Design and Construction of a Low Cost Manually Operated Interlocking Tile Moulding Machine

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Abstract- An intensive study of a manually operated interlocking tile moulding machine have been undertaken, in which its construction was made with mild steel as the material of choice. The component parts were joined mainly by bolt and nut for temporary joint and permanent joints obtained by welding. This machine is manually operated using a lever to raise the mould while the moulded tile remains on the pallet. The compressive safe load of mould cavity when loaded was calculated to give consideration for factor of safety with regards to modulus of elasticity of the mild steel used. It was observed that the machine has a critical load of 189.3MN, and a compressive save load of 126.2MN. Also, determined was the moment at both handle (A and B) which was obtained as 1133.7Nm and 619.2Nm respectively. The working stress of the machine was calculated as 1650KN.

Index Terms- Design, construction, interlocking machine, tile, moulding, compressive strength

I. Introduction

The construction industry is labour-intensive; the importance of mechanization has been realized and is growing rapidly [1-2]. The construction revolution of today has made contractors to equip their construction work so as to obtain the highest output with minimum construction cost. In order to have utmost output, parameters like accuracy, precision, quality, and cycle time have to be optimized [3-4]. Many construction of nowadays are done with interlocking tiles. Interlocking tiles have been extensively used in a number of countries for quite some time as a specialized problem-solving technique for providing pavement in areas where conventional types of construction are less durable due to many operational and environmental constraints [1, 5, 6]. Interlocking tile moulding machine was used in the United States in early 1970s as a replacement for conventional block moulding machine which had become scarce due to the post-war building construction boom. These blocks are rectangular in shape and had more or less the same size as bricks. The earliest known example of a construction made in the country was in 1837 at State Island, New York [6]. Some decade ago, interlocking concrete tile technology was introduced in Holland and Indian, for specific requirement via goth paths, parking areas, drive way etc., but currently is adopted extensively in different uses where the conventional construction of pavement using hot bituminous mix or cement concrete technology was not feasible or desirable [7-8]. In Nigeria, interlocking tiles block is widely used for construction work; however, the tiles are produced via traditional method of loading the pallet with the raw materials (cement, sand, water, concrete sealer, etc.) compressed with hand by using wood and allow for proper drying. This method is cumbersome and time consuming.

Interlocking tile moulding machine include; hydraulic interlocking tile moulding machine, electro hydraulic interlocking tile moulding machine, electric interlocking tile moulding machine [9]. However, there are two main categories of interlocking tile moulding machine; the vertical face interlocking tile moulding machine and horizontal face interlocking tile moulding machine. Making interlocking tile with vertical face machine require the face of the block of the machine to be in a vertical position and the block is simply lifted from the machine on its base plate. The horizontal face machine, so called a face down tile machine is made with the face plates which forms the bottom of the mould [10]. Nevertheless, the process of shaping the tile is different from that within a vertical face machine. The Principal difference in these two classes of machine is that the horizontal face machine is more convenient to use when it comes to pulling in special facing in moulding tiles, while in the vertical face tile moulding, the special facing is put on by the use of parting plate [11]. In this research work, the designed machine will work with the principle of horizontal face interlocking tile moulding machine.

The aim and objectives of this research work are as follow;

i. To produce a manually operated interlocking tile moulding machine with an interchangeable mould cavity.
ii. To encourage local skills development to boost income generating opportunity.
iii. To meet the growing demands of this interlocking tile in Nigeria
iv. To reduce production time and encourage mass production.
v. To produce a machine that is economically affordable and environmentally friendly

II. MATERIALS AND METHOD

2.1 Materials

Material selection poses a lot of challenges most especially in the area of research of materials to be used. Mild steel was chosen for the fabrication of this project which is a plain carbon steel and is an alloy of iron and carbon containing less than 0.15-0.25% carbon by weight; Practically other element are also present either as deliberate addition or as impurities. Mild steel was selected based on toughness and ductility with a maximum tensile strength of about 700N/mm^2. It is the cheapest and most versatile form of steel which serve every application requiring huge amount of steel. The higher the amount of carbon also makes mild steel vulnerable to rust. Naturally, stainless steel would have been preferred than mild steel for its rust free technology but mild steel is of better use in higher tonnage for structural purpose, and cost was another factor considered. After construction, the interlocking moulding machine will be painted with anti-rust paint before finally giving a befitting coloured finishing.

2.2 Method

In the design and construction of this manually operated interlocking tile moulding machine, the following operations were carried out;

i. Measuring and marking out of the material (mild steel)
ii. Cutting of the material(mild steel)
iii. Bending operation which is done at angle 45
iv. Drilling operation, Reaming operation
v. Joining operation(temporary and permanent joining) and
vi. Finishing which include assembly of component part and painting

2.3 Design Consideration

The strength of the material is an important factor in determining the geometry and dimension of the material. In such a situation, the strength is an important design consideration; design consideration refers to some characteristic influencing the design of the interlocking tile moulding machine. Sometimes, one of these considerations turns out to be critical, and when it is satisfied, the other are no longer needed to be considered. Factor such as strength, reliability, corrosion, wear, friction, cost evaluation, factor of safety, weight, noise, size, stiffness as well as its compaction. Some of these have to do with the dimension, material selection (mild steel), the design processes and joining of the component part of the project.

2.4 The Machine Operation

The machine has a manually fitted lever in which the round bar raises the mould at the application of force lifting the cavity and leaving the moulded tiles on the wooden pallet for removal. After accurate concrete mixing ratio have been achieved by measuring the dry material using bucket and some other type of measuring device, the concrete is then poured inside the mould cavity of a specific pattern and shape. Compaction is achieved manually by ramming using the top cover of the mould when a downward force is acted upon on the ejection lever to smooth and level the top surface of the moulded tile.

2.5 Design Calculations

Calculation on this machine involves the strength of material, the stability of the material under load. The material used for the construction is mild steel which has ultimate tensile strength of 3.3kN/m^2. The components are made of ductile materials which are subjected to external static forces. Yield strength is considered to be the criterion of failure. When such components are overloaded and the stress due to external force is exceeded, there is a small amount of plastic deformation which usually does not put the component out of service. Ductile components have a homogenous structure and the residual stresses can be relieved by proper heat treatment. The stress analysis is more precise in case of static forces and due to these reasons, the factor of safety is usually small. The load acting on the fixed supports is shown in Figure 1.

2.5.1 Determination of Critical Load

$$P_{euler} = \frac{\pi^2 El}{L_{e2}} \quad (1)$$

where,
E = Assumed modulus of Elasticity
P = Critical Load
I = moment of inertia
Le = Equivalent length of the column
Let factor of safety be 3
But,
$E = 95 \times 10^9$ N/m^2
Condition: Both ends are fixed supports
Length of the column is 19'' = 19 x 25.4 = 482.6mm

$$I = \frac{\pi}{64}(D^2 - d^2) \quad (2)$$

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Measurement of diameters from mould cavity
Let D = 33.782mm = 0.338782m
d = 13.548mm = 0.0135m

$$P_{euler} = \frac{\pi^2 \times 95 \times 10^9 \times \frac{\pi}{64}(0.152 \times 0.22225) - (0.1016 \times 0.13335)}{0.4826^2}$$

$$\frac{9.5764 \times 10^{-4} \times (4.6025 \times 10^{10})}{0.2329} = 189.3MN$$

$$safe\ load = \frac{P_{euler}}{FS}$$

$$\frac{189.3 \times 10^6}{0.2329} = 63.1MN$$

∴ Overall safe load = 2 x 63.1MN = 126.2MN

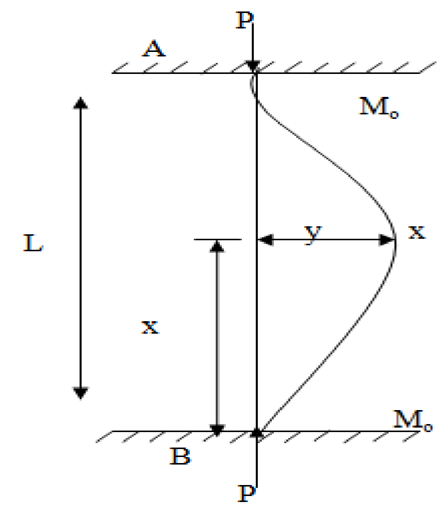

Fig.1: Load acting on the fixed supports

2.5.2 Calculation on Ejection Lever
Figure 2 shows the schematic diagram of the ejection lever

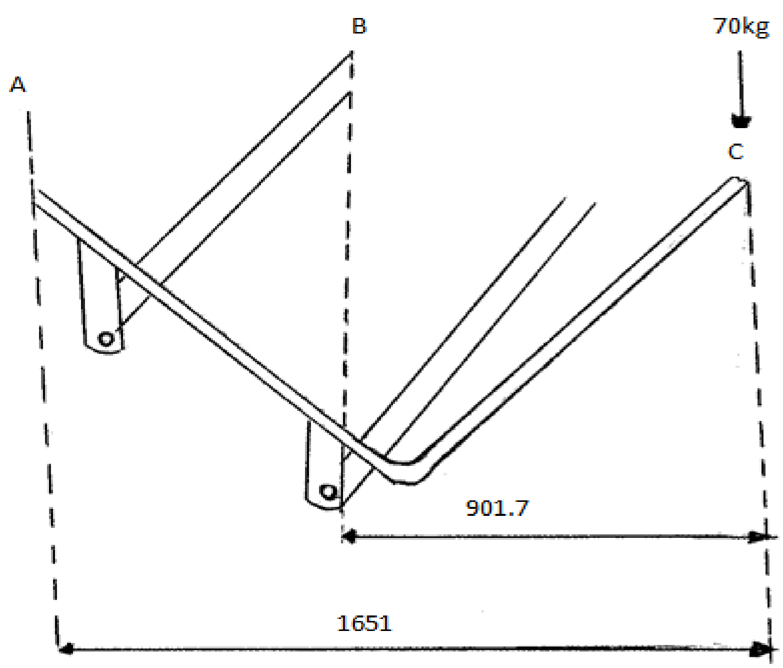

Fig.2: Schematic diagram of the ejection lever

But the moment of the handle at point A,
From,
Force = mass x acceleration (3)
F = 70 x9.81=686.7
Distance moved from A to B = 1651mm =1.651m obtain from the machine.
But,
M_A = Force x distance (4)
M_A = 1.651 x 686.7 = 1133.7Nm
Also,
Moment on the handle at point B
Distance moved from B to C=901.7mm=0.9017m
M_B = 686.7 x 0.9017= 619.2Nm
Force require for shearing the bar
Area = $\frac{\pi d^2}{4}$ (5)
Diameter of the lever is 50mm =0.05m
$A = \frac{\pi d^2}{4}$ (6)
$A = \frac{\pi \times 0.05^2}{4} = 1.964 \times 10^{-3}$
But,
Working stress = $1650KN/m^2$
Thus,
Compressing Force = δ x A (7)
Compressing Force = $1650x10^3$ x 1.964 x 10^{-3} m^2 = 3240N

2.5.3 Handle for Lifting the Mould
Diameter for the handle = 10mm = 0.01m
From,

$$A = \frac{\pi d^2}{4}$$

$A = \frac{\pi \times 0.01^2}{4}$ =7.855x10 $^{-5}$m
Working stress = $1650KN/m^2$
Force = δ x A
F = $1650x10^3$ x 7.855 x 10^{-5} = 129.6N

2.6 Fabrication Process of Interlocking Tile Moulding Machine
The project is purely based on mechanical concept. The procedures and steps used in getting the entire component in shape at required dimensions are:

i. Measuring and marking out of the material
ii. Cutting operation
iii. Bending operation
iv. Drilling operation
v. Reaming operation
vi. Welding operation

2.6.1 Measuring and Marking out Operation
The mild steel plate was measured with a steel rule, marked out with scriber and edge surface so as to ensure good fitting work

2.6.2 Cutting Operation
The steel plate with the aid of a cutting machine guiding with measurement was cut. Metal cutting or machining is the process of producing work piece by removing unwanted material from a block of metal, in form of chips. This process is important, since almost all the product gets their final shape and size by metal removed either directly or indirectly. Most cutting process have the same basic features where a single point cutting tool is used, a milling cutter, a drill and broach can be regarded as several single point tools. A single cutting tool consists of sharpened cutting part called its point and the shank. The part of the tool is bounded by face and side flank with the base. The side cutting edge is form by intersection of the face and the end flank. The chips are cut from the work piece by the side-cutting edge. A single point cutting tool may be either right or left handed cutting tool depending on the direction of feed. In a right handed cutting tool, the side cutting edge is on the side thumb when the right hand is place on the tool with the palm down ward and the finger pointed towards the tool nose

2.6.2 Force acting on A Single Point Tool

In orthogonal cutting where the tool cutting edge is perpendicular to the cutting direction, only two forces will act at the cutting tool point; cutting force F_C and the feed force F_F. F_C acting on the vertical plane and is tangential to the job. It will be downward for anticlockwise rotation of the job. F_F act in the horizontal plane, parallel to the axis of the job and in opposite direction of the feed. It helps in holding the tool in position. However, in oblique cutting, where the cutting edge is inclined to the cutting direction, another force 'normal force' F_N or 'radial force' F_R acts in the horizontal plane along the axis of the tool and normal to the job surface. The force will tend to push away the tool from the work piece which may cause chatter.

Thus,

$F_f = F_t = 0.3$ to 0.6

$F_C = F_r = 0.2$ to 0.4 F_C.

The three forces F_C, F_f and F_n are mutually perpendicular and can be represented in vector. The resultant force Fe which is the single equivalent force acting on the tool point can be determined as;

$$F_e^2 = F_C^2 + R^2 \quad (8)$$

Also,

$$R^2 = F_f^2 + F_n^2 \quad (9)$$

R is the diagonal of the horizontal plane.

$$Fe = F_C^2 + F_f^2 + F_n^2 \quad (10)$$

2.6.3 Energy Consideration in Metal Cutting

The total energy required per unit time during metal cutting E is given by Equation (11);

$$E = F_C \times V \quad (11)$$

The total energy consists of two main parts; the shear energy (E) required to produce the plastic deformation in the shear zone and the friction energy (E_f) used as the chip slides along the tool. Other small contributions to the total energy are: energy required to curl the straight chip, kinetic energy required to accelerate the chip and the surface energy required to produce the new surface area. These three type of energy are negligible so, as a first approximation.

$$E = Es + E_f \quad (12)$$

The energy per unit time divided by the volume removed per unit time is known as the specific energy.

$$Total\ specific\ energy, E = \frac{E}{btv} = \frac{F_C}{btv} \quad (13)$$

$$Total\ specific\ energy, E = \frac{E}{btv} = \frac{F_S V_S}{btv} \quad (14)$$

$$Total\ specific\ energy, E = \frac{E_f}{btv} = \frac{F_S V_S}{btv} \quad (15)$$

where,

b = the depth of cut

t = uncut chip thickness and

v = cutting speed

2.6.4 Bending Operation

This is another operation carried out during the fabrication of the interlocking tile moulding machine. This operation is a metal working operation by which a straight bar is transformed into a curve bar. It is a very common forming process for changing sheet and plate into channel, rod etc. During this operation, the outer surface of the material is in tension and the inside surface is in compression. The strain in the bent material increases with decreasing radius of curvature. The stretching of the bending causes the neutral axis of the section to move toward the inner surface. In most cases, the distance of the neutral axis from inside of the bend is 0.3t to 0.5t.

where;

t = thickness of the part.

2.6.5 Drilling and Boring Operation

Drilling operation is the process of cutting or initiating a round hole on the solid mild steel. The drilling tool and not the work piece is revolved and fed into the material along its axis. There are many way of classifying drills for example according to material, number and type of flutes, drill size, type of shank and cutting point geometry; however, the commonly drill type is fluted twist drill which is made from a round bar of tool material, and had three principal part, the point, body and shank. The drill is hold and rotated by its shank, the point comprises the cutting element while the body guides the drill in operation. The body of the drill has two helical grooves called "flutes" which cut into its surface. The flutes from the cutting surface also assist in removing chip out of the drilled hole. The two cutting edges are straight and are separated by web thickness of the drill which is provided to strengthen the drill structures.

Drilling machine select the appropriate bit to provide holes for the bolt and nut where joining becomes necessary. Apart from drilling machine, drilling operation can also be performed on the lathe machine

2.6.6 Boring Operation

This is employed to enlarge the diameter of an already existing hole, previously drilled with the aid of a boring bar or tool held in the tool post to the required diameter. Accurately sized hole with a good surface finish can be produced on the lathes machine by first, rough drilling and then finish machining with a boring tool. The process involves;

i. Holding the work piece securely on the chuck either three or four jaw chuck or face plate.
ii. Mount on the headstock
iii. Centre drill the component
iv. Using pilot drill, get the highest size of the hole possible
v. Clamping the boring bar to replace drill on the tail stock then bore to size
vi. Holes produced in this manner are concentric with all external diameters machined at the same setting

2.6.7 Welding Operation

After all part of the interlocking machine has been successfully made, the parts were permanently joined by means of electric arc welding. In this case, heat is liberated at the arc terminal and this heat is used to melt the metal to be welded at the point of contact, so that they will flow together and form an integral mass; thus different point may be joined. A filler material is also added to the surface of the metal.

III. RESULTS AND DISCUSSION

The machine was tested and evaluated for performance. The average production period of an interlocking tile was 20seconds. This was used to evaluate production rate per day.

$$Production\ rate = \frac{60 \times 60 \times 8}{20} = 1{,}440\ interlocking\ blocks\ per\ day$$

It was revealed that the machine can produce 1,440 interlocking tiles per day. The compression ratio, which is a measure of how well the mixture of cement, water, sand are properly compressed, is the change in volume of the compressed mixture as compared to the volume of the uncompressed mixture. The compression ratio of the machine was 0.71, and this was vital in selecting the mould size for a given target of compressed interlocking tile size. Cost was an important factor considered when selecting materials used for the fabrication. Cost of the project comprises of material cost and the labour cost. Analysis was carried out to evaluate if the machine was cost effective.

Table 1: Bill of Engineering Material and Evaluation

S/N	Component	Unit Price (₦)	Quantity	Total Price (₦)
1.	2mm thick mild steel plate	5,200.00	1	5,200.00
2.	5mm flat bar	1000.00	1	1000.00
3.	2mm angle iron	800.00	2	1,600.00
4.	4x4mm square pipe	2,100.00	1	2,100.00
5.	3x3mm square pipe	1,100.00	1	1,100.00
6.	20mm solid rod	750.00	1	750.00
7.	15 pieces of electrodes	10	15	150
8.	17mm Bolt & Nut	50	4	200
Total				12,100.00

Table 2: Labour Cost

S/N	Painting	500
1	Transportation	1200
2	Construction	1000
Total		2,700

Total Cost = Labour Cost + Material Cost = 12,100 + 2,700 = ₦14,800 = $40.88

The results of detail designed is summarize in Table 3. It was observed that the machine that the critical load is 189.3MN. However, for the system to be saved during compression operation, a saving load of 126.2MN is required. Also, determined was the moment at both handle (A and B). The moment at handle A and handle B were obtained as 1133.7Nm and 619.2Nm respectively. The working stress of the machine was calculated as 1650KN/m^2.

Table 3: Detail Designed Results

Parameter	Determined Value
Length of column	482.6mm
Diameter of mould	0.0135mm
Critical load	189.3Mn
Safe load	126.2MN
Moment at handle A	1133.7Nm
Moment at handle B	619.2Nm
Area of lever	$1.964E^{-3}$
Working stress	$1650KN/m^2$

IV. CONCLUSION

Interlocking tile moulding machine is designed to produce as many tiles as the operator intends of various and sizes relative to the mould pattern used. It is portable and need no further training or skills before uses. The ease of operation has made it not a skillful labour oriented as it can be use anywhere under any condition. The joint must be grease often to ensure easy movement of the arts. The interlocking tile moulding machine should be clean and kept in a safe place after used. The machine needs periodic maintenance for effective workability. Considering the Nigerian economy and the minimal cost of producing this interlocking mould machine which is operationally flexible in terms of interchangeability of mould pattern, the project concept will enhance the economic positively and the same time develop indigence technology.

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