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EFFECT OF PARTIAL REPLACEMENT OF AGGREGATE WITH GRANULATED POLYETHYLENE TEREPHTHALATE (PET) ON COMPRESSIVE STRENGTH OF CONCRETE

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Abstract

This paper is aimed at the development of appropriate combination of composite materials such as cement, aggregates and inclusion of Polyethylene Terephthalate (PET) in varying proportion in order to determine the optimal measure for the optimal strength. The study also, investigated the effect of PET aggregate on the compressive strength of concrete. Mix design targeting grade 25 concrete strength, using the Department of Environment (DOE) approach was adopted. Five different concrete samples were prepared accordingly, using natural aggregate as control mix and four others which consist of PET aggregate as partial replacement of fine aggregate at 5%, 10%, 15%, and 20% ratios respectively. The recycled fine aggregate (PET) was processed from bottle water waste, it was crushed, pressed and processed into finely material having river sand resemblance i.e., well distributed within sieve sizes of 0.075 and 2.00. The batching was done by weight. Cubes specimens were prepared, cured for 7, 14, and 28days and tested for compression. The results of the tests were analyzed statistically using regression method (Mintab) to establish optimal strength require mixture. The results and analysis established that there were reduction in compressive strength of the concrete containing PET aggregate and reduction rates increased with increase in the amount of PET inclusion in the concrete. The compressive strength values for 5%, 10%, 15% and 20% replacement of sand with PET at 28-day were 29.70N/mm^2, 25.95N/mm^2, 24.28N/mm^2 and 23.23N/mm^2 respectively. When compared with the control concrete specimens with an average value of 33.08N/mm^2 gave 11.38%, 27.48%, 36.24% and 42.40% reduction in strength respectively. It was recommended that, though, the use of PET aggregate in the production of concrete does not have significant appreciable effect on the concrete strength, its use will protect the environment and as well help to conserve natural resources used as materials in production of concrete elements which currently undergo excessive depletion.

Keywords: Aggregates, Compressive-Strength, Concrete, Environment, PET and Waste.

1.0 INTRODUCTION

Depletion of natural resources is a common phenomenon in developing country like Nigeria due to the rapid urbanization and industrialization involving construction of infrastructures and other amenities. In view of this, people have started searching for another suitable viable lternative materials for concrete so that the existing natural resources could be preserved to possible extent, for the future generation [1, 2]. Moreso, in the present world of consumerism, plastic and polymers have been the prime choice of materials in packaging industries and covered up to 53% of the products around the world [3]. With so large and varying applications; plastic contributes to an ever increasing volume in the solid waste stream [4]. It was reported in 2009 by [5] that according to the Central Pollution Control Board; the world produced nearly 150 million tonnes of plastic per year, which was 4.8 tonnes per second and a per capita production of 25kg/year.

These figures must have grown geometrically till date. Consequently, this has become a threat to the environment owing to some of the properties of the material. For instance; plastic possess little or no biodegradability property and therefore constitutes nuisance in landfills, terrestrial and marine environments. Presently, drainages in Nigeria are being blocked by PET bottles and major metropolises are being flooded during raining period. There are several types of wastes being generated from various industries and modern trends of living. Some of these wastes are harmful, if properly unattended to and require costly treatment and disposal to avoid harming the environment besides being costly, these require large amount of land which may otherwise be used for beneficial purposes. With the growth of population, the quantum of wastes being generated is increasing continuously. One of the methods to properly utilize and consume these wastes lies in the construction industry practices, wherein these wastes may be used and consumed, so as to prevent further pollution in our environment and perseveration of our natural sources [6].

The poly-ethylene terephthalate (PET) disposal is very complex issue whose degradation or incineration causes harmful effects on the environment and surrounding ecological conditions, which might also cause damage to vegetation [7]. A closer look into the construction sector in terms of natural aggregate resources, environmental protection, and limited waste storage area further reveals the importance of the utilization of recycled aggregates in the production of concrete to be used in many different applications. Moreover, such utilization will also offer benefits in terms of reduced fuel consumption related to the transportation of materials and reduced structural costs, not to mention the recycling needs [8].

The environmental impact of concrete constructions is huge in term of resources consumption. For this reason, the inclusion of recycled concrete aggregates in construction to obtain recycled aggregate concrete can lower the environmental impoverishment. Indeed, the use of polyethylene terephthalate (PET) as alternative aggregates for new concrete production improve natural resource preservation, reduces landfill disposal, and promotes construction sustainability [8].

2.0 MATERIALS AND METHODS

The materials used to carry out the investigation include: Portland limestone cement as cement, coarse aggregate, natural fine aggregate, polyethylene terephthalate (PET) processed fine aggregate, and water. The PET aggregate prepared from waste water bottles was crushed pressed and granulated to sand like particles. All the aggregates including PET aggregate were washed, air dried at room temperature before particles distribution size (sieve) analysis was carried out on each of the aggregate samples; the results of sieve analysis are shown in figures 1. The test cubes were prepared based on the outcome of the mix design targeting grade 25 concrete strength, using the department of environmental (DOE) approach. The detail of the mix designs is shown in Table 1.

Five different concrete samples were prepared accordingly, using natural aggregate as control mix and four others which consist of processed PET fine aggregate as partial replacement of natural fine aggregate at 5%, 10%, 15% and 20%. The batching was done in weight; mix ratio of constituents was 1:1.43:3.33 at 0.55 water-cement ratio. Cement, water and granite were kept constant for all the mixes while sand and PET aggregates were varied according to the percentage required for the mix.

Table 1: Mix Proportion

Mix	Mix Ratio	Mix Proportion (kg)				
		Cement	Sand	PET	Granite	Water
M1	1:1.43:0.00:3.33:0.55	12.692	18.136	0	42.318	7.014
M2	1:1.43:0.07:3.33:0.55	12.692	17.229	0.907	42.318	7.014
M3	1:1.43:0.14:3.33:0.55	12.692	16.322	1.814	42.318	7.014
M4	1:1.43:0.21:3.33:0.55	12.692	15.416	2.72	42.318	7.014
M5	1:1.43:0.29:3.33:0.55	12.692	14.509	3.627	42.318	7.014

The workability of the concrete was determined using slump test in accordance with EN 12350-2:2019. The apparatus for this test includes: Cone mould, tamping rod, steel rule and hand trowel. The internal surface of the mould was cleaned thoroughly and oiled or greased, then placed on a smooth; horizontal, rigid and non-absorbent surface free from vibration. The mould was held firmly in place while filling it with fresh concrete mix in three layers, with each layer properly compacted with 25 strokes of tamping rod evenly distributed over the cross section of the cone mould. After tamping the top layer, the surface is struck off level with a trowel. Any mortar leaked out between the mould and its base was wiped out immediately. The mould was lifted up vertically slowly and carefully. Slump is the difference between the original height of concrete in the mould and the highest part of the concrete in subsided position.

This test should be carried out within a period of 2minutes after taking sample for the mix. Compressive strength test was carried out on the experimental samples in accordance with EN 12390-3:2000. The samples were in the cube shape and tested in the compression machine. The equipment used for this experiment include: Compression testing machine, balance, moulds of cast iron with removable base plate bolted together (measuring 150 x 150 x 150mm), scoop, vibrating table or steel compacting bar, sampling tray and a shovel. The concrete cube specimens were of 150mm x 150mm x 150mm in dimension. A total of 45 cubes were cast for the five (5) concrete samples. Each sample of concrete was prepared with the respective aggregates and cast using the moulds. The concrete samples were stored and cured in the curing tanks until they are due for compressive test.

This test was carried out using 3 cubes each at 7, 14, and 28 days for concrete of the control mix and each of the varied fine aggregates replacement with processed PET fine aggregate concrete samples in accordance with BS EN 206-1 These concrete mixes were filled into the prepared moulds and vibrated by the means of vibrating table when finally filled into the moulds. After 24 hours the specimens were demould and stored in a curing tank at room temperature until the due testing day. The weight of cubes was obtained before crushing is done. The density and crushing strength were expressed as equations 1 and 2 respectively.

$$\text{Density (Kg/m}^3) = \frac{\omega\ (kg)}{v\ (m^3)} \quad (1)$$

where: ω is weight of cube and v is volume of cube

$$\text{Crushing strength (N/mm}^2) = \frac{l\ (N)}{\alpha\ (mm^2)} \quad (2)$$

where: l is crushing load and α is area of cube

3.0 RESULTS AND DISCUSSION

The results of the sieve analysis carried out for the aggregates was shown in figure 1. [9] in 1996 specified: $C_u \geq 6$ for well graded fine aggregate, $Cu \geq 4$ for well graded coarse aggregate and $1 \leq C_c \leq 3$ for well graded fine and coarse aggregates. The results revealed that, both the natural fine and coarse aggregates were partially well graded with $C_u = 2.5$, C_c=1.05 and $C_u = 2.4$, $C_c = 1.01$ respectively. While, PET was well graded with $C_u = 7.5$ and $C_c = 1.63$.

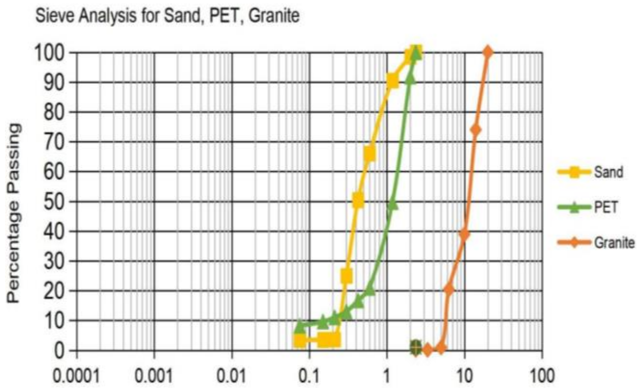

Figure 1: Granulometric Curves for Sand, PET, and Granite

Table 2: Slump Test Values for Different Mixes

S/N	Mix		Slump Value (mm)
1	M1	0% PET	50
2	M2	5% PET	42
3	M3	10% PET	35
4	M4	15% PET	30
5	M5	20% PET	25

The workability results were shown in Table 2 and revealed that the concrete samples with 20% PET was the least workable concrete with slump value of 25mm. All the samples containing PET had reduction in slump values. The lower workability was as a result of the increase in volume of PET aggregate compared to the sand replaced by weight and consequently increase the surface area of the constituent sample. The concrete samples with 5%, 10%, 15% and 20% of PET led to 16%, 30%, 40% and 50% reduction respectively in slump values when compared to control sample, this agrees with [10]. However, all the mixes fell within the slump value (30mm – 60mm) targeted for the mix design, except the sample containing 20% PET which had a value of 25mm.

Workability of the fresh concrete produced from PET aggregate was relatively stiffened. The workability of fresh PET aggregate concrete decreased at increase in the replacement amount of PET aggregate when the water/cement ratio was kept constant. Up to 10% replacement of fine aggregate with PET aggregate yielded the optimum strength. PET aggregate usage caused some deficiencies in the concrete inner structure that resulted in the reduction in strength, showing conformity with researches by [6].

Based on the results obtained for age 7-day of the cubes tested as shown in Table 3; The 7-day compressive strengths showed varying reduction depending on the increase in replacement of fine aggregate with granulated PET. The tested concrete samples containing replacement of fine aggregate with PET at 5%, 10%, 15% and 20% had

25.54N/mm^2, 23.18N/mm^2, 22.61N/mm^2 and 21.19N/mm^2 respectively. When compared to the strength of conventional concrete samples of 27.11N/mm^2 displayed reduction in strength of 6.15%, 16.95%, 19.90% and 27.94% respectively.

The results obtained for age 14-day of the cubes tested as shown in Table 4 revealed that 14-day compressive strength of the samples containing 5%, 10%, 15%, and 20% replacement of sand with PET showed similar reduction of strength trend. The values are 28.69N/mm^2, 25.02N/mm^2, 23.48N/mm^2 and 22.36N/mm^2 respectively. When compared to the control concrete sample of 29.65N/mm^2 gave strength reduction of 3.35%, 18.51%, 26.28% and 32.60% respectively.

28-day compressive strength of the partially replaced fine aggregate concrete samples as shown in Table 5 exhibit the same reduction trend pattern. The compressive strength values 5%, 10%, 15% and 20% are 29.70N/mm^2, 25.95N/mm^2, 24.28N/mm^2 and 23.23N/mm^2 respectively. When compared with the control concrete specimens with an average value of 33.08N/mm^2 gave 11.38%, 27.48%, 36.24% and 42.40% reduction in strength respectively.

Table 3: 7day of Compressive Strength of Concrete Samples

	Compressive Strength (N/mm^2)				Av. Density
Mix	Cube 1	Cube 2	Cube 3	Average	(Kg/m^3)
M1	26.98	26.84	27.51	27.11	2532
M2	25.60	25.02	26.00	25.54	2496
M3	23.02	22.80	23.73	23.18	2437
M4	22.93	22.53	23.38	22.61	2392
M5	20.98	21.60	20.98	21.19	2350

Table 4: 14day of Compressive Strength of Concrete Samples

	Compressive Strength (N/mm^2)				Av. Density
Mix	Cube 1	Cube 2	Cube 3	Average	(Kg/m^3)
M1	29.87	29.16	29.91	29.65	2512
M2	29.33	27.82	28.93	28.69	2498
M3	25.24	24.93	24.89	25.02	2392
M4	23.33	23.51	23.60	23.48	2386
M5	22.18	22.62	22.27	22.36	2364

Table 5: 28day of Compressive Strength of Concrete Samples

	Compressive Strength (N/mm^2)				Av. Density
Mix	Cube 1	Cube 2	Cube 3	Average	(Kg/m^3)
M1	32.40	31.78	35.07	33.08	2532
M2	30.40	30.40	28.31	29.70	2468
M3	25.73	25.95	26.18	25.95	2412
M4	23.87	24.22	24.76	24.28	2386
M5	23.02	22.71	23.96	23.23	2331

Generally, based on the results obtained for the three (3) various ages of the cubes tested as shown in Tables 3 to 5; the samples with 20% replacement of sand with PET, showed the least resistance to compressive forces. Although, the compressive strength results for all the partially replaced fine aggregate concrete samples showed lesser resistance to loading when compared to the conventional concrete samples, appreciable resistance was observed in samples with up to 10% replacement of fine aggregate. The compressive strength of the concrete specimens containing partial replacement of sand with PET had decreasing trend in strength for all the curing days. This agrees with conclusions by [6]. However, the concrete specimens with up to 10% fine aggregate replacement with PET relatively rise above the target strength of 25N/mm^2 at 28day curing.

For instance, the 5% replacement of sand with PET attained 29.70N/mm^2 while 10% replacement of same materials reached 25.95N/mm^2 at 28day curing respectively. Meanwhile, the concrete specimens with 15% and 20% replacement of sand with PET slightly fell below the target strength having 24.28N/mm^2 and 23.23N/mm^2 at 28day curing respectively. In spite of the lower compressive strength of the concrete containing PET as partial replacement of fine aggregate, all densities for all the concrete samples were observed to be within the range expected from normal weight concrete. The respective average densities for the cubes tested on the 28day for 5% PET, 10%PET, 15%PET, and 20%PET were 2468kg/m^3, 2412kg/m^3, 2386kg/m^3 and 2331kg/m^3. When compared to the density of the conventional concrete specimens of 2532kg/m^3, the reduction in densities of 2.60%, 4.98%, 6.12% and 8.62% was observed for 5%, 10%, 15% and 20% PET replacement of fine aggregate respectively. These agrees with [11, 12].

3.1 28day Regression Analysis: Compressive Strength versus Sand, PET

3.1.1 Regression equation

178 $$Compressive\ Strength = -36623 + 2021\,Sand + 2019\,PET \quad (3)$$

Table 6a: Coefficients

Term	Coef	SE Coef	T-Value	P-Value
Constant	-36623	28155	-1.30	0.323
Sand	2021	1552	1.30	0.323
PET	2019	1553	1.30	0.323

Table 6b: Model Summary

S	R-sq	R-sq(adj)
0.981937	97.11%	94.21%

3.1.2 Durbin-Watson statistic

$$Durbin_{Watson}\ Statistics = 2.36680 \quad (4)$$

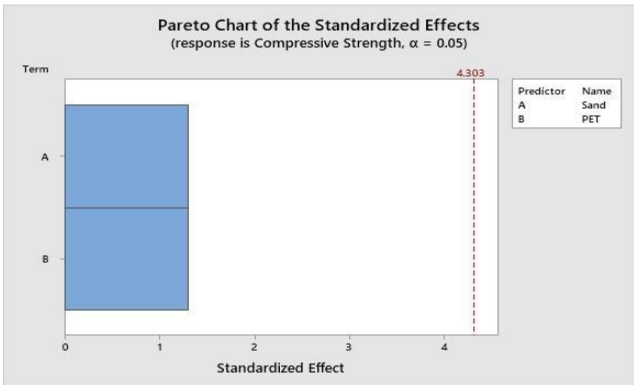

Figure 2: Pareto Chart for compressive strength (28-day)

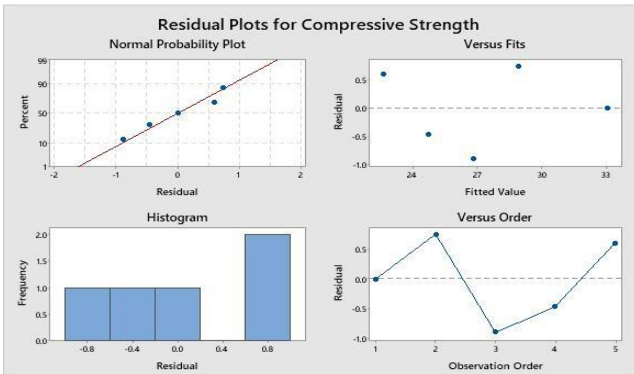

Figure 3: Residual Pots for Compressive Strength (28-day)

Based on the compressive strength values obtained for the concrete samples, regression analysis was performed using Mintab as presented in Tables 6a to 6b and Figures 2 to 3 respectively and a model was developed.

The model developed relates compressive strength to the varying constituents (Sand and PET) gave equations for the 28day compressive strength respectively as:

$$Compressive\ Strength = -36623 + 2021Sand + 2019PET \quad (3)$$

Where Compressive Strength is in N/mm^2 and Sand & PET are in Kg.

With the expressions obtained, compressive strength outcome for any of the days of interest can be obtained for material constituent other than the ones used in this study. For instance, 28day compressive strength of 17.150kg of sand and 0.987kg of PET would yield a compressive strength of 29.90N/mm^2.

The regression analysis for the compressive strength at 28day for coefficient, model summary, analysis of variance etc. as presented in Tables 6a to 6b and Figures 2 to 3 deduced that; the association is not statistically significant because the P-value of the terms (0.323) were above α(0.05). This reflection was established in Pareto chart as well. Hence, resulted in the negative influence of PET inclusion in the concrete. Meanwhile, the goodness-of-fit statistics in the model summary table established that the model fits the data very well. For the residual plots; the normal probability plot was straight, which established normal distribution of residuals. The residuals were randomly distributed and had constant variance. Also, the residuals versus order plot confirmed that the residuals independent from one another. However, the residual plots confirmed that the compressive strength model fit well. The Durbin-Watson statistic established negative autocorrelation in the regression model's output with a value of 2.36680 (slightly negative).

4.0 CONCLUSIONS

Based on the experimental studies conducted, the following conclusions were made:

1. The inclusion of PET in the production of concrete had relative adverse effects on it compressive strength. The effects depended on the increase in its inclusion level. Replacement up to 10% of fine aggregate with PET gave adequate strength of 29.70N/mm^2 and

$25.95N/mm^2$ for 5% and 10% respectively while PET inclusion from 15% and above exhibited low strength concrete of $24.28N/mm^2$ $23.23N/mm^2$ for 15% and 20% respectively.

However, this type of concrete still fulfilled the requirement many engineering concrete application. Generally, relative reduction in the compressive of PET aggregate concrete were observed. These strengths decreased with increase in the plastic aggregate due to lack of adequate bonding force and different adhesive strength characteristics in the PET aggregate. Also, the density of concrete decreased with increase in the percentage of plastic aggregate which is an advantage of the concrete to reduce self-load on structures.

2. Model for compressive strength of concrete containing PET aggregate was established and given as equation (3) for compressive strength model at 28day.

$$224\,Compressive\,Strength = -36623 + 2021Sand + 2019PET \quad (3)$$

With the expressions obtained; the compressive strength outcome at 28day can be obtained for material constituent to achieve a particular strength other than the ones in this study. For instance, 28day compressive strength of 17.150kg of sand and 0.987kg of PET would yield a compressive strength of $29.90N/mm^2$.

5.0 RECOMMENDATIONS

1. Though, the use of PET aggregate in the production of concrete does not have significant appreciable effect on the strengths of concrete as revealed in this study; it use will protect our environment and as well preserve our natural resources used as materials in production of concrete elements which currently undergo excessive depletion.
2. The amount of PET required for each percentage replacement is mixed with the natural fine aggregate to form a homogenous mixture of fine aggregate before mixed with other mixture constituents of concrete such as cement, water and coarse aggregate to form a wholly homogenous concrete for structural elements.
3. Further research to improve on the bonding and adhesive strengths properties of PET aggregate such as surface treatment, size and shape of the aggregate may be considered.

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