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Mechanical Properties and Durability of Polymer Tiles from Polyethylene Terephthalate (PET) Wastes and Fly ash

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ABSTRACT

Managing plastic waste is a global challenge that challenges the health of our ecosystem due to its high rate of production and non-biodegradability. However, it is important to handle PWs properly to curtail the environmental emissions associated with their incineration and dumping into landfills. This research investigates the possibility of producing tiles from polyethylene terephthalate (PET) waste bottles and fly ash. The mechanical characteristics and chemical tolerance of polymer tiles manufactured are reported in this study. PET waste was used in varying proportions (from 30% to 100%) by sand weight. Evaluation of the material's physical and mechanical qualities revealed that polymer tiles produced with 30% PET content performed better in terms of material density and strength compared to the samples with higher PET content. The highest compressive strength (6.88 MPa). According to the test findings, the produced PET tiles possess lower water absorption efficiency when compared to pure cement and ceramic tiles (the lowest water absorption value of 0.11 % and 0.1% was found in composite tiles made with 90% and 100% PET waste). The results from this study indicate that PET waste bottles can be used to produce long-lasting, good strength, and extremely low water absorption eco-friendly tiles for both residential and commercial applications. This prospect of tile production using polyethylene terephthalate (PET) waste and fly ash would not only minimize the cost of building products but will also act as a waste diversion to mitigate environmental emissions caused by plastic waste disposal.

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Abbreviations

ASTM America Society for Testing and Materials
BS EN British standard European Community
FA Fly ash
PET Polyethylene terephthalate
PFA Pulverized fly ash

Introduction

Rapid population growth and development have resulted in massive amounts of waste, and disposing of such waste provides a significant and ongoing challenge. The prevalent methods of landfilling and ground burying have shown to be hazardous owing to damage to the environment and water bodies. The fast development of the thermal power industry in industrialized countries has resulted in an increase in fly ash (FA) emissions. When brown or black coal is burned to generate electricity in a coal-fired power station, one of the combustion products produced is fly ash [1]. It produces three types of Fly ash: Class N, Class F, and Class C. Because fly ash pollutes the environment and accumulates on the ground, its proper disposal is a global concern. Annually, an estimated 600 million tons of Fly ash is produced globally, approximately 20 % of the total of the generated fly ash is being used in the manufacture of concrete, base course construction, soil improvement, zeolite synthesizing, and usage as a filler in polymers, among other applications. The rest is garbage that must be disposed of in ash ponds, dunes, and landfills [2]. Increasingly rigorous suitable disposal criteria, limited landfill area availability, and rising disposal costs are all expected in the future, necessitating the development of new fly ash recycling systems.

Another one of the most intriguing environmental concerns is waste plastic, which has emerged as a Centre for waste management due to its tremendous growth in manufacturing and use [3]. Global demand for plastics continues to rise with its related untenable waste generation. By 2030, it is anticipated that the volume of plastic in use will have increased from 236 million to 417 million tons per year [4]. On the other hand, to avoid accidental disposal of plastics, it is necessary to recycle or intentionally release polymeric materials into the atmosphere, thereby reducing the environmental pollution. Just 16 % of the polymers in the stream were processed for recycling in 2016, with the remaining 40% going to landfill and 25% being incinerated [4]. Plastics' ability to degrade is limited by their stability, a vital performance feature that encouraged their use. As a result, landfills are overburdened, and excess waste is released into the atmosphere [5]. Plastic materials are reportedly carcinogenic as they contain chlorine and other carcinogens. The burning of plastic wastes produces toxic gases such as phosgene, carbon monoxide, chlorine, sulfur dioxide, nitrogen oxide, and other deadly dioxins that are harmful to the environment [6,7]. Since plastic wastes account for the highest percentage of waste produced globally, there is a need to ensure proper management of such waste [7].

Literature Review

Consequently, researchers have suggested the use of plastic wastes in concrete production for two major reasons; first, to resolve the environmental problem associated with their disposal; and second, to reduce construction costs since they are available in great quantities [8]. However, even in developed regions, only a small percentage of waste plastic is recycled. For example, in 2018, Europe generated more than 62 million tons of waste plastics, but only 29.1 million tons were gathered, with only 32.5 percent being recycled [9]. Because waste plastics have comparable physicochemical qualities, ineffective separation drastically reduces the percentage of plastics wastes recycled and badly degrades the qualities of reclaimed materials [10].

Cement is generally used as a binder in the construction industry; however, the high cost of cement has prevented many people from building their houses and has hindered the advancement of the construction sector [11]. Hence, it is important to find a suitable replacement for this expensive and essential building material [12]. Also, CO2 is mostly generated during the carbonization of limestone (which accounts for approximately 80% of the ingredient of cement raw resources) and clay (around 20 percent of a constituent of cement raw material). Cement replacement with an alternative binder such as PET waste and fly will result in lower emissions of carbon dioxide (CO2) than Ordinary Portland Cement.

Fly ash is the most commonly utilized aluminosilicate ingredient in the production of geopolymer cement and concrete mixtures as a partial or complete substitution for Portland cement [13]. Pardon et al., used class F pulverized Fly ash (PFA) as cement replacement in tile production and discovered that 20% pulverized fly ash cement replacement reduces the water demand of the mix, resulting in less water usage and reduced the setting time of the cement of PFA blend as well as the compressive strength at 28 to 90 days [14]. The stimulation of lime and brine water inhibited Fly ash activity, and significant amounts of Fly ash use had a detrimental effect on binder strength growth and cementing characteristics [15]. Fly ash's physical properties, chemical capacities, and elemental composition contribute for its adaptation in the production of several kinds of cementitious materials [16,17].

Several types of research have shown that plastic wastes could be used as construction material. As an example, when coupled with sand, high-density polythene (HDPE) polymers, according to Mehdi, can be utilized to manufacture roof tiles [18]. The results of their study revealed that composite tiles made with 70% HDPE had better performance and quality after analysis. Shredded plastic waste is a recycled material that has drew a great deal of interest in the building sector [19]. Several experimental studies on the substitution of recycled PET bottles for aggregates made from natural materials in concrete have recently been published and as resin in polymer concrete. Akinwumi documented the production of stabilized soil blocks from shredded plastic waste and their study opined that 1% finely shredded PET waste (size 6.3 microns) by weight could be used for successful block stabilization [20]. Bamigboye, investigated the potential use of PET waste and river sand in the manufacturing of roof tiles [21]. The study revealed that, PET wastes can produce roof tiles with low water absorption compared to other conventional tiles.

According to Kumi-Larbi, production of sand blocks using plastic wastes only is possible, and the findings of their investigation demonstrated that sand blocks that are both sturdy and longlasting may be created using only plastic waste and no additional water [22]. Borg used PET fibers in concrete and discovered that at higher PET fiber contents, PET fibers significantly decreased sample compressive strength [23]. Al-Hadithi & Hilal investigated the manufacturing of selfcompacting concrete using plastic waste fibers and concludes that, the compressive strength of the sample increase with increasing plastic waste content [24]. Also, Dhawan investigated the potential use of PET waste and fly ash in the manufacturing of tile with reduced flammability and improved strength [25,26]. The study concludes that the addition of fly ash can reduced flammability and improved tensile strength.

Several researchers have studied the use of PET plastic waste has an aggregate replacement in concrete production, also as binder incomplete cement replacement, but, much work as has not been recorded on PET waste mixed with fly ash in the production of plastic tiles with reference to flammability, water absorption, and chemical tolerance. Also, since PET has poor resistance to flame, mixing it with fly ash which is rich in SiO2 will reduce the burning rate of the plastic and make it more durable. This research would examine into the feasibility of producing tiles using PET bottle waste as a binder instead of cement. The sole purpose of this research is to develop and produce long-lasting and dependable tiles made from recycled PET bottles and fly ash and to investigate the physical and mechanical performance of PET polymer tiles.

Considering that plastic waste makes for the vast bulk of global waste, proper waste management is critical. It is necessary to recycle in order to avoid unintended plastic disposal and pollution caused by incineration. Furthermore, the rapid development of the thermal power industry in industrialized countries has resulted in a significant increase in fly ash (FA) emissions, which pollute the environment and deposit on the ground, this research intends to transform these hazardous wastes into construction materials (tiles), which will not only reduce the cost of building products but will also serve as a waste diversion to reduce environmental pollution caused by these wastes and improve the health and sustainability of the environment.

Materials and Methods

Materials

The materials used in making the composite tiles were sourced locally; the locally sourced materials include plastic wastes, metal mold, wood stirrer, sieve, hand gloves, coal pot, face mask, and engine oil. The PET wastes used in this study were shredded plastic bottles wastes collected from a Waste Resource Management Company located at 14000 Bukit Mertajam, Penang, Malaysia. The class F pulverized Fly ash used was supplied to the School of Housing, Building, and Planning Resource Laboratory, Universiti Sains Malaysia. Figures. 1 and 2 show the class F pulverized Fly ash and the bags of shredded PET wastes sample, respectively. The shredded PET wastes were heated and melted inside an aluminum pot at a temperature of 230 oC before the addition of pulverized Fly ash into the melted plastic wastes at different percentages. The mixture was homogenized and poured into a 5-cm thick iron mold that had been lubricated with engine oil for easy removal. The edge of the mold was banged continuously for proper compassion. After one hour, the samples were de-molded, cooled, and cured at ambient temperature for forty-eight hours before testing (see Table 1 and Figure 3 and 4). Table 2 shows the chemical composition of the obtained fly ash. The following chemicals: acetone, benzene, acetic acid, hydrochloric acid (HCl), carbon tetrachloride (CCl4), sodium carbonate, and sodium chloride are used and supplied by the School of Housing, Building, and Planning to determine the chemical tolerance of the polymer tiles produced.

Figure 1: Fly ash sample

Figure 2: PET waste sample

Table 1: Different contents of PET waste and Fly ash used in this study

Sample	PET waste content (wt. %)	Fly ash content (wt. %)
PT1	30	70
PT2	50	50
PT3	70	30
PT4	90	10
PT5	100	0

Figure 3: Production process of the tile

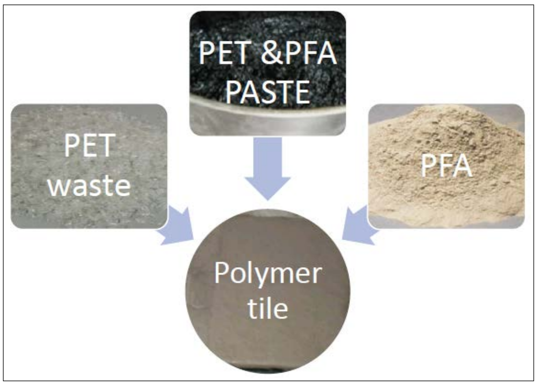

Figure 4: Polymer tile sample, materials used, and method

Table 2: Chemical composition of fly ash used

Composition	Mass percentage
SiO_2	58.6
Al_2O_3	24.01
Fe_2O_3	6.35
CaO	4.28
MgO	1.74
K_2O	2.46
TiO_2	0.85
Na_2O	1.71

Methods of testing

The compressive strength of plastic composite tiles was determined using the Geotech Universal Testing Machine and the BS EN 12390-2: 2009 specification which involved the casting of the homogenously mixed PET paste and fly ash into a standard cube for compression testing of size 50x50x50mm. Samples with lengths of 50 mm, widths of 50 mm, and thicknesses of 50 mm were prepared for strength testing for this test, the samples were tested on the Instron Universal Machine after de-molding and cooling for 48 hours at room temperature to determine their compressive strength. The chemical resistance test was performed on the samples in accordance with ASTM D543-14 by cutting the sample tiles into 20x20x20 mm sizes and soaked in a different chemical solution for a period of seven days, the purpose of this test was to evaluate the samples' resistance to various chemical reagents. The chemicals used for this study are acetone, benzene, acetic acid, hydrochloric acid (HCl), carbon tetrachloride (CCl4), sodium carbonate, and sodium chloride with 5% dilution. Furthermore, the ASTM D570 standard method was used to determine the relative water absorption rate of the polymer tiles sample after immersion in water for 72hours and the change in weight of the sample was calculated in percentage and recorded, all experiments were carried out at room temperature. The flexural strength of the PET polymer tiles was determined using ASTM D 72-64-15. For the testing, three prismoids measuring 40 x 40 x 160 mm3 were made from each batch of PET polymer paste. The prism specimen is placed on the ELE International Flexural Testing Machine loading frame with the assurance that the specimen to be examined is nicely centered and parallel with the two longitudinal levers located below and above the machine arms. The specimens were subjected to bending tests using a bending test machine loaded at a continuous rate of 50 N/s until they failed, and the failure load was recorded. The ultimate flexural strength was calculated by taking the average of three specimens from the same batch.

The average density of tiles specimens is discovered by taking the measurement of the weight of the sample of the polymer tiles and the diameter of the specimen. The polymer tile is prepared and pour into prism cube size 50mm x 50mm. Three to five samples of each mix are selected for the test. The weight of each sample is recorded. The density is calculated using this equation.

$\frac{J}{d^3} x\ 1000^3 (kg/m^3)$ Where: J is the sample weight and d is the diameter of the sample size. While the porosity was measured in accordance with the RILEM guidelines [26]. Cylinder specimens with diameters of 50mm and heights varying from 35 to 40 mm were cast. The samples were dried in an oven for 78 hours at 105±2 degrees Celsius. It was then cooled in a desiccator for 24 hours. The weight of the oven-dried samples was calculated and denoted as Wd. The sample was then placed in a dissector filled with de-aired and de-ionized water until it was completely immersed in water. The samples were held under a steady vacuum for 78 hours before being allowed to equilibrate. The weight of the samples was determined in both the air (Wa) and the water (Ww) (Ww). The absolute porosity, P for the samples is calculated using:

$$\mathbf{P}\ (\%) = \frac{Wa - Wd}{Wa - Ww} x\ 100$$

Results

Water absorption

PET polymer tiles produced with 30 % PET and 70 % fly ash achieved the highest value (0.98 %) while those produced with 100 PET and 90 % PET + 10 % fly ash presented the lowest values (see Figure 5). This means that the water absorption of the PET polymer tiles is directly a function of the PET content but inversely related to the fly ash content.

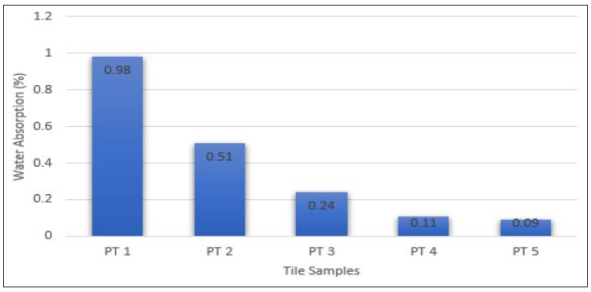

Figure 5: Water Absorption of the samples

Density

The density of the PET polymer tile was determined, and the result showed PT1, PT2, PT3, PT4, and PT5 (Table 1) are 1688, 1575.2, 1370.4, 1181.6, and 1070.3 kg/m3 respectively. The PET polymer tiles produced with 100 % PET had the lowest density (1070.3 kg/m3) while those produced with 30 % PET content had the highest density (1688.0 kg/m3) as shown in Figure.6. Therefore, increases in the PET content decreased the density of the PET polymer tile. Notably, other studies previously indicated that an increase in PET content reduced the density of the resulting composites [22,25].

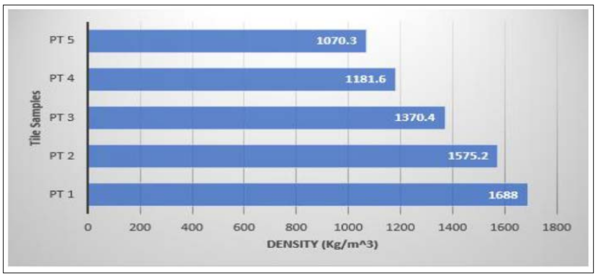

Figure 6: Density of the samples

Porosity

The PET polymer tiles produced with 30 % PET content presented the highest porosity value (4.14 %) while those containing 90 % PET achieved the lowest porosity value of 0.39 % (see Figure.7). The porosity values fall consistently as the fly ash percentage decreases, yet the percent the porosity of PT 5, which contains pure PET (no-fly ash), is higher than PT 3 and PT4, which contains 30% and 10% fly ash, respectively. This means that the presence of fly ash in the PET tiles has an effect on the porosity value of the PET polymer tiles but should not exceed 10% in a particular mix Ridham [25] made a similar observation.

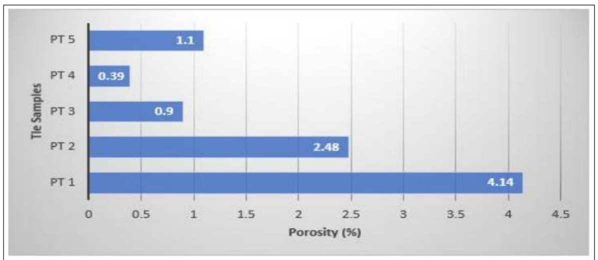

Figure 7: porosity of the samples

Compressive strength

PET composite that contains 100 % PET exhibited the lowest compressive strength value (0.012 MPa) while those produced with 30 % PET content had the highest compressive strength value (6.88 MPa) as shown in Figure 8. The compressive strength values (6.88, 5.49, 4.36, 2.94, and 0.012 MPa respectively) steadily increased with the fly ash content but decreased with increasing PET content. The results show that increasing the PET waste content reduces the compressive strength of the composite. [19,20, 24-25].

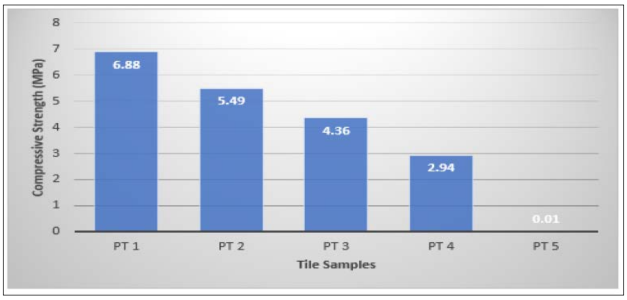

Figure 8: compressive strength of the samples

Flexural strength

The flexural strength of the PET polymer tiles was calculated in accordance with ASTM D 72-6415, and the results are shown in Figure 9. The sample with 100% PET content had the lowest flexural strength, while the sample with 30% PET content had the highest (6.75 MPa). This shows that the flexural strength improved as PET content decreased but increased as fly ash content increased. Because of this behavioral adjustment, the flexural strength of the PET polymer tile is dependent on the PET material. A similar observation was also previously reported and showed that flexural strength decreased as the amount of plastic waste in a structure increased [20,22-26].

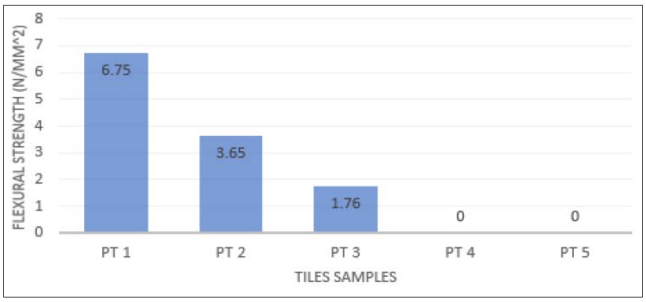

Figure 9: Flexural strength of the samples

Chemical resistance

Chemical resistance tests were performed on the samples in accordance with ASTM D543-14 guidelines. The samples were prepared with length = 20 mm, width = 20 mm, and thickness = 10 mm, then weighed and immersed in various chemicals hydrochloric acid (HCL), sodium chloride (NaCl), sodium carbonate (Na_2CO_3), acetone, benzene, acetic acid, and carbon tetrachloride (CCl_4). The experiment was carried out at room temperature for 168 hours, as shown in Figure 10. Following the soaking time, the samples were removed, rinsed with distilled water, and air-dried before measuring the weight and dimensions of the soaked samples and comparing them to the weight and size of the non-soaked samples. Comparative findings revealed no significant changes in sample weights or measurements after seven days of soaking in different chemicals; this finding is consistent with Dhawan et al. [25].

Figure 10: Sample soaked in different chemical

Discussions and limitation

- Based on the experimental results, the following observation was noticed:
- A higher PET content in the tile reduces water absorption. The percentage of water absorption decreased from 0.98 % to 0.1 %.
- Samples with 100% PET content had the lowest average density (1070.3 kg/m3), while samples with 30% PET content had the highest density (1688.0 kg/m3). When compared to control samples, density increased steadily with increasing fly ash content but decreased with an increasing percentage of PET waste.
- The compressive and flexural strength of the PET polymer tiles decreased as the PET content increased. The compressive strength decreased from 6.88 MPa for samples with 30% PET content to 0.012 MPa for samples with 100% PET content, while the flexural strength decreased from 6.75 MPa for samples with 30% PET content to 0 (brittle) for samples with 100% and 90% PET content.
- PET polymer tile tolerance in different chemical solutions has been demonstrated, with no significant changes in weight or dimensions found after 7 days of soaking in different chemicals.
- The major limitation is that class F pulverized fly ash was used for this research and the percentage PET content that produced the highest strength must not be more than 30% PET waste content and 70% fly ash to achieved maximum compressive strength.

Conclusion and future work

The results from this study indicate that pulverized Fly ash and melted PET waste bottles can be used to produce long-lasting, good strength, miniature water absorption, and eco-friendly tiles for both residential and commercial applications. This prospect of tile production using polyethylene terephthalate (PET) waste and fly ash would not only minimize the cost of building products but will also act as a waste diversion to mitigate environmental emissions caused by plastic waste disposal. Despite the great prospect of PET waste and fly ash tiles in construction applications due to their good durability and economic efficiency but the future researcher can use other additives to enhance the compressive strength.

Conflicts of interest

Authors declare no conflicts of interest

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References

1. American Coal Ash Association (ACAA), 2017. About Coal Ash- How much are CCPs worth. Retrieved from. https://www.acaa-usa.org/about-coal-ash.aspx
2. Malhotra S, Ranjit M, Punjab S (2018) Study of Polyethylene Terephthalate (Pet) Plastic Bottles in. Global Journal of Engineering Science and Researches 5: 466-481.
3. Yao D, Yang H, Hu Q, Chen Y, Chen H et al. (2021) "Carbon nanotubes from post-consumer waste plastics: investigations into catalyst metal and support material characteristics". Applied Catalysis B: Environmental 280: 119413.
4. Hundert mark T, Mayer M, Mcnally C, Simons T J, Witte C (2018) DECEMBER 2018 • How plastics-waste recycling could transform the chemical industry. Mckinsey on Chemicals December. https://www.mckinsey.com/industries/chemicals/our-insights/how-plastics-waste-recycling-could-transform-the-chemical-industry
5. Brahney J, Hallerud M, Heim E, Hahnenberger M, Sukumaran S (2020) Plastic rain in protected areas of the United States. Science 368: 1257-1260.
6. Liu G, Agostinho F, Duan H, Song G, Wang X et al. (2020) "Environmental impacts characterization of packaging waste generated by urban food delivery services. A big-data analysis in Jing-Jin-Ji region (China)". Waste Manag 117:157-169.
7. Taiwo O O, Abas NF (2021) Mechanical Properties and Durability of PET waste Aggregates in Roof Tiles Production. International Journal of Recent Technology and Engineering 9: 300-304.
8. Yu J, Sun L, Ma C, Qiao Y, Yao H (2016) Thermal degradation of PVC: a review. Waste Manag 48: 300-314.
9. Zhang Y, Jiang H, Wang H, Wang C (2020) Flotation separation of acrylonitrilebutadiene-styrene and polystyrene in WEEE based on oxidation of active sites. Miner Eng 146: 106131.
10. B Harini, K V Ramana (2015) Use of Recycled Plastic Waste as a partial replacement for fine aggregate in Concrete. International Journal of Innovative Research in Science, Engineering, and Technology 4: 85-96.
11. R Saxena, T Gupta, R K Sharma, S Chaudhary, A Jain (2020) "Assessment of mechanical and durability properties of concrete containing PET waste". Scientia Iranica. Transactions A: Civil Engineering 27: 1-9.
12. Velumani P, Karthik S G (2017) "Development of eco-friendly pressed roof tiles: A prologue study". International journal of scientific and engineering s research 8: 20302033 xvii.
13. Blissett RS, Rowson NA (2012) A review of the multi-component utilisation of coal flyash. Fuel 97: 1-23.
14. Pardon K Kuipa, Cledwyn T Magandas, Olga Kuipa, Admire Chawatama (2015) Use of Pulverised Fuel Ash in the Manufacture of Concrete Roofing Tiles. International Journal of ChemTech Research 8: 1019-1025.
15. Yan B, Kouame K J A, Wensheng Lv, Yang P, Cai M (2019) Modification and in-place mechanical characteristics research on cement mortar with fly ash and lime compound admixture in high chlorine environment. J. Mater. Res. Techno 8: 1451-1460.
16. Rakhimova NR, Rakhimov R Z (2019) Toward clean cement technologies: A review on alkali-activated fly-ash cements incorporated with supplementary materials. J. Non Cryst. Sol 509: 31-41.
17. El Gamal S, Selim F (2017) Utilization of some industrial wastes for eco-friendly cement production. Sustain. Mater. Technol 12: 9-17.
18. Mehdi S, Djamel B, Abdelouahed K, M I H (2017) The Possibility of Making a Composite Material from Waste

Plastic. International Conference on Technologies and Materials for Renewable Energy, and Environment 119:163-169.

19. Niaki M H, Fereidoon A, Ahangari M G (2018) Effect of basalt, silica sand and fly ash on the mechanical properties of quaternary polymer concretes. Bull. Mater. Sci 41: 69.
20. I I Akinwumi, A H Domo spiff, A Salami (2019) Marine plastic pollution and affordable housing challenge: shredded waste plastic stabilized soil for producing compressed earth bricks. Case Stud. Constr, Mater 11: e00241.
21. G O Bamigboye, B U Ngene, D Ademola, J K Jolayemi (2019) Experimental study on the Use of Waste Polyethylene Terephthalate (PET) and River Sand in roof tile production. Journal of Physics: Conference Series 1378: 042105
22. A Kumi Larbi, D Yunana, P Kamsoulounm, M Webster, D C Wilson et al. (2018) Recycling waste plastics in developing contries: use of low-density polyethylene water sachets to form plastic bonded sand blocks. Waste Manag 80: 112-118.
23. Borg R P, Baldacchino O, Ferrara L (2016) Early age performance and mechanical characteristics of recycled PET fiber reinforced concrete. Construction and Building Materials 108: 29-47.
24. AL Hadithi A I, Hilal N N (2016) The possibility of enhancing some properties of self-compacting concrete by adding waste plastic fibers. Journal of Building Engineering 8: 20-28.
25. Ridham Dhawan, Brij Mohan Singh Bisht, Rajeev Kumar, Saroj Kumari, S K Dhawan (2019) Recycling of plastic waste into tiles with reduced flammability and improved tensile strength. Process Safety and Environmental Protection 124: 299-307.
26. Rilem C (1984) 11.3. Absorption of water by immersion under vacuum. Mater Struct 17: 391-394.