Production of Lightweight Building Blocks from Clay-Plastic Composites for Earthquake Prone Areas in Ghana

[1]A. A. A. Appiah, [2]J. P. Mensah and [1]J. R. Dankwah
[1]University of Mines and Technology (UMaT), Tarkwa, Ghana
[2]Anglogold Ashanti, Iduapriem Mine, Tarkwa

Appiah, A. A. A., Mensah, J. P. and Dankwah, J. R., (2022), "Production of Lightweight Building Blocks from Clay-Plastic Composites for Earthquake Prone Areas in Ghana", *Proceedings of the 7th UMaT Biennial International Mining and Mineral Conference, Tarkwa, Ghana,* pp. 1 – 7.

Abstract

Waste plastics are often indiscriminately disposed of in the local environment, including the sea, rivers, and stormwater drainage systems. The non-biodegradable waste plastics pollute the environment and disturb aquatic life with deleterious impact on flora and fauna over long-term. Globally, waste plastics have become a major environmental problem, especially for developing countries such as Ghana where there are limited recovery and recycling systems for such wastes. In recent years, however, high-density polyethylene (HDPE) plastic waste, fly ash and wood sawdust have all been used in the construction of bricks. This research sought to investigate the viability of two categories of waste plastics, polyethylene terephthalate (PET) and polystyrene (PS) incorporated into bricks as a building material. The aim is to produce lightweight-fired clay bricks using waste plastics and establish the appropriate clay-to-plastics ratio needed for the production of robust lightweight-fired clay bricks. Shredded plastics passing 250 µm sieve were mixed with fine clay and known amounts of water at different ratios and then moulded. The bricks were then fired at a temperature of about 210 ºC for 11 hours after which their compressive strengths were measured. The test analyses and results showed that lightweight bricks incorporated with plastics have higher compressive strength than conventional bricks, with the Clay: PS ratio of 1:1 displaying the highest compressive strength of 23.26 Mpa. The overall findings, therefore, demonstrate a beneficial waste plastics utilization, leading to environmental clean-up and production of robust lightweight blocks suitable for use as building materials in Ghana's earthquake-prone areas.

Keywords: Plastics, Polystyrene, Polyethylene terephthalate, Clay and Bricks

1 Introduction

Non-biodegradable plastics (e.g., HDPE) are synthetic polymers derived primarily from petro-fossil feedstock and made-up of long chains of hydrocarbons with additives and can be molded into varieties of finished products (Deepak Shiri et al., 2015). Industrial and domestic waste has a significant percentage of polymeric materials in its constitution, which occupies a considerable volume on landfills. Therefore its recycling is interesting for research and development of technologies for minimizing the problems caused by this waste (Ghernouti et al., 2009). In time of need, plastic is found to be very useful but after its use, it is simply thrown away or improperly disposed of in landfills, creating all kinds of hazards. Poor plastic waste management systems could trigger serious environmental ecosystem destruction and public health hazard. Recovery and recycling infrastructure and opportunities for these materials are mostly non-existent in African countries compared to plastic waste generated (Ikechukwu and Shabangu, 2021). As a result, waste plastics have little or no value, resulting in uncontrolled disposal in a landfill. Also, researchers have found that these plastic materials can remain on the earth for over 4500 years without degradation. Plastics constitute approximately 3 to 7% of municipal waste and the world's annual consumption of plastic materials has increased from around 5 million tons in 1950s to nearly 100 million tons today and PET plastics waste is ranked as the 5th most produced plastics materials with a 41.56 million metric tons in 2017 with a 73.39 million metric tons generation forecast in 2020 (Deepak Shiri et al., 2015); *Glob. Waste Manag. Outlook*, 2016). To mitigate this rising global pollution crisis, these waste plastics are to be effectively utilized.

Also, the heavy weight of bricks warrants high structural load-bearing supports in construction and thus leads to more vulnerability against earthquake forces. It is, therefore, necessary to reduce the density of the bricks without loss of strength, as well as improve thermal insulation properties (Azimi et al., 2021; Veiseh and Yousefi, 2003). The Ghana Geological Survey had warned that Accra was on the verge of experiencing an earthquake due to the frequency of seismic readings in recent times" (The Ghana news Agency, 2020). The destruction caused by earthquakes can be minimized if buildings are constructed with robust lightweight brick.

This project seeks to incorporate selected waste plastics (PET and PS) into building materials used in the production of fired clay bricks to achieve: (a) lightweight products with high compressive strength and (b) markedly reduce the escalating environmental pollution caused by waste plastics.

2 Materials, Methods Used

Common clay and plastics were collected from the vicinity of UMaT. The clay was dried using natural sunlight and was milled using the laboratory mill to a size of -250µm. The plastics were also shredded using the laboratory shredding machine, after which they were subjected to melting, and quenching in water to render the material brittle and drying using the sun. Pulverization of plastics was done to a size of -250µm. Moulding of bricks were done in different clay: plastics volume ratios of 3:1, 2:1, 3:2, 1:1 and 1:3 with a known amount of water. Typically, the total volume of clay, plastic and water was about 0.35 dm^3. For instance, for a ratio of 1:1, an equal volume of clay and plastics 0.16 dm^3 was mixed with 0.08 dm^3 of water. Moulded bricks were allowed to dry after which test analysis was done. This experiment was repeated three times.

2.1 Clay preparation

Clay bricks are very durable, fire resistant, and require very little maintenance. They have moderate insulating properties, which make brick houses cooler in summer and warmer in winter, compared with houses built with other construction materials (Kadir and Mohajerani, 2011). Clay sample used for this project was obtained from the grounds of the University of Mines and Technology. The sample was dried in the sun for about 24 h to remove moisture from the clay. The dried clay was milled for about 30 min after which screening with a 250 µm sieve was done. The undersize which was about 6 kg was characterized by X-Ray Fluorescence (XRF) spectrometer before use.

2.2 PET plastics preparation

Sorting of waste plastics collection was done to obtain used PET water bottles. The lids of these bottles were first removed and the bottles were cut into two pieces. This was followed by shredding using a laboratory shredder. 3 kg of shredded materials were used.

Melting of the shredded plastics in a 4.5 L stainless steel container was done using a gas stove as the source of energy. The molten plastic was subsequently poured into a bucket of water for quenching. This process was repeated to melt all shredded plastics. Quenched plastics formed a big lump of brittle mass which was broken into pieces and allowed to dry in the sun for about 24 h.

Milling was done to achieve 80% passing 250 µm screen. The undersize (-250 µm) were used in molding the bricks in different ratios.

Figure 1 various stages of PET preparation.

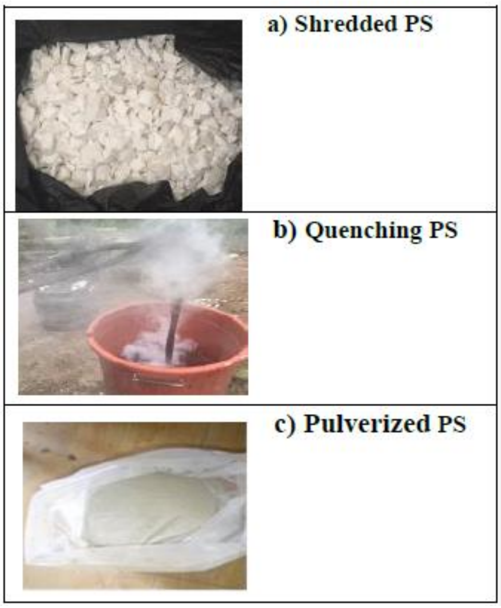
Figure 2 Shredded machine (5A 250V 0.4A 115DC)

2.3 PS plastics preparation

The PS used for this research was obtained from local waste collection sources in the form of foam packaging materials. 1.5kg of the foam were cut into pieces manually and then placed in a 4.5 L stainless steel container for melting using a gas stove.

After complete melting, the molten plastic was immediately poured into water to allow the melt to quench and prevent gradual solidification. It was observed that, the quenched PS solid product was less brittle than that of the PET. The quenched PS product was hammered into pieces and dried in the sun for about 24 h. Thereafter, a cone crusher was used to further reduce the particle size prior to fine milling.

Milling was done with a ball mill for about 60 min after which a 250 µm screen was used for sieving. The undersize (-250 µm) was used in molding the bricks in different ratios.



a) Shredded PS

b) Quenching PS

c) Pulverized PS

Figure 3 Various stages of PS to preparation.

2.4 Production of Light Weight Bricks

A wooden mould of dimensions 100 mm × 70 mm × 50 mm (length, height and breath) was used for casting bricks as shown in Fig 3.3. Different clay: plastics volume ratios of 3:1, 2:1, 3:2, 1:1 and 1:3 were used in moulding these bricks with a known amount of water. Typically, the total volume of clay, plastic and water was about 0.35 dm^3. For instance, for a ratio of 1:1, an equal volume of clay and plastics 0.16 dm^3 was mixed with 0.08 dm^3 of water. The inside of the mould was lined with adhesive tape and the inner surface then oiled with fresh engine oil before placing the mixed materials. This was done to ensure a smooth surface and easy removal of the bricks. The mixed clay and plastics were then poured into the mould and compressed with a 20KN. Clay and plastics mix at ratios of 3:1, 2:1, 3:2 and 1:3 were also moulded. This process was done for both PET and PS plastics.

The freshly cast bricks were allowed to stay in the mould for 4 days before they were removed, weighed and dried in the sun for a week. The dried bricks were then fired using a laboratory microwave oven (WAGTECH, 1250W). All moulded bricks were fired at 900 ºC for 2 h. After that they were removed and allowed to cool for 24 h at room temperature (25 ºC). Their masses were recorded and compressive strength was determined.

Figure 4 Wooden mould used.

Figure 5 Freshly cast bricks (PS)

Figure 6 MW oven for firing of bricks

Figure 7 Bricks after firing (PET)

3 Results and Discussions

3.1 Characterisation of Clay

Table 1 shows the chemical composition analysis of the clay sample using XRF. Evidently, silica (SiO_2) is the most predominant compound followed by aluminum oxide (Al_2O_3) and iron (III) oxide. The material also contained titanium oxide (TiO_2), potassium oxide (K_2O), manganese (II) oxide and other compounds in smaller quantities.

Table 1 XRF Analysis of Clay Material Used

Oxide Composition	**Concentration wt%**
Al_2O_3	17.44
SiO_2	70.77
K_2O	1.18
TiO_2	1.26
MnO	0.15
Fe_2O_3	9.06
V_2O_5	0.01
Cr_2O_3	0.04
Rb_2O	0.01
SrO	0.01
Y_2O_3	0.01
ZrO_2	0.04
SUM	100.00

3.2 Compressive strength

Compressive strength is the ability of a material to withstand loads that reduce the size of that material. The strength of a brick is often evaluated using a compressive strength tests. This test was done to evaluate if the lightweight bricks meet the requirements of the design specification for building construction. Compressive strength can be measured by plotting applied force against deformation in a resisting machine, such as universal testing machine (Figure 7).

Figure 8 Compressive Strength test.

The results of the compressive strength analysis carried out on lightweight fired clay bricks and their masses are presented.

Table 2 represents the various bricks moulded, masses after firing, maximum load and measured compressive strength values.

Table 2 Compressive strength of the bricks at various clay-to-plastic ratios (Mpa)

SAMPLE / RATIO	MASS (g)	LOAD (KN)	STRENGTH (MPa)
ONLY CLAY	810.5	28.42	4.90 ±0.92
CLAY:PET (1:1)	632.5	63.77	9.00 ±0.90
CLAY:PET (3:2)	670.5	61.89	8.74 ±0.92
CLAY:PET (2:1)	697.5	73.03	10.31 ±0.91
CLAY:PS (3:1)	695.0	100.94	14.26 ±1.01
CLAY:PS (1:1)	633.0	164.71	23.26 ±1.20
CLAY:PS (3:2)	600.0	135.50	19.17 ±1.19
CLAY:PS (2:1)	676.5	138.76	19.60 ±1.15

3.2.1 Discussion of Compressive Strength Results

(Journal *et al.*, 2008) investigated the study of plastic bricks made from waste plastic using sand and reported that compressive strength of plastic sand brick is 5.6N/mm2 at the compressive load of 96KN. (Binici *et al.*, 2012) also investigated the production of mortars with disposable polyethylene bottles without cement. The bottles were crushed, converted into fiber and then molted with different types of sands at the temperature range of 180–200 ºC. Some physical (water absorption and abrasion resistance) and mechanical (bending strength, compressive strength, toughness) properties of the mortar were tested. The results indicated that bending strength and toughness of mortars were improved, water absorption of mortar was negligible, and abrasion was nearly equal to zero. Polyethylene improved the flexibility of concretes and increased toughness. These researchers used sand and different waste plastics in bricks production but for this research, local clay was rather used. Also, (Ge et al., 2015; Hita et al., 2018) indicated that the binder to Clay brick aggregate ratio had a significant influence on strength which was evident in this research as different ratios gave different strengths.

Now from Table 3.1 PET-based bricks, the volume ratio of 2:1 gave the highest compressive strength (10.313 Mpa) compared with the other ratios 1:1 and 3:1. Although four (4) different ratios of bricks were formed using PET, only three were used for the test analysis due to the cracking of 3:2 at the heating stage.

The compressive strengths of the blocks formed were above the standard value of 3.5 Mpa according to the American Society for Testing of Materials (ASTM)(Dankwah and Nkrumah, 2016). Bricks made with PET plastic came out to have a higher compressive strength than the conventional block which has a minimum compressive strength of 3.5 Mpa. The least compressive strength among the three bricks tested was 8.741Mpa which is also higher than the average compressive strength of conventional bricks.

Also, bricks moulded with PS had a volume ratio of 1:1 had the compressive strength of 23.26±1.20 MPa which was the highest compressive strength among the various bricks moulded. The least among the four-volume ratios was 14.26±1.01 MPa. Both are much higher than the average compressive strength of the conventional building block which is 3.5 MPa (Dankwah and Nkrumah, 2016). Bricks moulded with PS exhibited higher compressive strength than those bricks with PET.

3.3. Masses of After Firing

From Figure 3a and Figure 3b it can be established that the mass of bricks incorporated with plastics are much lighter as compared with clay bricks that is without plastics. Conventional clay bricks had a mass of 810.50 g while plastic clay bricks had mass ranging from 632.5 g to 695 g. This demonstrated that plastic clay bricks are much lighter compared to clay bricks without plastics.

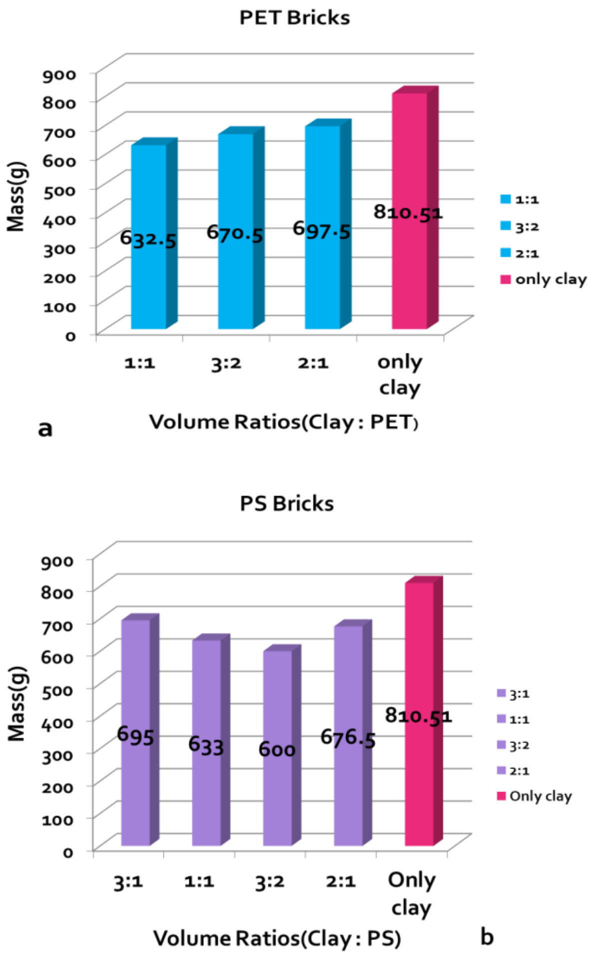


Figure 8 Masses of bricks after firing.

4 Conclusions

Based on the test results, it can be concluded that PET and PS are both effective binders in fired clay bricks production. These plastics have good adhesive properties which enable the fired clay bricks particles to bond strongly whilst being light in weight. The masses after the partial replacement of clay with plastics had decreased, therefore, producing a lightweight material. Also, it was clearly observed from the test results that PS gives fired clay bricks greater compressive strength than PET and Clay: PS ratio of 1:1 produced the highest compressive strength of 23.26 MPa.

Production of lightweight fired clay bricks will help reduce the rising issues of plastic pollution in the country and due its lightweight will cause a minimal destruction in an event of earthquake. The findings presented here provide practical, environmental, and economical solution to extract maximum value out of synthetic non-biodegradable plastics and ensure continued use in a closed loop system.

4.1 Recommendations

1. Moulded bricks should be well compressed to prevent cracking of bricks during the heating stage.
2. Further studies should be done using other plastics in the production of lightweight bricks.
3. Earthquake-prone zones such as Accra should start thinking of building with lightweight bricks.

References

Azimi, S.A., Allahverdi, A., Alibabaie, M., 2021. "Properties of Green, Lightweight, and High-Strength Reactive Powder Concrete Incorporating Modified Expanded Polystyrene Beads", *J. Mater. Civ.* Eng.Vol. 33.

Binici, H., "Gemci, R., Kaplan, H., 2012. Physical and mechanical properties of mortars without cement". *Constr. Build. Mater.* Vol. 28, pp. 357–361.

Dankwah, J.R., Nkrumah, E., 2016. "Recycling Blends of Rice Husk Ash and Snail Shells as Partial Replacement for Portland Cement in Building Block Production". *Ghana J. Technol.* Vol. 1, pp. 67–74.

Deepak Shiri, N., Varun Kajava, P., V, R.H., Lloyd Pais, N., Naik, V.M., 2015. "Processing of Waste Plastics into Building Materials Using a Plastic Extruder and Compression Testing of Plastic Bricks". *J. Mech. Eng. Autom.*

Ge, Z., Yue, H., Sun, R., 2015. "Properties of mortar produced with recycled clay brick aggregate and PET". *Constr. Build. Mater.*Vol. 93, pp. 851–856.

Ghernouti, Y., Rabehi, B., Safi, B., Chaid, R., 2009. "Use of Recycled Plastic Bag Waste in the Concrete Youcef Ghernouti", Bahia Rabehi, Brahim Safi and Rabah Chaid Research Unit: Materials, Processes and Environment, University M'Hamed Bougara of Boumerdes. Algeria. *J. Int. Sci. Publ. Mater. Methods Technol.*Vol. 8,pp. 480–487.

Global Waste Management Outlook, 2016. ," Global Waste Management Outlook". https://doi.org/10.18356/765baec0-en

Hita, P.R., Pérez-Gálvez, F., Morales-Conde, M.J., Pedreño-Rojas, M.A., 2018. "Reuse of plastic waste of mixed polypropylene as aggregate in mortars for the manufacture of pieces for restoring jack arch floors with timber beams". *J. Clean. Prod.*Vol. 198, pp. 1515–1525.

Ikechukwu, A.F., Shabangu, C., 2021. "Strength and durability performance of masonry bricks produced with crushed glass and melted PET plastics". Case Stud. *Constr. Mater.*

Journal, I., Bhushaiah, R., Mohammad, S., Rao, D.S., 2008. "IRJET-Study of Plastic Bricks Made From Waste Plastic Study of Plastic Bricks Made From Waste Plastic". *Int. Res. J. Eng. Technol.* 1122.

Kadir, A.A., Mohajerani, A., 2011. "Bricks: An Excellent Building Material for Recycling Wastes – A Review", in: *Environmental Management and Engineering* pp. 731,733: Unconventional Oil. ACTAPRESS, Calgary,AB,Canada.

Veiseh, S., Yousefi, A.A., 2003. "The use of polystyrene in lightweight brick production". *Iran. Polym. J. (English Ed.*

Authors

Alfredtina Akua Abrafi Appiah is a Teaching and Research Assistant at the Minerals Department in the University of Mines and Technology (UMaT). She obtained her bachelor's degree in minerals engineering at UMaT and her research interest extends in Extraction of Metals, Acid Mine Drainage Remediation, Hydrometallurgy, Flotation and Waste Management. She is a member of AuSIMM, Tarkwa Chapter and West African Institute of Mining, Metallurgy and Petroleum (WAIMM).

Mensah, Jeff Patrick obtained his bachelor's degree in minerals engineering at the University of Mines and Technology (UMaT) in Minerals Engineering and is currently working as a National Service Personnel at Anglogold Ashanti, Iduapriem Mine, Tarkwa. His research interest extends in extractive metallurgy and Process optimization.

James R. Dankwah is an Associate Professor of Metallurgical and Materials Engineering at the University of Mines and Technology, Tarkwa, Ghana. He obtained his PhD from the School of Materials Science and Engineering, UNSW-Australia, MSc (Process Metallurgy) from the Norwegian University of Science and Technology and BSc (Metallurgical Engineering) from the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. His current research areas include iron and steelmaking, high-temperature metallurgical processes, utilisation of waste polymers in metal extraction processes and recycling agricultural waste into building blocks materials for affordable housing for rural folks.