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Development of a Rectangular Mould with Vertical Screw Press for Polyurethane (Foam) Wastes Recycling Machine

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Abstract: *This paper presents the development of a rectangular mould with a manually operated vertical screw press for recycling of polyurethane foams. The polyurethane foams find their uses in different aspects of mankind thereby leaving enormous wastes behind after their useful lives. Polyurethane foams are non-biodegradable products that pollute the ecosystems. One of the solutions to the menace of environmental pollutions is to recycle the wastes, which can be mechanical, chemical or waste to energy conversion. Recycling should therefore be efficient and affordable to carry out, in other to produce new products from old foams wastes and save the environments since they are not biodegradable. With recycling, new useful products can be achieved. The polyurethanes processing industries generate enormous wastes and utilize big industrial machines for recycling these polyurethane wastes. It then means that these industries recycle only wastes they generate during their operations but not the old polyurethane foams which are abundantly polluting the environment. The costs of the big industrial machines make it almost impossible for small cottage industries to be engaged in recycling of old and used foams after their useful lives. This brought about the idea of developing small scale and cost-effective rectangular mould with vertical screw press for polyurethane (foam) wastes recycling machine. The manual vertical screw press acts to compress shredded foam crumbs in the rectangular mould at a volume ratio of 6:1 which is the same as the industrial recycling machine. The vertical screw press is a threaded shaft attached to a rectangular plate via a special locking system; the threaded shaft was carefully supported by two 30 mm rod at equidistant from the screw, this ensure the free vertical movement of the plate into the rectangular mould for effective compression, the entire component was suspended in the mould via a suspension bar on the frame. The two samples produced with the recycling machine and a reference sample from the industry were taken to University of Lagos Research Laboratory for testing and comparison of their mechanical properties. The results obtained from samples produced with this recycling machine were comparable to the results obtained from the reference sample produced by the industrial recycling machine. The chemical loss reduced from 150 kg on the industrial recycling machine to 3.0 kg on this small-scale machine was achieved, which translate to about 50:1 loss reduction. Furthermore, the same densification as those of the industrial machine was also achieved.*

Keywords: *Pollution, Polyurethane Foams, Polyurethane Recycling, Rectangular Mould, Recycling Machine, Vertical Screw Press.*

1.0 INTRODUCTION

Polyurethanes also known as poly-carbamates belong to a common class of compounds called polymers. Polyurethanes were first developed in the 1930s, and found utilization in many areas especially in the homes, offices, industries and insulations. Polyurethanes that are used for important commercial purposes usually have other groups in their structures, these groups include esters, ethers, amides, or urea groups that are for enhancing the structure of polyurethanes [1]. It is very important to recycle polyurethanes because they are non-biodegradables and remain in the environment for a long period thereby polluting the environments. Several attempts had been made in the past to recycle polyurethane foams wastes from polyurethane foams manufacturing processes, industries, households, and equipment to other useful purposes and benefits. These attempts include but not limited to physical and chemical recycling. These recycling can be done by several different or combine methods including mechanically by using compression moulds; chemically by the use of chemical reagent that will bond the foam crumbs together, and energy recovery (including waste-to-energy) which is either complete or partial oxidation of the polyurethane materials, to produce heat, energy, and different types of fuels, oils and chars as well as other by-products such as ashes (that can be disposed of), or by combination of several methods like mechanical and chemical recycling methods [2 – 7]. Recycling of polyurethane foam wastes can generate great incomes for the foam producing industries when they sell their wastes to recyclers and for the recyclers when they produce and sell new products produced from the recycled polyurethane foams [8]. Several studies were undertaken to obtain information on the state of recycling of polyurethane foam wastes in Nigeria. It was observed during the studies that some of the polyurethane manufacturing industries in Nigeria are recycling their polyurethane wastes by themselves but using big industrial recycling machines for the purpose. The small and cottage industries could not be involved in the recycling of polyurethane foam wastes recycling because of the huge costs involved in acquisition and running of the big industrial machines needed for the recycling. It was also observed during the studies that the present recycling processes are not efficient in materials and resources utilization. Hence, there is need to design and develop smaller machines that can carry out the same process of recycling of polyurethane foam wastes efficiently and cost effectively whether new or old foams. This will bring in more participants into the process of recycling polyurethane foam wastes and more revenue for the recyclers. This will generate more employment opportunities for the polyurethane value-chain. The machines needed for the mechanical recycling of polyurethane foams consists of a shredder, a mixing chamber, a mould with a vertical screw press (compressor), and steam boiler that supplies steam for curing of the mixture. This present work, “rectangular mould with vertical screw press” for the compression and bonding operation of the shredded foam crumbs wastes, is a subcomponent work of the entire polyurethane recycling machine. The shredder and the mixer for this particular polyurethane recycling machine were already developed and presented in earlier publications [9,10]. Hence, the objectives of this work are to design, fabricate and test a rectangular mould with manually operated vertical screw press with a rectangular pressing plate. The vertical screw press is provided with two supporting guides attached at both ends that ensures the centralization of the screw, the screw and the two supports are then attached to the rectangular pressing plate which is used to compress the shredded and blended foam crumbs in the moulding box as the screw moves vertically downwards. The developed mould and vertical screw press are then assembled with other machines [9, 10] to achieve polyurethane foam recycling machine.

2. MATERIALS AND METHODS

2.1 Materials

A number of factors were taken into consideration in the choice of materials for the construction of the mould and manual vertical screw press to produce a simple, efficient, reliable and stable product. During the selection processes, suitability of engineering materials, costs, availability, rigidity, fatigue strength, fracture toughness, weldability, corrosion resistance, resistance to acidic reaction, wear resistance and other properties were considered.

2.1.1 The rectangular mould: The rectangular mould shown in Figures 1a and 1b is a rectangular box made of galvanized steel with a sliding side. It receives the discharge of mixed foam crumbs and chemical from the mixing drum, the vertical screw press is then used to compressed the mixture in the mould to form the desired product. The rectangular mould is the “forming” section for the mixed foam crumps. It is fabricated with a 1.5 mm thick plate welded together in a cuboid shape and has the following dimensions, 640 mm, 520 mm, and 660 mm, length, breadth and height respectively. The mould is also brazed round with square pipes to ensure rigidity and prevent bulging which may affect the overall dimensions of the products. An opening is created on one side of the mould (as shown in Figure 1) to facilitate the easy of removal of the final product.

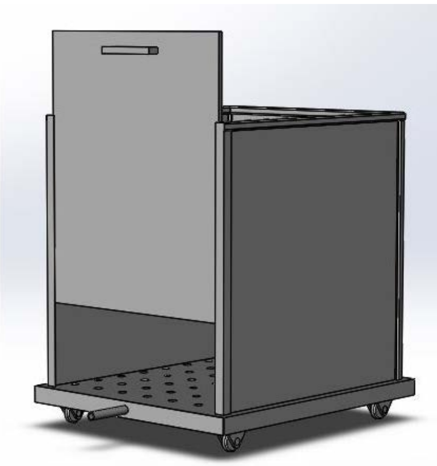

Figure 1a: 3-D model of the rectangular mould

Figure 1b: Fabricated rectangular Mould

2.1.2 Steam box: The steam box made of galvanized steel plate is shown in Figures 2a and 2b. This is the section that receives steam from the boiler and discharges the steam into the mould. It is fabricated with a 15 mm thick galvanized plate to cuboid of 40 mm, 710 mm and 610 mm for height, length, and breadth respectively. The top of the box is perforated with a 6 mm drill bit at 60 mm distance from each other to ensure effective percolation of steam into the box cavity. The mould was welded onto the steam box and the entire component was mounted on four Teflon tires to translate on a rail to and from under the mixer for discharge of foam mixture.

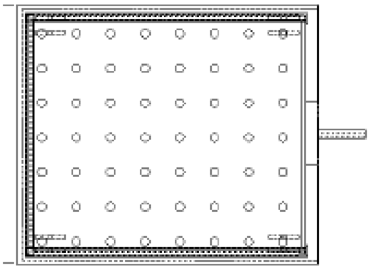

Figure 2a: 3-D model of steam Box

Figure 2b: Fabricated Steam Box

2.1.3 Vertical screw press: The manual vertical screw press, shown in Figure 3, consisting of different parts that were assembled by permanently welding together. It consists of a rectangular plate, vertical screw thread and two supporting rods that are 30 mm from each side of the screw.

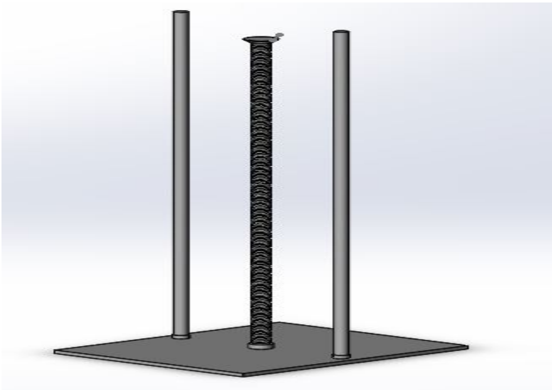

Figure 3: CAD Screw thread

2.2 Design Calculations

2.2.1 Capacity of the rectangular mould

The capacity of the moulding box was first ascertained to know the volume of the mixture to be discharged from the mixing drum into the mould. Since the rectangular mould is a cuboid of length, breadth and height 0.640 m, 0.520 m, 0.66 m respectively as shown in Figure 4, the volume is therefore calculated thus:

$$V_{mould} = 0.64 \times 0.520 \times 0.66 = 0.219648 m^3 = 0.22\ m^3$$

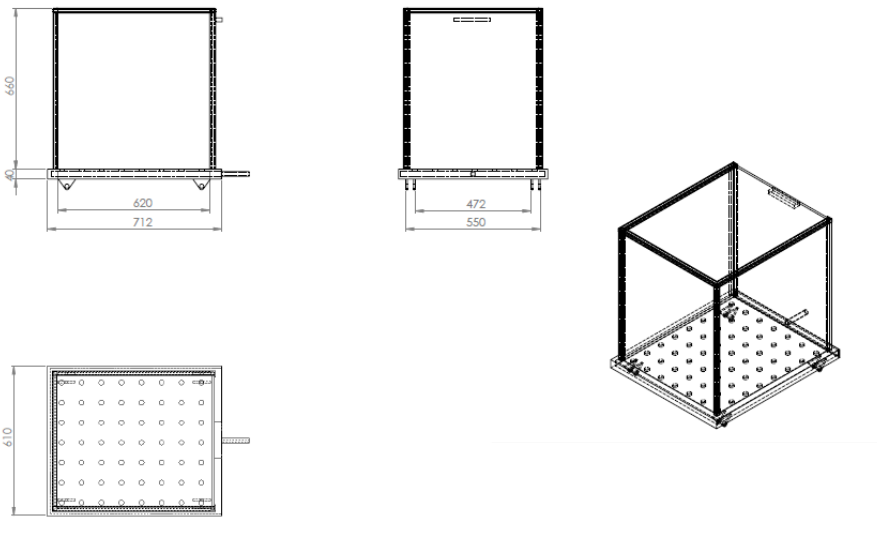

Figure 4: CAD view of the rectangular mould

Mass of different density of foam crumbs that can be charged into the mould

Mass of foams at different densities (13, 16, 18, 20, 22, 25 and 36 kg/m^3) that can be loaded into the drum at once is calculated using the formula, *Mass = density X Volume.* The values of the masses are tabulated and shown in the second column of Table 1. Since the values obtained for the actual mass of each density are exactly the space in the mixing drum without any clearance for proper mixing in the mixer, there is need to allow for clearance in the drum for ease and smooth operation of the machine. If 30% is allowed for the clearance and operations, then, the acceptable mass of foam crumbs at 0.22 m^3 volume are shown in the third column of Table 1.

Table 1: The actual mass of acceptable foam crumbs of each density in the mould

Density of foams (kg/m^3)	Maximum mass of foam the for Mould (kg)	Mass for mixing drum (kg)
13	2.9	2.0
16	3.5	2.5
18	4.0	2.8
20	4.4	3.1
22	4.8	3.4
25	5.5	3.9
36	7.9	5.5

But volume of the mould is more than the volume of the mixer, meaning that if additional mass of foam crumbs is required above what the mixer can take once for a particular density, additional foam crumbs can still be mixed for additional batch to balance what is needed to fill the mould to the desired volume and mass, provided the mould can handle such mass and volume of foam crumbs desired.

2.2.2 Design calculation steam box

Mass of steam box plate

As the compression occurs, all the weight of the mixture in the mould chamber act on the steam box. To avoid failure, it is important to ensure that the weight of the vertical screw press and foam crumbs are not more than the weight of the steam box.

Volume of steam box perforated plate

Length of the plate = 0.710 m, breadth of the plate = 0.610 m, and height of the plate = 0.014 m

$$\boldsymbol{Volume\ of\ steam\ box\ plate}, \boldsymbol{V_{plate}} = 0.71 \times 0.61 \times 0.014 = 0.006\ m^3$$

Since Density of steam box plate = 7850 kg/m^3 and Volume of steam box plate = 0.006 m^3

$$\textbf{Mass of steam box plate}, \boldsymbol{M_{steam\ box\ plate}} = 7850 \times 0.006 = 47.55\ kg$$

The weight of the steam box plate is therefore 475.5 N.

Since the weight of the presser is 393.9 N and the weight of the loaded crumbs on the press plate is approximately 30 N, the summation of these two weights will give the total weight that is acting on the steam box plate. The summed weight gives 423.9 N which is below the weight of the steam box plate of 475.5 N, as such it can be safely assumed that the weight of the steam box is sufficient to withstand the weight acted upon by both the screw press and foam crumbs.

Shear force and bending moment diagrams of steam box

To calculate the bending moment of the steam box it is important to identify all the loads acting on this component part as listed below:

Weight of the steam box perforated plate = 475.5 N,
Expected weight of the materials (crumbs, chemical and steam) = 78.48 N,
weight of screw = 137 N, Weight of the ram and support = 393.9 N

The force acting on the box is calculated as follows:

if Pressure = 753.4 N/m^2 and area of plate = 0.712 x 0.610 = 0.43 m^2
Acting force = 753.4 x 0.43 = 327.2 N

Total weight on the steam box support = 475.5 + 78.48 + 137 + 393.9 + 327.2 = 1412.08 N
Reactional forces at the supports are shown in Figure 5 are:

$$R_1 = 706.04N \text{ and } R_2 = 706.04N$$

Bending moment = area of the shear force diagram (M) = 706.04 X 0.356 = 251.35 Nm.
To calculate the bending stress $(\sigma) = \frac{Mc}{I}$,

where I = $\frac{bd^3}{12}$, and c = $\frac{d}{2}$.
I = moment of area of the steam box,
M = bending moment of the steam box,
b = length of the steam box,
d = depth of the steam box.
M = 251.35 Nm, b = 0.712 m, d = 0.014 m.

Therefore $\frac{c}{I} = \frac{6}{bd^2}$

$(\sigma) = \frac{6M}{bd^2}$ = 10806724.375143pa = 10.8067 Mpa.

Figure 5 is the free body diagram of the steam box and Figure 6 is the combination of the shear force and bending moments diagrams of the steam box.

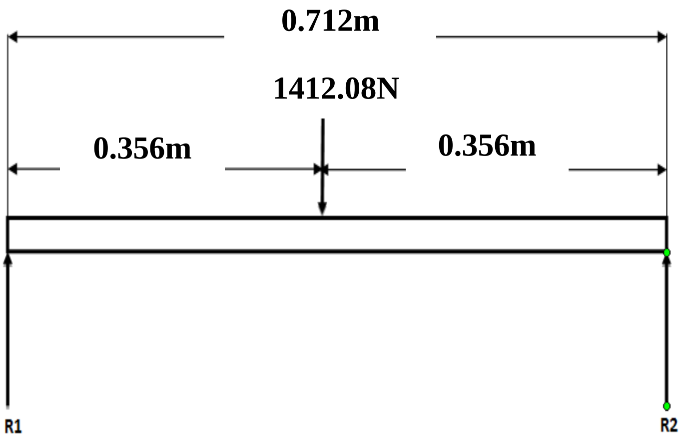

Figure 5: Free body diagram of the steam box base

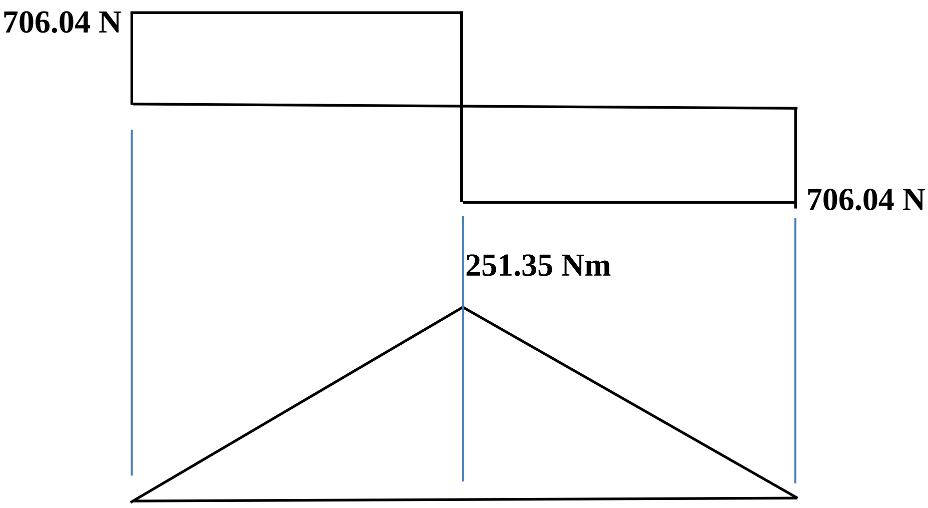

Figure 6: Shear force and bending moment diagram of the steam box base

2.2.3 Design calculations for the screw press

The design analysis for the vertical screw press was carried out to determine the pressure needed that will ensure maximum compression to the desired density, and also to ascertain the maximum torque needed to lower and lift the plate as well as specifications of the material dimension to be used to achieve the needed compression.

Maximum mass of crumbs to be compressed by the plate.

The density, mass and volume relation are adopted since different foam wastes has its unique density and the volume of the mould is 0.22 m^3, while the corresponding densities range from 13 kg/m^3 to 36 kg/m^3. The maximum densities and their corresponding masses of the mixture of various mixtures are given in the first and second column respectively in Table1.

$$Mass\ of\ crumbs, M_{crumbs} = Density\ of\ crumbs\ \times Volume\ of\ mold$$

Resistant force offered by the crumbs against the plate.

Due to the resilient and elastic nature of the polyurethane foam, it tends to offer some resistance to the plate during compression and this resistance is determined by the foam compressive strength and the area of the ram. The opposing force at different densities are tabulated in Table 2.

$$\boldsymbol{Opposing\ force = Compressive\ stress\ \times Area\ of\ plate}$$

Table 2: Results of opposing force of various foam densities used on the machine.

Density (kg/m^3)	Compressive strength of the foam crumbs (pa)	Area of the plate (m^2)	Opposing force (N)
13	359.6	0.3	107.9
16	445.2	0.3	133.6
18	506.9	0.3	152.1
20	565.1	0.3	169.5
22	606.2	0.3	181.9
25	650.7	0.3	195.2
36	753.4	0.3	226.0

Determination of the thickness of the plate.

The allowable area of the plate is 600 mm X 500 mm, this will also allow for clearance to move up and down without rubbing. Since the maximum opposing force of 226 N will occur, hence a plate with weight above 226 N is required. Selecting a plate with assumed weight 230 N (23.5 kg), which is far above the force needed to overcome the opposing force. The mass of the plate can be related to the volume and density to get the height since the length and breadth are known already.

Density of steel = 7850 kg/m^3, Selected mass =23.5 kg, Area of plate = 0.30 m^2, Volume = Ah.
$Volume\ (Area \times thickness) = mass/density$
$Thickness = mass/(density \times area)$, $Thickness = 23.5/(7850 \times 0.3) = 0.00997\ m$

The thickness of the plate is 9.97 mm. Therefore, a plate that is approximately 10mm thick is needed to produce the required force to compress the crumbs.

Maximum opposing force of the foam = 226 N.
Maximum compressive stress of the foam = 753.4 pa

Compressive stress of AISI 1020 steel is 294.74 MPa, which is way more than the compressive stress of the foam to be compressed.

Available weight to compress the foam = weight of supports + weight of plate.
Available force = 162.5 N + 230 N = 392.5 N, and this is higher than the opposing force of 226 N from the crumbs, in which the force from the threaded screw has not been included.

Determination of thread numbers and other parameters [11]:

Major diameter (D) = 40 mm, Pitch (p) = 6 mm
$minor\ diameter\ (d) = D - 1.29903p,$
$minor\ diameter\ (d) = 40 - 1.29903(6)$
$\boldsymbol{minor\ diameter\ (d) = 32.2\ mm}$

$pitch\ diameter\ (Pd) = D - 0.649519p,$
$pitch\ diameter\ (Pd) = 40 - 0.649519(6)$
$\boldsymbol{pitch\ diameter\ (Pd) = 36.1\ mm}$

$$\boldsymbol{Thread\ depth = thread\ width} = \frac{p}{2} = \frac{6}{2} = 3\ mm$$

$$\boldsymbol{mean\ diameter}, dm = D - \frac{p}{2} = 40 - \frac{6}{2} = 37\ mm$$

The total thread on the shaft is calculated thus:

Total length of shaft (L_s) =1500 mm

$$Number\ of\ pitch, Np = \frac{Length\ of\ rod}{pitch\ lenght} = \frac{1500}{6} = 250\ pitches$$

Since for every pitch we have one thread, therefore for 250 pitch we have 250 threads.

$$Thread\ per\ inch, Tpi = \frac{Total\ threads}{length\ of\ shafts\ (inch)}$$

$$Thread\ per\ inch, Tpi = \frac{250\ threads}{59\ inches} = \boldsymbol{4Tpi}$$

Determination of torque produced by the screw [11].

$$T_R = \frac{Fd_m}{2}\frac{l + \pi f d_m}{\pi d_m - lf}$$

$$T_L = \frac{Fd_m}{2}\frac{\pi f d_m - l}{\pi d_m - lf}$$

where T_L=*Torque required in lowering a load,*

T_R=*Torque required in lifting a load*

F = W = total weight suspended on the ram **= 404 N.**

d_m = mean diameter = 38mm and

d_r = minor diameter = 32.2 mm,

l =*np*, where *n* = number of threads per pitch, *p* = pitch = 6mm and *f* = frictional factor = 0.008.

When the above parameters are substituted into the equation above.

T_R = 0.973 Nm and T_L = - 0.197 Nm.

It is clear that the torque to raise the load is higher than the torque to lower the load, because when raising the load, the gravity acts on the entire weight on the plate. Also, the negative sign of T_L signifies that the load is going in negative y-direction.

Determination of force exerted by the screw on the crumbs

Since Force (F) = Torque (T)/radius of screw (r).

Radius of screw is 0.02 m,

Force to lower the ram (F_L) = T_L/r = **98.5 N**, Force to raise the ram (F_r) = T_r/r = **48.65 N**

Force exerted is F_L + W, where W= total weight of plate and support bars.

Force exerted = 98.5N+404N **= 502.5 N**

Determination of pressure exerted by the ram on the foam crumbs

Pressure exerted by the screw and plate = Force exerted/Area of plate = 502.5N/0.3 m^2

Pressure exerted by the ram and screw = **1, 675 pa = 1.675 kpa.**

Since this pressure (1, 675 pa) is far more than the maximum compressive stress (753.4 pa) the foam will offer, then the machine is safe.

2.2.4 Fabrication procedure.

The assembly of the mould with vertical screw press is shown in Figure 7.

The mould and the steam box

The frame was made with a hollow structural section (square pipe) of 30 mm x 30 mm with thickness of 1.5 mm. The square pipe was cut and joined permanently by welding to form a frame of height 1355 mm above the ground, length of 1710 mm and breadth of 680 mm. Four circular hollow structural sections of diameter 30 mm and thickness 3 mm was also introduced to the frame at four points to support and balance the load exerted on the frame by the mixer and the presser. The four frames' support each of height 1290 mm were joined permanently by welding to the two longest sides of the frame at distance 790 mm apart and 425 mm from both sides of the frame.

The vertical screw press

The suspension bar carries the screw nut, and also serves as the passage channel for the threaded shaft and the two supporting rods. The threaded shaft was then attached to the rectangular ram via some special mechaninism of circular and semi circular rings, which enables the threaded shaft to lift and lower the total weight of the ram and the screw supports. In other to gain maximum mechanical advantage during the manual rotation, a roller was attached to the top of the screw for turning it.

The mould usually moves horizontally via a rail, through this, the mould goes under the mixer to take delivery of the mixed crumbs when the mixer is opened, after this, the mould goes back under the vertical screw press for compression and steam is also supplied at the base of the mould through the steam box from a boiler to raise the temperature of the mixture and ensure rapid curing and better compression (pressing) of the foam crumbs.

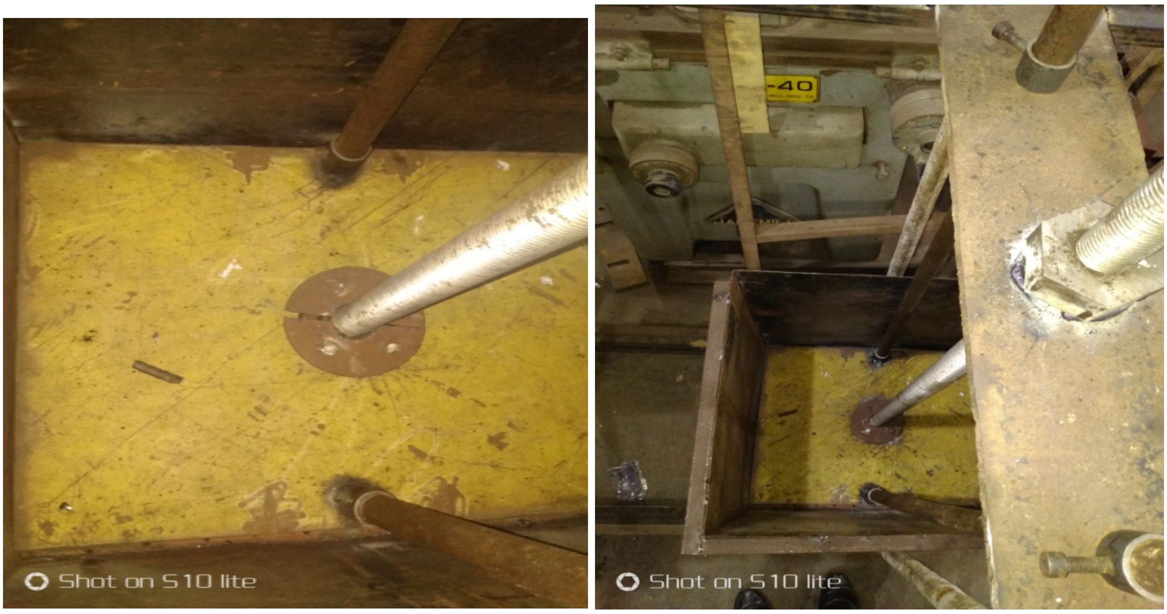

Figure 7: Fabricated and coupled view of the screw press in the mould.

3.0 RESULTS AND DISCUSSIONS

3.1 Machine Test

The fabricated rectangular mould and vertical screw press with rectangular plate was coupled to the main polyurethane foam recycling machine earlier developed [10] as shown in Figure 8 after the design, fabrication and assembly of the various parts of the recycling machine. The machine was tested to confirm if the aim and objectives of the recycling machine were achieved or not. This stage of testing to prove if the machine met the intended purposes which is to compress shredded polyurethane foam to a high-density cushion foam from the recycled foam crumbs that can be used for upholstery work (shown in Figure 9). Therefore, the machine was evaluated by producing four product samples with different densities but the same dimensions. Samples with the following densities were produced: 110 kg/m^3, 117 kg/m^3, 211.7 kg/m^3 and 226.7 kg/m^3.

Determination of densities of samples produced.

(M_w) = Mass of wet product

(M_d) = Mass of dry product

(M_s) = M_w - M_d = Mass of water retained

$$Density\ of\ wet\ product\ (Dw) = \frac{\text{Mass of wet product}}{Volume\ of\ product}$$

$$Density\ of\ dry\ product\ (Dd) = \frac{\text{Mass of dry product}}{Volume\ of\ product}$$

Figure 8: Vertical screw press inside the rectangular mould

Figure 9: Sample of the recycled product

3.2 Laboratory Test and Results

Four different samples were produced for the purpose of evaluating the performance of the mould and vertical screw press machine, Table 3. In Samples 1, 2 and 4, 3 kg of foam crumbs and 2.4, 1.2, and 1.2 kg of chemicals were used for samples 1, 2 and 4 respectively. Sample 3 contained 1.5 kg of foam crumbs and 1.2 kg of chemicals. Samples 1 and 3 are invariably the same composition by percentage. Sample 4 has as much as double weight of foam crumbs as Sample 3 but the same measure of chemical. Also, Sample 2 and 4 are the same except that weight loss in Sample 4 is slightly higher than in Sample 2. The materials recovered is higher in Sample 3 while it's the least in Sample 1. After producing these samples, two product samples (Samples 3 and 4) out of the four samples produced, and a Reference Sample, R, from the industry were taken to University of Lagos Central Laboratory to test their mechanical properties. The results of the tests obtained from the samples were shown in Table 4. The Reference Sample has the same sample composition as the Sample 3. The tests carried out were the Indentation Force Deflection (I.F.D), resilience, and Tensile Strength. Also, the percentage elongation and peak force were recorded from the machine after necking and breaking had occurred during the tensile test.

Table 3: Charged materials and Material percentage recovery [10]

Samples NO	**Crumbs (kg)**	**Chemicals (kg)**	**Total weight of product (kg)**	**M_d (kg)**	**Materials Loss (kg)**	**Percentage recovery**
1	3.0	2.4	5.4	5.35	0.05	99.07%
2	3.0	1.2	4.2	4.18	0.02	99.52%
3	1.5	1.2	2.7	2.60	0.10	96.30%
4	3.0	1.2	4.2	4.17	0.03	99.29%

Table 4: Results of tests carried out on samples.

Sample No	**Density (kg/m^3)**	**I.F.D (N)**	**Resilience (%)**	**Tensile**				
				Force @ peak (N)	**Tensile stress (MPa)**	**% Elongation (%)**	**Area (mm^2)**	**Gauge length (mm)**
3	110.0	994.33	47.42	13.68	1.708	28.062	78.54	100
4	211.7	994.33	19.35	4.66	0.581	8.445	78.54	100
R	110.0	988.75	48.39	7.38	0.921	16.665	78.54	100

3.3 Discussions

Three different samples were sent to the Laboratory for tests. The samples and their results are shown in Table 4. Samples 3 and 4 were produced with the Mould and Vertical Screw Press developed in this paper, and Sample R is the reference sample from the industry and was produced with the industrial recycling machine. Samples 3 and 4 results are then compared with the reference sample R from the industry which was tested along with the 2 other samples that were produced. The densities of Sample 3 and Sample R are the same but Sample 4 is almost twice as dense as the other two. The first test in column 3 was the indentation force deflection (IFD) which measures the hardness (resistance to depression) of the foam. The higher the IFD the stronger the foam and the better the foam will withstand compressive force (weight). The resilience is the measure of the foam's restoration ability after the withdrawal of the load (IFD). The higher the percentage of resilience the better. Sample 3's resilience is about 2% lower than that of the reference sample, this means they are almost the same in resilience. Both will be restored back to their original dimensional shapes at almost the same rate and time while Sample 4 will take twice the same time to gain back its dimensional integrity after removing the load (IFD) if at all. The peak force is the force that is required to break up the bonds of the foam. The more foam crumbs constituents in the foam sample, the lower the peak force. The peak force of Reference Sample is about half (53%) of Sample 3. Also, the tensile stress of sample 3 is higher than that of the reference sample likewise the percentage of elongation is higher. Consequently, Sample 3 is better than the reference sample and would therefore perform better. One of the many factors that could be responsible for this is the curing process during production. The density measures the quantities of matter in a particular volume, therefore, if the foam crumbs were properly cured, compressed properly and allowed to cool inside the mould, the cavity and pores will be less and the foam would perform better. These results actually satisfy the condition needed for the sample products produced to be used in orthopaedic and as cushion in upholstery, which is a clear indication that the machine fabricated has achieved what the industrial machine can do since the mechanical properties of the products produced from machine compares well with the one produced with the industrial machine. Table 5 shows the physical comparison of the industrial recycling machine with the one produced in this work.

Table 5: Comparative analysis of the industrial machine to the laboratory machine. [10]

Components and materials	Industrial Machine	Laboratory Size	Reduction ratio
Mixer volume	6.7m^3	0.178m^3	37:1
Mould Volume	8.325m^3	0.223m^3	37:1
Crumbs used	130kg	3kg	43:1
Chemical used	20kg	1.2kg	17:1
Density obtained	100 – 250kg/m^3	100 – 250kg/m^3	1:1

4. CONCLUSION

The development of a rectangular mould and vertical screw press with a rectangular plate (ram) was presented in this paper. After the development of the machine (design, fabrication and assembling of the components) the shredded and blended foam crumbs were compressed with the aid of vertical screw press inside the rectangular mould. The machine performance was evaluated by producing four different samples with different foam crumbs and chemical proportions to give different densities. The volume of shredded and blend polyurethane foam wastes was effectively compress in the rectangular mould to one sixth of the initial volume, that is, compression ratio of 6:1 was achieved. Test of the samples produced were carried out at a standard laboratory and the results compared with a reference material. The results obtained from the testing and experimentation of product samples from this machine confirmed that the aim and objectives of developing this machine were achieved. The machine produced in this work is able to reduce materials, energy and man hour loss when compared to the industrial machine as shown in Table 5. The rectangular mould and vertical screw press designed is commendable since the finished products produced with the process were comparable in quality to that which is produced on the industrial recycling machine and it costs less to produce than using bigger industrial machines. This indicates that it is better to use the smaller machine to produce better quality products it may cost a little higher recycling using this machine.

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