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Design, Fabrication And Functionality Testing Of A Mold Box For Double Interlocking Hollow Concrete Blocks

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Abstract
Owing to the rapid increase in population in developing countries, there has been a huge demand for more affordable housing units worldwide. Although efforts have been made to meet the rising demand, they have not been adequate. This has rendered low-income earners homeless, or living in deplorable conditions in slums. The Kenyan government, among other interventions, introduced the affordable housing programme that entails building low-cost units with a view to enable low-income earners acquire decent but affordable housing (Centre for Affordable Housing in Africa, 2019; Thuo & Odera, 2024). Although the replacement of conventional building units by hollow concrete blocks is a good strategy towards achieving low-cost housing, most block making machines used commercially are imported and expensive. Therefore, there is need for interventions that will reduce the cost of construction and help construct affordable housing units. This paper presents the design, fabrication and functionality testing of a mold box for making double interlocking hollow concrete blocks for affordable housing.
Three design alternatives for the hollow block making mold were made and the best design solution selected using the engineering design decision matrix based on three factors: ease of fabrication and assembly, ease of operation and efficiency as well as cost. The total fabrication cost of the mold was KSh. 7,500.
The eight samples of hollow concrete blocks made using the fabricated mold and cured for 30 days after compaction had an average compressive strength and average density of 3.7 N/mm^2 and 1582. Kg/m^3 respectively. They fall in grade A category, which has a lod bearing capacity.

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I. Introduction

Background

Owing to the rapid increase in population in developing countries, there has been a huge demand for more affordable housing units world over. Besides, there has been an upsurge in rural – urban migration resulting in rapid urban expansion and tremendous growth in urban population. This has put pressure on land, public space and housing, causing demand on infrastructure and services that outweighs supply (Schneider et al., 2011). By the year 2050, the global population is expected to increase by approximately 9 billion people doubling the global GDP. This exerts pressure on the construction industry. In Africa, the population is currently at approximately 1.48 billion people, which accounts for 18% of the world population. This figure is expected to rise significantly in the next decade (United Nations, 2022).

This situation is well replicated in Kenya, which ranks highly among countries with the highest population and urbanization growth rates in the world (Kenya National Bureau of Statistics, 2019). In an effort to solve the problem of housing, the Kenyan government, among other interventions, introduced the affordable housing programme with a view to enable low-income earners acquire decent but affordable housing (Centre for Affordable Housing in Africa, 2019; Thuo & Odera, 2024). This can be achieved through the adoption of cost-effective building methods such as the hollow interlocking concrete block technologies. Although this technology is a good alternative to fired clay bricks, and bush shaped stones, most of the equipment used for commercial purpose are imported and expensive. Use of locally made, cost effective equipment would play a vital role in reducing the cost of construction. This paper presents the design, fabrication and testing of a mold box for making double interlocking hollow concrete blocks.

Problem statement

In 2019, Kenya had a population size of 47.5 million people, 31% of which lived in urban areas. Although a larger percentage of the Kenyan population lives in rural areas, the urbanization trend is expected to continue, with 50% of the population projected to be live in urban areas by 2050. However, the rate of expansion of social services, especially housing, does not meet the increasing demand, resulting in majority of urban dwellers residing in slum areas with deplorable living conditions. Consequently, majority of low-income earners cannot afford decent housing. This problem is worsened by increasing cost of construction due to rise in the cost of building materials and expensive construction machines (Kenya National Bureau of Statistics, 2019).

Concrete is a common building material across the globe. It constitutes a mixture of cementing materials, coarse aggregates and fine aggregates (sand) with a specified amount of water (Bredenoord et al., 2019). Players in the construction industry have made interventions geared towards reducing the overall cost of construction by reducing material usage. One notable intervention is the use of hollow interlocking blocks, which are lighter and consume less material during construction. However, most of the existing hollow interlocking blocks can only interlock horizontally and are only preferred for landscaping. Besides, the available interlocking block molds need importation and are expensive.

Justification

The design, fabrication of a mold box for producing double interlocking hollow blocks was a vital intervention since the mold is locally made, easy to use and affordable. The mold box reduces the construction cost and speeds the construction process. It produces hollow blocks with features that allow for interlocking to occur both vertically and horizontal directions. This not only reduces the need for bonding material, but also increases the strength of hollow concrete structures. The hollow concrete blocks formed using the mold reduce the dead weight associated quarry blocks and helps to reduce land degeneration associated with production of quarry blocks. Besides, they interlock both horizontally and vertically hence enhancing structural stability and load bearing capacity of structures (Bredenoord et al., 2019; Thorat et al., 2015). The blocks do not require any alterations when interlock at a corner. This combination of benefits would be an important step towards delivering affordable housing to slum dwellers and low-income earners as Kenya strives to achieve Vision 2030 (Government of the Republic of Kenya, 2017).

Objectives
Main Objective
To design and fabricate a mold for double interlocking hollow concrete blocks.

Specific Objectives
i) To design a mold for producing double interlocking hollow concrete blocks
ii) To fabricate a mold for producing double interlocking hollow concrete blocks
iii) To test the functionality of the double interlocking hollow concrete block mold

II. Literature Review

Hollow Interlocking Concrete Blocks

The provision of affordable housing remains a big challenge in many developed and developing countries. In Kenya, the affordable housing program, under the social pillar of the big four agenda prioritizes the provision of at least 250,000 quality and affordable houses to low-income Kenyans every year (Thuo & Odera, 2024). The high rate of growth in urban population has resulted in high construction costs due to rising prices of urban land. With the high cost of materials in the construction sector, it is necessary to come up with cost cutting interventions so that low-income earners can afford to acquire homes. The use of hollow interlocking concrete blocks is an effective way of achieving cost reduction on construction works. The invention and adoption of interlocking hollow concrete blocks has made a significant shift away from the traditional building process, which relies on bricks. The technology has simplified the time consuming and labour-intensive traditional method of laying bricks significantly. Interlocking blocks differ from conventional building blocks because brick laying work does not mortar. Instead, the blocks interlock to form firm joints. This characteristic makes the process of building walls faster and requires little or no labour as the blocks interlock themselves (Bredenoord et al., 2019; Thorat et al., 2015).

Hollow Interlocking Concrete Blocks for Affordable Housing

The use of hollow interlocking blocks reduces the cost of construction since less material is used to make the blocks. Cost reduction can be extended even further by using alternative materials. for instance, a normal concrete block constitutes gravel, cement and sand in in a weight ratio of 1:2:5 or 1:3:5. Quarry dust can be used instead of gravel and this would lower the cost of production of the blocks with minimal variation in compressive strength. The use of interlocking blocks is less costly than standard blocks because they utilize less cement and do not need mortar between blocks or between adjacent courses. During manufacturing, gasoline, electricity or diesel is not needed. Construction projects involving use of concrete blocks give faster completion rates due to less time spent; they do not require laying down mortar for each course or levelling them continuously.

Renovation can be carried out in interlocking block-based concrete structures within a short period. For example, four men will require one day to complete 3m by 4m spaces to rooftop height. Due to their interlocking action, it only requires a few seconds to position the blocks. A block maker would only require a mold, a contractor's towel and a shovel. Unlike normal blocks, interlocking blocks are wet molded. Each frame interlocks with the adjacent block accurately, either in sequence or perpendicularly. Each hollow concrete blocks has voids that facilitates the rise and escape of warm air out of the building. The air-filled voids also give the blocks thermal insulation properties. Instead of electric power cables being chased into walls, they channeled into the voids in the blocks. If polysterene granules or shielding foam are added into these cavities, additional insulation is achieved. The act of laying the interlocking blocks does not require technical prior knowledge. It only requires minimal training.

III. Research Method

Figure 1 summarizes the research method used followed by a discussion on the Figure 1 diagram.

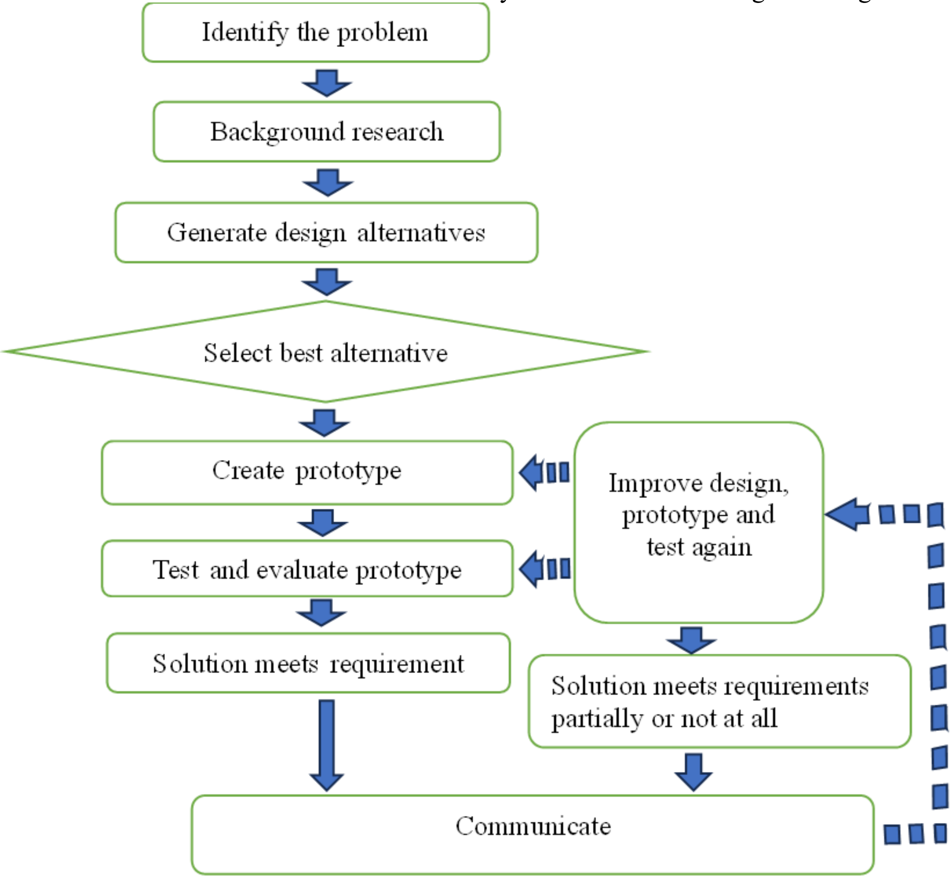


Figure 1: Summary of the Research Method

The following steps were used to achieve the objectives of the:

Step 1: A review on the basic principles of engineering design and other related subject areas was conducted. Various aspects of the existing mold designs were reviewed to ensure a unique design.

Step 2: The construction industry features a wide variety of building block molds. A visit to local building block making facilities (within Meru region and nearby areas) was conducted to obtain information on the existing block making molds. The study revealed that most block molds were integral parts concrete block making machines. Besides, the block molds were designed to produce vertically interlocking blocks only. The level of technology, production rate, initial cost and mechanism of operation of the machines were also studied. Although the machines were relatively easy to use, they were expensive to acquire.

Step 3: A list of design requirements was developed. This centred on ease of fabrication and assembly, ease of operation and efficiency as well as product cost. Free hand sketches of three different designs of hollow block making molds were developed. A layout drawing of the feasible alternatives was made in reference to the design requirements.

Step 4: Brainstorming was done to identify the alternative that best satisfies the requirements. The suitability of each design alternative was determined based on listed design requirements.

Step 5: The best alternative was chosen based on the engineering design weighted score matrix. The decision criteria were assigned weighted attributes reflecting their importance. The product cost refers to the total cost of a given mold design alternative compared to others.

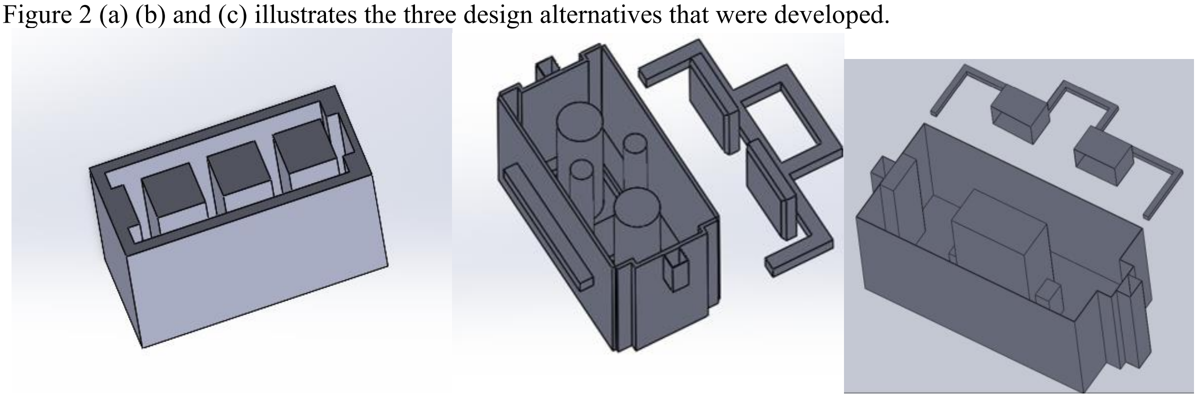
Step 5: Material selections guidelines by (Ashby, 2011) were used to select the best materials. This was done based on material properties such as strength, density, ease of manufacturing, economic traits of the materials (availability, production and cost).
Step 6: The approximate total cost of the selected mold block design was determined using a bill of quantities of the materials required for the fabrication of the design components in the current market prices in Kenya in 2024.
Step 7: The prototype of the selected mold box design was fabricated
Step 8: The fabricated mold was tested for functionality. This entailed determining the ease with which hollow blocks were made and compacted using the mold as well as the compressive strength of the blocks at 28 days of curing. The fabricated mold was set up and the necessary aggregates placed in the mold. The aggregates were compacted on a press machine and the excess mixture removed using a wood tamper. The compacted block was then ejected from the mold box. A total of seven hollow block specimens were made using by repeating the steps above. The blocks were kept away from the sun and wind by covering them with plastic sheets for 24 hours awaiting curing. They were then sprinkle-cured in a curing yard by pouring water three times a day for twenty-eight days (Rasheed & Akinleye, 2016). A compression test was done on the hollow blocks and the load at failure for each block recorded. The mass and dimensions (length, width and height) of the blocks were measured and density determined using equation 2. Equation 1 and equation 2 were used to determine the compressive strength and density respectively. Averages of these quantities were then determined and used as a more accurate estimation of these quantities.

$$Compressive\ strength = \frac{Load\ at\ failure\ (Newtons)}{Resisting\ area} = \frac{Load\ at\ failure\ (Newtons)}{Length \times breadth} \text{……………. Equation 1}$$

$$Density = \frac{mass\ (in\ kg)}{Volume\ (in\ m^3)} \text{…………………………………………………………….. Equation 2}$$

IV. Results And Discussion

Design Alternatives
Figure 2 (a) (b) and (c) illustrates the three design alternatives that were developed.



(a) Alternative 1 (b) Alternative 2 (c) Alternative 3

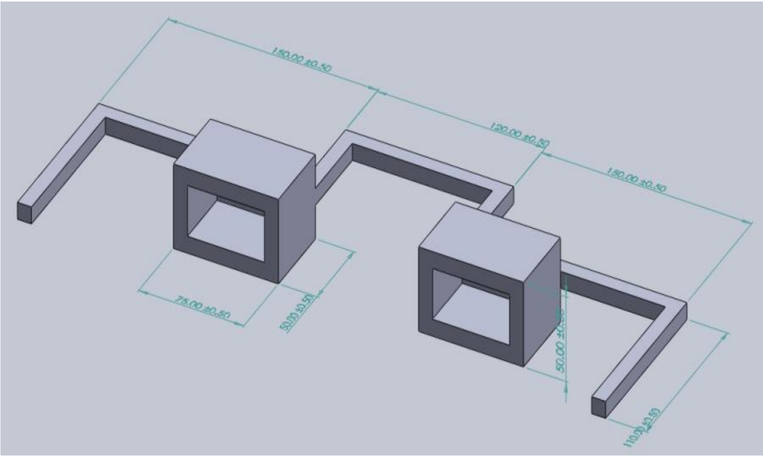
Figure 2: Isometric views of design alternatives

Best Design alternative

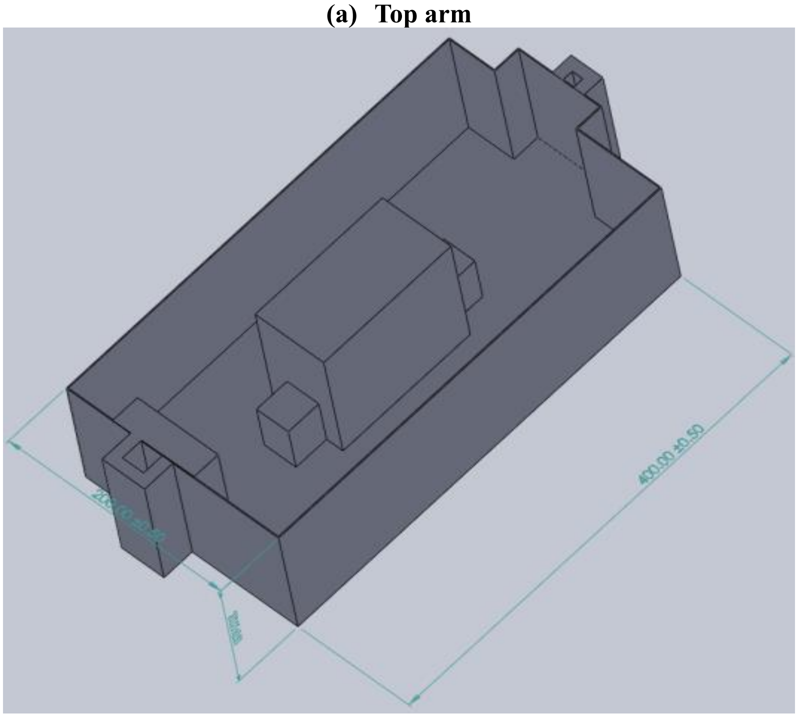
Table 1 shows the engineering design decision making matrix used to select the best design alternative. Based on the total scores, alternative design 3 was selected after having attained the highest score of 44, followed by alternative design 1, and alternative design 2 with scores of 39 and 32 respectively. The selected design alternative is presented in figure 3.

Table 1: The Engineering Design Decision Matrix for a Mold Block

		Alternative 1		Alternative 2		Alternative 3	
Selection criteria	**Weight**	**Score**	**Weighted score**	**Score**	**Weighted score**	**Score**	**Weighted score**
Ease of fabrication and assembly	3	4	12	3	9	4	12
Ease of operation and efficiency	5	3	15	3	15	4	20
Product (mold block) cost (cheaper scores higher)	4	3	12	2	8	3	12
Total			**39**		**32**		**44**



(a) Top arm



(b) Mold box

Figure 3 (a) and (b): A diagrammatic representation of the selected design mold box and top arm.

The selected design constitutes a mold box that can be used to make hollow interlocking blocks of size 400 × 200 × 200 mm. The fabricated mold is shown in Figure 4 (a). The design of the mold is such that the hollow interlocking block made using the fabricated mold can interlock in two directions: vertically and horizontally. This ensures that minimal cement, if any, is required for bonding adjacent blocks. Figure 4 (b) shows a hollow interlocking block that was made using the fabricated mold. The block has features that allow for interlocking both end to end and vertically. Figure 5 (a) shows a section of a wall built using the interlocking blocks. In the structure, the blocks interlock and form strong bonds, hence eliminating the need for bonding a medium such as cement. Figure 5 (b) on the other hand illustrates how the hollow blocks interlock at the corners.

(a) Fabricated mold box (b) Hollow interlocking block

Figure 4: Pictorial representation of the fabricated mold box and a hollow interlocking block made using the fabricated mold

Fabrication of the Selected Design of Hollow Concrete Block Mold Box

Supplies and Materials

The concept design, dimensions, supplies and materials as well as the tools and equipment used in the study are highlighted in this section.

Table 2 shows a list of the supplies and materials used for the fabrication of the hollow interlocking concrete blocks mold. The list includes the quantity, units and description of each item required. A list of tools and equipment used in this research project is shown in Table 2.

Table 2: Supplies and Materials

SNo.	Item Name	Description	Units	Quantity
1.	Square tube	Square, $\frac{3''}{4} \times \frac{3''}{4}$,gauge 16	pc	0.5
2.	Metal plate	Plain G.I sheet #16$\times$ 4′ $\times$ 4′	No.	0.25
3.	Welding rods	E6013, 3.2 mm	kilogram	0.5
4.	Grinding disc	115mm x 7mm Thick, Norzon,	Pc	1
5.	Cutting disc	AC-D SP, 125mm diameter, 2.5mm thickness	pc	1
6.	Paint	Blue oxide	Litres	0.5
7.	Paint thinner	MG Chemicals, Clear, 1L	Bottles	0.5
8.	Paint brush	wooden	Pc	1
9.	Turpentine	Relative density, 0.87	Litres	1
10.	Emery cloth	standard	pcs	2

Table 3: List of Tools and Equipment

SNo.	Item Name	Purpose
1.	Welding machine	Used to join metal parts
2.	Hammer	Shaping of metal to desired shape
3.	Angle grinder	Grinding and cutting metal (plain sheet and square tube)
4.	Hack saw	Cutting pieces of metal in various parts of the work
5.	Pliers	Safe holding of objects while welding
6.	Bench vice	Holding work firmly during fabrications (bending, grinding cutting)
7.	Steel rule	For measurement of exact length prior to cutting
8	Cylindrical grinder	To smoothen rough edges

All materials and tools needed were prepared followed by layout and marking of all measurements. The materials were held on the vices on a workbench and cut accordingly using a hacksaw. The plain sheets and square tubes were assembled in their respective positions and spot welded together. The parts were welded along designated joints to form a complete mold.

Figure 5 (a) and (b) show the front view and side view of a wall showing how the hollow blocks made using the fabricated mold interlock both vertically and horizontally. Figure 6 on the other hand shows how the hollow interlocking blocks made using the fabricated mold interlock at the corners. The cost of supplies, materials, labour and project overheads are summarized in Table 4. The total cost of fabrication of the mold box was KSh. 7,500.

(a) (b)

Figure 5: Front view (a) and side view (b) of a wall showing how the hollow blocks made using the fabricated mold interlock both vertically and horizontally.

Figure 6: A pictorial representation of how the hollow interlocking blocks made using the mold interlock at the corners

Table 4: Cost of Supplies and Materials

SNo.	Item Name	Description	Units	Quantity	Unit cost (KSh)	Total cost (KSh)
1.	Square tube	Square, $\frac{3''}{4} \times \frac{3''}{4} \times 16G$	pc	0.5	600	300
2.	Metal plate	Plain G.I sheet $8' \times 4' \times 4$mm, 16G	No.	0.25	10,000	2,500
3.	Welding rods	E6013, 3.2 mm	kilogram	0.5	500	250
4.	Grinding disc	115mm x 7mm Thick, Norzon,	Pc	1	300	500
5.	Cutting disc	AC-D SP 125mm diameter 2.5mm thickness	pc	1	300	300
6.	Paint	Blue oxide	Litres	0.5	800	400
7.	Paint thinner	MG Chemicals, Clear, 1L	Bottles	0.5	300	150
8.	Paint brush	wooden	Pc	1	200	200
9.	Turpentine	Relative density, 0.87	Litres	1	200	200
10.	Emery cloth	-	Pc	2	100	200
Sub-total						**5,000**
11.	Labour (40%)	-	-	-	-	2,000
12.	Overhead cost (10%)	-	-	-	-	500
GRAND TOTAL						**7,500**

Functionality of Fabricated Mold Box

Table 5 shows the results of compressive strength test as well as the density of the sample hollow interlocking blocks made from the fabricated mold box. The average compressive strength of the sample hollow blocks was 15 N/m^2 while the average density was 1582. Kg/m^3. This is comparable to published values of compressive strength for masonry specimens of hollow concrete blocks (Amalkar et al., 2013; Jayasinghe & Perera, 1999; Varshney, 2015). The blocks are thus categorized as grade A (density >1500 Kg/m^3 and minimum compressive strength varying between $5N/m^2$ and 15 N/m^2). These blocks have a load bearing capacity and thus usable. However, it is worthy to note that density and compressive strength of the hollow concrete blocks vary mainly according to block size, materials types and material proportions (Varshney, 2015).

Table 5: Results of compressive strength test

Sample no	Dimensions (mm)			**Weight (kg)**	**Density (Kg/m^3)**	**Load at Failure (Tonnes)**	**Compressive Strength (N/mm^2)**	**Average Compressive strength of cured blocks (N/mm^2)**	**Average Density (Kg/m^3)**
	Length	Breadth	Height						
1	399	200	198	22.40	1595	28.47	3.50	3.70	1582
2	401	199	199	22.70	1608	29.45	3.62		
3	398	198	201	22.25	1581	27.55	3.43		
4	402	198	199	22.45	1595	29.86	3.68		
5	398	202	201	22.43	1558	32.95	4.02		
6	399	201	202	22.50	1559	30.25	3.70		
7	399	202	201	22.60	1566	34.10	4.15		
8	402	199	198	22.40	1591	28.38	3.48		

V. Conclusions And Recommendations

Conclusions

A mold box was fabricated that was used to make hollow interlocking blocks with average compressive strength and density of 3.7 N/mm^2 and 1582 Kg/m^3 respectively. The blocks are thus categorized as grade A (density >1582. Kg/m^3 and minimum compressive strength varying between $5N/m^2$ and 15 N/m^2), which have a load bearing capacity. The fabricated mold box can thus be said to have the capacity to carry out the intended functions effectively as expected.

Recommendations

The mold box can be used to make a single hollow block at a time. To achieve higher productivity, it should be modified by introducing compartments that can allow production of multiple hollow blocks in one shift.

The mold should be made integral to a hydraulic mechanism as a source of power to make operations faster and simpler.

References

[1] Amalkar, M., Renukadevi, M., & Jagadish, K. (2013, October). Strength And Elastic Properties Of Hollow Concrete Block Masonry.

[2] Ashby, M. (2011). Materials Selection In Mechanical Design. Butterworth-Heinemann.

[3] Bredenoord, J., Kokkamhaeng, W., Janbunjong, P., Nualplod, O., Thongnoy, S., Khongwong, W., Ngernchuklin, P., & Mahakhant, A. (2019). Interlocking Block Masonry (Issb) For Sustainable Housing Purposes In Thailand, With Addidtional Examples From Cambodia And Nepal. Canadian Center Of Science And Education, 8(2).

[4] Centre For Affordable Housing In Africa. (2019). Kenya's Affordable Housing Programme. Centre For Affordable Housing Finance In Africa. Https://Housingfinanceafrica.Org/Documents/Kenyas-Affordable-Housing-Programme-Housing-Portal-Overview/

[5] Government Of The Republic Of Kenya. (2017). Kenya Vision 2030. Https://Www.Planning.Go.Ke/Wp-Content/Uploads/2020/11/Vision-2030-Popular-Version.Pdf

[6] Jayasinghe, C., & Perera, A. (1999, January). Studies On Load Bearing Characteristics Of Cement Stabilised Soil Blocks.

[7] Kenya National Bureau Of Statistics. (2019). 2019 Kenya Population And Housing Census Results. Kenya National Bureau Of Statistics. Https://Www.Knbs.Or.Ke/2019-Kenya-Population-And-Housing-Census-Results/

[8] Rasheed, A., & Akinleye, T. (2016). The Effects Of Production Methods On The Compressive Strength Of Hollow Sandcrete Blocks. 3(4).

[9] Schneider, M., Romer, M., Tschudin, M., & Bolio, H. (2011). Sustainable Cement Production – Present And Future. Cement And Concrete Research, 41, 642–650. Https://Doi.Org/10.1016/J.Cemconres.2011.03.019

[10] Thorat, V. M., Papal, M., Kacha, V., Sarnobat, T., & Gaikwad, S. (2015). Hollow Concrete Blocks-A New Trend. 5(5). Https://Www.Ijmer.Com/Papers/Vol5_Issue5/Version-1/C0505_01-1926.Pdf

[11] Thuo, S., & Odera, A. (2024). Delivering Affordable Housing In Kenya. Kenya Institute For Public Policy Research And Analysis. Https://Kippra.Or.Ke/Delivering-Affordable-Housing-In-Kenya/

[12] United Nations. (2022). World Population Prospects 2022. Department Of Economics And Social Affairs, Population Division. Https://Population.Un.Org/Wpp/Graphs/Probabilistic/Pop/Tot/900

[13] Varshney, H. (2015). A Review Study On Different Properties Of Hollow Concrete Blocks. 4(3). Https://Doi.Org/10.17577/Ijertconv4is03032