

Original Research Article

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

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 25 N/mm². The data obtained were subjected to regression analysis and analysis of variance (ANOVA) in the MINITAB 16 statistical software. Models were developed to predict compressive strength with curing period and plastic aggregate content as predictors at 5% level of significance, the result showed that, there is no significant difference between the predicted and the experimental values. The coefficients of determination, R² of 90.44% for the model of compressive strength is reasonably high, indicating a good correlation between the response and the predictor variables.

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 [15].

[13] 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 serious effects like hazard to health and wellbeing of the population, flooding due to blockage of drainages by waste, contamination of groundwater, etc [20]. Waste management techniques have been developed over the years and the concepts of

26 recycling, re-use and reduction of waste have played a significant role in that aspects though a lot is
27 still left to be done to synergise various actors along the waste sector [10].

28 Concrete and its products play a very essential role in infrastructure development. Concrete is made
29 up of cement, aggregates (fine and coarse) and water in definite ratios [14]. When water is added to
30 the properly mixed materials (cement and aggregate) a chemical reaction known as hydration takes
31 place between the cement and water and the mix becomes a paste which generally hardens (sets)
32 within 2 hrs with the concrete gaining strength as it cures [14]. Concrete is used as load bearing and
33 partition units depending on the value of its properties such as water absorption, density and
34 compressive strength [17]. The density of concrete increases the overall dead load of a structure.
35 Introducing lighter alternatives to materials used in making concrete like coarse aggregate will thereby
36 reduce its weight and possibly reduce the overall cost of a construction. Research carried out by [18]
37 has shown that fly ash, fume, silica, slag etc have fully or partially replaced aggregate in concrete.

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

43 **2. MATERIALS AND METHODOLOGY**

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

46 **2.1 Materials**

47 **2.1.1 Cement**

48 Ashaka brand of Portland cement was used for this research and was procured from a reputable
49 retailer in Jos Metropolis. This brand of cement conforms to [4] and tests carried out include
50 consistency and setting time; and soundness of cement.

51 The Vicat and Le Chatelier's apparatus were used to determine the consistency and setting time; and
52 soundness of cement respectively in accordance with [4] specification.

53 **2.1.2 Fine Aggregates**

54 The materials whose particles pass through [6] test sieve (5 mm) and retained on the 0.15 mm sieve
55 are termed as fine aggregate. Natural river sand obtained from a local supplier was used as fine
56 aggregate. The sand passed through the 2mm sieve but was retained on the 1 mm sieve. The tests
57 conducted include specific gravity and particle size distribution. The specific gravity and particle size
58 distribution of fine aggregate were determined in accordance with [7] respectively.

59 **2.1.3 Coarse Aggregate**

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

63 The specific gravity of coarse aggregate was obtained in accordance with [7]. The particle density
64 was calculated using Equation (1):

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

65 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,
66 soil and water; m_4 is the mass of bottle when full of water only.

67 The particle size distribution was determined in accordance with [5].

68 **2.1.4 Water**

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

71 **2.2 Plastic waste aggregate (PA)**

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

74 **2.2.1 Source and Preparation of Plastic Aggregate**

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

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

82 **2.2.2 Test on burnt waste plastic**

83 The following tests were used to determine the properties of the plastic aggregate-particle size
84 distribution and the dry sieving method in accordance with [5].

85 **2.3 M25 Grade Concrete Mix Design**

86 This was conducted in accordance with [1]. It is significant as it aids in achieving the required strength
87 and durability of concrete in relation to the ratio of materials used thereby making concrete production
88 economical. The mix ratio was calculated to give cement: sand: coarse aggregate: water as **1: 2.08:**
89 **3.12: 0.60.**

90 **2.4 Sampling/Specimen Design**

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

93 **2.5 Concrete Production**

94 **2.5.1 Mixing of Concrete**

95 The cement, fine aggregate, coarse aggregate, plastic aggregate and water respectively were
96 weighed and hand mixed to a uniform matrix. The fresh concrete workability was determined using
97 the Slump test. Three cubes for each plastic aggregate addition/replacement (0%, 10%, 20%, 50%,
98 60%, 80%, and 100%) and each curing day (3, 7, 14 and 28 days) were produced.

99 **2.5.2 Casting of Specimens**

100 Cast iron moulds of size 100 x 100 x 100 mm conforming to [2] were used to cast concrete blocks.
101 They were cleaned to remove dust and mineral oil was applied on all sides before pouring fresh
102 concrete (in three layers of equal height, followed by tamping 25 blows per layer) to the moulds.
103 Excess concrete was removed using a trowel thereby smoothly finishing the top surface. A total
104 number of eighty-four (84) cubes were produced.

105 **2.5.3 Slump Test**

106 The test was conducted in accordance with [8]. It gave an indication of the uniformity of concrete from
107 batch to batch.

108 **2.5.4 Curing**

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

112 **2.6 Tests on Hardened Concrete**

113 **2.6.1 Water Absorption**

114 This was conducted in accordance to [9] and calculated using Equation (2):

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

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

116 **2.6.2 Compression Test**

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

$$f_c = \frac{F}{A_c} - - - (5)$$

121 Where: f_c is the compressive strength in MPa (N/mm^2); F is the maximum load at failure in Newton (N)
122 and A_c is the cross-sectional area of the specimen on which the compressive force acts, calculated
123 from the designated size of the specimen (EN 12390-1) i.e. $100 \times 100 \text{ mm} = 10000 \text{ mm}^2$.

124 **3. RESULTS AND DISCUSSION**

125 **3.1 Cement**

126 From Table 1 and 2 above, the cement used was suitable as it met the requirements of minimum of
127 45 minutes initial setting (75 mins average), maximum of 10 hours (or 600 mins) final setting time
128 (251.67 mins average), and maximum of 10 mm soundness (1.5 mm average).

129 **Table 1: Consistency of cement**

S/N	Water content (%)	Depth of Penetration from Bottom (mm)
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1	29	65
2	30	52
3	31	50

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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

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133 3.2 Fine Aggregate

134 The specific gravity of the fine sand was 2.64 (Table 3) and conforms to [7] which states that specific
135 gravity value should be close to 2.65, lower values would suggest present of organic and clay matter.

136 The particle size distribution table and curve of the fine aggregates as shown in Table 4, and Figure 1
137 falls within the limit of zone II sand in compliance with [5]. The effective particle size D_{10} was 0.22 mm.

138 **Table 3: Some Physical Properties of Cement, Plastic Aggregate, Fine Aggregate and Coarse**
139 **Aggregate**

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Property	Cement	Plastic Aggregate	Fine Aggregate	Coarse Aggregate
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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

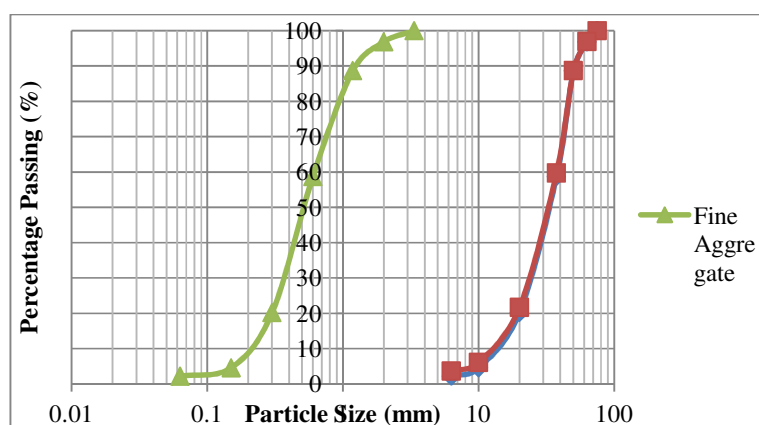
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Table 4: Particle size distribution of fine aggregate (Total weight of sample: 200g)

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	-

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Figure 1: Particle Size Distribution Curve

146 3.3 Coarse Aggregate

147 Table 5 and Figure 1 shows the particle size distribution table and curve for coarse aggregate with
 148 effective particle size of 16 mm. Table shows specific gravity of 2.71 conforming to [7] which states
 149 that specific gravity value should be close to 2.65.

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Table5: 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	-

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152 **3.4 Plastic Aggregate**

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

155 **Table 6: Particle Size Distribution of Plastic Aggregate (total weight of sample: 1000 g)**

BS Test	Mass	Percentage	Total
Sieve Size	Retained	Retained	Passing
(mm)	(g)	(%)	(%)
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	-

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3.5 Workability-Slump Test

Table 7 and Figure 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.

The workability of concrete with plastic aggregate was found to decrease with increase in amount of plastic aggregate with 9mm 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

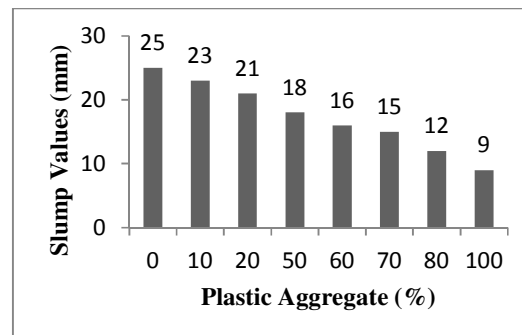


Figure 2: Slump Chart

3.6 Water Absorption

Form Table 8 and Figure 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 7day curing. This shows that increase in plastic aggregate used reduces the density and water absorption.

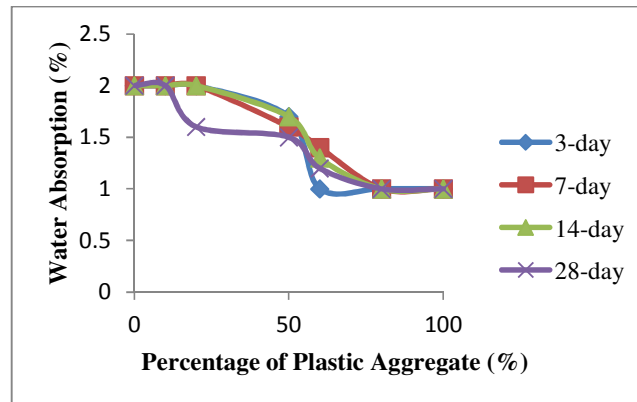
Table 8: Water Absorption Results

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

50	2.27	2.29	2270	2	14
	2.26	2.27	2260	1.6	28
	2.11	2.12	2110	1.7	3
	2.10	2.12	2100	1.6	7
	2.06	2.07	2060	1.7	14
60	2.08	2.10	2080	1.5	28
	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
	1.71	1.72	1710	1	3
100	1.64	1.66	1640	1	7

1.72 1.73 1720 1 14
1.67 1.68 1670 1 28

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Figure 3: Plot of Water Absorption and Percentage Plastic Aggregate

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3.7 Compressive Strength

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The compressive strength test result is presented in table 9, while figure 4 shows the plot of compressive strength of concrete versus percentage of plastic aggregate used to replace coarse aggregate in concrete. The compressive strength generally decreases as the percentage of plastic aggregate increases. For instance, at PA-10% coarse aggregate replacement, there was a strength decrease of 15.07%, 7.63%, 13.08% and 15.12% when compared to the compressive strength of control specimen (PA-0%) at 3, 7, 14 and 28 days of curing period respectively. Similarly, PA-20% exhibited strength decrease of 18.62%, 8.35%, 18.83% and 17.42% at 3, 7, 14 and 28 days of curing period respectively. All the remaining coarse aggregate replacement levels, exhibited similar pattern of strength loss when compared to the strength of the control sample. From all the results presented, it can be observed that higher plastic aggregate replacing coarse aggregate in concrete, results in greater reduction of compressive strength. This behaviour may be attributed to two reasons-the replacement of coarse aggregate with plastic aggregate in concrete, results in the increase of surface area for hydration, thus requiring more cement to bond with aggregate [12]; and secondly, since the coarse aggregate is much stronger than plastic aggregate, reducing the quantity of coarse aggregate and increasing the amount of plastic aggregate in the mix resulted in reduced strength when compared to plain Ordinary Portland Cement OPC concrete [16].

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Table 9: Compressive Strength Test Result for Plastic Aggregate Concrete

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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

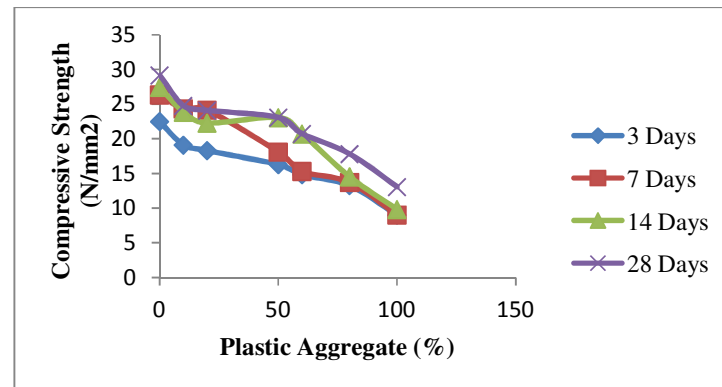


Figure 4: Plot of compressive strength versus plastic aggregate content

Figure 5 shows the plot of compressive strength of concrete versus curing periods. It can be observed that the compressive strength of the concrete containing plastic as aggregate increases as the curing age is prolonged irrespective of the replacement levels. According to the experimental findings, PA-10% at 3 days curing period, exhibited 27.32%, 24.86% and 29.51% increase in strength as compared to the control concrete at the end of 7, 14 and 28 days respectively. Similarly, PA-20% exhibited 31.84%, 21.68% and 31.51% increase in strength as compared with the corresponding strength of the plain concrete at the end of 7, 14 and 28 days of curing. All the remaining replacement levels, showed a similar pattern of strength increase. It can be seen from the values presented above that the percentage increase in strength for all concrete containing plastic as aggregate replacement increases slowly up to 28 days curing period. This shows that there is a significant strength gain with prolong curing. The possible explanation to this behaviour is that at early ages (28days and below), the plastic act as a filler in the concrete with no significant contribution to strength, but beyond 28 days, plastic react with Calcium Hydroxide released during hydration to produce the strength forming calcium silicate hydrates(C-S-H) [11]. The increase in compressive strength may be due to decrease in the size of plastic aggregate used when compared to aggregate from igneous source and thus improve bonding between the aggregate particles and the cement paste, by extension increase in bonding between the particles result in higher compressive strength [12].

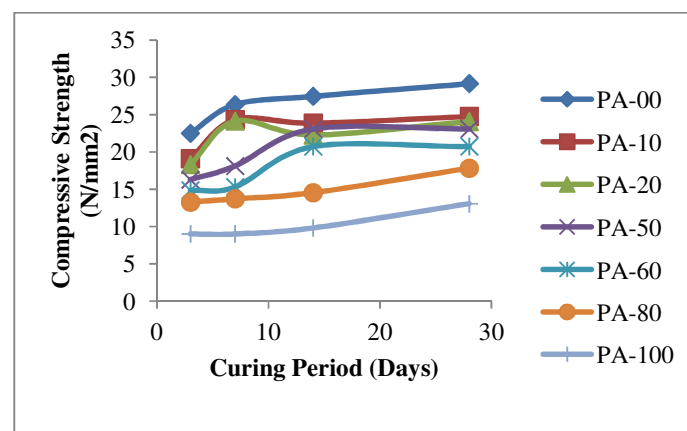


Figure 5: Plot of compressive strength versus age of curing

Table 9 and Figure 6 show the results for compressive strength. The 3days curing had maximum and minimum compressive strength values of 22.05 N/mm² and 8.47 N/mm² at PA-0% and PA-100% respectively. The 7day curing had maximum and minimum compressive strength values of 26.34 N/mm² and 9.07 N/mm² at PA-0% and PA-100% respectively. The 14 days curing had maximum and minimum compressive strength values of 27.45 N/mm² and 9.82 N/mm² at PA-0% and PA-100% respectively. The 28 days curing had maximum and minimum compressive strength values of 29.16 N/mm² and 13.06 N/mm² at PA-0% and PA-100% respectively. It was observed that, the highest compressive strength was recorded at 28 days curing for PA-0% (29.16 N/mm²) while the highest compressive strength for PA-100% also occurred at 28 days (13.06 N/mm²).

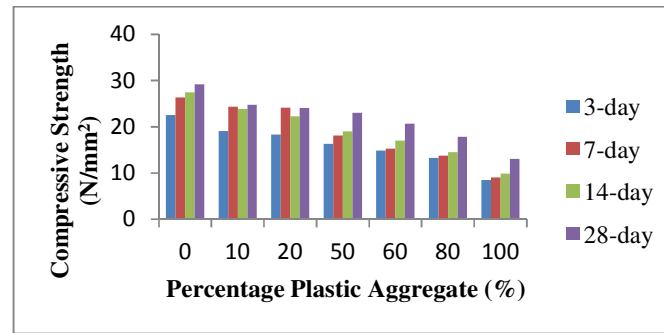


Figure 6: Bar Chart of Compressive Strength

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):

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

Where x_1 and x_2 (predictor variables) are plastic aggregate and curing period respectively, while C_s is the compressive strength (Response variable) which is the response in the model equation. The P -values is a measure of the likelihood that the true coefficient is zero. From the p -values of the terms in the model, it can be seen that the constant, x_1 & x_2 are highly significant at ($P=0.05$) and thus are useful predictors in the regression model developed. 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 % ($R^2=90.18$ %). This implies 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, $S = 1.84177$. The smaller the S value, the better the model equation, which shows a perfect correlation between predictors and the response, implying that the generated model is highly significant [11]. The compressive strength results were further subjected to a one-way analysis of variance (ANOVA). The computation is presented Table 10. Although, 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 ($p > 0.05$) 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	-	-	-	-

4. CONCLUSION

Based on the results obtained, the following conclusions were drawn:

- Compressive strength generally decreases with increase in plastic aggregate content and increase with increase in curing period.
- 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.
- The workability was reduced by incorporating plastic aggregate in concrete, hence more water is required to maintain uniform slump.
- 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.
- The statistical model developed provides good prediction for the compressive strength and there is no statistical significant difference between the experimental and predicted strength values at 5 % level of significance.
- Curing period and plastic aggregate content are useful predictors of the regression model for compressive strength.

5. REFERENCES

- British Standard Institution, BS EN 206-1: 2000 Concrete. Specification, performance, production and conformity standard by British-Adopted European Standard. London. British Standard Institution (published 02/15/2000)
- British Standard Institution, BS EN 12390-1: 2000 – Shape, dimensions and other requirements for specimens and moulds. London. British Standard Institution (published 15/12/2000)
- British Standard Institution, BS EN 12390-3:2000, Testing hardened concrete. compressive strength of test specimens. London. British Standard Institution (published 02/09/2001)

- 286 4. British Standard Institution, BS EN 196-3:1995, Methods of testing cement-Determination of
287 setting time and soundness. London. British Standard Institution (published 15/03/1995).
- 288 5. British Standard Institution, BS 812-103.1: 1985, Testing aggregates. Method for
289 determination of particle size distribution: Sieve tests. London. British Standard Institution
290 (Published 30/08/1985)
- 291 6. British Standard Institution, BS 410:1986, Specification for test sieves. London. British
292 Standard Institution (published 31/03/1986)
- 293 7. British Standard Institution, BS 1377 Part 2: 1990, Method for testing soils for civil engineering
294 purposes. Classification tests. London. British Standard Institution (Published 31/08/1990)
- 295 8. British Standard Institution, BS 1881-102: 1983, Method for determination of slump. London.
296 British Standard Institution (published 31/05/1983).
- 297 9. British Standard Institution, BS 1881-122: 1983, Testing concrete. Method for determination
298 of water absorption. London. British Standard Institution (Published 31/01/1983)
- 299 10. Coad, A., Collection of municipal solid waste: key issues for developing countries. United
300 Nations Human Settlements Programme (UN-HABITAT), Nairobi, 2011.
- 301 11. Duna, S, & Musa, A. Strength properties of concrete containing coconut shells as coarse
302 aggregate replacement. International Journal of Scientific and Engineering Research, 2017;
303 8(4): 1125-1134.
- 304 12. Duna, S., Musa, A. & Mohammed, A. Effect of metakaolin on the compressive strength of
305 concrete containing waste glass powder. International Journal of Research in Engineering
306 and Technology, 2016; 6(2): 137-142.
- 307 13. Guerrero, L. A.; Maas, G. and Hogland, W., Solid waste management challenges for cities in
308 developing countries. Waste Management 2013; 33:220-232.
- 309 14. Hirschi, T., Knauber, H., Lanz, M., Schlumpf, J., Schrabback, C. and Waeber, U., Sika
310 Concrete Handbook. 2005.
- 311 15. Marshal, R. E., and Farahbakhsh, K. Systems approaches to integrated solid waste
312 management in developing countries. Waste Management 2013; 33:988-1003.
- 313 16. Musa, A., Duna, S. & Mohammed, A. The effect of elevated temperature on the compressive
314 strength of waste glass powder and metakaolin concrete. American Journal of Engineering
315 Research, 2017.
- 316 17. Neville, A.M., Properties of concrete 3rd ed., Pitman Publishers Ltd., London. 1981.
- 317 18. Rust, B.E., Beneficial reuse of locally-available waste materials as lightweight aggregate in
318 lightweight concrete, Master's report, Michigan Technological University, 2014.
- 319 19. Wilson DC, Rodic L and Scheinberg, A Comparative analysis of solid waste management in
320 20 cities. Waste Management and Research 2012; 30: 237–254.
- 321 20. Wilson, D.C.; Velis, C.A.; Rodic, L., Integrated sustainable waste management in developing
322 countries. Waste resource management 2013; 166: WR2.