

# PLASTIC RECYCLING: AN INVESTIGATION INTO THE PROPERTIES AND PROSPECTS OF PLASTIC TILES

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## ABSTRACT

It is very clear that Nigeria has a waste problem. With the advent of modernization and urbanization has come the production of tons of different kinds of waste products of which plastics constitute a great percentage. Normally, it would be convenient to just discard those waste materials, but recycling is getting more popular every day. This paper narrows down the investigation into waste recycling to plastics and looks more specifically at the prospects of tiles made with plastics and sand. This research paper evaluates the physical and mechanical properties of plastic tiles as compared to the conventional cement tiles. The results obtained have showed that tiles made from different proportions of plastic and sand has the properties and potential to be a suitable alternative to cement tiles.

**Keywords:** Plastic waste. Fine sand. Plastic tiles. Properties.

## INTRODUCTION

Plastics are very essential materials which have become indispensable in our everyday lives. Their unique properties such as their low cost, ease of manufacturing, high durability, their thermal insulation, resistance to corrosion, etc, has made plastics a very important engineering material. Plastics are very versatile in use. They are utilized for many diverse purposes in almost every sector. Plastics are used to produce packaging. They are used in construction. In the textile, transport and manufacturing industries, plastics are also utilized.

However, a problem arises when we consider plastic wastes. These are plastics that have been used and discarded. They can also be referred to as post-consumer plastics. In a study carried out by Ritche and Roser (2018), it was stated that over 380 million tons of plastic waste are generated every year worldwide. In Nigeria, Magoum (2020) estimates the annual figure to be 2.5 million tons of plastic wastes. Although recycling rates have increased globally in recent years, still, the global rate of recycling still remains at 54%. Wrong management systems of waste plastics have a lot of adverse effects on man and the environment. Plastics, being non-biodegradable, remain unchanged after centuries. These plastics when buried in the ground ultimately reduce the agricultural utility of the concerned portion of land. Also, the method of open-air incineration of plastics is extremely harmful not only to our environment, but also to us. The reason why the sun seems to get hotter every passing year is partly because of the depletion of the ozone layer which contributes to global warming. This depletion of the ozone layer is a condition caused by the emission of greenhouse gases such as carbon(IV)oxide and chlorofluorocarbons (CFCs). These gases which produce this greenhouse effect are such gases which are produced by the burning of non-biodegradable wastes such as plastics. When plastics are burned, it releases dangerous chemicals such as hydrochloric acids, sulfur dioxides, dioxins, furans as well as particulates. These emissions are known to cause respiratory ailments, stress the human immune systems and are also potentially carcinogenic.

The objective of this research is to explore one of the options of recycling plastic wastes. Although efforts are being made to develop biodegradable plastics, there are still a lot of conventional plastic materials in circulation which needs to be diverted to the right alternative post-consumer system where they can be recycled.

The production of tiles from waste plastic is an innovative method of recycling waste plastics. These tiles can be used as an alternative to normal cement tiles. They can be used for outdoor pavements and even indoor tiles. They are made by mixing molten plastics with particular amounts of sand and transferred to a mould to shape and left to dry and solidify.

This research will have a great impact on the recycling rates in Nigeria and also in the construction sector. With the right technology and good marketing techniques, these plastic tiles have the potential to compete aggressively with cement tiles in the near future.

## **WASTE MANAGEMENT AND PLASTIC RECYCLING**

Waste production is an integral part of human existence. In our everyday lives, in almost every form of human activity, we make use of several tools, items or materials most of which, will end up as waste products once they have served their purpose.

Wastes can simply be defined as unwanted or completely used materials. They can be generally divided into two groups; biodegradable and non-biodegradable. The group of biodegradable wastes are wastes which can be naturally broken down, disintegrated or decomposed, while the non-biodegradables cannot be naturally broken down or decomposed.

Established already, is the inevitability of waste production. However, waste management has always been and continues to be a challenge in the Nigerian society. Waste management, in simple terms refers to “what we do with our wastes”. Conventionally in Nigeria, the most common methods of waste management are open-air incineration and land-filling. These methods of waste management are not only adverse to human health and to the environment, they are also a waste of what has been discovered to be valuable resources which could contribute immensely to the economy of Nigeria. The method of open-air incineration of wastes contributed to the depletion of the ozone layer and the emission of dangerous gases which could be harmful to human health. Also, the method of land-filling (especially inorganic non-biodegradable wastes) renders affected areas of land agriculturally infertile.

This analysis opens our eyes to the need of an alternative method of waste management. Waste recycling is simply the process of making new useless materials from old “useless” ones. Most of

the materials which are burnt up in the incinerator or buried in the ground are actually materials for which alternative uses can be found and can be recycled into many useful products. Paper, plastics, tires, metals and ceramics are some materials which can be recycled. In Nigeria, an estimated amount of about 32 million tons of solid wastes are generated annually and plastics constitute about 2.5 million tons of that figure. It is also estimated that less than 12% of plastic wastes are recycled in Nigeria, with the rest ending up in the water bodies, incineration sites or landfills.

Plastics which make up a significant amount of solid municipal waste are the primary subject of this research. Plastics can be recycled into polyester which is used in making clothes. It can also be recycled in a closed loop to produce new bottles. Plastics can also be subjected to a pyrolysis process which results in the production of diesel which can be used to run diesel engines. Apart from these, there are also a lot of other creative and innovative ways of recycling plastics such as using them in buildings as well as in art works. The aspect of plastic recycling which will be the major focus of this work will be the method of producing pavement tiles from a blend of plastic and sand.

## **THEORETICAL ANALYSIS**

Pavement tiles are materials which are conventionally made from a mixture of fine gravel, cement and sand. These ingredients are thoroughly mixed with the addition of a little amount of water. The mix is then transferred to a mould to form the desired shape. Tiles can be considered to be composite materials where sand is the reinforcement and cement, the matrix which serves as a solidifying medium or binder. The concern of this alternative method is to substitute cement with molten plastic.

Plastics are organic materials which are made from natural products like cellulose, coal, natural gas, salt and crude oil. The word “plastic” is derived from the Greek word “plastikos” which means “fit for moulding”. This refers specifically to the malleability of plastics which makes them suitable for serving as binding agents. Also, plastics are synthetic or semi-synthetic materials that use polymers as a main ingredient. They can be classified according to: the chemical structure of the polymer, the chemical process used in their synthesis, their physical properties and relevant qualities.

Sorting of plastics is a major step in the recycling of plastics. It is highly important to avoid mixing different resins of plastics together. When different plastics are melted together, they form an immiscible solution such as would be the case with oil and water. In 1988, resin codes originated from the Society of the Plastics Industry but were only actively administered in 2008 through the ASTM International Resin Identification Coding System. These codes designated numbers for identifying different plastic resins in industries internationally.

Table 1: Different Types of Plastic

PLASTIC TYPE	ABBREVIATION	RESIN CODE NUMBER
Polyethylene Terephthalate	PET/PETE	1
High-density Polyethylene	HDPE	2
Polyvinyl Chloride	PVC	3
Low-density Polyethylene	LDPE	4
Polypropylene	PP	5
Polystyrene	PS	6
Other plastics	O	7

The plastics are identified by observing the inscription on the body of the material. They are usually denoted by the recycling symbol with the appropriate resin code number written inside.

This is illustrated in Fig 1.

### Plastic Resin Identification Codes















 PETE	 HDPE	 PVC	 LDPE	 PP	 PS	 OTHER
Polyethylene Terephthalate	High-Density Polyethylene	Polyvinyl Chloride	Low-Density Polyethylene	Polypropylene	Polystyrene	Other
Common products: soda & water bottles; cups, jars, trays, clamshells	Common products: milk jugs, detergent bottles, shampoo bottles, flower pots, grocery bags	Common products: cleaning supply jugs, pool liners, twine, sheeting, automotive product bottles, sheeting	Common products: bread bags, paper towels & tissues, overwrap, squeeze bottles, trash bags, six-pack rings	Common products: yogurt tubs, cups, juice bottles, straws, hangers, sand & shipping bags	Common products: to-go containers & flatware, hot cups, razors, CD cases, shipping cushion, cartons, trays	Common types & products: polycarbonate, nylon, ABS, acrylic, PLA; bottles, safety glasses, CDs, headlight lenses
Recycled products: clothing, carpet, clamshells, soda & water bottles	Recycled products: detergent bottles, flower pots, crates, pipe, decking	Recycled products: pipe, wall siding, binders, carpet backing, flooring	Recycled products: trash bags, plastic lumber, furniture, shipping envelopes, compost bins	Recycled products: paint cans, speed bumps, auto parts, food containers, hangers, plant pots, razor handles	Recycled products: picture frames, crown molding, rulers, flower pots, hangers, toys, tape dispensers	Recycled products: electronic housings, auto parts,
						

Figure 1: Plastic Resin Identification Codes.

When considering the possibility of mixing plastic resins with sand to produce adequate engineering materials, it is important to note that different plastic resins mixed with sand will produce distinct results each suitable for particular purposes depending on the desired end product. A mixture of HDPE with sand can produce a composite which is suitable for use as a roofing material, while a mixture of LDPE or PET with sand can produce an end product which could be used as pavement tiles as well as indoor tiles. These processes can be adequately carried out in industries and commercialized as is already the case in Canada, India, Cameroon, Uganda and in some parts of Nigeria.

Next, we will go through the process of producing interlocking pavement tiles from Polyethylene Terephthalate(PET) and Low Density Polyethylene(LDPE) locally using easily accessible materials. The process described works for both PET and LDPE materials but the results that will be demonstrated are obtained by using LDPE. However, tiles produced from PET show similar results. This procedure requires little capital but a high level of carefulness and expertise. With the required meticulousity, products from this procedure can be made up to industrial standards and commercialized. This is hence, not only a breakthrough innovation in dealing with post-consumer and industrial plastics, but also a great business opportunity which is highly feasible and relevant to the Nigerian society.

## **METHODOLOGY**

### **1. COLLECTION OF NECESSARY EQUIPMENT AND SORTING OF PLASTIC.**

The first step is the collection of plastics, sand and other necessary materials needed for the process. The plastics need to be carefully sorted to avoid mixing up different plastic resins. Tools and equipment necessary for the procedure also need to be acquired. These tools are easily accessible and can be sourced locally. For this process, the needed materials include:

- Personal protective equipment such as coveralls, hand-gloves, nose-masks, safety boots, etc.
- A melting barrel.
- A tripod stand.
- Firewood.

- Stirring equipment.
- Moulds (about 4 cm deep).
- Sieves.
- Pairs of scissors.
- Engine oil.
- A table.
- Trowels.
- Spades.

## 2. PRELIMINARY PREPARATIONS.

- **The Plastics:** Plastics picked from refuse dumps and street corners are usually contaminated with dirt. Also, plastic cans usually contain little drink residues as well as brand labels attached to the body of the bottle. All these must be thoroughly removed before the plastics can be used for the process. The plastics need to be made as clean and free from contaminants as possible.

In the case of PET bottles, firstly, the bottle covers and neck lids (which are made of HDPE) are removed then the labels are torn off the body of the bottle leaving only PET material. The PET material is then put into a bath of water containing detergent where it is thoroughly washed to remove dirt and drink residues from the bottle. It is afterwards transferred to a bath of clean water where it is rinsed. The plastics are then left out to dry. After washing and drying the plastic cans, the next step is to cut them into smaller pieces. This is necessary in order to reduce the bulk size of the plastics and make them easier to handle and measure.

Plastic bags which are made of LDPE material also have to be adequately prepared before they can be processed. They also have to be washed, rinsed, dried and shredded before they can be mixed with sand. The shredding process can be carried out industrially using a shredding machine. Locally, a pair of scissors and cutters can be used.

- **The Mixing Barrel:** The mixing barrel is the container where the grinded plastics are melted and then mixed with sand. An oil drum which is open at one end can be utilized for this purpose. In preparation, the barrel is also washed and rinsed thoroughly to get rid

of any impurities which may be present. The metal drum is then set up on a tripod stand. The purpose of the tripod stand is to allow space for wood which will serve as fuel.

- **The Mould:** Another material which needs to be washed and prepared is the mould. After washing, the mould is oiled on the inside. The purpose of the oil is to prevent the mixture of plastic and sand from sticking to the body of the mould.
- **The Sand:** The sand to be used has to be fine sand usually used in construction. As a preparatory measure, the sand is sieved to break up lumps and achieve a uniform blend of sand. This serves to avoid the possibility of pockets of air or pores in the finished tile.

### 3. PROCEDURE:

- **Step 1 (Melting The Plastics):** The grinded plastic is transferred to the barrel in a definite proportion and heat is applied to the system. The plastic is allowed to heat up and melt until a black viscous liquid is obtained. During this process, the setup is constantly stirred to ensure a uniform melt and avoid the formation of clusters or precipitates. The fire should not get too hot and the plastic should not be heated to the boiling point.
- **Step 2(Mixing With Sand):** After the plastic has melted, a definite amount of sand is added to the setup. The properties of the finished tile depend on the mix ratio of the sand and plastic. For interlocking pavement tiles, a mixture of 75% sand and 25% plastic is suitable. Depending on the desired result, whether tiles or slabs or bricks, the mix ratio can be altered to obtain the specific properties. After the sand is added, the setup is stirred steadily and thoroughly to make sure the sand and plastic are uniformly blended. When the sand is added, the internal energy of the setup decreases, and so it is important to keep on applying heat while mixing the sand and liquid plastic.
- **Step 3(Mould):** The mixture of sand and molten plastic, at this point, looks like a grey coloured paste. The mixture is quickly transferred using a spade to the oiled mould. It is important to ensure that the mixture is well spread out in the mould to avoid a non-uniform finished product. Using a hand trowel, the surface of the tile is smoothened. It is also necessary to apply pressure and make necessary adjustments to ensure there are no air gaps in the tile. After a few minutes of setting the tile using the hand trowel, the



mould is removed and the tile is left to dry and solidify. The tiles solidify completely in about two hours.

### **SAFETY AND ACCURACY PRECAUTIONS.**

1. All tools used in the experiment must be cleaned before use. This is to avoid impurities which could interfere in the process and alter the final properties of the finished products.
2. Personal protective equipment (PPE) must be worn at all times throughout the duration of carrying out the process. Coveralls, hand-gloves, safety boots, masks, among other things must be worn always.
3. Plastics must be well sorted and segregated to avoid the introduction of unwanted materials into the mix.
4. During the melting process, the heat applied is to be controlled and not allowed to become excess to the point that the setup begins to boil.
5. A fire extinguisher should be kept nearby in the case of a fire outbreak.

### **QUALITY TEST.**

In order to ascertain the suitability of the finished product for application as pavement tiles for domestic use, it is important to pass them through a series of tests to determine its quality. Some important tests to be carried out are;

- Water Absorption Test.
- Abrasion Resistance Test.
- Impact Resistance Test.
- Transverse Strength/Flexural Test.
- Tensile Test.
- Hardness Test.

**WATER ABSORPTION TEST:** This is the test carried out to determine the amount of water absorbed under specified conditions. The test procedure involves comparing the weights of the materials when they are dry and also when they have been immersed in water and finding their percentage weight difference.

**ABRASION RESISTANCE TEST:** Abrasion is the process of scraping or wearing away due to contact with another material. This test measures the materials ability to resist abrasion. The resistance of materials to abrasion can be determined by a variety of methods. Specified abrasives can be applied to the material and its reaction, observed.

**IMPACT RESISTANCE TEST:** This test determines the ability of the material to withstand impact. Impact test determines the energy absorbed by a material during fracture. Impact resistance can be tested using some of the pendulum methods which include the Izod test and the Charpy tests. The Izod impact test is carried out using a machine known as the Izod impact tester. The arm of the tester is raised to a particular height and allowed to hit a sample of the material. The energy absorbed by the sample is then calculated by from the height the arm moves to after hitting the sample.

**TRANSVERSE STRENGTH TEST:** This can be defined as the amount of stress in a material before it yields in a flexural test. The test is usually carried out by the application of load to a material until rupture. Noting the load applied, the length, width and thickness of the material, a formula can be used to calculate the transverse or flexural strength of the material.

**TENSILE TEST:** Tensile testing is a common method of mechanical testing technique which determines the tensile strength (the ability to withstand tensile loads) of a material. It is a destructive test whereby controlled tension is applied to a sample until failure.

**HARDNESS TEST:** The hardness of a material is defined as a measure of its resistance to localized plastic deformation induced by either mechanical indentation or abrasion. The hardness of a material can be determined by pressing an indenter into the surface of the material and measuring the depth of the penetration made by the indenter.

These tests will give information on the properties of the manufactured tiles to determine their suitability for use. Some of these experiments and tests have been carried out on plastic tiles and their results are outlined below.

## **TEST RESULTS.**

According to Momin *et al.* (2014), “test results obtained from tiles made from plastic and sand have shown better results as compared to cement tiles”. They carried out tests on different mix

ratios of sand to plastic and the results of their tests on the water absorption, strength, abrasion and impact resistance are shown in table 2.

**Table 2:** Test Results On Plastic Tiles.

Test	Plastic percentage in the mix				Normal cement tile
	30%	40%	50%	60%	
Water absorption (%)	3.80	3.50	2.34	1.01	9.5
Transverse strength (N\mm <sup>2</sup> )	10.80	13.74	20.80	26.29	22.75
Abrasion resistance (cm)	0.90	0.82	0.24	0.24	0.79
Impact resistance (cm)	27	30	39	50	30

The above information can be better illustrated by plotting graphs of the tiles obtained from different mix ratios of sand to plastic and normal cement tiles against their properties.

- **WATER ABSORPTION.**

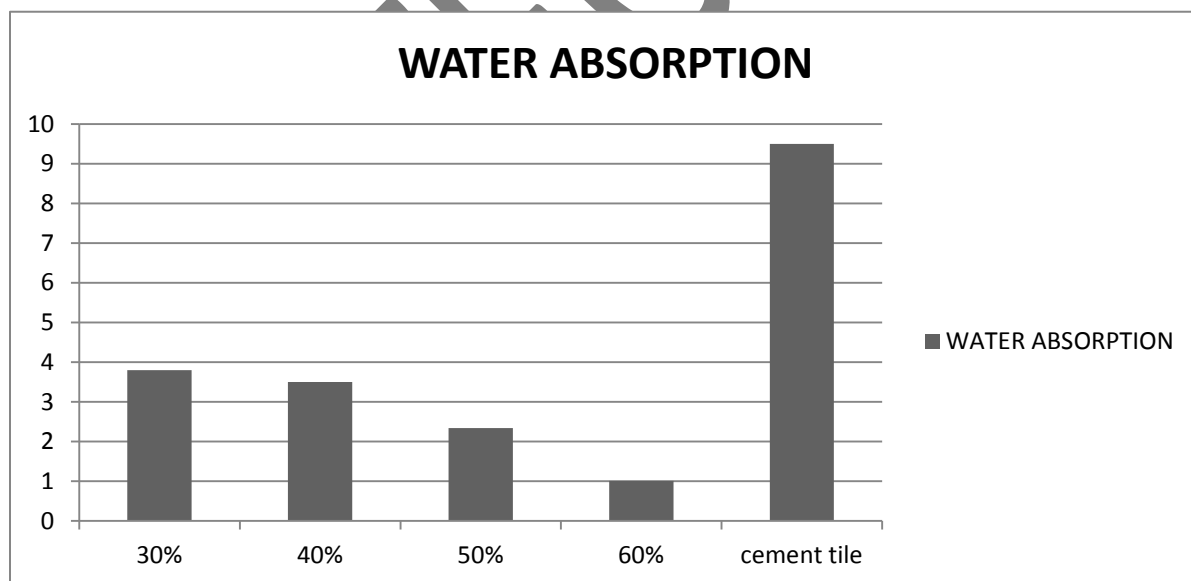
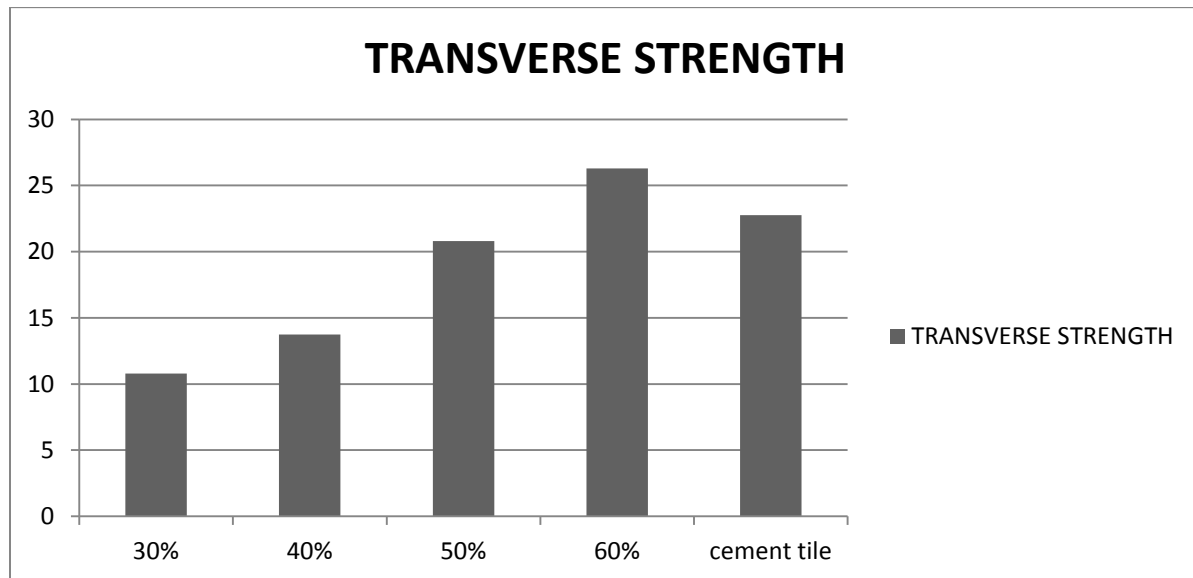


Figure 2: Water Absorption Test.

From figure 2, we can see that plastic tiles have very low rates of water absorption which is an essential quality for pavement tiles. It is also shown that higher amounts of plastic in the mixture produce lower rates of water absorption.

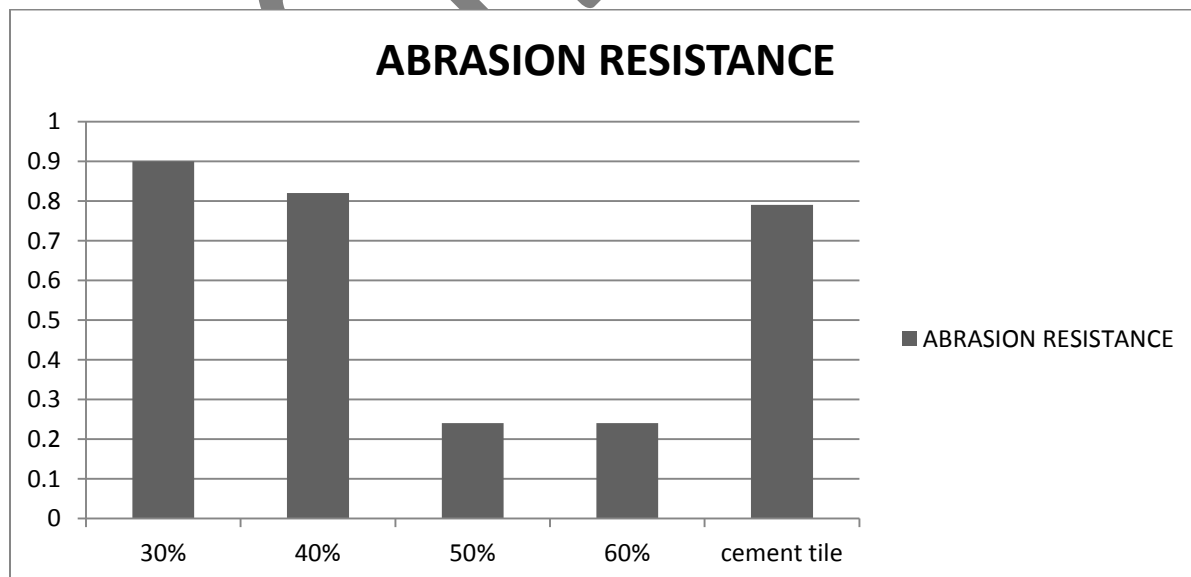
- **TRANSVERSE STRENGTH.**



**Figure 3:** Transverse Strength Test.

A high amount of transverse strength is also a necessary quality for pavement tiles. A mixture of 30% plastic and 70% sand shows a rather low level of transverse strength. However, increasing the amount of plastic in the mixture improves the transverse strength of the tile as shown in Fig 3

- **ABRASION RESISTANCE.**



**Figure 4:** Abrasion Resistance Test.

Plastic tiles also show suitable levels of resistance to surface abrasion as can be seen in Fig 4. Greater amounts of fine sand are necessary in the mix to improve levels of surface abrasion resistance.

- **IMPACT RESISTANCE.**

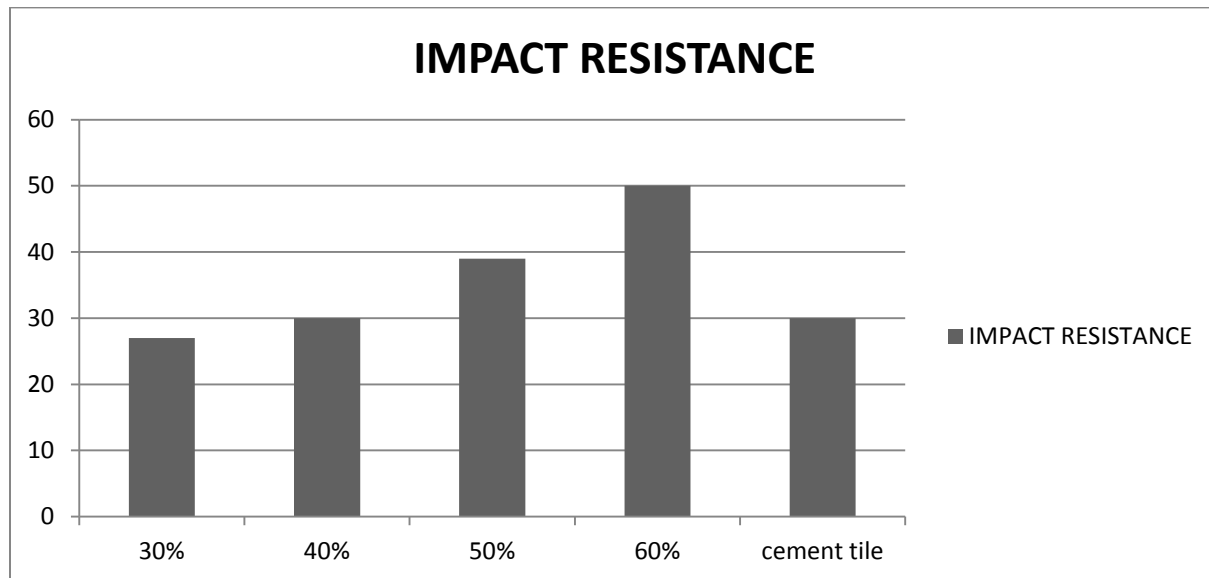


Figure 5: Impact Resistance Test.

Also, as shown in Fig 5, tiles made from plastic and sand are very resistive to impact and do not break easily. The tiles can be produced with impact resistance value set to be higher than that of the conventional cement tile depending on the mix ratio.

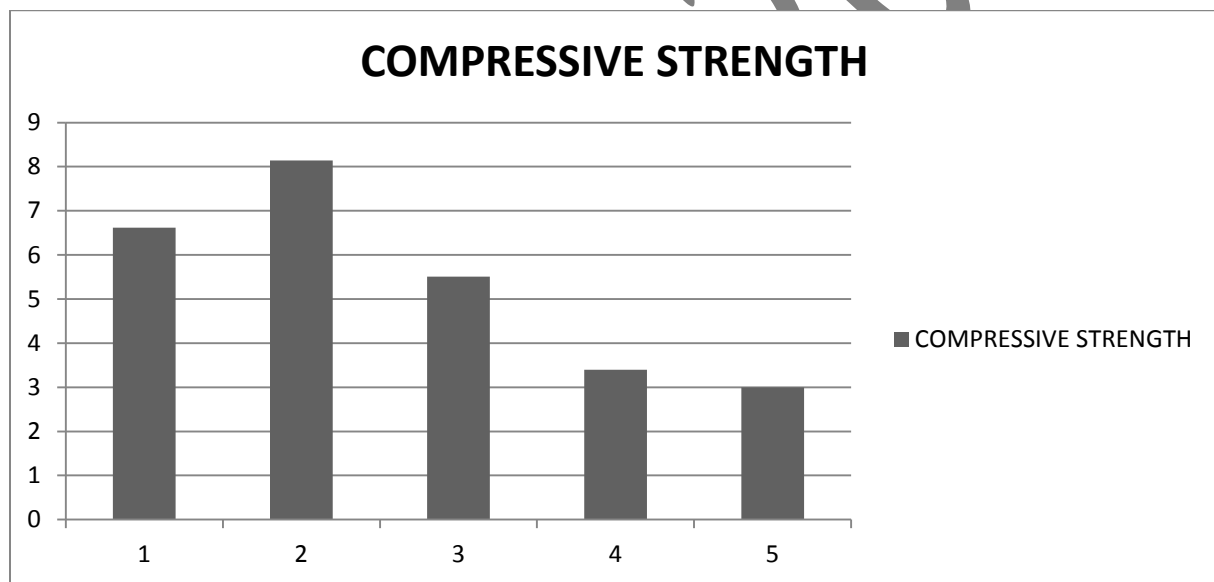
Test results as carried out by Bhatia *et al.* (2019) shows results of the compressive and tensile tests on tiles made from a mixture of plastic and fine sand. Their results are illustrated below:

The test shows results for varying ratios of plastic to sand. The varying ratios are shown in Table

Table 3: Plastic To Sand Ratios And Their Designations.

Designation	Plastic : Sand ratio
1	1 : 2.5
2	1 : 3.0
3	1 : 3.5
4	1 : 4.0
5	1 : 4.5

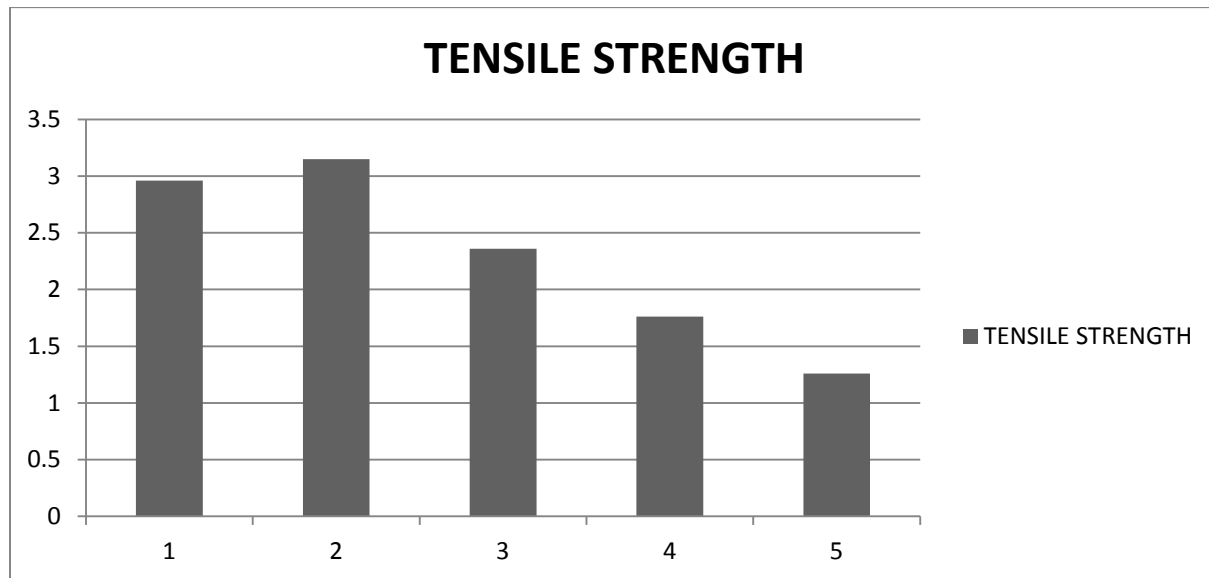
- **COMPRESSIVE STRENGTH.**



**Figure 6:** Compressive Strength Test.

The high levels of compression strength shown by the plastic tiles show their resistance to compressive load. This property is quite essential as tiles in use come under compressive load constantly.

- **TENSILE STRENGTH.**



**Figure 7:** Tensile Strength Test.

The tensile test measures the material's resistance to tension or tensile loads. The plastic tiles have also shown suitable qualities in this regard.

## **DISCUSSION**

This is a very interesting subject that requires a lot of investigation and development. Wastes are a major problem in Nigeria and plastic materials constitute a significant amount of solid municipal waste. The method described above shows the potential of post-consumer plastics. Plastics can be recycled to make a wide variety of useful items including clothing materials, fuel for diesel engines and tiles (as described above).

As engineers, we are saddled with the duty of applying the knowledge of science to solve human problems. This method of producing tiles from a blend of plastics and fine sand provides a good alternative to disposing plastic wastes. It also provides yet another option to the list of already existing plastic recycling technologies. This method should be employed and appropriately commercialized. A lot of jobs can be created and lives improved by the application of the above described technology on a medium or large scale. The tiles produced from this method, as have

been shown above, show adequate qualities for application in households, institutions and any other kind of structure where interlocking pavement tiles are to be installed and therefore can be produced industrially and sold to make profit.

## **CONCLUSION**

As already stated, the massive amount of waste products generated in Nigeria every single day is something that we must start to think of ways of addressing. Some wastes are recyclable, others are not. Most unrecyclable waste products are organic and biodegradable and therefore do not pose much of a threat to man and the environment. However, non-biodegradable wastes are dangerous to the environment and invariably to man. The litters of plastic waste which block drainage systems and eventually contribute to flooding during the rainy season, the contamination of the land and air are some of the effects of improper management techniques of non-biodegradable wastes such as plastics.

Plastics can be recycled through a process which involves grinding and mixing the plastics with fine sand, heating up the mix in a barrel and casting the resulting paste-like material into a mould to shape and allowed to cool and solidify. The product of this process is a tile which shows suitable qualities be used for outdoor pavements.



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