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Design, Construction and Testing Of a Multipurpose Brick/Block Moulding Machine

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ABSTRACT : *The provision of shelter is one the most basic demand of a Man all over the World. It is one the most important challenges a man faces in his life. The problem of good shelter varies from place to place. A good shelter provides, first and foremost Security and Privacy. In the developed world the problem is less pronounced, but in the developing nation like Nigeria, the problem of shelter is more pronounced. There is about eighteen (18) million housing units' deficit in Nigeria. One of the most important materials used for building of a shelter is block/brick, but majority of the people cannot afford these materials (blocks or bricks) due high cost. Therefore, the production of high quality and affordable blocks/bricks is paramount to solving housing problems in developing countries especially in Nigeria. Thus, this research focused on design construction and testing of a multipurpose machine that produces high quality blocks/bricks for low cost housing. That is, for low income communities/earners. The constructed motorized compressive earth brick (CEB)/block making machine can produce on average a total of 2,215 bricks per day and 950 blocks per day. The cost of production of the machine was two hundred and eighty six thousand, eight hundred ninety (₦286, 890.00) naira only. Whereas, the most common high-tech motorized CEB machine in Nigeria (Hydraform®) with an average capacity of about 3,000 bricks per day costs about six million naira (₦6,000,000.00K) only. Thus, the machine is very affordable for small scale enterprise (SME). In other words, bricks or blocks produced by using this machine are relatively cheap and affordable for those in the rural areas and for low income earners.*

KEY WORDS: *Compressive Earth Bricks (CEB), Bricks, Blocks,*

I. INTRODUCTION

It is an undisputed fact that shelter is one of the basic human necessities. However, irrespective of the importance of shelter, most people do not have access to good shelter, most especially in developing countries. In fact there is an estimated deficit of between 17 and 18 million housing units in Nigeria in 2012, [1]. The poor are most adversely affected by this housing shortage. The most important building materials for low-cost housing are blocks/bricks [2], but conventional quality concrete blocks are too expensive for low-income communities. Due to high cost of Portland cement, a lot of block producers use less than the recommended amount in the concrete mix making the blocks to be substandard. This is one of the most important contributing factors for the frequent building collapse in the country recently. Bricks / Blocks are solid pieces of hard substances, usually with flat sides, used as construction units [3]. They are sometimes referred to as masonry units (MU). Block and brick masonry are strong, fire-resistant, insect-proof building materials. They have a lot of thermal mass, which helps them retain heat and makes up for their relatively low insulation value. However, despite their similarities, block and brick have some major differences: Blocks are bigger in size as compared to bricks; blocks are usually made of concrete and hollow, while bricks, on the other hand, are smaller usually made of clay or other earthen materials and solid [4]. Compressed Earth Brick (CEB) is an alternative building material to concrete blocks which have been proved to be an excellent substitute. However, the full potential of CEB is yet to be utilized due to the fact that most of the commercially available machines that produce CEB are very expensive. The most common CEB machine (Hydrafoam®) is sold at about six million Naira. There are simpler and cheaper low income brick/block producing machines.

The example of such machines are the Light Manual Brick Press known as CINVA RAM [5], the Montgomery's dynamic CEB making machine [2], the Ajao et al's Hydraulic Brick Press [6], the Akerele and Akhire's three-mould Hydraulic Interlocking Brick Moulding machine [7] and so on.

Although simpler and cheaper machines are developed, but they require high level skilled operator and diligence to produce good quality block/brick. In addition, due to the tedious or awkward procedures of running these simple machines, they are used mostly by intending house owners themselves to make the blocks or bricks.

Locally fabricated Cinva Ram (Fig 1.1), is the most common manually operated lever-action CEB press. It costs between ₦120, 000 and ₦180, 000 defending on the quality of the fabrication. Even though it is very cheap, it possesses the following disadvantages: low capacity (usually not more than 1,000 bricks per day), the absence of quality control mechanism and high level of physical labour.

Fig 1.1: Locally fabricated Cinva Ram on site

Therefore, first and foremost, there is need to develop a machine that will be relatively in-expensive, easy to be maintained, easy to operate and, most importantly, has a good quality control mechanism (such as compaction pressure control). Secondly, although the basic principle of block/brick making whether concrete or earthen is the same, no commercially available machines, to best the knowledge of the authors, that produces both concrete block as well as compress earth bricks. Thus, this research seeks to address the aforementioned challenges.

II. MATERIALS AND METHODS

The materials used in this research were Sand, Portland Cement, Earthen Materials (laterite, clay), while the Constructed Multipurpose Brick/Block Moulding Machine, Compression Testing Machine, Shovels etc were the instruments/tools used. The machined was designed to produce bricks/blocks enough to build a two bedroom flat in five days. The flat has a total wall area of $340m^2$. The area of 1 brick is $0.022m^2$, thus the total required bricks was approximately equal to 15,500. This means that in day an approximate 3,100 bricks was required.

2.1. Design Considerations/Assumptions

Design Considerations/Assumptions are:

- The size of the block/brick for this project is 220mm x 220mm x 100mm;
- The compaction/compression pressure of the machine was $10MN/m^2$
- It was assumed the internal pressure/stress of the mould is distributed evenly.

2.2. Design Calculations

The design calculations for each component of the machine were done and base on the results, the materials were selected and the construction was executed. The design calculations for the following elements were carried out: The Mould, Rammer & Ejector Plates, Rammer and Struts, Hydraulic Beam, Main Columns, Hydraulic Cylinder and Hydraulic Power Pum. The details design calculations are contained in M.B. Umar's Work [8]

- **The Mould**

The distributed load intensity (ω), cross sectional modulus of the mould wall (Z), the Maximum Bending moment (M_{max}) and Maximum Stress on the mould wall were all calculated. The maximum deflection was also calculated. The factor of safety for the machine was determined also.

- **Rammer and Ejector Plates**

The same calculations were done for the Rammer and the Ejector Plates.

- **Rammer and Ejector Struts**

The sectional second moment of area, radius of gyration, slenderness radius, and the crippling load were all calculated. The maximum bending moment, sectional modulus, and bending stress were calculated for the hydraulic cylinder beam. Likewise the following calculations were carried out for the hopper viz the weight of the hopper, the reaction due to hydraulic cylinder force, the resultant moment (which is the sum of the resultant moments of the upper rectangular part of the hopper and the lower trapezium part) and maximum stress on the columns.

2.3. Selection of the Hydraulic Cylinder and Power Pump

The hydraulic cylinder and power point were selected after the necessary calculations like the cylinder caliber (internal diameter), cylinder stroke, speed and pump discharge, speed, pressure, power, torque respectively.

2.4. Electric Motor Selection

The electric motor is standard component and its selection was done after defining the followings:

- Power requirement of the hydraulic pump
- Shaft rotational speed requirement of the hydraulic pump
- Torque requirement of the hydraulic pump
- Weather and other environmental conditions of the site of application
  The selection was done in accordance with the National Electrical Manufacturers Association (NEMA) Standard Publication MG-1-2010 [9].

2.5. Fabrication Processes of the Machine

The summary of the fabrication processes is presented in table 2.1 below.

Table 2.1 summery of components fabrication and tools

S/N	COMPONENT	DESCRIPTION	EQUIPMENT/TOOL USED
1	mould	150 by 240mm box open at top and bottom. Made from welded 8mm low carbon steel plate	Abrasive cut-off disc Milling machine and SMAW
2	feeder	150 by 240mm box open at top and bottom. Made from 4mm metal sheet	Abrasive cut-off disc and SMAW
3	Rammer/Ejector	Metal plate 150 by 240mm, 15mm thick welded to a U-shaped strut made from 75PFC	Oxy-acetylene cutting torch, abrasive grinding, milling and SMAW
4	Hopper	500 by 500mm, 200mm high upper box welded to 300mm high lower frustum of pyramid made from 1mm sheet metal	Guillotine machine, sheet bending machine and SMAW
5	Frame	Framework of welded structural steel made from 75PFC and 35mm angle bar 570 by 700mm, 1312mm high.	Abrasive cut-off disc, drilling machine and SMAW.
6	Guide rods	Steel rods 35mm diameter 800mm long, threaded at both ends	Abrasive cut-off disc and lath machine
7	Rammer bar/Ejector bar	500mm long 75PFC with holes and 50mm flat bar brackets	Abrasive cut-off disc, drilling machine and SMAW.
8	Hydraulic cylinder bar	500mm long 75PFC with round holes and rectangular holes	Abrasive cut-off disc, drilling machine, milling machine and SMAW.
9	Pump-motor base	Rectangular base frame 570 by 225mm made of 75PFC, 35mm angle bars and 10mm thick metal plate	Abrasive cut-off disc, drilling machine and SMAW.
10	Pump bracket	L-shaped bracket 150 by 120mm 150mm high made from 10mm thick steel plate with holes	Abrasive cut-off disc, drilling machine, lath machine and SMAW.
11	Hydraulic cylinder bracket	Steel plate 120 by 100mm with round holes and rectangular hole	Abrasive cut-off disc, drilling machine, milling and SMAW.
12	Ejector latch	Flat bar 325mm long 50mm wide by 5mm thick with holes and cut out	Abrasive cut-off disc and drilling machine.

However, all the components of the hydraulic system are standard/adopted engineering components. These are: the Hydraulic Cylinder, Hydraulic Pump, Control Valve, Oil Tank and Filter, Hydraulics Hoses, hydraulic hoses' fittings and Electric Motor.

The fabricated multipurpose brick/block making machine is presented in fig. 2.1 below.

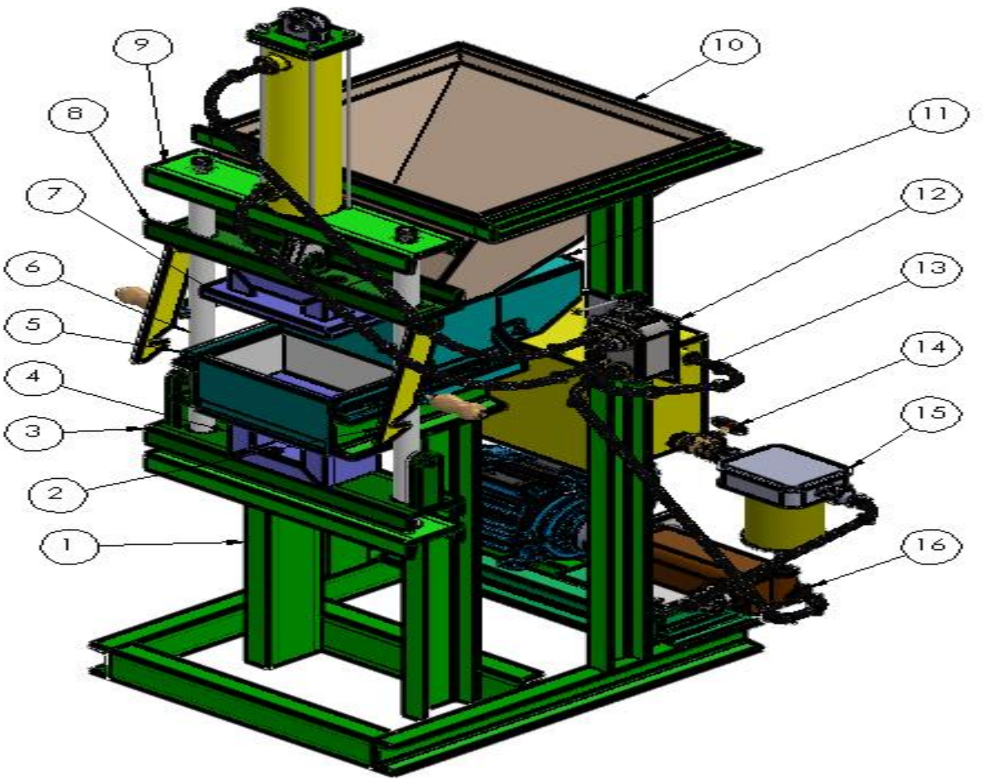

Fig. 2.1 Multipurpose Brick/Block Moulding Machine (3D CAD)

1. Main frame	2. Ejector latch	3. Ejector bar	4.Ejector
5. Mould	6. Guide rod	7. Rammer	8. Rammer Bar
9. Hydraulic cylinder bar	10. Hopper	11. Feeder	12. Control valve
13. Hydraulic oil tank	14. Oil supply valve	15. Oil filter	16. Hydraulic pump

2.6. The Cost Implication (Cost Analysis)

The cost of the machine comprises the cost of materials, the cost of production (labour costs) and transportation. The break down is presented in table 2.2

Table 2.2 Cost Breakdown

S/N	Item Description	Quantity	U/M	unit cost(₦)	Amount (₦)
1	100PFC C-channel	14	m	1,600.00	22,400.00
2	75PFC C-channel	14	m	1,200.00	16,800.00
3	35 x 5 equal angle	14	m	500.00	7,000.00
4	50 x 5 flat bar	21	m	200.00	4,200.00
5	8mm low carbon steel sheet	1	m^2	5,500.00	5,500.00
6	4mm low carbon steel sheet	1.2	m^2	3,000.00	3,600.00
7	15mm low carbon steel plate	0.2	m^2	12,000.00	2,400.00
8	1mm low carbon steel sheet	20	m^2	200.00	4,000.00
9	25mmØ polished rod	2	m	2,500.00	5,000.00
10	M24 Hex hd bolts and nuts	6	pcs	220.00	1,320.00
11	M8 Hex hd bolts 20mm long & nuts	35	pcs	30.00	1,050.00
12	M10 stud 1000mm long	6	pcs	125.00	750.00

13	12Hp, 3phs electric motor	1	pc	22,000.00	22,000.00
14	jaw coupling	1	set	5,000.00	5,000.00
15	220GPM, 45MPa Hydraulic Pump	1	pc	45,000.00	45,000.00
16	150 x 1000mm Hydraulic cylinder	1	pc	9,000.00	9,000.00
17	12mmØ, high pressure flexible hose	5	pcs	3,000.00	15,000.00
18	20mmØ, high pressure flexible hose	2	pcs	4,200.00	8,400.00
19	12mmØ, hydraulic hose fittings	15	pcs	320.00	4,800.00
20	20mmØ, hydraulic hose fittings	4	pcs	300.00	1,200.00
21	directional control valve	1	pc	12,000.00	12,000.00
22	hydraulics oil tank	1	pc	3,500.00	3,500.00
23	hydraulics oil filter	1	pc	4,200.00	4,200.00
24	1" gate valve	1	pc	500.00	500.00
25	1" pipe fittings	6	pcs	120.00	720.00
26	2.5mm^2, 4 core flexible cable	5	m	850.00	4,250.00
27	ball bearings (203)	6	pcs	300.00	1,800.00
28	welding electrodes	2	pkts	3,000.00	6,000.00
29	abrasive cutting discs	10	pcs	550.00	5,500.00
30	abrasive grinding discs	5	pcs	500.00	2,500.00
31	hack saw blades	5	pcs	300.00	1,500.00
32	hydraulic oil	15	lts	400.00	6,000.00
	Total				**232,890.00**
	tooling/labour cost				
33	machining				18,000.00
34	welding and fitting				25,000.00
35	Transportation				11,000.00
	Total				**54,000.00**
	Grand total				**286,890.00**

2.7. TESTING (Brick/Block Production Processes)

2.7.1. Testing Procedures

i) The materials used were soil, sand, cement, water and shovel. The selection of the soil for the production of the compressed earth brick (CEB) was in accordance with laid down guidelines [10]. One of such guidelines is that all soil types considered good for road construction are also good for making CEB. Therefore, the soil used was obtained from a road construction borrow site.

ii) The soil lump was crushed using wooden poll and then sieved to remove lumps and stones bigger than 5mm, because big stones and lumps will necessitate higher compression force according to P. Odul et al [11]

iii) Water was added to the soil by sprinkling and then mixed thoroughly with shovel until it was homogeneously damp (fig. 2.2)

FIG 2.2: Earth mix just after mixing

iv) The damp soil mix was then covered with a polythene sheet and allowed to soak for three days (fig 2.3) (as per ARS 674: 1996) [7]. This is to ensure that every lump is well permeated by the water.

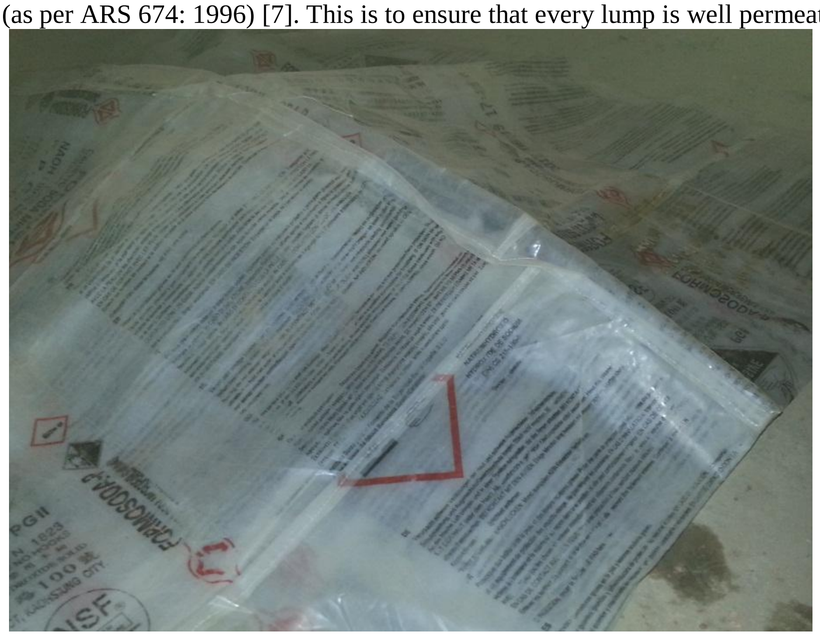

Figure 2.3 Soil Mix covered after mixing to soak

Then thereafter, the bricks were produced. The machine was operated under the following conditions:

1. Compression Pressure: 10Mpa
2. Moisture content: 6%
3. Curing time: 7days
4. Mould size (length x width x height): 235mm x 148mm x 150mm.

2.7.2. The brick production processes

The production of the bricks was carried out following the steps below.

1. The hydraulic oil tank was checked to ensure adequate oil level
2. The oil supply valve to the hydraulic pump was fully opened
3. The electric motor was then powered
4. Feeder was positioned directly under the hoper
5. Using shovel, the mix was fed to the hoper
6. Holding the feeder handle, the feeder was moved to a position above the mould and then the feeder was shaken back and forth to make sure that the mould was well filled (fig. 2.4)

Figure 2.4 Soil Mix being fed into Mould from hopper

7. By depressing the lever of the directional control valve, the rammer was lowered into the mould and therefore compressing the soil to its final density.
8. Using the same lever but this time upward, the compressed soil block is now ejected
9. Using palms of both hands (fig. 2.5) the *Green Block* was removed from the machine to curing area.
10. The cycle was repeated for other blocks

Figure 2.5 Compressed Soil Block lifted to curing yard

The same procedures were followed in the production of the concrete blocks. (fig. 2.6 and fig. 2.7)

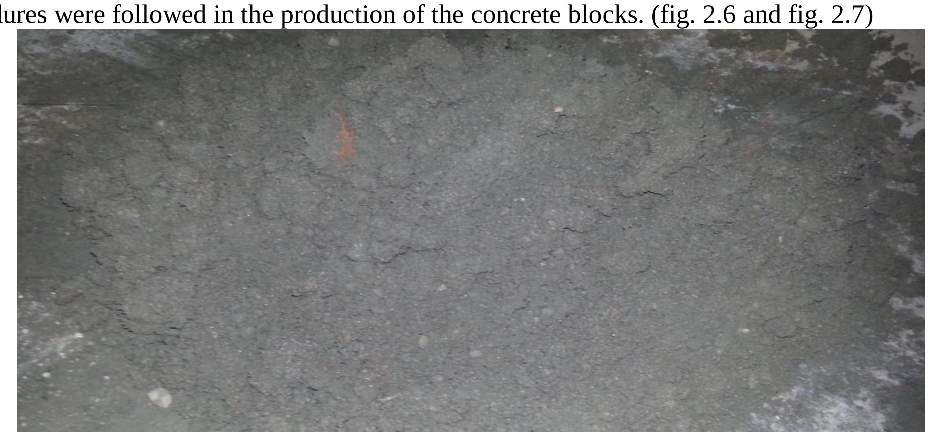

Figure 2.6 Concrete Mix

Figure 2.7 Concrete Block

2.7.3. Determination of the Mechanical and Physical properties of the bricks/blocks: The mechanical properties examined were: the compressive strength, bulk density, moisture content, compression ratio using the ASTM C 67 standard. The physical properties (squareness, surface smoothness/flatness, dimensional uniformity/accuracy) were also examined. For the bulk density determination, twelve (12) bricks were used, while for the compressive strength two (2) sets of seven bricks were used for both dry and wet conditions.

III. RESULTS AND DISCUSSION

3.1. Results: The results of the bulk density and compressive strength are presented in tables 3.1 and 3.2 respectively.

Table 3.1 Bulk Density and Physical Characteristics

TRIAL NUMBER	PRODUCTION PERIOD (s)	BLOCK HIGHT (m)	WEIGHT (kg)	VOLUME (m^3)	BULK DENSITY (kg/m^3)
1	14	0.0778	4.9177	0.00268	1833
2	12	0.0758	4.6998	0.00261	1798
3	12	0.0769	4.9059	0.00265	1850
4	13	0.0770	4.9176	0.00266	1852
5	15	0.0768	4.7591	0.00265	1797
6	12	0.0790	4.9009	0.00272	1799
7	13	0.0779	4.8918	0.00269	1821
8	14	0.0791	4.8935	0.00273	1794
9	12	0.0763	4.7466	0.00263	1804
10	13	0.0755	4.7280	0.00260	1816
11	12	0.0772	4.8159	0.00266	1809
12	15	0.0780	4.9518	0.00269	1841
AVERAGE	**13**	**0.0773**	**4.8440**	**0.00266**	**1818**

Table 3.2 The Compressive Strength

	Wet		**Dry**	
S/N	Max load @ failure (KN)	Compressive strength (N/mm^2)	Max load @ failure (KN)	Compressive Strength (N/mm^2)
1	96.98	2.79	249.01	7.16
2	95.43	2.74	251.21	7.22
3	97.67	2.81	248.99	7.16
4	96.19	2.77	253.07	7.28
5	95.98	2.76	249.18	7.16
6	98.07	2.82	250.25	7.20
7	95.79	2.75	248.59	7.15
average	96.59	**2.78**	250.04	**7.19**

3.2. Discussions

3.2.1 Compression Pressure

The hydraulic pressure of the system was maintained at 10MPa by means of adjusting the set-point of the Pressure Relief Valve (PRV) on the hydraulic power pump, and monitored through the Pressure Gauge as shown on Fig 3.1. This pressure is obtained at the motor speed of 1,450rpm.

Compression pressure (as per African Regional Standards for Compressed Earth Blocks ARS 674: 1996) is classified as follows: very low pressure 1 to 2 N/mm^2, low pressure 2 to 4 N/mm^2, medium pressure 4 to 6 N/mm^2, high pressure 6 to 10 N/mm^2, hyper-pressure 10 to 20 N/mm^2 and mega-pressure 20 N/mm^2 and over.

The size of this machine fall within the light hydraulic brick machine category, which usually provides high compression pressure (6 to 10 N/mm^2).

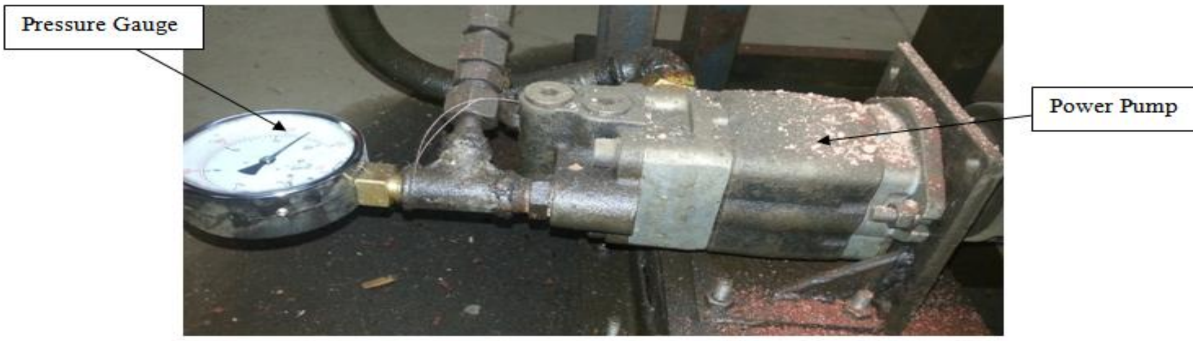

Figure 3.1 Hydraulic Power Pump with Pressure Gauge

3.2.2 Bulk Density

Dry density of the produced block is often the primary measure of performance of block machine [10]. The higher the bulk density of the block, the stronger the block is [10]. The bulk density of each of the twelve samples is presented in Table 3.1 and it was obtained by dividing the weight of the block by its volume. The average bulk density of the block is 1818kg/m^3 which is approximately 1,800kg/m^3. Although the most desirable CSB density is 2,000kg/m^3[12], 1,800kg/m^3 is also adequate for most applications [10]. Besides, this density can be improved by adjusting sand content and moisture content of the mix [10].

3.2.3 Production Rate

The production rate is a direct function of the *Capacity* of the power pump as well as the ability of the operator. The average production period of a block was 13seconds as presented in table 3.1. Therefore, in an eight-hour working day the average total bricks produce was:

$$Production\ rate/day = \frac{60\times60\times8}{13} = 2{,}215 \text{ bricks per day}$$

Compared with the design production capacity of 3,100 brick per day (section 2 above), this production rate is less than the desired. However, this rate can be boosted by increasing motor speed or by modifying the machine to produce two or more bricks at the same time.

3.2.4 Moisture Content

Moisture content, taken as a percentage of solid material by weight is usually within the range 2-10% [10]. For this work, 6% was used.

3.2.5 Compression Ratio

The compression ratio, which is a measure of how well the soil is compressed, is the change in volume of the compressed soil as compared to the volume of the uncompressed soil.

The compression ratio of the machine was 0.52. This is important in selecting the mould size for a given target of compressed block size. For example, if 100mm height of block is desired, then the Mould must be at least 200mm high for this soil type.

3.2.6 Compressive Strength

Compressive strength is one of the most important characteristics of all masonry units. The ASTM C46 standard procedure was used to measure the compressive strength of the bricks and blocks and the results are presented in table 3.2. The tests were carried out on two sets of seven specimens under two different conditions of *dry* and *wet*. This is because in practice, the CEBs are used under wet and dry conditions, hence their strength under the two conditions are important.

The *wet compressive strength* was 2.78N/mm^2 while the *dry compressive strength* was 7.19N/mm^2.
African Regional Standards for Compressed Earth Blocks ARS 674: 1996 - Compressed Earth Blocks Technical Specifications for Ordinary Compressed Earth Blocks recommends 3N/mm^2 and 6N/mm^2 as minimum wet and dry compressive strength respectively [5]. While, Nigerian Building and Road Research Institute (NBRRI) propose 1.65N/mm2 as minimum wet compressive strength for CEB [7]. Therefore, the bricks meet the laid down standards.

3.2.7 Dimensional Parameters

1. **Squareness of the block:** The dry compressed blocks were checked for squareness with a Try Square as shown in Figure 3.2 and it was found that all adjacent sides are square (i.e.90^o) to each other. In other words all opposite sides are parallel to each other.

Figure 3.2 Dry Block being checked with Try Square

2. **Dimensional uniformity of the block:** All dimensions measured with Vanier Calliper of the dry blocks (fig. 3.3) were consistent for all the produced samples with the exception of block height, which is also within the allowable limit of dimensional accuracy of ±2mm.

Figure 3.3 Dry Block being measured with Vanier Calipers

3. **Dimensional accuracy:** The Produced samples were measured at different points to ascertain consistency within the same sample. It was found that the differences between them are less than a millimetre, except also in the height dimension. The height discrepancy is controlled by adjusting inclination of rammer.

IV. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

- A multipurpose brick/block making machine was designed in accordance with the standard design calculations and it was then constructed using simple fabrication processes. Thereafter, the machine was used to produce affordable and quality bricks and blocks in line with the African Regional Standard for compressed earth blocks ARS 674: 1996 [5] and the Nigerian Building and Road Research Institute(NBRRI) standard.

- The cost of producing the machine was two hundred and eighty six thousand, eight hundred and ninety naira (N286,890:00) only. This is very cheap compared to the similar machine (Hydroform CEB machine) that costs about six million naira (6,000,000:00) only.
- The actual brick production rate was two thousand, two hundred and fifteen (2,215) pieces per day. This is lower than the designed rate of three thousand and hundred (3,100) pieces per day. However, this can be boosted by increasing the motor's speed or modifying the mould to produce two (2) or more bricks/blocks simultaneously.

4.2. Recommendation

- In order to be able to produce hollow masonry units, the mould has to be modified to a movable mould that will accommodate pallet.
- The machine could be automated especially the feeding and evacuation components (mechanism). This will improve its performance and the safety of the operator.

- This machine can be modified such that it can have bigger mould and a means of feeding and compaction of the mix in lifts, preferably automatically. This should be made simple and not expensive.

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