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Strength Properties of Rice Husk Ash Concrete with Shredded Pet Bottles as Coarse Aggregate Replacement

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Abstract
This study investigated the strength properties of Rice Husk Ash (RHA) concrete with shredded Polyethylene Terephthalate (PET) bottles as coarse aggregate partial replacement. Concrete mix, 1:2:4 was designed for all specimens with w/c of 0.5. Samples were prepared and examined at deferent replacement levels of cement with RHA (5, 10 and 15%) using shredded PET bottles (5, 10 and 15%) as coarse aggregate replacement. Concrete without RHA and shredded PET bottles served as control. A total number of 90 concrete cubes and 20 flexural beams were used to examine the strength properties of produced concrete specimens at 28 days. Results revealed that both compressive and flexural strengths of RHA-concrete decreased as the amount of shredded PET bottles increased. The compressive strengths obtained were 20.65, 17.44, 16.53 and 15.87 N/mm^2 while the flexural strengths were 10.49, 6.63, 6.59 and 5.72 N/mm^2 for 0, 5, 10 and 15% replacement levels respectively. This class of concrete could be used to produce both plain and reinforced concrete of light weight aggregate.
Keywords: Concrete, Rice Husk Ash, Coarse aggregate, PET aggregate, Compressive and Flexural strength.

Introduction
Concrete is a composite material which consists of cement, aggregates and water. It is commonly used all over the world in construction of buildings, bridges and roads. Light-weight concrete can be produced through the following three principles which are no-fine, aerated and lightweight aggregate concrete, either for structural or for non-structural applications (Newman and Choo, 2003). A number of researchers in Nigeria have confirmed the suitability of agricultural waste products such as rice husk ash (RHA), palm oil waste ash and sorghum/guinea corn husk ash as pozzolanic materials which are capable of reacting with the lime produced as by-product of hydration of Ordinary Portland Cement to produce additional Calcium Silicate Hydrate (C-S-H) thus improving the compressive strength of the concrete whilst decreasing the amount of cement required and the resulting CO_2 emissions (Ephraim *et al*., 2012; Oyejobi *et al.,* 2014; Ndububa and Nurudeen, 2015; Oyejobi *et al*., 2016; Raheem and Kareem, 2017; Tijani *et al*., 2018a&b). According to Tijani *et al.* (2018c) the chemical composition of rice husk ash varies from one another due to geographical and climatic conditions.
The mechanical performance of RHA in concrete was investigated by Oyejobi *et al*., (2014). Cement was replaced partially with RHA in concrete at 0, 10, 20 and 30% respectively. It was concluded that values for RHA concrete produced can be used for reinforced concrete. Ephraim *et al*. (2012) examined the compressive strength of concrete with RHA as partial replacement of OPC. Cement was replaced with RHA at 10, 20 and 25% and the result indicated an increase in RHA concrete water demand and strength. The effect of RHA on concrete was evaluated by Akeke *et al*., (2013). RHA was used to replace cement at 10 – 25 % with a mis ration 1:1.5:3. The compressive strength results was obtained to be between 33 - 38.4 MPa. Tsado *et al*. (2014) obtained the highest compressive strength of 30.58 N/mm2 for replacement samples of RHA at 10% while 26.51 and 17.68 N/mm2 were obtained for 20 and 30% replacement respectively. Similarly, Oyekan and Kamiyo (2007) reported the variation of compressive strength with RHA with the highest compressive strength of 29.35 N/mm^2 for the concrete cubes obtained at 5% RHA content which represented 16.8% increase over the strength obtained at zero percent ash content. Further increase in percentage of RHA led to drop in the compressive strength of the concrete cubes.

Plastic is a non-biodegradable material that persist in the environment for longer durations of time and cause issues related to their disposal. Out of various forms of plastics, polyethylene terephthalate (PET) is a widely used packaging material for soft drinks, bottled water, food items and other products. PET is a semi-crystalline thermoplastic polymer formed by polycondensation of terephthalic acid with ethylene glycol (Kuczenski and Geyer, 2010). Rapid expansion of PET bottle industry has led to a fast growth in global PET consumption (Foolmaun and Ramjeeawon, 2012). During 2009–2013, PET bottle industry grew at an average annual rate of 4.3% (Padhan *et al.,* 2013). Global PET bottle consumption is nearly 20 million tonnes and is rising at a staggering rate of 15% annually (Yao *et al.,* 2014). At the same time, recycling rate of PET bottles is low at just 29.3% (Frigione, 2010). To overcome the pollution menace of plastics in general, and waste PET bottles in particular, channels for reutilization of waste PET are being explored where it could be possibly used in bulk quantities. One such route of PET waste reuse has been in construction industry where it can be used as partial replacement for aggregates in concrete (Choi *et al.,* 2005; Siddique *et al.,* 2008; Saikia and Brito, 2012, Ferreira *et al.,* 2012; Rahmani *et al.,* 2013; Muhammad and Muhammad, 2015; Islam *et al.,* 2016).

As at today, Nigeria's population is presently over 198 million as reported by National Population Commission (2018). This teeming population is faced with housing problems due to the low income and high prices of building materials. By exploring waste products from the industries for concrete production, the costs of construction will be reduced and houses will be affordable. Besides, there will be economic value for these wastes and control of pollution associated with the wastes rather than open dumping on the land and into rivers. Moreover, to the authors' best knowledge, there are little or no literatures on the utilization of plastic wastes with the use of admixtures such as RHA in concrete production. Hence, this study investigates the strength properties of RHA concrete with shredded PET bottles as coarse aggregate replacement.

Materials and Methods

The materials used were shredded PET plastic bottles (Plate 1), RHA (Plate 2), cement (CEM II 32.5N), river sand and granite of 19mm nominal size. After collection, PET bottles were taking to a local plastic recycler in Ibadan where they were shredded into 10mm aggregate size for the purpose of this work. The open neck that hold the cap of the bottles were removed before shredding and the shredded PET aggregates were washed to remove stickers, papers and any other contaminating agents from the aggregates. Specific gravities for the sand, granite and PET aggregates used were 2.60, 2.69 and 0.91 respectively. The rice husk was oven dried to remove moisture content after which it was properly burn in a furnace under a controlled temperature of 600^{o}C for 4 hours. The burnt ash was grinded and sieved with 45microns sieve to required fines. The RHA then was taken to laboratory to determine for chemical analysis to verify its suitability as a pozzolanic material. The chemical composition analysis results shown in Table 1 showed that, the combination of SiO_2, Fe_2O_3 and Al_2O_3 in the RHA was found to be 72.97% which was more than 70% specified for pozzolans by ASTM C618-12a. Both sand and granite were obtained from local quarries in Ibadan, Nigeria and were air dried to obtain saturated surface dry condition to ensure that water/cement ratio is not affected. Coarse and fine aggregates conform to BS 882 specifications.

A total number of 90 concrete cubes and 20 flexural beams were cast for testing. These were cured and tested at 28days for density, compressive and flexural strengths. Concrete mix, 1:2:4 was designed for all specimens with w/c of 0.5. Samples were prepared by hand mixing in four batches at deferent replacement levels of cement with RHA (5, 10 and 15%) using shredded PET bottles (5, 10 and 15%) as coarse aggregate replacement. Concrete without RHA and shredded PET bottles served as control.

In this investigation for each mix 3-samples were tested and the average strength were compared to nominal mix of M20 grade. Hardened density was carried out in accordance with BS 1881, 1983. Totally 90-cubes of size 100 x 100 x 100mm were cast and tested at 28 days of curing. The test cubes were made in accordance with BS 1881: Part 1, 1983 and the compressive strength was determined according to BS 1881: Part 116, 1983. Flexural strength was carried out in accordance with the procedure of BS 1881: Part 118,

1983. It was measured by loading 100 x 100 x 500mm concrete beams which is a span length of at least three times the depth.



Plate 1: PET aggregate



Plate 2: Rice Husk Ash

Table 1: Results of Chemical Analysis of RHA

Chemical constituents	Percentage composition
SiO_2	67.28
Al_2O_3	4.90
Fe_2O_3	0.79
TiO_2	0.11
CaO	1.35
P_2O_5	0.03
K_2O	0.05
MnO	0.70
MgO	1.81
Na_2O	0.31
LOI	17.78

Results and Discussion

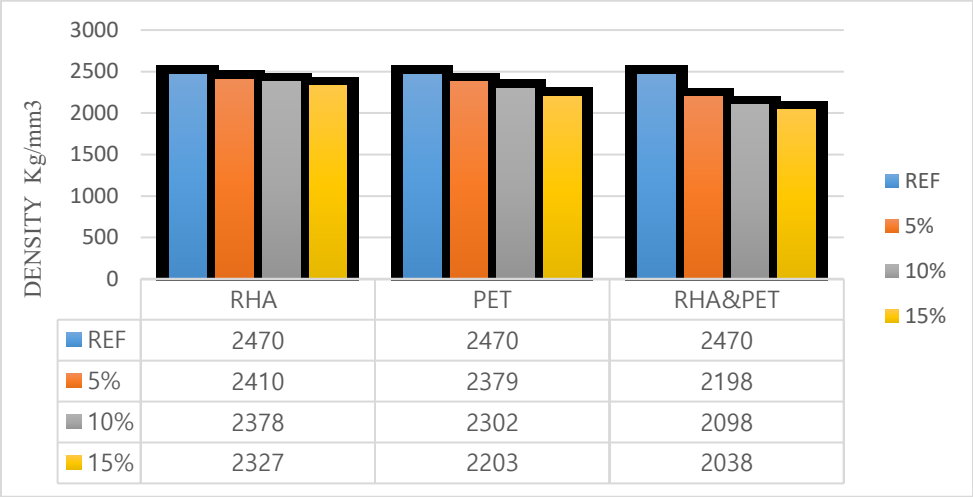
Hardened density of concrete

Figure 1 presented the results of hardened density of concrete cube specimens obtained at 28 day of curing. Substitution of granite by PET aggregate reduced the hardened density of all mixtures. The hardened density decreased with increase in the amount of RHA and PET aggregate. The values obtained for 0, 5, 10 and 15% RHA substitution were 2470, 2410, 2378 and 2327 kg/m^3 respectively. The reduction in hardened density could be attributed to the lesser specific gravity (2.1) of RHA as likened to OPC (3.15). Similar trend was observed by Oyekan and Kamiyo (2007), Ephraim *et al*. (2012). Oyejobi *et al. (*2014) and Tijani *et al.* (2018b). Furthermore, for 0, 5, 10 and 15% replacement level of PET aggregate, hardened densities were 2470, 2379, 2302 and 2202 kg/m^3 respectively. Addition of PET aggregate (0 – 15%) to RHA concrete also reduced the hardened density up to 17.5%. This decrease in hardened density of concrete is probably due to the substitution of a heavier material (granite) by the lighter material (PET). The specific gravity of PET aggregate is lower than that of granite by 67%. The lower density of concrete with plastic aggregates can be explained by the lower specific gravity of waste plastic (Islam *et al.,* 2016; Rahmani *et al.,* 2013; Saikia and Brito, 2012; Ferreira *et al.,* 2012).

Compressive strength of concrete

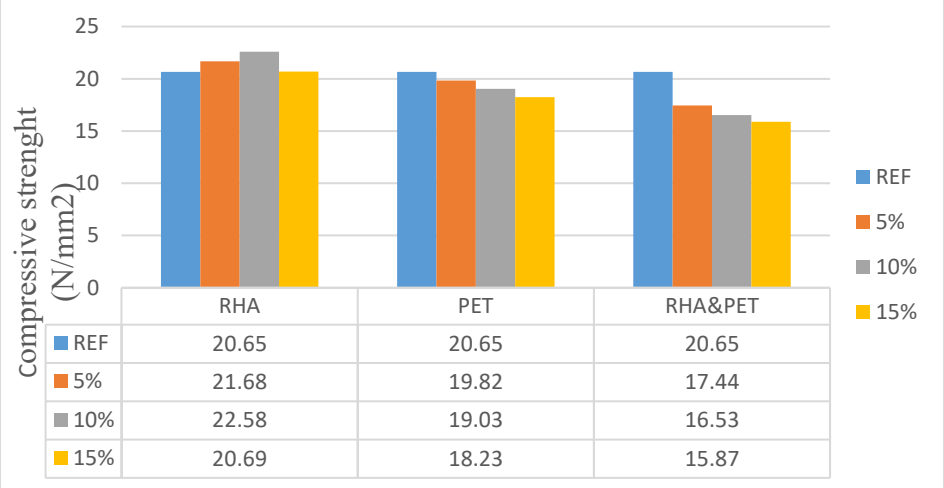
The 28 day compressive strength of investigated concrete specimens were presented in Figure 2. It was observed that compressive strength increases from 0 to 10% RHA addition before it decrease at 15% RHA substitution. This suggest 10% RHA as the best mix at 28 days of testing. The rise in compressive strength at 5 and 10% RHA could be credited to the filling outcome of the fine ash and also to its pozzolanic reaction. The 5 and 10% RHA compressive strength value was 4.99 and 9.50% higher than the control while that of 15% RHA reduced by 0.20%. Furthermore, the compressive strength of RHA concrete are found to be

between 20 – 25 N/mm^2 specified by BS 8110 (1997) for normal weight reinforced concrete. However, substitution of granite by PET aggregate reduced the compressive strength all PET aggregate mixtures. For 0, 5, 10 and 15% replacement level of PET aggregate, compressive strength were 20.65, 19.82, 19.03 and 18.23 N/mm^2 respectively. Addition of PET aggregate to RHA concrete reduced the compressive strength by 15.55, 19.95 and 23.15 N/mm^2 for 5, 10 and 15% PET aggregates respectively. It was observed that the PET aggregate does not fail under loading during compressive strength test but was deboned from the concrete matrix and this confirmed there is poor bonding between cement, RHA and PET aggregate. However, the compressive strength obtained for RHA-PET aggregate concrete were within 15 – 20 N/mm^2 specified by BS 8110 (1997) for light weight reinforced concrete. The compressive strength of concrete with various percentages of recycled waste plastic as coarse aggregates was investigated by various researchers (Choi *et al.,* 2005; Siddique *et al.,* 2008; Saikia and Brito, 2012, Ferreira *et al.,* 2012; Rahmani *et al.,* 2013; Muhammad and Muhammad, 2015; Islam *et al.,* 2016). Most authors reported a gradual decrease in the compressive strength with increasing waste plastic percentages. Islam *et al.* (2016) added that, since plastic aggregates have almost no water absorption capacity, water will accumulate in the ITZ, causing it to be more porous. This extra porosity will cause a reduction in compressive strength. Typically, the smooth surface of most plastic aggregates causes a weak bond between the cement matrix and aggregates, causing the lower strength of concrete.



	RHA	PET	RHA&PET
REF	2470	2470	2470
5%	2410	2379	2198
10%	2378	2302	2098
15%	2327	2203	2038

Figure 1: Results of hardened density

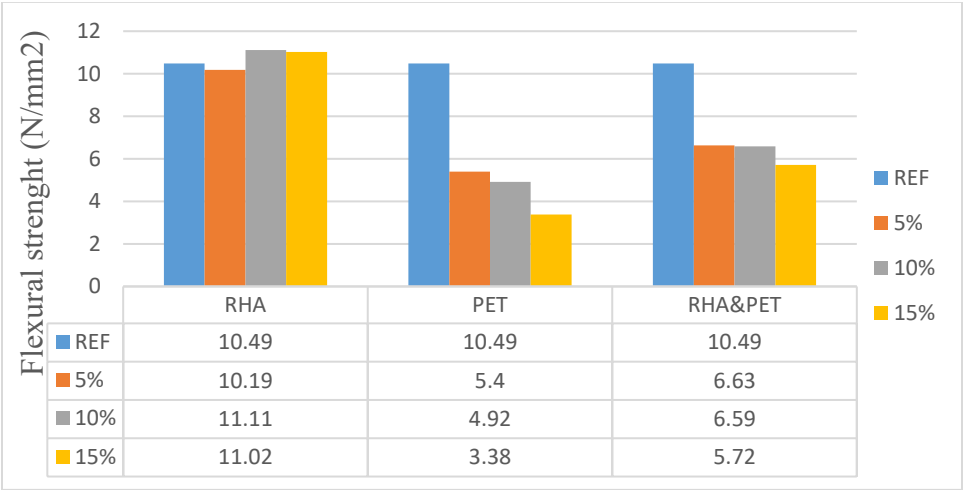


	RHA	PET	RHA&PET
REF	20.65	20.65	20.65
5%	21.68	19.82	17.44
10%	22.58	19.03	16.53
15%	20.69	18.23	15.87

Figure 2: Results of compressive strength at 28days

Flexural strength of concrete

The flexural strength of concrete specimens tested at 28 days were presented in Figure 3. The flexural strength of 10.49, 10.19, 11.11 and 11.02 N/mm^2 were obtained for 0, 5, 10 and 15% RHA addition respectively. This suggest 10% RHA as the best mix at 28 days of testing. The rise in flexural strength at 10% RHA could be credited to its pozzolanic reaction. However, substitution of granite by PET aggregate reduced the flexural strength all PET aggregate mixtures. For 0, 5, 10 and 15% replacement level of PET aggregate, flexural strength were 10.49, 5.40, 4.92 and 3.38 N/mm^2 respectively. Addition of PET aggregate to RHA concrete reduced the flexural strength from 10.49 N/mm^2 control value to 6.63, 6.59 and 5.72 N/mm^2 for 5, 10 and 15% PET aggregates respectively. This could be due to poor bonding that exist between PET aggregate and RHA concrete. It could also be as a result of honeycomb that are present in the concrete. This result is considered better compared to those obtained from the work mentioned in the review paper published by the author's Saikia *et al*. (2012). The reduction in the flexural strength of concrete might be due to either a poor bond between the cement paste and the plastic wastes or to the low strength of this plastic wastes (Siddique *et al.,* 2008 and Ferreira *et al.,* 2012).



	RHA	PET	RHA&PET
REF	10.49	10.49	10.49
5%	10.19	5.4	6.63
10%	11.11	4.92	6.59
15%	11.02	3.38	5.72

Figure 3: Results of flexural strength at 28days

Conclusion

This study investigates the strength properties of Rice Husk Ash (RHA) concrete with shredded Polyethylene Terephthalate (PET) bottles as coarse aggregate partial replacement. It is concluded that:

i. RHA had combination of SiO_2, Fe_2O_2 and Al_2O_2 that was more than 70% specified for pozzolans and therefore suitable for concrete production.
ii. Optimum RHA replacement level was obtained at 10%.
iii. Both compressive and flexural strengths of RHA-concrete decreased as the amount of shredded PET bottles increased. However, the compressive strengths obtained were between 15 and 20 N/mm^2 while the minimum flexural strength was above 3.13 N/mm^2 specified by British standard code.
iv. The class of concrete produced could be used to produce concrete of light weight aggregate.

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