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Effect Of Crushed Glass As Coarse Aggregate For Concrete Pavement

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ABSTRACT: *In the road construction process, different techniques have been proposed and used in order to reduce the financial implications involved while improving or maintaining the quality of the construction. This study was carried out to investigate the effect of using crushed glass as coarse aggregate on the compressive strength and workability of concrete used for rigid pavements. Keeping other concrete element material constant with a design mix ratio of 1:2:4, the coarse glass content was varied by partially replacing the coarse aggregate portion with different percentages of coarse glass (5%, 10%, 15%, 20%, 25%, 30%, 35% and 40 %). The results obtained from concrete compressive strength test for the samples with glass revealed an improved compressive strength at 7, 14, 21 and 28 days. At 28 days, the compressive strength gave an optimum value of 20.65N/mm^2 at 10% replacement with coarse glass. For the workability (slump) test, the results showed a decline, that is, the workability reduced as the coarse glass content was increased. Models were also developed to predict the properties of concrete. The models developed corroborated with those obtained from experiment with very good correlation coefficient values.*

Keywords: Aggregate, Crushed Glass, Slump, Compressive Strength.

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I. INTRODUCTION

Concrete as a structural material, is composed of three main ingredients; cement, aggregates and water. The type and ratio of the ingredients changes the properties of the final product. Coarse aggregate play a significant role in concrete production, as they occupy one third of the volume of concrete. The type of coarse aggregate used in concrete production goes a long way in determining the quality in terms of concrete properties. The workability and compressive strength of concrete are two important concrete properties considered by engineers in erecting any durable structure [1]. The workability of concrete is often referred to as the ease with which a concrete can be transported, placed and consolidated without excessive bleeding or segregation [2]. The compressive strength of concrete is one property that influences many other describable properties of the hardened concrete. The mean compressive strength required at a specific age, usually 28 days determines the nominal water-cement ratio of the mix [2].

Coarse aggregates are the larger part of the aggregate component of concrete. Coarse aggregate are considered as particles greater than 4.75mm but generally ranged between 9.5mm to 37.5mm in diameter [3]. They can either be from primary, secondary or recycled sources. Coarse aggregate ranging from 5-10mm are the most popular aggregate fraction used for the production of concrete and concrete structures, construction of roads, buildings and bridges etc. [4,5]. Aggregates control the unit weight, modulus of elasticity and dimensional stability of concrete because these properties depend on the physical characteristics of the aggregate [6]. Aggregates that possess very high density, high compressive strength and high Young's Modulus are considered fit for usage as coarse aggregate. This makes glass a potential material for usage as a coarse aggregate.

Waste glasses are used as aggregates for concrete [7,8,9]. Topcu and Canbaz [10] concluded that when waste glasses are reused in making concrete products, the production cost of concrete will go down. Gautam et al.[11] conducted a research of waste glass usage as partial replacement of fine aggregate in concrete production and discovered that glass can effectively replace sand up to 40%. However the applications are limited due to the damaging expansion in the concrete caused by alkali-silica reaction (ASR) between high-alkali pore water in cement paste and reactive silica in the waste glasses. The chemical reaction between the alkali in Portland cement and the silica in aggregates forms silica gel that not only cause crack upon expansion but also weakens the concrete and shortens its life. [12].

II. MATERIALS AND METHODS

2.1 Materials

i. The coarse aggregate used for this study was granite chippings of maximum size 12.5mm.
ii. The cement used was Dangote cement (R. 425, CB 4227) in accordance with the requirement of BS 12 [13] obtained from a local market shop in Port Harcourt.
iii. Fine river sand was used as the fine aggregate.
iv. The waste glasses used for this study were obtained from a waste glass assemblage in the University of Port Harcourt and were then washed, dried and crushed into smaller pieces. These crushed glasses were then sieved to obtain a maximum 12.5mm coarse glass.

2.2 Experimental Equipment

The Equipment used for the essence of this study were;

i. 150mm x 150mm x 150mm steel moulds.
ii. Slump cone (model HM-40, Gilson Company USA) which meets the requirement of BS 1882-102 [14].
iii. Compressive Strength Machine (Model 4207D, Chandler Eng. USA) which meets the requirements of BS 1881:115 [4]
iv. Others are; tags sieves, weighing instrument, trowel, curing tank, 8.2N weight, steel rod and electric concrete mixer.

2.3 Methodology

2.3.1 Experimental Design

This research involved experimental tests on concrete specimen, using glass as coarse aggregate in the production of concrete for rigid pavement. The crushed glass was used to partially replace the coarse aggregate at 0%, 5%, 10%, 15%, 20%, 25%, 30% and 40% with a constant mix proportion of 1:2:4 and 0.6 water-cement ratio.

2.3.2 Concrete Batching, Mixing and Curing

The coarse aggregate, coarse glass, fine aggregate and cement were thoroughly mixed together with the electric concrete mixer, after which water at 0.6 water-cement ratio was added. The constituents were mixed until an even paste was obtained. The aggregate were prepared in accordance with the requirements of BS 1017 [5]. The 1:2:4 nominal mix was employed as the mix design ratio. The concrete specimen produced were subjected to slump test to determine the workability. After which, they were cured for 7, 14, 21 and 28days for the determination of the compressive strength.

2.3.3 Slump Test

The slump cone was filled in three layers, each layer compacted using a steel rod with 25 blows before the pouring of the next layer. The surface of the slump cone was levelled and allowed for about 2 minutes. The slump cone was then lifted off the concrete, thus allowing the pile of unsupported concrete to collapse. The difference between the initial and the final height of the concrete was measured and recorded as the slump.

2.3.4 Compressive Strength Test

After the slump test, the cubes were cured for 7, 14, 21 and 28 days after which the compressive strength was determined using the compressive strength machine (Model 4207D, Chandler Eng, USA). The load at which the specimen failed was recorded and compressive strength calculated using Equation (1).

$$f_c = \frac{Maximun\ \ load\ at\ \ failure}{cross\ \ sectional\ area\ of\ cube} \qquad (1)$$

III RESULTS AND DISCUSSIONS

3.1 Slump

The result of slump (workability) test for the coarse glass-aggregate concrete are as presented in Table 1.

Table 1: Slump of coarse glass-aggregate concrete

% wt of crushed glass	Slump (mm)		
	(1)	(2)	Mean
0	90.00	88.00	89.00
5	84.00	86.00	85.00
10	79.00	81.00	80.00
15	62.00	60.00	61.00
20	44.00	46.00	45.00
25	35.00	32.00	33.50
30	22.00	19.00	20.50
35	15.00	15.00	15.00
40	11.00	9.00	10.00

The effect of coarse glass-granite fresh concrete on slump is shown in Figure 1. The concrete slump can be seen to reduce as the percentage replacement of glass as coarse aggregate increases. The reduction in workability can be attributed to the difference in density between the glass and granite chippings. Moreover, the slippery nature of glass lacking cohesive forces with other components especially with the presence of water can also be responsible for the reduction in slump.

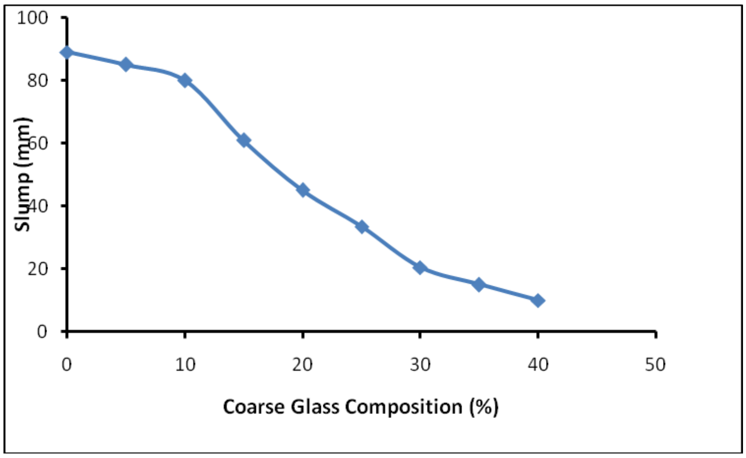

Figure 1: Slump vs % Coarse Glass Composition

3.2 Compressive Strength

The result of compressive strength test for the coarse glass-aggregate concrete are as presented in Table 2.

Table 2: Compressive strength of Glass-Granite Aggregate Concrete

% wt of crushed glass	Compressive strength (N/mm^2)											
	7 days			14 days			21 days			28 days		
	(1)	(2)	mean	(1)	(2)	mean	(1)	(2)	Mean	(1)	(2)	mean
0	10.40	10.50	10.45	11.95	13.15	12.55	16.00	15.50	15.75	19.50	19.20	19.35
5	11.25	10.95	11.10	13.20	13.10	13.15	16.70	17.00	16.85	20.00	19.70	19.05
10	12.40	12.50	12.45	14.20	15.00	14.60	18.05	18.05	18.05	20.60	20.70	20.65
15	9.00	8.50	8.75	11.05	12.05	11.55	15.10	15.40	15.25	19.00	19.02	19.01
20	8.50	8.60	8.55	10.50	10.90	10.70	15.00	14.60	14.80	18.90	18.80	18.85
25	8.20	8.30	8.25	10.30	10.40	10.35	13.50	14.50	14.00	18.00	19.00	18.50
30	8.02	8.00	8.01	10.00	10.10	10.05	13.70	13.60	13.65	17.50	17.60	17.55
35	8.00	7.90	7.95	10.03	10.01	10.02	12.90	13.00	12.95	16.20	15.80	16.00
40	7.90	7.80	7.85	10.00	9.80	9.90	12.50	12.40	12.45	8.00	9.00	13.20

The effect crushed glass on compressive strength of coarse glass-aggregate concrete is shown in Figure 2. From Figure 2, results show that the optimum percentage replacement is at 10%. Beyond this percentage replacement, the compressive strength decreases as the percentage replacement increases. At 15% replacement, there is a sharp decrease in compressive strength for the different curing ages well below that of the control specimen. At the optimum replacement of 10% coarse glass, the mean compressive strength recorded were 12.45N/mm^2, 14.00N/mm^2,18.05N/mm^2, and 20.65N/mm^2 at 7, 14, 21 and 28 days respectively.

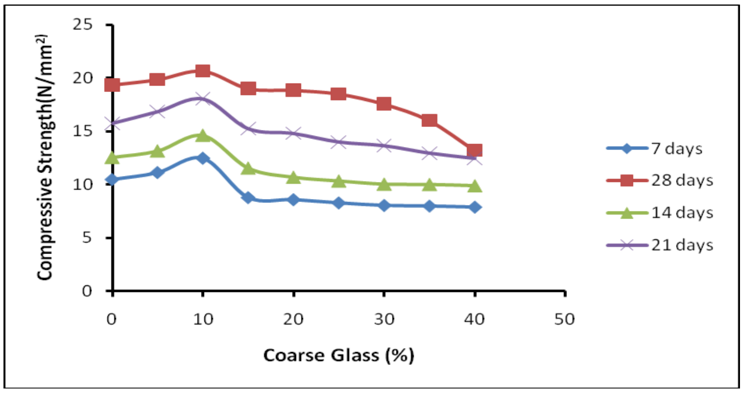

Figure 2: Strength vs % Coarse Glass

3.2.1 Ageing Effect

The result of the effect of crushed glass on the ageing of coarse glass-granite concrete is presented in Table 3 and Figure 3.

Table 3: Compressive Strength and Concrete Age

Age (Days)	Mean Compressive Strength (N/mm^2)								
	0	5	10	15	20	25	30	35	40
7	10.45	11.10	12.45	8.75	8.55	8.25	8.01	7.95	7.85
14	12.55	13.15	14.60	11.5	10.70	10.35	10.05	10.02	9.90
21	15.75	16.85	18.05	15.25	14.80	14.00	13.65	12.95	1.45
28	19.35	19.85	20.65	19.01	18.85	18.50	17.55	16.00	13.20

From Figure 3, results show that when coarse aggregate is replaced by 5% coarse glass, the compressive strength at 7 days increase by about 6.2%; and at 10% replacement, the material recorded a percentage increment of about 19.1% at 7 days. Also, at 28 days the material recorded a percentage increment of about 2.7% and 6.72% at 5% and 10% replacement respectively.

This result indicates that as the glass concrete ages, the compressive strength increment reduces with increase in percentage replacement. The percentage increment reduces from 6.2% to 2.7% at 5% replacement (7-28 days), at 10% replacement, the percentage increment reduces from 19.1% to 6.72% (7-28 days).
This reduction may be attributed to the damaging effect on the concrete caused by ASR between high-alkali pore-water in cement paste and reactive silica in the waste glasses.

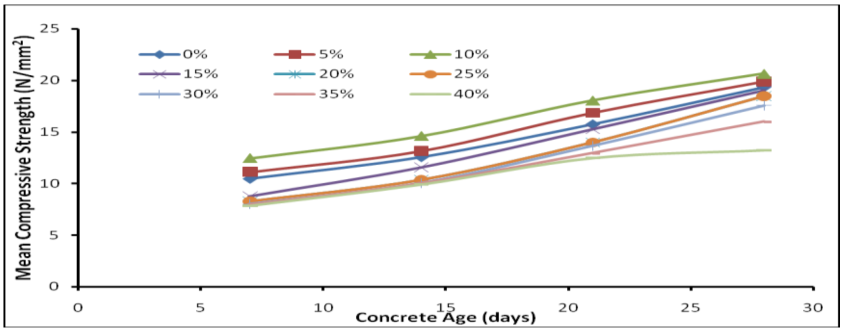

Figure 3: Mean Compressive Strength vs Age of Glass Concrete

3.3 Modelling the Properties of the Concrete Composites

The Newton Divided difference is adopted in the formulation of the model properties assuming a fourth order polynomial of the form indicated in Equation (2).

$$P_4(x) = f\,[x_0] + f\,[x_0,x_1](x - x_0) + f\,[x_0,x_1,x_2](x - x_0)(x - x_1) + f\,[x_0,x_1,x_2,x_3](x - x_0)(x - x_1)(x - x_2) + f\,[x_0,x_1,x_2,x_3,x_4](x - x_0)(x - x_1)(x - x_2)(x - x_3) \quad (2)$$

These models were formulated using percentage by weight replacement of 0%, 10%, 20%, 30% and 40%. Where the percentage by weight replacement represents x and f (x_i) represents concrete property. The algorithm approach as postulated by Oko [15] was followed.

3.3.1 Slump Model

x	0	10	20	30	40
f(x)	89.00	80.00	45.00	20.50	10.00

Get (n; $\{x\}_i^n = 0; \{f_0\,(x_i)\ _i^n = 0)$ =

n = 4; $x_0 = 0, x_1 = 10, x_2 = 20$

$x_3 = 30, x_4 = 40; f(x_0) = 89.00$

$f(x_1) = 80.00, f(x_2) = 45.00, f(x_3) = 20.50, f(x_4) = 10.00$

K: = 1

while (1 ≤ 4) = true

d_0:

$j = 0$

While (0 ≤ 4-1) = true

d_0:

$f\,(x_0,x_1) = \frac{f(x_1)-f(x_0)}{x_1 - x_0} = \frac{80.00-89}{10-0} = -0.90$

$f(0{,}10) = -0.9;\ j = j + 1 = 1$

end d_0

While (1 ≤ 3) = true

d_0:

$f\,(x_1,x_2) = \frac{f(x_2)-f(x_1)}{x_2 - x_1} = \frac{45-80}{20-10} = -3.5$

$f(10{,}20) = -3.5;\ j = j + 1 = 1 + 1 = 2$

end d_0

While (2 ≤ 3) = true

d_0:

$f\,(x_2,x_3) = \frac{f(x_3)-f(x_2)}{x_3 - x_2} = \frac{20.5-45}{30-20} = -2.45$

$f(20{,}30) = -2.45;\ j = j + 1 = 2 + 1 = 3$

end d_0

While (3 ≤ 3) = true

d_0:

$f\ (x_3, x_4) = \frac{f(x_4) - f(x_3)}{x_4 - x_3} = \frac{10 - 20.5}{40 - 30} = -1.05$

$f(30{,}40) = -1.05;\ j = j + 1 = 3 + 1 = 4$

end d_0

While (4 $\leq$ *3) = false >*d_0

end d_0

k = k + 1 = 1 + 1 = 2

While (2 $\leq$ *4) = true*

d_0

$j := 0$

While (0 $\leq$ *2) = true*

d_0

$f\ (x_0, x_1, x_2) = \frac{f(x_1, x_2) - f(x_0, x_1)}{x_2 - x_0} = \frac{-3.5 - (-0.90)}{20 - 0} = -0.13$

$f(0{,}10{,}20) = -0.13;\ j = j + 1 = 0 + 1 = 1$

end d_0

While (1 $\leq$ *2) = true*

d_0:

$f\ (x_1, x_2, x_3) = \frac{f(x_2, x_3) - f(x_1, x_2)}{x_3 - x_1} = \frac{-2.45 - (-3.5)}{30 - 10} = 0.0525$

$f(10{,}20{,}30) = 0.0525;\ j = j + 1 = 1 + 1 = 2$

end d_0

While (2 $\leq$ *2) = true*

d_0:

$f\ (x_2, x_3, x_4) = \frac{f(x_3, x_4) - f(x_2, x_3)}{x_4 - x_2} = \frac{-1.05 - (-2.45)}{40 - 20} = 0.07$

$f(20{,}30{,}40) = 0.07;\ j = j + 1 = 2 + 1 = 3$

end d_0

While (3 $\leq$ *2) = false >*d_0

end d_0

k = k + 1 = 2 + 1 = 3

While (3 $\leq$ *4) = true*

d_0

$j := 0$

While (0 $\leq$ *1) = true*

d_0

$f\ (x_0, x_1, x_2, x_3) = \frac{f(x_1, x_2, x_3) - f(x_0, x_1, x_2)}{x_3 - x_0} = \frac{0.0525 - (-0.13)}{30 - 0} = 0.0061$

$f(0{,}10{,}20{,}30) = 0.0061;\ j = j + 1 = 0 + 1 = 1$

While (0 $\leq$ *1) = true*

d_0

$f\ (x_1, x_2, x_3, x_4) = \frac{f(x_2, x_3, x_4) - f(x_1, x_2, x_3)}{x_4 - x_1} = \frac{0.07 - 0.0525}{40 - 10} = 0.0006$

$f(10{,}20{,}30{,}40) = 0.0006;\ j = j + 1 = 1 + 1 = 2$

While $(2 \lesssim 1)$ *= false >* d_0

end d_0

k = k + 1 = 3 + 1 = 4

While $(4 \lesssim 4)$ *= true*

d_0

$j := 0$

While $(0 \lesssim 0)$ *= true*

d_0

$$f\ (x_0, x_1, x_2, x_3, x_4) = \frac{f(x_1,x_2,x_3,x_4) - f(x_0,x_1,x_2,x_3)}{x_4 - x_0} = \frac{0.0006 - 0.0061}{40 - 0} = -0.0001$$

$f(0{,}10{,}20{,}30{,}40) = -0.0001;\ j = j + 1 = 0 + 1 = 1$

While $(1 \lesssim 1)$ *= false >* d_0

end d_0

k = k + 1 = 4 + 1 = 5

While $(5 \lesssim 4)$ *= false >* d_0

end d_0

Stop.

Polynomial becomes;

$S_m = P_4\ (x) = 89 - 0.9x - 0.13x\ (x - 10) + 0.0061x\ (x - 10)\ (x - 20) - 0.0001x(x - 10)\ (x - 20)\ (x - 30)$

3.3.2 28 - Day Strength Model

x	0	10	20	30	40
$f(x)$	19.35	20.65	18.85	17.55	13.20

et (n; $\{x\}_i^n = 0; \{f_0\ (x_i)\ _i^n = 0)$ *=*

n = 4; $x_0 = 0,\ x_1 = 10, x_2 = 20,\ x_3 = 30, x_4 = 40$

$f(x_0) = 19.35, f(x_1) = 20.65, f(x_2) = 18.85, f(x_3) = 17.55, f(x_4) = 13.20$

K: = 1

while $(1 \lesssim 4)$ *= true*

d_0:

j*: = 0*

While $(0 \lesssim 4\text{-}1)$ *= true*

d_0:

$$f\ (x_0, x_1) = \frac{f(x_1) - f(x_0)}{x_1 - x_0} = \frac{20.65 - 19.35}{10 - 0} = 0.13$$

$f(0{,}10) = 0.13;\ j = j + 1 = 1$

While $(1 \lesssim 3)$ *= true*

d_0:

$$f\ (x_1, x_2) = \frac{f(x_2) - f(x_1)}{x_2 - x_1} = \frac{18.85 - 20.65}{20 - 10} = -0.18$$

$f(10{,}20) = -0.18;\ j = j + 1 = 1 + 1 = 2$

end d_0
While $(2 \leq 3) = true$

d_0:

$f\,(x_2,x_3) = \frac{f(x_3)-f(x_2)}{x_3 - x_2} = \frac{17.55-18.85}{30-20} = -0.13$

$f(20{,}30) = -0.13;\; j = j+1 = 2+1 = 3$

end d_0
While $(3 \leq 3) = true$

d_0:

$f\,(x_3,x_4) = \frac{f(x_4)-f(x_3)}{x_4 - x_3} = \frac{13.20-17.55}{40-30} = -0.435$

$f(30{,}40) = -1.05;\; j = j+1 = 3+1 = 4$

end d_0
While $(4 \leq 3) = false > d_0$

end d_0
$k = k + 1 = 1 + 1 = 2$
While $(2 \leq 4) = true$

d_0

$j = 0$

While $(0 \leq 2) = true$

d_0

$f\,(x_0,x_1,x_2) = \frac{f(x_1,x_2)-f(x_2,x_1)}{x_2 - x_0} = \frac{-0.18-0.13}{20-0} = -0.0155$

$f(0{,}10{,}20) = -0.0155;\; j = j+1 = 0+1 = 1$

end d_0
While $(1 \leq 2) = true$

d_0:

$f\,(x_1,x_2,x_3) = \frac{f(x_2,x_3)-f(x_1,x_3)}{x_3 - x_1} = \frac{-0.13+0.18}{30-10} = 0.0025$

$f(10{,}20{,}30) = 0.0025;\; j = j+1 = 1+1 = 2$

end d_0
While $(2 \leq 2) = true$

d_0:

$f\,(x_2,x_3,x_4) = \frac{f(x_3,x_4)-f(x_2,x_3)}{x_4 - x_2} = \frac{-0.435-0.13}{40-20} = -0.0283$

$f(20{,}30{,}40) = -0.0283;\; j = j+1 = 2+1 = 3$

end d_0
While $(3 \leq 2) = false > d_0$

end d_0
$k = k + 1 = 2 + 1 = 3$
While $(3 \leq 4) = true$

d_0

$j{:}= 0$

While (0 ≤ 1) = true

d_0

$f\,(x_0, x_1, x_2, x_3) = \frac{f(x_1,x_2,x_3) - f(x_0,x_1,x_2)}{x_3 - x_0} = \frac{0.0025-(-0.0155)}{30-0} = 0006$

$f(0{,}10{,}20{,}30) = 0.0006;\ j = j+1 = 0+1 = 1$

While (0 ≤ 1) = true

d_0

$f\,(x_1, x_2, x_3, x_4) = \frac{f(x_2,x_3,x_4) - f(x_1,x_2,x_3)}{x_4 - x_1} = \frac{0.0283-(-0.0025)}{40-10} = -0.00103$

$f(10{,}20{,}30{,}40) = -0.00103;\ j = j+1 = 1+1 = 2$

While (2 ≤ 1) = false >d_0

end d_0

k = k + 1 = 3 + 1 = 4

While (4 ≤ 4) = true

d_0

$j := 0$

While (0 ≤ 0) = true

d_0

$f\,(x_0, x_1, x_2, x_3, x_4) = \frac{f(x_1,x_2,x_3,x_4) - f(x_0,x_1,x_2,x_3)}{x_4 - x_0} = \frac{-0.00103 - 0.0006}{40-0} = -0.0000408$

$f(0{,}10{,}20{,}30{,}40) = -0.0000408;\ j = j+1 = 0+1 = 1$

While (1 ≤ 1) = false >d_0

end d_0

k = k + 1 = 4 + 1 = 5

While (5 ≤ 4) = false >d_0

end d_0

Stop.

Polynomial becomes;

$C.S_{28} = P_4(x) = 19.35 + 0.13x - 0.0155x(x-10) + 0.0006x(x-10)(x-20) - 0.0000408x(x-10)(x-20)(x-30)$

3.3.3 Model Validation

The models deduced for the workability and 28th day compressive strength were validated using the coefficient of correlations (r) values. The r values were computed using Equation (3).

$$r = \sqrt{\frac{\sum (y_{est} \bar{y})^2}{\sum (y-\bar{y})^2}} \qquad (3)$$

Where; y_{est} = Predicted concrete property value from model.

y = Experimental or actual concrete value

$\bar{y}$ = Average experiment concrete value.

Using Equation 3, r value of 0.99 and 0.71 were obtained for slump model and 28 dayS compressive strength model respectively.

IV CONCLUSION AND RECOMMENDATION

4.1 Conclusion

From the results of the study, the following conclusions are hereby made.

1. The workability of fresh concrete made using coarse glass aggregate decreases as the coarse glass content increases.
2. The optimum percentage replacement of coarse glass with granite is found to be 10%.
3. The initial percentage strength increment recorded at the early stage reduces as the concrete ages.

4.2 Recommendation

1. Further research should be done on the use of glass as aggregate replacement using other mix designs.
2. The effect on the other concrete properties like elastic modulus, Poisson ratio etc. should be studied.

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