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# Assessment of Shredded Waste Poly-Ethylene Terephthalate (PET) Bottles Usage as Coarse Aggregate in Lightweight SHA Based Concrete Composite

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***Abstract:***

*In this research report, the use of shredded waste Poly-ethylene Terephthalate (PET) bottle flakes as a lightweight aggregate in concrete was examined. Investigation was carried out on two groups of concrete samples, one made with only granite as coarse aggregate (control) and second made with PET and granite aggregate together as replacement for coarse aggregate. The PET replaced the granite coarse aggregate a varying percentage of 0%, 5%, 10% and 15%. Additionally, Sorghum Husk Ash (SHA) was also used as the replacement of cement on mass basis at the replacement ratio of 10% to reduce the amount of cement used and provide savings. The water–binder (w/b) ratio used in the mixtures were 0.55. The size of shredded PET flakes used in the preparation of concrete mixtures were between 1 and 4 mm. The results of the laboratory study and testing carried out showed that concrete comprising only granite aggregate, concrete containing PET and granite aggregate, and concrete modified with SHA as cement replacement can be drop into structural lightweight concrete category in terms of unit weight and strength properties. Therefore, it was concluded that there is a potential for the use of shredded waste PET as aggregate in the production of structural lightweight concrete. The use of shredded waste PET due to its low unit weight reduces the unit weight of concrete which results in a reduction in the self-weight of a structural concrete member of a building. Reduction in the dead weight of a building will help to reduce the seismic risk of the building since the earthquake forces linearly dependent on the dead-weight. Furthermore, it was also concluded that the use of industrial and agricultural wastes such as PET flakes and SHA in concrete provides some advantages, i.e., reduction in the use of natural resources, disposal of wastes, prevention of environmental pollution, and energy saving.*

***Keywords:*** *lightweight aggregate, Poly-ethylene Terephthalate (PET), Sorghum Husk Ash (SHA), Strength properties, Unit weight.*

## Introduction

Lightweight aggregate is an imperative material in plummeting the density or unit weight of concrete to produce earthquake resilient constructions since the earth tremor forces are linearly reliant on the mass of the structure (Jafari & Mahini 2017, Semiha et al., 2010). The use of Lightweight aggregates is largely meant for the reduction of the unit weight of concrete through substituting the conservative aggregates. Currently, there are numerous lightweight concrete submissions made with natural or artificial lightweight aggregates in the literature (Saikia et al. 2014, Islam et al. 2016, Madandoust et al. 2019, Ashrafian et al. 2020, Záleská et al. 2018). Though, the cost of non-natural lightweight aggregate production is high owed to necessity of high burning temperature or thermal treatment (Semiha et al. (2010). Consequently, unlike other common materials, using waste plastic pellets as lightweight aggregate in the manufacture of lightweight concrete has engrossed considerable interest and keen devotion from the researchers. This method offers both recycling of the plastic waste

and manufacture of a lightweight concrete in an cost-effective manner (Hilal et al., 2021, Koide et al., 2002).
Poly-ethylene Terephthalate (PET), Polypropylene (PP), and Polystyrene (PS). Poly-ethylene (PE) are some of the plastic wastes used in lightweight concrete. The PET bottles are ahead of the wastes with its high growing speed of consumption. PET excels by its inherent values like strength, safety, cost-effectiveness and being lightweight, unbreakable and recyclable. Today, the food and beverages industry is increasingly using PET (polyethylene terephthalate) to replace glass and other materials. In Nigeria, the usage of PET started in a noticeable way only very recently. It is projected that the demand will grow appreciably, especially for packaging soft drinks and water. Research indicates that the main driver of growth for PET (polyethylene terephthalate) bottles in Nigeria has been the food and beverage sector with water industry accounting for about sixty-five percent (65%) of PET (polyethylene terephthalate) usage in Nigeria (Foraminifera Market Research, n.d, Tuleun & Jimoh, 2018).
As a result of wild increase in the usage of PET bottles in our environment, solid waste problem is upstretched and over a hundred of years is required to degrade the waste PET bottles naturally (Ioakeimidis et al., 2016, Pol 2010). Hence, one of the realistic approaches for disposal of PET wastes, which causes environmental pollution, is using these wastes in the other manufacturing expanses, thus recycling the PET for beneficial, ecological and economic purpose. Several experimental studies have been carried out on using waste PET bottles as resin in polymer concrete and as fibre in fibrous concrete in recent years (Asdollah-Tabar et al., 2021; Patil et al., 2020; Batista et al., 2021; de Luna et al., 2020; Alani et al, 2020). Nevertheless, the utmost cost-effective use of waste PET bottles in concrete as being described by researcher to be shredded waste PET bottles used directly as aggregate in concrete fabrication. Thus, the use of PET wastes as aggregate in concrete will afford benefit in the disposal of wastes and reduce the environmental damages owed to the use of natural mineral aggregates resources (Semiha et al., 2010). Limited study on concrete fabricated with waste PET flakes as coarse aggregate are reported in literature (Islam et al. 2016; Saikia and de Brito, 2014; Silva et al., 2013; Ghaly and Gill, 2004). Though, besides waste PET, other plastic wastes such as HDPE, PE and PS have been used as aggregates in preparing various concrete composites (Naik et al., 1996). Plastic bottles shredded into PET flakes and pellets may be used successfully as substitution for coarse aggregates in cementitious concrete composites and be used for structural concrete member.
In addition, SHA was used as a replacement of cement in concrete in previous studies. It is reported in many investigations that, the use of SHA in concrete as a cement replacement has positive influence on the properties of the fresh and hardened concrete (Ndububa & Nurudeen, 2015; Tuleun & Jimoh, 2018). In addition, it also provides economic benefits (Tuleun & Jimoh, 2018). It improves strength, reduces permeability and porosity, reduces alkali-silica expansion of hardened concretes (Ogork and Danja, 2018; Tijani, et al., 2019a; Tijani et al., 2019b). 10% SHA replacement level was reported as the optimum quantity for achieving a competitive value for compressive strength of resulting concrete (Ndububa & Nurudeen, 2015). Thus, in this research, SHA was also employed as a partial cement replacement to attain savings from the amount of cement used in the manufacture of lightweight concrete made with lightweight PET aggregates. The usage of SHA in concrete affords ecological advantages apart from the energy savings and contribution to the properties of strength and durability of concrete (Tuleun & Jimoh, 2018).
This study, hence, investigated the performance of lightweight concrete produced using SHA as the supplementary cementitious material and waste PET bottle, which partially replaced the mineral aggregates as coarse aggregate in varying percentage to optimize the most

suitable quantity of PET for a structural light weight concrete. This is achieved by examining the physical and mechanical properties of concrete containing PET aggregates.

**Materials and Methods**

In this study Portland cement (CEM 1 42.5N - Dangote 3X) produced by Dangote Cement Company was used as the binder for the control reference concrete mix. The Portland cement used as binder for both control reference concrete mix and blended mix in this research was Dangote 3X cement brand (CEM 1 42.5N). Initial and final setting times of the cement were 45 mins and 150 mins, respectively. While the Initial and final setting times of blended CEM 1 cement (90%) and SHA (10%) binder were 115 mins and 230 mins respectively. The specific gravity of the cement used was 3.15 g/cm3 and Blaine specific surface area was 3220 cm2/g.

Sorghum Husk used was gotten from a farm waste dump in wukara village of kyami district, FCT-Abuja, Nigeria. At first, the collected Sorghum Husk was treated by drying and screening to eliminate unwanted leaves and straw constituents. The treated Sorghum Husk were afterward burned in open air using a locally fabricated incinerator described in the literature (Abalaka and Okoli, 2013). The resulting Sorghum Husk Ash (SHA) was sieved to remove extraneous and unburned carbon materials. Ensuing, the resultant SHA particles were ground to sizes below 150 µm using a local milling device. Finally, the pulverized ash was sieved to 75 µm particles to obtain the SHA used for the subsequent experiments.

The specific gravity of SHA was 2.30 g/cm$^3$ and Blaine specific surface area was 4210 cm$^2$/g. The BET value for SHA was determined as 3.420 m$^3$/g. If the particles are porous, or have a rough surface structure, the BET surface area will be greater than the Blaine surface area. For this SHA particle, the particle was determined not to be porous. Blaine fineness along with chemical reactivity of cementitious or fine particles materials composition and fineness controls early strength development. Actually, most Type III cements today are simply higher fineness types of the regular Type I, II or V cement formed at the same plant. The chemical composition of cement and SHA are given in Table 1.

**Table 1:** Chemical composition of Portland Cement (CEM 1) and Sorghum Husk Ash (SHA).

| **Oxides (%)** | **NaO** | **MgO** | **$Al_2O_3$** | **$SiO_2$** | **$P_2O_3$** | **$K_2O$** | **CaO** | **$TiO_2$** | **MnO** | **$Fe_2O_3$** | **$SO_3$** | **LOI** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CEM 1** | 0.10 | 1.24 | 6.12 | 21.3 | 0.05 | 0.23 | 65.0 | 0.25 | 0.01 | 3.47 | 1.02 | 0.80 |
| **SHA** | 0.45 | 2.05 | 20.10 | 60.25 | 0.15 | 2.45 | 0.76 | 1.16 | 0.30 | 10.89 | 2.38 | 5.76 |

The shredded waste PET bottle flakes used as aggregate were supplied from Sarz Gen enterprise, a waste plastic recycled plant, in free trade zone, Sharada, Kano state, Nigeria. It was got by picking-up waste PET bottles and washing, then crushing into flakes by machines. The average maximum size of PET aggregate was 4 mm, and its specific gravity was 1.35 g/cm$^3$. River sand with maximum size of 4.75 mm was used in this study. The absorption value of the sand was 1.33% and, the relative density at saturated surface dry (SSD) condition was 2.62 g/cm$^3$. The grading of sand measured according to ASTM C33 (2019) showed that the present sand can be used in concrete production.

**Mix proportions, sample preparation and testing methods**

The water–binder (w/b) ratio used in this work was 0.55. CEM 1 Cement and SHA were used as the binder. SHA was used as a partial replacement of cement on weight base at the replacement ratio of 10%. Waste shredded PET flakes were used as substitution to coarse aggregate (crushes granite) in varying percentage of 0%, 5%, 10%, 15% and 20% in the M (1-

5) and S (1-5) mixtures. M (1-5) signifies mixture without SHA content, while S (1-5) mixture is the concrete produces with 10% blended cement mix. The proportions of concrete mixtures are given in Table 2.

**Table 2:** The proportions of concrete mixtures by weight (%).

| Mix ID | SHA (%) | PET (%) | SHA ($kg/m^3$) | CEM 1 ($kg/m^3$) | PET ($kg/m^3$) | Coarse Aggregate ($kg/m^3$) | Fine Aggregate ($kg/m^3$) | Water ($kg/m^3$) | SP (1%) |
|---|---|---|---|---|---|---|---|---|---|
| M1 | 0 | 0 | 0 | 404.26 | 0.00 | 1189.54 | 578.01 | 215.72 | 4.04 |
| M2 | | 5 | 0 | 404.26 | 59.48 | 1130.06 | 578.01 | 215.72 | 4.04 |
| M3 | | 10 | 0 | 404.26 | 118.95 | 1070.60 | 578.01 | 215.72 | 4.04 |
| M4 | | 15 | 0 | 404.26 | 178.43 | 1011.11 | 578.01 | 215.72 | 4.04 |
| M5 | | 20 | 0 | 404.26 | 237.91 | 951.63 | 578.01 | 215.72 | 4.04 |
| S1 | 10 | 0 | 40.43 | 363.83 | 0.00 | 1189.54 | 578.01 | 215.72 | 4.04 |
| S2 | | 5 | 40.43 | 363.83 | 59.48 | 1130.06 | 578.01 | 215.72 | 4.04 |
| S3 | | 10 | 40.43 | 363.83 | 118.95 | 1070.60 | 578.01 | 215.72 | 4.04 |
| S4 | | 15 | 40.43 | 363.83 | 178.43 | 1011.11 | 578.01 | 215.72 | 4.04 |
| S5 | | 20 | 40.43 | 363.83 | 237.91 | 951.63 | 578.01 | 215.72 | 4.04 |

Cubical and cylindrical specimens with 100 x 100 x 100 mm and 100 x 200 mm dimensions respectively were prepared from fresh concrete mixtures. They were afterwards demoulded after 24 hours and immediately cured in water at 22 ± 2°C for 7, 28 and 56 days (ASTM C192/C192M (2007). The samples were tested for compressive strength and tensile strength. In addition, slump test and the fresh unit weights test was conducted on the fresh concrete mix in accordance with the British Standards (BS EN 12350-2 (2009). While the dry unit weights test, was conducted on the hardened specimen. The compressive and tensile strength values of concrete specimens were measured by using the test methods according to (BS EN 12390-3, 2009 and ASTM C496/C496M, 2011). All testing measurements were obtained from three samples, and the average of three samples was presented and discussed in the study.

## Results and discussion

### Unit weight

Measured fresh unit weights and dry unit weights of concrete specimens at 7, 28 and 56 days are presented in Table 3. The fresh unit weights of M1-M5 and S1-S5 where M1 is mix without SHA and PET and S1 is mix containing 10% SHA and 0% PET which are the control samples. The mix proportions were presented in Table 2. The dry unit weights of all specimens decreased in course of time due to the evaporation of free water and as the due to the increase in percentage of the Pet in concrete due to the increase of the pore structure. The dry unit weight at 28 days hydration period values of concrete without SHA (M1-M5) and (S1-S2) were between 1138 $m^3$ and 2243 $kg/m^3$. The unit weight of M1-M5 is lower than the unit weight of S1-S2. Since the specific gravity of SHA was lower than CEM 1 cement as the binder, the dry unit weights of the concrete made with PET were lower than the concrete without PET (M1 and S1) serving as the control sample.

The relationship between the workability (slump) and the percentage replacement of the PET aggregate is displayed in Table 3. The slump value of both PET concrete containing 10% SHA by weight of cement and without SHA declines as the percentage replacement of the PET aggregate rises, as revealed in Table 3. The declining ratios of workability indicate 89.5%, and 94.7% in comparison with that of normal concrete at the percentage cement replacement ratio of 0%, and 10%, respectively. This may be attributed to not only the smooth shape of the PET but also to the absorption and hydrophilic property of SHA. The workability reduction experienced by the light weight concrete is due to the large surface area of the ash and the smooth surface of the PET. PET and SHA is capable of reducing the unit water content and the water-reducing agent content. It is expected that the reduction of the unit water content could compensate for the strength reduction of the PET/SHA concrete in the case of manufacturing the concrete with the same slump.

**Table 3:** Fresh and dry unit weights (kg/m$^3$) of concrete produced.

| Mix ID | SHA (%) | PET (%) | Fresh Unit weight (kg/m$^3$) | Dry Unit weight (kg/m$^3$) | | | Slump (mm) |
|---|---|---|---|---|---|---|---|
| | | | | 7 | 28 | 56 | |
| M1 | 0 | 0 | 2383.98 | 2254 | 2243 | 2201 | 95 |
| M2 | | 5 | 1915.72 | 2085 | 1831 | 1839 | 60 |
| M3 | | 10 | 1884.19 | 1965 | 1810 | 1847 | 50 |
| M4 | | 15 | 1855.44 | 1792 | 1744 | 1656 | 35 |
| M5 | | 20 | 1821.28 | 1557 | 1503 | 1453 | 10 |
| S1 | 10 | 0 | 2316.23 | 2174 | 2115 | 2046 | 80 |
| S2 | | 5 | 1896.84 | 1847 | 1808 | 1745 | 55 |
| S3 | | 10 | 1853.39 | 1802 | 1766 | 1662 | 45 |
| S4 | | 15 | 1818.22 | 1744 | 1482 | 1384 | 25 |
| S5 | | 20 | 1781.74 | 1254 | 1138 | 1058 | 5 |

**Compressive strength**

Structural lightweight concrete is defined by ACI Committee, as the compressive strength of 28 days, which is higher than 15–17 N/mm$^2$. ACI Committee also opined that the air-dry unit weight of a structural lightweight concrete should be lower than 1850 kg/m$^3$ (ACI Committee 213R, 1987). The air-dry unit weights of the ten mixtures presented in Table 3 were lower than 1850 kg/m$^3$; in other words, they complied with the above definition in terms of unit weight. The compressive strength values of concrete measured in the laboratory are presented in Table 4. Table 4 shows that the compressive strength values at 28 days of the concrete specimens were quite higher than 17 N/mm$^2$. When the unit weight and compressive strength values are considered together, M1-M5 and S1-S5 mixtures can be classified as a structural lightweight concrete

The 28 days compressive strength values of the mixtures containing only PET aggregates (M2-M5) were 33.28, 29.55, 26.27 and 23.40 N/mm$^2$. These values reached 36.76, 32.22, 30.48, 25.91 N/mm$^2$ at 56 days, respectively (Table 4). The compressive strengths of S2-S5 mixtures (including PET and SHA together) were 32.90, 26.50, 25.98 and 21.33 N/mm$^2$ at 28 days. At 56 days, their levels raised to 37.93, 34.11, 31.87 and 27.11 N/mm$^2$, respectively (Table 4). It was seen from these results that, the compressive strengths of the mixtures containing 10% SHA and varying percentage replacement of PET together were higher than the mixtures containing varying percentage replacement of PET without SHA at 56-day hydration period. This was an expected result. Nonetheless, the compressive strength values of PET aggregates with SHA blends (S2–S5) were found to be suitable. The compressive strength values of typical control normal weight concrete mixture (M1) which is set for evaluation purposes were 18.43, 32.54 and 34.35 N/mm$^2$ at 7, 28 and 56 days, respectively (Table 4).

**Table 4:** Compressive strength (N/mm$^2$) of concrete produced.

| Mix ID | SHA (%) | PET (%) | Compressive Strength (N/mm$^2$) | | | Tensile Strength (N/mm$^2$) | | |
|---|---|---|---|---|---|---|---|---|
| | | | 7 | 28 | 56 | 7 | 28 | 56 |
| M1 | 0 | 0 | 18.43 | 32.54 | 34.35 | 2.05 | 3.85 | 3.98 |
| M2 | | 5 | 16.84 | 33.28 | 36.76 | 1.46 | 3.73 | 3.88 |
| M3 | | 10 | 14.65 | 29.55 | 32.22 | 1.36 | 3.34 | 3.57 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| M4 | | 15 | 12.91 | 26.27 | 30.48 | 1.12 | 2.91 | 3.37 |
| M5 | | 20 | 10.44 | 23.40 | 25.91 | 0.73 | 2.39 | 3.13 |
| S1 | 10 | 0 | 14.44 | 31.20 | 34.96 | 1.69 | 3.70 | 4.18 |
| S2 | | 5 | 13.22 | 32.90 | 37.93 | 1.25 | 3.56 | 3.94 |
| S3 | | 10 | 11,39 | 26.50 | 34.11 | 1.12 | 3.38 | 3.74 |
| S4 | | 15 | 10.16 | 25.98 | 31.87 | 0.71 | 3.22 | 3.62 |
| S5 | | 20 | 8.49 | 21.33 | 27.11 | 0.34 | 3.04 | 3.44 |

It can be seen from Table 4 that the compressive strengths of concrete produced in this investigation developed rapidly at an early age up to 28 days, however, after 28 days the speed of compressive strength developments slowed down in long term (56 days). This result was found to be similar to the strength development of normal weight mortar. It can be observed from Table 4 that, in general, the compressive strength of the concrete modified with SHA as cement replacement corresponding in pattern with the compressive strength of the cement concrete at 7 and 28 days. After that, they passed the compressive strength of concrete made with only cement as the binder. Replacement of cement with SHA increased the compressive strength of concrete when compared to strength of concrete made with cement only especially at 56 days. This could be seen from Table 4 that strengths development of S2 to S5 were better than the strength developments of M2 to M5 for concrete with age 56 days. It was explained in the literature that, the strength of concrete modified with Supplementary Cementitious Materials (SCMs) as cement replacement was lower than the strength of NPC concrete at early ages (Semiha *et al.*, 2010). However, when it was cured adequately, its strength could be equivalent or higher than the control concrete in long term (Fernandez and Malhotra, 1990; Yeau and Kim, 2005; Bilim, 2006; Yazici, 2006; Oner and Akyuz, 2007). The result observed in this study for SHA concrete was found to be in-agreement with the literature.

**Splitting tensile strength**

The effect of substituting granite aggregate with waste bottle PET flakes at varying percentage with various w/c ratios is presented in Table 4. As illustrated in table 4, the general trend of tensile strength is decreasing when the amount of PET particles increases. For instance, for the both concrete mix without SHA (M2-M5) and concrete mix with 10% SHA, reduction occurred in tensile strength. This can be attributed to the negative effect of the smooth surface texture of the PET flakes on the bond strength between the PET, matrix and the aggregates. The increase surface area of PET particles compare to granite coarse aggregate is also a factor to consider. In addition, as the PET ratio increases, the reduction in splitting tensile strength is more significant.

**Conclusions**

The following conclusions were made from this experimental work:

i. Concrete containing only PET aggregate and concrete modified with SHA as cement replacement produced in this study drop into structural lightweight concrete category.

ii. The use of SHA reduced the slump and both wet and dry unit weight of the specimens. It also increased the compressive and tensile strength of the samples.

iii. The compressive and tensile strength values of the concrete containing PET and SHA together were higher than the concrete containing only PET aggregates.

iv. Based on the experimental study, the use of shredded waste PET flakes in concrete has a potential to reduce the dead weight of concrete, thus, can reduce the earthquake risk of a building, and it could be helpful in the design of an earthquake resistant building.

v. The usage of industrial and agricultural wastes such as shredded waste PET flakes and SHA in concrete production would be helpful and resourceful in solving a part of the world present day environmental concern, in reduction and recycling plastic waste which has become a menace to the environment and also for achieving a cleaner environment and reduce the depletion of the ozone layer and energy saving.

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