



Comparative Study on the Strength Properties of Paving Blocks Produced from Municipal Plastic Waste

C.T.G Awodiji^{1,*}, S. Sule², C.V Oguguo³

^{1,2} Department of Civil and Environmental Engineering University of Port-Harcourt, Rivers State, NIGERIA

³ Department of Civil Engineering, Federal University of Technology, Owerri, Imo State, NIGERIA

Abstract

In this study, municipal plastic waste is used in producing paving blocks. Binders in the form of melted waste plastic bottles (Polyethelene Terephthalate (PET)) and water sachets (High Density Polyethylene (HDPE) with river sand, were used in making the blocks. Mix ratios; 1:1, 1:1.5 and 1:2 of sand-plastic waste were considered. Sand-cement mixes were adopted as the controls. 230mm x 140mm x 55mm blocks were cast, cured in water at ambient temperature and tested for 72-hours for water absorption and 21 days compressive strength. 3 specimen were prepared for each mixture. Sand-HDPE mix produced stronger blocks than sand-PET and sand-cement mixes. Topmost compressive strength of 17N/mm² was generated from sand-HDPE mix of 1:2. Sand-PET blocks should be avoided since they generate very low strengths. Sand-plastic waste blocks melt faster at higher temperatures. Therefore, plastic paving blocks can only be used for light load pavements not subjected to high temperature.

Keywords: Municipal plastic waste, Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), compressive strength and paving block

1.0 INTRODUCTION

Block paving identified as brick paving is a frequently used ornamental means of producing a walkway. Paving blocks are building materials that can be used in erecting sidewalks, driveways, garage floors, and frequently used in surfacing roads [1]. They are made as tiles, bricks and paving stone which are usually used for external flooring. The foremost advantage of the blocks is that each one of them can be raised and replaced. This allows for easy and neat maintenance. Paving blocks are ordinarily made of concrete or clay. Sometimes, other substances are used with their unique construction methods (e.g. crushed rubbles and glass). The major contrast is in the manner of setting. Clay blocks are baked prior to their hardening. Concrete blocks stiffen by setting. Some form of coloring may be applied.

Plastics are man-made product of chemistry. They are made of units of reoccurring carbon atoms forming long chains of molecules [2]. The carbon atoms usually have sulfur, nitrogen, oxygen and hydrogen fillings. Plastics do not easily disintegrate due to their in-built

molecular stability. They are durable because of the chemical bonds holding the molecules together. When soft, they take the shape of the mold and later set into moderately elastic or rigid form. Some materials made of plastic includes freezer bags; dispensing containers; water bottles; plates, cups and spoons; trays, soft drinks and juice containers.

About 99% of plastics are processed from chemicals gotten from coal, natural gas and oil [3]. They are unrestorable and dirty resources. According to Alabi *et al.* [4], the different types of plastics are; Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), Di (2-ethylhexyl) phthalate (DEHP), Low Density Polyethylene (LDPE), Polypropylene (PP), Polystyrene (PS) and expanded polystyrene. Regularly, antioxidants are added to Polyethylene and Polypropylene to fortify them against breaking down.

Although plastic is valuable, its one time use and disposal is creating a great menace to the environment. It is estimated that for every one minute, one million plastic drinking bottles are purchased. While, about 5 trillion one-time-use plastic bags are used globally [5]. Half of the total plastic produced in a year is made to be disposed after single use. Geyer *et al.* [6] estimates that since the 1950's, above 8.3 billion tons of plastics have been manufactured. Approximately 60% of these amounts are littered in the

*Corresponding author (Tel: +234 (0) 7034300219)

Email addresses: chimbaegbu@yahoo.com (C.T.G Awodiji), cjblackdemakeitdonetend@gmail.com (C.V Oguguo), and samvictoryahead@yahoo.com (S. Sule)

environment and landfills. They further stated that barely 9% of these waste plastics are recycled and 12% burnt. 79% are gathered in dumps, natural environment and landfills. This collection is known as plastic pollution.

Plastic pollution is the gathering of plastic at a location, such that it starts to adversely affect the surroundings and cause challenges for mankind, animals and plants [7]. It is the collection of plastic particles and objects on the globe's environment that unduly affect humans, wild life habitat and wild life [8]. Asian and African countries are most affected due to poor solid waste management systems [9].

According to Ganguly and Choudhary [10] plastic waste generates a lot of problems in today's world. Toxic chemicals move from the waste into the ground via seepage. This pollutes ground water. Through storm-water runoff, they flow into rivers, seas and oceans or are dumped directly in these places from where they get into the food chain. When these polluted foods are eaten, diethylexyl phthalate, lead, mercury and cadmium are released into the body resulting to cancerous diseases. Through eating and entanglement, plastic kills water animals. They obstruct drain pipes leading to flooding. They assist in raising the prevalence of malaria by providing comfortable breeding sites for mosquitoes.

In order to reduce the effects of these problems on the earth, improved plastic waste management procedures must be developed and commercialized. Plastic waste must be prevented from entering water bodies and should be reused and/or recycled. This study seeks to help in managing these issues by the means of recycling. Investigation on the use of municipal plastic wastes, in the form of melted PET (plastic bottles) and melted HDPE (water sachets) for the production of paving blocks is carried out. The research is tailored at determining the compressive strengths and water absorption of paving blocks when melted municipal plastic wastes are used as binders and full replacement for Portland cement. The use of more and more plastics in concrete and mortar production for construction purposes will contribute in reducing the problem associated with the management of plastic waste. The information obtained from this work will further provide literature on this field of study. Finally, this work will enable the United Nations achieve its 12th (recycle paper, plastics, glass and aluminum) and 14th (avoid plastic to keep the oceans safe and clean) Sustainable Development Goals.

2.0 LITERATURE REVIEW

Researches in the use of plastic waste in concrete technology have continued to gain more and more interest over the years. Karthikeyan, *et al.* [11] worked on the

utilization of waste plastics in concrete. They made concrete by substituting Portland cement with waste plastic at a water-cement ratio of 0.35. Their study shows that the strength of concrete decreased above 10% replacement when compared to the control. They obtained structural concrete after 14 and 28 days of curing at 10% inclusion of plastic waste. Jibrael and Peter [12] reported that waste plastic bags and bottles can be used for non-structural concrete. They also observed that the strength of concrete reduced with the rise of plastic waste. The consequence of the drop in strength was pronounced for the plastic bags when compared to the plastic bottles.

Sule, *et al.* [13] stated that compressive strength of concrete, slump and density dropped as the portion of fine aggregate was replaced with granular plastic. They recommended that the use of plastic waste in concrete production was not good at advancing the compressive strength. However, they can be used for making lightweight concrete. Adela, *et al.* [14] observed that the split tensile and compressive strength of concrete made using plastic bottles and bags accordingly, reduced when the ratio of the plastic aggregates increased. They reported that the use of plastic bag aggregates for concrete production should be in the range of 11% to 14% replacement with conventional coarse aggregate. While that of plastic bottles should be in the limits, 35% to 37.5%.

Agyeman, *et al.* [15] worked on the topic "Exploiting recycled plastic waste as an alternative binder for paving blocks production." They experimented on the compressive strength and water absorption properties of paving blocks produced using melted plastic waste as binder. Compressive strength of the blocks increased with cement replacement with the plastic waste. This was due to the rise in the adhesive strength between the surface of the waste plastic and the neighboring aggregates particles. A control mix of 1:1:2 (cement: quarry dust: sand) was applied for the study. Higher compressive strengths that are more than the control mix were recorded for the blended blocks having a smaller amount of plastic on a mix ratio of 1:1:2 and that with a higher amount of plastic on a mix ratio of 1:0.5:1 after curing for 21 days. They proposed that this paving block be used where there is no traffic e.g. walkways and foot paths. They also noticed that the more the plastic in the mix, the lesser the water absorption property experienced. The concrete blocks were seen to take-in more water than the plastic blocks because the plastic waste blocks were hydrophobic in nature [15]. So, plastic blocks can be used in waterlogged areas.

Ojuri and Agbolade [16] in their study, improved the engineering properties of Igbo-koda sand with the use of shredded polyethylene waste. They modified the sand

with strips of high density polyethylene (HDPE) waste of sizes 15 x 20mm, 20 x 25mm and 25 x 30mm consecutively and reported that when the amount of the shredded polyethylene in the concrete mix was raised, the permeability of the concrete dropped. In addition, a rise in cohesion and angle of friction was observed. Angle of friction increased from 18° to 28° . Murana, *et al.* [17] used waste polyethylene pure water sachets to influence the properties of hot mix asphalt. Overall, they noticed that including the plastic waste in the making of bitumen improved its engineering properties. As the amount of the plastic waste increased, the % air void in the bitumen dropped. Besides, stability and bulk density of the bitumen improved. However, air void reduced. Stability of bitumen increased from 4.64kN to 8.84kN while bulk density increased from 2.21g/cm^3 to 2.34g/cm^3 . A drop from 3.6mm to 2.98mm was seen for the air void.

A review of literature on studies on the use of plastic waste in concrete manufacture carried out by [18] revealed that most of the researchers worked on the strength properties of concrete. They mainly considered compressive, flexural and tensile strengths. Some also investigated on the modulus of elasticity. Some other took a step further to examine the durability properties such as water absorption, abrasion resistance, sorptivity, permeability, UPV, sulphate attack and porosity of the concrete. They all used plastic as either a full or partial replacement for aggregates (fine). Only Karthikeyan *et al.* [11] used plastic waste as a cement replacement.

This research seeks to take a step further into the investigation of the use of plastic waste in the production of paving blocks. The components for the production of the paving blocks include, the plastic wastes and river sand. PET and HDPE were used as full replacement for portland cement accordingly. The compressive strength, water absorption and resistance to fire were investigated.

3.0 Materials and Methods

3.1 Materials

For this investigation, the following materials were used: polyethylene terephthalate (PET), high density polyethylene (HDPE), Portland cement, river sand and water.

3.1.1 Polyethylene terephthalate (PET)

Polyethylene terephthalate (PET) in the form of waste plastic water bottles were collected from the surrounding waste disposal points at the Federal University of Technology, Owerri and Umuchima village all in Owerri West Local Government Area of Nigeria. Fig 1a shows some samples of the waste plastic bottles used

for the study. Typical chemical composition of the PET plastic waste is as shown in Table 1.

3.1.2 High density polyethylene (HDPE)

This type of plastic, in the form of waste plastic water sachets, was also obtained from the waste disposal locations at the Federal University of Technology, Owerri and Umuchima village. Fig 1b presents samples of the material.

3.1.3 Portland cement

The 42.5R brand of the Dangote Portland cement (PC) was used. It was purchased from the surrounding local market at Umuchima Village.

3.1.4 River sand

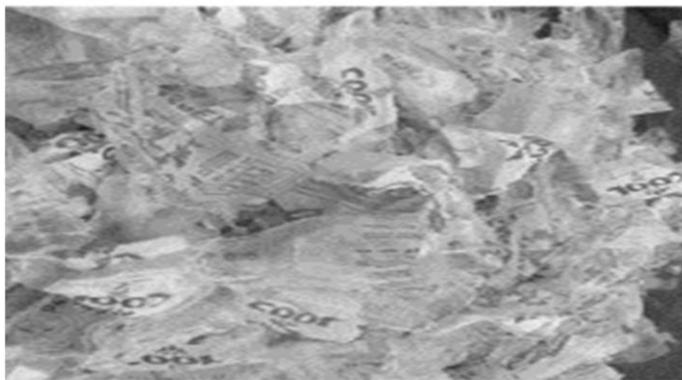
Sand was obtained from Otamiri River also located in Owerri West Local government area of Imo State. It consists of natural sand from the river bed, with most of its particles smaller than 5mm.

3.1.5 Water

Water was gotten from the Federal University of Technology, Owerri. It was potable in nature.



a. Plastic bottles (PET)



b. Plastic water sachet (HDPE)

Figure 1(a and b): Samples of plastic waste used for the study

3.2 Methods

The following procedures were conducted.



Figure 2: Samples of paving blocks produced

3.2.1 Sieve analysis of river sand

Sieve analysis to determine the grain size distribution of the river sand was carried out with respect to BS 812 [20]. It is the operation of dividing a sample of aggregate into various fractions each consisting of particles of the same size. Coefficient of curvature (C_c) and uniformity (C_u) were determined using Eqn. 1 and Eqn. 2. The knowledge of the grading of aggregate helps a mix designer prescribe a concrete that could be compacted to a maximum density with a reasonable amount of work, and for a given water-cement ratio. The grading of aggregate also affects the workability of a concrete mix.

$$\text{Coefficient of uniformity } (C_u) = \frac{D_{60}}{D_{10}} \quad (1)$$

$$\text{Coefficient of Curvature } (C_c) = \frac{(D_{60})^2}{(D_{10}) \times (D_{30})} \quad (2)$$

where, D_{10} , D_{30} , D_{60} are the effective particle sizes with 10%, 30% and 60% of the sample by weight being finer accordingly.

3.2.2 Bulk density of river sand

The bulk density of the surface dried river sand was obtained according to ASTM C29 /C29M [21]. Eqn. 3 was used to determine its value.

$$\text{Bulk density of sand } (\rho) = \frac{M_2 - M_1}{V} \quad (3)$$

Where; M_1 is the mass of empty density container, M_2 is the mass of density of container + dry soil (g), M_3 is the mass of dry soil ($M_2 - M_1$) (g) and V is the volume of density container (cm^3).

3.2.3 Sample preparation.

a. Sand-PET

The used plastics were cut open, washed to remove any impurities and dried in the open air until absolutely no moisture was present on them. They were shredded into flakes and sent to the laboratory for experimentation. Sand-PET mix ratios considered were 1:1, 1:1.5 and 1:2. Six paving blocks were produced for each of them.

Calculated amount of PET flakes were placed into a pot on a gas burner and heated to a melting point temperature of about 260°C . Next, determined amount of river sand was gradually added into the melted plastic flakes and the mix was thoroughly stirred to ensure homogeneity. Finally, the pot was taken down and the hot mix was discharged into lubricated molds of $230\text{mm} \times 140\text{mm} \times 55\text{mm}$ and left to set for about 24 hours before demolding.

Three samples for each mix (used for compression test) were placed in water tanks at atmospheric temperature to cure for 21 days, while the other three samples (for each mix) were oven dried until there was no more change in weight. The dried samples were placed in water for 72hours before subjecting them to water absorption test.

b. Sand-HDPE

Similarly, the used waste plastic water sachets were washed, dried in the open air and shredded into flakes. Sand-HDPE proportions of 1:1, 1:1.5 and 1:2 was also investigated. The procedure for preparing this sample is same as in the sand-PET mix, only that the melting point of the flaked HDPE was 110°C .

c. Sand-cement

The sand-cement paving blocks of mix 1:1, 1:1.5 and 1:2 at a constant water-cement ratio of 0.4, were used as control. For each of the samples, required weight of sand was measured out and placed on an impervious layer before adding the pre-determined quantity of Portland cement. The components were properly mixed using a shovel. Water was added and mixing continued until a homogenous state was achieved. The mortar produced was placed into molds of size $230\text{mm} \times 140\text{mm} \times 55\text{mm}$ and allowed to set for about 24hours. Six blocks were prepared for each mix proportion. The samples were then demolded and placed in water tanks to cure for 21 days and 72hours as described in the sand-PET sample production. The mix proportions used for producing the blocks are shown in Table 2.

Table 1: Chemical composition of waste polyethylene terephthalate.

Components	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	Na ₂ O	MgO	K ₂ O	P ₂ O ₅	TiO ₂	SO ₃	MnO	Loss on ignition	
Value % wt.		10.32	4.49	3.13	16.0	0.67	1.32	0.3	0.69	0.07	0.27	0.11	61.2

Source: Jablonska, et al., [19]

Table 2: Summary of all mix proportions for one mold of paving block.

Sand-cement mix									
1.1			1.1.5			1.2			
Mix No.	Sand (kg)	Cement (kg)	Mix No.	Sand (kg)	Cement (kg)	Mix No.	Sand (kg)	Cement (kg)	
1C1	2.1	2.1	2C1	1.7	2.6	3C1	1.5	3	
1C2	2.1	2.1	2C2	1.7	2.6	3C2	1.5	3	
1C3	2.1	2.1	2C3	1.7	2.6	3C3	1.5	3	
Sand-PET mix									
1.1			1.1.5			1.2			
Mix No.	Sand (kg)	PET (kg)	Mix No.	Sand (kg)	PET (kg)	Mix No.	Sand (kg)	PET (kg)	
1P1	1.32	1.32	2P1	1	1.5	3P1	0.8	1.6	
1P2	1.32	1.32	2P2	1	1.5	3P2	0.8	1.6	
1P3	1.32	1.32	2P3	1	1.5	3P3	0.8	1.6	
Sand-HDPE mix									
1.1			1.1.5			1.2			
Mix No.	Sand (kg)	PET (kg)	Mix No.	Sand (kg)	PET (kg)	Mix No.	Sand (kg)	PET (kg)	
1H1	1	1	2H1	0.73	1.1	3H1	0.6	1.2	
1H2	1	1	2H2	0.73	1.1	3H2	0.6	1.2	
1H3	1	1	2H3	0.73	1.1	3H3	0.6	1.2	

3.2.4 Water absorption test on the blocks

The water absorption of the various blocks was estimated after immersing specimens in water for 72 hours using the Eqn. 4;

$$\% \text{ water absorption} = \frac{w_2 - w_1}{w_1} \times 100 \quad (4)$$

Where, w_2 is the final wet weight of the block and w_1 is the dry weight of the block.

3.2.5 Compressive strength test

The compressive strength test was conducted on the 230mm x 140mm x 55mm paver blocks using the universal testing machine according to BS 1881-116 [22] to determine their failure loads after curing for 21 days. Eqn. 5 was used to determine the compressive strengths of the blocks.

$$F_{cu} = \frac{Q}{A} \quad (5)$$

Where F_{cu} is the compressive strength of concrete in N/mm², Q is the crushing load in Newtons (N) and A is the cross-sectional area of the specimen in mm².

3.2.6 Fire resistance test.

The resistance of the specimen to higher temperature was investigated and the following improvised method was carried out during the test;

A tripod stand was set up in order to provide a platform to place the specimen on fire. Charcoal was lighted up at the base of the tripod stand and allowed to heat for about a temperature between 110°C to 140°C. A stop watch was used to determine the time when the plastic paver blocks started to melt. This was recorded as the time of failure. Paver block produced from cement and sand was considered failed when visible cracks occurred after delivering three blows from masonry hammer.

4.0 Results and Discussions

4.1 Characterization of the river sand

Fig 3 shows the grain size distribution of the river sand. Coefficient of uniformity (C_u) and coefficient of curvature (C_c) were obtained as 3.24 and 1 respectively. Since $C_u < 6$ and $C_c = 1$, then the sand is poorly graded [23].

The bulk density of the river sand was 1.55g/cm^3 . This means that the sand has normal weight [24].

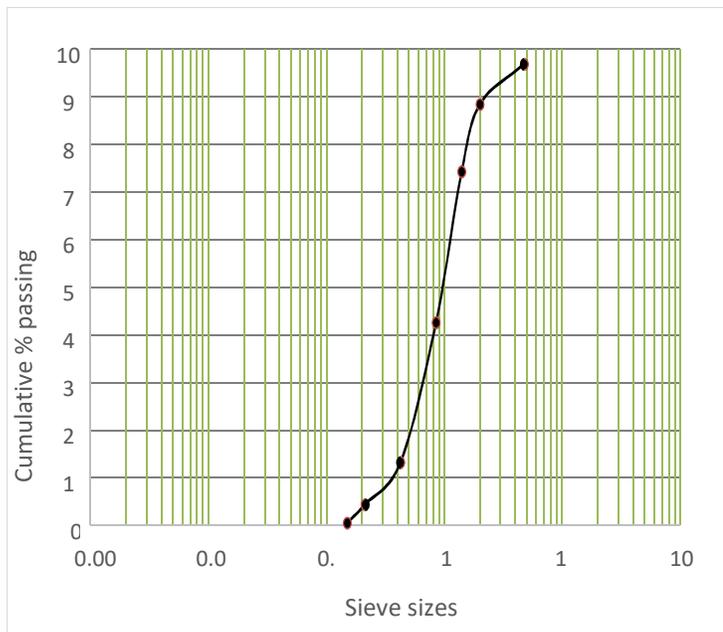


Figure 3: Grain size distribution of river sand

4.2 Water absorption test

Results of the water absorption test on the various mix ratios for the paving blocks are illustrated in Figure 4. Overall, the sand-HDPE paving blocks, experienced the least water absorption after 72 hours of immersion in water at ambient temperature. The 1:1 (sand-HDPE) mix had a water absorption of 4.87%. While, that of 1:1.5 and 1:2 did not absorb water at all. This implies that the more the quantity of HDPE in the mix, the lower the water absorption.

For the sand-PET mix, a water absorption of 7.35% was recorded for mix 1:1. At the same time, the mix 1:1.5 and 1:2 had 3.06% and 0% water absorption one after the other. These results also show that increasing the amount of PET causes a drop in the water absorption property of the paving blocks. However, using HDPE gave a better water absorption property than the use of PET in making the paving blocks. Considering the blocks produced using Portland cement as binder, it was observed that all three mix ratios sustained some level of water absorption. Topmost value of 4.04% was reported for mix

1:1 (sand-cement) and 2.9% was obtained for mix 1:1.5 and 1:2 respectively. These values depict that the use of plastic waste materials as binders in the manufacture of paving blocks, produce blocks with better water absorption properties than the use of portland cement. But, it should be noted that the sand-PET mix of 1:1 gave a water absorption value that is greater than 6%, which is the maximum allowable value according to IS 15658 [25]. So, its use should be avoided for durability purpose.

4.3 Density and Compressive strength

The results of the 21 days compressive strength test conducted on the paving blocks against the densities of the blocks are presented in Fig 5 to Fig 7. From the figures, it was observed that the bulk densities of the paving blocks produced from the sand-PET mix were higher than those from the sand-HDPE mix.

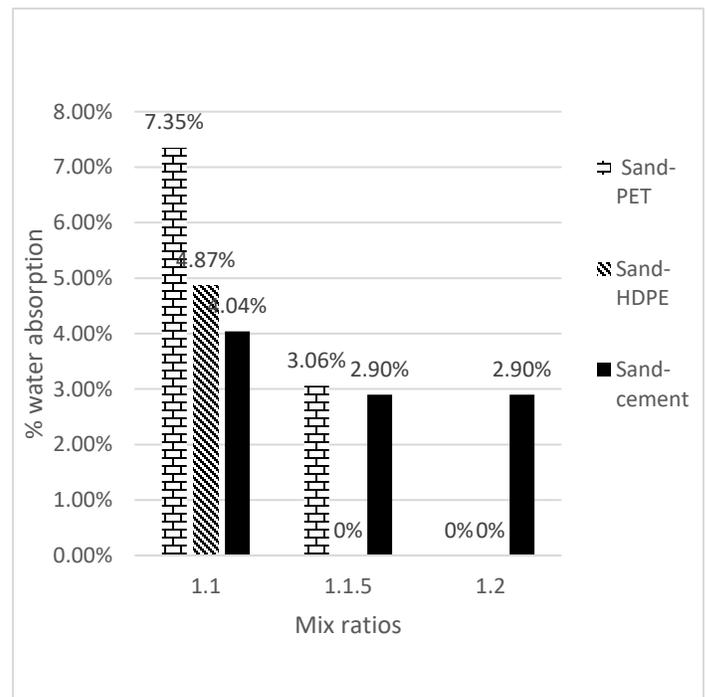


Figure 4: Relationship between % water absorption and mix ratios

However, they were less than those manufactured from the sand-cement mix. The sand-HDPE paving blocks were light weight in nature having density values that are less than 1000kg/m^3 and greater than 890kg/m^3 for the three mix proportions considered. But, they gave higher strength values when compared to the other mixes. For the sand-PET mix, density and compressive strengths of the blocks reduced as the amount of PET increased. But for the sand-HDPE mix, density reduced and strength increased when the HDPE content was raised.

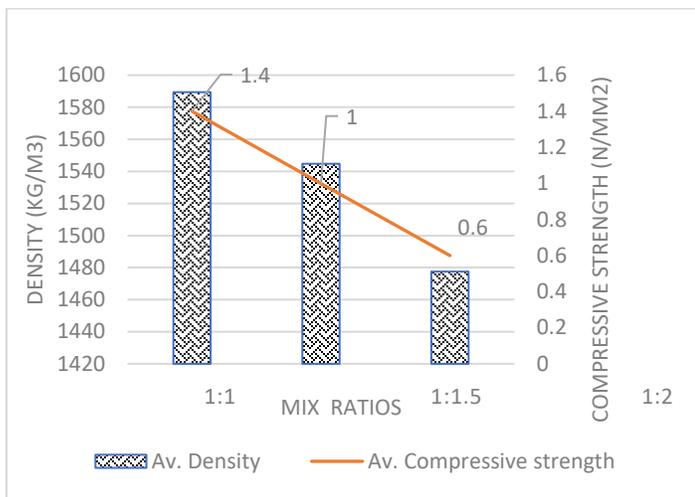


Figure 5: Relationship between density (kg/m^3) against 21 days compressive strength (N/mm^2) for sand-PET mix

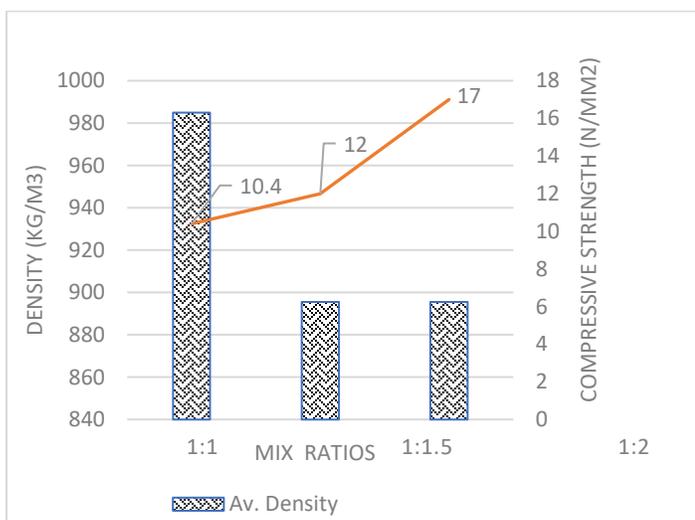


Figure 6: Relationship between density (kg/m^3) against 21 days compressive strength (N/mm^2) for sand-HDPE mix.

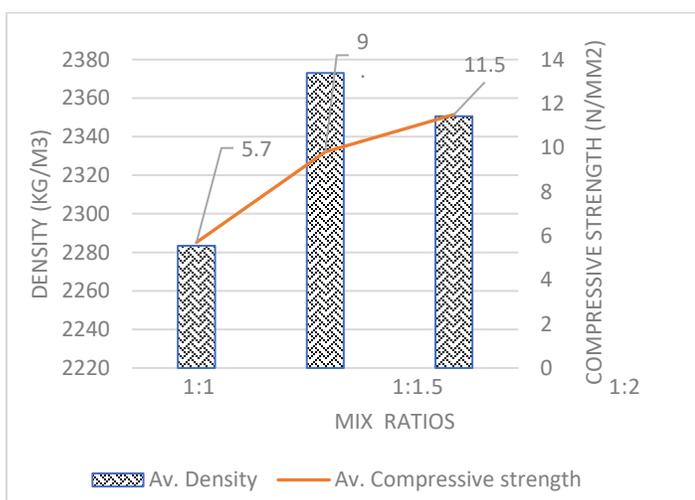


Figure 7: Relationship between density (kg/m^3) against 21 days compressive strength (N/mm^2) for sand-cement mix.

From Figure 8, the compressive strengths generated from all the mix proportions of the sand-HDPE paving blocks, were much higher than those obtained from the control mix (sand-cement) and the sand-PET mix. At mix ratio 1:1, compressive strengths of sand-HDPE paving blocks were greater than those of sand-PET and sand-cement by 86.54% and 45% respectively. For mix 1:1.5, sand-HDPE blocks had better compressive strength values than the sand-PET and sand-cement blocks by 91.67% and 18.33% in succession. Lastly, a difference of 96.47% for the compressive strength of sand-PET paving blocks and 32.35% for sand-cement paving blocks were observed when compared to the sand-HDPE blocks at mix 1:2.

These results prove that using the sand-HDPE mix, gives better compressive strength values than sand-PET mix or sand-cement mix. The lower strength of sand-PET blocks could be as a result of its low-density nature [26]. On the contrary, HDPE is lightweight, but it is strong, flexible and have good impact resistance than PET [26]. This led to the generation of higher values of compressive strength results when compared to the sand-PET and sand-cement mixes. The use of the sand-PET mix when PET acts as the only binding material should be avoided since it generates very low compressive strength values. Utmost compressive strength result obtained from this study is 17N/mm^3 at a mix ratio of 1:2 (sand:HDPE).

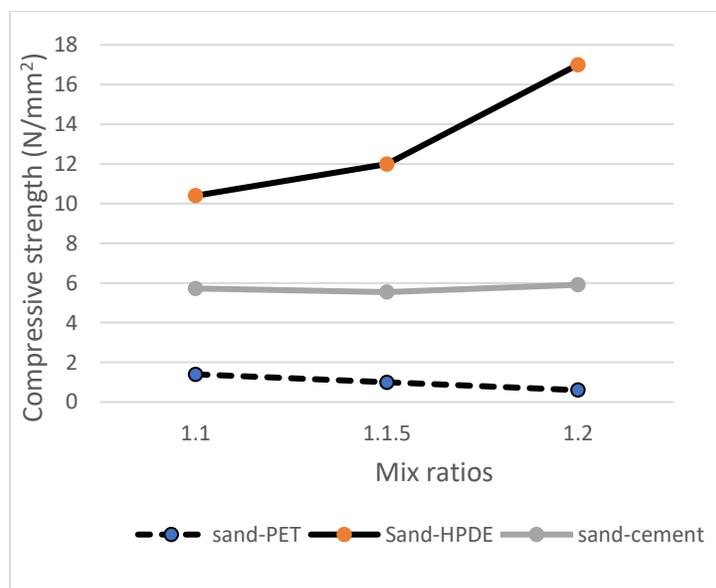


Figure 8: Relationship between compressive strengths and the mix ratios.

Figure 9 illustrate the relationship between the % water absorption and compressive strengths of the paving blocks. For the sand-PET blocks, it is seen from the trend line that as the quantity of PET in the mixture increased,

the %WA property as well as the compressive strength of the block reduced.

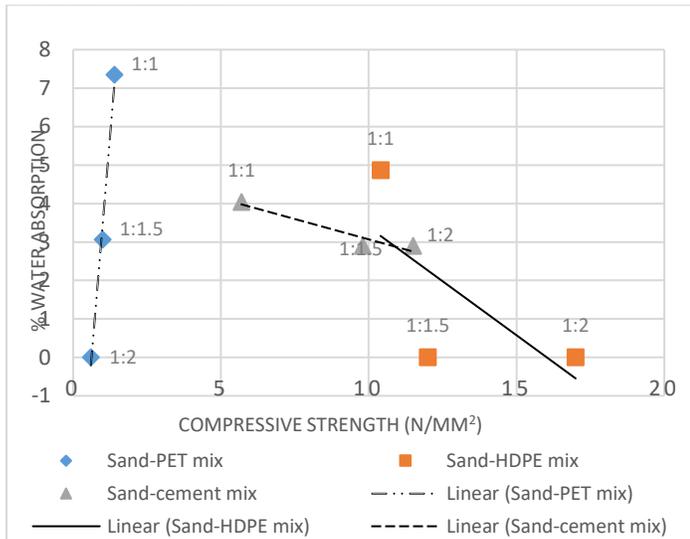


Figure 9: Relationship between % water absorption and compressive strengths for the various mix combination and proportions

On the contrary, for the sand-HDPE and sand-cement mixtures, increase in the content of HDPE and cement dropped the %water absorption ability but increased the compressive strengths of the blocks accordingly. However, highest strength obtained was not up to 20N/mm² which is the ACI 318 [27] recommended strength for structural concrete. The improvement in the water absorption property of the sand-waste plastic paving blocks can be attributed to the hydrophobic nature of the plastic [15]. In addition, the bond between the sand and melted plastic helped in reducing air voids in the aggregate, thereby leading to decreased permeability of the mixture [16]. Therefore, the paving blocks can be used in areas where the load to be applied on the pavement is mild e.g. walk ways. The sand-HDPE can also find application in water logged areas due to its low water absorption characteristics.

4.4 Fire resistance

The result of the fire resistance test shows that the sand-cement mix can resist higher temperatures more than the sand-PET and Sand-HDPE paving blocks. For temperature in the range of 110°C to 140°C, the sand-cement paving blocks can stay up to 30 minutes before it starts to fail. While the sand-HDPE blocks will begin to melt at about 5 minutes from the time the heating starts. Sand-PET blocks showed sign of melting after 6 minutes of heating. This result implies that the sand-plastic paving blocks must not be used in areas where the environmental

temperature is quite high. Its use is very suitable in temperate environment. See Table 3.

Table 3: Average failure time of blocks after being subjected to temperature between 110°C to 140°C

Mix	Time of heating before failure occurred
Sand-PET	6 mins
Sand-HDPE	5 mins
Sand-cement	30 mins

5.0 CONCLUSIONS

In this research, waste plastic in the form of plastic bottles (PET) and water sachets (HDPE) were successfully used in making paving blocks. The sand-waste plastic paving blocks had better water absorption properties than sand-cement blocks. This quality makes the sand-plastic paving blocks suitable for use in damp areas.

Sand-HDPE mix gave better compressive strength values than sand-PET and sand-cement mixes. Topmost compressive strength values obtained were 17N/mm² for sand-HDPE mix of 1:2; 11.50N/mm² for sand-cement mix of 1:2 and 1.40N/mm² for 1:1 sand-PET mix. It was also observed that the improvement in the compressive strengths of sand-HDPE mix, did not depend on the densities of the paving blocks but on the quantity of HDPE in the mix. Therefore, sand-waste plastic paving blocks can be used for constructing light load bearing pavements. However, production and use of sand-PET paving blocks should be discouraged due to the very low compressive strengths it generates.

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