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EVALUATION AND DESIGN OF PAVEMENT BLOCKS WITH LOW DENSITY POLYETHYLENE (LDPE) WASTE

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Abstract: Nigeria is suffering from huge problem of solid waste management in this age of rapid development and the major portion of this solid waste comprise of polyethylene, especially Low Density Poly Ethylene (LDPE). Plastic waste has become one of the major environmental problems, so by utilizing plastic in a useful way, we can reduce the burden on environment by a huge margin. The main objective of this study was to investigate the feasibility of using waste low density polyethylene (LDPE) as partial replacement for sand in the production of concrete pavement blocks. In this study cement, sand, coarse aggregate, and ground plastic were used. The mix proportion was 1: 1.5: 3 (cement: sand: coarse aggregate). The plastic was used to replace the sand by volume at 0%, 10%, 20%, 30%, 40%, 50%, and 60%. It was observed that density, compressive strength, flexural strength, and splitting tensile strength decreased as the plastic content increased. However, the water absorption increased as the plastic content increased. Compressive strengths level ranging from 15.67N/mm^2 - 33.62N/mm^2 were achieved when water cement ratios of 0.30 and 0.40 were used. Although, the strengths of the pavement blocks decreased as the plastic content increased, compressive strengths of 20N/mm^2, 30N/mm^2, and 40N/mm^2 which are satisfactory for pedestrians walk ways, light traffic and heavy traffic situations respectively could be achieved if 10% - 50% plastic contents are used. The results found are compatible and hence it can be suggested that plastic waste can be used for the making of pavement blocks. It is concluded that the modified pavement blocks would contribute to the disposal of plastics in the world.

Keywords: Pavement Blocks, Waste Material, LDPE, water cement ratio, compressive strength, curing age.

1.0 INTRODUCTION

Plastic waste has become one of the major environmental problems, so by utilizing plastic in a useful way we can reduce the burden on environment. By using plastic as a binding material rather than cement can be proved beneficial to the environment in multiple ways:

- Cement industry is the largest energy consuming industry in the world.
- By reducing use of cement, we can reduce the carbon emission from cement industries.
- Plastic poses many environmental problems which can be avoided.
- It solves the increasing problem of dumping of polyethylene in dumping grounds.

In this study pavement blocks were made using molten plastic waste (LDPE) and sand mix. Different mixes of different Plastic: Sand ratio will be prepared and then tested. The results will then be compared with that of conventional pavement blocks.

The cost of road construction using concrete paving blocks has remained high and, there exist enough evidence that it will even proliferate to unprecedented levels. Plastic wastes not only endanger marine life but also intoxicate human beings (Andersson & Wesslén, 2012). Whereas the impact of plastic pollution on the ecosystem is specifically an environmental issue, perhaps reserved only to the environmentalist, the truth is that even engineering interventions can also lead to a total, or at reasonable levels, elimination of the problem. More genuinely, there exists a window or gap in which plastic wastes can be used in making recycled plastic paving blocks. And, this initiative, if brought into practice, will help solve the challenges of road construction and environmental conservation.

For a long time now, the Civil Engineering and Construction fraternity has struggled, the world over, to come up with alternative ways of constructing cheaper and durable roads. In this regard, the use of reinforced concrete slabs and paving blocks have been proposed and researched widely, than ever, with a view to achieving the purpose (Concrete Manufacturers Association; 2004). However, some of the construction problems–

proliferating expenses, short deign life and others –have constantly remained a challenge. Specifically, to concrete paving blocks, the problems of spalling, breakage under sustained loading and other factors have haunted their use for quite some time now (Nanda & Muraleedharan, 2010). Moreover, any attempt to solve these problems will be of prudence not only to the road clients, contractors and the engineering community, but also to the society as a whole. It is undeniable that the use of plastic wastes in achieving this will be one of the most productive and efficient and prudent mechanism ever thought of. Low-density polyethylene (LDPE) offers excellent technical qualities, excellent resistance to chemical substances, and has a wider range of applications. However, it has some drawbacks, such as a low melting point, high flammability and reduced thermal stability. Be that as it may, the fact that LDPE has good binding properties has made it easy for plastic blending especially with regard to polymer composites. To this end, there are a number of studies that show that mixing LDPE with clay results in a much stronger material that can be applied in many areas such in construction and civil engineering design.

Concrete paving blocks are susceptible to breakage especially when subjected to high vehicular wheel loads. In other words, roads made from these blocks may not be applicable for use by heavy commercial tracks and machinery. Second, these conventional paving blocks have a shorter design life than would be expected, and this is for reasons such as: rutting and spelling (Nanda & Muraleedharan, 2010). Rutting on concrete block pavements are caused by uncontrolled ingress of water into the road foundation resulting into plasticity and dispersion of the sub-grade materials. This leads to uneven surfaces; a challenge in achieving a desired drive comfort. This ingress of water is caused by gaps left in between the paving blocks due to their uneven edges.
It was these desired properties (mechanical and chemical) of LDPE including its ability to be molded in any desired shape that inspired this research. It aimed at coming up with paving blocks made of polyethylene, and sand with a view to replacing conventional paving blocks based on credible reasons ranging from failure to efficiency, construction economics to road durability and efficiency. The study also evaluated the influences of sand on the compressive strength of melted polyethylene.

2.0 LITERATURE REVIEW

2.1. Introduction

The complications associated with road construction, in general, revolve around the ever-proliferating costs, inefficiencies, failures and durability. The characteristic failures, inefficiencies and durability problems are challenges that do not just apply to concrete paving blocks. Flexible pavements as well as concrete (reinforced) slabs have often failed to meet the desired characteristics in terms of performance and efficiency. Whereas the conventional methods of road construction continue to plague the development goals and policy making on one hand, environmental pollution pose serious threat to both animals and plants on the other. Plastic wastes do endanger all life forms including human beings, and the time ignore it has surely passed; means must be found to eliminate this threat.

2.2 Characteristics and Failure of Concrete Paving Materials

The failure of conventional road construction methods have been evaluated for a long time. Subject to research by Naik etal (1996), Concrete paving blocks could the best alternative to conventional HRA paving. However, this is not possible until the problems of crack formation and poor jointing problems are solved. The research focussed on determining the durability of concrete paving blocks on roads by evaluating cracking and breakage. Concrete paving blocks were observed for destress properties– cracks and jointing. The result was that about 25% of the blocks showed cracks immediately after construction and joints were not uniform and smooth. The main reason for the development of cracks could be due to poor design, but the researchers concluded that recurrent traffic loading led to strain which later manifested into cracks and later, breakage. In addition, the researchers established that frequent repairs of the broken blocks increase the cost of construction.

Another research by Nanda and Muraleedharan (2010), also emphasized the failures of interlocking concrete blocks as an alternative road paving material. The research observed sub-base material failure and rutting, spalling, and breakage of the surfacing blocks (Nanda & Muraleedharan, 2010). Subject to the research findings, Concrete Block Pavement (CBP) fail in two main ways –primary and secondary. Primary failures include variation of the sandbed and rutting of the surface interlocking blocks. Sandbed variation poses one potential threat to the CBP design life; it leads to surface undulation which may result in water pudding problems (Nanda & Muraleedharan, 2010). Secondary failures of CBP are breakage and spalling that result from rutting. The surface interlocking blocks may break or spall depending on the nature of the foundation thus leading to reduced road durability.

In addition, Radlińska et al (2012) conducted a research on the spalling of pervious concrete paving blocks. The researchers noted that reactive chemicals in both water and soil pose a serious danger to concrete paving materials. This is because these chemicals always cause raveling of concrete surfaces especially during snow falls and heavy downpours. The research noted that, alongside raveling, there are also some corrosion activities which cause spalling thereby reducing the durability of concrete paving blocks. This problem is seen to even mutate into a bigger challenge during snowfall where thawing and freezing make road surfaces lose the outer lining aggregates. Therefore, unless these challenges of spalling and corrosion of concrete paving are not solved, the researchers conclude that concrete paving will continue to remain costly and inefficient.

According to Bell & Edwards (2014), the use concrete paving blocks in road construction could be one of the most efficient and reliable method ever thought of were it not for surface rutting. While conducting research aimed at evaluating the performance of paving blocks on streets and airfields, the researchers noted that the efficiency of such paving materials are affected by rutting. In fact, subject to the research findings, some road sections experienced even deeper rut depths than would be allowable. First, a comprehensive literary work evaluation was conducted in order to identify the kinds of blocks used, their manufacturing processes, strength characteristics and design standards. It was the outcome of the review that necessitated the need to conduct a study on the performance of these paving blocks with respect to rutting.
In order to conduct the study, the researchers installed a group of paving blocks, with known strength and design properties at some specified sections of the road. A dump truck was then passed several times on the blocks and the rutting depths observed. In conclusion, the researchers established that paving blocks are susceptible to surface rutting as their uneven edges allow infiltration of water into the road foundation (Bell & Edwards, 2014). This infiltration, if uncontrolled, causes plasticity of the sub-grade materials thereby resulting in surface deformation called rutting.

2.3. Mechanical properties of plastics
Potential research by Bell & Edwards (2014) shows that plastic, and more so polyethylene, has good mechanical properties that if modified, can be of great use in many engineering aspects. Low Density Polyethylene (LDPE), for example has a good resistance to chemical attack, excellent fatigue and appropriate wear resistance. More importantly, several studies have confirmed that the addition of clay materials improves the mechanical properties of polymers. Physical properties such as high compressive, tensile and yield strength, impact strength, hardness, stiffness, thermal stability and dimensional stability are some of the properties that improve with the addition of clay (Bell & Edwards, 2014).
According to Durmus, etal (2008), the large surface area of clays additionally expands the inter-facial interactions in the middle of polymer and filler bonds contingent on the correct physico-chemical conditions and handling impacts. Consequently, effective enhancements in mechanical properties could be arrived at with low clay loadings and polymer composites.

3.0 Methodology
3.1 Materials
The materials used to develop the plastic concrete pavement blocks (PCPBs) in this study consist of ordinary Portland cement (OPC), fine aggregate (sand), coarse aggregate (stones), ground plastic (GP) and water.

3.1.1 Cement
Ordinary Portland cement (CEM I 42.5 N) produced by Dangote Cement that conformed to EN 197-1 and labelled OPC was used. The mean particle size (μm) and specific gravity of the OPC were 4 and 3.14 respectively.

3.1.2 Sand, Coarse Aggregate, Ground Plastic and Water
Natural river sand from Ogun rivers abound Abeokuta town was used for the PCPBs. The sand was dried in an opened place to remove the moisture. The sand conformed to zone II as per IS: 383 – 1970. The ground plastic used conformed to zone I as per IS: 383 – 1970. The coarse aggregate used in this study were 10 mm nominal

size, and were tested as per IS: 383 – 1970. Table 1 shows the physical properties of the materials used. Potable water was used for the preparation and curing of the PCPBs specimens.

Table 1: Physical properties of sand, stones and ground plastic

Materials	Specific Gravity	Bulk Density (Kg/m^3)	Finess Modulus	Moisture Content (%)
Fine Aggregate	2.60	1695	2.50	2.04
Coarse Aggregate	2.63	1723	1.97	1.39
Ground Plastic	1.10	813.6	3.51	-

3.1.3 Preparation of the Ground Plastic

Waste water sachets (type of low-density polyethylene) were collected and cleaned. They were cut into pieces. The plastics were put on fire until they got melted. This caused the plastic's long chain polymer chains to break apart. The plastics in the liquid form were poured on roofing sheets and were allowed to solidify. With the aid of metallic mortar and pestle, the solidified plastics were ground into small particles.

3.2 Methods

3.2.1 Proportion of the Mix

The mix proportion was 1: 1.5: 3 (cement: sand: coarse aggregate). The percentage weight of the ground plastic was 0%, 10%, 20%, 30%, 40%, 50%, and 60% by volume of sand. Different water cement ratios (0.30 and 0.40) were used for the experiment. The plain concrete was used as a control test and the rest of the batches with ground plastic were the volume percentage of ground plastic with varying W/C ratio. Table 2 exhibits the mix proportion of the aggregates used for the PCPBs.

Table 2: Mix proportion

% of Plastic	w/c Ratio	Constituents of PCPB (kg)				
		Water	Cement	Coarse Aggregate	Fine Aggregate	Ground Plastic
0	0.30	0.88	2.94	8.84	4.42	0.00
	0.40	1.18	2.94	8.84	4.42	0.00
10	0.30	0.88	2.94	8.84	3.98	0.44
	0.40	1.18	2.94	8.84	3.98	0.44
20	0.30	0.88	2.94	8.84	3.54	0.88
	0.40	1.18	2.94	8.84	3.54	0.88
30	0.30	0.88	2.94	8.84	3.10	1.33
	0.40	1.18	2.94	8.84	3.10	1.33
40	0.30	0.88	2.94	8.84	2.65	1.77
	0.40	1.18	2.94	8.84	2.65	1.77
50	0.30	0.88	2.94	8.84	2.21	2.21
	0.40	1.18	2.94	8.84	2.21	2.21
60	0.30	0.88	2.94	8.84	1.77	2.65
	0.40	1.18	2.94	8.84	1.77	2.65

2.2.2 Preparation and Curing of PCPB

Mixing of concrete and compaction of the blocks was done mechanically. The prepared PCPB were packed on boards for 24 hours before curing started. They were cured under a shed. Water was poured on them twice in every day. This was done in order to prevent excessive evaporation of water from the PCPB.

2.2.3 Testing of Specimens

The density of the PCPB was determined in accordance with BS 1881 – Part 114 (1983). The water absorption was tested in conformity with ASTM C 642 (2006). The compressive strength test was performed in accordance with BS 6717 – Part 1 (1986).

To test the flexural strength, a centre line was marked at the top of the specimen, using a red marker perpendicular to its length. The PCPBs were tested under the centre line load while simply supported over supporting span of 150 mm (BSI, 2001). The flexural strength was then calculated from the formula;
$\sigma = 3/2\ (LF / BD^2)$,
Where;
σ is the flexural strength (N/mm^2),
L is the span length (mm),
F is the maximum applied load (N),
B is the average width of the specimen (mm), and
D is the average thickness (mm).

For the splitting tensile test, line loads were applied to the top and bottom of the PCPB using two steel bars. Plywood strips were inserted between the bars and the blocks to ensure even load distribution. Upon failure, the maximum applied load was recorded and the splitting tensile strength was calculated from the formula;
$T = (0.868 \times K \times F) / (L \times D)$.
Where,
T is the splitting tensile strength (N/mm2),
F is the load at failure (N),
L is the length of the failure plane (mm),
D is the thickness of the specimen at the failure plane (mm), and
K is the correction factor for the thickness, calculated from the equation, K = 1.3 – 30 (0.18 – t/1000)2,
t is the thickness of specimen.

4.0. Results and Discussion

4.1 Effect of W/C Ratio and Plastic Content on Strengths of PCPBs

Table 3 displays the results of the strengths of the PCPB for various W/C ratios and plastic contents. It can be noticed that the compressive strength, splitting tensile strength, and flexural strength increase as the W/C ratio increases. These indicate that the compressive strength, the splitting tensile strength, and the flexural strength were raised by about 21.3%, 18.5%, and 15.2%, respectively when the W/C ratio moved from 0.30 to 0.40 regardless of the plastic content used. A possible reason for the increase in strength may be due to the different quantities of water used for the preparation of the PCPBs. Concrete required certain amount of water for it to achieve its maximum strength during the hydration reaction of the cement paste. W/C ratio of 0.30 may be insufficient for the hydration reaction process. However, when the W/C ratio moved from 0.30 to 0.40, it presuppose that the cement was getting adequate amount of water needed for the hydration process and consequently it had a positive effect on the various strengths.

Table 3: 28-day Strengths Tests Results

Water cement Ratio	Plastic Content (%)	Compressive Strength (N/mm^2)	Splitting Tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)
0.3	0	33.62	3.36	4.64
	10	29.51	3.11	4.42
	20	26.68	2.95	4.16
	30	24.26	2.71	3.74
	40	20.17	2.33	3.22
	50	16.07	2.09	2.96
	60	13.77	1.72	2.51
0.4	0	37.83	3.77	5.15
	10	32.56	3.45	4.52
	20	27.72	3.08	4.11
	30	24.58	2.61	3.76
	40	22.09	2.39	3.58
	50	18.63	2.16	3.31
	60	15.67	1.91	3.27

It can also be observed that the strengths of the PCPBs decreased as the plastic content increased (Table 4). The decrease pattern of the strengths is similar for different W/C ratios. These suggest that the compressive strength, the splitting tensile strength, and the flexural strength were reduced by about 42%, 31.5%, and 26.2%

respectively when 60% of the total sand was substituted with plastic irrespective of the W/C ratio used. The reason for the reduction in strengths could be attributed to the smooth surface of the plastic particles which might have reduced the adhesion between the boundaries of the plastic particles and the cement paste. The findings are supported by Batayneh et al. (2007). who experienced a reduction in compressive strength, flexural strength, and splitting tensile strength of plastic concrete as the plastic content increased.

3.2 Impact of Curing Age on Strengths of PCPBs

The impact of curing age on the strengths of PCPBs is exhibited in Figures 4, 5, and 6. It is obvious that the compressive strength, the splitting tensile strength, and the flexural strength increase as the curing age increases regardless of the plastic content used. Critical examination of the figures shows that the compressive strength, the splitting tensile strength, and the flexural strength were increased by about 33%, 34%, and 32% respectively when the curing age moved from 7 days to 28 days irrespective of the plastic content used. The increase in strengths may be attributed to the hydration reaction of the cement paste which increases the strengths of concrete as curing age increases.

3.3 Influence of Plastic Content on Density and Water Absorption

3.3 Influence of Plastic Content on Density and Water Absorption

The influence of plastic content on density and water absorption is demonstrated in Table 4. It is observable that the density decreases as the plastic content increases. The density was lowered by about 10% when 60% of the total fine aggregate was replaced by plastic. The slump in density may be due to the low specific gravity of plastic (1.1) as compared to that of sand (2.6). The difference in the specific gravity exhibits that sand is heavier than plastic. Partially replacing volume of the sand by plastic would certainly reduce the masses of the PCPBs. Similarly, Al-Manaseer and Dalal (1997), Choi et al. (2005), Marzouk et al. (2007), and Suganthy et al. (2013) reported that density of plastic concrete decreased as the plastic content increased. It can also be realized that there was a linear correlation between plastic content and reduction in density (Figure 1). The coefficient of determination (R^2) = 0.991 means that 99.1% of the variation in reduction in density of PCPBs can be explained by the plastic content.

It is also noticeable that the water absorption increases as the plastic content increases (Table 4). The water absorption moved from 1.62% to 2.08%, indicating a rise of about 28.4% when 60% of the sand was substituted with plastic. This upsurge may be influenced by the increase of voids in PCPBs as a result of the poor bond between the plastic particles and the cement paste in the mix. The relationship between plastic content and % increase in water absorption was found to be linear (Figure 2). The R^2 = 0.936 indicates that 93.6% of the variation in water absorption can be explained by plastic content.

Table 4: Effect of plastic content on density and water absorption for 0.4 Water/Cement ratio

Water cement Ratio	Plastic Content (%)	Density (Kg/m^3)	% Reduction in Density	Water Absorption (%)	% Increase in water absorption
0.4	0	2328.31	0.00	1.62	0.00
	10	2289.04	1.69	1.69	4.32
	20	2242.96	3.67	1.73	6.79
	30	2218.63	4.71	1.77	9.26
	40	2178.79	6.42	1.82	12.35
	50	2137.96	8.18	1.98	22.22
	60	2078.21	10.74	2.08	28.40

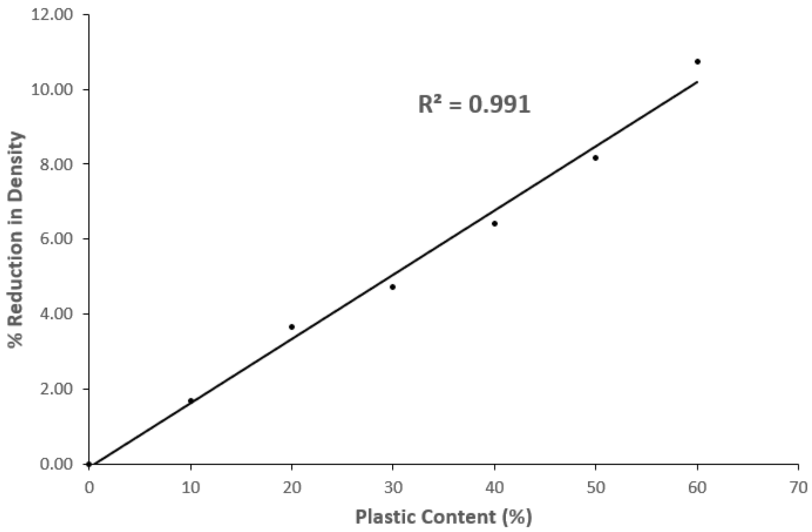

Figure 1: Relationship between plastic content and reduction in density (%)

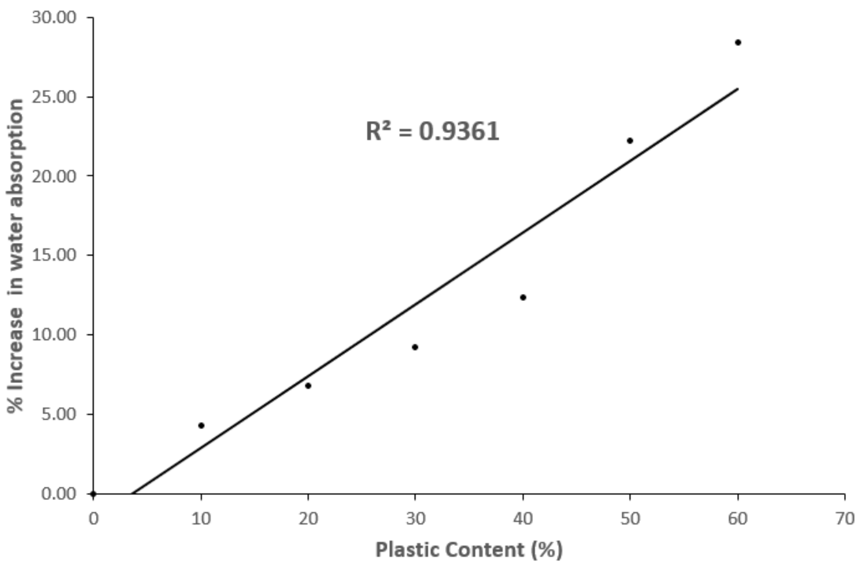

Figure 2: Relationship between plastic content and % increase in water absorption

3.4 Relationship between Density and Compressive Strength

Figure 3 displays the relationship between density and compressive strength of the PCPBs for water cement ratio of 0.40. It is apparent that there is linear correlation between the density and the compressive strength. The R^2 was found to be 0.9703. This suggests that 97.03% of the variation in compressive strength can be explained by the density of the PCPBs. It is also noticeable that compressive strength (Cs) = 0.089d – 170.14. The –170.14 is the constant value for determining the compressive strength. The 0.089 means if density (d) is increased by one-unit compressive strength will on average increase by 0.089.

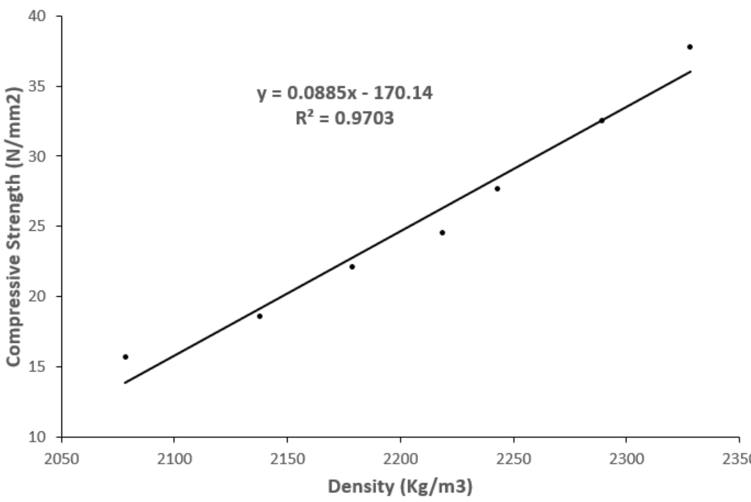

Figure 3: Relationship between density and compressive strength for W/C Ratio of 0.40

5. Conclusions

The tests result of this study demonstrate that there is great potential for the utilization of waste low density polyethylene in concrete pavement block mixes, including 10%, 20%, 30%, 40%, and 50%. Based on these results, the following can be concluded:

Both physical and mechanical properties of plastic concrete pavement blocks were affected when plastic was used as a replacement for sand. Decrease in density, compressive strength, flexural strength, and splitting tensile strength was observed when part of the sand was substituted with plastic. The rate of reduction in density and strengths increased as the percentage of plastic increased. However, the water absorption of PCPBs increased as the plastic content increased.

Although, the strengths of PCPBs decreased as the plastic content increased, compressive strengths of 20N/mm2, 30N/mm2, and 40N/mm2 which are satisfactory for pedestrians walk ways, light traffic and heavy traffic situations respectively could be achieved if 10% - 50% plastic contents are used. The amount of waste plastic being accumulated in the world has created a big challenge for their disposal. Utilizing them in concrete pavement blocks will help to mitigate their effects.

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