thickness of the bar in  $mm$



Plate1: The mixing chamber



Plate 2: Rotating shaft and bars

### The conveyor system

The conveyor is 2000mm long and stands at a height of 730mm above the ground. It is composed of 50mm by 100mm (2in by 4in) U-channel (body frame), 60mm hollow pipes (legs and braces) and rollers (mild steel hollow pipe of internal diameter 50mm) which are interconnected with sprockets (60mm diameter) and chain as shown in Plate 3. The first and the last rollers are positioned 100mm from the ends of the u-channel frame while others are spaced at 300mm on centre, making 7 rollers in all.



Plate 3: The conveyor (vibrator)

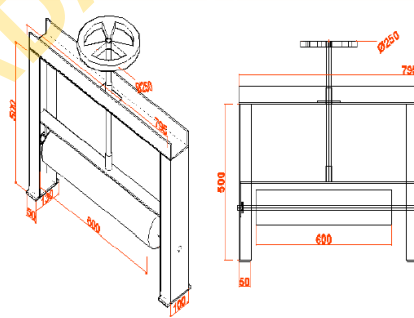


Figure 2: The compacting unit

**The Spreader:** This is made up of a flat bar (mild steel) mounted on a 10mm thick square rod and anchored on a 50mm square pipe. This is connected to a threaded shaft which controls the up-and-down movement of the flat bar. The flat bar spreads and determines the thickness of the slurry which eventually gets to the compacting unit.

**Compacting Unit:** The compacting unit of the former is made of galvanized metal pipe. The galvanized pipe is held in position by 302 graded pillow bearings (15mm bore) mounted on two short flat bars. These bars are anchored on a long bar (Fig. 2) which in turn is connected to a threaded rod. The roller compacts the composite mix as the mould containing the slurry is conveyed through the press to the other end. The threaded rod has a steering wheel (made of cast iron) at the top which govern the up-and-down movement of the press to control the extent of compaction.

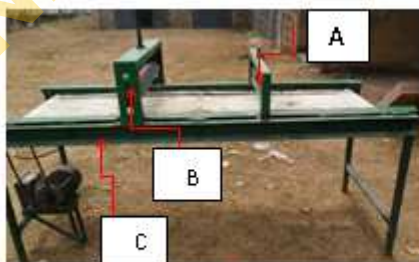


Plate 4: The conveyor unit (A) incorporated with compacting (B) and the spreading (C) units



Sawdust was sourced from the woodwork laboratory at the Department of Agricultural and Environmental Engineering, University of Ibadan. Portland cement was purchased from a retail shop at Olomi Area, Ibadan. Chemical accelerator (calcium chloride) was bought from a reputable Science Laboratory at Challenge, Ibadan.

Sawdust was cleaned and soaked in cold water for 24hr to remove the extractive contents which tend to inhibit cement hydration, air-dried (until a moisture content of about 12% was reached) and screened to 600 $\mu$ m, 850 $\mu$ m and 1.18mm particle sizes. A pre-determined quantity of Portland cement (based on formulation ratio) was mixed with suitable amount of wood material in dry state for a few minutes. The mixture was then blended with required quantity of water to give desired workability and consistency. The mixing and blending of furnish was carried out in the mixer.

After mixing and blending, which lasted for 20 minutes, the conveyor system was turned on and the blended slurry uniformly deposited on the moving mould through the discharge slot of the mixer at the rate of 200mm<sup>3</sup>/s. A quarter inch-thick plywood, 600mm  $\times$  600mm overlaid with polythene interface served as caul plate and metal mould (570mm  $\times$  570mm) positioned on it to give the required geometry. The slurry was vibrated (through resonance) as it moved from the discharge point down to the press end where it was finally compressed to the required thickness of 12.5mm. The mould was carefully removed at the other end and placed in a safe space for further processing. The products were wrapped in air-proofed polyvinylchloride (PVC) for 48 hours to reduce air voids and impact improved initial strength development. After the first 48 hours, the products were kept in a room conditioned at 75 $\pm$ 2 RH for a period of 3 weeks.

At the end of 28 days curing in cold water the products were exposed to ambient conditions to dry to 12% moisture content. Trimming of the products was done at the end of drying to square the edges. Three methods of production were experimented; these are hand, manual and motorized means of production. Effects and impacts of these methods on various parameters are presented and discussed.

**Water Absorption Test:** 12.5mm  $\times$  75mm  $\times$  75mm samples were used for this test. The samples were first weighed and then fully immersed in clean water at room temperature. The samples were placed in a bowl of water at 15mm equidistance both vertically and horizontally to one another. At the end of 2 hours and 24 hours of soaking in water, the samples were re-weighed to determine the extent of water absorption and percentage water absorption.

$$WA \% = \frac{W_f - W_i}{W_i} \times 100$$

$W_i$  = initial weight before soaking in water;

$W_f$  = final weight at the end of 2hr and 24hr soaking in water.

**Thickness Swelling Test:** The size of test samples for this test was same as for water absorption test. The procedure was similar to WA test, only that the thickness of each sample at a pre-determined spot was taken at the end of 2h and 24hr immersion in clean water.

**Density Test:** Three samples each were taken from boards produced by hand, manual and motorized operation at different levels of particle geometry (i.e. 600 $\mu$ m, 850 $\mu$ m and 1.18mm). Each sample was weighed using electronic weighing balance that could measure to 0.01g. The volume of the samples was calculated from the sample dimension: length  $\times$  breadth  $\times$  thickness. The average density of the board then calculated using the relation:

$$Density = \frac{Mass (g)}{Volume (cm^3)}$$

## RESULTS AND DISCUSSIONS

### Effect of method of production on mixing time

The average time taken for mixing the constituents (at different levels) in the dry state and subsequent blending with water is presented in Table 1. As expected, the time required for mixing and blending increased as the quantity of the constituents increased. The total time taken for mixing and blending with hand, at the given levels of quantity, was considerably higher than the time taken when the machine was operated manually or motorized.

Manual operation of the mixer saved between 34.65% - 50.81% of the total time taken to mix and blend the constituents with hand; while a further reduction of about 53.14% - 62.09% was observed when the machine was motorized (Table 2). This indicates that the mixer is considerably more time efficient than hand mixing.

### Mixing time and mixing energy required by each production method

Table 3 shows the average energy expended in mixing the constituents by hand and the mixer. It was assumed that the average power a healthy man can generate is 250Watts in 8hrs. In Table 4, reduction in the mixing energy following manual operation of the mixer was 56.46% for 9kg of constituents and 75.80% for 6kg of constituents. Although it was assumed that same power was exerted when the constituents were mixed with hand and when the mixer was manually operated. However, due to considerable reduction in the mixing time using the mixer, the mixing energy required for manual operation was significantly lower. Motorized operation is more efficient than when manual and hand mixing operation were used.

**Table 1: Time Elapsed for dry and wet mixing**

Quantity (min) (kg)	Mixing Time (min)			Blending Time (min)			Total Time		
	H	M	Mo	H	M	Mo	H	M	Mo
3	10.22	5.10	3.28	12.15	6.34	5.20	22.37	11.44	8.48
6	15.11	7.02	5.48	19.56	10.23	8.33	35.07	17.25	14.23
9	23.44	15.01	10.11	25.54	17.56	13.43	49.38	32.57	23.54

Note: H – by Hand; M – by Manual operation; Mo – Motorized

**Table 2: Reduction in time taken for mixing and blending**

Quantity (kg)	Total Time (min)			Time Reduction (min)		Time Reduction (%)	
	H	M	Mo	Manual	Electric	Manual	Electric
				(H – M)	(H – Mo)	(H-M)/H	(H-Mo)/H
3	22.37	11.44	8.48	11.23	14.29	50.20	62.09
6	35.07	17.25	14.23	18.22	21.24	50.81	60.57
9	49.38	32.57	23.54	17.21	26.24	34.04	53.14

**Table 3: Mixing Energy**

Quantity (kg)	Total time (min)			Mixing energy (W-hrs.)		
	H	M	Mo	H	M	Mo
3	22.37	11.44	8.48	93.21	47.75	106.00
6	35.07	17.25	14.23	146.13	71.88	177.88
9	49.38	32.57	23.54	205.77	135.72	294.25

**Table 4: Reduction in Mixing Energy**

Quantity of constituents (kg)	Reduction	
	(W-hrs.)	%
3	3.21	73.96
6	8.08	75.80
9	11.93	56.46

**Influence of production method on water absorption property**

The mean water absorption for boards made by hand ranged between 5.52 – 11.20% and 9.21 – 13.60% following 2hr and 24hr immersion in cold water respectively (Table 5). However, boards produced with the machine (manually operated or motorized) absorbed less water. A reduction of about 22.39 – 23.08% in water absorption after 2h immersion was realised with boards produced by the machine when operated manually. As seen in Table 5, water absorption potential of the boards increased as the particle size increased.

**Table 5: Average water absorption of boards after 2h and 24hr immersion in cold water**

Particle size (Method of production)	Water absorption (%)					
	Hand		Manual		Motorized	
	2hr	24hr	2hr	24hr	2hr	24hr
600µm	5.52	9.21	4.51	6.24	4.40	6.42
800µm	6.02	9.73	5.22	8.31	5.34	8.10
1.18mm	11.20	13.60	9.10	12.80	9.11	12.60

**Influence of production method on machine capacity**

9Nos. of 12.5mm × 570mm × 570mm on the average were produced per hour when the machine was manually operated. In Table 6, the capacity of the machine increased when motorized to about 12 boards per hour. Production by hand yielded less than 5Nos. of same board size in an hour. This is attributable to the higher time required for mixing the constituents and vibrating the slurry. And since the source is purely human power, the operator is bound to be weak with fatigue.

### Machine Efficiency

The throughput efficiency of the machine at three levels of the mixer capacity is shown in Table 6. The efficiency was 57.14% for manual and 66.67% for motorized operation.

**Table 6: Throughput efficiency of the machine**

Capacity	Quantity (kg)	Number of boards		Efficiency (%)
		Expected	Actual	
One-quarter	27.50	7	4	57.14
One-third	36.67	10	6	60.00
Half	55.00	15	10	66.67

### CONCLUSIONS

- i. The machine reduced the mixing and blending time by about 34.04 and 62.09% for manual and motorized operation respectively.
- ii. A capacity of about 9 boards/hr. and 15boards/hr. was realized when manually or motorized operated respectively;
- iii. The throughput efficiency of the machine was 57.14% for manual operation and 66.67% when motorized.
- iv. More uniform compaction level achieved with the machine resulted in improved and homogeneous physical properties of the boards;

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