Utilization and Durability of PET Waste Aggregate for Floor Tiles Production

Omosebi Taiwo O, Noor Faisal Abas

***Abstract:** Managing plastic waste is a global problem that threatens the safety of our environment due to its high generation and non-biodegradability. However, the PWs must be carefully managed in order to reduce the pollution involved in incineration and disposal of landfills. Plastic waste can be recycled into fresh, functional construction materials. In this study, the shredded PET waste aggregate from the recycling centre was heated to 230 0C and used as a binder for the full substitution of cement with river sand for the manufacture of floor tiles. The properties of the aggregate materials and floor tiles (including their distribution of particle size, silt, clay and dust content, relative density, water absorption, porosity, flexural and compressive strength) were evaluated on various PET wastes: sand mixing ratio, 100%, 90%, 70%, 50% and 30%. Results showed that the tiles formed by 30 per cent PET and 70 per cent River Sand (3:7) had a higher density, flexural and compressive strength than the other percentages of the mixture. The compressive strength of the tiles produced with 30% PET waste composition was higher than that of cement (with 28 days of curing) for residential buildings. Based on the strength, low water absorption and eco-friendliness, PET waste can be used for floor tiles with 30% PET substitution based on the test results.*

***Keywords:** Paving stones; Plastic wastes; Pollution; Interlocks; Aggregates; Recycling; etc*

I.INTRODUCTION

Plastic is a liquid, durable polymer based on hydrocarbons; it may be either a thermoplastic or a thermosetting material. Thermoplastic is a plastic material which, when cooled, can soften when heated and harden; hence, it can be formed into various forms. When solidified, thermosetting materials cannot be re-melted; they are used primarily as Bakelite[1]. Because of their lightweight, flexible touch, versatility, non-corrosiveness and toughness, plastics are widely used. Plastics are safe packaging materials and containers but plastic waste is a significant source of environmental pollution; after incineration they emit toxic gases and are not biodegradable. Allegedly, plastic products are carcinogenic, as they contain chlorine and other carcinogens. Plastic waste combustion creates poisonous gases such as phosgene, carbon monoxide, ammonia, sulphur dioxide, nitrogen oxide and other potentially damaging, lethal dioxins. Given that plastic waste accounts for the highest percentage of waste generated worldwide, such waste needs to be better handled. Plastics are widely used as packaging materials but their waste can be used in the construction industry to manufacture building products, such as floor tiles, roof tiles, building blocks, etc. This will reduce the building costs and mitigate emissions from the environment. Plastic wastes, for example, can be combined with sand and other chemicals to manufacture building materials [5].

Recycled plastic waste is increasingly replacing traditional materials such as cloth, concrete, wood / timber, and sand, protecting the natural world as a result. Proper handling of solid wastes through recycling into new goods would help foster a healthy climate, natural resource protection and cheap raw materials [4]. In the other hand, the absence of effective solid waste disposal would contribute to the current environmental problem; thus, solid waste must be better handled by converting it into fresh, usable items [3, 5]. Since plastic waste cannot easily decompose and is created in large amounts, its disposal into landfills may not be a permanent solution [13]. Recycling is not actually as simple plastic materials processing technique, since it is a labor-intensive process [9]. Plastics were historically deemed environmentally sustainable products that conserve resources, reduce the production of raw materials and tackle climate change. However, the rate of production of plastic waste has risen exponentially, and management has become a serious concern. Researchers have also proposed the use of plastic waste in concrete construction, for two key reasons: (i) Solving the pollution challenge associated with their disposal; and (ii) reducing building costs, as they are available in vast quantities [9]. Cement is commonly used as a binder in the construction industry; however, the high cost of cement has discouraged many people from building their homes and hindered the growth of the construction sector [15][16]. It is therefore important to find an acceptable substitute for this costly and necessary building material [17, 18]. Tiles are structural and decorative objects used to cover floors, roofs and walls. Most of them are used in a variety of locations, such as building floors, partitions, warehouses and stores, art galleries, industrial garage, classrooms and factories. Tiles may also be extended to include small pieces of non-ceramic surface material such as tapestry, wood, stone or cork [19]. The aim of this research is to investigate the feasibility of using PET waste as a binder for floor tiles production in the complete substitution of cement. The key objectives of this research are to determine the feasibility of recycling PET waste for the manufacture of floor tiles, as well as to investigate the physical properties and strength of the floor tiles.

II. MATERIALS & METHODS

2.1 Materials used to make the Floor Tiles

The materials used in making the floor tiles were sourced locally; the locally-sourced materials include plastic wastes, sand, metal mold, wood stirrer, sieve, hand gloves, coal pot, nose mask, and engine oil.

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2.1.1. Production of the floor tiles

Followed the following measures to produce floor tiles:

I. Processing of sand and PET waste

Shredded plastic water bottles obtained from a Waste Resource Management Company located at 14000 Bukit Mertajam, Penang, Malaysia were the PET waste used in this report. The river sand used was supplied to the Resource Laboratory for Housing, Building, and Planning. Figs. 1 & 2 showed shredded PET waste samples and a sample of river sand, respectively.


Fig. 1. Shredded PET wastes **Fig. 2. River sand**

The shredded PET wastes are heated and melted inside the aluminum pot at a temperature of 230oC before applying a separate proportion of the fine river sand to the molten plastic waste. The mixture was homogenized and poured into a 5 cm thick iron mold for quick processing, which was lubricated with the engine oil. For due consideration the side of the mold was constantly banged. After one hour, the samples were de-molded, cooled and cured for forty-eight hours before processing under ambient temperature (see Figures 3 - 6).




Fig. 3. Melting of PET waste Fig.4. PET waste & sand mixture Fig. 5. Floor tile mold Fig.6. Plastic floor tile produced.

III.EXPERIMENTAL ASSESSMENT

The aim of this study is to determine the physical and mechanical properties of roofing tiles produced by PET waste. The following experiments were carried out on both aggregates and tiles.

3.1 Analysis of physical properties of materials (aggregates)

3.1.1 Seven Analysis and Fineness Modulus

The test shall be carried out on river sand and PET waste aggregates to determine the definition of the particle size distribution of aggregates and the fineness modulus, which shall signify the fineness and uniformity of aggregates. The effect would be influenced by the overall proportion as well as the workability, porosity, shrinkage and durability of the tiles. This test is conducted in accordance with ASTM C-136.

3.1.2. Silt and dust contents of sand

The percentage of silt and sand dust test performed to decide the amount of silt or particle finer than 74um which produces a lower bond between the aggregates and may influence the quality and strength of the tiles. This test is conducted in accordance with ASTM C117.

3.1.3 Specific gravity and absorption capability

This is used to determine the bulk specific gravity at the oven-dry and saturated surface base, apparent specific gravity, and absorption of the fine aggregate. It is the ratio of the sum to the mass of the actual volume of water. According to ASTM C33, the bulk of natural aggregates have a basic gravity of 2.4-3 and 0.2 per cent-2 per cent absorption. Low specific gravity may mean high porosity and contribute to weak longevity and low strength, since density is significantly dependent on specific gravity[20].

3.2 Testing of the Tile Mechanical Properties

3.2.1 Test of Dry Density

The test is intended to assess the dry density of plastic tiles. Samples are dried and measured, the weight in the sample is reported and separated by its volume in order to achieve a dry density.

3.2.2 Water absorption

The amount of increase in the mass (expressed as a percentage of dry matter) of the tiles is determined by the dry mass of the tiles after being dried in the oven as specified and cooled in the desiccator, the tiles are immersed in water for 24 hours as specified show in figure 7 and re-weighed. The device used is purified water, balance of weight, oven and balance of weight. The frictional difference in mass is measured based on various compositions of the individual tiles. The test shall be done in compliance with ASTM C373. The percentage of the mass (percent of the absorption of water) is calculated by

$$\% \text{ water absorption} = \frac{W2-W1}{W1} \text{X } 100$$

Where:

W_1 is the dry weight (weight after oven dried)

W_2 is the wet weight (weight after soaking in water)

Fig. 7. Water Absorption test.

3.2.3 Compressive Strength

This test evaluates the action of the materials under crushing pressure. Specimen compression deformation at different loads is noted. The specimen shall be placed parallel to the surface between the compressive plates see figure 7 below. The standardized rate of compression test is performed. Full load (KN) and compressive strength (MPa) are reported.

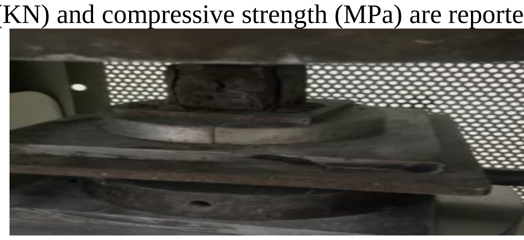

Fig. 8. Compressive Strength Test

3.2.4 Flexural Strength

The flexural strength was measured in conjunction with IS 516;1959[21] to calculate the overall bending load of the stone. Sample samples were mounted parallel to the 3-point loading system and crushed see Figure 8 below. Flexural strength is calculated as

$F = 3PL/2bd^2$

Where:

P = Max. breaking load

L = Length of the specimen/ beam

B= Width of the specimen/ beam

D= Width of the beam/ specimen

Fig. 9. Flexural strength test.

3.2.5 Test for chemical tolerance

3.2.5.1. Alkali Test

The solution of 20% sodium hydroxide (NaOH) was prepared by combining NaOH granules with purified water, and the specimens were dipped in the solution for 72hours. The weight of the specimens was observed prior to immersion and physical description see figure 9.

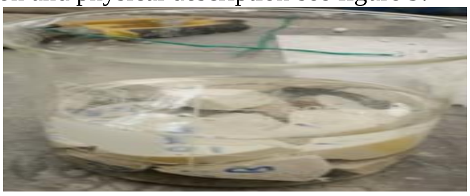

Fig. 10. Chemical resistance test

3.2.5.2 Examination of acid

The specimens were dipped to 10% of the concentrated hydrochloric acid (HCL) for 72 hours, the change in the mass of the specimens was noticed in the physical appearance.

IV.RESULTS & DISCUSSION

4.1 Sand Sieve analysis

The sieve analysis test is aimed at evaluating the sand aggregate rates. The test result (shown in Table 1 & Fig. 11) shows accurate gradation of the sand sample. The values obtained for uniformity coefficient (0.2), gradation coefficient (0.6), and fineness modulus (1.93) supported the aggregate 's suitability for construction purposes as per the ASTM C33 specification.

Table 1 Sand particle size distribution; the weight of the dry sample used = 500 g

Sieve no	Diameter (mm)	Soil retained (g)	Soil retained (%)
5.00 mm	5	0.00z	0.00
2.36 mm	2.36	1.00	0.20
1.18 mm	1.18	23.00	4.70
600 µm	0.6	113.00	23.40
300 µm	0.3	191.00	39.60
150 µm	0.15	114.00	23.60
Pan		41.00	8.50
	TOTAL:	483.00	

Fineness Modulus = 1.93

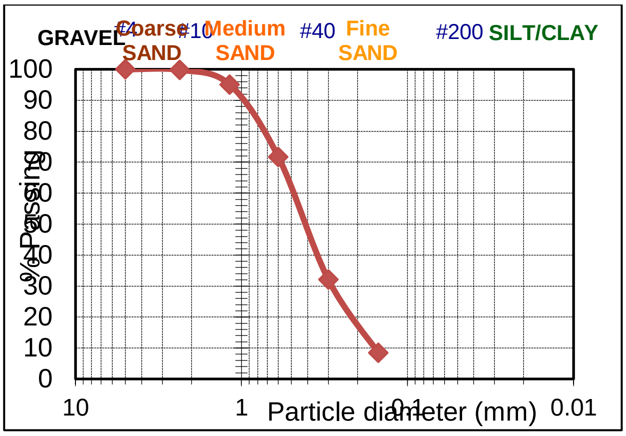

Figure 11: Particle size distribution of river sand

4.2. Relative Density and Water Absorption of Sand Aggregates.

Approximately 500 g of the sand sample was immersed in water for 24 hours to assess the sand's relative density and water absorbability. Until sun-drying the sand and re-weighing on dried soil, the original weight of the soaked sand has been observed. Until calculating the total relative density and water absorption potential the sand was further dried for 24 hours. The findings revealed that the sample had an average relative potential of 2.38, and a percentage of water absorption of 0.07 percent (Table 2). The outcome was within the range set by ASTM C128 for fine aggregates. It has been proposed that the relative density of natural aggregates could be within 2.4- 2.9 [24.30]

Clay, Silt and Dust Content

The soil sample (500 g) was dried for 24hrs and washed thoroughly with water before being sieved and measured by a 75-um sieve. The soil sample was oven-dried again for 24 hours and re-weighted before measuring the percentage of silt, clay, and dust content as follows:

Dried weight (A) = 487 g Pre-wash sample

Dried weight (B) after washing sample = 478 g

Silt, clay &dust content (percentage) =

= x 100 (487- 478/478)

= x 100 (9/478)

= 1.88 %

4.4 PET Wastes Sieve Analysis

Also, Sieve analysis on the PET waste aggregates was done to assess the gradation.

The result (Table 3 and Fig. 12) revealed that the aggregates' fineness module was 2.75 indicating a good gradation of the aggregates for construction purposes in compliance with ASTM C33 requirements.

Table 2.The particle size distribution of PET waste aggregates; (weight of dry sample= 500g)

Sieve no:	Diameter (mm)	Soil retained (g)	Soil retained (%)	Soil passing (%)
28.0 mm	28	0.00	0.00	100.00
20.0 mm	20	0.00	0.00	100.00
10.0 mm	10	2.20	0.44	99.56
5.0 mm	5	380.30	76.09	23.47
2.36 mm	2.36	94.00	18.81	4.66
1.18 mm	1.18	22.00	4.40	0.26
Pan		1.30	0.26	0.00
Total:		499.80		

Fineness modulus of PET aggregate=2.75

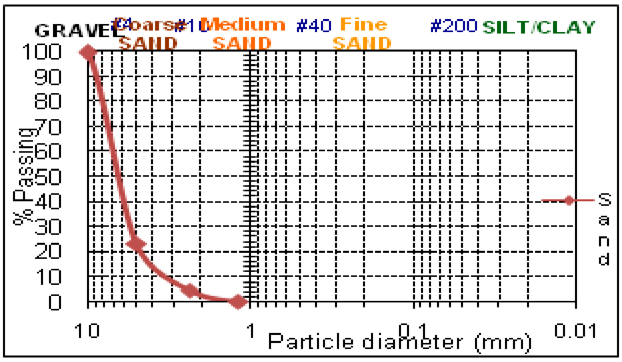

Figure 12.The particle size distribution of PET waste aggregates

4.5 Density of the Plastic Tiles

The floor tile density was determined, and the result showed that the tiles produced with 100% PET had the lowest density (1,070.13 kg / m3), while those produced with 30% PET content had the highest density (1,946.7 kg / m3), as shown in Fig. 13. Noticeably, increases in the PET content decreased the PET composite density.

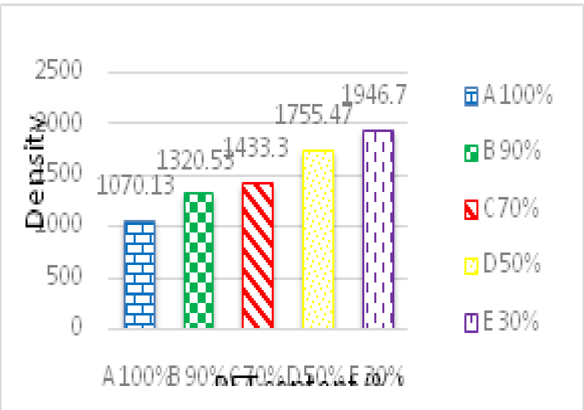

Figure 13: Average density of the floortile

4.6 Compressive Strength of the Floor Tile:

PET floor tiles containing 100% PET exhibited the lowest compressive strength value (0.012N / mm2), whereas those produced with 30% PET content had the highest compressive strength value (19.708 N / mm2), as shown in Fig. 14. The value of the compressive strength increased steadily with the sand content but decreased with the increase in PET content. In this study the observed compressive strength value was significantly higher than the residential concrete value of 28 days (17 N / mm2; $p<0.05$). The standard ASTM C39 recommended a compressive strength of 2500 psi/17.237 MPa/17.237 N / mm2 for residential building.

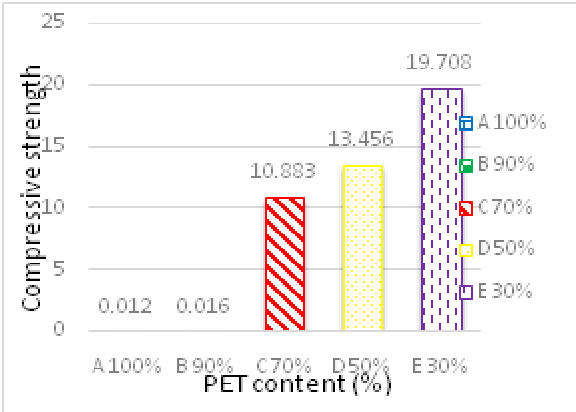

Figure 15: Average compressive strength of the floor tile

4.7 Porosity of the Tile.

The PET plastic composites produced with 50 % PET content presented the highest porosity value of 2.97 % while those containing 100 % PET achieved the lowest porosity value of 1.35 % (see Fig. 15). This implies that the porosity value of the PET polymer concrete decreases with increasing PET content.

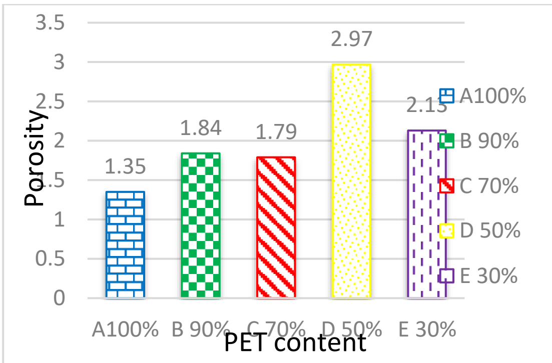

Figure 15. The average porosity of the floor tile

4.8 Flexural strength of the Floor Tile

Plastic floor tiles produced with 30 percent PET and 70 percent sand recorded the highest flexural strength (5.828 N/mm2), while those produced with (100 percent PET) and (90 percent PET + 10 percent sand) displayed the lowest values (see Fig 16). This means the floor tiles' flexural intensity is specifically a function of the sand content but inversely related to the PET material.

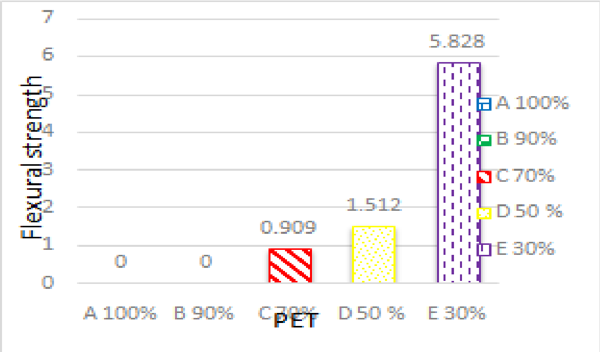

Figure 16. Flexural strength of the Floor Tile

V. CONCLUSION

Plastic waste is not biodegradable and can take many years to decompose and pose a danger to the environment. Plastic waste can be recycled into construction materials asway to reduce the cost of building materials and thereby preserve the environment. The paper discussed the potential for the manufacture of PET polymer concrete for floor tiles using PET waste. The study of the developed floor tiles showed that PET waste (based on its physical and mechanical performance) can serve as a binding agent for the complete replacement of cement in the production of floor tiles. However, the test results showed that the total PET content for maximum production should not exceed 30 per cent PET + 70 per cent sand, as this combination would produce floor tiles with higher compressive strength than cement concrete after 28 days of curing. The 30% PET tiles also had a higher density, flexural and water absorption potential than all of the other percentage formulations. In conclusion, the use of 30% PET waste and river sand can yield solid, inexpensive and eco-friendly floor tiles that can be used in many areas, most especially in frost and water-logged environment due to thier very low water absorption.

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