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Design And Development Of Multi-Pattern Reinforced Clay Roof Tile Fabricating Machine From Locally Available Materials, Enhancing Inclusive And Integrated Strategies For African Sustainability In Engineering Entrepreneurship

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ABSTRACT
The two-piece multi pattern reinforced clay roof tile production machine was conceived, designed and developed to enhance entrepreneurial integration and involvement of Nigerian/ African youth in achieving the desired sustainable development. The machine is cheap to fabricate, assemble, and easy maintain. A total manufacturing cost of N48977:50k could help an entrepreneur, focused on inclusive and integrated development to produce 115 roof tiles (360x280x10mm size) in 8hours of an average man working at normal pace; thus, yielding about 345 roof tiles in 24hours shift. This particular machine therefore can accommodate four sets of the two – piece pattern where 460 roof tiles produced in 8-hour average man working at normal pace; and 1380 roof tiles in 24 hours shift. It has been ascertained also that about 10 roof tiles can cover 1m^2 of roof area, and successfully covering 138 square meters in just one-day production; under 25seconds of vibration for semi dry compaction.

***Key words**: Reinforced Clay roof tile, Vibro-compaction, green strength, and patting powder.*

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I. INTRODUCTION

It is a general said that shelter is as old as man. Hence, acquisition and provision of shelter has become necessary for man, if not compulsory. In developed countries, campaign for provision of shelter for all has been in place since 1970s and was successful. The United Nations Organisation (UNO), around 1980s, mandated every member nation to provide shelter for her citizens by the year 2000. This has been an uphill task for many governments in Africa because of the high cost of building materials (OKEYINKA, 2014).

Nigeria, one of the leading African countries, is blessed with many unexplored raw materials. The exploration and utilization of these raw materials requires a new and appropriate technology to meet the needs of under-privileged Nigerians in the area of provision of roofing materials. In the light of this, there is the need to develop an appropriate technology through the design of a compact machine for producing roof tiles.

In recent times, the vibrated technology has gained acceptance among contemporary building material manufacturers because of its inherent satisfaction in the provision of various forms of tiles, slabs, and blooms (Marbie, 1978).

Few roof tile fabricating machines designed to achieve similar objectives were produced in the past (Agarwal, 1984): Parry associates developed a hand –powered roller press, which was based on small-scale production utilizing clay to produce bricks a d tiles. This machine latter became obsolete because clay roof and bricks era were being gradually phased out due to the excessive use of fuel for firing (Parry, 1986). When the vibration technology was realised, the Scotch-yoke mechanism was developed. This machine, however, does not allow even distribution of the casting materials on the pattern because the vibration is longitudinal rather than vertical. Similarly, parry Associates developed another machine, but was not popular because of its low production output per day (Parry, 1986; Krishnamurthy,2015).

Bolyn construction Nigeria Limited also developed a gear-ratchet type vibration machine whose viability was limited by its hand-powered system. A similar roof tile making machine was designed with some limitations where vibration table was used as pattern for the moulding and unspecified pulley sizes (Liman, 1997). Utilizing locally available raw materials for roofing, an electricity powered vibrator type compact machine was design and developed for roofing tile production machines with limitation of possible crack on the (360x280x10 mm) roof tile (Zaka, et'al; 2002)

This work addresses the issue of the frequent crack experienced from previous literatures, enhancing the strength of roofing tile to favourably compete with the modern roofing sheets in Nigerian markets today.

II. MATERIALS AND METHODS

Materials for Machine and Pattern Fabrication

Locally available materials are sourced for the fabrication of the machine as well as the roof tile pattern. The materials were chosen on the basis of their suitable properties, economically readily availability, and viability in service (Thomas, 1978). Mild steel (0.15% to 0.25% Carbon content), due to its availability, suitability, and economic performance in service was utilised for the construction of the machine as presented in table 1.

Table 1: Machine Parts, Materials and Selection criteria

S/No.	Part Name	Material selected	Criteria
1	Base Plate	Mild steel 0.15% to 0.25% carbon content	Availability, High strength and Toughness, Low cost, and Shock resistance
2	Screed Frame	〃	〃
3	Bearing housing	〃	〃
4	Shaft	〃	〃
5	Machine stand	〃	〃
6	Vibrator Cover	〃	〃
7	Countersunk Screws	〃	〃
8	Cam disc	〃	〃
9	Pattern	Aluminium	Toughness and corrosion resistance
10	Ball Bearing	Cast iron	Toughness, hardness, self-lubricating, and shock resistance
11	Flexible Shaft	Butyl rubber	Torsional resistance
12	Springs (Automobile Valve Spring)	Cast iron	Vibration excitation, toughness, hardness, and shock resistance
13	Electric motor		Availability, and low cost.

The orthographic projection of the machine showing its front elevation is presented on figure 1, while the pattern which comprises of the cup drag type is also presented of figure 2.

Materials for the Clay Roof-Tile

The composition of the constituent material to be used for the production of the reinforced clay roof tile is obtained in two methods:

1. 20% fine sand, 30% Clay, 15% Rice husk, 18% Asphalt, and 10% plant resin are properly ground and homogenized; 7% water is then added after thorough mixture for semi-dry forming. This recipe can properly be summarised on figure 3 below.

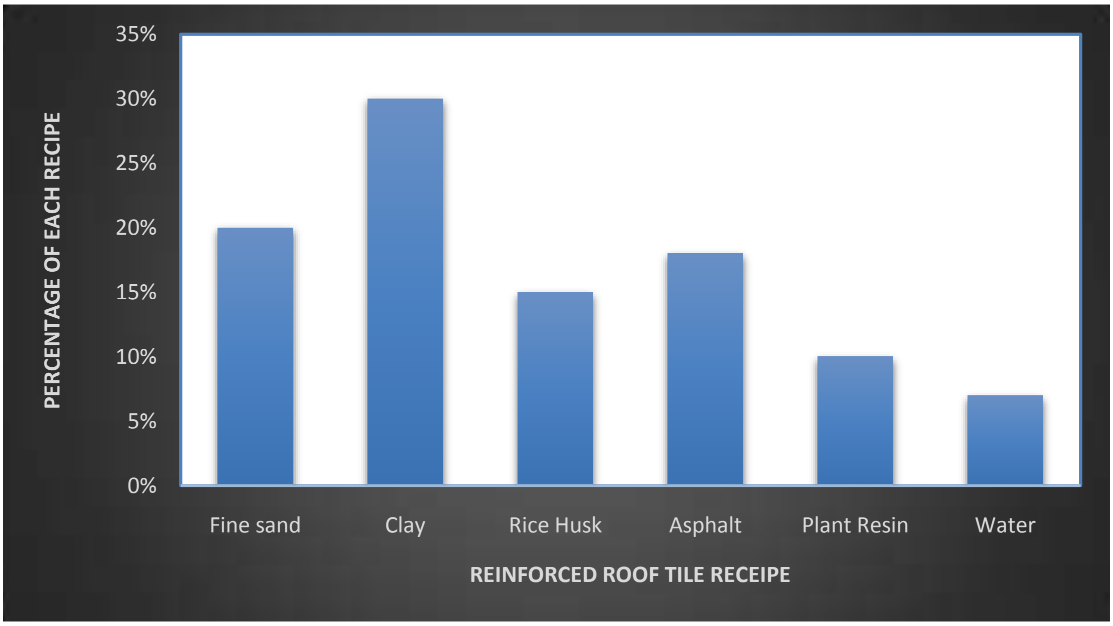


Fig. 3: The Percentage Representation of the Reinforced Clay Roof Tile Using asphalt with plant resin as binder.

2. 23% fine sand, 28% Clay, 13% Rice husk, 20% Cement, and 8% plant resin are properly ground and homogenized; 8% water is then added after thorough mixture for semi-dry forming. This recipe can properly be summarised on figure 4 below.

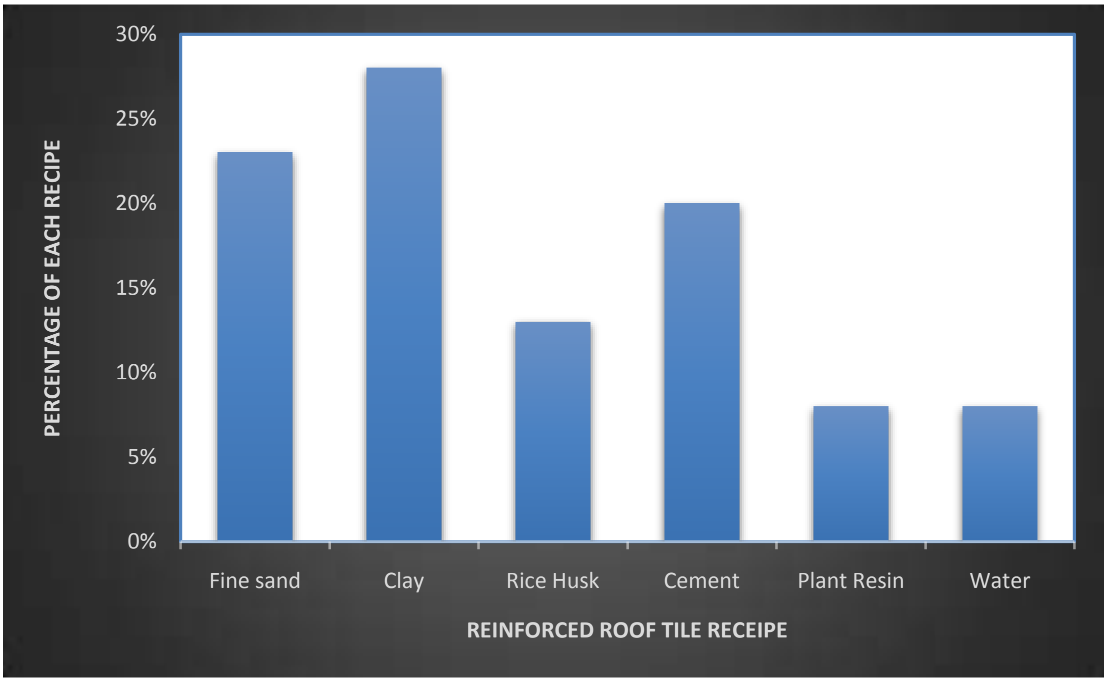
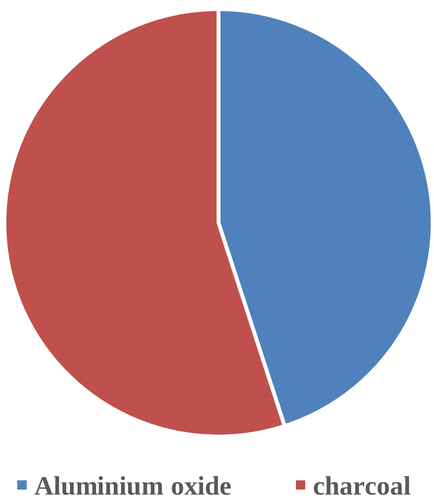


Fig. 3: The Percentage Representation of the Reinforced Clay Roof Tile using Cement with plant resin as binder.

A special parting powder of 45% Aluminium oxide mixed with 55% charcoal, grinded into fine powder was used to enable easy separation of the upper and lower patterns during the casting process.



Description of the Machine

The multi-pattern roof tile fabricating machine is a vibro-compaction type capable of producing a roof-tile 360x280x10mm dimensions.

Some of the major components of the machine include:

- The vibrating table: The multi- two piece patterns inclosing the roof tile recipe are placed on this table during operation.
- The vibrating table locking cover: Steadily and firmly holds the multi two-piece pattern in stable position during vibro-compaction process.
- The vibrating unit: comprise of an eccentric cam disc whose housing is welded under the vibrating table intersecting its horizontal and vertical centre points.

- The Helical springs: There are four (4) in number used as interphase connecting the vibrating table to the frame; and aids the excitation of the vibration processes.
- An Electric motor: providing the rotational motion for the eccentric cam disc vibrator.

III. PRINCIPLE OF OPERATION.

When forces acting in an individual part are such that the displacement of the mass centre of the part is oscillating or periodically reversing, it is said to be vibrating (Marbieet'al; 1978; and Nakra, 2003). The vibrational motion produced by the vibrator unit is transferred to the multi two piece patterns placed on the spring supported vibration table without machine failure. Utilizing the vibrational force with careful damping of the rotational force produced by the driving unit (Electric motor) the unbalanced rotating member produces the required operational force.

The unbalanced rotating member (eccentric mass) rotates with the same speed as that of the driving unit; causing the vibration of the base plate with simple harmonic motion as excited springs. This same vibrational effect is then transferred to the multi two-piece pattern carrying the mould. The vibro-compaction green strength is achieved after sometime. the roof tile is then dried in a controlled wind environment and diffused sunlight.

IV. THEORETICAL EQUATIONS AND PERFORMANCE EVALUATION.

The conceptual idea of the principles of the vibration of the machine would be very important in determining the performance of the machine. Some important equations are highlighted as follows.

1. The Total Stiffness Coefficient (K_t) of the machine. If there four (4) springs of same material, ($4K = K_t$); Spring diameter (D = 0.03m); Wire diameter of the spring (d = 0.004m); Number of spring coils (9); and the rigidity modules of the spring(83GN/m^2).

$$K_t = 4K = 4(\frac{Gd^4}{64nD^3}) = 5.465\, KN/m^2$$

2. The natural frequency (ω_n). When the mass of the vibrating table (m = 14Kg).

$$\omega_n = (\frac{K_t}{m})^{\frac{1}{2}} = 20\, rad/\sec = 1146\, rpm$$

3. The Amplitude (X). When an impressed force f_0 is experienced.

$$X = \frac{f_0 / K_t}{\sqrt{[1-(\omega/\omega_n)^2]^2 + [2\zeta(\omega/\omega_n)]^2}} = 0.15mm$$

4. Electric motor speed (ω) = 3000rpm
5. Frequency ratio $(\frac{\omega}{\omega_n}) = \frac{3000}{1146} = 2.62$
6. Stress at critical point (S_x). Where critical point stress (C = 0.5d); Moment due to bending stress M; and the Moment of inertia I are experienced by the member.

$$S_x = \frac{MC}{I} = 1.4MN/m^2$$

7. Torsional stress (τ_{xy}). If the torsional moment M_t, shaft radius r, and the polar moment of inertia J are experienced by the member.

$$\tau_{xy} = \frac{M_t r}{J} = .680.88GN/m^2$$

8. Maximum normal stress due to shear $S_{n(max)}$. IFF

$$S_y = 0 \;\; S_{n(\max)} = \frac{S_x - S_y}{2} + \sqrt{\frac{(S_x + S_y)^2}{2} + (\tau_{xy})^2} = .680.88GN/m^2$$

9. Minimum normal stress due to shear $S_{n(min)}$. IFF

$$S_y = 0 \;\; S_{n(\min)} = \frac{S_x - S_y}{2} - \sqrt{\frac{(S_x + S_y)^2}{2} + (\tau_{xy})^2} = -680.88GN/m^2$$

10. Normal maximum torsional stress (τ_{xy}).

$$\tau_{(\max)} = \frac{[S_{n(\max)} - S_{n(\min)}]}{2} = .680.88 GN / m^2$$

V. RESULTS AND DISCUSSION

The total cost of the machine including 10% inflation cost was N48,977:50 as at 20th July, 2018.

For one-man shift (24hrs), taking 10% of the total production time for auxiliary works, rest, breakfast etc.; the number of roof tiles produced per 25sec compaction time during this shift will be: $(\frac{86400\sec}{25\sec})10\% = 345.6\ Roof\ Tiles$. Thus, ≈ 346 of reinforced clay roof tile per one-man shift was realised; and 115 of reinforced clay roof tiles in 8 hours production time.

In the case of where multi pattern (four Sets of pattern), about 460 reinforced clay roof tiles realised in 8-hour one-man shift; and 1,348 reinforced clay roof tiles realised in 24-hour shift.

The roof tile was tested to have very less moisture holding and penetration properties.

The usefulness of any machine depends on the relevance of the results obtained from subsequent analysis that are of practical achievement. Table 2 below summarised the analysis results.

Table 2: Machine parameter Values

S/No.	Parameters	Values
1	The Total Stiffness coefficient (K_t) of the four Spring	55.465KN/m^2
2	The Natural frequency (ω_n)	1146rpm (20 rad/sec).
3	Electric Motor speed (ω)	3000rpm (52.36rad/sec).
4	The amplitude (X)	0.15mm
5	The frequency ratio (ω/ω_n)	2.62
6	The stress at critical points (S_x)	1.4MN/m^2
7	Torsional stress (τ_{xy})	680.88GN/m^2
8	Maximum torsional stress ($\tau_{max.}$)	680.88GN/m^2
9	Minimum Normal stress ($S_{n(min.)}$)	-680.88GN/m^2
10	Maximum Normal stress ($S_{n(max.)}$)	680.88GN/m^2
11	Machine cost estimate(including 10% material cost inflation)	N48977:50k

VI. SUMMARY

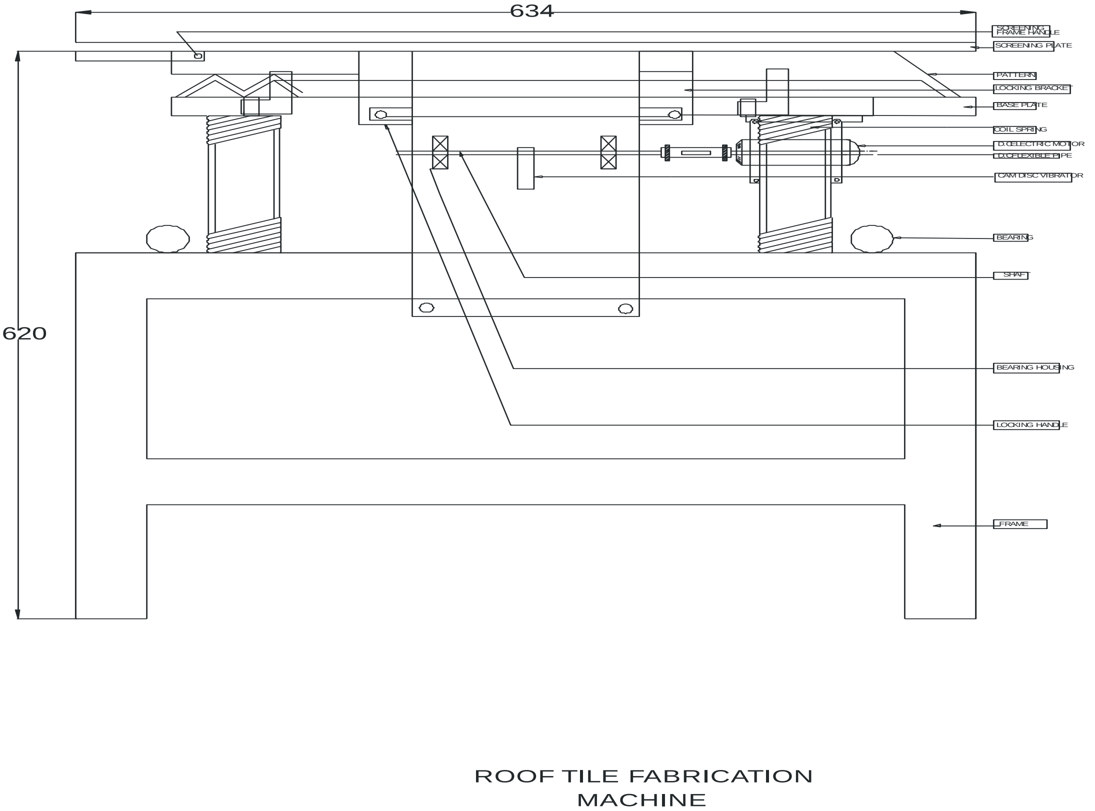
The multi pattern two-piece roof tile production machine is easy and cheap to fabricate, assemble, and requires little maintenances. About N48977:50k can acquire the machine, which could produce 115 roof tiles (360x280x10mm size) in 8hours of an average man working at normal pace, and about 10 roof tiles can cover 1m^2 of roof area. The semi dry compaction rate is 25seconds of vibration.

VII. RECOMMENDATIONS

- Entrepreneurial embracement of this technology will help unlock the economic challenges amongst Nigerian and African Youths.
- The involvement of private sectors and non-Governmental agencies will help easy acquisition of the machine, and operational/ maintenance trainings less privileged Africans.
- Readiness for inclusive and integrated participation to achieve the strategic African sustainable development and self-reliance should be preached in all areas of leaning about this latest African technology.

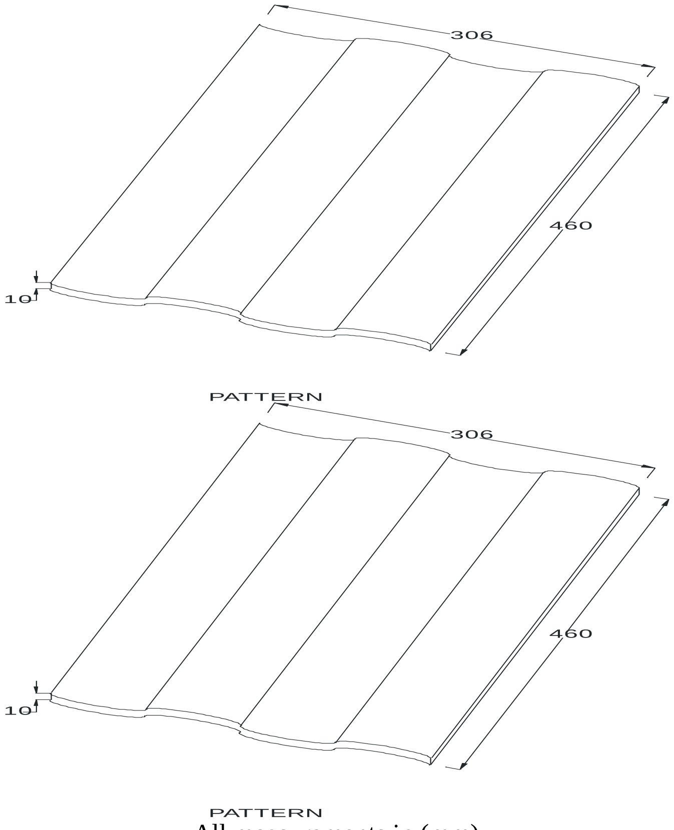
VIII. CONCLUSION

This machine, designed and developed using locally untapped abundant natural resource should be embraced for small, and medium scale entrepreneurship.



All measurements in (mm)

Fig. 2



All measurements in (mm)

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