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COMPARATIVE STUDIES ON THE COMPRESSIVE STRENGTH OF PAVEMENT BLOCKS MADE FROM DIFFERENT GEOLOGICAL MATERIALS WITH PLASTIC WASTE ADDITIVES AND CEMENT PAVEMENTS FOR USE IN ROAD CONSTRUCTION

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ABSTRACT

Effective plastic waste management has been of immense concern to environmentalist especially due to its non-biodegradable nature. The research was therefore aimed at using waste plastic materials as binding groundmass in place of cement thereby reusing plastic waste for socio-economic benefit. This will proffer a good solution to the environmental menace posed by indiscriminate disposal of plastic waste and the ecological challenges posed by the ever-increasing use of plastics. Plastic wastes (LDPE type) and PETs were melted at temperatures between 180˚C-250˚C and mixed in different proportions with granite dust, sand and clay to produce sample paver blocks and cement paver blocks. Sample blocks' specimens were subjected to compressive, water absorption and oven tests. The sample blocks were also activated with H_2SO_4 acid of pH value 6 to simulate the ruggedness posed by acidic soil condition. Compressive tests were carried out on the paver blocks (activated with acid) at interval of 10 days up to 100 days respectively. Based on these tests, comparison was drawn on the effect of acidic condition on the compressive strength of plastic derived paver blocks against concrete paver blocks in terms of durability, sustainability and viability. Results showed higher strength and durability from the compressive test, low water absorption rate and high resistance to corrosion for plastic paver blocks over cement pavers in the order Plastic/Granite > Plastic/Sand > Plastic/Clay pavers. It could therefore be concluded, that plastic paver blocks are a better and sustainable alternative to cement blocks in the construction of more rigid roads.

Keywords: Plastic Paver Blocks, Plastic Waste, Cement Paver, Compressive Strength

INTRODUCTION

One of the most widely used material in recent times is plastic owing to its moisture resistance, being light in weight, inexpensiveness and flexibility. These qualities increase our propensity towards plastic and hence making its use very common (Huda and Anzar, 2016). The economic growth, geometric population growth and changing pattern of consumption are resulting in the rapid increase in the use of plastics in the world. The use of plastic materials has increased from 5 million tons in the 1950s to 100 million tons in the 2000s (Tuffour, 2016). Although, there is little research-based information on the amount of plastic waste generated in Nigeria, a report in the Business Day Newspaper of January 3, 2019 states that Lagos is estimated to generate about 14 to 15 thousand tons of waste daily. Of that, roughly 30 percent is recyclable, and 50 percent of this is plastic. In essence, about 2,250 tons of plastic waste is generated in Lagos on a daily basis (Folorunsho and Amadi, 2020).

The challenge of waste disposal has become one of the most serious environmental problems facing many cities in Nigeria. Landfills are becoming scarce and the cost of building landfill sites are increasing. These results in open dump site burning (thereby causing great environmental pollution), blockage of drainages and waterways among other environmental challenges (Amadi *et al.*, 2012). Plastic wastes pose a greater management challenge because of its non-biodegradability. They are corrosion resistant, have long life, maintenance free and light weighted. All these attributes that makes its waste management difficult could however be exploited to replace cement as the binding material for aggregates in the production of paver blocks (Folorunsho and Amadi, 2020). Recycling technology has been a solution of choice in the developed countries. Mahmud and Nurudeen (2022), used metakaolin as a partial replacement for cement in concrete production and revealed that the concrete displayed a sustainable good durability, compressive and tensile strengths at 20% replacement of cement. Expanded polystyrene (EPS) based waste, High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), Polyethylene Terephthalate (PET) waste bottles, polypropylene fibers and polyethylene bags have all been used in different forms by researchers in concrete (Kodua *et al.*, 2018).

The causes of road failure in Nigeria as identified by many researchers include poor construction materials, poor design and specification, road usage, use of non-professionals, poor drainage, geological and geotechnical factors (Aghamelu and Okogbue, 2011; Ofonime and Aniekan, 2005; Jegede, 2000; Adeyemi and Oyeyemi, 2000; Gidigasu, 1980). The nearness of the saturated zone to the land surface and the manner of fluctuation of this zone has direct effect on the geotechnical properties of the soil. These in turn influence the stability of engineering structures (houses, bridges, dams, roads, etc.) (Brattebo and Booth, 2003). Permeable interlocking concrete pavements are the best option for effective storm water management and surface/subsurface drainage interactions. Pore water under pressure beneath road pavements on marshy sites rises through capillary action to the surface above the groundwater level and can adversely affect road pavement structure if there is inadequate subsurface drainage facility (Scholz and Grabowiecki, 2007).

The area of study lies within Offa municipality, Offa local government area of Kwara State. The study area falls between latitudes 8°6'43"N and 8°8'10"N and longitudes 4°43'00"E and 4°44'00"E with elevations of between 400m to 440m above sea level. It occupies a landmass of about 15 sq Km. (Encyclopedia Britannica). All the geomaterials used for this study were taken from within the study area.

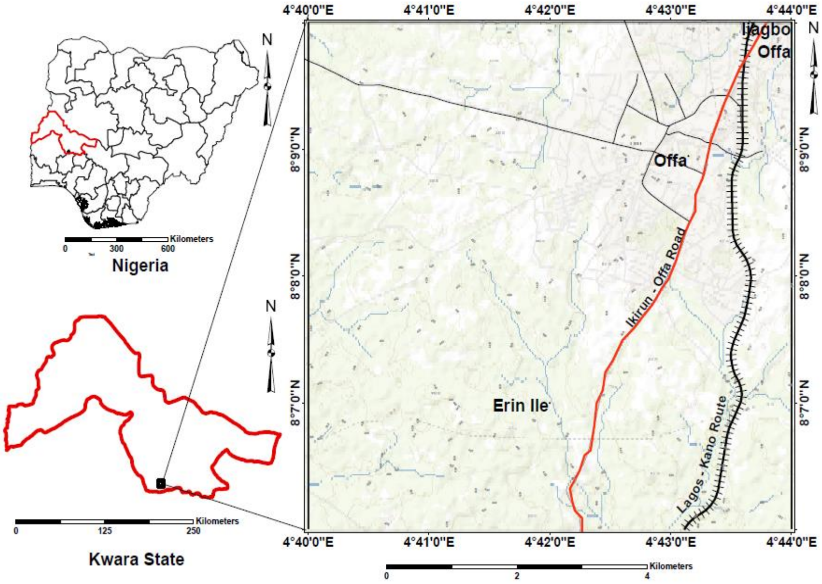

Figure 1: Location map of the study area: Offa Municipality in Kwara sate

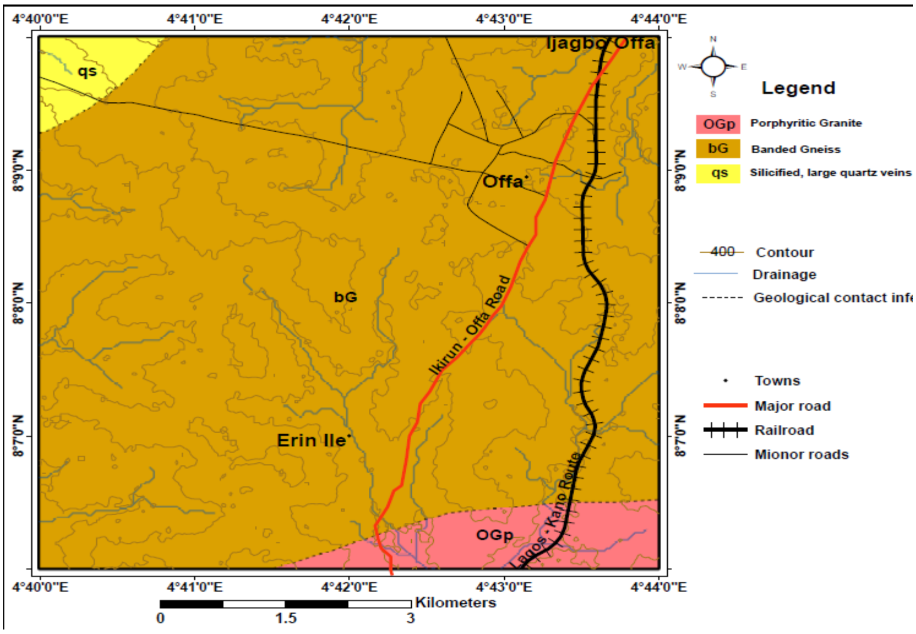

Figure 2: Geological map of the study area: Offa Municipality in Kwara state

Despite the great prospect the cement pavement blocks have, there are shortcomings that needed to be addressed especially disintegration caused by alternating wetting and drying, as well as weakening by corrosion. LDPE and PET plastic which are major components of Municipal Solid Waste (MSW) could thus be melted and mixed with aggregates to produce more durable, cost effective, corrosion resistant pavement blocks. Polymer modified pavement blocks in essence could be the perfect alternative to the less durable asphalt pavement as well as the cement derived pavement blocks (Folorunsho and Amadi, 2020). This work is aimed at using plastic waste as an alternative to cement as a binding material in the production of paver blocks to cater for the shortcomings of the cement paver blocks and also proffer solution to the environmental menace of plastic waste.

MATERIALS AND METHODS

Materials

The following underlisted materials and their specification were used for the research

i. *Clay*: Clay was collected from a hand dug well around Owode market in Offa and has a specific gravity of 2.7. The clay was sundried, pounded (to loosen the particles) to a fine powder.
ii. *Sand*: Natural river bed sand was collected and used. Clean sand was collected along Alagbaa River channel in Offa, Offa local Government, Kwara State. It has a specific gravity of 2.65 and fitness modulus 0.4.It was oven dried at the civil Engineering department of the Federal Polytechnic, Offa.
iii. *Cement***:** Ordinary Portland cement designated as CEM I in the present Nigeria Industrial Standard for cement NIS 444-1:2003 was obtained from the open market

(i.e. cement with 95% to 100% blinker and gypsum, and 0%-5% minor additional constituent)

iv. *Granite dust*: Granite dust was collected from local stone crushing unit from Offa, Kwara state. It was dry at the point of collection and was sieved by IS: 4.75mm sieve at the civil Engineering department, Federal Polytechnic, Offa. It has specific gravity of 2.57, fitness modulus of 2.41, density of 1.85gm/cc and void ratio of 0.42

v. *Plastic Materials*: The plastic materials (PET and LDPE) were sourced from restaurants, campuses and Owode market- all in Offa municipality. They were washed and then shredded into very small pieces by a grinder at a local plastic processing outlet

vi. Other tools and materials used were safety boots, nose marks, Hand gloves, Industrial gas as source of heat, 1 melting barrel, Hand trowel, A spade with a metal shaft for staring of hot mix, Mold (200mm x 100mm x 75mm), Used engine oil for lubrication, Metal table for Mold placement and a Pyrometer.

Methods

All the pavement block samples produced for this research work were molded from a metal Mold measuring 200mmx100mmx75mm. 80 Pavement block samples were produced for each of the different mix ratios. Clean shredded plastic waste materials were melted at a temperature of about 180-250˚C and mixed in different proportions by volume.

Mix Ratio

i. Cement and aggregates

-The materials (cement, sand and granite dust in the ratio 1:2:4 respectively) were mixed thoroughly with a shovel until a uniform mix was obtained.

-Water was added in a ratio not exceeding 0.6 to cement.

-The resultant mix was hardened and cured

ii. Plastic melt and granite dust

Pavement blocks were produced by mixing plastic melt and granite dust in three (3) different proportions by volume in ratios of 50:50, 40:60 and 30:70.

iii. Plastic melt and clay

-Production of pavement blocks by mixing plastic melt and clay in three (3) different proportions by volume in ratios of 50:50, 40:60 and 30:70.

iv. Plastic melt and sand

-Production of pavement blocks by mixing plastic melt and sand in three (3) different proportions by volume in ratios of 50:50, 40:60 and 30:70.

Laboratory Tests

1. Compressive Strength Test before activation with acid

Here, the blocks were placed under a compression apparatus, and the compression strength at failure was recorded. Three samples were tested for each specimen and their average values were taken as the compressive strength of that specimen. The Universal Testing Machine was used to measure the load that crushes each sample. The compressive strength was calculated using the following Formula

Compressive strength = $\frac{load}{Area}$; where the surface area for each sample is 200mm×100mm =20,000mm^2

2. Compressive Strength Test after activation with acid

Block samples were activated with a weak sulphuric acid (H_2SO_4) with pH value of 6 (to simulate the rugged condition of some corrosive sub-base materials) for 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100days. Compressive strength tests was then carried out on the block samples after 10, 20, 30, 40, 50, 60,70,80,90 and 100 days. The results obtained was then compared to results obtained the compressive strength test prior to activation with acid.

3. Water Absorption Rate (WAR) Test

This test was carried out to give a clue on the internal structure of aggregates. To carry out the WAR test, the pavement block samples were oven dried for 24 hours and weighed, the weight was taken as weight$_{dry.}$ The blocks were then socked in water for 24 hours and the weight taken as weight$_{wet.}$ The water absorbtion rate was calculated as

$W.A.R = \frac{Weight_{wet} - Weight_{dry}}{Weight_{dry}}$ x 100%

4. Oven Test

Oven test was carried out to determine the temperature at which the pavement block samples made from plastic wastes will fail. This gives an idea of the heat resistance ability of the blocks. However, the cement blocks were not subjected to the oven test because heat do not cause a change of state in concrete as it does in plastic materials and their derivatives.

Data Analysis

The mean values of three specimens of every sample were taken at every instance to represent the sample for each test carried out and presented in tables. Simple Bar graphs were used to present the data from each test.

RESULTS AND DISCUSSION

Compressive test result before activation with acid

Below is the table (Table 1) showing the result for the compressive strength test carried out for the various ratio of mix of geo-material with plastic additives and that of concrete mix.

Table 1: Table of compressive strength of each of the 10 sample paver blocks

Samples	Load (N)	Compressive Strength (N/mm2)
50% Granite dust	300,000	15.00
60% Granite dust	256,000	12.80
70% Granite dust	154,000	7.70
50% Sand	251,000	12.55
60% Sand	180,000	9.00
70% Sand	110,000	7.50
50% Clay	198,000	9.90
60% Clay	118,000	8.60
70% Clay	168,000	8.40
Cement/Concrete mix	118,000	5.90

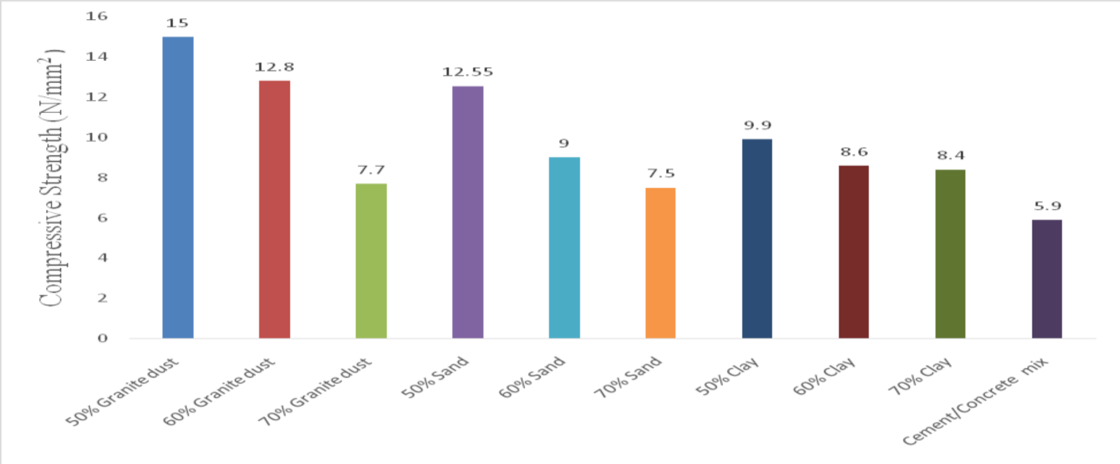

Figure 3: Comparison of pavers from varying ratio of plastic melts/geological materials and Cement pavers based on their compressive strength.

It could be seen from the results that granite dust mixed with plastic melt in the ratios 50:50, 60:40 and 70:30 had the compressive strengths of 15.0, 12.8 and 7.7 N/mm^2 respectively. This shows a decrease in strength as the plastic component reduces and underscores the fact that the characteristics of plastic plays a significant role in the strengthening of the sample blocks.

Sand mixed with plastic melt in the ratios 50:50, 60:40 and 70:30 had the compressive strengths of 12.55, 9.0 and 7.5 N/mm^2 respectively. This shows a decrease in strength as the plastic component reduces and underscores the fact that the characteristics of plastic plays a significant role in the strengthening of the sample blocks.

Clay mixed with plastic melt in the ratios 50:50, 60:40 and 70:30 had the compressive strengths of 9.9, 8.6 and 8.4 N/mm^2 respectively. This shows a decrease in strength as the plastic component reduces and underscores the fact that the characteristics of plastic plays a significant role in the strengthening of the sample blocks.

The mix ratio 50:50 (plastic melt: granite dust) has the highest compressive strength of 15.0N/mm^2, ^{a} value which is almost three times the 5.9 N/mm^2 value of the cement pavement block. In the medium category of compressive strength values are granite 60:40, Sand 50:50, Sand 60:40, clay 50:50 with strength values 12.8, 12.55, 9.0 and 9.9N/mm^2 respectively. All these have strength values that are about twice the strength value of the cement pavement block. The samples granite 70:30, sand 70:30, clay 60:40 and clay 70:40 all have vales close to the 5.9N/mm^2 strength value of the cement pavement block.

Compressive test result after activation with acid.

Table 2 below shows the compressive test results after block samples were digested with a weak sulphuric acid (H_2SO_4). The result of the compressive strength before activation with weak sulphuric acid were also presented alongside those after activation with weak sulphuric acid for easy reference and comparison.

Table 2: Table of the Compressive Strengths (N/mm^2) before and after activation with acid

SAMPLES	COMPRESSIVE STRENGTHS (N/mm^2) before activation with acid	COMPRESSIVE STRENGTHS (N/mm^2) on activation with acid									
		10 Days	20 days	30 days	40 days	50 days	60 days	70 days	80 days	90 Days	100 days
50% Granite dust	15.00	15.00	15.00	14.80	14.78	14.38	14.18	14.05	13.91	13.91	13.88
60% Granite dust	12.80	12.80	12.78	12.63	11.80	11.44	11.35	11.30	11.20	11.10	11.05
70% Granite dust	7.70	7.70	7.61	7.28	6.90	6.78	6.53	6.28	6.10	5.88	5.80
50% Sand	12.55	12.55	12.54	12.54	12.54	12.32	12.15	12.05	11.90	11.80	11.75
60% Sand	9.00	9.00	9.00	9.00	8.92	8.89	8.89	8.61	8.58	8.42	8.30
70% Sand	7.50	7.50	7.50	7.48	7.44	7.42	7.42	7.18	7.04	6.90	6.80
50% Clay	9.90	9.90	9.88	9.75	9.60	9.55	9.33	9.15	9.02	8.91	8.80
60% Clay	8.60	8.60	8.60	8.48	8.36	8.32	8.05	7.80	7.63	7.42	7.20
70% Clay	8.40	8.40	8.38	8.25	8.18	7.84	7.36	7.25	7.08	6.92	6.80
Cement/ Concrete mix	5.90	5.83	5.78	5.10	4.30	3.50	3.15	2.63	2.18	1.41	1.25

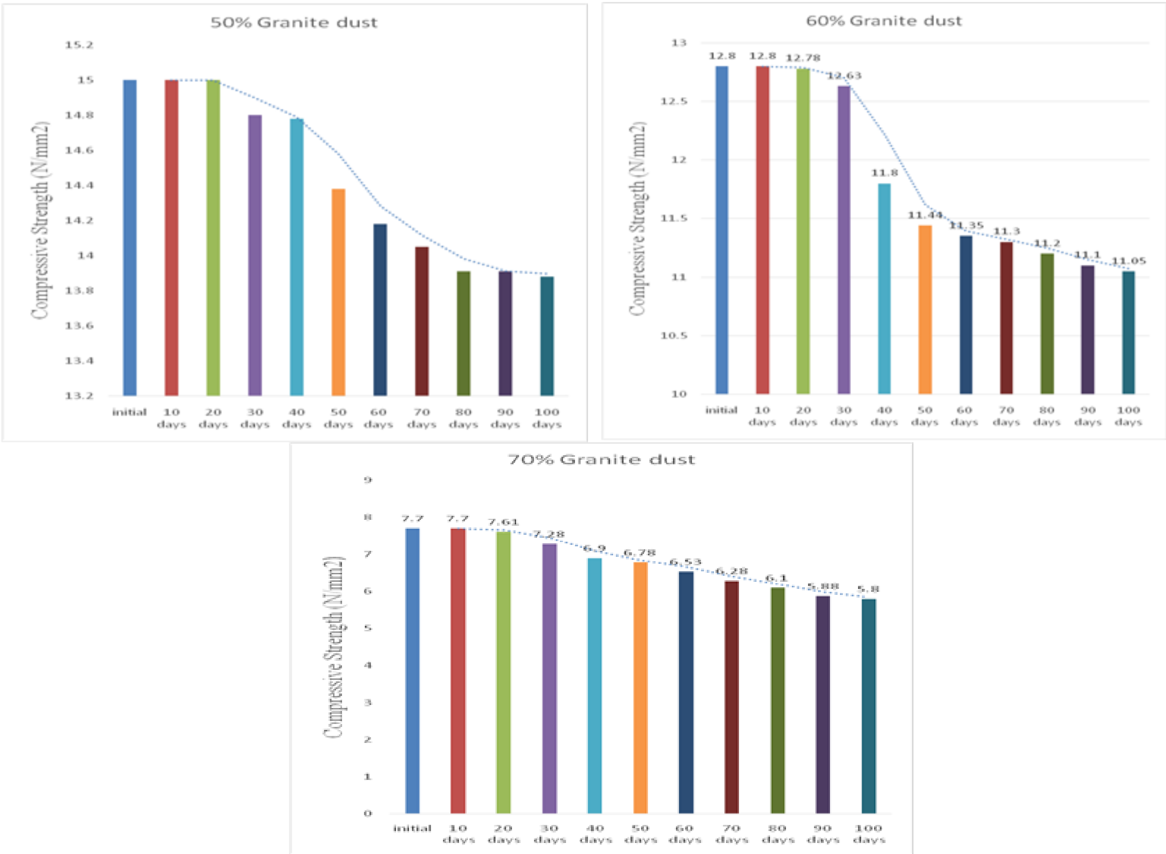

Figure 4 a-c: Chart of compressive strengths of pavers made of granite and plastic additives in different ratios a: Granite/Plastic=50/50, b: Granite/Plastic=60/40) and c: Granite/Plastic=70/30 on activation with weak sulphuric acid for between 0-100days.

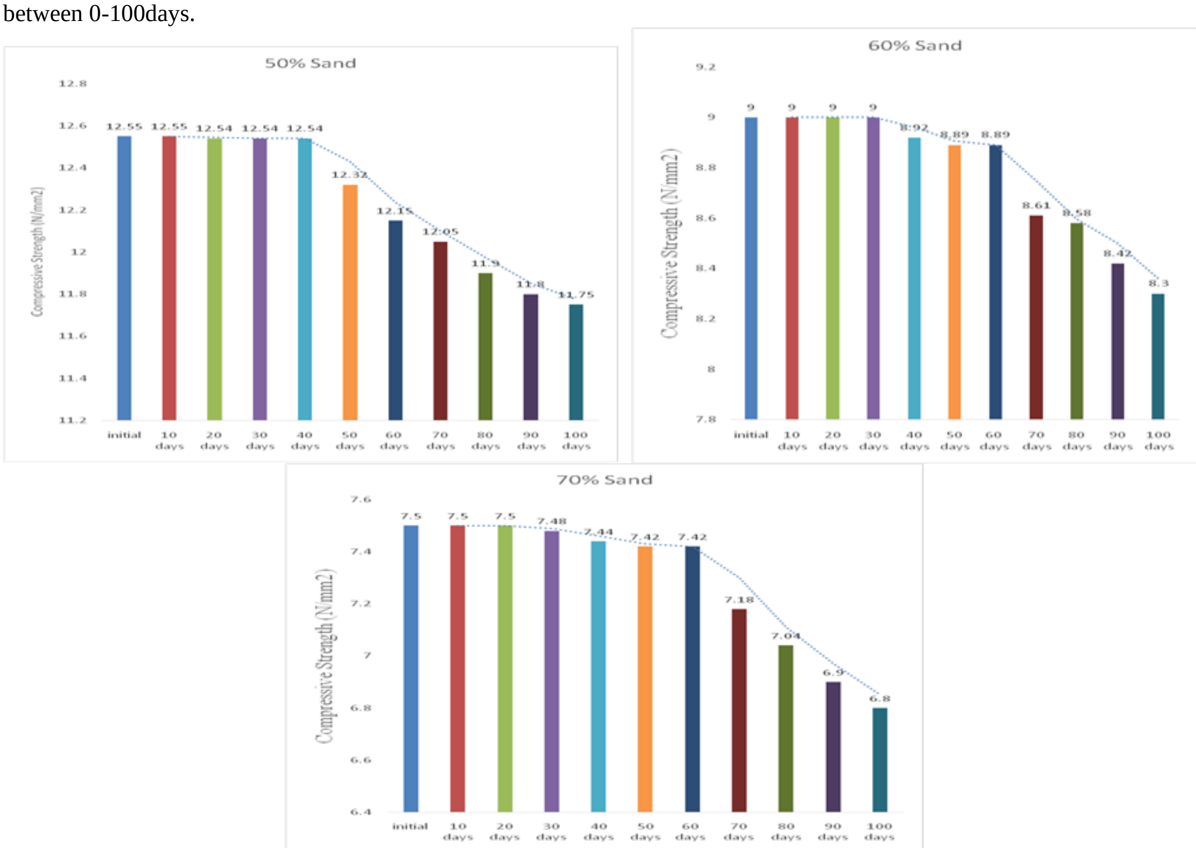

Figure 5 d-f: Chart of compressive strengths of pavers made of sand and plastic additives in different ratios a: Sand/Plastic=50/50, b: Sand/Plastic=60/40) and c: Sand/Plastic=70/30 on activation with weak sulphuric acid for between 0-100days.

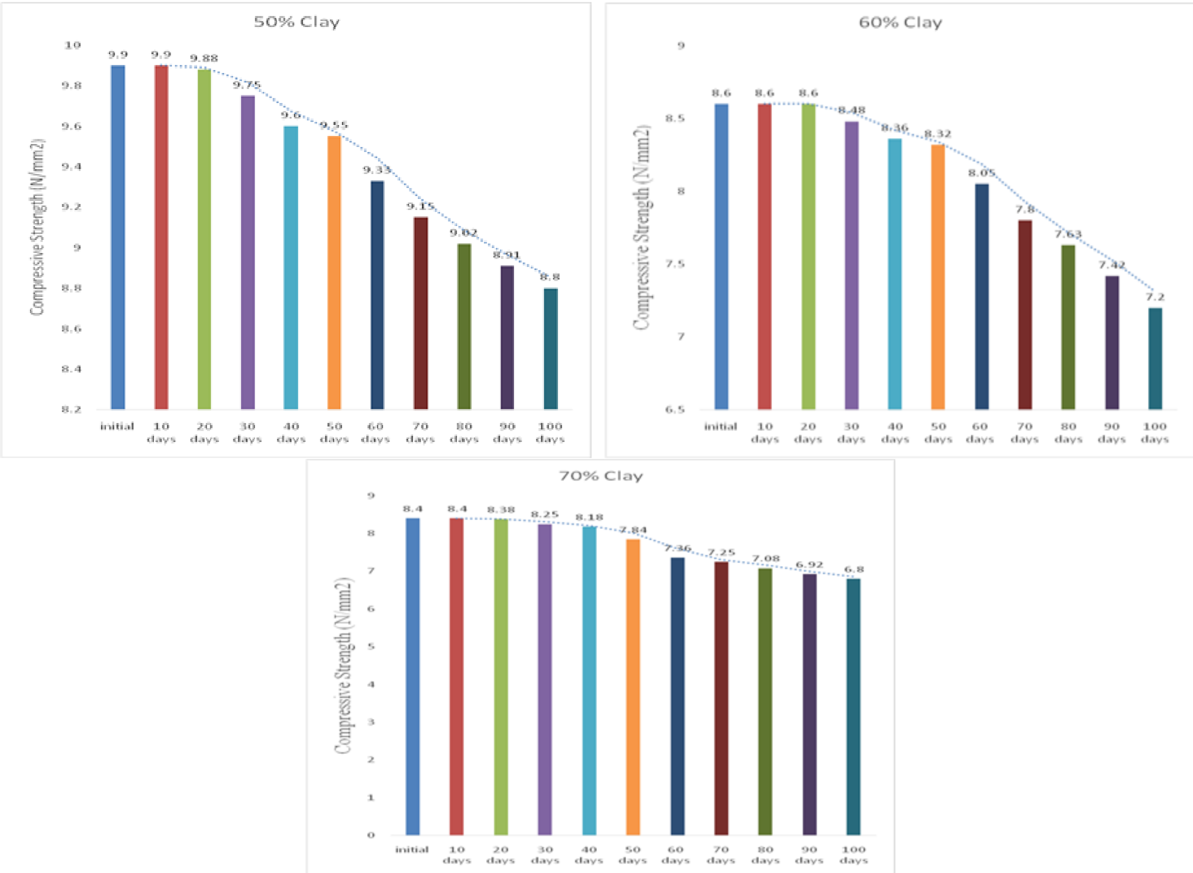

Figure 6 g-i: Chart of compressive strengths of pavers made of clay and plastic additives in different ratios a: Clay/Plastic=50/50, b: Clay/Plastic=60/40) and c: Clay/Plastic=70/30 on activation with weak sulphuric acid for between 0-100days.

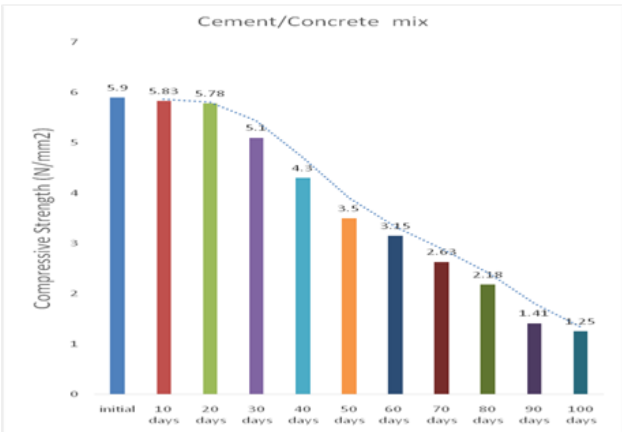

Figure 7 j: Chart of compressive strengths of pavers derived from cement on activation with weak sulphuric acid for between 0-100days

Discussion of compressive strength after activation with acid

The compressive strengths of granites (50/50), (60/40) and (70/30) samples showed (1.12, 1.60 and 1.90) N/mm^2 drops respectively. This shows that corrosion resistance decreases with decrease in plastic additive content. The compressive strengths of sands (50/50), (60/40) and (70/30) samples showed (0.8,0.7 and 0.7) N/mm^2 drops respectively. The minimal drop in the strength here could be attributed to the mineralogy of sand which is predominantly quartz rich and has high resistance as compared to granite and clay. The compressive strengths of clay (50/50), (60/40) and (70/30) samples showed (1.1, 1.4 and 1.6) N/mm^2 drops respectively. This shows that corrosion resistance decreases with decrease in plastic additive content. However, the cement derived sample shows 4.65 N/mm^2 drop in compressive strength after 100days. This difference is about 78% of the initial strength, which is suggestive of a major reason for early failure.

Water Absorption Test

Below is the table (Table 3) showing the result for the water absorption test carried out for the various ratio of mix of geo-material with plastic additives and that of concrete mix.

Result of Water Absorption Test (W.A.R)

Table 3: Table of water absorption rate (%) of each of the 10 sample paver blocks

Samples	Water Absorption Rate (%)
50% Granite Dust	*1.59*
60% Granite Dust	*1.68*
70% Granite Dust	*1.71*
50% Sand	*1.70*
60% Sand	*1.81*
70% Sand	*1.83*
50% Clay	*1.76*
60% Clay	*1.84*
70% Clay	*2.01*
Concrete Mix	*17.33*

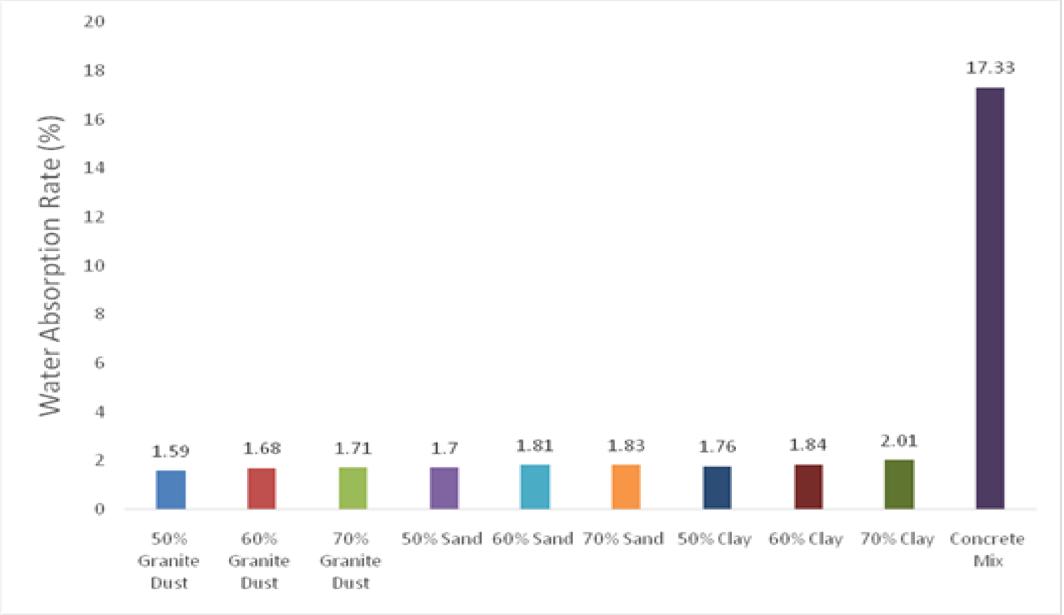

Figure 8: Comparison of pavers from varying ratio of plastic melts/geological materials and Cement pavers based on their water absorption rate.

All the sample blocks produced from plastic melts have water absorption values ranging from between 1.59% to 2.01%. All these values are abysmally lower than the W.A.R 17.33% value of the cement pavement block. This means disintegration of the cement pavement blocks by alternate wetting and drying is more likely than in the plastic derived pavement blocks. There is also the likelihood of the surface of the blocks supporting the growth of algae and spirogyra thereby reducing its strength and aesthetic value. The lower W.A.R. recorded by the plastic derived pavement blocks give them an edge in terms of durability especially in water logged areas

Result of Oven Test

Table 4: Showing the Temperature at which each of the plastic paver block fails (^{0}C)

Samples	Temperature of Failure (˚C)
50% Granite Dust	*180.00*
60% Granite Dust	*185.00*
70% Granite Dust	*185.00*
50% Sand	*180.00*
60% Sand	*185.00*
70% Sand	*185.00*
50% Clay	*200.00*
60% Clay	*205.00*
70% Clay	*210.00*

The results obtained from the oven test shows that there was no visible change in the shape, size and rigidity of all the plastic derived pavement blocks at a temperature below 180˚C. For the mixes of granite dust, changes were noticed for mix 50:50 at 180˚C while changes were noticed for mixes 60:40 and 70:30 at 185˚C. For the mixes sands, changes were noticed for mix 50:50 at 180˚C while changes were noticed for mixes 60:40 and 70:30 at 185˚C. For the mixes of clay, changes were noticed for mix 50:50 at 200˚C while changes were noticed for mixes 60:40 and 70:30 at 205˚C and 210˚C respectively.

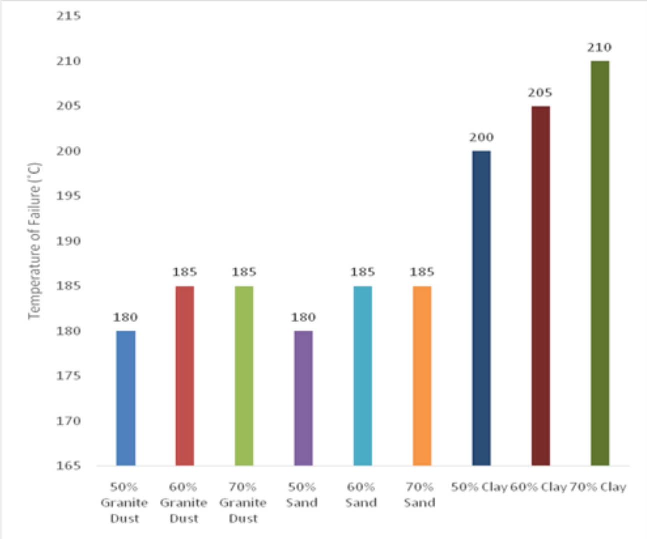

Figure 9: Comparison of failure temperatures of pavers from varying ratio of Plastic/geological materials

The better results shown by the pavers blocks in this research, made with plastic additives of different ratio is in alignment with the findings of Folorunsho and Amadi (2020), Mahmud and Nurudeen (2022); Shanmugavalli *et al.* (2017) and others. The only difference lies in the ratio of the mix and the content of the mix. They mix different materials at a time in different ratios with varying plastic additives, varying only the ratio of the materials at each test but keeping the content of the materials used constant. The findings of their research also showed a more positive outcome for plastic derived pavers except for their compressive strength which proved concrete paver blocks to be better. However in this research, all test showed better results for all the parameters tested for; including the compressive strength.

CONCLUSION

The outcome of this study revealed that the plastic paver blocks are better substitutes to the cement paver blocks for use in construction of roads that are failure resistant. This was evident from the result of the tests for all the engineering properties that was carried out with the plastic derived pavement blocks showing better engineering properties than the cement derived pavement counterpart. This makes the plastic paver block a good alternative for use in any part of the country with ease in terms of sourcing as well as low cost of production and maintenance. It is therefore highly recommended that the government and individuals in Nigeria should embrace the use of the more durable and cost effective plastic derived pavement blocks for road construction, walk ways, parks and the likes as an alternative to the cement paver blocks owing to its better engineering properties.

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