# DESIGN CONSTRUCTION AND EVALUATION OF AUTOMATED COCOPEAT COMPACTION MACHINE

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## ABSTRACT

*Coconut is one of the major crops grown by small-scale farmers in Kenya coast. This crop has a great potential to contribute to the economy of the region, owing to the wide applications of its products. Virtually all parts of the crop including its leaves, fruit, stem and roots are useful for many products, such as food, beverages, cosmetics, medicine, furniture, textiles and cocopeat. Cocopeat is used as a planting medium in soilless culture in agricultural production and as a soil substitute in containerized crop production. Recently, these soilless media have received much interest in commercial applications in Kenya, especially in horticultural farms. Since the cocopeat is a loose material, its transportation poses a challenge due to its bulkiness. Therefore, a need for compacting it for ease of transportation from the point of production to the point of use.. For this purpose, an automated cocopeat compactor was developed and its performance evaluated. The compactor is a machine that is used to reduce the volume of the cocopeat material through compaction in a confined space. In performance evaluation of the cocopeat machine, dry cocopeat of 2.8% moisture content was compacted at pressures of 2.2 bar to 25 bar and compaction force of 4.5 kN to 50 kN Below 2.2 bar the cocopeat blocks produced disintegrated easily while above 20 bar the blocks produced had irregular edges and easily deformed on handling. For moisture content values below 10%, blocks were obtained at high pressures, while for moisture contents of above 30%, the excess moisture was squeezed out. Well compacted blocks were realized for moisture contents of between 10% and 30%. The cocopeat block machine developed has a blocking capacity of 48 blocks per hour.*

**Keyword:** *Coconut, Cocopeat, Moisture content, Density, Compaction.*

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## 1.0 INTRODUCTION

In Kenya coastal counties, over 100,000farmers rely on the Coconut Crop for their livelihood. Kenya has 436,634 acres of land under coconut cultivation with a tree population of 9.9 million producing over 246 million mature nuts annually (Agriculture and Food Authority, 2019). According to the Agriculture, Fisheries and Food Authority, over 120 products can be produced from coconut for Nutrition and Health (Agriculture and Food Authority, 2016). According to the Economic survey 2018 report, in 2017, Kenya produced 124,000 metric tons of coconuts of which 10,000 metric tons were used as animal feed, 34,000 metric tons was processed, 72 metric tons as food while 8000 metric tons became waste. It is estimated that the coconut sub sector has the potential to contribute up to 4.5% of the Agricultural Gross Domestic Product (GDP) and 1.2% of the national GDP (Kenya Bureau of Statistics, 2019).

The estimated potential of the coconut industry stands at KES 25 billion annually with the current exploited monetary value at KES 12.2 billion which is only 48% of the estimated potential (Agriculture and Food Authority, 2019).

The coconut sector is faced with many challenges that have made it not to realize its full potential. These challenges include: excessive harvesting of old coconut orchards, lack of proper storage facilities for harvested coconuts, lack of technologies for mass production, lack of machines in the coconut value chain to assist in coconut processing,, declining markets for traditional coconut products, limited research on ways to improve the coconut value chain and the exploitation of coconut farmers by middlemen in the value chain. These challenges have led to researchers to focus on the development of coconut processing machines in the country, their design, manufacture, fabrication and performance evaluation, to realize maximum benefits in both products and by-products in the coconut value chain to improve the income levels of farmers in coconut growing areas in Kenya.

In compaction, the fine materials, which deform under high pressures, need no binders. Valence forces, interlocking forces or the van der Waals forces influence the compaction characteristics of the materials. The prevailing high-pressure forces act on the natural components of the compressed cocopeat to become binders (Fernando & Amarasinghe, 2017).

The development of cocopeat compaction machines is essential for the agricultural sector. The compacted blocks must have the right compaction characteristics to avoid disintegration during transportation. Press pressure and cocopeat moisture content are critical for the achievement of the required characteristics (Lardinois & Klundert, 1993)

**1.1 Problem statement.**

The coconut sub-sector demonstrate an immense potential to drive the economic development in the coconut growing areas. This potential has necessitated a re-look at the coconut value chain to realize its full utilization. In the coconut value chain, cocopeat transportation to agricultural firms was difficult due to its bulky and spongy nature therefore the need to compact it into blocks of optimum density for ease of transportation. The cocopeat compaction machines available for this purpose and in small-scale use in the country, are manual with no data relating to their maintenance, operation and performance. On the other hand, the machines in industrial use are powered, automated, and efficient and have high production rates. These machines are expensive for small-scale use in terms of purchase, maintenance and operation as they cost over 10 million shillings. Thus, the need to develop a low cost locally- fabricated and automated cocopeat compaction machine that is efficient, accessible, easy to operate and easy to maintain, the machine will cost less than one million Kenya shillings.

**1.2 Research objectives**

The main objective of this study was to design, develop, and carry out performance evaluation of a cocopeat compaction machine.

**2. METHODOLOGY**

**2.1 Research Tests**

Laboratory tests were done to determine the design parameters after which the design, fabrication and testing of the machine was carried out.

**2.2 Design of an automated compaction machine**

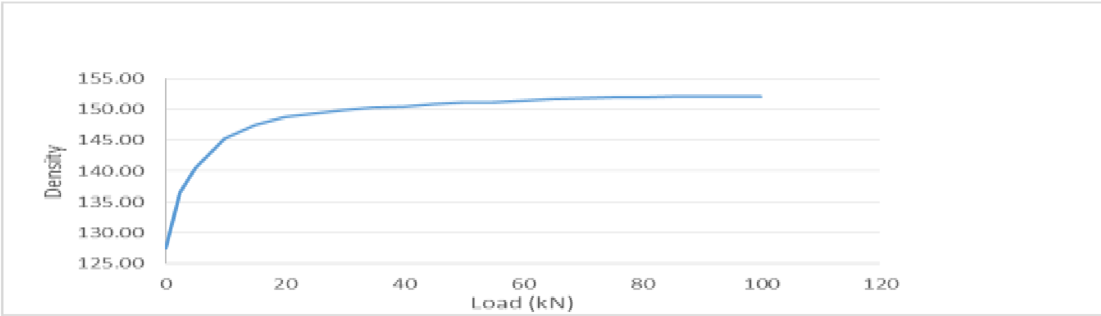
The design process of the compacting machine followed the following guidelines

a. Preliminary research,
b. Machine design considerations
c. Design concept development
d. Compaction machine fabrication and automation
e. Testing
f. Evaluation

**2.3 Compacting cocopeat using Ultimate tensile testing machine and a cuboid mould**

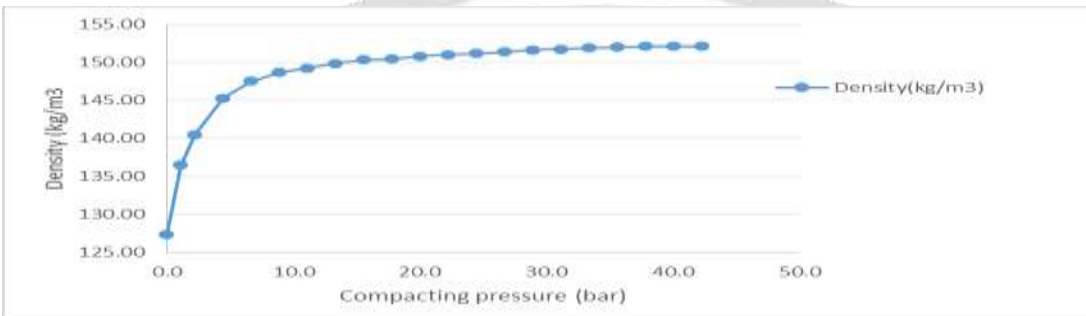
The ultimate tensile testing machine and a cube mould of dimensions 150 mm by 150 mm by 150 mm were used. The results obtained in (Appendix 4) was used in generating the graphs below.

On varying the compacting load, the density of the blocks increased up to a load of 25kN there after the density remained relatively constant. This is because the cocopeat particles held together at 25kN and no voids were left to fill.



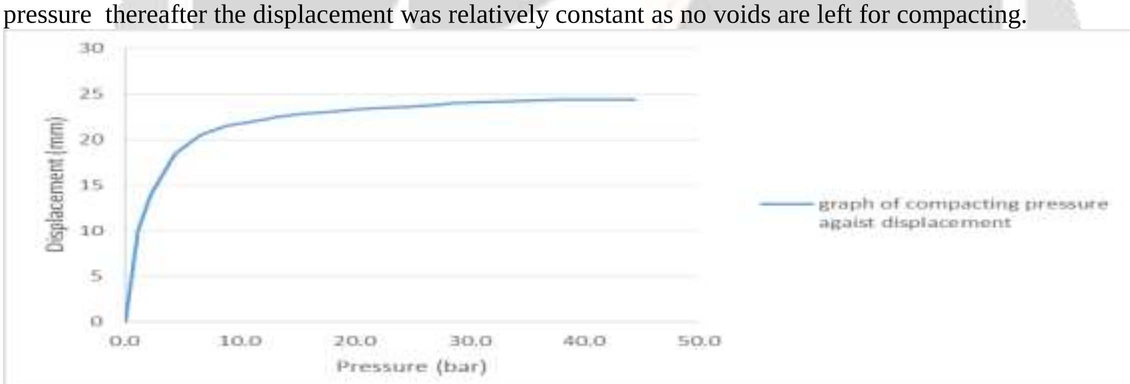
Graph of density as a function of load

On varying the compacting pressure at a given moisture content, the density of the blocks increased up to a pressure of 20 bar there after the density remained relatively constant. This is because the cocopeat particles held together at 20 bar and no voids were left for compacting.



Graph of density as a function of compacting pressure.

During the compacting process, increase in compacting pressure increased the displacement up to 20bar pressure thereafter the displacement was relatively constant as no voids are left for compacting.

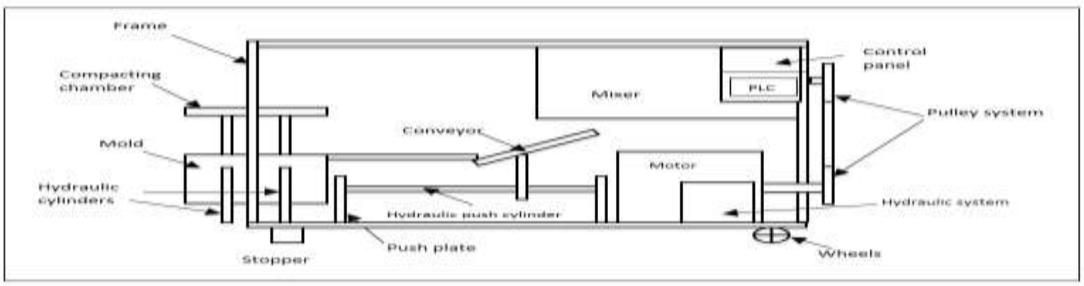


Graph of displacement as a function of compacting pressure

Using data extracted from these graphs, the cocopeat that was compacted was dry with a moisture content of 2.8%. It was observed that quality cocopeat blocks could be compacted when the compacting pressures are between 2.2 bar and 15 bar. Below 2.2 bar, the dry cocopeat does not hold together as the block density is below 140 kg/m$^3$, therefore, it easily disintegrates on application of any slight force by hand during handling. Between 2.2 bar and 15 bar blocks of density between 140 kg/m$^3$ and 150 kg/m$^3$ are obtained. The cocopeat blocks of densities within this range hold together and does not disintegrate on application of grip force by hand during handling. The blocks have straight edges which makes it easy to handle. On exposing the blocks to the atmosphere, the blocks absorb moisture in the air and expand in volume. This makes the blocks to readily disintegrate. On application of compaction pressure of above 15 bar, the bocks developed are not uniform, and blocks produced do not have straight edges. The pump used for compacting must have a pump pressure above 20 bar and able to produce a force above 50 kN. Based on these findings, a cocopeat compacting machine was designed. It was concluded that cocopeat can be compacted when dry if high compacting pressures are used. On varying the moisture content for the cocopeat, it was found that for moisture values of 10% to 30% the blocks produced had straight edges. Blocks with straight edges are easier to stack than those with irregular edges. The desired densities were achieved at compaction pressures of between 2 bar and 15 bar. For the moisture value of below 10%, high pressures were used to obtain the blocks and above 30% moisture content, the excess water was squeezed out when compacting. These results compared well with a research on Design and fabrication of a coir pith machine [18]. The cocopeat blocks are hygroscopic therefore they expand by absorbing atmospheric moisture and increase in size and eventually disintegrate. Blocks with high moisture content dry up on being left in the open and eventually disintegrate. The blocks therefore need to be sealed completely immediately after production in air tight containers.

**2.4 Design Concept**

The machine comprises the frame, hopper, the mixing chamber, the compactor and the mould. At the bottom end of the frame is the mold that is used to produce the blocks. On top of the mold is the compacting chamber. Beside the mold chamber is the mixing cylinder for breaking the lumps in the cocopeat and evenly mixing the cocopeat with moisture. Solid works® software was used to produce engineering drawings for the various sections.




Design concept of cocopeat compacting Machine

**2.5 Design calculations**

In the design, the calculations were based on the tests that were done using the Ultimate Tensile Testing (UTS) machine. The design calculations were as follows.

**The frame material properties**

The material used was mild steel with the following properties (Khurmi R & Gupta, 2005)

| | |
|---|---|
| Ultimate tensile strength | 400 Mpa |
| Yield strength, tension | 250 Mpa |
| Yields strength, shear | 145 Mpa |
| Modulus of elasticity (E) | 200 Gpa |
| Modulus of rigidity | 77.2 Gpa |
| Density (r) | 7860 Kg/$m^2$ |
| Coefficient of thermal expansion | 11.7 Gpa |

**Determination of Yields stress**

Maximum allowable stress = yield stress point/ Factor of safety ..........................................................................1

62.5 Mpa

**Frame**

The frame is the housing of the machine. The front section of the frame houses the mould and the compactor, has guides for the mould and compactor and it also has the compacting plate while the rear side has the mixing chamber, motor and the pulley.

**The mould**

The mould was designed based on the size of the cocopeat block to be produced and the amount of the cocopeat mixture needed to produce the block, a constant volume approach was used. This was preferred as it produces blocks of the same dimensions for ease of stacking and transportation. The mould chamber was 600 mm by 300 mm by 80 mm

**The factors considered include**

- The cocopeat block dimensions (L x W x H) 300 mm x 150 mm x 150 mm
- Factor of safety = 4
- The mould chamber to produce 4 blocks in a cycle
- Mould dimension of 300 mm by 150 mm by 150 mm
- Block Cross -Sectional area = (0.3 x 0.15) = 0.045 $m^2$

- Design compaction pressure 20 bar (2MPa) [2]
- Design force 50 kN

**Mold Plate Thickness**

The mould plate thickness was calculated using the relation of circumferential stress

Hoop/ circumferential stress $\sigma_h = Pd / 2t$ ……………………………………………………2

Where $\sigma_h =$ hoop stress (62.5 Mpa)

P = Internal pressure in the tube or cylinder (2 Mpa).

D = internal diameter of tube of cylinder (150 mm)

t = tube or cylinder wall thickness.

Thickness of the plate for the mold was 2.4 mm. From Appendix 2, mild steel sheet metal plate thickness of 3M was selected

**Deflection of the mold**

To ensure that the blocks were uniformly straight, deflection of the edges were checked.

The maximum deflection given by $y_{max} = \frac{5wl^4}{384EI}$ (Khurmi R & Gupta, 2005)………………3

Where:

W = distributed load (N/m)

L = Length of applied load (m)

I = area moment of inertia ($m^4$)

E = Youngs Modulus of elasticity (Pa or $N/m^2$)

$y_{max}$ = Maximum deflection

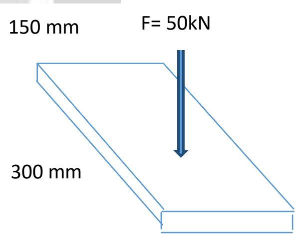
Maximum deflection ( $y_{max}$ ) = $\frac{5wl^4}{384EI}$ ………………………………………………4

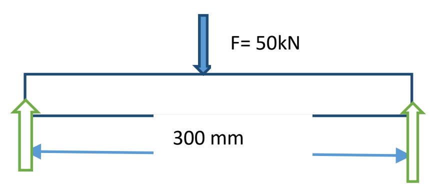
Therefore deflection, $y_{max} =$ 0.002 m

From the calculations, the maximum deflection was 2mm

This was considered negligible and therefore, the blocks was considered to be of straight edges. The partitions in the mold chamber were joined by arc welding.

**The design of compacting plate**




(a) Mould bottom cover (b) Mould botton cover cross section

Design of mould compacting plate

The compacting plate was flat with uniformly distributed load over the total area. The thickness (t) of a rectangular plate subjected to a pressure (p) uniformly distributed over the total area was calculated as below.

$$t = abk_2\sqrt{\frac{p}{\sigma_t\,(a^2+b^2)}} \quad \ldots\ldots 5$$

Where

a = Length of the plate (300 mm)

b = Width of the plate (150 mm)

p = Uniformly distributed pressure

$\sigma_t$ = Allowable design stress

The value of the coefficient of $k_2$ is given in table in appendix 8

The thickness of the compacting is calculated as 3.7 mm.

**Cocopeat extruder barrel design**

The mixing cylinder is where a rotating shaft joined to mixing screw carries out the mixing process.

**The hopper**

The hopper outlet was designed from the potente et al. (Potente & Klarholz) equation below.

$B = \frac{\sigma_c H(\theta)}{\rho g}$……………………………………………………………………………………….6

Where B = outlet width

$\sigma_c$ = consolidated stress generated in an arch at the outlet (kPa),

$H(\theta)$ = friction that takes into account of vibration in the arch thickness, hopper half angle and hopper geometric configuration,

$\rho$ = bulk density of material ($kg/m^3$)

g= acceleration due to gravity

Cocopeat bulk density = 21 $kg/m^3$

Max coefficient of friction of mild steel, m = 0.62 (zinash, Evans, Agidi, & Adeshina, 2016)

For free flow the relationship between the angle of inclination and the coefficient of friction is as below (Amol, Ulkesh, Prashant, Tejas, & P.K., 2015).

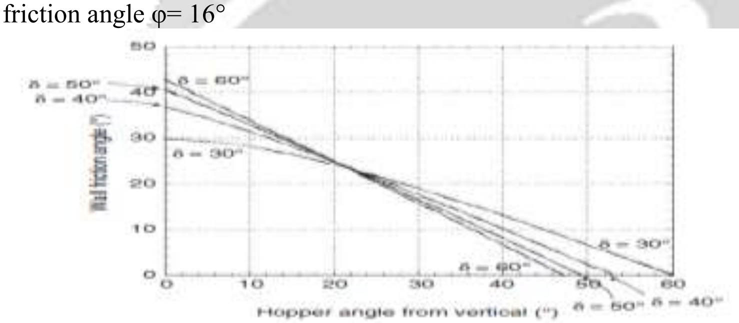
Tan q>m where therefore $q = \tan^{-1} m = q = \tan^{-1} 0.62 = 31°$

The design angle was chosen as 34, 3° above calculated value. This because of a repose of cocopeat increase when the cocopeat contains a lot of docking .The hopper opening remains empty and acts as a conduit to avoid spilling of cocopeat.

The effective angle of friction δ, wall friction angle φ, are estimated from the chart below.

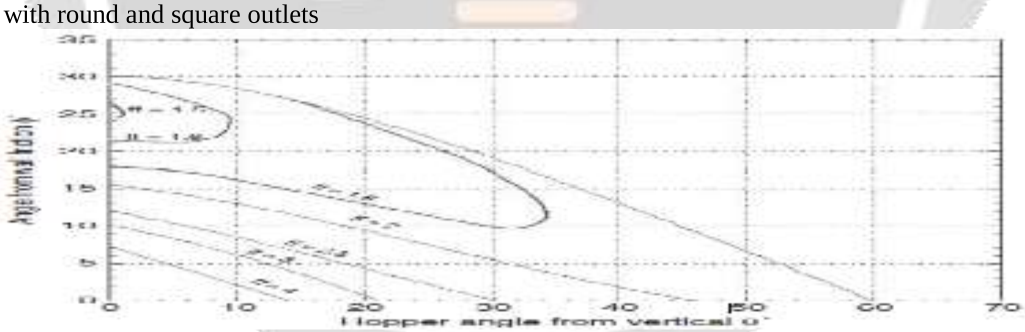
Effective angle of friction δ = 30°

Wall friction angle φ= 16°




Theoretical mass flow hopper angles for hoppers with round and square outlets

The friction factor ff of 1.8, was determined from the chart below Theoretical mass flow hopper angles for hoppers with round and square outlets




Flow factor for conical hoppers.

For slotted outlet $H(\theta) = \frac{200° + (\theta)}{200°} = 1.1$

Vertical load and stress under an arch in wedge hopper.

| Wall friction angle [°] | Hopper half angle [°] | Load [N] | Stress [Pa] |
|---|---|---|---|
| 25 | 30 | 28563 | 4760 |
| 20 | 30 | 23835 | 3973 |
| 15 | 30 | 20000 | 3333 |
| 10 | 30 | 16782 | 2797 |

$B = \frac{\sigma_c H(\theta)}{\rho g}$ B = 20cm

The hopper outlet must be large enough to prevent cohesive arches or stable rat holes from developing. The outlet size therefore depends on the cohesive strength and the bulk density of the cocopeat dust. The hopper was made of mild steel sheets to standard at an inclined angle of 34°. A hopper outlet dimensions were 0.2 m by 0.27 m and 0.3m high

**Determination of barrel dimensions**

The mixing cylinder was designed to accommodate the volume of mix needed to produce at least 20 blocks per cycle. A plate of thickness 2.4 mm was used.

Volume of the mold (L x W x H)

The needed volume = 0.135 $m^3$

Talking a compaction ratio of 5, Volume for mixing chamber cocopeat = 0.675 $m^3$

The length of the mixing chamber = 1.0 m, therefore, the diameter of the mixing chamber was given by……………………………………………………………………………………………….…………7

$$V = \frac{\pi D^2 l}{4} \quad \text{……7}$$

From which the diameter of the chamber is determined as 0.66 m.

**Shaft diameter**

The bending stress of the shaft was calculated using the equation below (Khurmi and Gupta, 2015)

$$\sigma_b = \frac{32BM}{\pi d^3} \quad \text{……8}$$

$\sigma_b$ = bending stress (N/$m^2$), BM = bending moment (NM), d = diameter of the shaft,

Using the bending moment equation, Hibler (2002)

$$BM = \frac{ql^2}{8} \quad \text{……9}$$

Using the $\sigma_b = \frac{32BM}{\pi d^3}$, d=20mm standard shaft was used

Maximum shear theory, $\tau_{max\ shear}$= 0.5 x $\tau_{yield\ stress}$ / factor of safety

T (torque) = $\frac{\pi \times \tau_{max} d^3}{16}$

**Extruder Auger design**

Taking a the pitch = 0.1m

Diameter of the screw D = 0.6m

Diameter of the shaft d = 0.02m

$$l = \sqrt{d \, x \, \pi^2 + P^2} \quad \text{……10}$$

$$L = \sqrt{d \, x \, \pi^2 + P^2}$$

$internal\ diameter\ of\ the\ auger, d' = \frac{D-d}{\frac{L}{l}-1}$ = 0.02m

$outside\ diameter\ of\ the\ auger = D - d + d'$=0.6m

**The capacity of the conveyor**

Conveyor capacity is given by Q=$60 \, x \, \frac{\pi}{4} \, x \, D^2 x S x N \, x \, \rho \, x \, \alpha \, x \, C$ ……11

Where Q= screw capacity (Kg/hr)

D= screw diameter in m (0.6m)

S = screw pitch in m (0.1)

N = screw speed in rpm 70rpm

ρ = material loose density in kg/$m^3$ (2.1kg/$m^3$)

$\alpha$ = loading ratio (1.5 for short pitch)

Pitch=0.5 diameter

C=inclination correction factor, 1 for horizontally installed screw

The capacity of the conveyor is 374 kg/h

**Power required for motor selection**

Power =2$T \pi N/60$ ……12

T = torque (49Nm)

N= revolutions per minute (70rpm)

Calculated Power = 0.359 = 0.4kW
A motor of 2.2 Kw and 1400rpm was selected taking into account a safety factor of 4.

**Machine speed reduction**

Gears were used in speed reduction in the machine.
The machine parameters were
Shaft speed = 90 rpm, Motor power = 2.2 Kw, Motor speed = 1450 rpm

**Torque calculation**

Input torque $= 2\pi NT/60$

T = torque (output = 49Nm)
N= revolutions per minute (output 90rpm)
N= revolutions per minute (input 1400rpm)
Power required is 0.5kW.

Input torque = $P \ x \ 60 \ /2\pi N$ = 15 Nm

Output torque = $P \ x \ 60 \ /2\pi N$ = 300Nm

**The design of hydraulic cylinders**

Design parameters used in hydraulic cylinder designs.
Design Force 50 kN
Design pressure 2 Mpa
Piston length (0.6 m)

Using the Euler's equation, force per rod, $F_{cr}$ is given by, $Fcr = \frac{C\pi^2 EI}{L^2}$ , ………………………………13

Where
*E*= modulus of elasticity or young's modulus for the material
*A*= area of cross section
*L*= length of the beam
*C* =constant representing the end conditions of the piston or end fixity
*I* = moment of area
$F_{cr}$ = 50kN L = 0.6 m

Considering a circular rod, $I = \frac{\pi r^4}{\;}$, $F_{cr} = \frac{c\pi^2 E(\pi r^4)}{4L^2}$, $r^4 \geq \frac{4L^2 Fcr}{\pi^3 E}$ $r^4 \geq \frac{4L^2 Fcr}{\pi^3 E}$, r = 10.4 mm

L

Thus, the diameter of the piston rods is 20.0 mm
Hydraulic cylinder of 1000 mm stroke, bore diameter 32 mm, rod diameter 25 mm, pressure of 20 bar and oil flow for 8.63 L /min, 65.5 kN Push, pull 52.5 kN was used.

**Capacity of the hydraulic fluid tank**

The capacity of the tank will be 4 times the LPM = 40 litres

**Summary of design parameters**

| No. | Item description | Dimensions |
|---|---|---|
| 1. | Frame | 2m x0.6m x1m |
| 2. | Mold chamber | 0.6m x 0.3m x 0.3m |
| 3. | Mold plate | 0.6m x .03m x 2.4 m |
| 4. | Compactor plate | 0.6m x 0.3m x 0.0037m |
| 5. | Hopper | 0.2m x 0.27m x 0.3m |
| 6. | Barrel dimension | 1.0m x 0.6m diameter |
| 7. | Barrel shaft diameter | 1m x x20mm |
| 8. | Extruder auger | Screw diameter 0.6m , shaft diameter 0.02m |
| 9. | Conveyor capacity | 374kg/hr |
| 10. | Motor | 2.2 Kw, 1400rpm |
| 11. | Hydraulic cylinder | Force 50kN, pressure 2MPa, piston stroke 0.6m |
| 12. | Hydraulic oil tank capacity | 40L |
| 13. | Gear box | 2.2kN, 93rpm, ratio 15:1 torque 213Nm, force 2950N |
| 14. | Hydraulic power unit | Powerlux |

**Machine Testing**

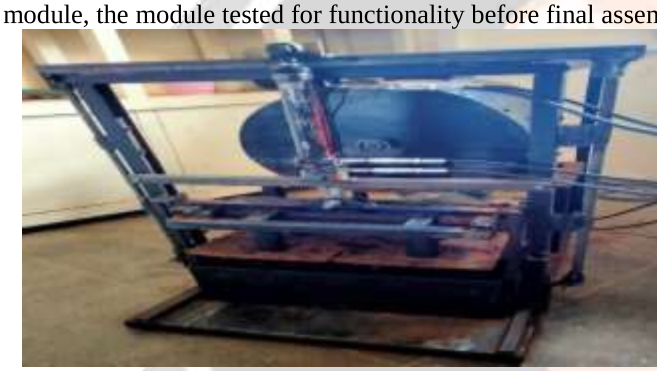
The fabricated machine was tested using available hydraulic system in the materials laboratory at multimedia university. Each component was tested for performance separately before testing the whole machine. The hydraulic system was first tested manually by means of directional control valves to ensure it works according to the design, by trying to move the pistons up and down using buttons on hydraulic control system. The pressure control and the relief valves also tested to be sure that they are working well and that their performance is as required. The pressure indicator was monitored to ensure that the piston motion stops at the required pressure. The machine was tested and worked correctly as per the design.

## 3.0 RESULTS AND DISCUSSION

In this chapter, analysis of Cocopeat Compaction Machines, fabrication and testing of the cocopeat compacting machine as well as the machine performance will be discussed. Laboratory experiments were conducted using various pressures and moisture content to determine the required design parameters. From the experiment, the optimum compacting pressures and moisture content was found. These were used in the design of the compactor for small scale farmers

### 3.1 Machine fabrication and testing

Fabrication, production of the various components, assembly and testing of the compaction machine was carried out in the mechanical engineering workshop at JKUAT and Multimedia University. Standard parts were purchased from local dealers. The fabrication was modular and at each stage on completion of a module, the module tested for functionality before final assembly.



Fabricated machine

### 3.3 Machine Performance Evaluation

The cocopeat production process was a systematic sequence and if one-step was left out then the results obtained would be blocks of poor quality. The blocks produced were stored in polythene-bags to shield them from the effects of the environment in readiness for transportation.

In performance evaluation, the cocopeat compacting machine was used in compacting cocopeat obtained from coco grow limited. The blocks were produced and the results were used to generate graphs showing the relationship between the compacting pressure, moisture content and density as in table 7. This shows that as the moisture content increases, the density of the blocks increases since the moisture content gets to fill the spaces in the compacted cocopeat dust. In addition, as the compacting pressure increases the density increases because increase in compaction reduces the spaces between the cocopeat dusts. This conforms the study by Manjunath el al. which showed similar results.

The machine blocking capacity is a measure of the machine production rates. The blocking capacity for the machine was 48 blocks per hour with a volume reduction ration of 5:1

## 4.0 MACHINE COST ANALYSIS

The cost of the machine comprises of the cost of the materials, the cost of production / labor cost and transport cost. Material costs are the costs incurred in the purchasing of materials that are used in the fabrication of the machine. Production costs are the costs that are incurred during the production of the machine. These include machining costs, welding and fitting costs. Transportation costs are the costs incurred in transporting materials to the where the machine is fabricated. Labour costs are the costs that are used to pay the people who are involved in machine fabrication. The breakdown of the costs was ksh 718, 280.

## 5.0 CONCLUSION

The cocopeat compaction machine was designed in accordance with the standard design calculations and constructed using simple fabrication processes. The machine was thereafter used to produce cocopeat blocks. The cocopeat was found to compact without any additive. In machine performance evaluation, the desired blocks were produced when compacting cocopeat between 2 bar and 20 bar and a moisture value of between 10% and 30%, above 30% the cocopeat blocks produced did not have straight edges. The blocking capacity for the machine was 48 blocks per hour and a volume reduction ration of 5:1 cocopeat dust to cocopeat blocks. The machine is recommended to be used by small scale farmers in coconut growing areas. Further research should be carried out to investigate the effect of using binders in the compaction process with a view to reduce the compacting forces.

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