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Research Article

# Preparation and Characterization of Paving Blocks from Polyethylene-Based Plastic Waste and Natural Fibre

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## Abstract

The current methods of managing plastic waste especially in developing countries have become an issue of environmental and public health concern globally. This has led environmentalists and scientists to work on finding day-to-day activities that can help to reduce the plastic waste disposal problem. Recycling and reuse of plastic waste into construction materials is a valid way to reduce the effect of this improper disposal of plastic waste. This will help to reduce the negative impact of the high cost of cement in the construction industry. In this research, polyethylene waste (table water sachet) was used as a replacement for cement in the construction of paving blocks. The sample with a 1:4 mixing ratio was found to have the highest compressive strength among the different mix ratio examined. Paving blocks were then produced with this mixing ratio from plastic-aggregates and plastic-aggregate-fibre and compared with the standard cement-aggregate paving blocks for their compressive and tensile strengths, water absorption, thickness swelling, density, and thermal properties (thermogravimetric analysis (TGA) and horizontal burning rate). Scanning Electron Microscopy (SEM) with Energy Dispersive X-ray (EDX) was also conducted on the paving blocks to determine the distribution of the particles of the blocks, the compatibility of the matrix, and their elemental composition. The results of the compressive strength test showed 18.1667 $Nmm^{-2}$ for plastic-aggregate block, though lower when compared with the cement-aggregate block with a compressive strength of 21.6667 $Nmm^{-2}$. The plastic-aggregate block has the least water absorption value among the three samples. The 0.1350% and 1.8861% water absorption values obtained for the plastic-aggregate and plastic-aggregate-fibre bricks respectively showed an impressive water absorption which falls within the maximum of 5% water absorption for quality paving blocks. The plastic-aggregate and plastic-aggregate-fibre both also recorded lower density when compared with the cement-aggregate block, which gives them a logistic advantage over the cement-aggregate block in the case of transporting them from one location to another. The blocks were found to be stable at low temperatures. The SEM images of the plastic-aggregate and plastic-fibre-aggregate paving blocks clearly showed a consistent dispersion of the plastic waste particles within the aggregate matrix over that of the cement-aggregate paving block. Therefore, plastic-aggregate brick can be recommended for use as paving bricks for low-traffic roads, walkways, parks, and gardens, although there is need to carry out further studies on other material properties of the plastic-based paving block.

## Keywords

Plastic, Waste, Paving Blocks, Strength, Aggregates, Fibre

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# 1. Introduction

The management of plastic waste has become a high-profile global environmental and public health problem [1-4]. This problem has led to a major setback in modernization and economic development [5]. This is a result of the unhealthy waste disposal methods currently being practiced especially by developing countries. Such practices include the open burning of plastic waste which emits large amounts of hazardous gases that affect human and animal health as well as the environment landfilling and stock-piling which may lead to chocking of sewers when they find their ways into sewages, clogging of soil and death of animals [6-10]. This poor system of plastic waste management and its slow biodegradable rate are major factors that have contributed immensely to the accumulation of plastic waste in the environment.

The accumulation of plastic waste has also been attributed to other factors such as the increase in the use of plastic as a result of the change in economic character and consumption patterns, population growth, urbanization, industrialization and change in lifestyle [11-13]. This is because plastics in their various forms are useful in our day-to-day lives because of their compact nature, strength and lightweight, robustness, flexibility, and rigidity [8, 14, 15]. Plastics have also been found to serve as short-term replacements for many costlier alternatives because of their inexpensiveness [11]. These unique properties have led to an increase in the global use of plastics from about 5 million tons in the 1950s to over 100 million tons in the 2000s [16].

But as important as the use of plastic materials is, they become waste after use [2, 9, 17]. The use of plastics has been noted to be the largest and most problematic source of waste globally [6]. This is because plastics can stay in the environment for up to a century due to their slow biodegradation [10, 11]. This accumulated plastic wastes have hazardous effects on humans, animals, plants as well as the environment [9, 10, 15, 16, 18]. This menace of uncontrolled plastic waste disposal has raised concern amongst Scientists and environmentalists, they are therefore working on finding a solution to this problem [8]. The focus is on finding day-t o-day human activities that help to reduce plastic waste disposal problems thereby minimizing its effect on human health and the environment [8, 15, 18]. One such valid solution to reducing these effects is the recycling and reuse of plastic waste into construction materials such as paving tiles [6, 11, 17].

Paving tiles are superficial precast covering used in the construction of roads, footpaths, parking areas, sidewalks, gardens, and bus stops [1, 19]. They are versatile, aesthetically attractive, and require little or no maintenance if properly manufactured and laid, it is also cost-effective except for the high cost of cement [20]. It is therefore necessary to look for a cheaper alternative to cement to bridge the infrastructure gap created by the high cost of cement. This practice of making paving tiles from plastic waste will not only help in the physical removal of plastic waste from the environment but also in the reduction of the environmental impacts that arise as a result of burning plastics [9, 18]. It also helps to conserve the depleting natural resources from which construction materials such as cement are made [20]. A way of achieving this is by completely replacing the conventional cement used in the production of paving tiles with plastic waste [21]. It will help to reduce the cost of construction caused by the high cost of cement and at the same time solve environmental problems caused by the use of plastic. This is increasingly becoming popular because of the economic as well as environmental benefits that can be derived from this practice [14]. Many researchers have worked on various types of plastic materials ranging from low-density polyethylene, high-density polyethylene, polypropylene, and polystyrene to polyethylene terephthalate either as a partial or total replacement for cement in the manufacture of paving tiles and blocks as the case may be [1-3, 5, 6, 9-11, 13-16, 18, 19, 21, 24-26].

Many of these researches have shown that plastic paving blocks can sustain high loads due to high compressive strength. They have also shown that a plastic-aggregate mix ratio of 1:4 gives the highest compressive strength among various mix ratios tested. They reported that the disintegration of plastic paving blocks as a result of alternative wetting and drying is more unlikely than in cement paving blocks because of the low water absorption of plastic aggregate paving blocks. Most of them therefore concluded that plastic paving blocks can serve as an eco-friendly and cheaper alternative to conventional cement paving blocks. But, in as much as many authors have reported the compressive strength, water absorption, and heat resistance of plastic waste paving blocks, not much has been reported on the morphological analysis; to assess the microstructural behaviour and performance of the plastic aggregate paving blocks. Also, the effect of plant fibre on the compressive strength and other properties of the plastic aggregate block has not been reported by many authors. This research therefore intends to incorporate plant fibre into the bricks to produce plastic fibre aggregate blocks. The plastic aggregate paving block and the plastic fibre aggregate paving blocks were then tested for compressive strength, tensile strength, water absorption, thickness swelling, density, and thermal resistance and scanned with a scanning electron microscope (SEM).

# 2. Materials and Methods

## 2.1. Materials

The materials used for this research include plastic (low-density polyethylene) waste popularly referred to as table water sachet, aggregates (fine aggregate (sand) and coarse aggregate (quarry gravel stone)), fibre (straw of spear grass; *Heteropogon contortus*), water, and cement. Other equipment and apparatus used are weighing balance, metal mould, local heating system, steel heating pot, trowel, iron rod, hand gloves, and nose mask.

## 2.2. Methods

### 2.2.1. Sample Collection

The plastics used for the preparation of the plastic-aggregate pavement block (PAPB) and the plastic-fibre-aggregate pavement block (PFAPB) were collected from dumpsites around the Old Airport Area of Sokoto Metropolis. The cement used in the preparation of the cement-aggregate pavement block (CAPB) was obtained from Sokoto metropolis. The fine and coarse aggregates were obtained from Roads Nigeria PLC's quarries in Maru, Maru Local Government Area of Zamfara State, and Yelwa in Yauri Local Government Area of Kebbi State respectively. The fibre (straw of spear grass; *Heteropogon contortus*) was obtained from Shuni, in the Dange-Shuni Local Government Area of Sokoto State.

### 2.2.2. Sample Compositions

***Table 1.*** *Composition of different brick samples.*

| Samples | Composition |
|---|---|
| CAPB | Cement + Aggregates |
| PAPB | Plastic + Aggregates |
| PAFPB | Plastic + Aggregates + Fibre |

### 2.2.3. Preparation of Samples

The plastic waste and aggregates were weighed at 1:4 plastic/aggregate ratio. The plastic was then heated in a metal container until the plastics melted. The other materials (i.e., aggregates and fibre) were added accordingly to the molten form of the plastic and stirred continuously until a homogeneous mixture was formed. The mixture in the molten form was then transferred to a clean metal mould in the hot condition and allowed to stay for 24 hours, to allow it to dry. After drying, the paver blocks were removed from the mould and it was ready for analysis [20]. The cement, fine aggregate, and coarse aggregate were weighed using a weighing balance and mix. Water was added in appropriate proportion and mixed thoroughly before the mixture was transferred to the mould and allowed to dry. The blocks were removed after being allowed to dry for 24 hours and then cured.

## 2.3. Mechanical and Physical Properties

### 2.3.1. Compressive Strength

Compressive strength is the most important property being considered in construction materials. It is the capacity of a material or structure to withstand load before failure. It is the most important of the many tests being carried out on concrete. It gives an idea of the characteristics and durability of the concrete [13, 27]. Therefore, a compressive strength test was conducted on triplicate samples of each of the cement-aggregates bricks, Plastic-aggregates bricks, and Plastic-aggregates-fibre bricks to determine the load-bearing capacity of the bricks. A compressive strength test for the various bricks was carried out using the FORM TEST SEIDNER compressive testing machine of the Roads Nigeria PLC, Sokoto, Nigeria. The specimen of 100mm x 100mm x 100mm dimension was placed into the compressive testing machine to determine the load-bearing capacity [13]. The compressive strength was calculated using Equation 1 below.

$$F = \frac{P}{A} \tag{1}$$

Where F = Compressive strength of the bricks, P = Load at failure in N, A = Cross section area of the cube in $mm^2$

### 2.3.2. Tensile Strength

A tensile strength test was carried out on triplicate samples of each of the cylindrical cement-aggregate bricks, plastic-aggregate bricks, and plastic-aggregates-fibre bricks by placing the cylindrical brick of 10cm length and 6cm diameter horizontally on a Universal Testing Machine (UTM) of Roads Nigeria PLC, Sokoto and apply load [6]. Tensile strength helps to determine the extent and size of cracking in the structure as a result of applied force. This is aimed at determining the ultimate tensile strength of the specimen.

The tensile strength in $N/mm^2$ was calculated using Equation 2

$$Fct = \frac{2P}{\pi LD} \tag{2}$$

Where Fct = Tensile strength of the bricks, P = Maximum load at failure in Newton, L= Length of the specimen in mm, D = Diameter of the specimen in mm

### 2.3.3. Water Absorption

A water absorption test was conducted on bricks to determine the amount of water absorbed by the bricks in a water or humid environment [15]. It determines absorption by measuring the increase in mass of the bricks resulting from the absorption of water over some time. The bricks were weighed after 24 hours of drying and the weight was recorded. The bricks were then fully immersed in a tank of fresh water for 24 hours and then cleaned with a dry cloth, then reweighed [13].

The procedure was repeated until a constant weight was obtained. The percentage of water absorption was calculated using Equation 3.

$$Water\ Absorption\ (\%) = \frac{W_2 - W_1}{W_1} \times 100 \quad (3)$$

Where; $W_1$ = Dry weight of the specimen, $W_2$ = Wet weight of the specimen

### 2.3.4. Thickness Swelling

The thickness swelling of the samples was determined as specified by [28]. The initial thickness of the samples was taken with a Vernier calliper and recorded as $T_{i.}$ The samples were then immersed in fresh water for 24 hours and the thickness of each sample was recorded as final thickness ($T_f$). The procedure will continue until a constant dimension is obtained. The percentage of swelling was calculated [29]. The thickness swelling was calculated using Equation 4.

$$Thickness\ swelling\ (\%) = \frac{T_f - T_i}{T_i} \quad (4)$$

Where $T_i$ = Initial thickness of the specimen, $T_f$ = Final thickness of the specimen

### 2.3.5. Density

The density of each cube brick was determined by measuring the weight of a 10cm length, 10cm width, and 10cm height brick using a weighing balance. The density was calculated by dividing the weight obtained for each cube by the volume of each cube as shown in equation 5.

$$P = \frac{m}{v} \quad (5)$$

Where P = density of cube in kg/$m^3$, m = mass of Cube in kg, v = volume of Cube in $m^3$

## 2.4. Thermal and Morphological Properties

### 2.4.1. Thermogravimetric Analysis

Thermogravimetric analysis was performed on the bricks to determine the mass change in the powdered sample. The powdered samples were taken from brick specimens after drying. The brick was placed in a mortar and a downward pressure was applied to crush the brick with a pestle till it became fine powder. The powdered sample was then tested from 35 ℃ to 950 ℃ at a heating rate of 10/min under a nitrogen atmosphere using a TGA machine at Central Science Laboratory, Usmanu Danfodiyo University Sokoto. The signals produced from the TGA were then used to calculate the weight loss of the powder sample during heating [30].

### 2.4.2. Horizontal Burning Rate

The specimens were evaluated for their flammability using the horizontal burning test according to the UL-94 HB test as described by [31]. In this test, the specimens of a sample size 150mm x 50mm x 10mm (length x width x thickness) marked at 25, 60, and 125mm positions were tested in horizontal orientation. The flame was applied to the free end of the specimen for 60 seconds and then removed, the flame extinguished upon withdrawal of the flame. The samples met the criteria for horizontal burning rate in Table 2 below.

***Table 2.*** *Horizontal burning rate criteria.*

| Test criteria | Burning rate in V | UL-94 HB rating |
|---|---|---|
| When the flame extinguished before the first mark or upon the withdrawal of the flame | 0mm/min. | HB pass |

Source: Bachtiar *et al*., 2019.

### 2.4.3. Morphological Properties

A morphological study was carried out to determine the distribution of the particles of the bricks, compatibility of the matrix, and elemental composition of the bricks using Phenom-ProX Scanning Electron Microscope with Energy Dispersive X-ray (SEM-EDX) of Ahmadu Bello University Zaria. The samples were placed on a double adhesive, which was on a sample stub, and then coated with a sputter coater by Quorum Technologies Model Q150R, with 5nm of gold. The samples were thereafter taken to the chamber of the SEM machine where they were viewed via NaVCaM for focusing and adjustment, and then transferred to SEM mode, then, focusing, brightness, and contrasting were carried at x500, x1000, and x1500 magnifications for every sample.

# 3. Results and Discussion

## 3.1. Results

### 3.1.1. Results of Mechanical and Physical Properties Different Paving Blocks

The results of mechanical and physical properties of the cement aggregate, plastic aggregate and plastic fibre aggregate paving blocks are shown in table 3.

*Table 3. Mechanical and physical properties of cement aggregate, plastic aggregate, and plastic fibre aggregate paving blocks.*

| Mix-composition | Samples | Compressive strength ($Nmm^{-2}$) |
|---|---|---|
| Compressive Strength | CAPB | 21.67 ±2.52 |
| | PAPB | 18.17 ±1.04 |
| | PFAPB | 4.17 ±0.29 |
| Tensile Strength | CAPB | 1.19 ±0.18 |
| | PAPB | 2.19 ±0.17 |
| | PFAPB | 2.25 ±0.14 |
| Water Absorption | CAPB | 0.79 ±0.06 |
| | PAPB | 0.15 ±0.04 |
| | PFAPB | 1.89 ±1.57 |
| Thickness Swelling | CAPB | 0.03 ±0.04 |
| | PAPB | 0.09 ±0.09 |
| | PFAPB | 0.020 ±0.03 |
| Density | CAPB | 2391.90 ±12.19 |
| | PAPB | 1769.00 ±48.04 |
| | PFAPB | 1861.5 ±77.04 |

### 3.1.2. Results on Horizontal Burning Rate

*Table 4. Horizontal burning rate of the cement-aggregate, plastic-aggregate, and plastic-aggregate-fibre paving blocks.*

| Samples | Burning rate in V | UL-94 HB rating |
|---|---|---|
| CAPB | The flame extinguished upon withdrawer of the flame source | HB Pass |
| PAPB | The flame extinguished upon withdrawer of the flame source | HB Pass |
| PFAPB | The flame extinguished upon withdrawal of the flame source | HB Pass |

### 3.1.3. Results on Thermogravimetric Analysis

*Table 5. Percentage weight loss of cement-aggregate, plastic-aggregate, and plastic-aggregate-fibre paving blocks.*

| Sample | Onset Temp (℃) | Completion Temp (℃) | Weight Loss | %Weight Loss |
|---|---|---|---|---|
| CAPB | 74.65 | 928.42 | 4.63 | 34.94 |
| PAPB | 54.90 | 593.36 | 7.3 | 68.80 |
| PFAPB | 85.70 | 873.61 | 4.78 | 33.38 |

Figures 1, 2 and 3 are thermograms from the thermogravimetric analysis showing the weight loss of the cement-aggregate brick, plastic-aggregate brick, and plastic-aggregate-fibre brick over a heating period.

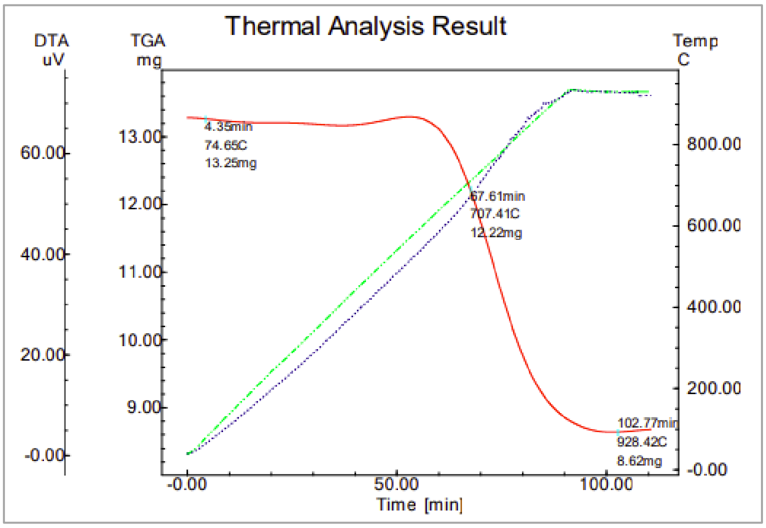


***Figure 1.** Result of thermogravimetric analysis of cement-aggregate brick.*

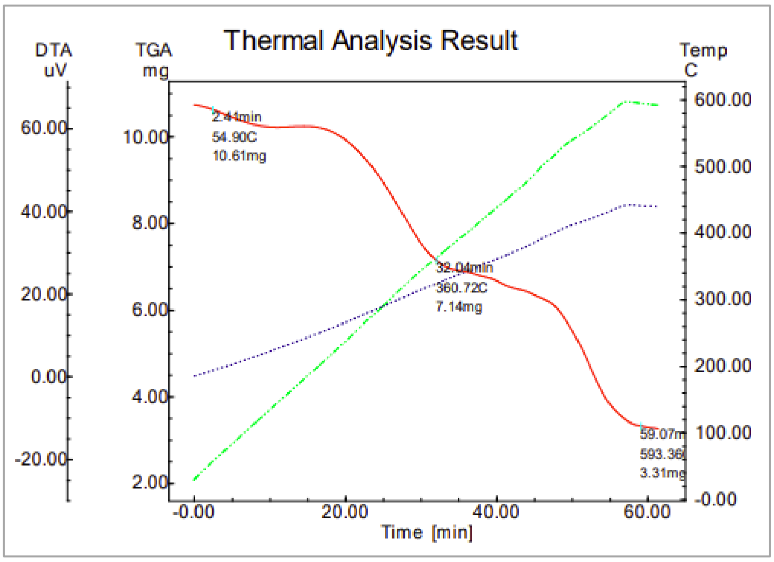


***Figure 2.** Result of thermogravimetric analysis of plastic-aggregate brick.*

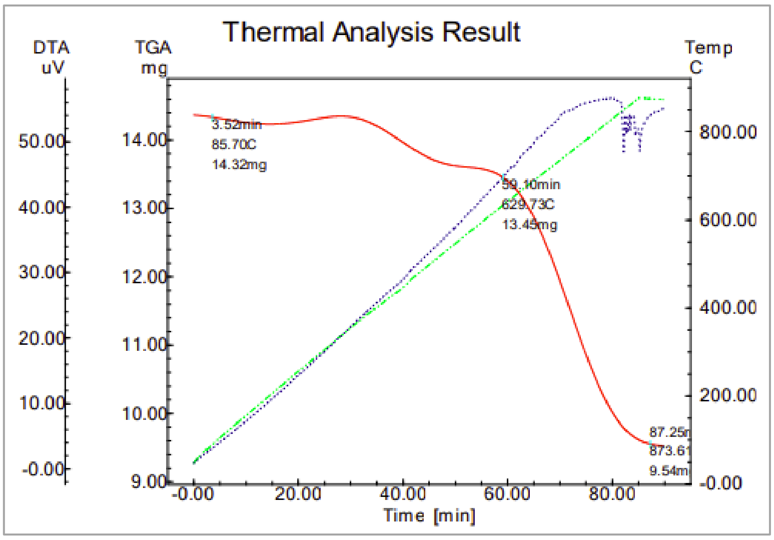


***Figure 3.** Result of thermogravimetric analysis of plastic-aggregate-fibre brick.*

### 3.1.4. Results of Morphological Properties

### (i). Scanning Electron Microscopy

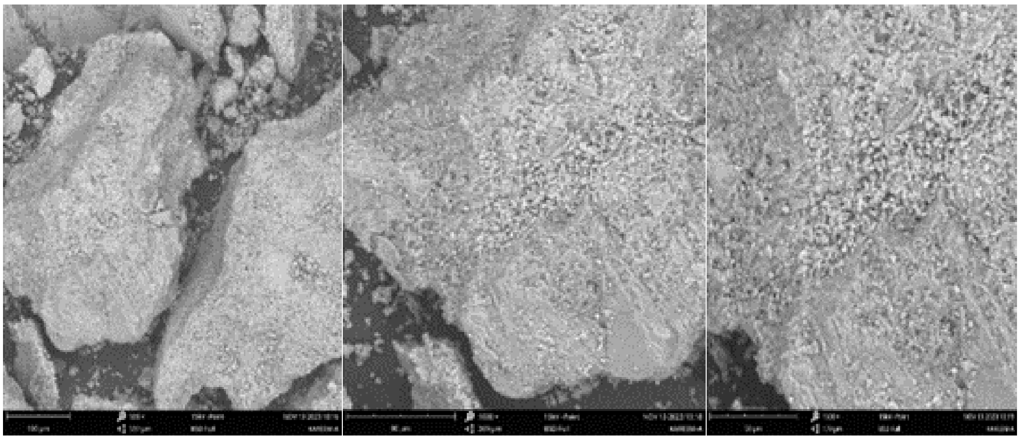

*Figure 4.* *SEM micrographs of the cement aggregate paving blocks at x500, x1000, and x1500.*

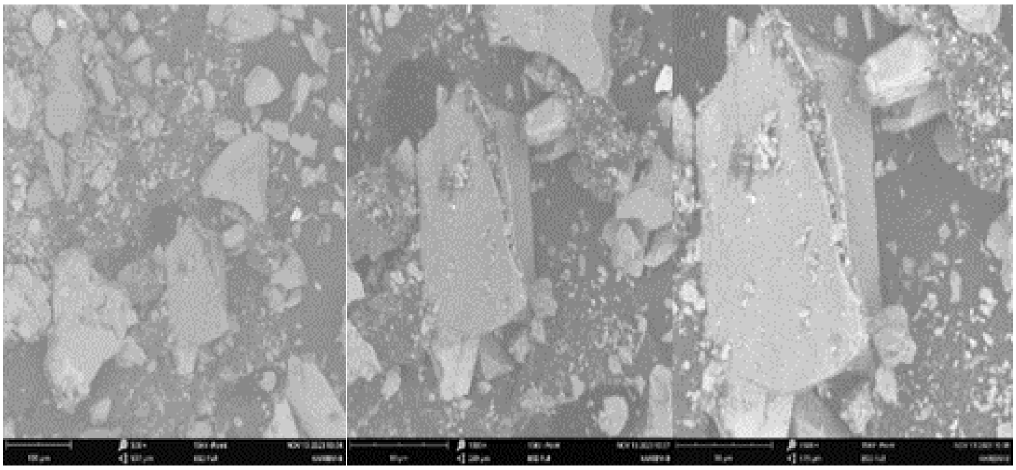

*Figure 5.* *SEM micrographs of the plastic aggregate paving blocks at x500, x1000 and x1500 magnifications.*

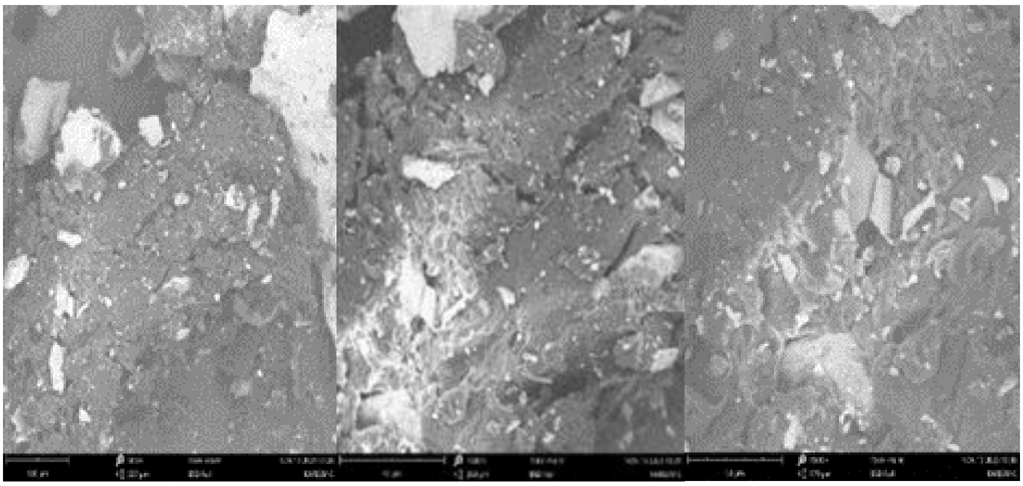

*Figure 6.* *SEM micrographs of the plastic fibre aggregate paving blocks at x500, x1000, and x1500 magnifications.*

## (ii). Elemental Composition of the Bricks

***Table 6.*** *Elemental composition of the cement aggregate paving block, plastic aggregate paving block, and the plastic fibre aggregate paving block.*

| Name of Elements | Symbol of Elements | Weight Conc. Of CAPB | Weight Conc. Of PAPB | Weight Conc. Of PFAPB |
|---|---|---|---|---|
| Calcium | Ca | 55.01 | 2.90 | 2.87 |
| Silicon | Si | 18.58 | 57.34 | 53.49 |
| Aluminum | Al | 8.96 | 17.06 | 17.16 |
| Sodium | Na | 1.69 | 3.35 | 6.37 |
| Iron | Fe | 3.90 | 3.25 | 6.14 |
| Phosphorus | P | 2.22 | 2.27 | 3.34 |
| Potassium | K | 1.71 | 7.64 | 4.14 |
| Sulfur | S | 1.99 | 2.35 | 2.87 |
| Magnesium | Mg | 3.21 | 2.50 | 2.04 |
| Chlorine | Cl | 1.20 | 1.32 | 1.68 |
| Titanium | Ti | 1.54 | 0 | 0 |

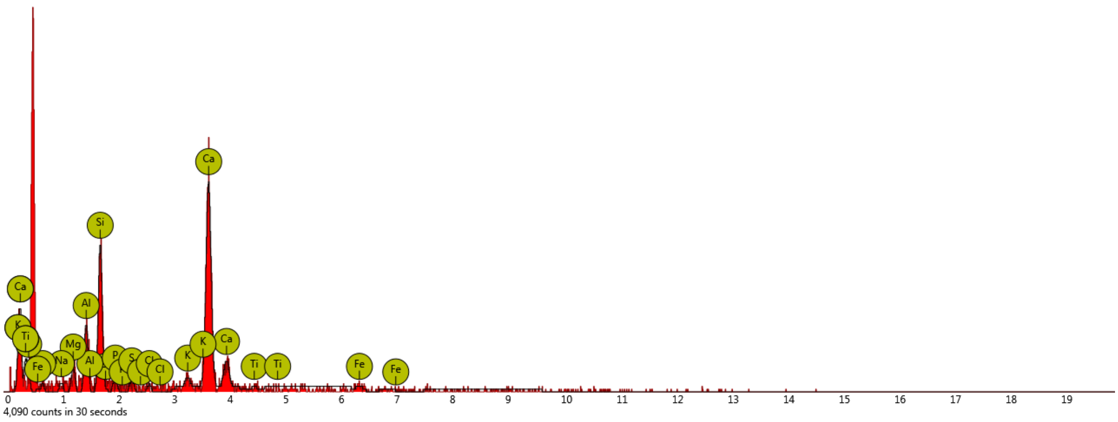


***Figure 7.*** *EDX Microanalysis of the cement-aggregate paving block.*

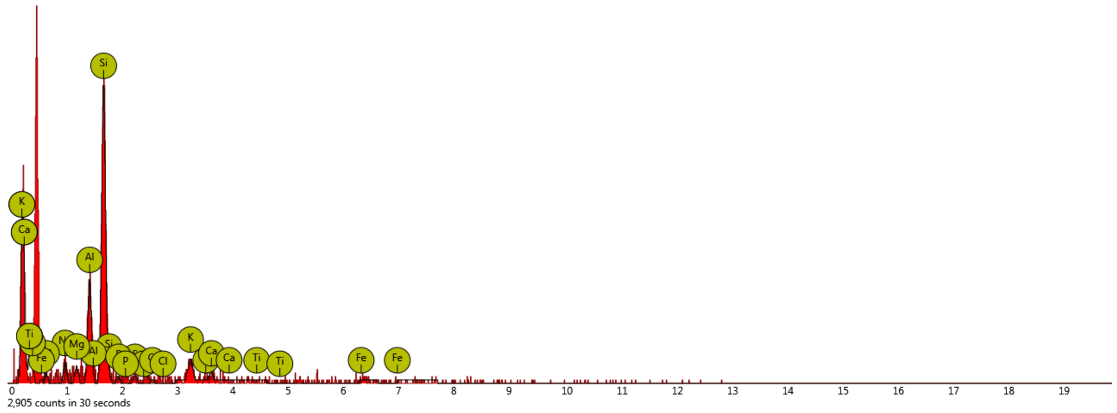


***Figure 8.*** *EDX Microanalysis of the plastic-aggregate paving block.*

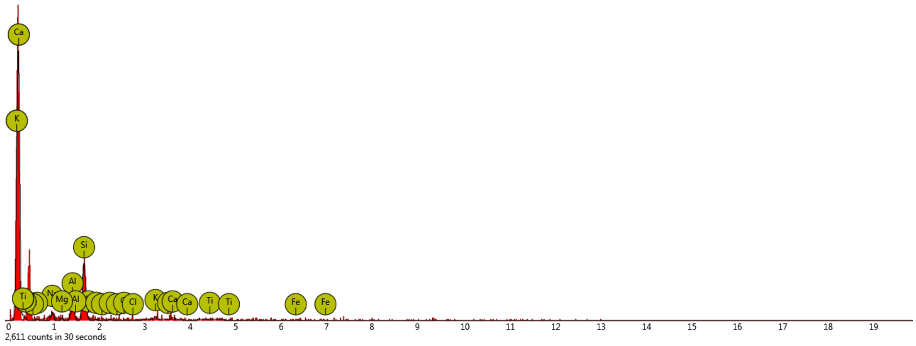


***Figure 9.*** *EDX Microanalysis of the plastic-fibre-aggregate paving block.*

### 3.2. Discussion

Table 3 presents the results of the mechanical and physical properties for cement-aggregate pavement block (CAPB), plastic-aggregate pavement block (PAPB), and plastic-fibre-aggregate pavement block (PFAPB).

The CAPB, PAPB and PFAPB have compressive strength of 21.67 Nmm$^{-2}$, 18.17 Nmm$^{-2}$, and 4.17 Nmm$^{-2}$ respectively. The 18.17 Nmm$^{-2}$ compressive strength obtained for the PAPB is lower than that of the CAPB with compressive strength of 21.67 Nmm$^{-2}$. The PFAPB has the least compressive strength of 4.17 Nmm$^{-2}$. The low compressive strength obtained for the plastic-fibre-aggregate may be attributed to the hydrophilic nature of the fibre. The 18.17 Nmm$^{-2}$ compressive strength obtained for the PAPB is higher than various compressive strength of between 2.32 Nmm$^{-2}$ to 15 Nmm$^{-2}$ reported by many authors [1, 3, 16, 18, 19]. Some other authors have also reported compressive strength of between 18.4 Nmm$^{-2}$ to 38 Nmm$^{-2}$ which is higher than the 18.17 Nmm$^{-2}$ obtained for the plastic-aggregate paving block [2, 10, 13, 22]. The 18.17 Nmm$^{-2}$ obtained for the plastic-aggregate block falls within the international standard of compressive strength 15Nmm$^{-2}$-28Nmm$^{-2}$ for paving blocks [18]. Therefore, the plastic-aggregate blocks can be used in low-traffic roads and pedestrian walkways, while the plastic-fibre may not be suitable for such construction load-bearing structures because of the low load-bearing capacity of the bricks.

The tensile strength of concrete is an important property that greatly affects the extent and size of cracking in structures. The tensile strengths obtained for the PAPB and PFAPB are 2.19 Nmm$^{-2}$ and 2.24 Nmm$^{-2}$ respectively. The tensile strengths of both the PAPB and PFAPB are higher than the 1.19 Nmm$^{-2}$ tensile strength obtained for the CAPB. Various authors have reported higher tensile strengths of 5-6.1Nmm$^{-2}$ for plastic aggregate paving blocks [3, 32]. The low tensile strength of the CAPB may be attributed to the brittle nature of the cement brick. The tensile strength results show that bricks made from plastic waste have a lesser tendency to crack compared to cement-aggregate bricks.

The cement-aggregate paving blocks (CABP), plastic-aggregate pavement blocks (PAPB), and plastic fibre aggregate pavement blocks (PFAPB) have water absorption of 0.79%, 0.15%, and 1.89% respectively. The least water absorption of 0.15% was recorded for the PAPB while the PFAPB has the highest water absorption of 1.89%. The low water absorption of the PAPB may be attributed to the hydrophobic nature of plastic which can result in lower porosity of the PAPB as explained by [13]. But the addition of fibre to the plastic-aggregate brick has been found to increase the water absorption of the brick, which been attributed to the hydrophilic nature of the plant fibre [13]. The water absorption value of 0.15% obtained for the PAPB is lower than between 0.369%, to 1.42% obtained by various authors [3, 13, 14, 18]. Other researchers have also obtained higher water absorption of between 0.98% to 4.6% for different mix-ratios of plastic aggregate paving blocks [16, 19, 32]. Though a higher water absorption of 1.89% was obtained for the plastic-fibre-aggregate paving block (PFAPB), the water absorption values for both plastic and plastic-fibre aggregate bricks are within the specified standard of less than 5% water absorption [13].

The densities of 1769.0 kg/m$^3$ and 1861.5 kg/m$^3$ were obtained for plastic-aggregate paving block (PAPB) and plastic-fibre-aggregate paving block (PFAPB) respectively. These values are less than the density of 2371.9 kg/m$^3$ obtained for the cement-aggregate paving block (CAPB). These results are similar to values reported by other authors for plastic aggregate paving blocks when compared with conventional cement aggregate paving blocks [2, 11]. The density of the PAPB and PFAPB are similar to 1766.4 kg/m$^3$ reported by another author for cement-bonded wood particles [28]. The low density of the plastic-aggregate and plastic-aggregate-fibre blocks may be attributed to the lightweight characteristics of the polyethylene waste from which the blocks are made and the fact that water was not added during the production of the blocks. The low density of plastic-aggregate bricks may serve as an advantage in transporting the bricks from one location to another.

The values 0.0300%, 0.1000%, and 0.0333% represent the thickness swelling for cement-aggregate paving block (CAPB), plastic-aggregate paving block (PAPB), and plastic-fibre-aggregate (PFAPB) respectively. The CAPB has the least swelling of 0.03% which is similar to the trend in water absorption. The low thickness of the plastic fibre aggregate paving blocks has less thickness swelling compared to plastic aggregate paving blocks but is similar to the conventional cement aggregate paving blocks. The low thickness swelling obtained for all the bricks agrees with findings by other researchers, which has been low porosity of the bricks, leads to low thickness swelling [23].

Results from the table 4 show that all the block samples; cement-aggregate paving block (CAPB), plastic-aggregate paving block (PAPB), and plastic-aggregate-fibre paving block (PFAPB) ignited upon introduction of flame but lost their flames upon withdrawal of the flame source. This shows that PAPB, as well as the CAPB, will not continue to burn once the source of the flame is withdrawn, hence all the samples passed the UL-94 HB fire-resistant test.

The thermal behavior of the cement-aggregate paving block (CAPB), plastic-aggregate paving block (PAPB), and plastic-fibre-aggregate paving block (PFAPB) presented in Figures 1, 2 and 3 are summarized in Table 5. Results from Table 5 show that the plastic-aggregate paving block (PAPB) started decomposing at a lower temperature of 54.90℃ and lost 68.8030% of its initial weight at a completion temperature of 593.35℃ compared to the cement-aggregate paving block (CAPB) which started decomposing at a slightly higher temperature of 74.65℃ and loss only 34.9434% of its initial weight at a higher completion temperature of 928.42℃. The degradation rate of the PAPB was drastic, increased with increasing temperature, and reached completion at a lower temperature compared to the CAPB. This increased degradation rate with increasing temperature agrees with the results of other authors [2, 11]. The large loss of weight of the PAPB as a result of decomposition over the CAPB may be attributed to the low molecular weight of the polyethylene from which the plastic-aggregate block is made.

The morphological and microstructural features of the paving blocks were characterized by scanning electron microscope (SEM) with energy-dispersive X-ray spectroscopy (EDX). SEM investigation helps to get a better understanding of the morphology of the paving blocks. It offered valuable microstructural insights into the composition of the cement-aggregate paving block (CAPB), plastic-aggregate paving block (PAPB), and the plastic-fibre-aggregate paving block (PFAPB) as presented in Figures 4, 5, and 6. The SEM images of the PAPB and PFAPB clearly show a consistent dispersion of the plastic waste particles within the aggregate matrix over the CAPB. This signifies a well-executed mixing procedure for the plastic-aggregate mix. This homogeneous distribution of the components of the mixture of the bricks helps to transfer the exerted load evenly all-round the bricks [28]. This has been reported to play a pivotal role in boosting the mechanical properties of the bricks [22]. The CAPB shows the presence of pores in some regions of the specimen. This presence of pores is evident in the value of water absorption obtained for the CAPB over the PAPB.

The EDX microanalysis and the result of the energy-dispersed X-ray (EDX) showing the elemental compositions of the various paving blocks are presented in Figures 7, 8 and 9 and Table 6. The EDX microanalysis of the CAPB depicts the presence of Ca, Al, and Si as the main elements, while those of the PAPB and PFAPB have Al and Si as the main elements. The CAPB contains high percentage of Ca and Mg over the PAPB and PFAPB. This can be linked to CaO and MgO which are major compositions of cement used in the manufacture of the brick. Also, the CAPB contains Ti which is absent in the PAPB and PFAPB, which can may attributed to $TiO_2$; a composition of cement which helps in hydration of cement and internal structure development of the bricks [12]. The PFAPB has a slightly higher contents of Na, Fe and P when compared to the CAPB and PAPB, this may be attributed to the contribution of the plant fibre added to the brick.

## 4. Conclusion

The research has revealed that pavement blocks made from plastic waste mixed with aggregates show impressive mechanical, physical, and thermal properties. It can therefore be concluded that plastic waste can serve as a costless alternative to cement for the production of paving blocks used for the construction of low-traffic roads and walkways, thereby reducing the infrastructural gap caused as a result of the high cost of cement. This may also help to provide a solution to the age-long environmental problems caused by the indiscriminate disposal of plastic waste. However, more research needs to be carried out on other material properties of the paving blocks.

## Abbreviations

| | |
|---|---|
| CAPB | Cement-Aggregate Pavement Block |
| PAPB | Plastic-Aggregate Pavement Block |
| PFAPB | Plastic-Fibre-Aggregate Pavement Block |

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## Conflicts of Interest

The authors declare no conflicts of interest.

## References


[1] Kumar L. P., Babu, C. C. S., Vineetha M., Surya, S. and Suman, A. (2019) An experimental study on recycled plastic paving stone. *International Journal of Research and Analytical Reviews* 6(2): 156-165.

[2] Kumi-Larbi A., Yunana D., Kamsouloum P., Webster M., Wilson D. C. and Cheeseman, C. (2018) Recycling Waste Plastics in Developing Countries: Use of Low-Density Polyethylene Water Sachet to form Plastic Bonded Sand Blocks. *Waste Management* 80: 112-118. https://doi.org/j.wasman.2018.09.003

[3] Mohan D. M. S Vigneh, J., Iyyappan, P. and Suresh, C. (2018) Utilization of Plastic Bags in Pavement Blocks. *International Journal of Pure and Applied Math*. 119(15): 1407-1415.

[4] Shiri, N. D., Kajava, P. V., Ranjan H. V., Pais, N. L. and Naik V. M. (2015) Processing of Waste Plastic into Building Materials Using a Plastic Extruder and Compression Testing of Plastic Bricks. *Journal of Mechanical Engineering and Automation* 5(2B): 39-42. https://doi.org/10.5923/c.jmea.201502.08

[5] Agyeman, S., Obeng-Ahenkora, N. K., Assiamah, S. and Twumasi, G. (2019) Exploiting Recycled Plastic Waste as an Alternative Binder for Paving Blocks Production. *Case Studies in Construction Materials.* (Online) http://creativecommons.org/licences/by-nc-nd.4.0/

[6] Alaloul, W. S., John, V. O and Musarat M. A. (2020) Mechanical and Thermal Properties of Interlocking Bricks Utilizing Wasted Polypropylene Terephthalate. *Int J Concr Struct Mater* 12: 24 https://doi.org/10.1186/s40069-020-00399-9

[7] Kognole R. S. Shipkule, K., Patil M, Patil, L. and Survace U. (2019) Utilization of Plastic Waste for Making Plastic Bricks. *International Journal of Trend in Scientific Research and Development.* 3(4): 878-880.

[8] Ronak, S., Himanshu G., Parth G., Rashmi, P. and Anand D (2017) Study of Plastic dust brick made from waste plastic. *International Journal of Mechanical and Production Engineering* 5(10): 120-123.

[9] Singh L. B., Singh, L. G., Singh, P. B. and Thokehom (2017) Manufacturing Bricks from Sand and Waste Plastics. *International Journal of Engineering Technology and Applied Science.*

[10] Ingabire D., Ntihemuka F., Mugabe G., Isabane R. S. and Turatimana T (2018) Recycling High-Density Polyethylene (HDPE) into Construction Materials as a Key Step in Plastic Waste Reduction: Case in Kigali. *Rwanda Journal of Engineering, Science, Technology and Environment*. 1(1) https://dx.doi.org/10.4314/rjeste.vlil.2S

[11] Chauhan, S. S., Kumar B., Singh, P. S., Khan, A. Goyal, H. and Goyal, S. (2019) Fabrication and Testing of Plastic Sand Bricks. *IOP Conf. Materials Science and Engineering* 691 https://doi.org/10.1088/1757-899X/691/1/012083

[12] Diamantopoulos G., Katsiotis M., Fardis M., Karatasios I., Alhassan S., Karagianni M., Papavassiliou G., and Hassan J. (2020) The Role of Titanium Dioxide on the Hydration of Portland Cement: A Combined NMR and Ultrasonic Study. *Molecules.* 25(22): 5364. https://doi.org/10.3390/molecules25225364 PMID: 33212832; PMCID: PMC7696996.

[13] Tagbor, T. A., Adjei, D., Baokye, A. K., and Annan G. (2019) The Use of Plastic Waste as Transition Materials in the Production of Pavement Blocks *Civil Eng Res J;* 9(1) https://doi.org/10.19080/CERJ.2019.09.555753

[14] Bhushaiah, R., Mohammad, S. and Rao, D. S. (2019) Study of Plastic Bricks Made from Plastic Waste. *International Resources in Engineering and Technology*. 6(4): 1122-1127.

[15] Reddy C. S. K., Kamar B. S. C. and Asadi, S. S. (2019) Utilization of Low-Density Polyethylene in the Manufacture of Paver Brick. *International Journal of Recent Science and Engineering* 7(6C2): 62-67.

[16] Folorunsho, O. W and Amadi, A. N. (2020) Production of Pavement Blocks from Plastic Waste. *The Pacific. Journal of Sci and Tech*. 21(2). http://www.akamaiuniversity.us/PJST.htm

[17] Chhazed A., Marianas M. V., Chavda N. and Navlakhe A. (2019) Utilization of PET Waste in Plastic Bricks, Flexible Pavement and as Alternative Construction Material – A rewiew. *International Journal of Applied Engineering Research*. 14(3): 616-620.

[18] Dinesh, S., Dinesh, A. and Kirubakaran, K. (2016) Utilization of Waste Plastic in Manufacture of Bricks and Paver Blocks. *International Journal Applied and Engineering Research* 11(3). http://www.replublication.co/ijaer.htm

[19] Abdulrahiman, P. H., Danish, P. K., Fatimath Nesrin, C. H., and Mashoor Muhammed, C. C. (2019) Experimental Study of Utilization of Waste Plastic Bags in Pavement Blocks. *International Journal of Scientific & Engineering Research* 10: 130-134.

[20] Shanmugavalli B., Gowtham K., Nalwin, P. J. and Moorthy E. S., (2017) Reuse of Plastic Waste in Paver Blocks. *International Journal of Engineering Research and Technology* 6(2): 313-315.

[21] Constantin J. T. Y., Gariy Z. C. A., Shitote S. M. and Ronoh E. K. (2019) Influence of Coarse Aggregate on the Physical and Mechanical Performance of Paving Blocks Made Using Waste Plastic. *International Journal of Engineering Research and Technology.* 12(6): 912-916.

[22] Agrawal R., Singh S. K., Singh S., Prajapat D. K., Sudhanshu S., Kumar S., Durin B., Srajbek M., and Gilja G. (2023) Utilization of Plastic Waste in Road Paver Blocks as a Construction Material. Civil Eng 4(4): 1071-1082; https://doi.org/10.3390/civileng4040058

[23] Aguda, L. O., Ajayi, B., Bakare, B., Aguda, Y., Olaoye, K., Akala, A., and Adegoke, O. (2021). "Strength and dimensional stability of cement bonded board reinforced with tomato stem particles and coconut husk dust," *BioResources* 16(1), 572-582.

[24] Chaves Pabon, S. B., Baquero E., Molano Barrera, C. W., Ospina Garcia, M. A. and Lizarozo Godoy, J. O. (2020) Technical and Economic comparison between recycled plastic and Hydraulic concrete pavers. *Revista Espacios* 41(21). Available at: https://www.revistaespacios.com

[25] Hamid N. B., Ab Rasak S. N., Mokhtar M., Sanik M. E., Kaamin M, Nor A. H. M. And Ramli M. Z. (2019) Development of Paving Blocks using Waste Materials. *International Journal of Innovation Technology and Exploring Engineering*. 8(9S3): https://doi.org/10.10.35940ijitee.13288.0789S319

[26] Suresh P., Azam, M. D. and Harish, B. (2019) Recycling Plastic Waste into Paving Blocks. *Journal of Architecture and Technology* 11(11): 48-56.

[27] Jaya R. P. (2020) Porous Concrete Pavement Containing Nanosilica from Black Rice Husk Ash. *New Materials in Civil Engineering*. https://doi.org/10.1016/B978-0-12-818961-0.00014-4

[28] Odeyemi S. O., Abdulwahab R., Adeniyi A. G., and Atoyebi O. D. (2020) Physical and Mechanical Properties of Cement-bonded Particle Board Produced from African Balsam Tree (*Populous Balsamifera*). *Results in Engineering* 6. https://doi.org/j.rineng.2020.100126

[29] Jawaid M., Abdul Khalil H. P. S. Noorunnisa Khanam P. and Abu Bakar A. (2011) Hybrid Composites Made from Oil Palm Empty Fruit Bunches/Jute Fibres: Water Absorption, Thickness Swelling and Density Behaviours. *J Polym Environ* 19: 106-109.

[30] Rahman E., R. Ong P. J., Nabinejad O., Islam I., Khandoker N. A. N., Pakrashi V. And Shorowordi K. M. (2018) Utilization of Blended Waste Materials in Bricks. *Technologies* 6(20). https://doi.org/10.3390/technologies6010020

[31] Przytas A., Jovic M., Salmeia K. A., Rentsch D., Ferry L., Mispreuve H., Perler H and Gaan S. (2018) Some Key Factors Influencing the Flame Retardancy of EDA-DOPO Containing Flexible Polyurethane Foams. *Polymers* 10(1115); https://doi.org/10.3390/polym10101115

[32] Tolashie S. K., Baodu E. K., Kokota F., and Mensah D (2020) Plastic wastes to pavement blocks: A significant alternative way to reducing plastic wastes generation and accumulation in Ghana. *Construction and Building Materials* 241 https://doi.org/10.1016/j.conbuildmat.2020.118044