Mechanical Properties and Durability of PET waste Aggregates in Roof Tiles Production.

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***Abstract:** Managing plastic waste is a global challenge that challenges the protection of our ecosystem due to its high rate of generation and its non-biodegradability. PWs must, however, be carefully handled to mitigate the emissions involved with their incineration and dumping into landfills. Plastic waste can be recycled into new usable building materials. In this analysis, shredded PET waste aggregate from a recycling center was heated at 230 ^{0}C and used as a binding aggregate incomplete replacement of cement with river sand to produce floor tiles. The properties of the aggregate materials and roof tiles (including their distribution of particle size, silt, clay and dust content, relative density, water absorption, porosity, flexural and compressive strength) were tested on different PET waste: sand mixing ratio, 100%, 90%, 70%, 50%, and 30%. Results revealed that the tiles produced by 30% PET and 70% river sand (3:7) achieved higher density, flexural and compressive strength than the other percentages of the mixture. The compressive strength of the tiles produced with 30 percent PET waste composition was greater than that of cement concrete (at 28 days of curing) for residential buildings. As a result of this low water absorption and eco-friendliness, PET waste can be used for roof tiles at 30 percent PET substitution based on the test results.*

***Keywords:** Plastic wastes; Pollution; Aggregates; Recycling.*

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 that, 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. Plastic waste combustion creates poisonous gases such as phosgene, carbon monoxide, ammonia, sulfur 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 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].

Manuscript received on January 21, 2021.
Revised Manuscript received on January 29, 2021.
Manuscript published on January 30, 2021.
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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]. On 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 constructing their homes and has impeded the growth of the construction sector [15][16]. Therefore, it is important to find an acceptable substitute for this costly and necessary construction material [17, 18]. Tiles are structural and decorative objects which are used to cover roofs and walls. Most of them are used in diverse places such as building roof, partitions, warehouse and store, art galleries, industrial garage, classroom, and factory. Tiles may also be expanded to include small pieces of non-ceramic surface material such as tapestry, wood, stone, or cork [19]. This research aims to investigate the feasibility of using PET wastes as a binder to manufacture roof tiles with incomplete substitution of cement. The key aims of this research are to determine the durability of recycling PET wastes for the manufacture of roof tiles, as well as to investigate the physical properties and strength of the roof tile.

II. MATERIALS & METHODS

2.1 Materials used to make the Roof Tiles

The materials used in making the roof 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.

2.1.1. Production of the Roof tiles

Followed the following measures to produce roof 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 discarded PET waste bags and a sample of river sand, respectively.

Figure 1 : River sand sample

Figure 2 : Sample of PET wastes

The shredded PET wastes are heated and dissolved inside the aluminum pot at a temperature of 230 ^{0}C 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 engine oil. After one hour, the samples were de-molded, cooled, and cured for forty-eight hours before processing under ambient temperature (see Figures 3 & 4).

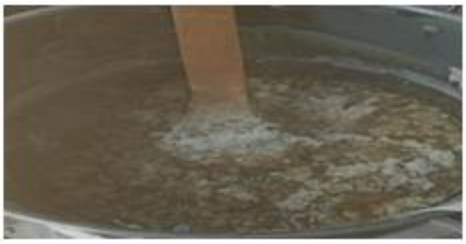

Figure 3 : Melted PET wastes mixed with sand

Figure 4. PET plastic roof tiles samples

III. RESULTS & DISCUSSION

3.1 Sand Sieve analysis

The sieve analysis test is aimed at evaluating the sand aggregate rates. The test result (shown in Table 1 & Fig. 5) shows the 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 standard.

Table 3.1 Sand Particle size Distribution; Weight of Dry Sample (g):500.0

Sieve Number	Diameter (mm)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
5.00mm	5	0.00	0.00	100.0
2.36mm	2.36	1.00	0.20	99.8
1.18mm	1.18	23.00	4.70	95.1
600μm	0.6	113.00	23.40	71.7
300μm	0.3	191.00	39.60	32.1
150μm	0.15	114.00	23.60	8.5
Pan		41.00	8.50	0.0
	TOTAL:	483.00		

The Fineness Modulus is 1.93

Table 3.3. PET Wastes Particle Size Distribution Test Results; Weight of Dry Sample (g): 500.0

Sieve Number	Diameter (mm)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
28.0mm	28	0.00	0.00	100.00
20.0mm	20	0.00	0.00	100.00
10.0mm	10	2.20	0.44	99.56
5.0mm	5	380.30	76.09	23.47
2.36mm	2.36	94.00	18.81	4.66
1.18mm	1.18	22.00	4.40	0.26
Pan		1.30	0.26	0.00
	TOTAL:	499.80		

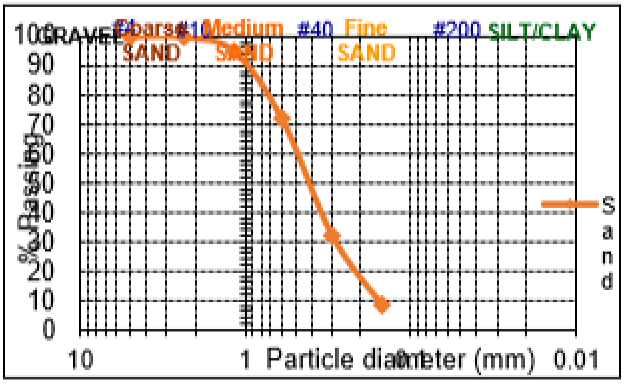

Figure 5 : Particle size distribution of river sand

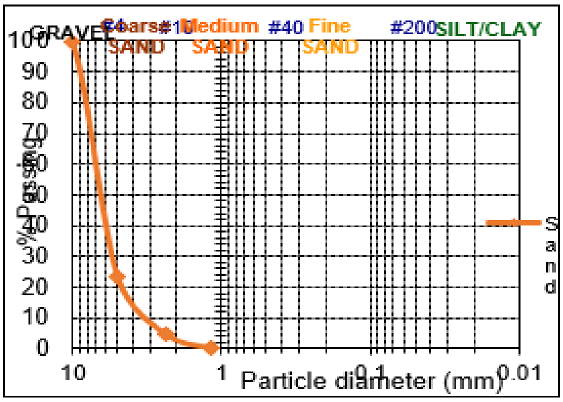

Figure 6 : Particle size distribution of

3.2. 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 (Kosmatka et al., 2013).

Table 3.1. 2: Determination of Relative Density and Water Absorption of Sand Aggregate.

TEST NO:	A (g)	B (g)	C (g)	D (g)	Relative Density (Oven-Dried Basis) $\frac{D}{A-(B-C)}$	Relative Density (Saturated Surface Dried) $\frac{A}{A-(B-C)}$	Water Absorption % of Dry Mass $\frac{100\,(A-D)}{D}$
1	471	1,801	1,540	471	2.24	2.24	0
2	498	1,819.3	1,508.1	497	2.66	2.67	0.20
3	497	1,822.2	1,506.6	497	2.74	2.24	0
AVERAGE					2.55	2.38	0.07

3.3. 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:

First dried weight A= 487g (before washing)
Second dried weight B =478g (after washing)
% of Silt, Clay & Dust = A-B/B X 100
= 487-478/478 X100
= 9/478 X 100

% of Silt, Clay & Dust = 1.877%

3.4 PET Wastes Sieve Analysis

Also, Sieve analysis on the PET waste aggregates was done to assess the gradation. The result (Table 3 and Fig. 6) 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.

3.5 Density of the PET plastic roof tile

The roof tile density was determined, and the result showed that the tiles produced with 100% PET had the lowest density (1070.10 kg / m3), while those produced with 30% PET content had the highest density (1946.69 kg / m3), as shown in Fig. 7. Noticeably, increases in the PET content decreased the PET composite density.

3.6 Compressive Strength of PET plastic roof tile

PET roof 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 (19.71N / mm2), as shown in Fig. 8. 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 force of 2500 psi/17.237 MPa/17.237 N / mm2 for residential building.

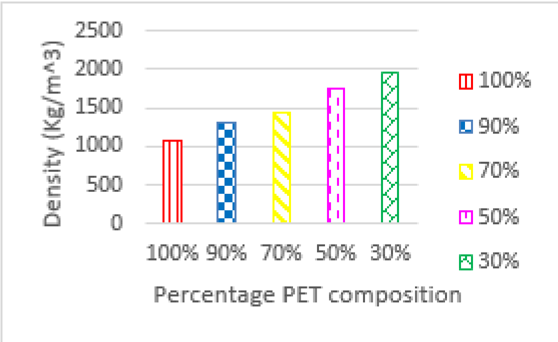

Figure 7 : Average density of the samples

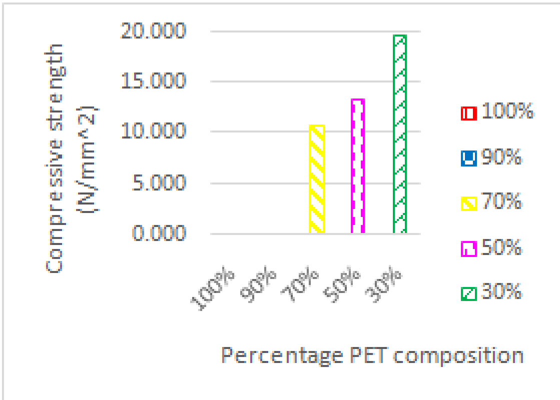

Fig. 3 : Average compressive strength values of the respective samples

3.7 Porosity of the PET plastic roof tile

The PET plastic composites produced with 50 % PET content presented the highest porosity value of 2.971 % while those containing 100 % PET achieved the lowest porosity value of 1.351 % (see Fig. 9). This implies that the porosity value of the PET plastic roof tiles decreases with increasing PET content.

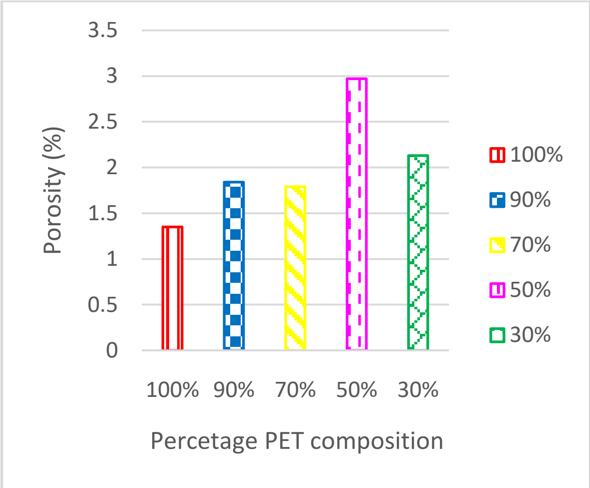

Figure 4 : Porosity of the samples

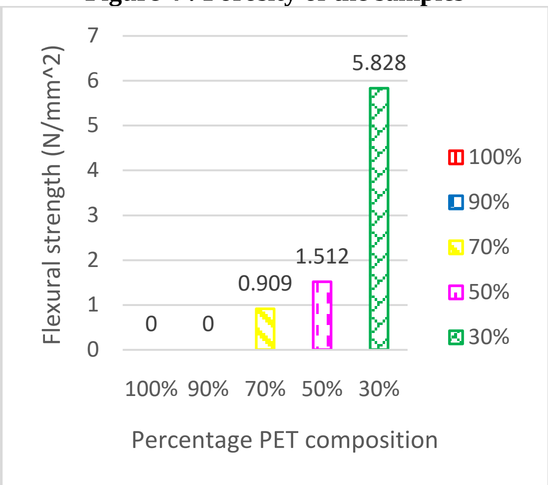

Figure 5 : Flexural strength of the samples

3.8 Flexural strength of the PET plastic roof tile

Plastic roof 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 10 above). This means the roof tiles' flexural intensity is specifically a function of the sand content but inversely related to the PET material.

IV. CONCLUSION

Plastic waste is not biodegradable, which can take several years to decompose, thereby posing a hazard to the ecosystem. Plastic waste can be recycled to make construction materials as a solution for reducing the cost of building materials and thus protecting the world. This thesis explored the potential for the manufacture of PET polymer concrete for roof tiles using PET wastes. The study of the roof tiles created showed that PET waste (based on its physical and mechanical performance) would serve as a binding agent as a complete replacement of wood /cement in the production of roof tiles. However, the test results showed that the overall PET content for optimum output could not exceed 30 percent PET + 70 percent sand, as after 28 days of curing this ratio would yield roof tiles with higher compressive strength than cement concrete. The 30 percent PET concrete also had higher density, flexural strength, and water absorption potential than any of the other percentage formulations. In conclusion, the use of 30 percent PET waste and river sand in a cost-effective manner will yield solid and eco-friendly roof tiles. The roof tiles created can be used in many areas, especially in frost and water-logged environments.

Conflict of interest

There is no conflict of interest.

ACKNOWLEDGEMENTS

The authors are thankful to the Chancellor and management of Universiti Sains Malaysia and the School of Housing, Building and Planning, USM., for the platform made available for the research.

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