Cement-Plastic Based Composites as the building blocks of future Ghanaian Mega-Structures

Major T Kadonzvo
major.kadonzvo@ashesi.edu.gh

Mumuni Mohammed
mumuni.mohammed@ashesi.edu.gh

Abstract
Civil engineering is one of the oldest fields of engineering that recently has begun to investigate the sustainable management of the environment. Research in this field is focusing on moving away from old methods of construction to new approaches that are environmentally friendly. Construction that has minimum negative impact on the environment is termed green construction. On the other hand, poor management of plastic waste poses a threat to the environment. Plastics like polyethylene tetraphthalate are non-biodegradable and very hard to handle as waste in the world and especially in Ghana. This paper describes how the need for better plastic waste management can be harmonized with the quest to find greener methods of construction. Traditional cement blocks are compared to a new breed of cement blocks that contain waste plastic as part of reinforcement. The mechanical and thermal properties of conventional blocks and those of the new blocks with different plastic compositions are compared using statistical methods and tools. There were statistically significant differences in the compressive strength, flexural strength, hardness and thermal conductivity of the newly engineered blocks.

Keywords:
Cement blocks, Polyethylene Tetraphthalate (PET), Composite, Green construction

Department of Engineering, Ashesi University, Berekuso, Ghana

1. Introduction

There is an increasing demand for housing in Ghana due to the increase in population growth [1]. Consequently, millions of tons of materials go into the construction process. With the current population growth rate of Ghana and a population of 29.7M in 2018[2], one can predict the efforts required by the civil engineering and construction industry to meet infrastructural demand. The high population growth rate means that more land space and building materials needs to be churned into this ever-growing industry. This idea raises concerns over the need for efficient use of land and construction methods that point towards environmentally sustainable practices in construction. Research is ongoing in the field to look for better ways of building with the least possible negative impact on the environment. These better methods will define a new form of construction - green construction – which will be more environmentally friendly. On the same note of being ecologically conscious, several researchers have been raising awareness on the adverse impact of poor plastic waste management. Plastics are synthetic organic hetero-atomic polymers that are often synthesized in large quantities from oil, coal, and natural gas [3]. They are generally non-biodegradable in the presence of enzymes or microbes [4]. This raises environmental issues, since approximately 30% of worldwide production of plastics goes into food packaging and the making of detergents and chemicals, with the annual global economic growth of this industry being around 12% [5]. One of the most commonly used forms of plastics is polyethylene tetraphthalate (PET). According to Albertson, approximately 140 million tons of human-made polymers, including PET, are manufactured around the world annually, with a utility rate of around 12% [6]. Ghana Times argues that 250 tons of plastic packaging waste are produced daily in Ghana alone [7]. Although PET can be degraded by chemical, photodegradation, thermal, and some sophisticated biodegradation techniques [8], there is a need to recycle it into other functional materials [9]. To harmonize the ideas of green construction and sustainable waste management this study seeks to create a new breed of blocks that contains PET granules as part of the reinforcement. These new blocks would replace the traditional cement blocks, which are composites with cement as the matrix and sand as the reinforcement, and clay-based bricks. The conventional blocks and bricks are used for their aesthetic nature, high flexural strength, high compressive strength, fire protection, good porosity, sound attenuation, insulation, wear-resistance, and durability. The incorporation of PET into the blocks would go a long way to improve plastic waste management as plastic waste will be recycled into something useful. Moreover, the new breed of blocks will replace vitrified clay bricks thereby reducing carbon dioxide emissions that are associated with the vitrification of clay bricks. On the construction side, the question is; will the addition of PET significantly alter the mechanical and thermal properties of the blocks. This is a crucial question as any small change in these properties will affect the applicability of the blocks in construction. Therefore, this study will investigate whether the changes in the properties of plastic-cement brick will be better than those of the standard cement brick.

2. Methods

Processing the Low-Density PET

Plastics commonly used in the packaging of water in Ghana were collected in the form of empty sachets from Berekuso, a small town in the Eastern region of Ghana. They were washed in water to clean off dirt and cut into pieces of dimension 1cm by 1cm. The pieces were added to kerosene (fig 1. a), which was being heated at 140°C until the saturation point was reached. The slurry produced was cooled by dipping the metallic containing vessel into ice, while maintaining the temperature at approximately 5°C. The resulting mixture of plastic condensate and the kerosene was separated by filtration (fig 1. b), leaving the plastic component on a filter paper to be dried. A white granular substance was obtained after 24 hours of drying. The particles obtained were in a fine powdery state.

Molding the blocks

A rectangular molder was designed that had the dimensions $l = (65 \pm 0.5)mm$, $w = (55 \pm 0.5)mm$ and $h = (20 \pm 0.5)mm$. The standard blocks were made from a mixture of one-part cement and three parts sand, with each part weighing $(280 \pm 0.1)g$. The cement-plastic based composites (CPBC), block P, was made by adding approximately $8.5g$ of PET per $1120g$, mass of the brick. The subsequent CPBC blocks, Q, R, S respectively, had 1.5% PET, 2.25% PET, 3.00% PET by mass. The mortar was poured into the molders (fig 1. c), and the blocks were allowed to dry for seven days, after which the following tests were carried out:
Hardness test, Triple point bent test, Compressive strength test, Thermal conductivity test.

Hardness Test

An electronic hardness tester (fig 1. d) was used to test the surface of three blocks from each sample, and the results were recorded. The method used was to follow the manufacturer's instructions.

Triple Point Bent Test

Using the universal MTS machine (fig 1. e), the triple point bent test was carried out on three blocks from each sample and the data was recorded. The specimens were loaded under displacement control until they failed. The flexural strength was calculated using the relation [10];

$$\sigma_f = \frac{3F_oL}{2BW^2} \qquad (Equation\ 1)$$

Where

σ_f is the flexural strength,

F_o is the force at failure,

L is the distance between the pivoting points,

B is the breadth of the specimen,

W is the width of the specimen.

Compressive Strength

Using the Universal Mechanical testing machine, the compressive strength tests were carried out under displacement control at a displacement rate of $0.01mms^{-1}$ and a strain rate of $0.01s^{-1}$. The specimens were monotonically loaded until they failed. Using the dimensions of the block measured with a pair of Vernier calipers, the compressive strength was calculated from the relation [10]:

$$\sigma_c = \frac{F}{A_o} \qquad (Equation\ 2)$$

Where:

σ_c is the compressive strength,

F is the force at failure,

A_o is the cross-sectional area of the specimen.

Thermal Conductivity

The blocks were all placed on a hot plate at the same time (fig 2. b), each having 10mm x 55mm in contact with the hot plate for the same period, 10 minutes. From the conductivity formula [11]:

$$\lambda = \frac{\dot{Q}L}{A\Delta T} \qquad (Equation\ 3)$$

Where:

λ is the thermal conductivity W/m K,

$\dot{Q}$ is the amount of heat transfer through the material in J/S or W,

A is the area of the body in m^2,

ΔT is the difference in temperature in K.

Based on the assumption that negligible energy was lost in the heating process, the wattage of the hot plate was approximated as the amount of heat energy transferred (Q) and the area of contact was estimated as the size of the blocks. The length traveled through each block was estimated from the infrared photographs (fig 2. C-S), and the change in temperature was also read off the infrared photographs. The difference in temperature can be clearly seen in fig 2 where the red color represents the area with the highest thermal conductivity. The thermal conductivity of three blocks from each sample was calculated and stored for data analysis.

Figure 1. Procedure (a) Melting of plastics, (b) Drying of the plastic granules, (c) Molding of blocks, (d) Testing Hardness, (f) Microscopic surface analysis of different samples.

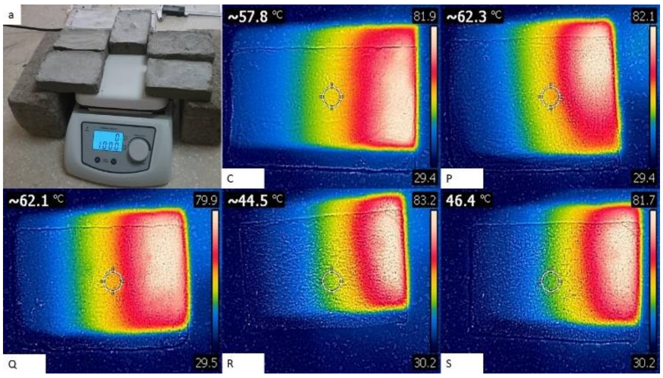

Figure 2. Thermal conductivity test (a) Heating the blocks, (C-S) Infrared heat signature of each block.

Surface Analysis

The surface was analyzed using an electronic microscope. The surfaces were different for each sample as shown in (fig 1. f).

3. Results and Discussion

Hardness Test

The measured hardness ranged from 88.98 for the 0.75% PET sample to 94.23 for the 3.00% PET sample. The average measurement is depicted for the hardness of each block type. The error bars show the standard deviation. Each group is as a result of $n = 4$ replicates (fig 4).

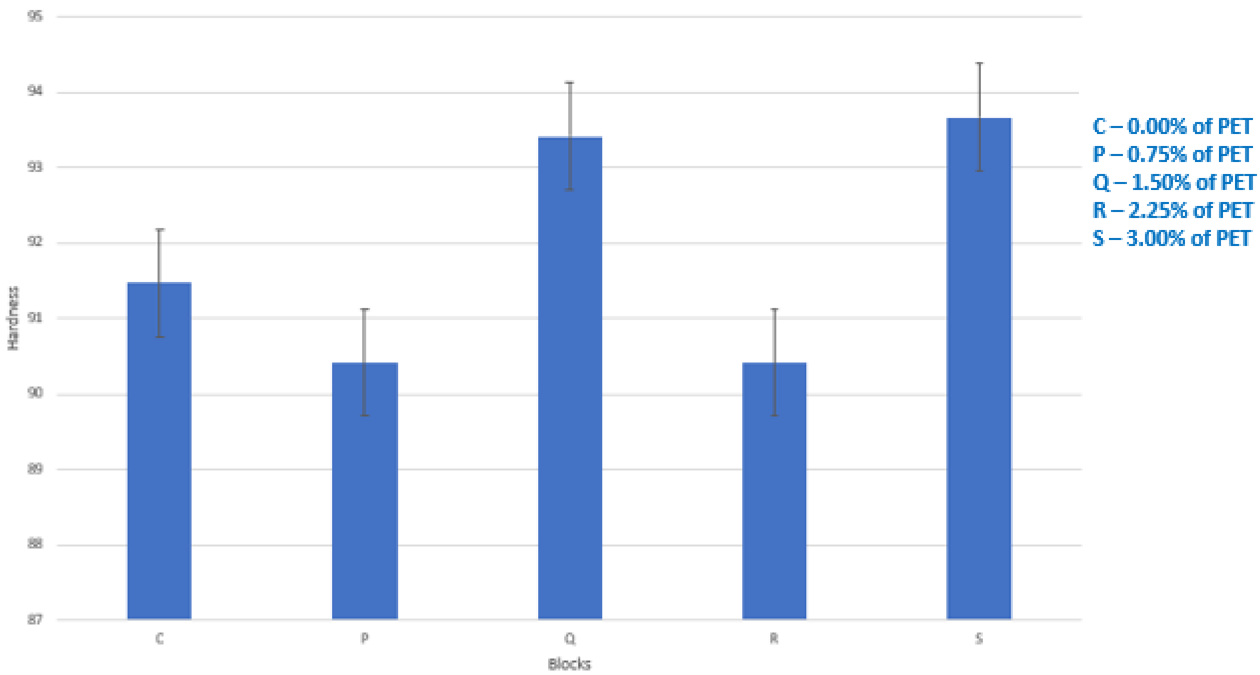

Figure 3. Hardness of each sample.

Flexural strength

From the results of the triple point bent test, the different block failed to varying forces with the control bearing the highest load (fig 4).

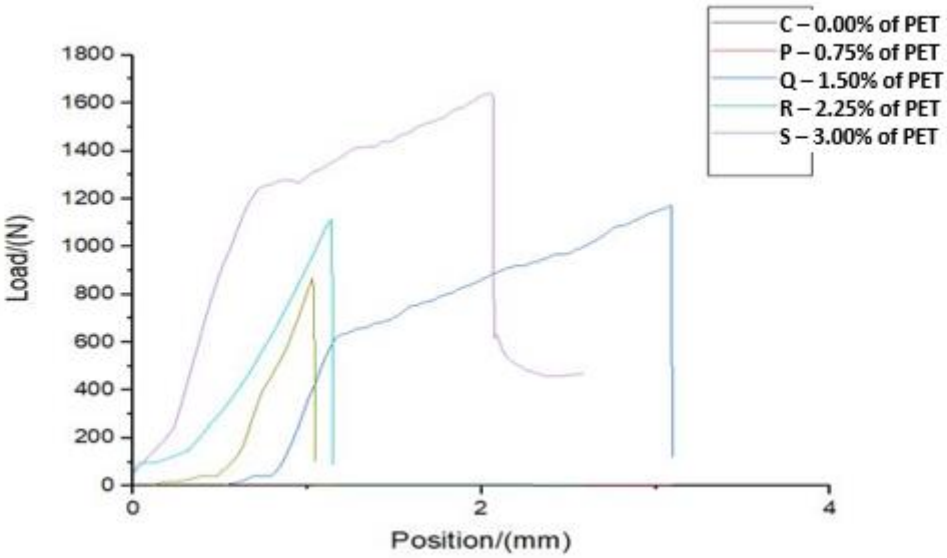

Figure 4. The breaking force for each sample for flexural strength.

Compressive Strength

The compression test carried out for each block type is shown in (fig 5). The figure also shows the failure point in the compression test for each specimen.

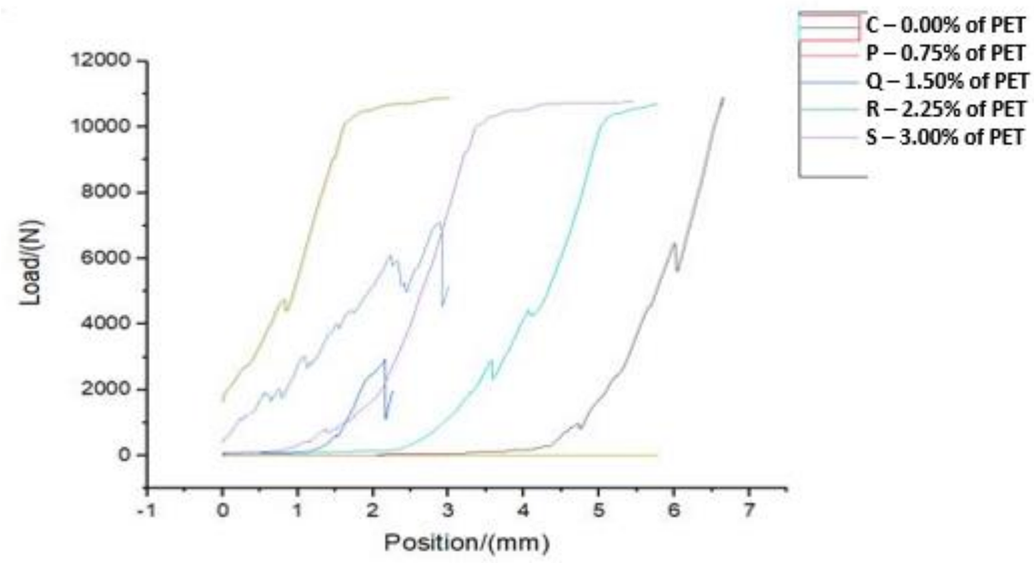

Figure 5. The breaking force for each sample for compressive strength.

Thermal Conductivity

The thermal conductivity decreased as the content of the PET increased in the samples. The average measurement is depicted for the thermal conductivity of each block type. The error bars show the standard deviation. Each group is as a result of n = 4 replicates (fig 6).

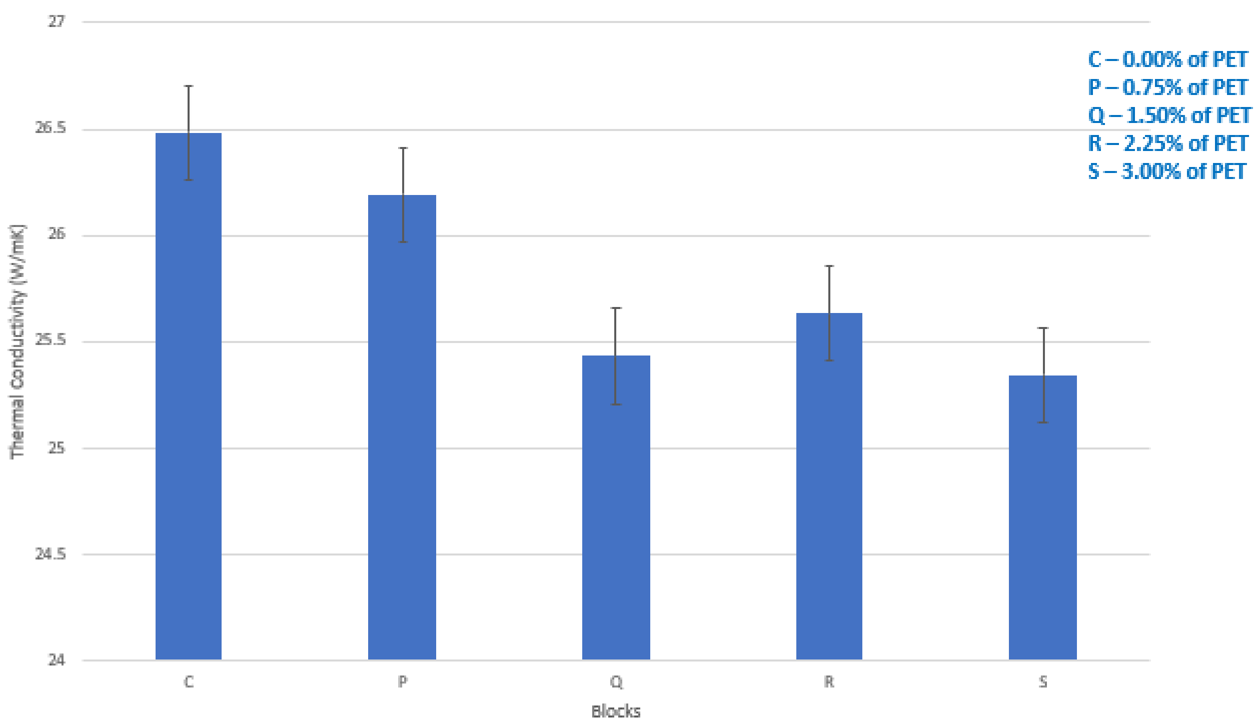

Figure 6. The thermal conductivity of each sample.

Surface Analysis

The surface of the blocks changed notably under the microscope as more grains of the PET were added (fig 1. f). This change, however, is not notable by the human eye. The specimen surfaces appear to be the same when examined using the naked eye.

Statistical Analysis

After carrying out the tests on three specimens from each composite sample, the data obtained were used to calculate the mean values for each sample. From the scientific hypothesis, statistical hypotheses were made, which are summarized in fig7.

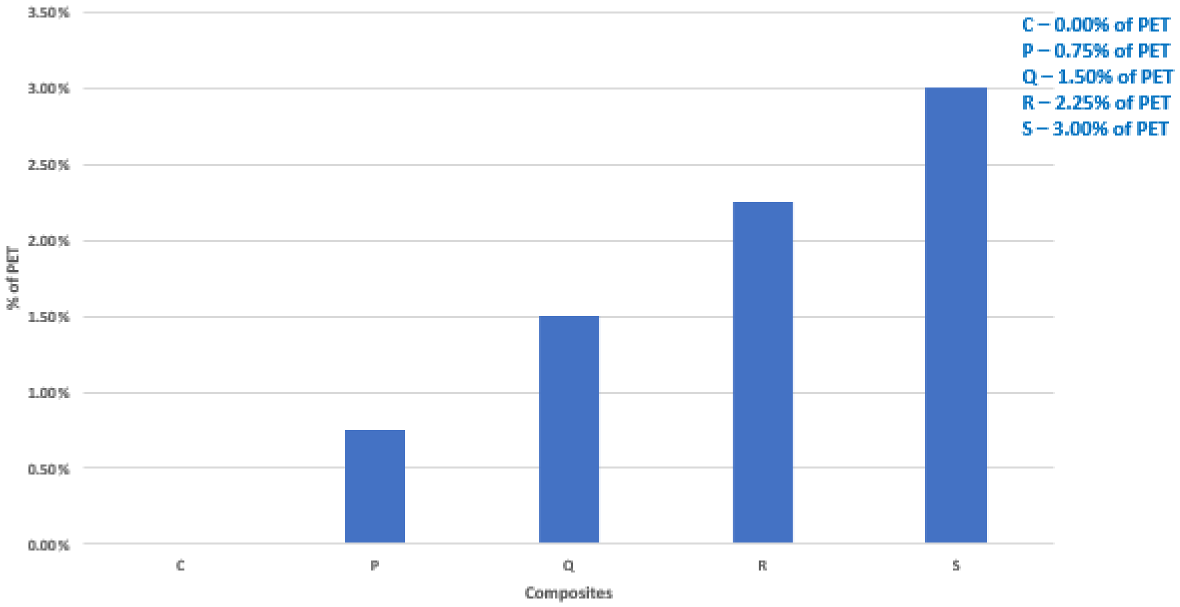

Figure 7: Composites made with % PET

The normality of the data was checked using the Shapiro-Wilk test. Based on its results, an ANOVA test or a Kruskal Wallis test was performed on each category. In the cases where the ANOVA test showed that there were differences, the Tukey test was performed to pinpoint the differences. The results of the tests are summarized in the table below;

Table 1. Summary of the results obtained from the tests.

Property	Shapiro Test	Kruskal Wallis	Anova
Hardness	0.1147		5.21E-0.6
Flexural Strength	0.0342	0.0091	
Compressive Strength	0.0043	0.0073	
Thermal Conductivity	0.2580		0.0256

From the Tukey tests performed on the hardness and thermal conductivity data, it was noted that all except 2.25% of PET and 0.75% of PET, and 3.00% of PET and 1.50% of PET were different for Hardness and also all except 0.00% of PET and 3.00% of PET were similar for Thermal Conductivity.

4.Conclusion

From the statistical analysis and tests carried out, it can be concluded that there are statistically significant differences in the compressive strength, flexural strength, hardness, and thermal conductivity of the blocks.
From the Kruskal Wallis test, both compressive and flexural strength for all the block types were similar.
From the Tukey tests, there are statistically significant differences in the Hardness and Thermal conductivity of the blocks. For the hardness test, all except 2.25% of PET and 0.75% of PET, and 3.00% of PET and 1.50% of PET were different from the Tukey's test. For the thermal conductivity, all except 0.00% of PET and 3.00% of PET were similar from the Tukey's test. This shows that the mechanical properties are changed by the introduction of PET.
The differences in mechanical properties of the blocks of different PET contents show that the amount of PET granules does change the structure of the material significantly.
Scientifically, PET reinforced blocks could be used in low-stress bearing applications where aesthetics, durability and low thermal conductivity are of paramount importance.

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