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Tiles from Recycled Plastic Bottle (Pet) Wastes and POFA: Strength Properties and Durability

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Abstract Plastic waste management is a global problem that threatens the health of our planet due to its high rate of development and non-biodegradability. Also, palm oil fuel ash (POFA) is a residue produced when waste products including palm oil fiber, palm kernel shells, and palm oil hush are burned. This study investigates the feasibility of making tiles out of polyethylene terephthalate (PET) waste bottles and POFA (Palm oil fuel ash). This study reports on the mechanical properties, durability, and chemical tolerance of PET-wall tiles. PET waste was used in different amounts with POFA by weight (from 30% to 100%). The physical and mechanical characteristics of the tiles were examined, and it was discovered that, in terms of material density and strength, tiles containing 30% PET, have highest compressive strength of 8.37 N/mm^2 while samples made with higher PET content (100%) have the least compressive strength lowest water absorption value (0.12%). All the tiles produced outperformed pure cement and ceramic tiles in terms of durability, and they have a very low water absorption efficiency; the water absorption values were between 1.82% and 0.12% and good chemical tolerance. In conclusion, based on this experimental result, PET waste bottles and POFA can be used to produce long-lasting, good strength, and highly low-water-absorption eco-friendly wall tiles for both residential and commercial applications. This possibility of producing tiles from polyethylene terephthalate (PET) waste and POFA would not only reduce the cost of construction materials but also serve as a waste diversion to reduce environmental pollution generated by plastic waste.

Keywords Polyethylene Terephthalate, Recycling, Compressive Strength, Water Absorption, POFA

1. Introduction

Plastics are widely used because they are lightweight, soft, flexible, non-corrosive, and long-lasting, and they can be thermoplastic or thermosetting. Thermoplastic is a type of plastic that softens when heated and hardens when cooled, allowing it to be shaped into a variety of shapes. When thermosetting materials solidify, they cannot be remelted and are primarily used as Bakelite [1]. Plastics are widely used because they are lightweight, soft, flexible, non-corrosive, and long-lasting. Plastics are widely used because they are lightweight, soft, flexible, non-corrosive, and long-lasting. Plastics are useful packaging materials and containers, but their waste is a major source of pollution; when burned, they release toxic gases and are not biodegradable. Since they include chlorine and other carcinogens, plastic products are said to be carcinogenic [2]. When plastic waste is burned, harmful chemicals like carbon monoxide, phosgene, Sulphur dioxide, chlorine, nitrous oxides, and other dangerous toxic substances are produced. Since plastic waste accounts for the lion's share of global waste production, proper waste management is critical [3]. Plastics are widely used as packaging materials, but their waste can be used to manufacture construction materials such as floor tiles, roof tiles, building blocks, and so on. This will reduce construction costs and pollution. Plastic waste, for example, maybe combined with sand and other additives to manufacture building materials [4,5]. Currently, recycled plastic wastes are increasingly replacing natural materials such as fiber, metal, wood/ timber, and sand, thus protecting the natural environment. Recycling solid waste into new items would contribute to a healthy climate, the conservation of natural resources, and the availability of low-cost raw materials [4]. On the other hand, insufficient solid waste disposal would exacerbate the current environmental problem; hence, solid waste must be properly handled by transforming it into new usable products [3,5]. Since plastic wastes are difficult to decompose and are manufactured in large amounts, dumping them in landfills may not be a permanent solution [6]. In the construction sector, cement is often used as a binder; nevertheless, the high cost of cement has deterred many people from building their homes and hampered the construction industry's growth [7] [8]. As a result, finding a suitable substitute for this costly and necessary building material is critical [9].

Palm oil fuel ash (POFA) is a type of ash produced by the combustion of waste products such as palm kernel shells and palm oil chaff [10]. POFA is typically dumped in landfills, causing an increase in Ash deposit year after year, which has now become a nuisance [11]. Malaysia's palm oil plantation area is estimated to be over 5.07 million hectares, according to the Malaysian Palm Oil Board [12]. According to the United States Department of Agriculture, palm oil production is expected to exceed 64.5 million metric tons in 2016 and 2017 [13]. Southeast Asian countries generate the majority of palm oil. The amount of POFA produced grows over time as the amount of palm oil produced increases. Malaysia is the world's largest palm oil exporter and producer [14]. The annual production of POFA in Malaysia is expected to be over 10 million tons [14]. Leaving this material to deteriorate is a significant environmental concern in and of itself. In Malaysia, about 1000 tons of POFA were thrown into lagoons and landfills, with little consideration given to the material's potential use in other industries [15]. As a result, innovative approaches to use waste materials while avoiding potential dangers are required. This field's researchers must concentrate on achieving higher sustainable development in the construction sector by using alternative recycled materials like palm oil waste. When it comes to cost savings, employing POFA as an aggregate in plastic tiles production will lower the cost of tiles manufacturing as well as mitigating and lowering garbage in landfills, this will benefit the ecosystem. In the 1009s, Tay [16] started investigating the potential of palm oil fuel ash as a concrete additive. Replacement of Portland cement with POFA in amounts ranging from 10% to 50% was used in the experiment. The compressive strength of the specimens was reduced when between 20% and 50% of the cement was substituted with POFA. Since then, numerous studies have been carried out in order to improve the properties of concrete. POFA, for example, was discovered to have a significant impact on preventing and decreasing sulphate attacks by Awal and Hussin [17].

Several studies have identified the possible suitability of plastic waste as building materials. Mehdi et al. [18] stated that when mixed with sand, High-density polyethylene (HDPE) plastics can be used to make roof tiles. After research, the results of their study showed that composite tiles made with 70% HDPE performed and were of higher quality. Several experimental investigations into the usage of recycled PET bottles as a substitute for natural aggregates in concrete as well as resin in polymer concrete have recently been released [19]. Akinwumi [20] demonstrated the development of stabilized soil blocks from shredded plastic waste, concluding that 1% finely shredded PET waste (size 6.3 microns) by weight could be used for active block stabilization. Kumi-Larbi [21] announced the efficient production of sand blocks using plastic waste, and their results shown that solid and long-lasting sand block could be made without using extra water, using only plastic waste. Yang [22] explored the possibility of creating eco-friendly door panels by mixing plastic waste with wood dust. In one study, shredded PET waste was used to make roof tiles and it was discovered that the sample's compressive strength decreased as the PET volume increased. Borg [23] investigated the use of PET fibers in concrete and discovered that at higher PET fiber contents, PET fibers greatly reduced the sample’s compressive strength. Al-Hadithi and Hilal [24] investigated self-compacting concrete made from plastic waste fibers and discovered as the plastic waste percentage rose, so did the sample's compressive strength. The purpose of this study is to look into the viability of employing PET waste as a binder. The primary goals of this research are to assess the feasibility of recycling PET waste to manufacture wall tiles, also, PET tiles' physical and mechanical properties will be investigated.

2. Materials & Methods

2.1. Materials

Plastic waste, metal molds, wood stirrers, sieves, hand gloves, coal pots, nose masks, and engine oil were among the locally manufactured products used to make the wall tiles. Shredded plastic bottle wastes and POFA were collected from a Waste Resource Management Company in Penang, Malaysia, at 14000 Bukit Mertajam, and a palm oil processing company in Penang, Malaysia, respectively. The shredded PET wastes were heated and melted inside the aluminum pot at 230^{0}C before adding finely dried and sieved POFA at various percentages to the melted plastic wastes. The mixture was homogenized before being poured into a 5-cm-thick iron mold lubricated with engine oil for easy removal. After one hour, the samples were de-molded, cooled, and cured for 48 hours at room temperature before testing (see Table 1).

Table 1. Different contents of PET waste and POFA used in this study

Sample	PET waste content (wt. %)	POFA content (wt. %)
PPT1	30	70
PPT2	50	50
PPT3	70	30
PPT4	90	10
PPT5	100	0

Note: wt. % = weight percentage

2.2. Characterization

The compressive strength of plastic composite tiles was determined using Gotech Universal Testing Machine and in compliance with BS EN 12390-2: 2009. For this test, samples with lengths of 50mm, widths of 50mm, and thicknesses of 50mm were prepared for strength testing. The sample was subjected to a chemical resistance test in conjunction with ASTM D543-14, with the aim of determining the samples' resistance to various chemical reagents. In addition, the ASTM D570 standard method was used to evaluate the relative water absorption rate of the polymer tiles sample after immersion in water for a specified time, all of the tests were carried out at room temperature.

3. Results & Discussion

3.1. Water Absorption

PET wall tiles made of 30%, 50%, 70%, 90% and 100% PET content had the water absorption values of 1.82, 1.02, 0.96, 0.81 and 0.12 (%) respectively. It was observed that, PET wall tile containing 30% PET and 70% POFA had the highest value (1.82%), while those made of 90% PET + 10% POFA and 100% PET had the lowest values of 0.81 and 0.12 percent, respectively (see Table 2 and Fig 1). This means that the water absorption of PET wall tiles is directly proportional to their PET content but inversely proportional to their POFA content. The water absorption efficiency of these polymer tiles is 75% lower than the concrete or ceramic tile and the result is similar to Bamigboye [25] observation. He noticed a gradual drop in water absorption values down to 100 percent PET, with 20-100 percent of PET falling within the standard's 2% range. And concluded that increasing the plastic content resulted in a reduction in water absorption up to 100% PET, which is in conformity with British Standard (BS EN ISO 62). (1999) [25,27].

Table 2. Water absorption, density, flexural strength, compressive strength, and porosity of the PET wall tiles of different PET and POFA contents

Sample	Water absorption (%)	Density (Kg/m^3)	Compressive strength (MPa)	Porosity (%)
PPT 1	1.82	1333.6	8.37	8.05
PPT 2	1.02	1247.8	6.03	4.82
PPT 3	0.96	985.6	2.01	2.71
PPT 4	0.81	771.2	1.17	1.71
PPT 5	0.12		0.01	1.1

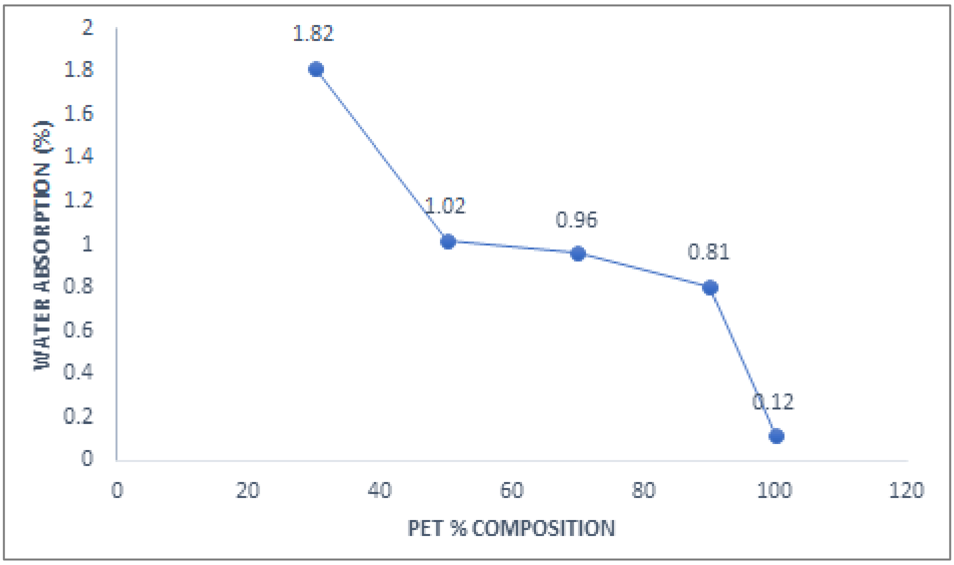

Figure 1. Water Absorption of the sample

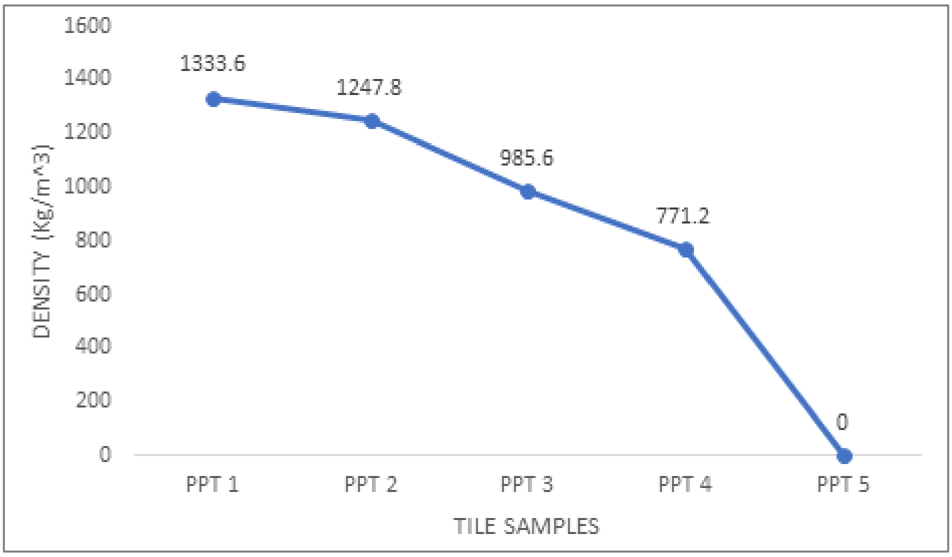

Figure 2. Density of the samples

3.4. Density

The density of the PET wall tile was calculated, and the results showed that PWT1, PWT2, PWT3, and PWT4 were 1333.6, 1248.8, 985.6, 771.2 kg/m^3, respectively. The manufactured PET tiles with 90 percent PET had the lowest density (771.2 kg/m^3), while those produced with 30 percent PET content had the highest density (1331.6 kg/m^3), as shown in Figure.2. Increases in PET material, on the other hand, decreased the density of the PET wall tile. Notably, as previously mentioned, the increase in PET content has decreased the density of the resulting composites [25,26].

3.5. Porosity

PET wall tiles with a 30 percent PET content had the highest porosity value (8.1 percent), whereas those with 90 percent and 100 percent PET had the lowest porosity values of 1.6 percent and 1.1 percent, respectively (see Table 2 and Figure. 3). This means that as the PET material increases, the porosity of the PET wall tiles decreases [26].

3.5. Compressive Strength

As shown in Figure 4, PET wall tiles containing 100 percent PET had the lowest compressive strength value (0.012 MPa), while those containing 30 percent PET had the highest compressive strength value (8.37 MPa). The compressive strength values (8.37, 6.03, 2.01, 1.17, and 0.012 MPa, respectively) increased steadily with the POFA content but decreased with the PET content. The findings show that increasing the PET waste content decreases the compressive strength of the PET tile [20, 24-26].

3.6. Chemical Resistance

Chemical resistance tests on the samples were carried out in compliance with ASTM D543-14 guidelines. The samples were prepared with length = 20mm, width = 20 mm, and thickness = 10mm, then weighed and immersed in different chemicals (HCL, NaCl, Na_2CO_3, Acetone, Benzene, Acetic Acid, and Carbon Tetrachloride) (CCl_4). The experiment was carried out at room temperature for 168 hours. Following the soaking period, the samples were removed, rinsed with distilled water, and air-dried before measuring and comparing the weight and size of the soaked samples to the weight and size of the neon-soaked samples. After 7 days of soaking in various chemicals, there were no major changes in sample weights or measurements, which is consistent with Dhawan et al. [26].

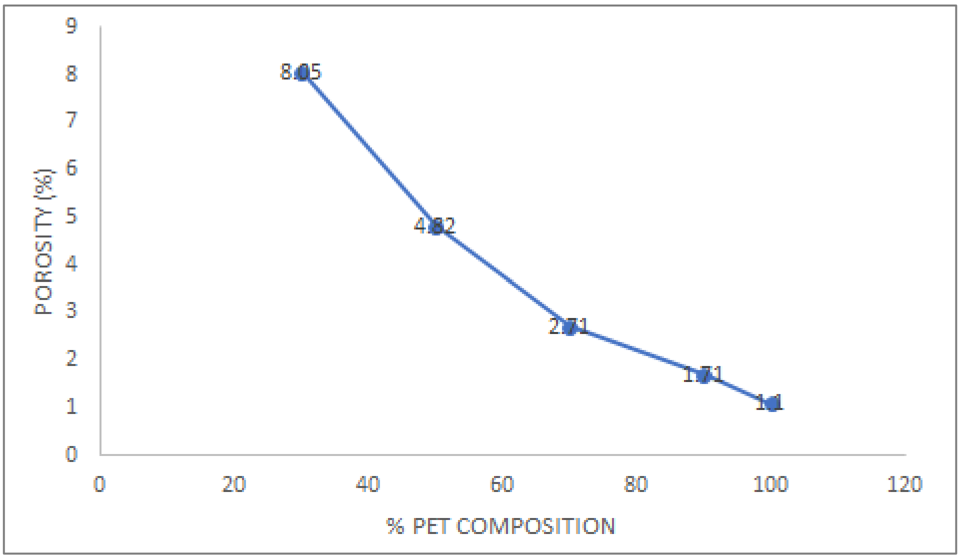

Figure 3. Porosity of the samples

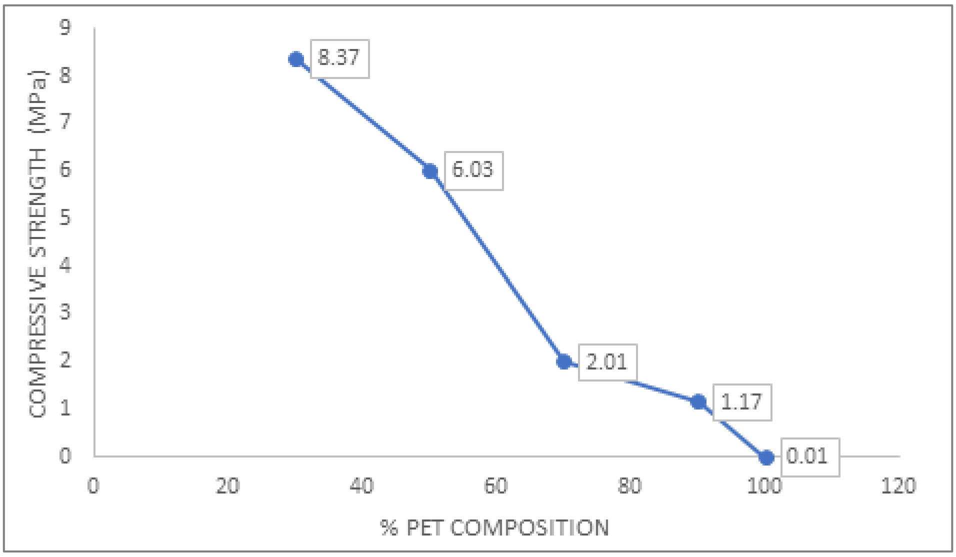

Figure 4. Compressive strength of the samples

4. Conclusions

The following conclusions were drawn based on the experimental results:

- A higher percentage of PET in the tile decreases water absorption. The percentage of water absorption fell from 1.82 percent to 0.12%.
- Samples containing 90% PET had the lowest average density (771.2 kg/m^3), whereas samples containing 30% PET had the highest density (1333.6 kg/m^3). When compared to control samples, the density increased steadily as the POFA content increased.
- As the PET material increased, so did the compressive and flexural strength of the PET wall tile. The compressive intensity decreased from 8.37 MPa for samples with 30% PET content to 0.012 MPa for samples with 100% PET content.
- PET tile tolerance in various chemical solutions has been demonstrated, with no major changes in weight or measurements observed after 7 days of soaking in various chemicals.

The findings of this study suggest that PET waste bottles can be used to create long-lasting, high-strength, and highly low-water-absorption eco-friendly tiles especially for wall for both residential and commercial applications where attention is much on durability than strength. The prospect of producing tiles from polyethylene terephthalate (PET) waste and POFA (palm oil fuel ash) waste not only reduces the cost of construction materials but also acts as a waste conversion to wealth. The future research may work on improving the strength properties of these tiles to may them suitable for heavy load.

Conflicts of Interest

Authors declare no conflicts of interest.

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