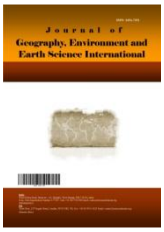

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Structural Evaluating the Production of Paving Stone by Using Recycled Nylon and Plastic Wastes

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This research project is concerned with the Structural Evaluating the Production of Paving Stones by Using Recycled Nylon and Plastic Waste. Nylon and Plastics have become widely used materials in Nigeria, ranging from home, commercial and industrial use. Managing the wastes generated through the industrial booms has become a concern because of its harmful environmental effects. The study work is mainly limited to the Federal Polytechnic Offa and Offa community in Kwara State for materials gathering for data collection. This study assesses the volume of nylon and plastic wastes generated within the study area. Three samples of wastes (polymer) named A, B and C ' sachet water's nylon, packaging nylon and pet bottles', were selected for the process. The recycling process involves sorting, cleaning, and drying. Further, the thermoplastic *materials undergo* a melting process using a temperature range of 150-165oC with the aggregate compositions of moulding materials and produced eight prototype models of paving stones. The sample was subjected to a water absorption test, flexural test, and oven test and observed that; samples A, B and C in ratios 1:1, 1:1, and 1:2 have greater values of tested parameters compared to paving stone made with conventional cement and granite dust. Hence, paving stones made from nylon and plastic materials (Polymers) have greater strength and resistance to water absorption. Therefore, the researchers

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suggested an open platform for a close collaboration between the government and the professionals in the built environment to encourage the use of waste material to replace cement.

Keywords: Recycling of nylon; plastic waste; manufacturing; paving stones.

1. INTRODUCTION

Global warming has become one of the significant concerns today. Recycling waste is one of the vital roles used in protecting the environment. Recycling waste has become a much more profitable business today [1]. There are many kinds of recycling waste and recycling business ideas on industrial output. However, while considering recycling as a venture, a few requirements are needed, making a choice enhance visibility studies, to know what type of waste to recycle since there is plenty of garbage that demands recycling like household, construction, electronics waste and so on [2]. Therefore, having deep knowledge of the recycling process enables the researcher to know what kind of machines and tools need in the processing phase. Marketing research is one of the critical factors that can allow the sustainability of waste recycling ideas to succeed. The process helped protect the environment and earned profits on the other end [3].

The need to recycle nylon (sachet water nylon) and plastics in our environment as an institution has brought about the innovation of using them as raw materials for manufacturing paving stones. Paving stone is versatile, aesthetically attractive, functional and cost-effective and requires little or no maintenance if correctly manufactured and well fixed. Most concrete block paving stones manufactured in Nigeria also have performed satisfactorily [4]. "Still, two main areas of concern are occasional failure due to excessive surface wear and variability in the strength of the block. Naturally, resources are depleting worldwide while the generated waste from the industry, public places and residential areas is increasing tremendously. Sustainable construction development involves using non-conventional and innovative materials and recycling waste materials to compensate for the lack of natural resources and find alternative ways of protecting our environment from depletion" [5].

Nylon and plastic wastes considered for use in this research come from the trash generated in our immediate environment, most especially in our institution and other nearby selected institutions where there is a high generation of the same. In Federal Polytechnic Offa alone, it is estimated that 2600 tons of nylon are generated annually at the temporary site alone, which adversely impacts man, animals and the natural habitat cycle of the environment. So it is necessary to safely dispose of these plastics to reduce their adverse effect on the environment and gainfully use them in manufacturing paving stones for economic advantages and a better institutional environment [6, 7].

The nylon and plastics industries have developed considerably since the invention of various means for producing polymers from petrochemical sources. Plastics have a significant advantage in low weight, durability and lower cost compared to many other materials. Still, the waste generated through these has become a source of concern because of the considerable quantity generated daily and its harmful effect on the environment. It necessitates recycling plastic wastes to free our environment from its harmful effects and turn them into useful material for manufacturing paving stones in road construction.

The needs for recycling nylon and plastic wastes as a substitute for cement in the manufacturing of paving stones in Federal Polytechnic Offa are basically to achieve the following objectives:

- To assess the volume of nylon and plastic wastes generated within the campus of Federal Polytechnic Offa.
- To safely recycle the generated wastes from nylon and plastics as a way of minimizing waste's havoc on the environment.
- To effectively use the recycled materials to manufacture paving stones for road construction within Federal Polytechnic Offa.

2. LITERATURE REVIEW

PVC recycling is a polyethene chloride used mainly in manufacturing pipes, tense and others.

A rejected PVC can be taken and then treated for manufacturing PVCs. Chemical processes like pyrolysis, hydrolysis and heating are used to convert the waste into chemical components. However, the results of products like sodium chloride, calcium chloride, hydrocarbon products and heavy metal are used to produce new PVCs as viewed from many manufacturing processes or views for energy recovery [7].

Construction and reliable waste recycling are solid waste is non-biodegradable. Collecting this type of waste from the construction site and manufacturing it into a brick after complete treatment of the waste, compression is applied to produce a new shape that makes it more robust with a long life cycle. These bricks can be sold to new construction houses in proportionalities. It is applicable in nock tiles, partition boards, cling materials and others, which require miniature fashionable painting [8].

Medical waste recycling is generally known to be dangerous. A large portion of waste like syringe needles can be recycled. Autoclaving, gas sterilization, chemical disinfection, microwave, irradiation, thermal inactivation and many more were the primary method used to recycle [3], [8].

There is the possibility of the intoxicating kitchen without even realizing the action. All activities like cooking, cleaning and eating produce a significant level of waste. In most cases, cooking utensils were disposed of as a waste, commonly recycled since most of the utensils were products of steel, copper and iron. So, when recycling process can be used to produce new utensils and sell them to other kinds of businesses.

The commercial for Glass recycling review for the improvement in the recycling of glass within the hospitality of businesses, hubs and restaurants sold over two hundred thousand the tones of glasses every year. Glass material can be easily melted down and remade into different kinds of shapes. Drinking glasses, moulding sculptures and glass fibre were most of the noble materials used in the world today. Once collected, it is broken into small pieces, crushed, soldered and cleaned. They can be molten into with another constituent-like sound which can be moulded into the desired shape [9].

"The use of nylon and plastics appear to have come to stay in Nigeria, as some people prefer it to other products when wrapping sundry items. For many, nylon is the go-to disposable container for preserving foods and other perishable items in the freezer" [10]. It seems evident that this amount of material that isn't meant to break down can wreak havoc on the natural environment, leading to long-term issues for plants, animals, and people (Conserve Energy Future, 2018). "Plastics have substantial benefits in their low weight, durability and lower cost relative to many other material types" [11 - 12]. "The indefinite period it takes for the average plastic bag to break down can be hundreds of years. Every bag that ends up in the country's woodlands threatens the natural progression of wildlife. Because the breakdown rate is so slow, the bag's chances of harmlessly going away are incredibly slim. Throughout the world, plastic bags are responsible for the suffocation deaths of woodland animals and for inhibiting soil nutrients" [13-15]. "There is no way to strictly limit the effects of plastic bags on the environment because there is no disposal method that will help eliminate the problem. While reusing them is the first step, most people either don't or can't base on store policies. They are not durable enough to stand up to numerous trips to the store, so often, the best that citizens can do is reuse them when following pooper scooper laws" [16]. "Nylon and plastic waste form part of the total waste generated in the state. Presently, Offa in Kwara State generates about 3 000 metric tons of waste daily. The researchers discovered that a lot of waste material in the environment could be recycled to make more useful items and serve many purposes. When you say waste to wealth, you are turning waste into items you can make money from, which is an extensive topic [17]. Burning of waste nylon and plastic bottles can cause air pollution. Poisonous gases such as carbon monoxide, furans and dioxins are released into the air. They can endanger public health, destroy the ozone layer and contribute to global warming. So how can we efficiently remove and manage the enormous heaps of waste nylon and plastic bottles around us without destroying our environment? Green recycling is the way forward" [18 -20].

3. METHODOLOGY

In this research work, experimental method was adopted by determining the volume of nylons and plastics generated on a daily, weekly or monthly basis in the research area. The Enumerated Areas (EA) as targeted areas included six (6) higher learning institutions from Offa in Kwara State. These are densely populated communities where nylon and plastic materials are regularly generated as waste.

These location are; permanent site and mini campus of Federal Polytechnic, college of Health and Sciences, Lense Polytechnic, Graceland Polytechnic, Offa, Summit University, all are in Offa. The materials were transported to the destination, Federal polytechnic Offa mini campus in Kwara State.

3.1 Sorting of Nylon and Plastic (Polymers)

All the collected materials from different point of collection were sorted out according to their texture and the classes. They were subjected to cleaning process were cut open to get rid of any liquid droplet that can hinder the melting process by spreading on a clean plain floor to air-dried. Industrial standing fan was introduced in order to speed up the drying time.

3.2 Study Area Description

Offa Kwara State (Fig. 1), the sub-economic hub of Nigeria, was chosen as the case study because of the over one million population, many industries and the large amount of plastic waste generated daily. The sharp sand, and plastic wastes were sources in entire Offa city.

Geologically, Offa consists of sedimentary formations belonging to the tertiary and quaternary sediments. Tertiary sediments are unconsolidated sandstones, grits with mudstone band and sand with layers of clay (Fig. 1). The granite dust was sourced from Offa in Kwara State (Fig. 2) because of its availability in Offa community and its environment.

Fig. 1. Geology Map South-western Nigeria showing the Study Area (Federal Polytechnic Offa Kwara State)

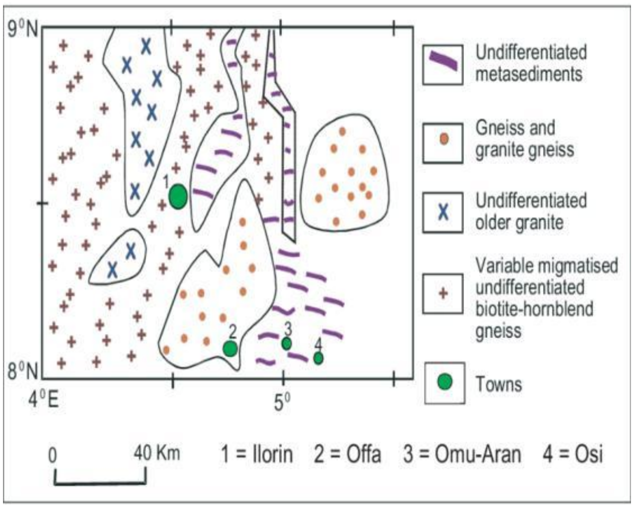

Fig. 2. Geology Map of Parts of Kwara State Showing Offa (where granite dust was sourced)

3.3 Research Materials

3.3.1 Cement Composition requirement

Ordinary Portland cement was obtained from the open market designated as CEM I in the present Nigeria Industrial Standard for cement NIS 444-1:2003 (cement with 95% to 100% blinker and gypsum and 0%-5% minor additional constituent).

3.3.2 Components of ordinary portland cement

There are various types of cement available in the construction industry. The types of projects to be undertaken determine the choice of cement with the various required component. Ordinary Portland cement was used in this research work. The chemical components of ordinary Portland cement and each component's functions are tabulated in Table 1.

Other equipment/ consumable materials used are hand gloves, nose masks, safety boots, one melting barrel, a spade with a metal shaft for staring of hot mix. Industrial gas as a source of heat, mould (200mm x 100mm x 75mm), used engine oil for lubrication, metal table for mould placement, hand trowel, and a thermometer.

Table 1. Functions of components of cement

S/N	Composition	Percentage	Function
1	Lime (CaO)	60-67 %	• This is calcium oxide or calcium hydro allow the cement to have the required strength, • Deficiency in lime reduces the strength property of the cement. • Deficiency in lime causes the cement to set quickly. • Excess lime makes cement unsound. • Excessive presence of lime causes the cement to expand and consequently disintegrate.
2	Silica (SiO_2)	17-25 %	• Silica gives strength to cement. • Silica usually presents to the extent of about 30 percent cement
3	Alumina (Al_2O_3)	3-8 %	• It enables quick setting of the cement. • Clinkering temperature is lowered by the presence of the requisite quantity of alumina. • If in excess, it weakens the cement
4	Iron Oxide (Fe_2O_3)	0.5-6 %	• Iron oxide gives color to the cement. • It acts as a flux. • At a very high temperature, it influence the chemical reaction with calcium and aluminum to form tricalcium alumino-ferrite. • Tricalcium alumino-ferrite gives hardness and strength to cement.
5	Magnesia (MgO)	0.5-6 %	• Quantity of Magnesia should not be more than 2% in cement. • Excess of magnesia will reduce the strength of cement
6	Sulphur trioxide (SO_3)	1-3 %	• It should not be present for more than 2%. • Excess of it causes the cement to be unsound
7	Soda and/ Potash (Na_2O+K_2O)	0.5-1.3 %	• It should not be present more than 1%. • Excess of it causes efflorescence

Sand: Natural clean riverbed sand was collected and used for the research work. Clean and sharp sand was collected from the entire Offa community in Kwara State has a specific gravity of 2.65 and a fitness modulus of 0.4. It was oven-dried at the Federal Polytechnic Civil Engineering Department, Offa.

Granite dust: Granite dust was collected from a local stone crushing unit from Offa, Kwara state (Fig. 3). It was dry at the point of collection and was sieved by IS: 4.75mm sieve at the Building Technology Department, Federal Polytechnic, Offa. It has a specific gravity of 2.57, fitness modulus of 2.41, a density of 1.85gm/cc and a void ratio of 0.42. See Fig. 2.

3.4 Plastic Materials

The plastic materials (PET, HDPE and LDPE) were washed, cut open and air-dried to allow easy melting during heating processing. These materials were in three classes and classified as; the sachet water nylon (soft) sample A, packaging nylon (slightly more complex) sample B and pet bottle, sample C, as shown in Table 3.

3.5 Melting and Casting Procedure of the Materials

The half-cut metal drum was placed on the lit industrial gas burner. When the drum had been heated, 6.2 kg of sample (A) nylon was poured into the metal drum and stirred until completely melted at a temperature of about 150-165˚C at Fig A. Crushed stone dust less than 4.5mm was gradually poured mixed with turning stick until a homogenous mixture was achieved in Fig C. The mixture was poured into a lubricated steel mould, a metal mould type measuring 200mmx100mmx75mm, with a spade and hand trowel. The paste was thoroughly compacted by taping the sides of the mould to avoid any air pocket in the cast. The sample was kept under a room temperature shade to avoid any harsh weather interference. The stone (block) was de-moulded after seven hours. At this point, the volume of dust used was calculated to be 6.19kg, and the mix of the two materials was a ratio of 1:1. The procedure was repeated for the remaining two samples, Fig B and C, and the corresponding values of materials used were recorded. The produced stones were stored in a cool/ dry place at room temperature, which served as a curing method for forty-eight hours (48 hrs.) before carrying out any test on it Fig 3a,b,c,d,e.

Cement and Aggregates Mix Ratio: The materials required composition (cement, sand and granite dust in the ratio of 1:2:4 respectively) shown in table 4 were mixed thoroughly with a shovel until a uniform texture was achieved and portable drinking water was added to form the required texture was obtained.

- Water was added in a ratio not exceeding 0.6 to cement.
- The mixture was poured into lubricated mould
- The resultant mix was hardened and cured

Laboratory Tests: Five tests were conducted for the study: the Compression test, Water absorption test, Flexural test, corrosion test and Oven test. The comparison was made based on all except the oven test. It determined the temperature at which the products would fail instability.

Table 2. Showing physical properties of igneous rock

S/N	Property of Igneous
1	It's very dense in silica content
2	Due to large presence of Silica in its composition, granite is highly resistant to decay.
3	Granite is an easily quarried stone. This is due to the presence of a mural joint.
4	Similarly to the quarrying, the rift and the grain that are present in abundance make its dressing easy for utilising in various purposes
5	The igneous properties of granite makes it incredibly publishable for construction purposes as a polished and hard surface can last relatively longer than other stones. 6. it has a reasonable resistance to fire due to the presence of fewer minerals. 7. Similarly, granite also offers a reasonable resistance to frost due to the presence of fewer minerals. 8. Granite is relatively free from fracture

Table 3. Showing chief chemical constituents of portland cement.

S/N	Sample	Composition
1	Sachet water's nylon	Polythene
2	Wrapping Nylon	Polyethyllene terephthalate
3	Pet bottle	Pellet

Table 4. Mix ratio for the stone (block)

S/N	Material	Mix ratio
1	Sachet water's Nylon	**1:1**
2	Wrapping Nylon	**1:1**
3	Pet bottle	**1:2**

Compressive Strength Test: The Universal Testing Machine measured the load that crushes each sample. The compressive strength was calculated using the following formula:

Compressive strength=Load/Area;

where the surface area for each sample is 200mm×100mm = 20,000mm2. The outcome showed

Water Absorption Test: The weight of each oven-dried sample was measured as weight dry - The weight of each piece soaked for 24 hours was measured as weight wet.

The water absorption rate was calculated using the following Formula water absorption rate = (weight wet - weight dry)/weight dry ×100%.

Flexural Test: The flexural test was carried out using an automatic Universal Testing Machine. By this test, the amount of force at the breaking point of each sample was determined and recorded.

Oven Test: The oven test was carried out by placing plastic-derived paver stones in the oven and recording the points at which they failed.

Acid Test: Stone samples used were incorporated with a weak sulfuric acid (H2SO4) pH value of 6. Both compressive and flexural tests were carried out on the block samples after 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 days. These test results were compared to results obtained before activation with acid.

A: Drying process of nylon and plastic waste **B: Weighing of the stone dust**

C Melting of nylon on gas burner **D Cast melted nylon with stone dust**

E: Produced stone from nylon plastic wastes

Fig. 3. Showing the stages involved in the casting process of the stones

4. RESULTS AND DISCUSSION

4.1 Data Analysis

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

4.1.1 Compressive strength test of the prototype mould

Table 5 shows the result for the compressive strength of the different samples represented on the bar graph in Fig. 6.

Table 5. Table showing the compressive strength of each of the 4 sample paver blocks prototype

Samples Size	Load (N)	Compressive Strength (N/mm2)
50% Granite dust sample A	356,560	17.83
50% Granite dust Sample B	256,000	13.26
50% Granite dust Sample C	154,000	12.68
Cement/Concrete (1:2:4)	118,000	5.9

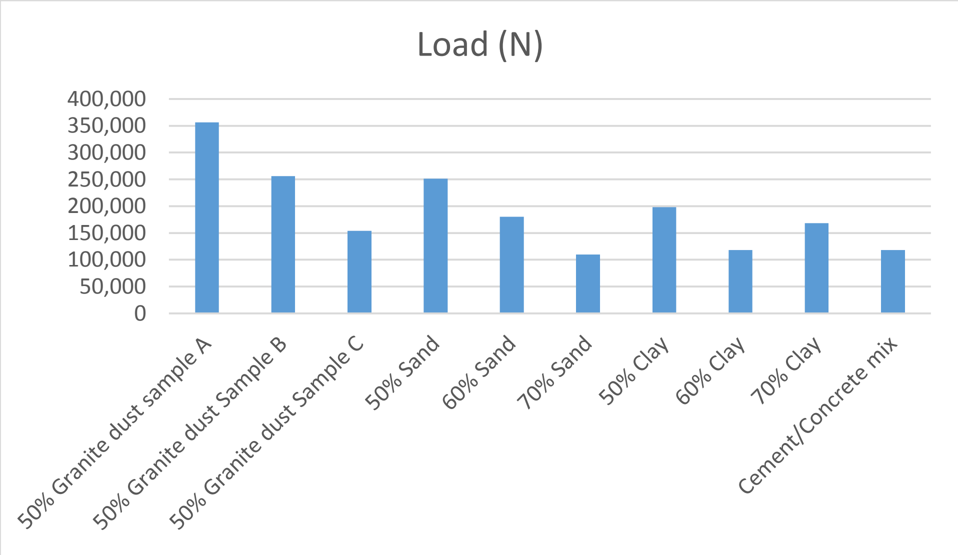

Fig. 4. Bar chart of paving stones at different ratio versus their respective load

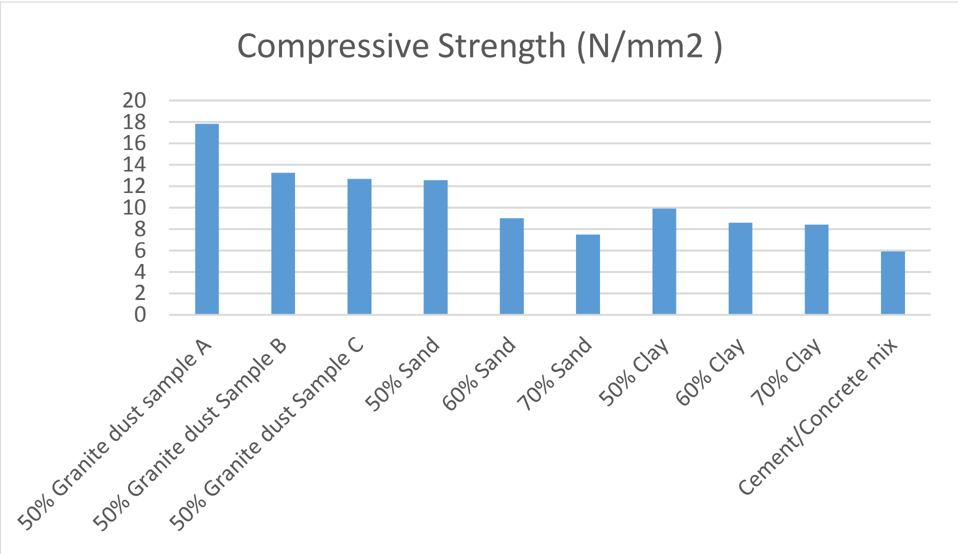

Fig. 5. Bar chart of paving stones at different ratio versus their respective compressive strength

The Compression test shows that the mix ratio of 1:1 (melted plastic: granite dust) sample A has the highest compressive strength of 17.83N/mm2, while B and C have 13.26 N/ mm2 and 12.68mm2 respectively, but cement concrete has5.9N mm2 from the Table 5. This result revealed that stone manufacture with igneous stone dust and melted Nylon and plastic waste materials (polymers) has higher compressive strength than a concrete paving block.

Water Absorption Test: From the outcome of water absorption rate ratio in table 6, its can be inferred that water absorption of sample A, B and C were 1,59. 1.68 and 1.71 respectively which are very low when compare to the value of concrete mix for the stone with the highest value of WAR 17.33. This means disintegration of the cement paving stones by alternate wetting and drying is more likely than in the plastic-derived paving stones shown in Fig. 6. It also underscores the reason why cement paver blocks support the growth of algae, spirogyra and mosses on its surface [19-22].

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 [21]. The lower WAR recorded by the plastic-derived pavement blocks gives them an edge in terms of efficiency and durability, especially in waterlogged areas.

Flexural Test: Table 6 shows the result of the flexural test of the samples. It is important to note that forces at breaking point reduce with various materials of Plastic and Nylon of the same mix ratio. This implies that each of the materials has a different chemical composition which determines their flexural strength. Nevertheless, it was deduced that the flexural strength of nylon /plastic wastes-derived paving stones is more significant when compared with that concrete value of 1.98KN.

Oven Test: Table 7 shows the result of the oven test of the samples. The oven test was carried out to ascertain the temperature at which each paving Stone fails. The results obtained from the oven test show that there was no visible change in the shape, size and rigidity of all the plastic-derived paving Stones at a temperature below 180˚C which means that it can still withstand temperatures below 180˚C, as shown in Table 8.

Table 6. Showing the water absorption rate (%) of each of the four (4) sample paving stones

Samples	Water Absorption Rate (%)
50% Granite Dust Sample A	1.59
50%Granite Dust Sample B	1.68
50%Granite Dust Sample C	1.71
Concrete Mix	17.33

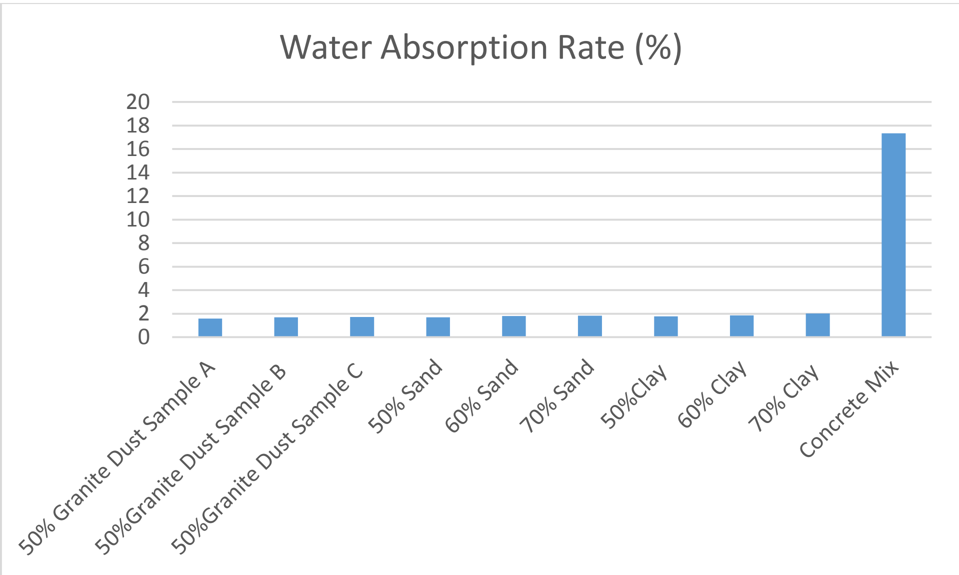

Fig. 6. Bar water absorption rate of pavers from varying ratio of plastic melts/geological materials and cement

Table 7. Shows the Force at Breaking Points (N) of each of the three (3) Sample Paver Stones and concrete block

Samples	Force at Breaking point
50% Granite Dust, Sample A	12,640
50% Granite Dust, Sample B	10,400
50% Granite Dust, Sample C	8,360
Concrete Mix	1,980

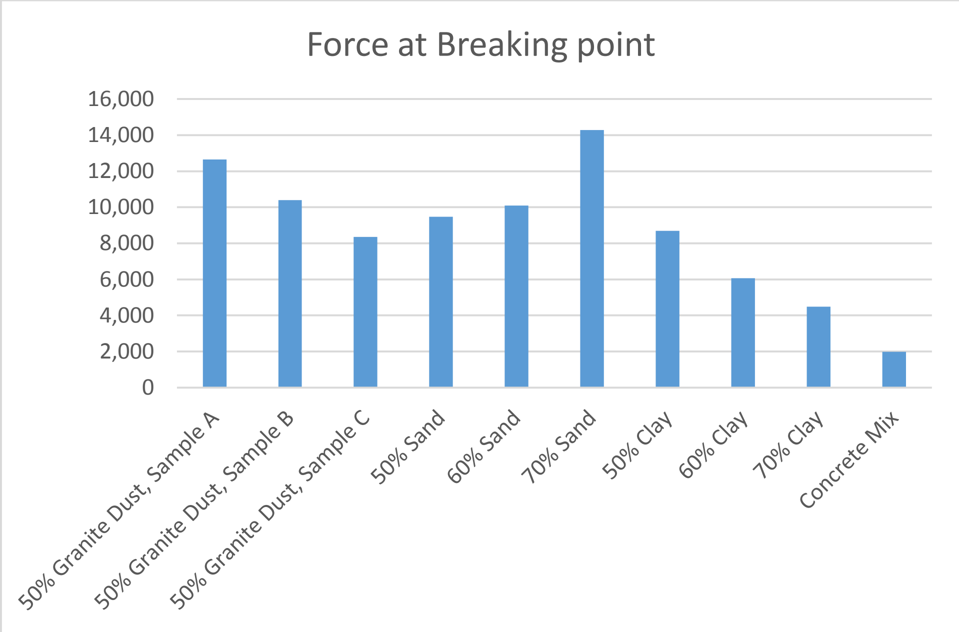

Fig. 7. Bar chart of breaking points of geomaterials at different materials in the same ratios

Table 8. Showing the oven test of the paving stones

Samples	Temperature of Failure (˚C)
50% Granite Dust Sample A	180
50% Granite Dust Sample B	185
50%Granite Dust Sample C	185
Concrete mix ratio 1:2:4	315

5. CONCLUSION

The present study has efficiently and effectively demonstrated the application of waste plastic and nylon into valuable constructional materials and reducing its harmful effects on our environment. The plastic wastes littered all over the environment can be converted into valuable constructional materials that are more economical and eco-friendlier than cement-based materials. The waste materials were melted on the industrial gas burner and mixed with igneous rock dust in the ratio 1:1. It was concluded that, for waste material sachet water's nylon (sample A) of ratio 1:1, wrapping nylon (sample B) of ratio 1:1 and pet bottle (sample C) of ratio 1:2 have their respective compressive strength at ratio 1:1, !:1 and 1:2 respectively. Therefore, the three samples have greater compressive strength, tensile strength, However, the recycling process involves sorting, cleaning, and drying. Further, the thermoplastic materials undergo a melting process using a temperature range of 150-165oC with the aggregate compositions of moulding materials and produced eight prototype models of paving stones. Based on the results of the various tests, the study has established that plastic-derived paver stones are more rugged, more rigid, have low water absorption, high resistance to heat and are corrosion-resistant when compared to concrete paver stones produced from conventional Portland cement.

6. RECOMMENDATION

Given the conclusion of the study, the following recommendations are made:

1. It is recommended that recycled nylon wastes (polymers) based-stone be used for paving roads as an alternative to asphalt materials because of their high compressive strength, tensile strength, heat resistance and low water absorption advantages over cement-based stones.
2. It should be used in a moist environment to prevent discolouration and algae growth on the stones' surface.

3. Government should incorporate this innovation into entrepreneurship learning for the students in technical education.
4. Government should encourage recycling materials in the construction industry.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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