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Performance of Concrete Using Burnt Waste Plastic as Partial Replacement for Coarse Aggregate

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Authors' contributions

This work was carried out in collaboration between both authors. Author SD designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author FBW managed the analyses of the study and the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

This study utilized plastic waste aggregate as partial replacement for coarse aggregate in concrete. The plastic was sourced from household and shop waste. It was sorted, cleaned, dried, burnt (openly), cooled and processed into average size of 20 mm while the physical properties were assessed. Concrete was produced using the burnt plastic waste as aggregate replacement at 10%, 20%, 50%, 60%, 80% and 100% by weight. A true slump with a maximum value of 23 mm was obtained at 10% plastic aggregate addition. Grade M25 concrete was produced and cured by water immersion for 3, 7, 14 and 28 day respectively. Assessment of water absorption, density and compressive strength were carried out. The result generally showed that the water absorption and density decreased with increase in plastic aggregate (PA) and curing period except for 50% and 60% plastic aggregate which showed a slight increase from 1.0% to 1.5 and 1.2% respectively from 3 day to 28 day curing. Similarly, the compressive strength decreased with increase in PA but there was increase in compressive strength along the days of curing. Concrete cubes made with (10-20) % plastic aggregates and cured for 28 days, achieved the 28 days target strength of

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25 N/mm^2. Regression and analysis of variance (ANOVA) in the MINITAB 16 statistical software was carried out on the research data. A model was developed to predict compressive strength with curing period and plastic aggregate content as predictors at 5% level of significance. The outcome showed a possibility for the replacement of coarse aggregate by plastic aggregate in concrete. The coefficients, R^2 of 90.18% developed from the regression model is adequate for prediction of compressive strength*.*

Keywords: Concrete; aggregate; plastic waste; water absorption; density; compressive strength.

1. INTRODUCTION

This paper is centred on the re-use of burnt waste plastic as replacement for coarse aggregate in the production of light weight concrete. The growing problem of waste management and constraints of land and resources to manage waste necessitates this study. Historically, some factors that instigated solid waste management include-concerns of public health, the environment, resources scarcity, public awareness and climate change [1].

[2] recorded waste generation (kg/capita/day) in Pretoria (South Africa), Bangkok (Thailand) and Masaya (Nicaragua) as 0.65, 1.10 and 0.40 respectively for researches conducted between 2009 and 2010. Municipal solid waste usually consists of paper, food, metals, garbage, glass, wood, ashes etc. Waste that is not properly managed can have deleterious effects like hazard to health and wellbeing of the population, flooding due to blockage of drainages by waste, contamination of groundwater, etc [3]. Waste management techniques have been developed over the years and the concepts of recycling, re-use and reduction of waste have played a significant role in those aspects though a lot is still left to be done to synergise various actors along the waste sector [4]. Notable concepts have also developed like 'Integrated Waste Management (IWM)' and 'Integrated Sustainable Waste Management (ISWM)' with the former focusing on incorporating technology mostly in developing economies, while the latter looks at 'key aspect-physical (collection, disposal and recycling) and governance aspects (inclusivity, financial sustainability, proactive policies and sound institutions)' [5].

Concrete and its products play a very essential role in infrastructural development. Concrete is made up of cement, aggregates (fine and coarse) and water in definite ratios [6]. When water is added to properly mixed materials (cement and aggregate) a chemical reaction known as hydration takes place between the cement and water and the mix becomes a paste which generally hardens (sets) within 2 hrs with the concrete gaining strength as it cures [6]. Concrete is used as load bearing and partition units depending on the value of its properties such as water absorption, density and compressive strength [7]. The density of concrete increases the overall dead load of a structure. Introducing lighter alternatives to materials used in making concrete like coarse aggregate will thereby reduce its weight and possibly reduce the overall cost of construction. Research carried out [8] has shown that fly ash, silica, slag, volcanic light weight aggregate and granulated polyethylene terephthalate (PET) have fully or partially replaced aggregate in concrete. These have shown various characteristics like ductility, brittle failure and application to load and non-load bearing units [9-10]. Other advantages of using lightweight aggregate are chloride attack resistance and migration as seen in research on slag cement and fly ash concrete respectively [11-12].

This research is geared toward recycling plastic waste (which is non-biodegradable and has negative effects on the environment) as concrete raw material and aims to compare properties of concrete made with and without plastic as coarse aggregates with adequate curing. It will determine the physical properties of the plastic waste, optimum percentage as aggregate replacement, compressive strength, density and water absorption.

2. MATERIALS AND METHODS

Tests carried out on materials and produced samples are discussed in this section followed by a description of the mix design and curing procedure adopted.

2.1 Materials

2.1.1 Cement

Ashaka brand of Portland cement was used for this research and was procured from a reputable retailer in Jos Metropolis. This brand of cement conforms to [13] and tests carried out include consistency and setting time; and soundness of cement.

The Vicat and Le Chatelier's apparatus were used to determine the consistency and setting time; and soundness of cement respectively in accordance with [13] specification.

2.1.2 Fine aggregates

The materials whose particles pass through [14] test sieve (5 mm) and retained on the 0.15 mm sieve are termed as fine aggregate. Natural river sand obtained from a local supplier was used as fine aggregate. The sand passed through the 2mm sieve but was retained on the 1 mm sieve. The tests conducted include specific gravity and particle size distribution. The specific gravity and particle size distribution of fine aggregate were determined in accordance with [15] respectively.

2.1.3 Coarse aggregate

This is material retained on the 5 mm sieve. Angular shaped crushed stones obtained from a local quarry was used with the maximum size of coarse aggregate as 20 mm and free from dust before used in concrete production. Test conducted include specific gravity and particle size distribution.

The specific gravity of coarse aggregate was obtained in accordance with [15]. The particle density was calculated using Equation (1):

$$P_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \tag{1}$$

Where: m_1 is the mass of density bottle; m_2 is the mass of bottle and dry soil; m_3 is the mass of bottle, soil and water; m_4 is the mass of bottle when full of water only.

The particle size distribution was determined in accordance with [16].

2.1.4 Water

The water used for the experiment was clear, free from impurities and almost fit for drinking. As such, no test was conducted on it.

2.2 Plastic Waste Aggregate (PA)

Recycled plastic was used as partial replacement for coarse aggregate for making concrete specimens. The size range available for plastic aggregate was 20-40 mm.

2.2.1 Source and preparation of plastic aggregate

The plastic aggregate was sourced from households (drinking water sachets, containers and trash bags) and shops (drinking water sachets and packaging).

Low density Polyethylene (drinking water sachets) were collected, cleaned and cut into pieces. The plastic was fired till it melted causing the long chain polymers to break apart. The melted plastic was poured onto aluminium roofing sheets to cool and solidify. The solidified plastic was pounded in a metallic mortar and pestle and sieved through a 20 mm sieve to obtain small particles between the sizes of 2.36 mm-20 mm.

2.2.2 Test on burnt waste plastic

The following tests were used to determine the properties of the plastic aggregate-particle size distribution and the dry sieving method in accordance with [16].

2.3 M25 Grade Concrete Mix Design

This was conducted in accordance with [17]. It is significant as it aids in achieving the required strength and durability of concrete in relation to the ratio of materials used thereby making concrete production economical. The mix ratio was calculated to give cement: sand: coarse aggregate: water as 1: 2.08: 3.12: 0.60.

2.4 Sampling and Specimen Design

The samples/specimen was divided in to four groups according to curing times (3, 7, 14 and 28 day) with each group consisting of 3 cubes 100 x 100 x 100 mm respectively.

2.5 Concrete Production

2.5.1 Mixing of concrete

The cement, fine aggregate, coarse aggregate, plastic aggregate and water respectively were weighed and hand mixed to a uniform matrix. The fresh concrete workability was determined using the Slump test. Three cubes for each plastic aggregate addition/replacement (0%, 10%, 20%, 50%, 60%, 80%, and 100%) and each curing day (3, 7, 14 and 28 days) were produced.

2.5.2 Casting of specimens

Cast iron moulds of size 100 x 100 x 100 mm conforming to [18] were used to cast concrete blocks. They were cleaned to remove dust and mineral oil was applied on all sides before pouring fresh concrete (in three layers of equal height, followed by tamping 25 blows per layer) to the moulds. Excess concrete was removed using a trowel thereby smoothly finishing the top surface. A total number of eighty-four (84) cubes were produced.

2.5.3 Slump test

The test was conducted in accordance with [19]. It gave an indication of the uniformity of concrete from batch to batch.

2.5.4 Curing

Curing was achieved by submerging specimens in to water for 3, 7, 14 and 28 days. This process prevented loss of moisture while maintaining satisfactory temperature so that hydration of cement may continue until desired properties are developed.

2.6 Tests on hardened concrete

2.6.1 Water absorption

This was conducted in accordance to [20] and calculated using Equation (2):

$$Water\ Absorption(\%) = \frac{W_1}{W_2} * 100 \qquad (2)$$

Where: W_1 is the dry weight of concrete and W_2 is the saturated weight of concrete.

2.6.2 Compression test

The test was conducted in accordance with [21]. A Universal Testing Machine (UTM) (of 10 tonne capacity without eccentricity and a uniform loading of 0.3 kN/min was applied till failure of cube specimen) was used to test the compressive strength of specimen. The maximum load was noted and compressive strength was calculated using Equation (3):

$$f_c = \frac{F}{A_c} \qquad (3)$$

Where: f_c is the compressive strength in MPa (N/mm^2); F is the maximum load at failure in Newton (N) and A_c is the cross-sectional area of the specimen on which the compressive force acts, calculated from the designated size of the specimen [18] i.e. 100 x 100 mm=10000 mm^2.

3. RESULTS AND DISCUSSION

3.1 Cement

From Tables 1 and 2 below, the cement used was suitable as it met the requirements of minimum of 45 minutes initial setting (75 mins average), maximum of 10 hours (or 600 mins) final setting time (251.67 mins average), and maximum of 10 mm soundness (1.5 mm average).

Table 1. Consistency of cement

S/No.	Water content (%)	Depth of penetration from bottom (mm)
1	29	65
2	30	52
3	31	50

Table 2. Physical properties of cement

Consistency	Initial setting time (mins)	Final setting time (mins)	Soundness (mm)
31	75	255	1.5
30	75	250	1.6
29	75	250	1.4
Average = 30	75	257.67	1.5

3.2 Fine Aggregate

The specific gravity of the fine sand was 2.64 (Table 3) and conforms to [14] which states that specific gravity value should be close to 2.65, lower values would suggest present of organic and clay matter.

The particle size distribution table and curve of the fine aggregates as shown in Table 4, and Fig. 1 falls within the limit of zone II sand in compliance with [16]. The effective particle size D_{10} was 0.22 mm.

3.3 Coarse Aggregate

Table 5 and Fig. 1 shows the particle size distribution table and curve for coarse aggregate with effective particle size of 16 mm. Table 3 shows specific gravity of 2.71 conforming to [15] which states that specific gravity value should be close to 2.65.

3.4 Plastic Aggregate

Table 6 and Fig. 1 shows the particle size distribution table and curve for coarse aggregate with effective particle size of 15 mm. Table 3 shows the specific gravity of plastic aggregate at 1.06.

3.5 Workability-slump Test

Table 7 and Fig. 2 shows the workability results for the concrete mix. The concrete was designed for medium workability of 30-50 mm. The slump values are within the range of 9-25 mm which shows a true slump.

Table 3. Some physical properties of cement, plastic aggregate, fine aggregate and coarse aggregate

Property	Cement	Plastic aggregate	Fine aggregate	Coarse aggregate
Specific gravity	3.15	1.06	2.64	2.71
Bulk density (Kg/m^3)	-	648	1588	1437
Loss on ignition	1.0	-	-	-
Blaine fineness (m^2/Kg)	370	-	-	-
Aggregate crushing value (%)	-	3.34	-	22.33

Table 4. Particle size distribution of fine aggregate (Total weight of sample: 200 g)

BS test sieve size (mm)	Mass retained (g)	Percentage retained (%)	Total passing (%)
3.35	0.00	0.00	100.00
2	6.30	3.20	96.90
1.18	16.30	8.20	88.70
0.6	59.90	30.00	58.80
0.3	77.00	38.50	20.30
0.15	31.20	15.60	4.60
0.063	4.80	2.40	2.20
Passing 0.063	4.50	2.30	-
Total	200.00	100.00	-

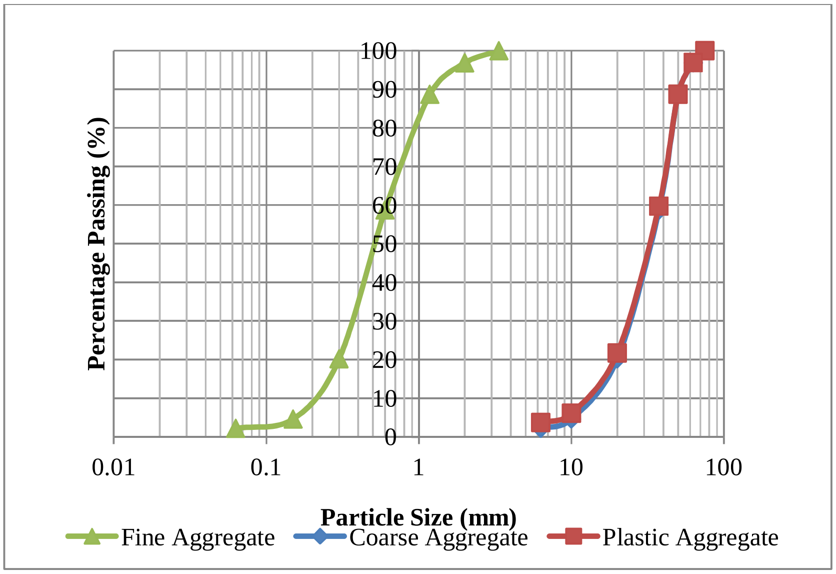

Fig. 1. Particle size distribution curve

Table 5. Particle size distribution of coarse aggregate (total weight: 1000 g)

BS test sieve size (mm)	Mass retained (g)	Percentage retained (%)	Total passing (%)
75	0.00	0.00	100.00
63	31.50	3.20	96.90
50	81.50	8.20	88.70
37.5	299.50	30.00	58.80
20	385.00	38.50	20.30
10	156.00	15.60	4.60
6.3	24.00	2.40	2.20
Passing 6.3	22.50	2.30	-
Total	1000	100.00	-

Table 6. Particle size distribution of plastic aggregate (total weight of sample: 1000 g)

BS test sieve size (mm)	Mass retained (g)	Percentage retained (%)	Total passing (%)
75	0.00	0.00	100.00
63	30.50	4.20	96.90
50	82.50	9.20	88.70
37.5	289.50	40.00	58.80
20	380.00	43.50	20.30
10	156.00	15.60	4.60
6.3	24.00	2.40	2.20
Passing 6.3	21.50	2.30	-
Total	1000	100.00	-

The workability of concrete with plastic aggregate was found to decrease with increase in amount of plastic aggregate with 9 mm slump corresponding to 100% of plastic aggregate. Further increase in plastic aggregate will decrease workability which may lead to decrease in compressive strength of concrete.

Table 7. Slump test result of plastic aggregate concrete

Mix-ID	Slump (mm)
PA-0%	25
PA -10%	23
PA -20%	21
PA -50%	18
PA -60%	16
PA -70%	15
PA -80%	12
PA -100%	9

3.6 Water Absorption

From Table 8 and Fig. 3 it is seen that water absorption remained fairly the same with increase in curing days. There was a slight reduction and increase in water absorption for 50% plastic aggregate and a slight increase and reduction in water absorption for 60 and 80% plastic aggregate.

The densities of the cubes decreased with increase in percentage plastic aggregates. The maximum and minimum recorded values of densities are 2460 kg/m^3 and 1640 kg/m^3 respectively which occurred at 7 day curing. This shows that increase in plastic aggregate used reduces the density and water absorption.

3.7 Compressive Strength

The compressive strength test result is presented in Table 9 and Fig. 4. The compressive strength generally decreases as the percentage of plastic aggregate increases. The 3 day curing had maximum and minimum compressive strength values of 22.05 N/mm^2 and 8.47 N/mm^2 at 0% and 100% plastic aggregate respectively. The 7 day curing had maximum and minimum compressive strength values of 26.34 N/mm^2 and 9.07 N/mm^2 at 0% and 100% plastic aggregate respectively. The 14 day curing had maximum and minimum compressive strength values of 27.45 N/mm^2 and 9.82 N/mm^2 at 0% and 100% plastic aggregate respectively. The 28 day curing had maximum and minimum compressive strength values of 29.16 N/mm^2 and 13.06 N/mm^2 at 0% and 100% plastic aggregate respectively. It is seen that the highest compressive strength was recorded at 28 day curing for 0% Plastic Aggregate (29.16 N/mm^2) while the highest compressive strength for 100%

addition of Plastic Aggregate also occurred at 28 curing (13.06 N/mm^2). Decrease of compressive strength with increase in PA can be related to boost in surface area for hydration thereby necessitating more cement to bond with aggregate [22-23].

The plot of compressive strength of concrete versus curing periods is shown in Fig. 5 while the bar chart of compressive strength (with standard error bars) is shown in Fig. 6. There is notably an increase in compressive strength in succeeding age/days of curing regardless of PA replacement. In day 3 of curing at PA-10%, percentage increase in strength corresponds to 27.32%, 24.86% and 29.51% compared to the control concrete at the end of 7, 14 and 28 days respectively. For PA-20%-31.84%, 21.68% and

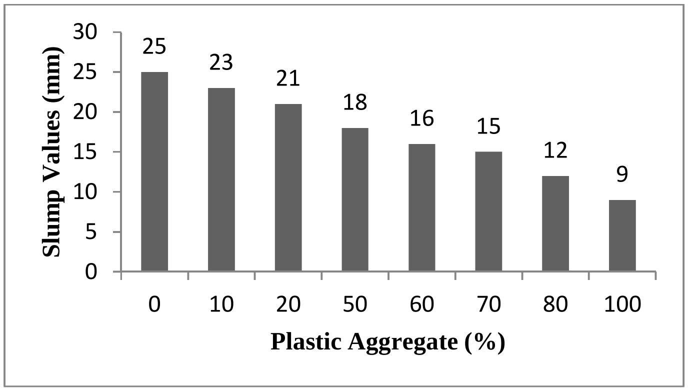

Fig. 2. Slump chart

Table 8. Water absorption results

PA (%)	Weight before curing (kg)	Weight after curing (kg)	Density (kg/m^3)	Water absorption (%)	Curing (Days)
0	2.43	2.45	2430	2	3
	2.46	2.47	2460	2	7
	2.44	2.52	2440	2	14
	2.45	2.46	2450	2	28
10	2.31	2.3	2310	2	3
	2.31	2.33	2310	2	7
	2.32	2.34	2320	2	14
	2.32	2.33	2320	2	28
20	2.27	2.29	2270	2	3
	2.27	2.29	2270	2	7
	2.27	2.29	2270	2	14
	2.26	2.27	2260	1.6	28
50	2.11	2.12	2110	1.7	3
	2.10	2.12	2100	1.6	7
	2.06	2.07	2060	1.7	14
	2.08	2.10	2080	1.5	28
60	1.93	1.94	1930	1	3
	1.93	1.95	1930	1.4	7
	1.93	1.95	1930	1.3	14
	1.86	2	1880	1.2	28
80	1.82	1.83	1820	1	3
	1.83	1.86	1830	1	7
	1.82	1.83	1820	1	14
	1.81	1.82	1810	1	28
100	1.71	1.72	1710	1	3
	1.64	1.66	1640	1	7
	1.72	1.73	1720	1	14
	1.67	1.68	1670	1	28

Table 9. Compressive strength test result for plastic aggregate concrete

Curing period	Compressive strength (N/mm^2)						
	PA-0%	PA -10%	PA -20%	PA -50%	PA -60%	PA -80%	PA -100%
3 days	22.50	19.11	18.31	16.29	14.85	13.27	9.02
7 days	26.34	24.33	24.14	18.10	15.31	13.72	9.07
14 days	27.45	23.86	22.28	23.07	20.72	14.54	9.82
28 days	29.16	24.75	24.08	23.07	20.72	17.82	13.06

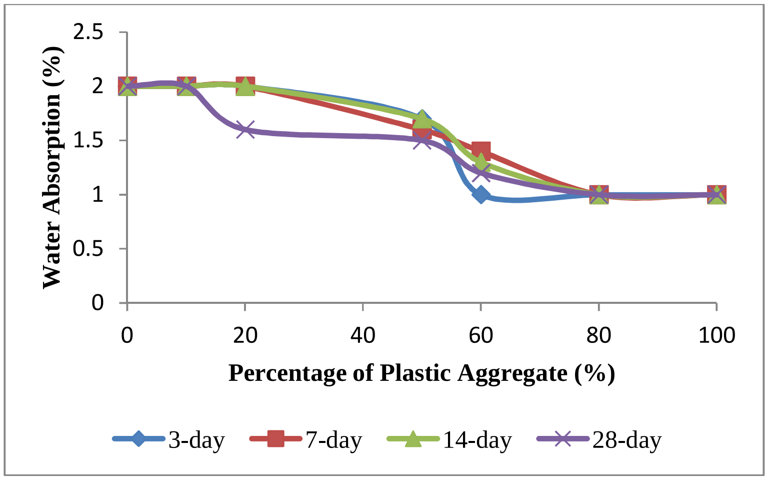

Fig. 3. Plot of water absorption and percentage plastic aggregate

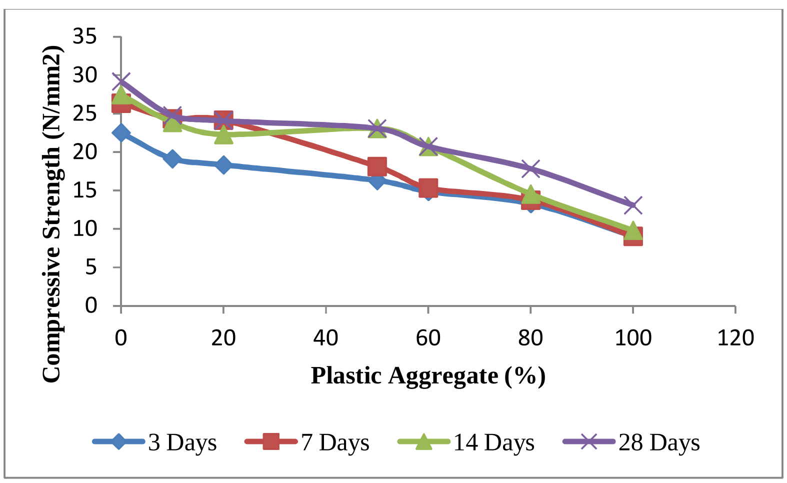

Fig. 4. Plot of compressive strength versus plastic aggregate content

31.51% represented the increase in strength in comparison to plain concrete at the end of 7, 14 and 28 days of curing. Furthermore, a similar pattern was noted for the remaining PA replacements. The percentage increase in strength for all concrete containing plastic as aggregate replacement increases slowly up to 28 days curing showing that there is a significant strength gain with prolong curing [24]. It is important to note that the plastic initially (between 0-28 days) acts as a filler in the concrete without meaningfully adding to its strength, but in advance of the 28 days, the plastic reacts with Calcium Hydroxide (given off as a result of hydration thereby producing strength forming calcium silicate hydrates (C-S-H) [25]. An alternative explanation is that the coarse aggregate from igneous sources (which has better bonding) are larger in size than the plastic aggregate used thereby resulting in higher compressive strength [22].

3.8 Statistical Analysis of the Compressive Strength Results

Statistical analysis of the data presented in Table 5 resulted in Table 10, which shows the result of regression analysis on compressive strength results. The regression equation is given by Equation (4):

$$c_s = 23.0744 - 0.14188x_1 + 0.203268x_2 \quad (4)$$

Where the predictor variables x_1 and x_2 are plastic aggregate and curing period respectively, the response variable C_s to the model equation is the compressive strength. The P-values is a measure of the likelihood that the true coefficient is zero. The P-values (P=0.05) shows that x_1 & x_2 (constants) are highly significant and are appropriate indicators in the regression model. Therefore, it can be concluded that all predictor variables significantly influence the response (Compressive strength in this case). The coefficient of variation of the selected model obtained was 90.18% (R^2=90.18%) implying that 90.18% of variation in the compressive strength is explained by the regression model with plastic aggregate and curing period as predictor variables. The standard deviation of the model equation is S =1.84177. There is a perfect correlation between predictors and response as seen from the low standard deviation value and thus implying that the generated model is highly significant [25]. The compressive strength results were further subjected to a one-way analysis of variance (ANOVA). Although Table 10 shows the concrete cubes containing PA have lower compressive strength compared to the control samples, there was no statistically significant difference between the compressive strength of control samples and those of concrete containing PA ($\rho > 0.05$) at 5 % level of significance.

Table 10. Regression analysis of compressive strength

Predictor	**Coeff.**	**SE coeff.**	**T**	***P***	**Remarks**
Constant	23.0744	0.747712	30.8600	0.000	Significant
x_1	-0.1419	0.010065	-14.0971	0.000	Significant
x_2	0.2033	0.036587	5.5557	0.000	Significant
			Basic ANOVA		
Source	**DF**	**SS**	**MS**	**F**	***P***
Regression	2	778.810	389.405	114.797	0.000000
x_1	1	674.111	674.111	198.729	0.000000
x_2	1	104.699	104.699	30.865	0.000302
Error	25	84.803	3.392	-	-
Total	27	-	-	-	-

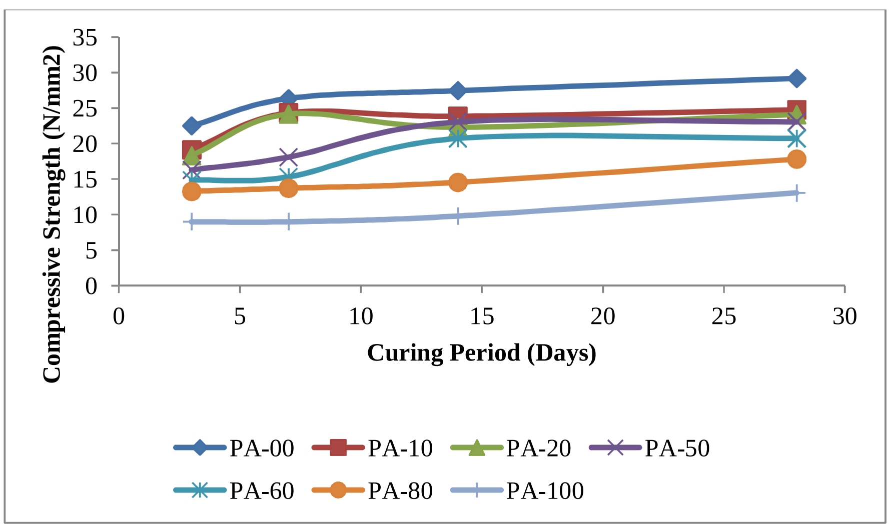

Fig. 5. Plot of compressive strength versus age of curing

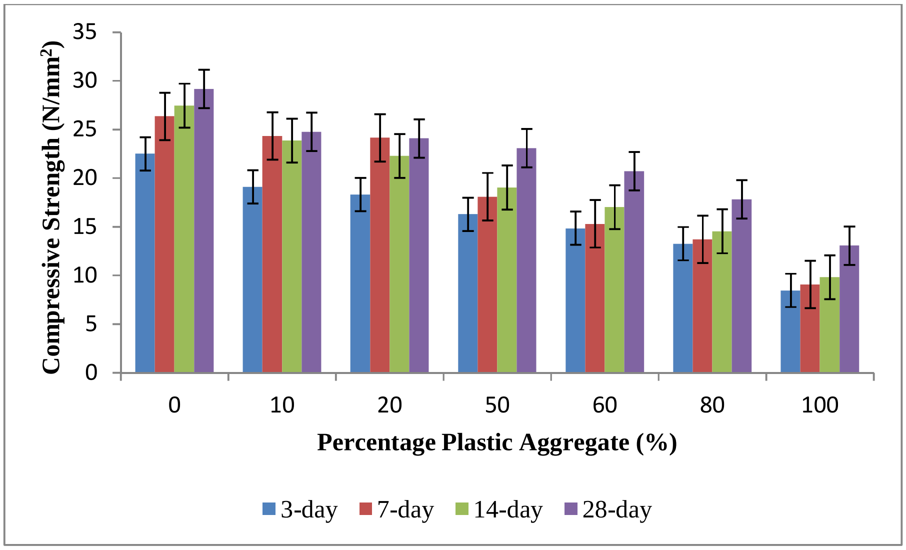

Fig. 6. Bar chart of compressive strength

4. CONCLUSION

The following summarizes the conclusion of this research:

1. The use of plastic aggregate in concrete tends to reduce the water absorption, density and compressive strength of the concrete.
2. The unit weight of concrete with addition of plastic aggregate is reduced compared with normal concrete with aggregate.
3. Notwithstanding the above, the concrete produced using Plastic Aggregate is light weight and can find application in construction on low load/non-load bearing walls (facade, partition, concrete panels, etc) thereby reducing the dead weight of the overall structure.
4. The regression model for compressive strength is given by $c_s = 23.0744 - 0.14188x_1 + 0.203268x_2$, R^2=90.18 % where x_1 and x_2 are plastic aggregate content and curing period respectively.
5. At 5% level of significance, there is no difference (statistical) between the experimental and predicted strength. Thereby providing a good prediction for the compressive strength.
6. Therefore, plastic aggregate satisfied the requirement of lightweight aggregate for structural concrete as per ASTM C330 (2004) specification.

It is recommended that further study should be carried out on insulation properties of concrete (with 10% Plastic waste as aggregate replacement).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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