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# Exploiting recycled plastic waste as an alternative binder for paving blocks production

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ABSTRACT

The management of solid waste continues to be a major challenge, particularly in the urban agglomeration in low and middle-income countries. One type of solid waste that is of national and global concern is plastic wastes. This study sought to explore the potential of using plastic waste as a binding material for paving blocks production. Concrete paving blocks (cement: quarry dust: sand = 1:1:2) by weight or volume were produced to serve as Control having tested the compressive strength and water absorption properties. Composite paving blocks less in plastic (LP) on a mix ratio of 1:1:2 and high in plastic (HP) on a mix ratio of 1:0.5:1 by weight or volume were also produced and tested in the laboratory for compressive strength at 7, 14, and 21 days curing via water sprinkling and water absorption test were done after the 72 -h of soaking. The study revealed after 21 days old that paving blocks in HP and LP having compressive strengths of 8.53 N/mm$^2$ (water absorption = 0.5%) and 7.31 N/mm$^2$ (water absorption = 2.7%) respectively were higher than the Control value of 6.07 N/mm$^2$ (water absorption = 4.9%). The authors recommended that the paving blocks made from the recycled plastic waste should be used in non-traffic areas such as walkways, footpaths, pedestrian plazas, landscapes, monument premises and in waterlog areas due to their low water absorption property and relatively low compressive strengths compared to global specs thresholds of 5–25% and low-density to moderate concrete strength 0.69–17.24 N/mm$^2$ respectively.



## 1. Introduction

Events in the 20th and early in the 21 st century and compendia of waste researches indicate that wastes in whatever form or classification solid, liquid or toxic have become a major sequel of modernisation and economic development [1,2]. The global waste generation rates are rising faster than ever, estimated at about 1.3 billion tons/year in that year 2015 and expected to increase to roughly 2.2 billion tons/year by 2025 with 15 years projected per capita waste generation rates from 1.2 to 1.42 kg/person/day. Specialists have therefore cautioned that the growth will not decrease unless individuals revised how to use and reuse natural resources. In the sub-Saharan Africa in which Ghana is part, waste generation in is close to 62 million tons/year. Though the per capita waste generation is usually low in this region, it spans from 0.09 to 3.0 kg/person/day representing an average of 0.65 kg/capita/day [3].

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In 2005, Ghana generated about 3.0 million tons of solid waste at per capita generation of 0.45 kg/person/day based on the then national population estimate of 22 million. This value has increased with a corresponding increase in the country's population to approximately 0.47 kg/person/day according to Amaniampong [4] and [5] (i.e., expanding on 2015 generation waste of 12,710,000 kg per day per the current population of 27,043,093). The current statistic has pegged Ghana's plastic waste generation close to 22,000 tons annually but recycled only 2%. The national waste generation statistic on non-recyclables like metals, glass, textiles, leather and rubbers is 0.096 kg/person/day. The high rate of population growth and snowballing per capita income have resulted in the generation of huge volumes of heaped solid wastes which pose a serious menace to environmental quality and human health. More so, the control of solid waste at large is a key challenge in urban areas throughout the world that cannot be limited to cities in Ghana as a developing country [6,7].

The municipalities in Ghana are the second highest in terms of solid waste generation according to Miezah et al. [5] and they generate close to 0.40 kg/person/day. The organic and inorganic waste streams are largely categorised as putrescible, fermentable and non-fermentable wastes [3]. Municipal solid waste (MSW) generation rate in Sunyani on the average is about 0.49 kg/person/day, which is higher than the national average of 0.47 kg/person/day. In the Northern Savanna Zone in which Sunyani is inclusive, the plastics waste composition is 14% of the total waste generation, which is an increase in percentage fraction compared to other zones. In Ghana, solid waste management is one of the core mandates of the metropolitan, municipal and district assemblies (MMDAs) in order to keep their operational areas clean in lieu of Ministry of Local Government and Rural Development (MLGRD) [5]. The MMDAs have sanitation agencies such as Zoomlion Ghana limited and other private waste companies as managers of the waste generated from human activities. Despite all these efforts put in place by the MMDAs and other waste management companies, solid waste management problem is common everywhere in the country, particularly in the Sunyani municipality. The future waste management problems in Ghana would be compounded as projections Miezah et al. [5] and Quartey et al. [6] indicate that generation rates of MSW composition classified as organic, paper, plastic, glass, metals, and others are expected to upsurge as the country's population increases.

In the year 2015, the total MSW generated in the Sunyani municipality was estimated as 2,516,823.3 kg/month that translated into an average of 83,894.11 kg/daily with an average waste generation rate of 0.57 kg/person/day. Of the overall total, the average amount of plastic waste generated daily was found to be 23,851.7 kg at 0.14 kg/person/day (22.93% of the MSW). The two highest percentages after sorting the plastic waste as observed by Amaniampong [4] were low-density polyethene (LDPE) of 17.26% and high-density polyethene (HDPE) with sachet water plastic bags category of 34.61%. The plastic waste component of the MSW as asserted by Appaw-agbola [8] and Quartey et al. [6] is quite problematic if indiscriminately disposed into streets, gutters, parking lots, vehicle terminals, schools, markets, homes and venues of social functions. This because if stayed in the environment for a considerable length of time may cause all sorts of environmental, social, health and economic problems [4,6,8,9].

The common and oldest management of plastic waste in the municipality as observed in most parts of the country is through burning and landfilling which are not environmentally friendly and sustainable since these may release smoke, carbon dioxide, carbon monoxide and nitrous oxide, major contributors to global warming (greenhouse gases - GHGs) and methane as leachates that contain pathogens [4,10]. Moreover, landfilling polymer waste such as plastic waste is not desirable since plastic is non-biodegradable and no economic value would have been derived from the waste in that case. Furthermore, livestock in the municipality may die because they are dieting on plastic waste and being choked [6]. Choked gutters with plastic waste also become fertile breeding grounds for mosquitoes infesting the general populace with malaria coupled with other attended health challenges like epidemic cholera, dysentery among others via food and water contaminations [5,11,12]. One other concern is that the municipal streets have been inundated with sachet water plastic waste marring their aesthetic beauty and driveways of one of Ghana's excellent planned cities, meanwhile, the wastes could be recycled for construction purposes [10]. For the moment, the use of plastic products and their derivatives for packaging purposes (shopping bags, sachet water production, food rappers, bottling, communication gadgets etc.) is also on the increase in Ghana [4–6]. The means that plastic wastes generation will continue to increase in the near future in Ghana. However, recycled plastic products are currently nascent and gaining various engineering applications all over the world in road pavements (bitumen and aggregates), furniture, fishing threads making, other recycled plastic products etc., but less exploited for the production of paving units. This study, therefore, explored the potential of using plastic waste as a binding material for paving blocks making by determining the compressive strength and water absorption properties of blocks made with RPW (recycled plastic waste), and normal weight aggregate (NWA). Test results were compared with global specs thresholds on paving units or blocks as well as structural lightweight concrete (LWC) and recommendations made.

## 2. Experimental: materials and methods

### 2.1. Field sampling of plastic wastes

The RPW used to manufacture the paving blocks were collected from the surrounding waste collecting points in the municipality. These used plastics were cut open, washed to remove any impurities, and dried in the open air until absolutely no moisture was present. The processed RPW material (polythene bags, sachet water bags, wrappers etc.) were bagged and sent to the laboratory for the experiments. The RPW used has thermoplastic properties, which means it can be moulded and remoulded recursively when heated. As a highly flexible material, it also comprises copious side chains that upsurge the

**Fig. 1.** (a) Unwashed plastic bags form waste bins and (b) Processed plastic bags.

distance between the main C—C chains as well as compact packing and intermolecular attraction. Its density varies within the range of 0.91–0.94 g/cm$^3$ [12]. Samples of the collected and unprocessed waste are shown in Fig. 1.

### *2.2. Coarse aggregate sourcing and preparation*

The local mining silica sand as fine aggregate and quarry dust with specific gravities of 2.64 and 2.68 respectively were sourced from OSS Urban Services Limited. The quarry dust samples were oven-dried for one week before been measured to get the required proportions for each test. The quarry dust sizes of 0/4.75 mm via BS (British Standard) sieve size were used for the subsequent laboratory tests. According to the Cement and Concrete Institute [13], continuous grading usually facilitates compaction. For this reason, - paving blocks usually made from semi-dry mixes, chunky particle shape will expedite compaction. Therefore, if the material is inadequately graded for use on its own, good grading may be achieved by blending two or more materials.

### *2.3. Cement*

An ordinary Portland cement (OPC), Ghacem Super Rapid class CEM II /B-L PLC 32.5R with a specific gravity of 3.15 conforming to BS EN 197-1 [14] specs were bought from a local store in the Sunyani Municipality of Ghana. The major oxide compositions in this type of cement according to Bediako & Amankwah [15] are CaO, $SiO_2$, $Al_2O_3$, $Fe_2O_3$ with MgO, $Na_2O$, $K_2O$, MnO, $TiO_2$, $P_2O_5$ and $SO_3$ minor oxides.

### *2.4. Water*

Stand tap pipe water, clean and pure fetched from Building Technology Lab of Sunyani Technical University was used for moulding of the specimens that conformed to BS EN 1008 [16] for the study.

The mix proportions of Cement, Sand, Quarry Dust and RPW materials were obtained by weight or volume batching method as tabulated in Table 1. Individual components required for the preparation of the paving blocks were weighed until the required masses were obtained. The weighed sample was dried in the sun to remove moisture contents present. The required tools and apparatus used in the experiments are shovel (1), head pan (1), hand trowel (2), pyros glass (1), wooden mould (1), tamping rod (1), concrete base platform (1), protective cloths (2), safety boot (2) and wooden stirring rod (1).

The mixing, casting and curing for the making of the Control was done per the ASTM C192/C192M - 16a standard. The required quantities were weighed using electronic balance according to the designed proportions stated in Table 1. The weighed quantities were dried and mixed on the concrete platform for about five minutes until a uniform mixed colour was obtained without any lumps or clusters. About 0.48 litres per m$^3$ of water was then added to the mix until the required paste was formed. Cleaned and lubricated 200 mm × 100 mm × 100 mm mould was then used for casting of the specimens.

For the casting of composite paving units, various doses of molten RPW material were used to fill the mould in three layers and subjected to 25 blows using a 16 mm diameter and 600 mm long tamping rod. In total, 24 specimens (8-Control, 8-rich in plastic and 8-less in plastic) were moulded and left for 24 h for partial drying before demoulding them as shown in Fig. 2. The freshly moulded concrete and RPW paving blocks were cured adequately to ensure that they gained the maximum required strength. The Control specimens were labelled with a waterproof marker and subjected to curing via water sprinkling to improve their quality for 7–21 days according to ASTM C192/C192M [25] standards-.

### *2.5. Laboratory testing*

The moulded specimens were then conveyed to the laboratory for testing to determine their respective engineering properties. All the test protocols executed in the laboratory were in accordance with ASTM Standards, British Standards Institute (BSI) and European Standards (EN) as given in Table 1. The specimens were properly prepared in order not to cause

**Table 1**
Test results, testing standards and specs thresholds for concrete paving blocks.

| Specimen | Sample ID | Mix Ratio | Mix Ratio by Volume ($m^3$) or Weight (kg) | | | | | w/c Ratio (kg) | Compressive Strength ($N/mm^2$) | | | Average Density ($kg/m^3$) and Porosity (%) | | | Water Absorption at 72 h (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Cement | Sand | Quarry Dust | Plastic | Total | | 7 days | 14 days | 21 days | Bulk | Dry | Porosity | |
| Control | CB-001 | 1 : 1 : 2 | 0.022 (1.13)[a] | 0.022 (1.13) | 0.043 (2.26) | 0 | 0.087 | 0.48 | 3.81 | 4.23 | 5.56 | 1688.00 | | | 4.6 |
| | CB-002 | | | | | | | | 6.02 | 6.42 | 6.58 | 1738.50 | | | 5.2 |
| *Average* | | | | | | | | | *4.92* | *5.33* | *6.07* | *1713.25* | *1057.15* | *35.35* | *4.9* |
| Less in Plastic | LP-003 | 1 : 1 : 2 | 0 | 0.035 (1.65) | 0.069 (3.29) | 0.035 (1.65) | 0.139 (6.59) | – | 5.88 | 6.61 | 7.01 | 2052.50 | | | 2.9 |
| | LP-004 | | | | | | | | 6.04 | 7.26 | 7.61 | 2229.00 | | | 2.5 |
| *Average* | | | | | | | | | *5.96* | *6.94* | *7.31* | *2140.75* | *1064.89* | *19.22* | *2.7* |
| High in Plastic | HP-005 | 1 : 0.5 : 1 | 0 | 0.056 (2.38) | 0.028 (1.92) | 0.056 (2.38) | 0.140 (6.68) | – | 9.51 | 9.53 | 7.06 | 2287.50 | | | 0.44 |
| | HP-006 | | | | | | | | 7.26 | 7.29 | 9.99 | 2285.50 | | | 0.56 |
| *Average* | | | | | | | | | *8.39* | *8.41* | *8.53* | *2286.50* | *1072.64* | *13.72* | *0.50* |

Test results compared with specs or standards for concrete paving blocks and Testing Standards

| Physical & mechanical Property | Average Test Results | South Africa [17] | Ghana Standard (GS MoT:2007) | Europe [18] | USA [19] | India [20] | Remark |
|---|---|---|---|---|---|---|---|
| Compressive Strength ($N/mm^2$) | 7.31 (LP[b])<br>8.53 (HP[c]) | ≥25 (light traffic)<br>≥35 (heavy traffic) | ≥30 (footpaths and bicycle lanes)<br>≥35 (limited vehicular access)<br>≥7 (sandcrete paving blocks | – | ≥55 | 30 (non-traffic)<br>35 (light traffic) | Failed |
| Tensile Strength ($N/mm^2$) | – | ≥2.2 (light traffic)<br>≥2.8 (heavy traffic) | – | ≥3.6 | – | – | – |
| 72-hour Water Absorption (%) | 2.7 (LP)<br>0.5 (HP) | ≤6.5 | ≤5.0 | ≤6.0 | ≤5.0 | <7.0 | Passed |

| Specimen Number | Specimen | Compressive Test | Water Absorption Test |
|---|---|---|---|
| 1 | Control | [21] | [22] |
| 2 | Composite Paving Block | [23] | [24] |

[a] Values in bracket are weights in kg.
[b] Low/Less (LP) in Plastic.
[c] High/Rich (HP) in Plastic.

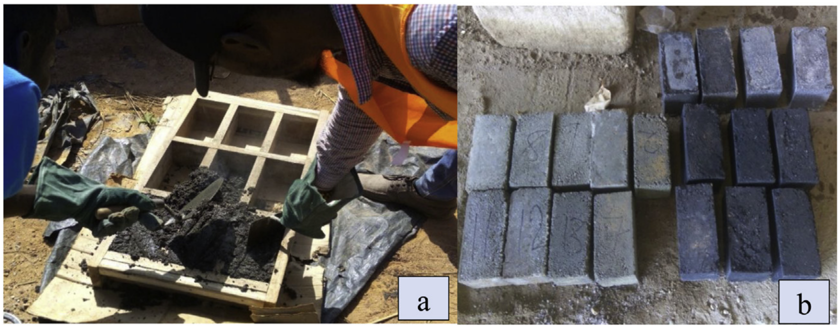


**Fig. 2.** (a) Moulding of RPW blocks and (b) demounded RPW blocks.

destructions and to obtain the exact results. After curing the specimens for the specified ages (7, 14 and 21 days), the specimens were cleaned with an unsoiled dry cloth to absorb their surface water and wipe off all dirt on their surfaces [26]. Some were marked to get the right measurement for placement on the Universal Compression Test Machine. The test complies with ASTM D638 [23] and BS EN 12390-5 [27] for RPW and Control paving blocks correspondingly.

ASTM C1585 [22] and BS 1881-122 [24] standards were applied in the experiment to estimate the water absorption rates, densities and porosities of the hardened Control and RPW specimens respectively. The 72 h of soaking was to achieve the mass difference before as dry weight and after soaking in the water as wet weight by measurement. The mass difference was used in calculating the water absorption rate (%).

## 3. Results and discussion

The raw results from the experiments were entered into Microsoft Excel spreadsheet and analysed via descriptive statistics (averages). Tested engineering properties of the specimens were evaluated by comparing results with Ghana Standards (GS), Bureau of Indian Standards (BIS), ASTM, South African National Standards (SANS) and EN Standards and conclusions drawn. After a series of laboratory tests by fully replacing cement with molten recycled plastic waste, the results are presented in Table 1.

### *3.1. Compressive strength*

This is commonly defined as the resistance to failure under the action of compressive forces and it is a significant parametric property that engineers use to gauge the performance of the material throughout service conditions. Kosmatka et al. [28] have opined that concrete resistance to impact and abrasion is associated with its compressive strength and the type of aggregate. Results from Table 1 showed a significant variation in the strengths of the concrete specimens.

As would generally be expected, the compressive strength of the Control increased with the ageing of the specimens (7 to 21 days). The compressive strength of the cement concrete sample used as Control before replacing cement with plastic waste had an average compressive strength of 5.12 N/mm$^2$ after curing for 7 days and increased to 6.07 N/mm$^2$ at 21 days (an increase of about 18% in strength). The results for the rich or high in plastic (HP) and less or low in plastic (LP) showed similar trends. That is, from 5.96 N/mm$^2$ for LP specimen and 8.39 N/mm$^2$ for HP at 7 days old to 7.31 N/mm$^2$ and 8.53 N/mm$^2$ at 21 days old respectively. This corresponds to an increase of roughly 25% in compressive strength for LP blocks and a marginal increase of about 2% for the HP blocks. However, the compressive strength of the HP specimen was about 17% higher than that the LP block.

Generally, the compressive strength of the specimens increased when the plastic waste was used to replace cement, this clearly shows that concrete paving blocks are inferior in compression than RPW paving blocks using the same mix ratio of 1:1:2. This according to Jassim [29] could be credited to the increase in adhesive strength between the surface area of the waste plastic and the neighbouring aggregate particles. Huang et al. [30] observed in their experiment that the subsequent increase in contact area would usually result in strength improvement. Results, however, vary with that of Quarcoo [31] who partially substituted 9%–25% by weight of cement with low-density polyethene (LDPE) waste after 28 days curing aged. Frigione [32] also observed in his study after replacing sand with waste polyethene that the compressive strength and splitting tensile strength of plastic concrete were of 0.4–1.9% lower than that of the Control but with somewhat higher ductility.

### *3.2. Water absorption, density and porosity*

The aim of the water absorption test was to determine the moisture absorption capacity of the various specimens [33]. From Table 1, the water absorption rate after 72 h for Control after curing was 4.9% (175 g), less in plastic (LP) 2.7% (116 g) and high in plastic (HP) 0.5% (23 g). The results indicate that the concrete paving blocks absorbed more water (hydrophilic) than the RPW paving blocks as they were gauged to be hydrophobic. Youssef et al. [34] asserted that RPW demonstrates the lowest water absorption because of its hydrophobicity having soaked results from 6 h to 1 week between 0.0–1.0%. Sharma and Batra [35] stated that the moisture absorption capacity of a paving block should not be in excess of 6% by mass and in individual samples; it should be limited to 7%. More so, the range for LWC may vary from a few percentages to as high as 45% depending on the aggregate pore structure [36]. The average saturated surface dry density range of 1064.89–1074.40 kg/m$^3$ were within the specified threshold values of 500–1900 kg/m$^3$ recommended for LWC. Also, the obtained porosity values of 19.22% for LH and 13.72% for HP are less than the Control result of 35.35% and other limits reported in most literature [37].

### *3.3. Evaluating the RPW blocks for pavement construction purposes*

The average results of the mechanical properties of the composite paving blocks in Table 1 were compared to universal best practice specifications of paving units. According to Gianni [38], compressive strength is one of the significant phyisco-mechanical property parameters when evaluating the quality of paving blocks. He emphasised further on the two known key indices for characterising mechanical properties of concrete like compressive strength and splitting tensile strength. Based on these assertions, the test results were evaluated in tandem with established specification thresholds relating to compression strength and water absorption. Even though the water absorption rate is not often used as a gauge of the quality of concrete, most good concretes have absorption of less than 10% [38].

The average compression strength of the composite paving blocks did not meet the specification threshold values of BIS, ASTM, GS, SANS and EN Standards as paving materials. However, the maximum water absorption specifications thresholds for RPW paving blocks were met by the test results. The results, however, met the 28-day compressive strength requirement for a sandcrete paving block of the minimum value of 7 N/mm$^2$ stated by MoT [39] and structural LWC requirements of low-density concrete having a compressive strength ranging from 0.69–6.89 N/mm$^2$ and moderate strength concrete with approximate compressive strength between 6.89–17.24 N/mm$^2$. Though the test results failed to meet the compression test requirements for used as concrete paver blocks for high load-bearing structures, the RPW paving blocks may be used as LWC to make paver blocks for use on non-traffic areas as materials good in tension are mostly preferred in the construction of such structures according to Sharma and Batra [35]. These areas may comprise building premises, footpaths, malls, pedestrian plaza, landscapes, monuments premises, public parks, shopping complexes, terminals, parking areas and railway platforms.

## 4. Conclusions

After a series of laboratory tests, the results attained from the lab test clearly indicate that the Control (without plastic) specimens were low compressive strength than that of the low and high in plastic specimens. In addition, concrete paving block specimens absorbed more water than the composite specimens did. The results revealed further that paving units could be made from RPW wastes ranging from shrink-wrap, dry cleaning film, merchandise bags, grocery sacks and stretch wrap, recycle bags, redemption bags, pure water sachet rubber, bubble packaging film, commercial/industrial liners/bags to commercial overwrap. This usage would serve another way of recycling waste plastics while producing less costly (site transporting and handling of block units) paving blocks for constructing non-traffic semi-rigid pavement structures. The implication is that plastic wastes that have until now became a social, environmental and economic nuisance, as well as health and safety challenges in major cities in Ghana, can effectively be utilised for sustainable construction. A significant time-saving in the manufacturing process is an added advantage, as they attain more than 80% of their final strength within a day. In fast construction and in waterlogged areas, paving blocks produced from plastic wastes would have an advantage over those produced from ordinary concrete due to their fast curing and low water absorption properties making it relatively less prone to chemical attack, physical stress and mechanical damage as compared to other LWC. However, the potential practical implications of using the RPW in paving blocks making in the municipality would heavily depend on 4A's (acceptability, accessibility, adaptability and affordability) concept of marketing this new product. Other barriers may be an investment in recycling technologies, technical expertise, educational avenues on advantages of plastic pavers over other concrete paving blocks in use, purchasing of extruders or recycled plant startup cost and many more.

The authors, therefore, recommend the ensuing to government agencies and stakeholders in the construction industry that:

1 RPW may be apt to replace cement as a binder in the making of paving blocks and production of LWC for use in low-load bearing structures.
2 Waste plastic materials may be used as a binding material for making of paving blocks capable of supporting low load-bearing purposes such as walkways, footpaths, building premises among others in highly moist environments due to their low water absorption capacity.
3 Ghana Highway Authority (GHA) should revise their existing specifications on concrete paving blocks to include the practice for making and curing RPW paving blocks in the laboratory and field applications.

## Conflict of interest

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