Development of a Wall Panel Moulding Machine

***Kolajo T.E.[1], Odule O.E.[2] and Safiu M.A.[3]**

[1,2,3] Department of Wood Products Engineering, University of Ibadan

---

Abstract: The quantity of waste papers generated yearly is enormous and disposal methods could be potentially carcinogenic. Hence, the need for the conversion of these wastes to a value added material. Wall panels can be made from waste papers, they are functional as well as decorative, providing insulation and soundproofing, uniformity of appearance, durability and ease of replaceability. A manually operated moulding machine was designed and constructed for the production of wall panels from waste papers. The machine is comprised of the mould, counter mould, screw shaft lowering mechanism and a support frame. The moulds are removable and can be changed to the dimension and shape of the desired moulded products. The counter mould, also removable is imprinted with the pattern that is transferred to the wall panels for aesthetics. Bleached grade waste papers were converted into pulp slurry of 5% consistency before moulding into wall panels. The machine gives enough compaction such that no addition of binding agents is required. The wall panels produced has an average density and impact strength of 380.3kg/m3 and 1756.15J/m, respectively.

Index terms: Moulding machine, Pulp slurry, counter mould, impact strength

Introduction

Paper is one of the most critical consumer products ever invented by man. The global production of paper and paper products were approximately 419.7 million metric tons while consumption stood at 423.3 million metric tons in 2017 [1]. The physiochemical properties of paper fibres such as its durability and flexibility [2],[3] have made it possible to be fashioned into a variety of products used in notable areas including education, sanitation, security and communication [4]. Paper and paper products used in everyday life contains, but are not limited to tissue papers, diapers, serviettes and sanitary towels used in sanitation; newspapers, texts, journals, handbills and posters in print; cardboard paper for electronic hardware, currency notes among others. Most of these are disposed after a single use. Paper, as compared with other materials has a high potential of recycling. Recycling is the conversion of wastes into new useful materials, which may or may not bear resemblance to the waste raw material. The recycling of paper products has been found to be beneficial to the environment as it reduces emission of green house gases, saves the forests, decreases operation costs and preserves the environment from air and water pollution associated with virgin pulp production.

Paper recycling processes generally involve the collection of waste papers, sorting them into grades, cleaning them to remove pins and clips, disintegrating in to pup slurry and converting them to other useful products. Recycled paper and paper products have been in use for decades and have provided an alternative solution useful in the production of interior walls and ceilings. An example of the use of paper in residential construction is the Papercrete system [5] where there is partial replacement of the plate aggregates with shredded paper. Short length fibres from paper recycling wastes are made into light weight bricks [6]. The inclusion of vegetable fibres, such as recycled paper fibres in building components such as wall panels and ceilings have been reported to produce a lighter weight composite, reduce thermal conductivity and reduce specific heat [7].

A major constraint to recycling of waste papers has been the cost and sophistication of recycling machines. Recycling technology has increased over time and its reception has been difficult, especially for local users who find it difficult to keep up with the pace of evolving technologies. The design and construction of this wall panel moulding machine therefore aims to develop and domesticate cheap, eco-friendly and easily operated paper recycling processes in the production of wall panels.

Materials and Methods

Materials Collection and Preparation

The machine was made majorly from mild steel which was obtained locally at the iron market in Ibadan, Nigeria. The waste papers for performance evaluation were collected as waste materials from business centres around the University of Ibadan.

Design Considerations

The components of the mould were made of mild steel with appropriate thickness to withstand the stress and strain imposed on the components during service. Due to the nature of the pulp slurry, the components were adequately coated to prevent corrosion. The machine parts were designed such as there were no dead spots for ease of cleaning and maintenance. The mould is designed to drain water easily in the fibre mixture during the production of the fibre composite. The mould and counter mould are designed to be detachable for ease of loading of raw materials and removal of final products.

Design analysis

The design of the pulp moulding machine was majorly determined by the shape and size of the final product, which is in conformity with existing wall panel sizes. This determined the size of the mould which in turn affects all other component parts. The choice of material for construction and design parameters was guided by literature [8] [9] [10]. The components of the moulding machine include:

a) The mould: This holds the fibre mix and gives shape to the moulded product.
b) The counter mould: This impacts the decorative pattern and compresses the moulded product to the desired thickness.
c) The machine frame: This holds all the parts together and giver it clearance above the ground.
d) The screw shaft: This helps lowers the counter mould in compressing the moulded product.

(a) The Mould

The mould is a square cross-section structure with malleable screen of Ø2mm attached to its base. This part is designed to hold the fibre mixture during the compression process. The effluent is discharged from the base of the mould where the screen is attached. The mould is detachable from the main housing of the machine and this allows for multiple productions as there is no limit to the number of moulds that can be used with the machine.

The dimension of the square cross-section mould is also the sum of the actual product size and clearance which was necessary for accuracy and uniformity of edges after trimming the product to the actual size.

$$The\ desired\ dimension\ of\ wall\ panel\ =\ 300mm\ by\ 300mm\ by\ 18mm$$

$$Cross-sectional\ area\ of\ the\ mould\ = l \times b = 90{,}000mm^2 \equiv 0.09m^2$$

$$Allowable\ clearance\ on\ both\ sides\ =\ 12mm$$

$$Height\ of\ the\ mould\ =\ 75mm$$

$$Volume\ of\ the\ mould\ = l \times b \times h = 312mm\ by\ 312mm\ by\ 75mm$$

$$Thickness\ of\ unmoulded\ slurry\ =\ 70mm\ to\ be\ compressed\ to\ 18mm$$

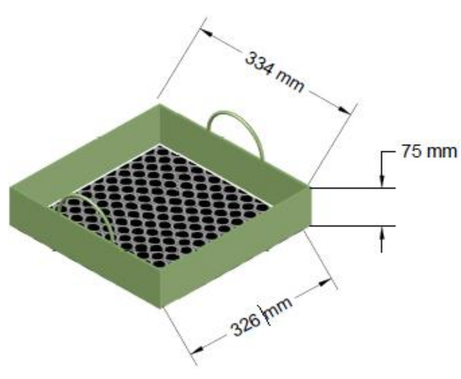


Figure 1: Mould

(b) The Counter Mould

The design template of the fibre composite is imprinted on the counter mould. The counter mould is designed to be detached from the screw shaft to allow easy loading and unloading of the mould.

The dimension of the counter mould is such that it fits into the mould.

$$Length = 300mm + 10mm = 310mm$$

$$Width = 300mm + 10mm = 310mm$$

$$Thickness\ of\ the\ counter\ mould\ plate = 5mm$$

The weight of the counter mould is necessary to impact the decorative pattern while compacting the moulded product. The force is required as no additional binder is added to the final product. The maximum compressive force exerted mould can be varied by increasing or decreasing the weight of the counter mould.

Compressive stress exerted by the counter mould on the pulp moulding:

$$Compressive\ stress = {}^{F}/_{A} \ldots (1)$$

$$F = mg \ldots (2)$$

Where:

F = Force exterted by the counter mould

A = Cross-sectional area of the counter mould

m = mass of the counter mould

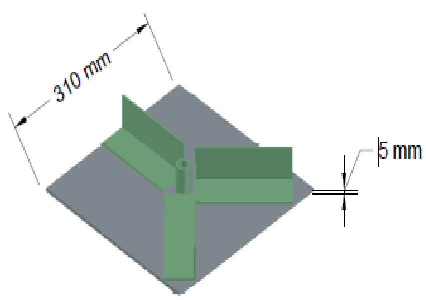


Figure 2: Counter mould

(c) The screw shaft

This is the part that determines the compression limit of the mixture. The design is guided by the expected torsional and bending moment as well as shock and fatigue factor and shear stress of the shaft material. These factors determined the diameter of the shaft according to Khurmi and Gupta (2005). The screw shaft is driven by a handle. Square threads are made on a round rod Ø30mm to make the screw shaft. This is driven into the matching part on the counter mould thereby exerting pressure on the composite. This further allows drainage of the water in the mixture and also allows compaction of the composite mixture in the mould.

The handle of the screw shaft used to turn it is 298mm *in length.*

$$The\ total\ height\ of\ the\ screw\ shaft = 458mm$$

$The\ height\ after\ maximum\ compression\ = 258mm.$

$Therefore, the\ height\ for\ compression\ =\ 458mm - 258mm\ =\ 200mm$

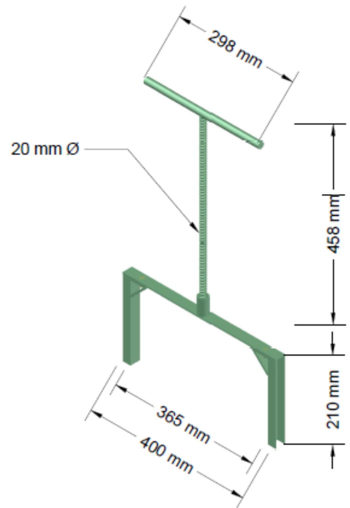


Figure 3: The screw shaft

(d) The frame

The frame of the mould is a rigid structure with a height of 750mm above the ground level. The frame also contains a screen attached to it, on which the mould sits. The screen is attached to further restrain fibre in the slurry from draining with the water. The frame to which the screw shaft is attached is also detachable for easy cleaning and maintenance.

The mould seat is a square cross sectional structure with a malleable screen of Ø2mm at the base. This is the platform on which the mould sits. The dimension of the mould seat is the sum of the dimension of the mould (including the thickness of the metal plate used for fabrication) and clearances.

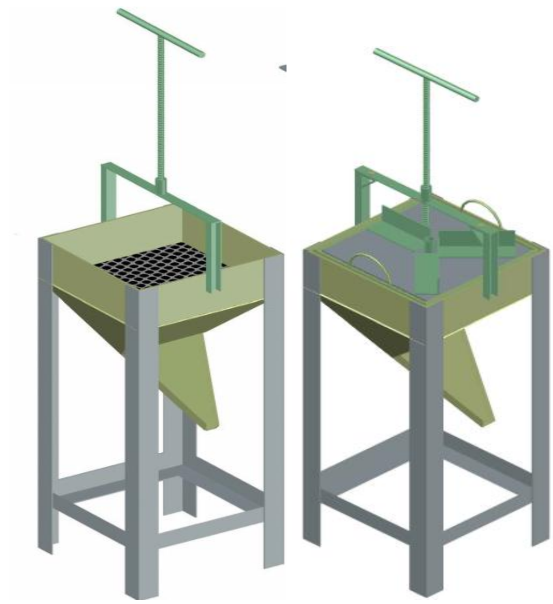
The length and width of the mould seat = length and width of the mould + allowable clearance

$Therefore, the\ length\ and\ width =\ 334mm + 12mm\ = 346mm$

$The\ height =\ height\ of\ the\ mould\ +\ clearance = 75mm\ +\ 32mm =\ 107mm.$

$The\ clearance\ between\ the\ mould\ seat\ and\ the\ frame\ screw\ shaft =\ 133mm.$

This allows easy loading and removal of the mould. The extruded water channel is attached to the mould seat, allowing passage of the effluent into a collection bowl.



(a) (b)

Figure 4: (a) Isometric view of the wall panel moulding machine (b) Wall panel moulding machine with the counter mould

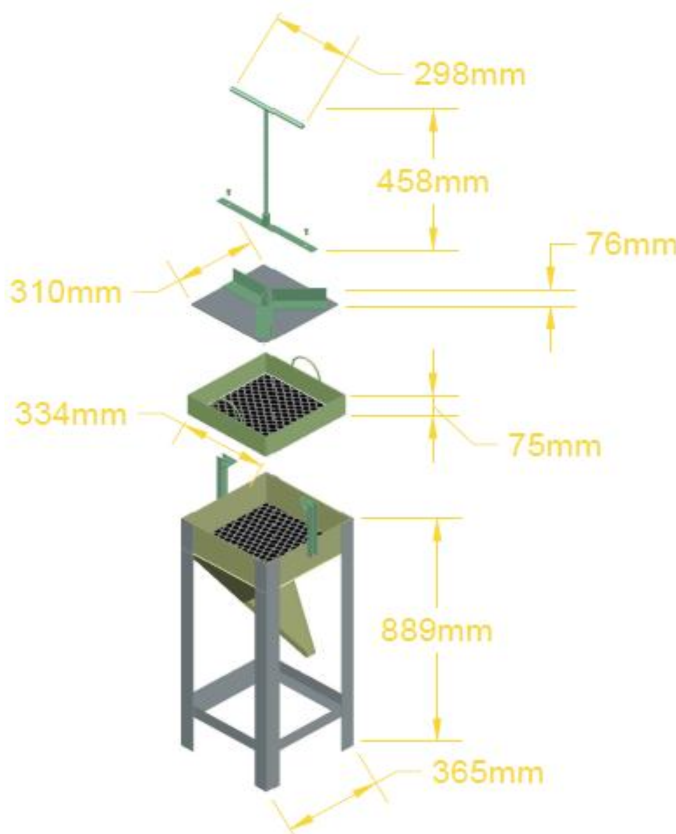


Figure 5: Exploded view of the machine

Fabrication of the Machine

The fabrication of the mould followed the design process. The processes involved include marking out and cutting of the materials into the required sizes, setting up the framework, welding and grinding of the component parts, coupling of the component parts, coating and painting of the machine.

Cost Estimation

The cost of machine production was estimated.

Testing and Performance Evaluation

The performance of the machine is evaluated by its ability to produce wall panels with desirable physical and mechanical characteristics. The machine was tested with bleached grade waste papers which were sorted, cleaned to remove foreign matter such as staple pins, weighed and disintegrated into pulp slurry of 5% fibre consistency (Plate 1). The wall panels produced were evaluated for density, low velocity impact test and flexural stress-strain test using the Instron Universal Testing Machine at the Department of Agricultural and Environmental Engineering, University of Ibadan. The evaluation was as follows:

$$Density = \frac{mass\ of\ moulded\ pulp\ product}{volume\ of\ the\ moulded\ pulp\ product} \ldots (3)$$

$$Flexural\ stress: \sigma_f = \frac{F}{A} \ldots (4)$$

$$Flexural\ strain: \in = \frac{\Delta L}{L} \ldots (5)$$

$$Modulus\ of\ Elasticity = \frac{\sigma_f}{\epsilon} \ldots (6)$$

$$Modulus\ of\ Rupture = \sigma_r = \frac{3FL}{2bd^2} \ldots (7)$$

$$Low\ Velocity\ Impact\ Strength = \frac{Impact\ energy\ (J)}{thickness\ (mm)} \ldots (8)$$

$$Impact\ Energy: E_0 = mgh_0 * N \ldots (9)$$

Where:

F = applied load, A = cross sectional area of material, ε = strain, ΔL = change in length, L = original length of the material, b=width of the material, d = depth or thickness of the material, m= the mass of the ball, g= gravitational force, h= height of impact, N= number of drops before failure.

Results and Discussions

The constructed moulding machine and wall panels produced are shown in Plate 3. The type of end connection given to the parts determines their performance. The compressive stress exerted for compaction on the pulp moulding has a resultant effect on all parts of the machine. Therefore, the connection used is fixed type, as the parts are welded together to give adequate rigidity.

The results for the machine components and description are as presented in Table 1 while the cost estimate of the machine is presented in Table 2.

Table 1: Components Designed and Description

S/No	Machine Components	Description
1.	Mould	Material: 4mm thick Mild steel, Volume: $6.75 \times 10^{-3} m^3$
2.	Counter mould	Material: Mild steel, angle iron, Thickness: 5mm
3.	Screw and shaft	Material: Ø30mm Carbon steel round rod
4.	Frame	Material: Angle iron, Thickness: Ø2*mm* screen

Table 2: Cost Analysis

S/N	MATERIAL	SPECIFICATION	QUANTITY	AMOUNT (₦)
1.	Mild steel sheet	3mm thickness	0.5m	7,500
2.	Angle iron	50mm * 50mm	1 length	7,500
3.	Screen	Ø2mm	0.91m*0.91m	7,700
4.	Channel	25mm * 50mm	1.22m	4,200
5.	Round rod	Ø30mm	0.61m long	3,500
6.	Cutting disc	*Flexovite*	1 piece	700
7.	Grinding disc	*Powerflex*	1 piece	600
8.	Electrode	Gauge 12	1 packet	2,200
9.	Paint		2 litres	2,800
10.	Workmanship			8,300
	Total			**45,000 or $116.40**

Plate 3: Wall panel moulding machine

Plate 4: Moulded wall panels before trimming

Parameters Evaluated	Thickness	Density	Modulus of Elasticity	Modulus of Rupture	Impact Energy	Impact strength
Waste paper	18±0.4mm	380.3kg/m³	2.1N/mm²	30.6N/mm²	22.83J	1756.15J/m

The wall panels produced have an average thickness of 18±0.4mm with a density of 380.3kg/m³. This value is comparable to Recipanels (550kg/m³) made from a mixture of paper, cement and water of 15mm thickness [11]. Flexural tests reveal a Modulus of Elasticity of 2.1N/mm² while Modulus of Rupture averages 30.6N/mm². The modulus of elasticity compares well with 4.00N/mm² of Recipanels. Impact energy gives 22.83J while its impact strength was evaluated to be 1756.15J/m.

Conclusion

The machine constructed has successfully produced wall panels from bleached grade waste papers. It is a veritable tool that can be employed in the moulding of both paper and other fibre products. Its design is suitable for both teaching and low scale commercial applications. Its application does not require the use of energy, and can therefore be described as low cost and eco-friendly. Its use at cottage level will eliminate the loss of valuable raw materials in form of waste papers as they can be easily converted to useful products. The machine can also be adopted for the production of ceiling boards and floor tiles from fibre and cement composites.

References

[1] Garside M. 2019. Paper Industry – Statistics and Facts. Chemical and Resources: Pulp and Paper. Accessed from www.statista.com/topics/1701/paper-industry/dossierSummary_chapter5 on 1st August, 2020.

[2] Suhr, M.; Klein, G.; Kourti, I.; Gonzalo, M.R.; Santoja, G.G.; Roudier, S.; Sancho, L.D. 2015. Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board (Industrial Emissions Directive 2010/75/EU; Publications Office of the European Union: Luxembourg, Luxembourg; p. 906.

[3] Berg, P. and Lingqvist, O. 2017. Pulp, Paper and Packaging in the NEXT decade: Transformational Change. McKinsey & Company, 2017. Available online: https://www.mckinsey.com/industries/paper-and-forestproducts/our-insights/pulp-paper-and-packaging-in-the-next-decade-transformational-change (accessed on 12 November 2018)

[4] Environmental Paper Network (EPN): The State of the Global Paper Industry 2018. Available online: http://environmentalpaper.org/tools-and-resources/reports/ (accessed on 4 December 2018).

[5] Lyon, A. 2007. Materials for architects and builder. Elsevier, London.

[6] Raut S.P., S. Rohant, D. Sunil, Ralegaonkar R.V., Mandavgane S.A. 2012. Reuse of recycle paper mill waste in energy absorbing light weight bricks. Constr Build Mater 2012; 27:247–51.

[7] Cristel Onésippe, Nady Passe-Coutrin, Fernando Toro, Silvio Delvasto, Ketty Bilba, Marie-Ange Arsène. 2010. Sugar cane bagasse fibres reinforced cement composites. Therm Consider Compos: Part A 2010;41:549–56.

[8] Khurmi, R. S., and Gupta, J. K. (2005). A textbook of machine design (1st ed.). Ram Narga, New Delhi: Eurasia publishing house (PVT.) LTD.

[9] Oreko, B.U., Okiy, S., Emagbetere, E., and Okwu, M. (2018). Design and Development of Plantain Fibre Extraction Machine, Nigerian Journal of Technology (NIJOTECH) 37(2), 397-406.

[10] Omoniyi T.E.and Ayodele E. B. 2020. Development of a coir fibre extracting machine. International Research Journal of Engineering and Technology (IRJET). Vol.7 Issue 7. P-ISSN: 2395-0072.

[11] Hernán C. E., C. Sanchez Henao, Julio. 2012. Recipanel: Recycled paper panels. DYNA. 79. 132-137.