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Suitability of using post-consumer polyethylene terephthalate wastes in cement-based hollow sandcrete blocks

I E E Davies[1] and O M Olofinnade[1]
[1]Department of Civil Engineering, Covenant University, Ota, Ogun Sate, Nigeria

*Corresponding author: rotimi.olofinnade@covenantuniversity.edu.ng

Abstract. In recent times, efforts are channeled towards limiting the impact of waste plastic pollution on the environment. This study examines the beneficial utilization of polyethylene terephthalate (PET) wastes, which is a non-biodegradable waste materials as a partial substitute for sand in the production of non-load bearing hollow sandcrete blocks. The physical and mechanical properties such as density and compressive strength of the hollow sandcrete blocks using PET waste as a replacement for fine aggregate at 5%, 10%, 30% and 50% were determined. Tests results show that the density of the produced sandcrete blocks decreases as the waste PET content increases. Results showed that the density varied from 1391.33 kg/m^3 for 50%PET content to 1954.54 kg/m^3 for 5%PET content, while the density of the reference sandcrete was 2002.15 kg/m^3 for 7 days. The values of densities ranged between 1453.88 kg/m^3 for PET 50% and 1851.09 kg/m^3 for PET 5% and the density of reference sandcrete was 1991.77 kg/m^3 at 28 days. The sandcrete blocks also demonstrate a similar reduction trend in compressive strength as the PET content increases. The compressive strength ranged between 1.140 N/mm^2 for 50%PET and 2.564 N/mm^2 for 5%PET content and 1.510 N/mm^2 for 50%PET to 2.991 N/mm^2 for 5%PET respectively, as the curing age increases from 7 to 28 days. The hollow sandcrete block containing an optimum 5% replacement percentage of sand with PET waste showed comparable strength to the conventional sandcrete blocks. This will help to mitigate the menace of marine plastic pollution and promote responsible consumption.

Keywords: Sandcrete blocks, Natural aggregate, Compressive strength, Density, Coefficient of uniformity, Specific gravity

1. Introduction

Annually, global waste generation both organic and inorganic materials have been on the increase due to rise in world population and urbanization. Polyethylene terephthalate (PET) is rated as the most produced plastic types and are used globally in packaging of different products such as water, beverage, foods, soft drinks and other consumer's goods [1, 2]. The consumption of PET used in bottling of drinks was reported to be about 10 million tons and estimated to rise at about 15% annually [1]. The PET waste is the most recycled plastic waste, a study by [3] reported that PET is the most abundant type of plastics found in urban municipal waste streams. Polyethylene terephthalate (PET), is one of the major sources of environmental pollution, thus the need for an urgent attention in the management of this non-biodegradable waste materials. One of the ways advocated of addressing this menace is to find an alternative re-use or recycling approach of the PET wastes [4, 5]. Huge quantities of plastic wastes are generation and indiscriminate dumping of this hydrocarbon byproduct, has spark a lot of research towards the possibility of recycling of these wastes in concrete, in the production of sandcrete block as

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partial replacement to natural aggregate particularly where strength may not be a necessary criteria under consideration and also as a constituent pavement construction [6]. Many researchers have researched on the effect of replacement of PET on the density of sandcrete block such as [7-10]. A study by Safi et al. [9] opined that production of lighter density or light mortar could be achieved by partially replacing sand with PET waste aggregate [11-15]. The focus of this study is to show the suitability of utilizing the enormous quantity of PET in the environment as an alternative aggregate material in the production of hollow sandcrete blocks. This work will examines the use of PET waste, as partial replacement to fine aggregates through the determination of density and compressive strength properties of the produced hollow sandcrete blocks.

2. Materials and Method

2.1 Materials

The ordinary Portland cement used in this research was produced by Dangote cement. This cement type is the most widely used binder material in the production of hollow sandcrete blocks in Nigeria. Hence, it was used as adhesive in the mix design of the hollow blocks. The cement grade was 42.5 and complied with the specification prescribed in BS EN 197-1:2000 [16] and NIS 444-1:2003 [17]. The river sand was used as the natural fine aggregate in the hollow sandcrete block mixes. The sand was purchased in Ota, Ogun state and brought to Civil Engineering Laboratory. The bulk density, specific gravity and water absorption capacity were carried out on the sand according to BS EN 1097-3:1998 [18] and is presented in Table 3, while the grading size distribution of the sand is shown in figure 1.

In addition, the PET plastic bottles were collected, gathered and shredded into granulated form in Covenant University. The bottle used were pre-washed with water, dried, melted at about 280 ^{0}C and 320 ^{0}C and allowed to solidify before being grounded into fine granulated form (below 4.75mm sieve size) by a crushing machine. The acquired PET plastic were smooth finely granulated PET Aggregate. Physical properties such as density, specific gravity and water absorption capacity were determined according to BS EN 1097-3:1998 [18]. These results are tabulated in Table 3**.** The grade size distribution of the PET Aggregate is describe in figure 1. Potable water was employed for the mixing of the matrix composite in accordance to BS 3148:1980 [19].

2.2 Fabrication procedure of the hollow sandcrete blocks

Manual mould was used to produce the sandcrete block. The internal dimension of the block mould was 450 × 150 × 225mm (Length × Width × Height). The mould had a void quantifying about half the volume of the block. In this study, cement-to-aggregate mix ratio was 1:6 based on the specification given by the Nigerian National Building Code [20]. The granulated PET was used to replace sand as aggregate at 5%, 10%, 30% and 50% by weight in the aggregate mixture. The experimental design of the aggregate is shown in Table 1. Hand mixing was employed in the mixing of the cement and aggregate. After mixing the constituent materials, potable water was supplied to the mixture to secure a fluid slurry. The water/cement ratio used was 0.55. After mixing, the fluid slurry was poured into the hand block mould. After which, the blocks were removed from the mould and were placed carefully in separate rows with adequate spacing between each successive blocks. Thereafter, the block samples were openly cured for 7 days and 28 days, by sprinkling water once daily and covering with polyethylene nylon after 24 hours of moulding. Figure 2 depicts the produced hollow sandcrete block samples with PET before covering with polyethylene nylon after water sprinkling.

2.3. Tests

i. Chemical composition of PET-aggregate - oxides composition of PET-aggregate was determined by using X-ray fluorescence (XRF).
ii. Physical properties of natural aggregate and fine granulated PET aggregate test - physical properties such as density, particle size distribution, specific gravity and water absorption capacity were determined according to BS EN 1097-3:1998 [18].
iii. Density of the hollow sandcrete block samples were measured in accordance to BS EN 772-11:2011 [21].

iv. Compressive strength - the compressive strength test was carried out on the hollow sandcrete blocks according to BS 6073-2:2008 [22]. Figure 2 shows a block sample under compressive load.

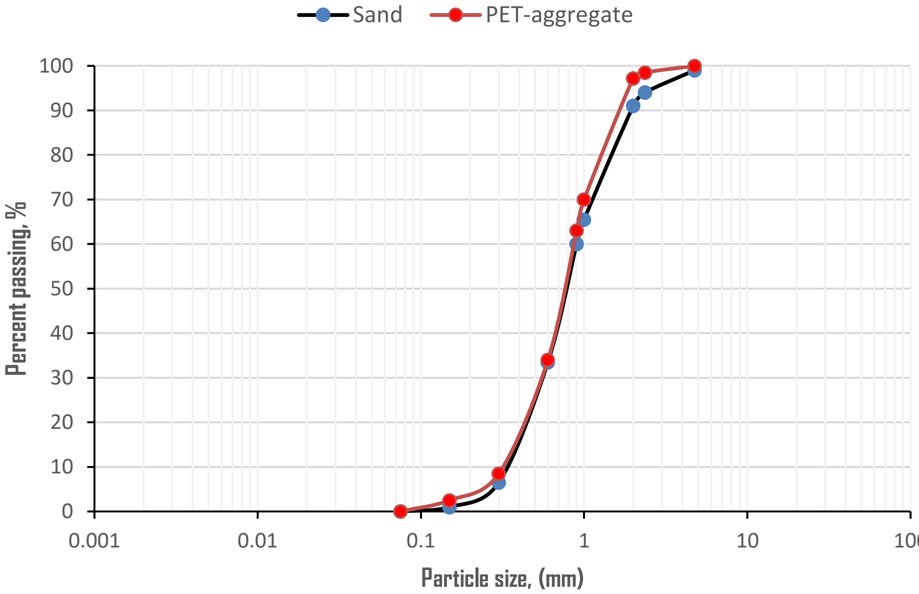

Figure 1. Particle size distribution of sand and PET aggregate

Figure 2. Hollow sandcrete block after water sprinkling; and under compressive load

Table 1. Experimental Design

Samples	% cement content	% sand content	% PET-aggregate	Water/ cement ratio	Remarks
AB	100	100	0	0.55	Reference sandcrete
A1	100	5	95	0.55	5% sandcrete block
A2	100	10	90	0.55	10% sandcrete block
A3	100	30	70	0.55	30% sandcrete block
A4	100	50	50	0.55	50% sandcrete block

3. Results and Discussion

3.1 Particle size distribution

The results of the particle size distribution of PET wastes bottle are shown in figure 1. The coefficient of uniformity of sand and PET wastes bottle were 2.66, and 2.61, respectively. The coefficient of curvature of sand and PET were 1.02 and 1.16 respectively. This is an indication that the sand is well graded. The particle sizes of PET waste aggregate fell within the nominal sizes of 0.150 to 4.75 mm, while grain distribution curve shows that 1.0% of the river sand particle sizes were bigger than 4.75 mm. The coefficient of curvature of the PET aggregate is close to the reported coefficient of curvature reported for palm kernel shell and periwinkle shell [23].

3.2 Physical properties and chemical composition of aggregate

Some of the physical properties of natural aggregate and PET waste plastic are shown in Table 2. The specific gravity of river sand and PET waste plastic were 3.00 and 1.42. Bulk densities of uncompressed river sand and PET waste plastic 1292 kg/m^3 and 846.17 kg/m^3. The water absorption capacity of river sand and PET waste plastic were 0.95%, and 0.02% respectively. Thus implies that the PET aggregates is of lighter weight and low water absorption capacity compare to the conventional sand materials.

Table 2. Physical properties of aggregates

Properties	Sand	PET
Specific gravity	3.00	1.42
Water absorption, %	0.95	0.02
Bulk density, kg/m^3	1292	846.17

Meanwhile, the results of the chemical composition of the granulated PET aggregate materials showed that the main oxide compositions of the material include; SiO_2 (56.4%), AI_2O_3 (23.71%) and Fe_2O_3 (7.38%), MgO (2.95), Na_2O (2.7%) and CaO (2.12). These are the major chemical oxides in the granulated PET material. The recorded loss on ignition (LOI) for the PET plastic is 1.2. Aggregate with high quantity of reactive silica has the potential to react with alkali in cement. The possibility of Alkali-silica (ASR) compound in the sandcrete blocks was not investigated due to the moderate percentage of Na_2O. A likely occurrence of ASR can be detrimental to the long term performance of the sandcrete blocks [24, 25]. Meanwhile, the plastics contain some severe and toxic organic and inorganic chemical compounds that are dangerous to human health such as nickel, lead, cadmium, chromium, mercury, bromine, tin, antimony, bisphenol A, and chloro-ethane monomer.

3.3 Density of sandcrete blocks

The results of densities for the different weight percentages of waste PET plastics for the production of sandcrete blocks are shown in figure 3. The density varied from 1391.33 kg/m^3 for PET 50% to 1954.54 kg/m^3 for 5% PET, while the density of reference sandcrete was 2002.15 kg/m^3 at 7 days curing age. The values of densities ranged between 1453.88 kg/m^3 for 50% PET and 1851.09 kg/m^3 for 5% PET, while the density of reference sandcrete was 1991.77 kg/m^3 at 28 days curing age. It was observed that the recorded density for all the hollow sandcrete block samples achieved the minimum requirements for density and compacted bulk density of lightweight coarse aggregate, which are 880 kg/m^3 [26] and 1000 kg/m^3 [27]. According to BS 2028 [28], hollow sandcrete blocks with density of 1500 kg/m^3 are grouped as Type A: dense aggregate concrete blocks. However, the density decreased significantly with increased incorporation of PET waste aggregates as partial replacement for fine aggregate. The observed reduction in density of sandcrete blocks could be adduced to the replacement of heavier material (sand) with the lightweight material (crushed PET waste aggregate). A similar reduction in density was reported for sandcrete blocks produced from crushed plastic at replacement percentages of 0%, 5%, 10%, 15%, 20% and 100% at the end of 28 days [29].

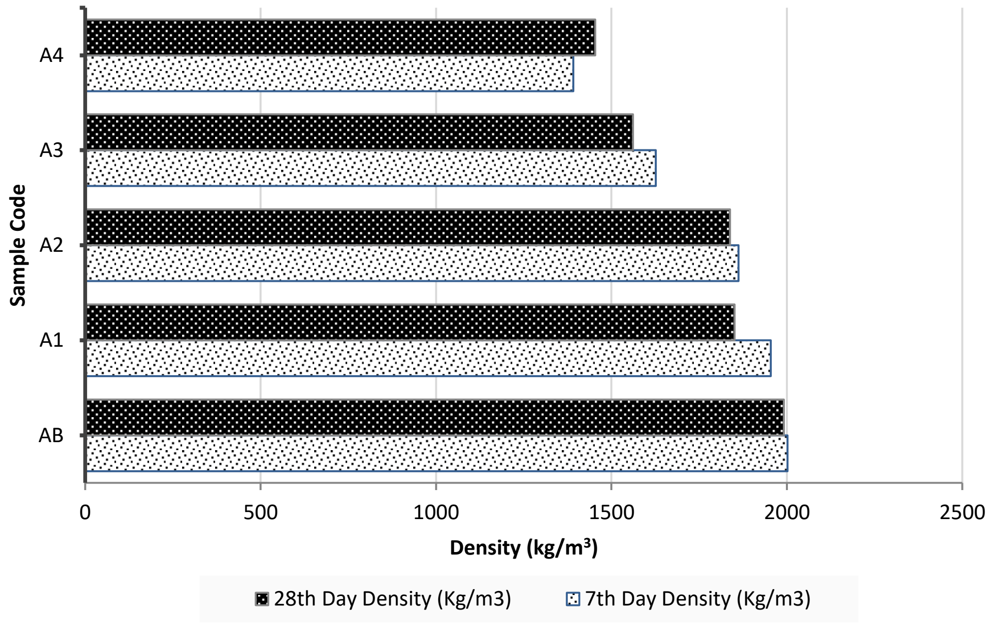

Figure 3. Density of hollow sandcrete blocks

3.4 Compressive strength of sandcrete block

The compressive strength of sandcrete blocks at different PET waste percentages for 7 days is presented in Figure 4. The compressive strength ranged between 1.140 N/mm^2 for PET 50% and 2.564 N/mm^2 for 5% PET and 1.510 N/mm^2 for 50% PET to 2.991 N/mm^2 for 5% PET respectively, as the curing age increases from 7 to 28 days. The compressive strength of reference sandcrete blocks increased from 2.707 N/mm^2 to 3.419 N/mm^2 as the curing age increases from 7 to 28 days. The results obtained from the tests were compared relatively with the recommended strength values of Nigerian Building and Road Research Institute [30], Nigerian Building Code [20], and Nigerian Industrial Standards [31] for manually produced non-load bearing hollow sandcrete blocks. The results indicated that the reference hollow sandcrete block samples and hollow sandcrete block samples produced from 5% and 10% PET waste replacement for sand satisfied the minimum requirement of 2.5 N/mm^2 recommended for compressive strength of hollow sandcrete blocks at 28 days curing age by NIS 87: 2000 [32] for non-load bearing walls application. These results are higher than those reported in the work of [33] with values ranging from 1.01 N/mm^2 to 1.68 N/mm^2 and 0.53 N/mm^2 to 1.59 N/mm^2 for sandcrete blocks containing sawdust as replacement for cement at 28-days curing age. Study by [34] reported a decreasing trend in the compressive strength of cement-based composites as the percentage levels of waste plastic increases. Also, a related study by [35] showed that the compressive strength of the manually compacted sandcrete block samples ranges between 2.61 N/mm^2 to 2.89 N/mm^2 compare to mechanically compacted sandcrete block samples with varied between 2.26 N/mm^2 to 3.03 N/mm^2 as the curing age increases.

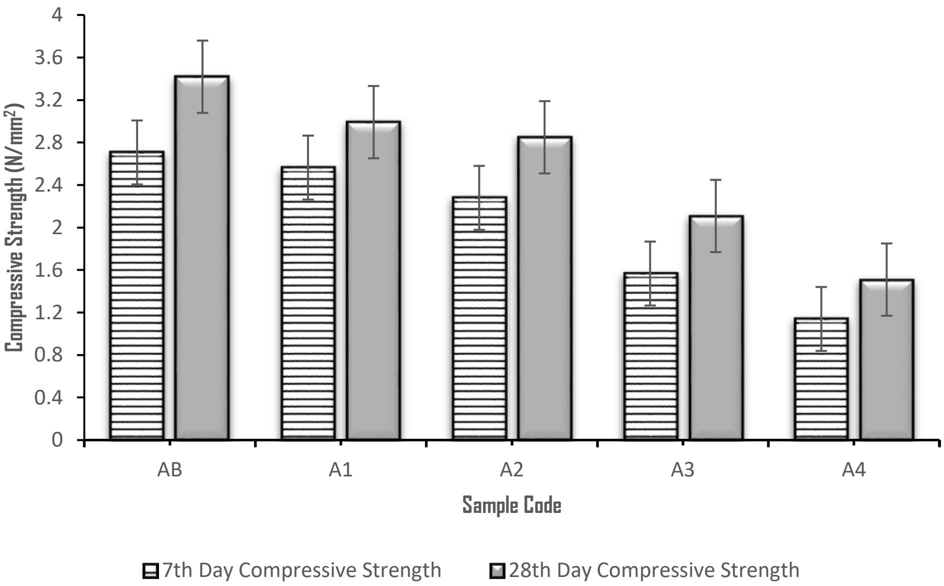

Figure 4. Compressive strength of hollow sandcrete blocks

4. Conclusion

This study showed that the control sandcrete block sample had highest density compare to all other sandcrete blocks containing the crushed PET waste as replacement for sand. In addition, the compressive strength of sandcrete blocks reduced with increasing percentage replacement of the natural aggregate content with PET aggregate waste in the mixes for all the samples. However, reference sandcrete block sample had the highest compressive strength. However, hollow sandcrete blocks containing 5% granulated PET aggregate showed comparable strength to the reference sandcrete blocks, thus implies the possibility of using the granulated PET at an optimum of 5% to partially substitute sand in mix for the production of non-load bearing hollow sandcrete blocks for sustainable construction.

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