Structural performance of plastic block masonry unit

Gildas Mahougnon Tokpomehoun a,*, Walter Odhiambo Oyawab, Thuo Joseph Ng'ang'ac, Victoria Akoth Okumud c

a Civil Engineering, Pan African University Institute for Basic Sciences, Technology and Innovation, Kenya
b Jomo Kenyatta University of Agriculture and Technology, Kenya
c Dedan Kimathi University of Technology, Kenya
d Multimedia University of Kenya, Kenya

ARTICLE INFO

Keywords:
Compressive strength
Inserted bottle blocks
Plastic bottles
Soil
Wall panel

ABSTRACT

The use of innovative materials with a sustainable application can have important benefits. Plastic bottles are increasingly becoming a menace to the environment due to their improper disposal. In this work, Polyethylene Terephthalate (PET) bottles of 500 ml volume were used and filled with different types of soil: Red Coffee Soil (RCS), Murram Soil (MS) and Black Cotton Soil (BCS). The objective of this work was to investigate the structural performance of plastic bottles filled with soil inserted into cement mortar as a walling material. The compressive strength of Inserted Bottle Block (IBB) and Inserted Bottle Wall (IBW) has been tested and results have been discussed. At 28 days, compressive strength test results show that, Inserted Bottle Block filled with Red Coffee Soil Block (IBB-RCS) and Inserted Bottle filled with Murram Soil Block (IBB-MS) had a compressive strength of 2.7 MPa and 2.8 MPa, respectively. These values were higher than the minimum requirement for masonry units specified by the Kenya standard, which is 2.5 MPa, while the compressive strength of the Inserted Bottle filled with Black Cotton Soil Block (IBB-BCS) was 1.8MPa. A compressive strength test on Inserted Bottle Wall (IBW) shows that Inserted Bottle filled with Murram Soil wall (IBW-MS) has a compressive strength of 1.2 MPa while Inserted Bottle filled with Red Coffee Soil wall (IBW-RCS) and Inserted Bottle filled with Black Cotton Soil wall (IBW-BCS) have a compressive strength of 1.4 MPa and 0.8 MPa respectively. This study revealed that Inserted bottle filled with soil blocks could be used as construction materials.

1. Introduction

Global management of solid waste is the major concern of the century. Poor management of solid waste is the major source of environmental degradation. One of the aspects of environmental degradation is the abundance of plastic waste and the fact that it is not biodegradable.

Generally, the reuse of plastic bottles involves some processes, which limits their reuse [1]. For this reason, plastic bottles are found everywhere in our cities, especially in areas where storm water has accumulated them. Recycling these waste plastic bottles is a key component in contributing to environmental protection and reducing the trend of global warming.

Recently, plastic waste has been recycled in many areas around the globe for various purposes. Many researchers have used recycled plastic bottles as construction material in the construction industry as [2, 3, 4, 5, 6, 7, 8, 9]. For instance, they have been used for greenhouse construction, and road reinforcement. They have also been used in other areas, such as art decoration and agriculture.

Rathinam et al. [1] have investigated the properties of bricks made with plastic bottles filled with sand. Furthermore, they investigated the indoor temperature compared to the corresponding outdoor temperature of a wall structure that was made with plastic bottles filled with sand. Results revealed that the bottle houses are designed to be bio-climatic, which means that while it is frigid outside, it is warm inside, and vice versa.

Sultan et al. [10] have explained how plastic bottles are used in construction. The blocks were manufactured and properties such as compressive strength and water absorption were investigated. They found that the result was similar to that of lateritic stone used as building materials.

AL-Kaabi et al. [11] have used chopped plastic bottles as partial replacements for coarse aggregate in concrete, which was considered as a useful and effective method of recycling plastic bottles. The result demonstrates that as more plastic bottles are used to substitute coarse aggregate, the concrete's strength and density drop, which is due to the plastic bottle's lighter weight when compared to coarse aggregate. The
results from the experiment proved that plastic bottles could be used as a partial replacement of aggregate in concrete.

To contribute to this area, the aim of this research was to use plastic bottles filled with soil and insert them in cement mortar to manufacture blocks that can be used in construction as alternative materials. In addition, this study involves the investigation of the behavior of the wall panels made of these blocks. The significance of this study lies in the fact that it contributes to the effective reutilization of waste plastic bottles.

2. Materials and methods

2.1. Materials

2.1.1. Plastic bottles

In the present work, 500 ml plastic bottles were used as shown in Figure 1. The bottles were collected from waste collectors in Nairobi. The bottles used are from one of the bottled water sellers in the country. Everyday, thousands of them are dumped. These bottles are made of thermoplastic materials derived from petroleum hydrocarbons. They are manufactured from a reaction between ethylene glycol and terephthalic acid. Plastic bottles are durable materials that provide very good chemical resistance and high impact resistance. They are not generally suitable for hot fill applications. Plastic bottles do not have good adherence when they are used with soil and cement. In this study, they will be considered as homogenous materials.

2.1.2. Cement

The important binding material used in this work is cement. It was used to make blocks and to build the wall. Cement was bought from the nearest hardware store in Juja. Commercial Pozzolanic Cement grade CEM IV/B-P 32.5R manufactured in Kenya is used as the main binding material. Its composition is as shown in Table 1.

The average initial and final setting time of the cement used were found to be 122 min and 261 min, respectively. Consistency refers to the relative mobility of a freshly mixed agent, such as cement paste, in its ability to flow. The consistency of cement was obtained after more testing was carried out, thus resulting in 150 ml corresponding to 37.5%. Results from the test are recapitulated as shown in Table 2.

2.1.3. Fine aggregate

The fine aggregate used complied with BS 1200 and was free from deleterious substances, purchased in Nairobi. The aggregate particle size distribution, bulk density, specific gravity, water absorption, and moisture content were done in accordance with BS EN 1097-6:2013; BS 812-2:1995; BS 812-102:1995; BS 813-2:1995; and BS 812-109:1990, respectively. The results were as summarized in Table 3. The particle size distribution graph in Figure 2 shows that the fine aggregate fits well within the recommendation value.

2.1.4. Soil

Three different types of soil were used in this work. The soils are RCS, MS, and BCS as shown respectively in Figure 3, Figure 4 and Figure 5, were all collected in Juja town (Kiambu County, Kenya). Physical properties test such as particle size distribution, optimum moisture content, maximum dry density, and Specific Gravity were done to classify the nature of the soils accordingly to BS: 1377; part 2, 1990.
The dry density of RCS (1158 kg/m³) and BCS (1265 kg/m³) are less than 1500 kg/m³. MS has a dry density of 1620 kg/m³, which is greater than 1500 kg/m³. The particle size distribution is a combination of wet sieving tests (Hydrometer Test) for RCS and BCS and dry sieving tests for MS. The results from the test are shown in Table 4 and the particle size distribution curve is drawn in Figure 6. The soils are found to be classified as ML (Silt), CL (Lean Clay) and CH (Fat Clay) respectively for RCS, MS and BCS in accordance with USCS (Unified Soil Classification System).

### Table 4. Recapitulated results of the different soil test.

| Properties                | RCS   | MS    | BCS   |
|---------------------------|-------|-------|-------|
| Optimum moisture content (%) | 29.5  | 18.39 | 29    |
| Maximum dry density (kg/m³) | 1158  | 1620  | 1265  |
| Specific Gravity          | 2.5   | 2.33  | 2.46  |
| Classification            | Silt  | Lean Clay | Fat Clay |

![Figure 3. Red Coffee Soil.](image)

![Figure 4. Murram Soil.](image)

![Figure 5. Black Cotton Soil.](image)

![Figure 6. Particle Size Distribution Curve for RCS, MS and BCS.](image)

### 2.2. Methods

The bottles were filled with different soils and compacted with a steel bar till they were completely full. Before filling them with the soil, they have been sieved through a sieve of 25.4 mm to remove the insalubrities from the soil. The soil was compacted in the bottles with the help of an iron bar so that they fill the maximum vacuum in the bottles. The soil was compacted after each layer was introduced into the bottles. Three layers were carried out in order to better compact each bottle.

The ideal would be to fill the bottles with soil at the optimum moisture content to achieve the maximum dry density, but this method does not allow filling the bottles properly, and it was hard to fill the bottles due to the sliding effect of the wet soil in contact with the walls of the bottles. In order to prevent the bottles from scattering in the mortar, they were tied into groups of four using a steel wire, as shown in Figure 7 (a). By tying the bottles, it was intended to reduce the sliding effect of the bottles in contact with the mortar, which is a liquid material. Cement mortar was made with a ratio of 1:3 (cement to sand). The prepared tied bottles were inserted into the mould and mortar was added to it to make blocks as shown in Figure 7 (b, c and d).

The compressive strength test of the block was carried out using a Universal Testing Machine according to BS 1881 part 166: Standard British, 1983. Figure 8 shows compressive strength testing set up of the bricks. The loading was applied continuously to failure at a uniform rate of 0.05 MPa/s. The inserted bottle blocks were subjected to compressive test after 7 and 28 days of curing. The value was calculated as the mean value of three sample blocks for each type of soil used.

The wall panels were built with the IBB thus manufactured as shown in Figure 9. They were tested for compression as a beam column having fulcrum ends at the top and bottom per BS EN772-1:2011 after 28 days of curing. The wall loading frame machine for the compressive strength is as shown in Figure 10 and Figure 11. Table 5 and Table 6 show the labels used for the types of blocks and walls.
3. Results and discussion

3.1. Compressive strength of inserted bottles filled soil blocks

The results of 28 days compressive strength testing on IBB show that IBB-RCS and IBB-MS have compressive strengths of 2.7 MPa and 2.8 MPa, respectively. These values are greater than the minimum requirement for masonry units specified by Kenya standard (2.5 MPa) KS:02-107:1993.
while IBB-BCS has a compressive strength of 1.8 MPa. The IBB-BCS value is slightly lower than the 2 MPa minimum requirement for masonry units specified in The New Mexico Code [12]. The IBB compressive strength test results are shown in Figure 12.

The average compressive strengths of the IBB were found to be 2.7 MPa, 2.8 MPa, and 1.8 MPa for RCS, MS, and BCS, respectively. These findings are in comparison to the compressive strength of compressed stabilized blocks. According to the African Standard WD-ARS 1333:2018(E), the values of IBB-RCS and IBB-MS satisfied the requirement of Class B of Compressed Stabilized Earth Blocks, which is 2 MPa–3 MPa, while IBB-BCS satisfied the requirement of Class C of Compressed Stabilized Earth Blocks, which is 1.5 MPa–2 MPa [13]. These values are quite low in comparison to the compressive strength of new extruded earth block masonry, which is typically around 3.5 MPa [14]. The compressive strength values obtained from this study are found to be close to the minimum recommended value for masonry work. However, Salih et al. [15] and Danso H & Adu S. [16] recommended a minimum value of 1 MPa and 2 MPa respectively. According to a recent study, the compressive strength obtained in the present work is comparable to that obtained by Olofinnade et al. [17], who substituted crushed PET for sand to produce hollow sandcrete blocks. Furthermore, the IBB results were compared to the results of Adobe blocks discovered by Costa et al. [18], which ranged from 0.30 to 3.50 MPa. As shown in Figure 13, the failure mode was the same for all the blocks tested. Also, cracks appeared before the maximum load and were located on the lateral face of the blocks.

The results show that IBB-MS panels have a mean compressive strength of 1.2 MPa, while IBB-RCS and IBB-BCS panels have mean compressive strengths of 1.4 MPa and 0.8 MPa, respectively. The displacements measured for IBW-MS, IBW-RCS, and IBW-BCS are 13 mm, 34 mm, and 32 mm, respectively. The panel made of IBB-MS performs better than other panels because the displacement recorded is smaller. As a result, we can conclude that using MS to fill bottles is preferable for better structural performance. This remark was also reported by Jannat, et al. [15, 19, 20, 21].

**Figure 12.** Compressive strength of inserted bottles brick.

**Figure 13.** Inserted Bottle Block after failure.

**Figure 14.** Inserted bottles wall after loading.

**Figure 15.** Maximum compressive strength.

**Figure 16.** Loads-displacement curve of inserted bottle wall.

### 3.2. Compressive strength of wall made with plastic bottles

After 28 days of curing, the walls were tested. The panels were made of IBB and various types of soil. The mortar mix proportion for the entire wall was 1:3 (cement to sand), with the type of blocks as a variable. The walls were loaded to the maximum load that can cause failure. Figure 14 show the state of the panel after failure. The mean value of compressive strength was calculated and shown in Figure 15, and a curve depicting the panel's behavior is drawn as shown in Figure 16 and Figure 17.
4. Conclusions

This paper aims to provide more information about the various ways in which plastic waste can be used or combined with construction materials. This study discovered that inserted bottle blocks can be used as a masonry construction material. When compared, IBW-RCS and IBW-MS have higher compressive strength than IBW-BCS. These values are 2.8 MPa, 2.7 MPa, and 1.8 MPa for IBW-RCS, IBW-MS, and IBW-BCS, respectively. These values (2.8 MPa and 2.7 MPa) exceed the minimum compressive strength requirement for masonry units specified in Kenya standard KS:02-107:1993.

The compressive strengths of IBW-BCS, IBW-MS, and IBW-BCW were also measured to be 1.4 MPa, 1.2 MPa, and 0.8 MPa, respectively. The displacement at failure is 34 mm, 14 mm, and 32 mm for IBW-RCS, 150 kN for IBW-MS, and 94 kN for IBW-BCS, respectively, under a maximum load of 180 kN for IBW-RCS, 150 kN for IBW-MS, and 94 kN for IBW-BCS. The results of compressive strength and displacements values of the wall panel show that:

- Blocks made of bottles filled with MS give better compressive strength compared to those made of bottles filled with RCS and BCS. The displacement observed in the panel made of IBB-MS is less than the one with IBB-RCS and IBB-BCS.
- MS can be used as a material to fill bottles when using them as construction materials.

Plastic waste, which is becoming increasingly widespread, can be effectively used in block production. By using plastic, we can reduce plastic waste in our environment while also reducing pollution. The incorporation of plastic waste into blocks has the potential to reduce the amount of plastic discarded into the environment. Waste plastic is a high-quality product that can be used or combined with construction materials. This study discovered that inserted bottle blocks can be used as a masonry construction material.

The systematic use of plastic aggregate in the construction industry could be a good way to reduce this environmental impact.

Declarations

**Author contribution statement**

Tokpomehoun Gildas Mahougnon: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Walter Odhiambow Oyawa, Victoria Akoth Okumu: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Thuo Joseph Ng’ang’a: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

**Funding statement**

Gildas Mahougnon Tokpomehoun was supported by African Union Commission through the Pan African University (PAU/ADM/PAUSTI/2017/5).

**Data availability statement**

Data will be made available on request.

**Declaration of interests statement**

The authors declare no conflict of interest.

**Additional information**

No additional information is available for this paper.

**References**

[1] R.M. Rathinam, T.R. Ku, M.S. Raman, B. Umanath, Reuse of Bottles for Wall Construction and Crafting 7, 2017, pp. 6693–6696, 4.
[2] O.D. Ablayyan, A.M. Salawu, B.I. Dahansi, A.O. Odetoye, I. Alkabob, An evaluation of compressive and flexural properties of laterite filled pet bottles as a wall 9, 2018, pp. 1783–1792, 8.
[3] R.A. Oppong, T. Amfo, Alternative wall material (AWM): comparing PET bottle bricks with cement blocks and compressed earth blocks for housing in Ghana department of architecture 2002, 2017. Figure 1.
[4] M. Mokhtar, et al., Application of plastic bottle as a wall structure for green house, ARPN J. Eng. Appl. Sci. 11 (12) (2016) 7617–7621.
[5] Z. Moyen, T.N. Barna, M.N. Hoque, Strength properties of plastic bottle bricks and their suitability as construction materials in Bangladesh 27, 2016, pp. 362–368, 3.
[6] S.P. Pandey, S. Gotmare, P.S.A. Wankhade, Waste Plastic Bottle as Construction Material, 2017, pp. 1–6.
[7] U. Patil, et al., Utilization of waste PET bottles and brick kiln dust as construction Material for Low Cost Housing 1, 2018, pp. 13–15, 6.
[8] S. Premalatha, N.S. Pavithraparvathi, N. Aparna, J.R. P, P. Jeeshma, Utilization of waste PET bottles and industrial by products as a construction material, 2016, pp. 1459–1462.
[9] A. Shah, H. Patel, Waste plastic bottles offering innovative building materials with sustainable 3, 2016, pp. 38–45, 3.
[10] M. Sultan, R. Jaival, R. Jaival, F. Ram Sahu, M. Sahu, A. Professor, Utilization of waste plastic in manufacturing of plastic sand bricks, Accessed: Aug. 28, 2020. [Online]. Available: www.ijies.net, 2020.
[11] J.J.F. Al-Kabi, M. Al-Soudani, A.A.K. Sharba, Practical study on the effect of partial replacement of coarse aggregate with plastic waste on some normal concrete properties, IOP Conf. Ser. Mater. Sci. Eng. 870 (2020), 012036.
[12] S.M. Alcorro, et al., The new Mexican City Building Code Requirements for Design and Construction of Masonry Structures, in: 9th North American Masonry Conference, 2003, pp. 656–667.
[13] F. Edition, AFRICAN WD-ARS 2018, 2018.
[14] F. Stazi, M. Serpilli, G. Chiappini, M. Pergoloni, E. Fratalocchi, S. Lenci, Experimental study of the mechanical behaviour of a new extruded earth block masonry, Construct. Build. Mater. 244 (2020), 118368.
[15] M.M. Salih, A.I. Osofero, M.S. Imabari, Critical review of recent development in fiber reinforced adobe bricks for sustainable construction, Front. Struct. Civ. Eng. 14 (4) (2020) 839–854.
[16] H. Danso, S. Adz, Characterization of compressed earth blocks stabilized with Clay pozzolana, J. Civ. Environ. Eng. 9 (1) (2019) 1–6.
[17] O.M. Olofinmade, I.E.E. Davies, I.W. Egwumukwu, Recycling of Polyethylene terephthalate wastes in production of hollow sandcrete blocks for sustainable construction, Solid State Phenom. 318 (May 2021) 49–58.
[18] C. Costa, D. Arduin, F. Rocha, A. Velosa, Adobe blocks in the center of Portugal: main characteristics, Int. J. Architect. Herit. 15 (3) (2021) 467–478.
[19] N. Jannat, A. Hussien, B. Abdullah, A. Cotgrave, Application of agro and non-agro waste materials for unconfined earth blocks construction: a review, Construct. Build. Mater. 254 (2020), 119346.
[20] H. Mato, U.E. Edike, Y.H. Labaran, J.Z. Yau, The impact of soil types on the mechanical properties of sustainable bottle bricks 7, 2020, pp. 177–186, 4.
[21] M. Mokhtar, et al., Application of plastic bottle as a wall structure for green house 11, 2016, pp. 7617–7621, 12.