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Experimental Study on Effect of Plastic Waste as Coarse Aggregate on Concrete Properties

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Abstract- High demand for aggregate to meet day-to-day activities in construction industry has intensified mining of the natural aggregate resources, thereby resulting in depletion of the resources and which raised concerns on compromise of the future generation needs. Over time, the cost of construction kept increasing due to high cost of aggregates. Serious environmental concerns have been raised on the ineffective management of the plastic waste generated globally and which has caused environmental, ecological and economic sabotage. Interest in the environmentally friendly recycling of plastic waste as materials for concrete is being considered. This study investigates the performance of concrete with addition of plastic Poly ethylene terephthalate (PET) aggregate. The plastic PET aggregate was used as substitution for coarse aggregate at 10%, 20% and 30% replacement levels. Effects of the presence of plastic PET aggregate in concrete on workability, density, compressive strength, flexural strength and water absorption were determined.

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Experimental Study on Effect of Plastic Waste as Coarse Aggregate on Concrete Properties

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Abstract- High demand for aggregate to meet day-to-day activities in construction industry has intensified mining of the natural aggregate resources, thereby resulting in depletion of the resources and which raised concerns on compromise of the future generation needs. Over time, the cost of construction kept increasing due to high cost of aggregates. Serious environmental concerns have been raised on the ineffective management of the plastic waste generated globally and which has caused environmental, ecological and economic sabotage. Interest in the environmentally friendly recycling of plastic waste as materials for concrete is being considered. This study investigates the performance of concrete with addition of plastic Poly ethylene terephthalate (PET) aggregate. The plastic PET aggregate was used as substitution for coarse aggregate at 10%, 20% and 30% replacement levels. Effects of the presence of plastic PET aggregate in concrete on workability, density, compressive strength, flexural strength and water absorption were determined. The results showed that the workability increases as the proportion of PET plastic waste increases in the concrete matrix. In comparison with the control concrete, the compressive and flexural strength of concrete reduces as the content of plastic PET aggregate increases. Compressive and flexural strength reduction trends of 25%, 47% and 53% and 38%, 43% and 51% for concrete containing 10%, 20% and 30% of plastic PET aggregate respectively. The loss of strength can be attributed to the ineffective bonding between plastic PET aggregate and mortar due to the smooth surface of the plastic PET aggregate. Also, plastic PET aggregate has relatively no water absorption and which makes excess water in the concrete. Upon hydration, the excess water gets evaporated and which creates voids in the concrete and weak region around the aggregates in the concrete. However, improvement in water absorption capacity were observed. As the content of plastic PET aggregate increases, the water absorption capacity reduces. However, significant reduction in strength properties was obtained for concrete with 20% and 30% of PET plastic waste. Meanwhile, the water absorption capacity of the concrete composite gets higher as the proportion of the PET plastic waste increases. From the study, it can be said that sand can be substituted with PET plastic waste up to 10% replacement levels in concrete matrix.

Keywords: alternative materials; compressive strength; environmental impact; coarse aggregate; flexural strength; and plastic pet aggregate.

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I. Introduction

There has been yearly rapid growth in the demand for construction materials, largely due to rise in population, urbanization and industrialization. Concrete is one of the major construction materials, and aggregates represents about 65 – 85 % by volume in concrete composite (Bahij et al., 2020). Currently, the yearly demand for concrete is estimated to be about 10 billion tons, and which has been projected to increase to 18 billion tons by the year 2050(Asadi et al., 2018). The high rate of usage of aggregates for day-to-day activities in construction has raised concern on the depletion and overexploitation of the natural resources, thereby, hindering the future needs of this resources by future generations. It becomes imperative to seek for alternative materials that could match up with the engineering properties of the conventional aggregates for structural and non-structural purposes.

Ecosystem and ecological systemsare becoming unsafe from generated plastic waste. Continuous increase in plastic usage and plastic waste generation growth have posed serious environmental concerns. In the year 2012, about 280 million tons of plastic waste was generated globally, and it rose to 335 million tons in the year 2016. It has been estimated to be around 1 billion tons by the year 2050 (Bahij et al., 2020).However, the global management of the large chunk of plastic generated is still low, as 22 % was recycled, 27 % incinerated and the majority ended up in landfills and dumpsites(Li et al., 2020). In Nigeria, about 32 million tons of plastic waste is generated annually, below 12% is recycled and about 80%finds their way to landfills and dumpsites (Kehinde et al. 2020). It has been reported that over 10 million tons of plastic waste ended up in ocean annually, and which contributed to the death of 100,000 marine animals and 1 million sea birds (Faraj et al., 2020). It has been forecasted that oceans will have more plastics than fishes by 2050 (Kehinde et al. 2020). It becomes necessary to improve the management of plastic waste generated. One of the effective ways is the recycling of plastic waste as aggregate for construction purposes. Being a new material, there is need to investigate the performance of concrete produced with plastic waste as aggregate. There are different types of plastics, but plastic Polyethylene Terephthalate (PET) is one of the larger percentages of plastic waste as it is commonly used daily by human. Efforts are geared towards the adoption of plastic waste as alternative materials in construction industry. Hence, the study focused on recycling plastic PET as partial replacement for fine aggregate in concrete matrix.

Boucedra et al. (2020) conducted an experimental study on concrete containing plastic wastes as aggregate. The plastic waste was substituted for fine aggregate at 25%, 50% and 75% replacement levels. Their findings showed reduction in density of concrete as the contents of plastic waste aggregate in the concrete increases. Nevertheless, replacement levels of up to 50% gave density that falls within the range of lightweight concrete. Similarly, behaviour of concrete with addition of plastic waste aggregate at 25%, 50% and 75% replacement levels were studied by Belmokaddem et al. (2020). Their study results indicated that the content of plastic aggregate is inversely proportional to the density of concrete. The higher the contents of plastic aggregate, the lower the density of concrete. Almeshal et al. (2020) incorporated plastic waste aggregate in concrete matrix in dosage of 10%, 20%, 30%, 40% and 50% replacement of fine aggregate. Results revealed slight reduction in compressive strength for 10% and 20% incorporation of plastic waste aggregate, compare to control mix. Beyond that, the reduction in strength became significant. Over 30% reduction in compressive strength when 40% plastic waste aggregate was incorporated in concrete mix. The decreasing trend was attributed to the reduction in composite bulk density. Effect of 5, 10 and 20% of plastic waste aggregate in concrete matrix was experimentally studied. The plastic aggregate was added as replacement for sand. Compare to the control concrete, it was observed that the compressive strength reduces by 7, 12 and 24% for concrete containing 5, 10 and 20% plastic aggregate respectively. The reduction trend was explained to be as a result of lower compressive strength of plastic aggregate compare to sand (Mustafa et al., 2019). Needhidasan et al. (2020) used plastics from electronic materials (E-plastic) as replacement for conventional coarse aggregate in concrete mix. It was found out that, up to 22% of E-plastic waste can be incorporated into concrete mix with minimal reduction in compressive strength. At 28 days, the target strength of 40MPa was achieved for concrete with 22% E-plastic waste. Experimental investigation of the properties of concrete with PP and LDPE plastic waste. The results revealed that the presence of plastic waste in concrete reduced the flexural strength of concrete mix of all replacement levels. Meanwhile, concrete with PP plastic waste showed better flexural strength performance than LDPE aggregate concrete. This can be explained to be due to the higher tensile strength of PP plastic aggregate over LDPE plastic aggregate. Concrete mix with 5% of PP as replacement for fine aggregates indicated 18% variation to the control concrete. However, concrete with incorporation of 5% and 10% PP plastic waste and 5% LDPE plastic waste gave considerable variation of 18%, 38% and 41% to conventional mix respectively. It was observed that there is decreasing trend of flexural strength as the contents of plastic waste increase and decrease in fine aggregate contents (v Visweswara Sastry Dhara&kumar, 2018).

II. Materials and Methods

All materials used for the study are sourced locally. The materials comprise of cement, fine aggregate (sand), coarse aggregate, plastic waste PET and water. The cement used for producing the concrete samples was Ordinary Portland Cement (O.P.C). Dangote cement brands of 42.3R grade and which conform to NIS 444-1:2003 based on the NIS trademark on the bag was procured. The cement was purchased from a retail shop at Oke-odo, Tanke, Ilorin. River sandwas used as fine aggregates and which can be regarded as sharp sand based on visual examination. Crushed aggregate or granite was used as coarse aggregate. Both fine and coarse aggregates were sourced from a construction site in the University. Precautions were taken that the aggregates did not have impurities such as grass, waste materials among others. Both fine and coarse aggregates conform to BS 822.Plastic waste of Polyethylene Terephthalate (PET) bottles was bought in packs from a local vendor at Tanke, Ilorin. After procurement, all materials were transported to the laboratory for further test before use in concrete. The water that conforms to WHO standards was sourced from the laboratory.

a) *Preparation of Plastic Waste PET as Coarse Aggregate*

The preparation of the PET coarse aggregates follows several steps. Firstly, the PET bottles were fragmented into small pieces or flakes, then it was washed thoroughly with detergent and water to remove any impurities. The PET bottles flakes were poured in a pan and heated at a temperature of 15^{o}c/min up to 250^{o}c using cooking gas. The PET flakes were continuously stirred to ensure uniform melting of the plastics. Then, it was transferred to the moulds and allowed to cool and solidify into a boulder form. The plastic waste PET in its boulder form was crushed to obtain desired plastic waste PET coarse aggregate with maximum size of 25 mm. The acquired plastic waste PET coarse aggregates were round in shape and had smooth surface texture. The physical properties of the materials such as particle size distribution, specific gravity and aggregate impact value were carried out in accordance with BS EN 933-1, 2012; BS EN 1097-2, 2020; BS EN 1097-3, 1998respectively.

b) *Mix proportion*

Conventional mix ratio of 1:2:4 (cement: fine aggregate: coarse aggregate) was employed for the proportions of constituent materials for the control concrete with a target strength of 20N/mm^2 at 28 days. The water-cement ratio was fixed at 0.5 for all the concrete mixes. The plastic PET aggregate was incorporated as substitute to the natural coarse aggregate at 10%, 20% and 30% levels. Table 1 shows the mix design of the relative proportion of each of the constituent materials in concrete production.

c) Test specimens

The batching method of the constituent materials employed was by weight. For the concrete workability, slump test was carried out on the fresh concrete in accordance to BS EN 12350-2: 2019. The total number of thirty-six (36) cubes of 150 mm x 150 mm and thirty-six (36) beams of 100 mm x 100 mm x 500 mm were casted. Nine (9) cubes and nine (9)beams were used for control (that is concrete of 0% of PET) while the remaining twenty-seven (27) cubes and (27) beams contain plastic PET aggregates at 10%, 20% and 30% respectively. The cubes and beams were cured in water for 7, 14 and 28 days. At the end of each curing ages, specimens were removed from the curing tank and surface dried. The bulk density, compressive strength and Flexural strength of concrete containing plastic PET aggregates and that of control (0% of PET) was determined. Universal Testing Machine (UTM) was employed for the compressive and flexural tests on the concrete specimens in compliance to BS EN 12390-3: 2019 and BS EN 12390-5: 2019. Concrete cubes were oven dried for 72 hours at 110^{o}c. It was removed and allowed to cool for a day. Afterwards, the cubes were weighed and recorded. Then, it was immersed in water for 30 hours. The weight was measured and recorded after expiration of 30 hours. The water absorption was determined in accordance to BS 1881-122: 2011.

Table 1: Mix Proportion of Cement, Fine and Coarse aggregate and PET for Cubes

% Mix of PET	Cement (kg/m^3)	Fine Aggregate (Sand) (kg/m^3)	Coarse Aggregate (kg/m^3)	Plastic PET Aggregate (kg/m^3)	Water-cement ratio
0%	359.84	719.67	1439.01	0.00	0.50
10%	359.84	719.67	1295.11	143.90	0.50
20%	359.84	719.67	1151.21	287.80	0.50
30%	359.84	719.67	1007.31	431.70	0.50

III. Results and Discussion

Figure 1 and 2depicts the particle size distribution for fine and plastic PET aggregates respectively. The fine aggregate used for this experimental study was uniformly graded soil because the coefficient of uniformity, C_U is 3.33 and which is less than 6 as specified by BS 812-103-1. Also, the Plastic PET aggregate used for this research work was uniformly graded aggregate because the coefficient of uniformity, C_U is 3.15, and which is less than 4as specified by BS 812-103-1.As shown in Table 2, the physical properties of plastic PET aggregate indicates that it is a lightweight material. Plastic PET aggregate has lower specific gravity, aggregate impact value, aggregate crushing value and coefficient of gradation compared to natural coarse aggregate. Also, zero water absorption was obtained for plastic PET aggregate.

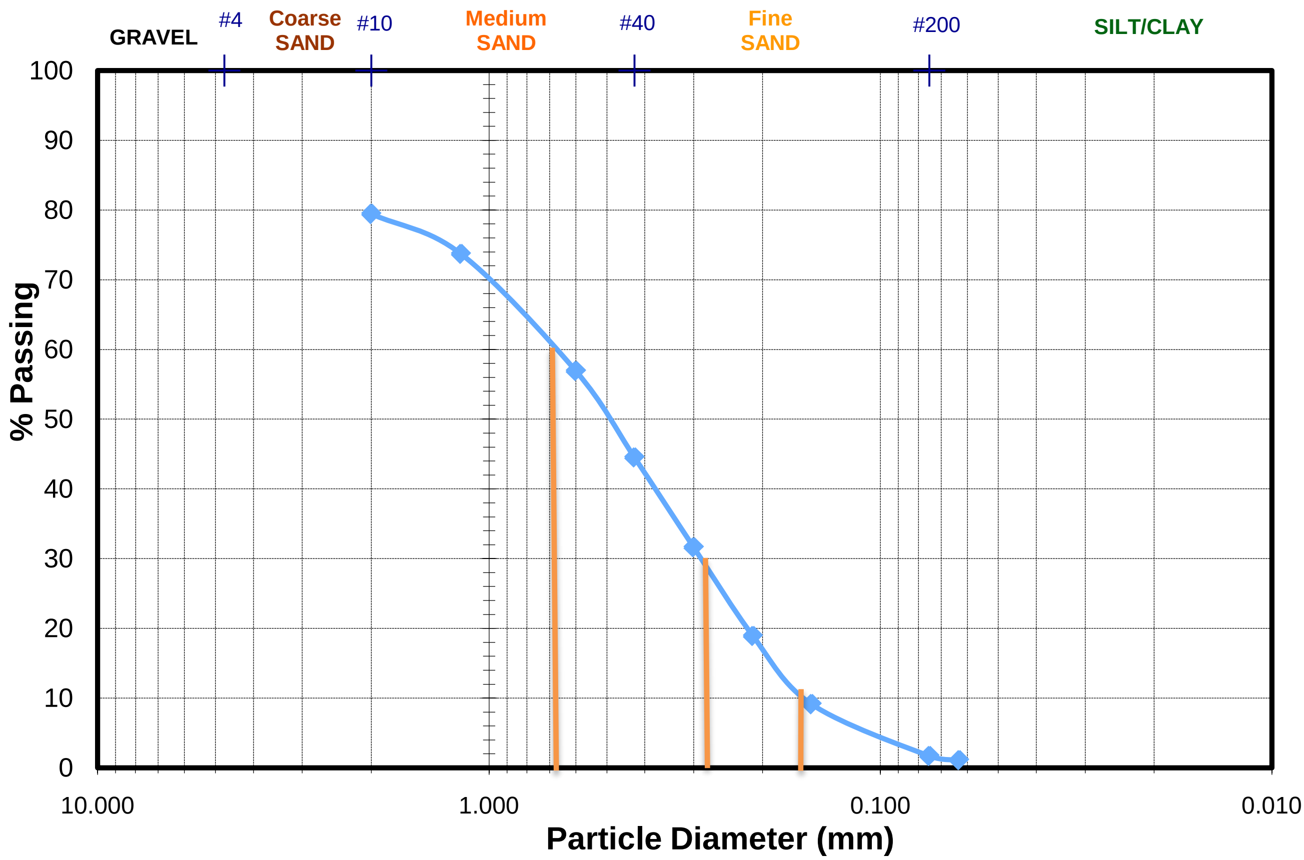

Figure 1: Sieve Analysis curve for Fine Aggregate

Grain Size Distribution Curve Results:

% Gravel:	0.0	D_{10}:	0.18	C_u:	3.33
% Sand:	97.2	D_{30}:	0.42	C_c:	1.63
% Fines:	2.8	D_{60}:	0.6		

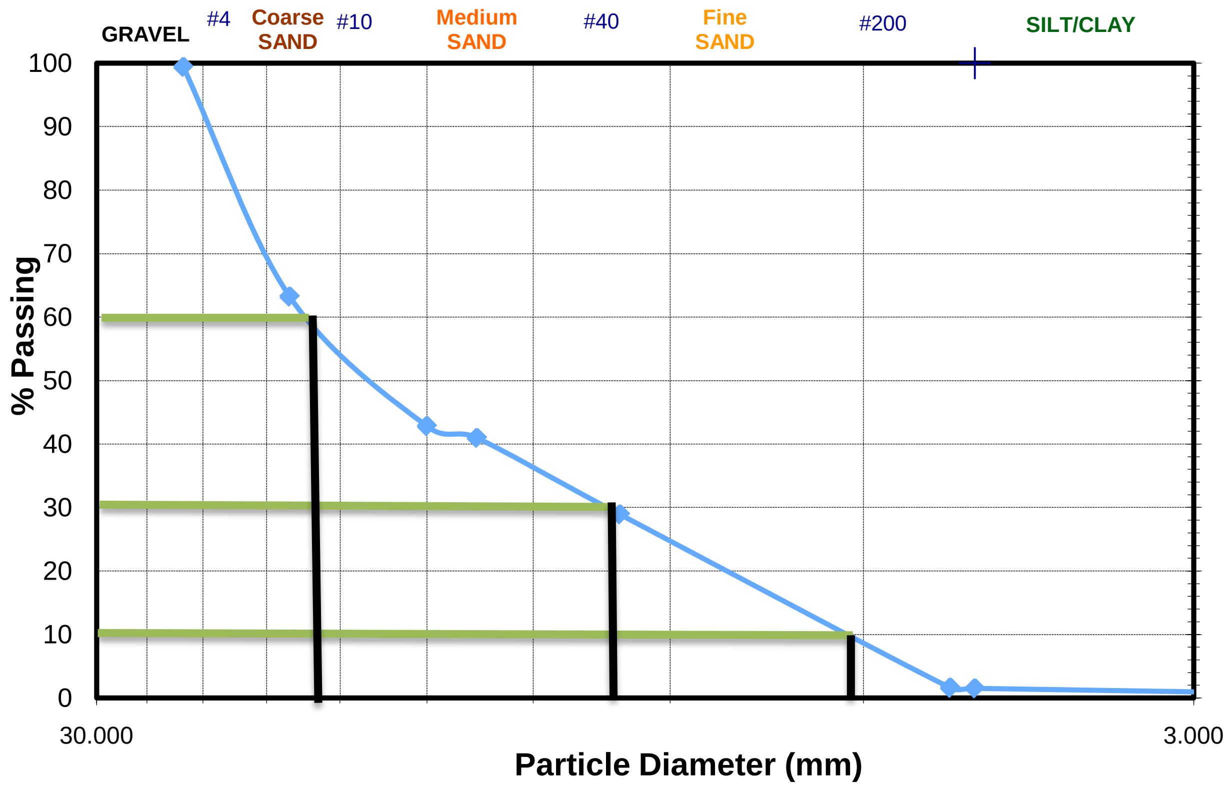

Figure 2: Sieve analysis curve of plastic PET coarse aggregate

Grain Size Distribution Curve Results:

% Gravel:	50.0	D_{10}:	6.20	C_u:	3.15
% Sand:	30	D_{30}:	10.4	C_c:	0.89
% Fines:	20	D_{60}:	19.5		

Table 2: Physical Properties of Constituent Materials

Materials	Specific Gravity	Aggregate Impact Value (%)	Aggregate Crushing Value (%)	Water Absorption (%)	Density (g/cm^3)	Maximum Aggregate Size (mm)	Coefficient of Gradation (Cc)
Coarse Aggregate	2.65	18.5	45.76	0.7	-	25	1.17
Sand	2.43	-		2.2	1.81	4.75	1.63
Plastic PET Aggregate	1.53	5.1	10.08	0	1.02	25	0.89

a) Effect of plastic waste aggregate on concrete slump value

The result for the slump test is presented in Figure 3. From the results, the workability of concrete with partial addition of plastic PET aggregate increases as the percentage of plastic PET aggregate increases. This can be explained to be as a result of the hydrophobic property of the plastic PET aggregates because it repels mix water to provide excess water in the concrete. The availability of excess water increases the flowability of the concrete matrix.

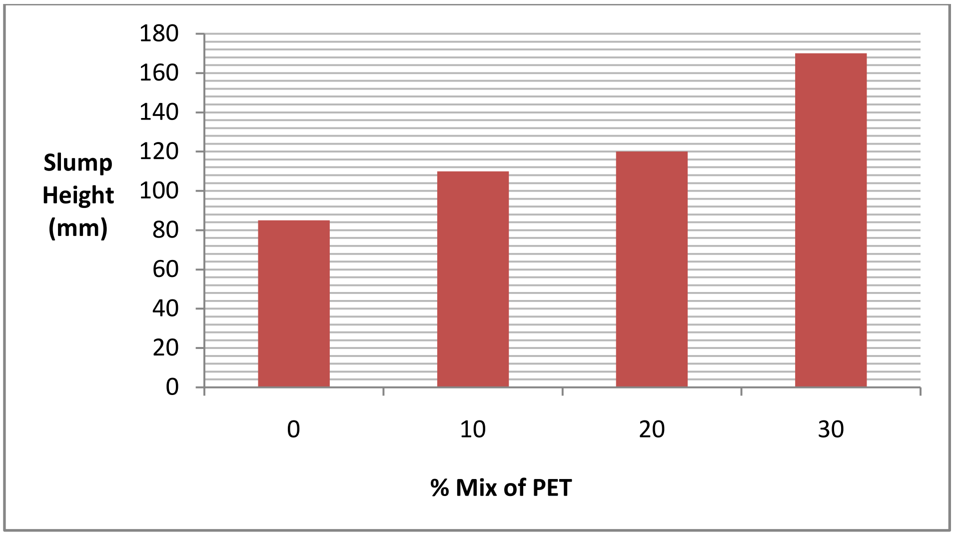

Figure 3: Slump at various percentage content of plastic as fine aggregate

b) Effect of plastic PET aggregate on concrete bulk density

Figure 4 presents the results of bulk density against percentage of plastic PET aggregate. From the results, it can be seen that the bulk density of concrete decreases as the percentage of plastic PET aggregates increases. Concrete with 0% of plastic PET aggregate has the highest bulk density with a value of 2785kg/m^3. When 10% plastic PET aggregate was added to concrete matrix, there was 4% reduction in density and the decrement increased to about 22% when 30% of natural coarse aggregate was substituted with plastic PET aggregate.

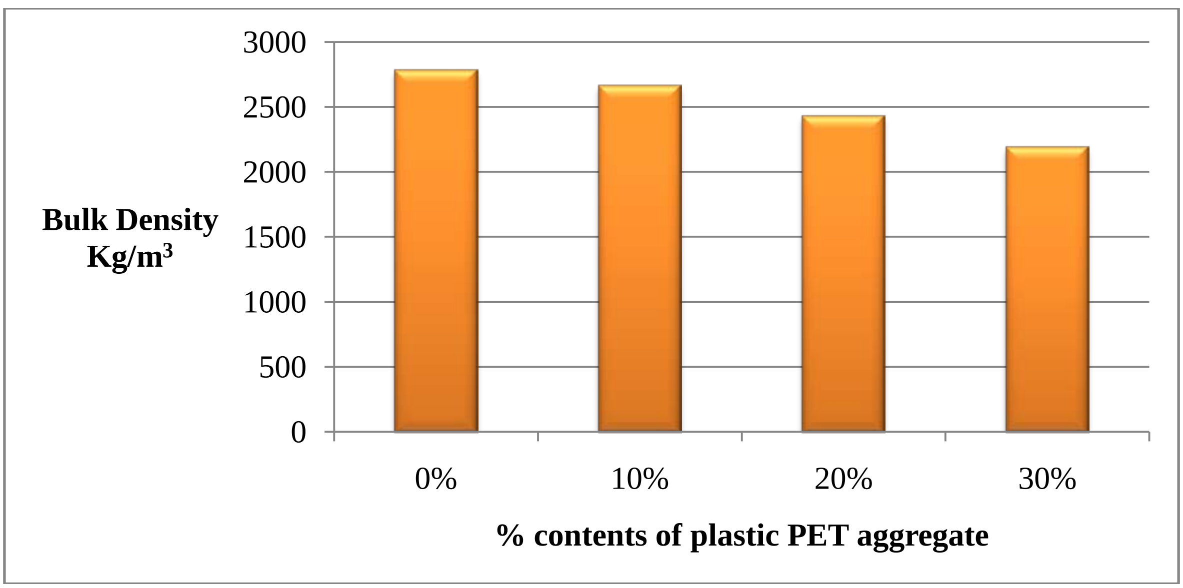

Figure 4: Bulk Density of Plastic PET Aggregate Concrete

c) Effect of plastic PET aggregate on concrete compressive strength

Figure 5 depicts the compressive strength result of the Plastic PET aggregate concrete. The result shows that the concrete strength increases as the curing ages increases and decrease with the incorporation of plastic PET aggregate in concrete matrix. Reduction in compressive strength associated with concrete containing plastic PET aggregate increases as the content of plastic PET aggregate increases. At 28 days, the compressive strength values trends decreased by 25%, 47% and 53% for concrete containing 10%, 20% and 30% of plastic PET aggregate respectively. The decrement of the compressive strength values as the plastic PET aggregates increases is as a result of the deficient bonding of the plastic PET aggregates and the cement paste, due to the smooth surface of the plastic PET aggregate. Also, plastic PET aggregate has low water absorption and which makes excess water in the concrete. After hydration, the excess water gets evaporated and which creates voids in the concrete and weak region around the aggregates in the concrete.

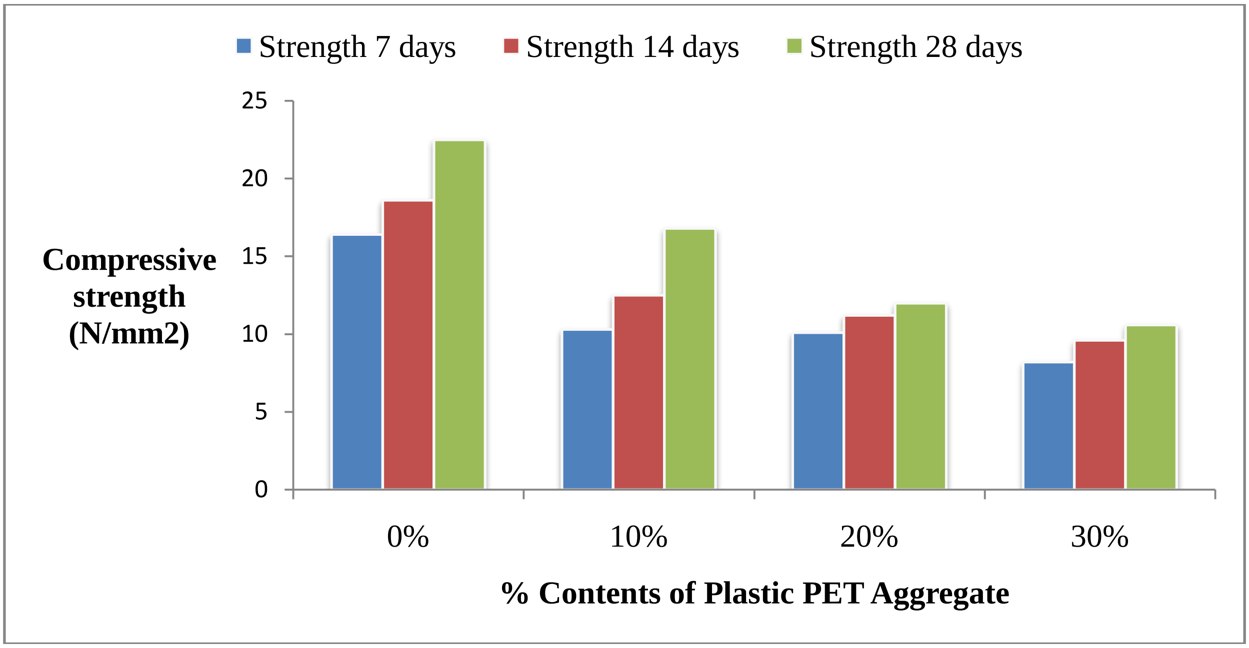

Figure 5: Compressive strength of Plastic PET Aggregate Concrete

d) Effect of plastic PET aggregate on concrete flexural strength

Figure 6 presents the result of flexural strength of the Plastic PET aggregate concrete. It can be observed that the flexural strength increases as the curing ages increases. From the results, there was reduction in flexural strength of concrete with plastic PET aggregate compare to the control concrete. The strength trends declined as the percentage of plastic PET aggregate increases in the concrete mixture. In comparison with the control concrete, significant drop in flexural strength of 38%, 43% and 51% were obtained for concrete matrix containing 10%, 20% and 30% plastic PET aggregate respectively. Similar to compressive strength, the reduction in strength can be adjudged to be as a result of ineffective cohesion between the plastic PET aggregate and the cement paste due to the smooth surface of the plastic PET aggregate. Also, excess water in the concrete due to hydrophobic characteristic of plastic PET aggregate, and upon evaporation of the excess water, voids were created. The voids magnified as the content of plastic PET aggregate increase. The decrement of the flexural strength values as the PET aggregate increases is as a result of the weakness property inherent in the PET.

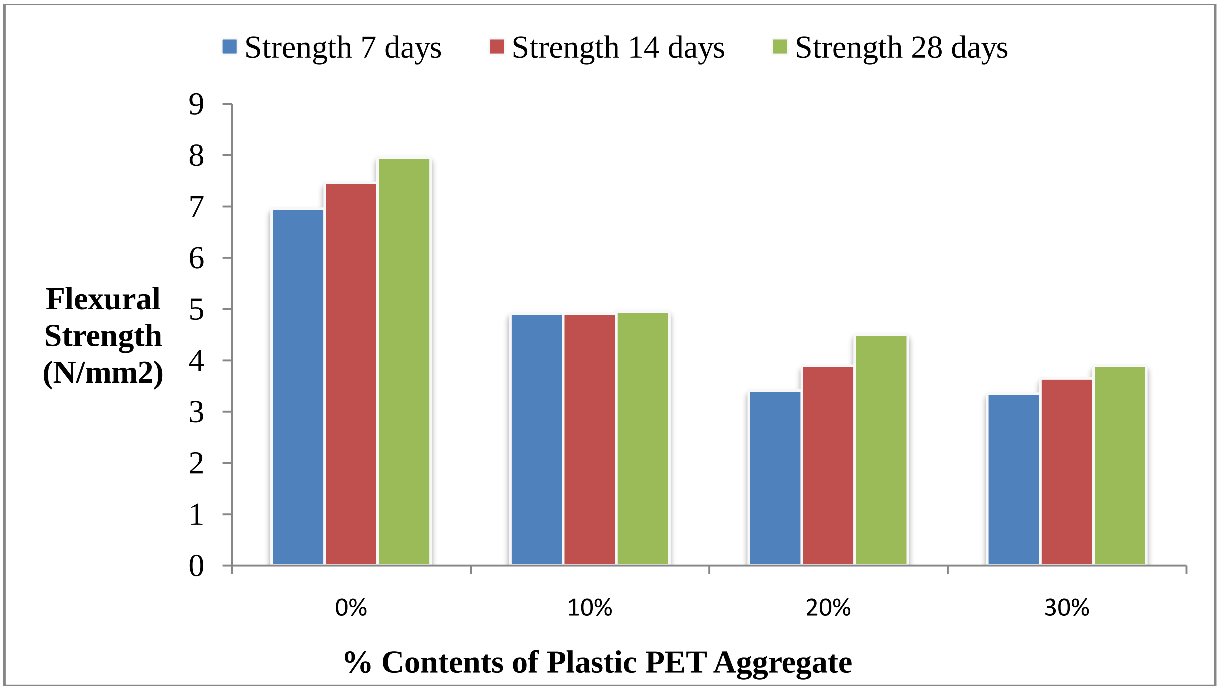

Figure 6: Flexural Strength of Plastic PET Aggregate Concrete

e) *Effect of plastic PET aggregate on concrete Water absorption*

Water absorption is measure of concrete durability against percolation of water into the concrete and which can result into concrete volume expansion to crack formation and disintegration. The water absorption capacity results of the plastic PET aggregate concrete are shown in Figure 7. As indicated, the water absorption property of concrete decreases with increase in plastic PET aggregate content in concrete mix. The water insulation of concrete appreciates by 44.7%, 57.3% and 85.7% as the percentage content of plastic PET aggregate rose up to 10%, 20% and 30% respectively. This can be attributed to the impermeability of plastic PET aggregate.

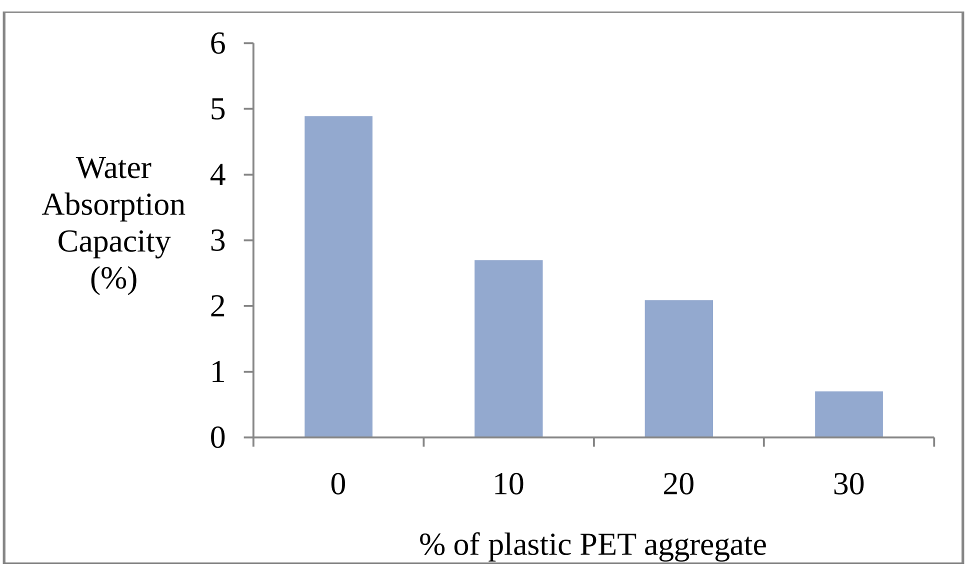

Figure 7: Water Absorption of Plastic PET Aggregate Concrete

IV. Conclusions

The following conclusions were drawn from this study:

i. The PET coarse aggregate is weak and light because its impact and crushing values are 5.10% and 10.08% and which are lower than the values specified by BS 812-112.

ii. As the percentage replacement of coarse aggregate with recycled PET plastic aggregate increases, so does the workability. This can be attributed to the smooth surface and low absorption characteristics of Plastic aggregate.

iii. The higher the percentage replacement of the coarse aggregate with recycled PET plastic aggregate, the lesser the compressive and flexural strength. Concrete mix with addition of plastic PET aggregate has lower water absorption property compare to the control concrete, and which is a function of the proportion of the plastic PET aggregate in the matrix.

iv. It is recommended that PET concrete should not be used as reinforced concrete due to the fact that the values gotten at 28days for 10%, 20% and 30% of PET aggregate replacement were lower than the strength recommended by standards. However, it can be used where light weight concrete coupled with water proof or resistance is required.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References Références Referencias

1. Almeshal, I., Tayeh, B. A., Alyousef, R., Alabduljabbar, H., & Mohamed, A. M. (2020). Eco-friendly concrete containing recycled plastic as partial replacement for sand. *Journal of Materials Research and Technology*, *9*(3), 4631–4643. https://doi.org/10.1016/j.jmrt.2020.02.090
2. Asadi, I., Shafigh, P., Abu Hassan, Z. F. bin, &Mahyuddin, N. B. (2018). Thermal conductivity of concrete – A review. In *Journal of Building Engineering* (Vol. 20, pp. 81–93). Elsevier Ltd. https://doi.org/10.1016/j.jobe.2018.07.002
3. Bahij, S., Omary, S., Feugeas, F., & Faqiri, A. (2020). Fresh and hardened properties of concrete containing different forms of plastic waste – A review. In *Waste Management* (Vol. 113, pp. 157–175). Elsevier Ltd. https://doi.org/10.1016/j.wasman.2020.05.048
4. Belmokaddem, M., Mahi, A., Senhadji, Y., &Pekmezci, B. Y. (2020). Mechanical and physical properties and morphology of concrete containing plastic waste as aggregate. *Construction and Building Materials*, *257*. https://doi.org/10.1016/j.conbuildmat.2020.119559
5. Boucedra, A., Bederina, M., & Ghernouti, Y. (2020). Study of the acoustical and thermo-mechanical properties of dune and river sand concretes containing recycled plastic aggregates. *Construction and Building Materials*, *256*. https://doi.org/10.1016/j.conbuildmat.2020.119447
6. BS 1881-122. (2011). *Testing Concrete: Method of Determination of Water Absorption*. British Standards Institute.
7. BS EN 933-1. (2012). *Tests for geometrical properties of aggregates. Determination of particle size distribution. Sieving method*. British Standards Institute.
8. BS EN 1097-2. (2020). *Tests for mechanical and physical properties of aggregates Part 2: Methods for the determination of resistance to fragmentation*. British Standards Institute.
9. BS EN 1097-3. (1998). *Tests for Mechanical and Physical Properties of Aggregates Part 3: Determination of Loose Bulk Density and Voids*. British Standards Institute.
10. BS EN 12350-2. (2019). *Testing Fresh Concrete – Slump Test*. British Standards Institute.
11. BS EN 12390-3: (2019). *Testing hardened concrete - Part 3: Compressive strength of test specimens*. British Standards Institute.
12. BS EN 12390-5. (2019). *Testing hardened concrete - Flexural strength of test specimens*. British Standards Institute.
13. Faraj, R. H., Hama Ali, H. F., Sherwani, A. F. H., Hassan, B. R., & Karim, H. (2020). Use of recycled plastic in self-compacting concrete: A comprehensive review on fresh and mechanical properties. In *Journal of Building Engineering* (Vol. 30). Elsevier Ltd. https://doi.org/10.1016/j.jobe.2020.101283
14. Li, X., Ling, T. C., & Hung Mo, K. (2020). Functions and impacts of plastic/rubber wastes as eco-friendly aggregate in concrete – A review. In *Construction and Building Materials* (Vol. 240). Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2019.117869
15. Mustafa, M. A. T., Hanafi, I., Mahmoud, R., &Tayeh, B. A. (2019). Effect of partial replacement of sand by plastic waste on impact resistance of concrete: experiment and simulation. *Structures*, *20*, 519–526. https://doi.org/10.1016/j.istruc.2019.06.008
16. Needhidasan, S., Vigneshwar, C. R., & Ramesh, B. (2020). Amalgamation of E-waste plastics in concrete with super plasticizer for better strength. *Materials Today: Proceedings*, *22*, 998–1003. https://doi.org/10.1016/j.matpr.2019.11.253
17. v Visweswara Sastry Dhara, V. N., &kumar, S. K. (2018). Experimental Investigation on Mechanical and Durability Properties of Concrete with Plastic Waste. In *International Journal of Engineering & Technology* (Vol. 7). www.sciencepubco.com/index.php/IJET