INVESTIGATION OF RECYCLED PLASTIC WASTE INTO BRICKS FOR THE CONSTRUCTION OF HOUSING PROJECTS IN GHANA

ABSTRACT

Alternative materials are now being used for the construction of various projects in Ghana due to the expansion of infrastructure in the country. The quantity of materials needed to build infrastructure presents a significant opportunity to reuse some of the waste products. It has become possible to investigate the recycling of plastic waste into the construction of bricks due to the substantial discrepancy between the supply and demand of traditional building materials. In this study, an effort was made to recycle a sizable amount of HDPE waste gathered from markets, shopping centers, landfills, and supermarkets for utilization of bricks for housing projects. To determine the efficacy and durability of the bricks made from recycled plastic waste for various uses in civil engineering projects, several experimental tests including the compressive strength test, split tensile test, and water absorption tests were conducted. The mix ratios for the plastic bricks for compressive and tensile strength are 1:3, 1:4, and 1:5.5, respectively, while their water absorption mix ratios are 1:2, 1:3, and 1:4. The experimental findings demonstrated that the bricks produced had good compressive strength, tensile strength and low water absorption rates. Additionally, it was observed that the manufactured bricks are lightweight, have a smooth surface and fine edges, and can be an excellent substitute for clay and conventional concrete blocks, which have been used for decades to build the housing projects in the country.

Key words: Plastic waste, compressive strength, tensile strength and water absorption

1. INTRODUCTION

Construction businesses in many developing nations have embraced innovative techniques for building sturdy infrastructures for both public and private use using variety of building materials (Atta *et al*., 2021). The used materials demonstrated variety of attributes, including strength and endurance to withstand any loads imposed to it after being used in specific infrastructural sectors. It is vital to employ high-quality and durable building materials to complete the task at hand because the goal is to provide infrastructure amenities for a population that is rapidly growing (Moghayedi *et al*., 2017). Thus, throughout many decades, the development of homes and other infrastructure projects has made use of building materials from a variety of suppliers (Malindu, 2022). Roads, houses, and railway lines have all been constructed for a long time using resources like cement, sand, stones, wood, and rocks (Danso, 2013). Each material serves a variety of purposes due to its unique characteristics, qualities, and durability. However, the quality, durability, and economic viability of the materials used in certain construction projects are taken into consideration while making the decision (Olanrewaju and Lee, 2022). Before the commencement of housing projects, regular meetings between structural engineers and architects are held to assess the ability of the materials to support loads (Gyima and Oppong, 2016). Traditional building materials are getting more difficult to locate, according to recent observations. The inability of manufacturing industries to satisfy the needs of the construction industries have had major consequences for many current building and other infrastructure projects, even though it was thought that this was the industry that would be most viable for many housing projects (Kineber and Hamed, 2022). A number of industries attempts to produce the essential building materials have, once more, had a very unfavorable effect on construction projects all over the world.

Furthermore, due to a lack of raw materials that could be utilized to produce building materials for housing projects, many poor countries throughout the world now largely rely on recycled items as an alternative choice of building materials (Yehia *et al*., 2015). The materials used for construction projects over the past few years have proven to have the maximum strength and durability for the duration of their use in diverse structural applications (Zheng *et al*., 2021). However, as its final application in construction has been underutilized, there is a gap between awareness of and implementations of recycled plastic materials as a choice of sustainable building materials in the construction sector (Du and Jiang, 2021). Plastics, paper, metals, wood, glass, and other solid waste items are among the materials that are most frequently recycled. Due to the emergence of recycled plastics as alternative building materials and their use in civil engineering for the construction of housing projects, researchers have thoroughly conducted comparison studies into recycled materials that may be used for construction (Tulane *et al*., 2022). For this reason, solid waste products from supermarkets, retail outlets, and landfills have been recycled, assessed in civil engineering laboratories, and demonstrated to be suitable for use in construction. As a substitute building material for housing projects in Ghana, plastic recovered materials was employed in this study.

Recycling of plastic waste has been seen as a superior option to cement mixes or concrete mixture for the purpose of disposing of plastic waste due to its advantages in terms of economy and the environment as a replacement or substitution of a particular part of aggregate in concrete mix (Singh *et al*., 2023). Additionally, lightweight concrete, which has a number of uses in construction, would be a potential option for a novel technique to recycle plastic waste (Thiounn and Smith, 2020). Numerous studies looking into the use of different waste materials in construction have been described in published literature. Other researchers have thoroughly studied the literature on replacing fine aggregate in concrete with bottom ash, waste foundry sand, copper slag, plastic garbage, recycled rubber waste, and crushed glass aggregate (Pooja *et al.*, 2021). The building and civil engineering industries are paying increasing attention to worries about the potential of plastic waste mixed with cementitious based combinations like polyethylene for construction (Nyika and Dinka, 2022).

2. MATERIALS AND METHOS

2.1 MATERIALS

2.1.1 High-Density Polyethylene (HDPE) plastic waste

High-Density Polyethylene (HDPE), a thermoplastic polymer made from petroleum, is stronger, more opaque, and more heat resistant. It is a flexible plastic substance with many uses that makes it extremely valuable to be recycled into building materials for civil engineering projects. In addition to plastic bottles, milk jugs, juice containers, shampoo and body wash bottles, cutting boards, pipes, and milk and juice bottles, HDPE is used in a wide range of products. The substance exhibits strong impact resistance, a low melting point, high strength-to-density ratio, and good tensile strength. In order to create the plastic for the bricks, the waste plastic materials were first crushed in a plastic shredder machine.

2.1.2 Clay

The main component of the raw materials used to make the bricks, along with plastic waste, is clay. The manufacturing of plastic bricks started with the gathering of clay-based raw materials. Clay, which served as a binder to facilitate bonding, was used to harden and adhere to the plastic materials.

2.2 Methodology

The following methodology were adopted for the research:

- Collection of plastic waste

- Batching
- Melting
- Mixing
- Moulding
- Curing

2.2.1 COLLECTION OF PLASTIC WASTE

Low-density polyethylene (LDP), which was collected from stores, markets, and landfills, was employed as the plastic waste material for the experimental examination. They are constructed from a lightweight, flexible plastic that is appropriate for the test. Among the plastics that are gathered are water bottles and plastic bags. These were kept dry and secure in rice sacks, and any natural moisture that would have compromised analysis was only partially removed before being air dried in pans. After drying, the samples were transferred to the laboratory so that any hazardous components, including roots, could be removed there. The final samples for the tests were made by crushing the samples with a mortar and pestle before being run through a sieve (i.e., a sieve with a mesh size of 5 mm). Plastic materials are reduced to shredded form using a shredder machine that can create bits up to 1 cm long. The cement used was common Portland cement (OPC), obtained from a nearby market.

2.2.2 BATCHING OF PLASTIC WASTE

The measurement of materials for the production of brick was carried out using a batching equipment in the laboratory. The various plastics to be tested were separated, and any extraneous garbage that was present in the gathered material was taken out and examined to make sure it was prepared for burning. The plastic debris was burned in a controlled location to prevent the discharge of poisonous fumes into the environment that could endanger human life.

2.2.3 MELTING

During the melting process the arrangement of stones, drum and the required firewood were done to enable successful burning of the materials. The stones are arranged to hold the drum stable and firewood is placed in the gap and it is ignited. The drum is placed over the setup and it is heated to remove the moisture present in it. Shredded plastic pieces required for making one brick in the weight proportions of 1:4 (plastic: clay) were added into the drum and allow it to fully melt so as to form a hot thick slurry. Fig. 1 shows how the burning of the plastic waste were carried out by the researchers in the study.

Fig 1: Burning of plastic waste

2.2.4 MIXING OF THE MATERIALS

The materials were thoroughly mixed in order to produce bricks that are both consistent and strong for the construction of housing projects. The mixture was prepared with the goal of achieving homogeneity, uniform color, and consistency. The graded dirt (which is 4.75mm passing) was added to the pan as soon as the plastic has melted which was thoroughly mixed with a trowel equipment. It was risky to allow the heated substance to come into touch with the skin when handling the mixture, thus the appropriate safety procedures were taken. Prior to the melting process, the soil and plastic were appropriately batch-stacked in the required proportion.

2.2.5 MOULDING

During the moulding procedure, the prepared mix was put into the mould of dimension 225 x 125 x 75 and compacted with a tamping rod. Before filling the mould, an oil was used to lubricate the interior walls to prevent mix from clinging to the surface and to make it easier to remove the bricks for testing. Fig. 2 shows the moulding of plastic bricks in the laboratory.

Fig. 2: Moulding of plastic bricks in the laboratory

2.2.6 Curing

The samples were taken to a separate room to prevent outside influences from disturbing the prepared bricks before they were allowed to dry for 48 hours before being remove for testing. The samples were then given a curing period of 7, 14, 21 or 28 days, as appropriate.

3. EXPERIMENTAL PROGRAMME

3.1 Compressive Test

The test was performed on the specimen using universal testing machine with a maximum force of 3000 kN at a speed of 3.7 kN/min. During the experimental investigations, the bricks which were of dimensions 225 mm × 125 mm × 75 mm were arranged uniformly in the machine. The load was gradually released until the bricks deformed or broke was observed. The experiment was performed in compliance with (ASTM C67). The compressive strength of the specimen was determined at 7, 14, 21, and 28 days using the equation below:

$$\text{Compressive strength} = \frac{Applied\ \ maximum\ \ load\ \times 1000\ (N)}{Cross\ Sectional\ \ area\ \ (\text{mm } 2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

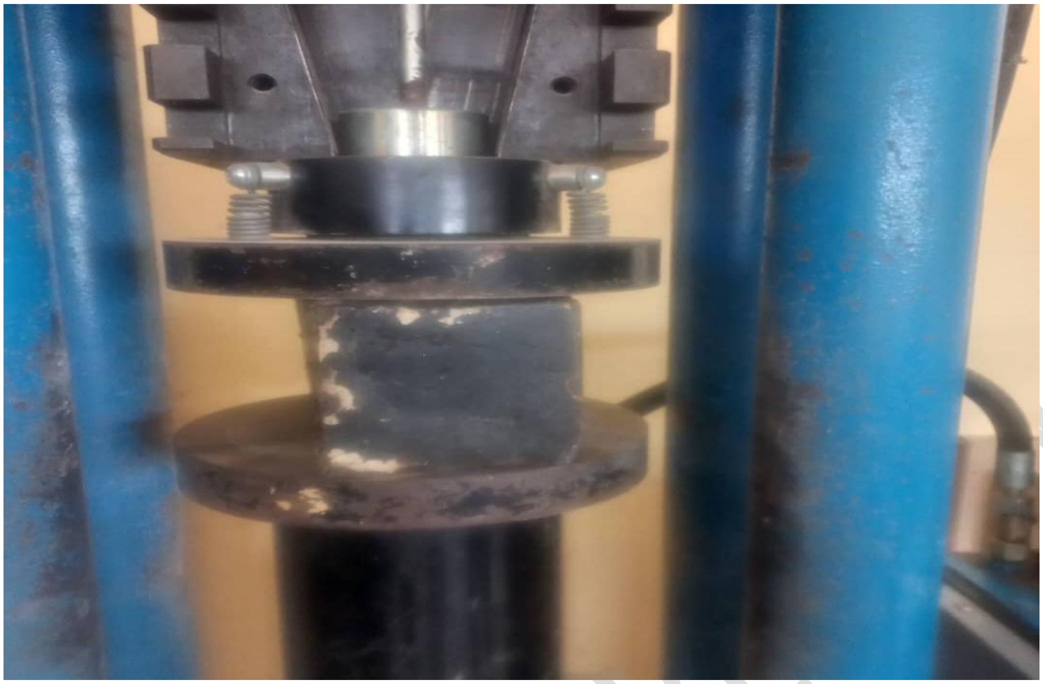

Fig. 3: Compressive strength test of plastic brick

3.2 Split Tensile Test

The split tensile test was carried out in accordance with American Society of Testing and Materials (ASTM C496). After numerous cycles of soaking and drying, samples of the manufactured bricks underwent tensile strength tests. Similar to the bricks tested previously for the compressive strength test, the bricks have the same dimensions. On the tensile testing equipment, the bricks were positioned in between the bearing blocks. To guarantee even distribution of applied pressure, a piece of mild steel measuring 90 mm in width by 190 mm in length, 4 mm thick, is positioned horizontally along the upper and lower load-bearing length of the bricks. The highest load for the test was recorded along with the split tensile strength, which was computed using the tensile load rate of 4000 N/mm.

Fig. 4: Split tensile test of plastic brick

3.3 Water Absorption Test

The test was performed to assess how much water the brick absorbed and to ensure that they did not absorb more than 12% of its weight in water. The bricks having a lower water absorption rate were thought to be of higher quality. The test bricks were heated to remove any moisture content before being dried in an oven at a temperature of between 105°C and 115°C until they attained a consistent weight. The weight (W1) of the bricks was then determined when they had cooled to room temperature. The brick (W1) was fully dried, weighed, and then immersed in fresh water for 24 hours at a temperature of 27–20°C. When bricks were taken out, the water and weight were immediately removed, and the bricks were weighed and noted as (W2). The test was performed in accordance with ASTM D570. The formula presented below was used to determine the percentage of water absorbed:

$$\text{Water absorption} = \frac{W2-W1}{W1} \times 100$$

where

W2 being the weight of the dry brick measured in kg

W1 being the weight of the wet brick measured in kg

4. RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1 Test results of compressive strength

Table 1: Compressive strength of bricks tested at day 7

Sr. No.	Age in Days	Size of bricks (mm)	Cross-sectional area (mm^2)	Maximum load applied (kN)	Compressive strength (N/mm^2)
1	**7**	225 x 125 x 75	16875	325	9.190
2	**7**	225 x 125 x 75	16875	175	10.370
3	**7**	225 x 125 x 75	16875	155	19.260

Table 2: Compressive strength of bricks tested at day 14

Sr. No.	Age in Days	Size of bricks (mm)	Cross-sectional area (mm^2)	Maximum load applied (kN)	Compressive strength (N/mm^2)
1	14	225 x 125 x 75	16875	335	11.141
2	14	225 x 125 x 75	16875	215	12.700
3	14	225 x 125 x 75	16875	188	19.850

Table 3: Compressive strength of bricks tested at day 21

Sr No.	Age in Days	Size of bricks (mm)	Cross-sectional area (mm^2)	Maximum load applied (kN)	Compressive strength (N/mm^2)
1	21	225 x 125 x 75	16875	202	11.970
2	21	225 x 125 x 75	16875	225	13.333

3	21	225 x 125 x 75	16875	342	20.267

Table 4: Compressive strength of bricks tested at day 28

Sr No.	Age in Days	Size of bricks (mm)	Cross-sectional area (mm^2)	Maximum load applied (kN)	Compressive strength (N/mm^2)
1	28	225 x 125 x 75	16875	215	12.741
2	28	225 x 125 x 75	16875	235	13.926
3	28	225 x 125 x 75	16875	350	20.741

Table 5: Average compressive strength (N/mm^2)

Age (Days)	Area of bricks (mm^2)	Average crushing load (kN)	Average compressive strength (N/mm^2)
7	16875	218.333	12.938
14	16875	252.667	14.973
21	16875	256.333	15.190
28	16875	266.667	15.802

4.1.2 Test results of tensile strength

Table 6: Tensile strength of bricks tested at day 7

Sr No.	Age in Days	Size of bricks (mm)	Cross-sectional area (mm^2)	Maximum load applied (kN)	Tensile strength (N/mm^2)
1	**7**	225 x 125 x 75	16875	35.00	2.074
2	**7**	225 x 125 x 75	16875	60.00	3.556
3	**7**	225 x 125 x 75	16875	70.00	4.148

Table 7: Tensile strength of bricks tested at day 14

Sr No.	Age in Days	Size of bricks (mm)	Cross-sectional area (mm^2)	Maximum load applied (kN)	Tensile strength (N/mm^2)
1	14	225 x 125 x 75	16875	38.00	2.251
2	14	225 x 125 x 75	16875	69.00	4.089
3	14	225 x 125 x 75	16875	70.00	4.889

Table 8: Tensile strength of bricks tested at day 21

Sr No.	Age in Days	Size of bricks (mm)	Cross-sectional area (mm^2)	Maximum load applied (kN)	Tensile strength (N/mm^2)
1	21	225 x 125 x 75	16875	55	3.259
2	21	225 x 125 x 75	16875	75	4.444
3	21	225 x 125 x 75	16875	90	5.333

Table 9: Tensile strength of bricks tested at day 28

Sr No.	Age in Days	Size of bricks (mm)	Cross-sectional area (mm^2)	Maximum load applied (kN)	Tensile strength (N/mm^2)
1	28	225 x 125 x 75	16875	60	3.550
2	28	225 x 125 x 75	16875	78	4.622
3	28	225 x 125 x 75	16875	95	5.630

Table 10: Average compressive strength (N/mm^2)

Age (Days)	Area of bricks (mm^2)	Average crushing load	Average tensile strength

		(kN)	**(N/mm^2)**
7	16875	27.50	1.629
14	16875	59.00	3.496
21	16875	73.33	4.345
28	16875	77.67	4.603

4.1.3 Test results of Water Absorption

Table 11: WATER ABSORPTION TEST

Sample ratio	Samples dry mass M1 (kg)	Samples wet mass M2 (kg)	Absorption rate (%)
1:2	2.585	2.849	10.21
1:3	2.650	3.048	15.019
1:4	2.771	3.214	15.99

4.2 DISCUSSION

The results of the tests were useful for conducting further analysis and discussion after carrying out the experimental studies on the recycled plastic waste that was used to make the plastic bricks. The plastic bricks made as a result of the experimental research gradually increased in compressive strength. At day 7, the strength of the bricks tested was 12.938 N/mm^2. The strengths for the different days, namely 14, 21 and 28 days are 14.973 N/mm^2, 15.190 N/mm^2, and 15.802 N/mm^2 using mix ratios of 1:3, 1:4 and 1:5.5. The findings from the experimental investigations showed that the bricks produced from the recycled plastic waste are of excellent quality and perform brilliantly, making them appropriate for use in housing projects in Ghana. Tables 6 to 9 offer a distinctive presentation of the tensile strength of the plastic bricks at the various test days, including 7, 14, 21 and 28 days. There was only very slight improvement in the tensile strength of plastic bricks, as it was noticed. These increases, meanwhile, might be brought on by the high plastic content in the bricks. From Table 10, it can be observed that at day 7 the split tensile strength of the brick produced from the test was 1.629 N/mm^2. The split tensile strength of the bricks significantly increased between days 7 and 14 followed by a modest continuation at days 21 and 28 respectively, as shown in Table 10 of this study. In order to analyze the effectiveness of the bricks in terms of how water plays a crucial role in the brick creation, the plastic bricks used in the study were evaluated for water absorption, which varied from 10.21% to 15.99%. All of the water absorption values obtained from the experimental test fall within the acceptable range when compared to the values for standard bricks, which ranged from 12% to 20%. The water absorption test findings can be used to deduce that the bricks produced are of a high level and might be used to construct homes in the country.

5. CONCLUSION

The following conclusions were drawn from the research:

1. The utilization of recycled plastic waste for construction applications will considerably increase environmental sustainability and provide a dependable source of resources for construction.
2. The plastic bricks tested well in terms of compressive strength and tensile strength, which means that no features that can cause the bricks to expand and crack. This makes the bricks even more resilient to fire and durable when utilized in housing construction projects.
3. The water absorption of the plastic bricks tested in the study ranged from 10.21 % to 15.99 % and whereas it ranges from 12% to 20% of normal clay bricks. These results for water absorption met the requirements for normal clay bricks, proving that the plastic bricks produced are reliable, compliant, and suitable for use in housing projects.
4. The use of plastic waste in construction has the advantage of promoting economic growth in the sector and offers manufacturing companies the chance to consider recycling plastic waste as a secondary option for creating materials for construction applications.

REFERENCES

Atta, N., Valley, D. A., Campioli, A., Chiaroni, D. and Talamo, C. (2021), Construction Technologies for Sustainable Affordable Housing within Fragile Contexts: Proposal of a Decision Support Tool, *Sustainability*, pp. 1-14.

Du, G. and Jiang, R. (2021), Study on Recycling and Reuse of Waste Materials in Building Industry, *American Journal of Environmental and Resource Economics*, Vol. 6(2): 46-53.

Malindu, S. S. (2022), Environmental Impacts of Construction in Building Industry-A Review of Knowledge Advances, Gaps and Future Directions, *Knowledge*, pp. 140-156.

Moghayedi, A., Awuzie, B., Omotayo, T., Jeune, L. K., Massyn, M., Ekpo, O. C., Braune, M. and Byron, P. (2021), A Critical Success Factor Framework for Implementing Sustainable Innovative and Affordable Housing: A Systematic Review and Bibliometric Analysis, *Buildings*, pp. 1-31.

Nyika, J. and Dinka, M. (2022), Recycling plastic waste materials for building and construction Materials: A minireview, *Materials Today: Proceedings*, pp. 1-6.

Gyimah, K. A., and Oppong, R. A. (2016), Building Materials and their Energy Demand: A Case in Ghana, *African Journal of Applied Research*, pp. 35-46.

Danso, H. (2013), Building Houses with Locally Available Materials in Ghana: Benefits and Problems, *International Journal of Science and Technology*, pp. 225-231.

Olanrewaju, A. and Lee, A. J. H. (2022), Analysis of the poor-quality in building elements: providers' perspectives, *Frontiers in Engineering and Built Environment*, Vol. 2, No. 2, pp. 81-94.

Pooja, L., Dilraj, P. K., Seema, R. and Jyoti, S. (2021), Recycling/Reuse of Plastic Waste as Construction Material for Sustainable Development: A Review, *Environmental Science and Pollution Research*, pp.1-24.

Singh, A., Srivastava, K. A., Singh, G., Singh, D. A., Singh, K. H., Kumar, A. and Singh, K. G. (2023), Utilization of Plastic Waste for Developing Composite Bricks and Enhancing Mechanical Properties: A

Review on Challenges and Opportunities, *Advances in Polymer Technology*, pp. 1-24.

Thiounn, T. and Smith, C. R. (2020), Advances and Approaches for Chemical Recycling of Plastic Waste, *Journal of Polymer Science*, pp. 1347-1363.

Tulane, R. D. S., Afonso, R. G. D. A., Daiane, C., Markssuel, T. M., Mugahed, A., Roman, F., Nikolai, V., Maria, K., Sergey, K. and Maciej, S. (2021), *Materials*, pp. 1-19.

Kineber, F. A. and Hamed, M. M. (2022), Exploring the Sustainable Delivery of Building Projects in Developing Countries: A PLS-SEM Approach, *Sustainability*, pp. 1-19.

Zheng, Y., Zhang, Y. and Zhang, P. (2021), Methods for Improving the Durability of Recycle Aggregate Concrete: A Review, *Journal of Material Research and Technology*, 6367-6386.

Yehia, S., Helal, K., Abusharkh, A., Zaher, A. and Istaitiyeh, H. (2015), Strength and Durability Evaluation of Recycled Aggregate Concrete, *International Journal of Concrete Structures and Materials*, Vol. 9, No. 2, pp. 219-239.