Journal of Engineering and Applied Sciences 12 (20): 5121-5128, 2017
ISSN: 1816-949X

Reliability of Gravel in Place of Granite in Concrete Production

[1]Gideon Bamigboye, [2]Adeola Adedeji, [1]David Olukanni and [1]Kayode Jolayemi
[1]Department of Civil Engineering, Covenant University, Ogun State, Ota, Ogun State, Nigeria
[2]Department of Civil Engineering, University of Ilorin, Kwara, Nigeria

Abstract: The study investigated the reliability of gravel as partial replacement of granite in concrete production. Concrete was produced using various percentages of granite/gravel combination. Two different mix ratios of 1:2:4 and 1:3:6 were employed. Slump tests were carried out on fresh concrete, compressive and split tensile strength tests were performed on hardened concrete. Reliability analysis was carried out on available data to estimate the failure probability. The reliable percentage of gravel from compressive strength view point was 40% with a value of 21.15 N/mm^2 for 1:2:4 and 30% with 15.17 N/mm^2 for 1:3:6 mix ratios at 28 days. Satisfying minimum requirement of BS 8110:1997. There was a significant reduction in split tensile strength as gravel percentage increases beyond 40% for 1:3:6 mix ratio. Similar trends were observed for 1:2:4 mix ratio. Linear regression analysis was used to reliably predict characteristic strength based on any coarse aggregate combination with positive high values of coefficients of correlation (R^2) of 0.983 and 0.937, respectively for compression and tension behavior. Comparing the result of the probability of failure obtained with the ISO 2394:1998 (E) standard it was found that $g(\underline{x})>0$ limit state was satisfied which indicated that the structure is safe.

Key words: Concrete, coarse aggregates, compressive strength, reliability, regression analysis, Nigeria

INTRODUCTION

Construction materials quality impact greatly on the integrity of built structures (Bamigboye *et al*., 2016). The reliability (probability of survival or no failure) of a structure is its ability to fulfil its design purpose for some specified time period. A fundamental assumption of structural design is that malfunction can occur in a finite number of failure modes described by a family of limit states. Hence, reliability is the probability that a structure will not attain each specified limit state during a specified reference period. The complementary event, i.e., the probability that a structure will attain or exceed a specified limit state is called the probability of failure. Folic (2003) reported that reliability is the probability of a structure to fulfill the given function in its service lifetime. Stake holders have been advocating for the use of locally-available materials as to reduce the cost of infrastructural systems and thereby making buildings affordable to the middle and low class residents (Bamigboye *et al*., 2016). Hence, any advocacy for adopting a new material or for blending new materials should be tested to assess the reliability and technical viability of adopting them for structural applications. Stewart and Melchers (1997) found that system failures represent events such as collapse of a building structure, flooding of a construction site, road or rail tunnel explosion. Typical failure modes to be considered in a reliability analysis of a structural system are yielding, buckling (local and global), fatigue and excessive deformation. For many years, it has been assumed in design of structural system that all loads and strength are deterministic. The strength of an element was determined in such a way that it exceeded the load with a certain margin. The ratio between the strength and the loads was denoted by the safety factor. This number was considered as a measure of reliability of the structure. Loads, structural strength and methods of reliability analysis are the three components require for the reliability-based design and the components are necessary for the development of resistance factor design and reliability-based load. Assakkaf (2012) concluded that reliability-based design and analysis methods use all available information on the basic random variables for strength and load effects and do not simplify the limit state functions in any manner. Concrete is a composite material made with Portland cement, aggregates, water and various types of admixtures (Ede and Agbede, 2015). Ede and Aina (2015) concluded that concrete has very good compressive strength and resistance to fire. Fowler and Quiroga (2003) reported that aggregates generally occupy 60-75% of the concrete and strongly influence the strength of freshly mixed concrete and play a major role in the hardened strength of the concrete. Kosmatka *et al*.

Corresponding Author: Gideon Bamigboye, Department of Civil Engineering, Covenant University, Ota, Ogun State, Nigeria

(2002) found that close to half of the coarse aggregate used in portland cement concrete in North America are gravels while most of the remainder is crushed stones. Due to the quantity of aggregates required for a typical civil engineering application the strength, reliability, cost and availability of the aggregates are important when selecting an aggregate source (Bamigboye *et al*., 2015; Mamlouk and Zaniewski, 2011). Granite is relatively strong and more expensive while gravel is much more affordable. Previous studies on coarse aggregates have been predominantly on 100% granite and 100% gravel without combining both and examine the reliability aspect of the combination. The economic condition is one of the major factors that make gravel more attractive for building development. Gravels result from the natural disintegration of rocks and are usually rounded and as such require less amount of cement paste. This saves about 4-5% cement paste (Ede *et al*., 2015). Researches on the impact of aggregates on the strength of concrete abound in literature. Abdullah (2012) concluded that the strength of the concrete at the interfacial zone essentially depends on the integrity of the cement paste and the nature of the coarse aggregate. Aitcin and Mehta (1990) tested four different types of coarse aggregate and discovered that the compressive strength and elastic modulus were significantly influenced by the mineralogical characteristics of the aggregates. Raheem and Aderonmu (2002) investigated the effect of aggregate sizes on the strength of concrete and concluded that the compressive strength of concrete increases with increase in sizes of coarse aggregate up to a maximum of 25 mm. Based on the facts highlighted above it is imperative to determine the granite-gravel contents that will produce reliable concrete without compromising strength and safety requirements. This research therefore studies the reliability of gravel as partial replacement of granite in concrete production.

Reliability and failure probability: The limit state design process is defined by the principle of structural reliability, ISO 2394:1998 (E). Two types of limit states identified include ultimate limit state and serviceability limit state. Total failure of a structure by any mechanism (fracture, buckling, overturning, etc.) is considered to be failure under ultimate limit state. Other forms of limit state may however cause a structure not to be fit for purpose. The function $g(\underline{x})$ describes the limit state as:

- $g(\underline{x})>0$ limit state is satisfied (safe set)
- $g(\underline{x})<0$ failure occurs (unsafe set)
- $g(\underline{x})>0$ failure surface

with $\underline{x}$ a vector of statistical variable which takes into account uncertainties.

Code requirement for reliability: As earlier noted, the product of failure probability and cost of failure defines the risk level or target level of reliability. According to Rafiq *et al*. (2004) uncertainties associated with modeling of deteriorating structures have strong influence on management decisions such as when to inspect and scheduling of maintenance and repair actions. In this regard structural elements that are frequently inspected, show warning signs if failure is approaching or can redistribute its loads to other elements and hence less likely to cause loss of life at failure. ISO 2394:1998 (E) suggested for serviceability limit state a target level of reliability, $\beta = 0$ for reversible and $\beta = 1.5$ for irreversible limit states.

MATERIALS AND METHODS

This study present the materials used in the experimental program as well as the procedures adopted to perform each of the tests. Gravel and granite were used as coarse aggregates for this study and natural river sand as fine aggregate. Dangote brand of ordinary portland cement was used. The 1:2:4 and 1:3:6 were adopted as concrete mix ratios, cement-fine-aggregate ratios.

About 150 mm^3 and 150×300 mm cylinders concrete specimens were produced and tested for compressive and split tensile strength test in line with BS 1881, using Denison Universal Testing Machine at the Structure Laboratory of Department of Civil Engineering, Covenant University, Ota. Percentages of gravel in replacement for granite were 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100%. For each percentage replacement, three concrete cubes were tested after curing for 3, 7, 14, 21 and 28 days and mean values represented the compressive and spilt tensile strength. Particle distribution analyses were carried out for coarse and fine aggregates in accordance with the British standards. The maximum sizes of aggregates adopted were 19-25 and 2.36 mm for coarse aggregates (granite and gravel) and fine aggregates (sharp sand), respectively. The slump test to measure the consistency of concrete was conducted in accordance with the British standards. The trend of variation of compressive and splitting tensile strengths was assessed using linear regression analysis given in Eq. 1 to reliably predict characteristic strength based on any given coarse aggregate combination. Also, descriptive statistics were used to assess the characteristics and level of uncertainty of a given quantity of granite and gravel combination compressive strength by investigating the data available such as observations and test results. Equation 2 was used to determine the central measures which were also used to determine the sample mean in Eq. 3. The dispersion of the data set was characterized by simple variance given in Eq. 4 while the standard deviation is the square root of variance given in Eq. 5. As a means of comparison between the dispersions of different data sets the dimensionless sample coefficient of variation V is convenient, samples coefficient of variation is defined as the ratio of the sample standard deviation to the sample mean given in Eq. 6 to determine the degree of data set the sample coefficient of skewnes which is a logical extension of the sample variance is suitable given in Eq. 7, sample covariance was used to do measure of correlation as given in Eq. 8. Equation 9 gives the sample correlation coefficient. Equation 10 gives failure probability with sufficient accuracy. Reliability index was determined using Eq. 11:

$$y = mx+c \tag{1}$$

Where:

y = Percentage ratio of granite/gravel
x = Compressive strength/splitting tensile strength
c = Intercept
m = Slope

$$x = (x_1\ x_2, \dots, x_n)^T \tag{2}$$

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} xi \qquad \bar{y} = \frac{1}{n}\sum_{i=1}^{n} yi \tag{3}$$

Where:

$\bar{x}$ and $\bar{y}$ = The sample mean
x_i and y_i = The variables (experimental compressive strength results of 1:2:4 and 1:3:6 mix ratio)
n = The number of observations of the variable x_i

$$S^2 = \frac{1}{n}\sum_{i=1}^{n} (x_i - \bar{x})^2 \tag{4}$$

Where:

S^2 = The sample variance which measure dispersion around the sample mean
$\bar{x}$ = The sample mean
x_i = Variables (experimental compressive strength results)
n = The number of observations of the variable x_{ii}

$$S = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{5}$$

Where:

S = The standard deviation
$\bar{x}$ = The sample mean
x = The variables (experimental compressive strength results)
n = The number of observations of the variable x

$$V = \frac{S}{\bar{x}} \tag{6}$$

Where:

S = The standard deviation and
$\bar{x}$ = The sample mean which is central measure
V = The coefficient of variation

$$\eta = \frac{1}{n}\frac{\sum_{i=1}^{n}(x_i - \bar{x})^3}{S^3} \tag{7}$$

Where:

η = The sample coefficient of skewness
S^3 = The sample variance which measure dispersion around the sample mean
$\bar{x}$ = The sample mean
x_i = The variables (experimental compressive strength results)
η = The number of observations of the variable x_i

$$S_{xy} = \frac{1}{n}\sum_{i=1}^{n} (x_i - \bar{x})\times(x - \bar{x}) \tag{8}$$

where, S_{xy} is the sample covariance:

$$\rho = \frac{\sum xy}{\sqrt{\sum x^2 \sum y^2}} \tag{9}$$

Where:

ρ = The sample correlation coefficient
x and y = The variables (experimental compressive strength results of 1:2:4 and 1:3:6 mix ratio)

$$P_f = 1 - \Phi(\beta) \tag{10}$$

Where:

P_f = The probability of failure
$\Phi(\cdot)$ = The cumulative probability distribution factor of the standard normal distribution
β = The reliability index

$$\beta = \frac{\mu_R - \mu_s}{\sqrt{\sigma_R^2 + \sigma_S^2}} \tag{11}$$

Where:

μ_R and μ_C = The means
σ_R and σ_S = The standard deviation of the load and resistance variables
ϕ = The cumulative density function of the standard normal distribution

RESULTS AND DISCUSSION

Aggregate grading: The particle size distribution curves of sand, gravel and granite were determined. The coefficient of uniformity (C_u) of 2.29 for sand, 2.95 for

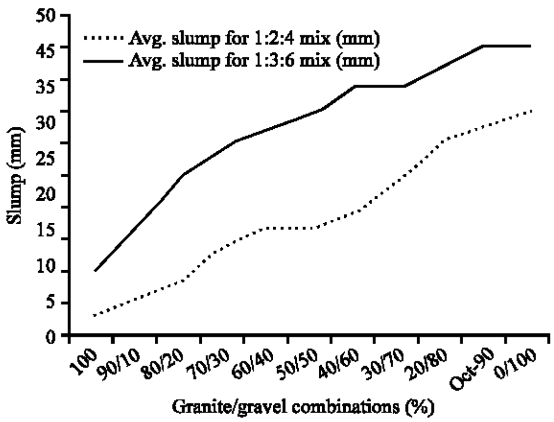

Fig 1: Slump values for various percentage replacements

gravel and 4.08 for granite were determined and they conform to the spread of particle sizes according to (Bowles, 1992). Since, the values of coefficients of uniformity fall between 1 and 5, it can be concluded that the fine and coarse aggregates were well graded and are therefore, suitable for making good concrete.

Slump results: The slump test results given in Fig. 1 indicated that the workability increases with decrease in granite content a constant water/cement ratio. This informed higher workability values for concrete mix 1:3:6 over 1:2:4. The slump greatly increased as the gravel content increased. This indicated that the concrete would become more workable as the gravel content increased.

Compressive strength results: From Fig. 2, 60 up to 100 percentages of granite gave values ranging between 21.15-25 N/mm^2 for mix ratio 1:2:4 and from Fig. 3, 70 up to 100% of granite gave values ranging between 15.17-16.69 N/mm^2 for 1:3:6 mix ratio at 28 days. These values met the minimum requirement of 20 N/mm^2 and 15 N/mm^2 for 1:2:4 and 1:3:6 mix ratio, respectively specified by the British standards also in with Bamigboye findings. Having confirmed the impact of granite/gravel substitution on the compressive strengths of concrete, efforts were made to assess its strength and economic reliability. Cement and fine aggregates remain constant while coarse aggregates (granite/gravel) were varied in different percentages.

Split tensile results: The summary results of the mean splitting tensile strength for concrete cylinders made with granite/gravel combinations are given in Fig. 4 and 5, it was observed that gravel incorporation at various percentages decreases the splitting tensile strength with respect to control (Shetty, 2001). Figure 4 showed that there was a significant reduction in tensile strength as gravel percentage increases beyond 40% for 1:3:6 mix ratio

Table 1: Compressive and split tensile strength for 1:3:6 concrete mix at 28 days from experimental investigation

Granite content (%)	Split tensile (N/mm^2)	Compressive strength (N/mm^2)
100	6.25	18.64
90	5.77	15.38
80	5.20	15.20
70	4.70	15.17
60	4.25	14.10
50	3.80	13.64
40	3.57	13.18
30	3.37	12.68
20	3.11	11.80
10	3.01	11.20
0	3.00	10.90

Table 2: Best fit lines for 1:3:6 concrete mix

Granite content (%)	Split tensile (N/mm^2)	Compressive strength (N/mm^2)
100	5.85	16.42
90	5.52	15.86
80	5.19	15.30
70	4.85	14.74
60	4.52	14.18
50	4.18	13.63
40	3.84	13.07
30	3.51	12.52
20	3.17	11.95
10	2.84	11.39

at 28 days. The results confirm that the higher the percentage of gravel the lower the tensile strength. Similar trends were observed for 1:2:4 mix ratio at 28 days as indicated in Fig. 5.

The findings from the experimental investigation agreed with Shetty (2001) that recommended minimum tensile strength of 10 N/mm^2 for 1:2:4 mix proportions at 28 days and 4 N/mm^2 for 1:3:6 mix proportion at 28 days. This is also in line with 9.26 N/mm^2 at 28 days for 1:2:4 mix proportion and 4.41 N/mm^2 at 28 days for 1:3:6 mix proportion produced from 100% granite by (Raheem and Abimbola, 2006). This present study produced 11.44 N/mm^2 at 28 days for 1:2:4 and 6.25 N/mm^2 at 28 days for 100% granite 1:3:6 mix proportion. From these findings, it was observed that 60 of granite for 1:2:4 mix ratio is in line with the submission by Raheem and Abimbola (2006) minimum splitting tensile strength of 100% granite. Since, tensile strength of concrete is one of the parameters that control the rate of reinforcement corrosion on increase in its value from 60 up to 100% granite indicates the potential for an increase in the useful service life of the concrete. This is in line with the findings by Almusallam *et al*. (2004) that improvement in splitting tensile strength results in an increase in the useful service life of concrete by decreasing cracking due to reinforcement corrosion.

Analytical study of variation of concrete strength with curing age: The results of linear regression analysis in Table 1 and 2 were obtained using Eq. 1 with reference to Table 3 and 4 serves as experimental value at 28 days

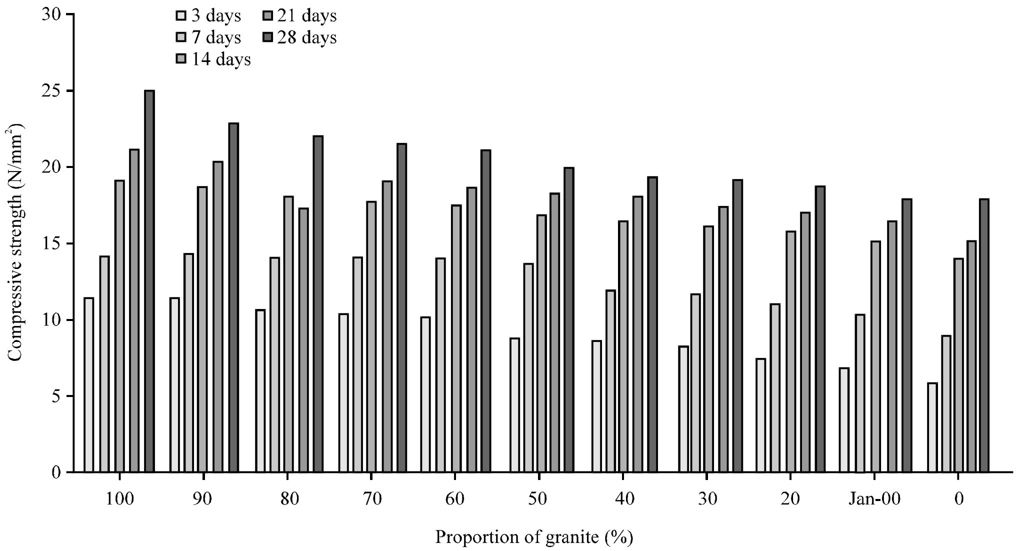

Fig. 2: Compressive strength of concrete produced from 1:2:4 mix ratio for varying granite proportion

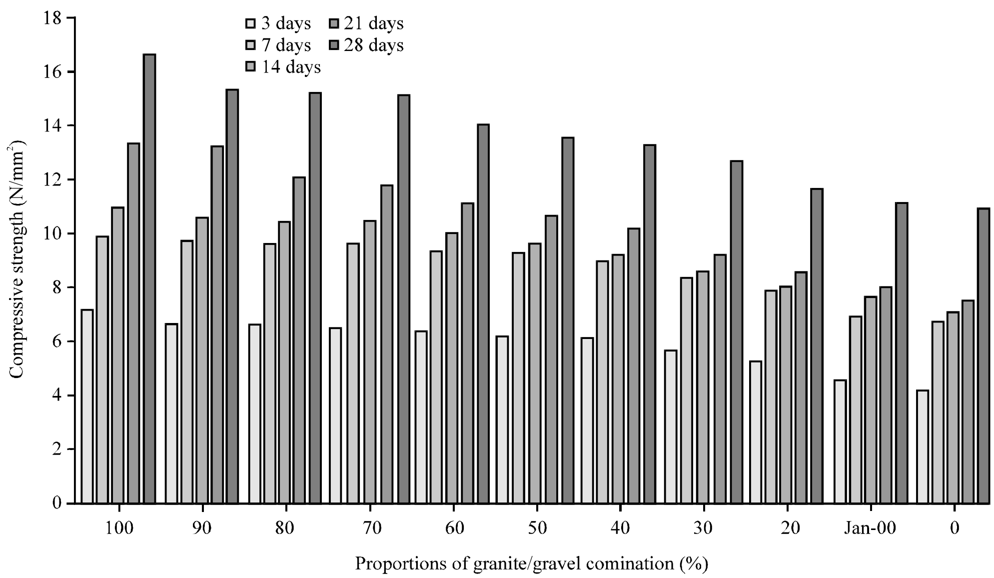

Fig. 3: Compressive strength of concrete produced from 1:3:6 mix ratio for varying granite proportion

Table 3: Compressive and tensile strengths for 1:2:4 concrete mix at 28 days

Granite content (%)	Split tensile (N/mm^2)	Compressive strength (N/mm^2)
100	11.44	24.96
90	10.98	22.90
80	10.62	22.26
70	10.50	21.60
60	10.36	21.15
50	9.900	19.95
40	9.260	19.54
30	8.730	19.22
20	8.380	18.85
10	8.010	18.10
0	7.980	17.63

Table 4: Best fit lines for 1:2:4 concrete mix

Granite content (%)	Split tensile (N/mm^2)	Compressive strength (N/mm^2)
100	11.49	23.85
90	11.12	23.19
80	10.76	22.54
70	10.39	21.88
60	10.02	21.22
50	9.62	20.56
40	9.28	19.90
30	8.92	19.24
20	8.55	18.59
10	8.17	17.92
0	7.89	17.27

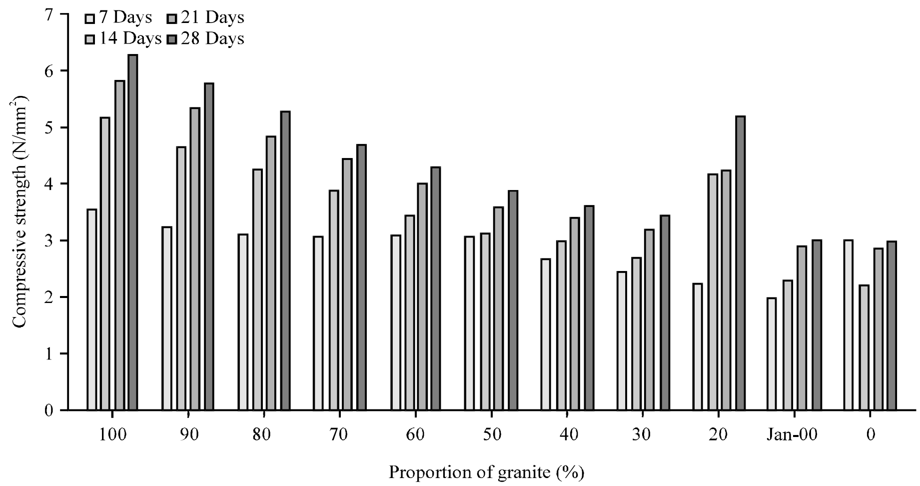

Fig. 4: Split tensile strength of concrete from 1:3:6 mix ratio for varying granite proportions

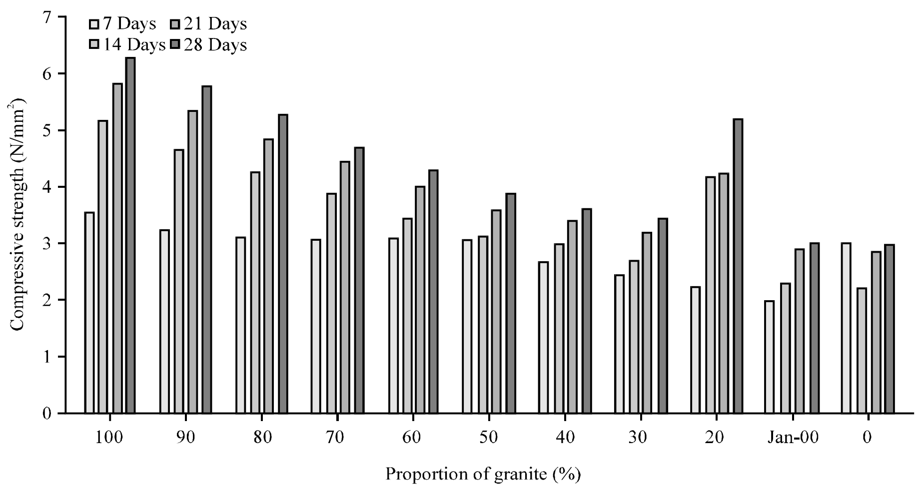

Fig. 5: Split tensile strength of concrete from 1:2:4 mix ratio for varying granite proportions

showing the relationship between the compressive and splitting tensile strengths and percentage granite content in the coarse aggregate. Figure 6 shows a linear relationship for both the compressive and splitting tensile strengths for 1:3:6 mix proportion with respect to the granite contents. The positive high values of coefficients of correlation (R^2) of 0.983 and 0.937, respectively for compression and tension behavior are clear evidence of reliability of the linear equation to predict characteristic strengths based on any given coarse aggregate combination presented in Table 3.

Similarly, Fig. 7 presents the relationship between strength (compressive and splitting tensile) as a function of percentage granite contents in the coarse aggregates of a 1:2:4 concrete mix proportion. The relationships clearly show a linear relationship between strength and granite or gravel content for compressive strength and splitting

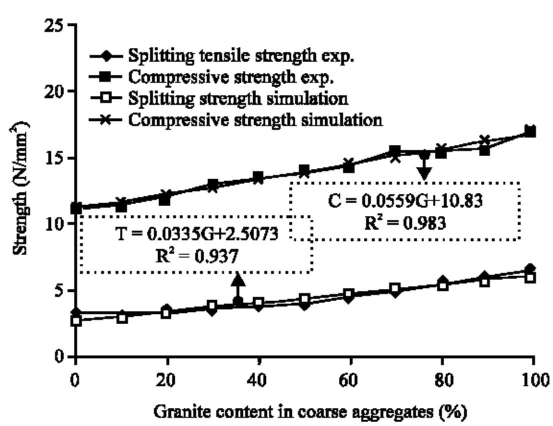

Fig. 6: Plots of splitting tensile and compressive strengths against granite content in coarse aggregates for 1:3:6 concrete mixes

Table 5: Reliability index, failure probability and correlation coefficient between compressive strength 1:2:4 and 1:3:6 mix ratios of granite/gravel combination as coarse aggregate at 28 days

Granite/ gravel (%)	1:2:4 (Nmm^2) (x)	1:3:6 (Nmm^2) (y)	$x-\bar{x}$ (x_i)	$y-\bar{y}$ (y_i)	x_i^2	y_i^2	x_iy_i	xy	x^2	y^2	x_i^3	x_i^4
100/0	24.96	16.64	4.37	3.01	19.09	9.060	13.150	415.33	623.00	276.89	83.45	364.69
90/10	22.90	15.38	2.31	1.75	5.34	3.060	4.040	352.20	524.41	236.54	12.33	28.47
80/20	22.26	15.20	1.67	1.57	2.79	2.460	2.620	338.35	495.51	231.04	4.66	7.78
70/30	21.60	15.17	1.01	1.54	1.02	2.370	1.560	327.67	466.56	230.13	1.03	1.04
60/40	21.15	14.10	0.59	0.47	0.35	0.220	0.280	298.22	447.32	198.51	0.21	0.12
50/50	19.95	13.64	-0.64	0.01	0.41	0.001	-0.001	272.12	398.00	186.05	-0.26	0.17
40/60	19.95	13.18	-0.64	-0.45	0.41	0.200	0.290	262.94	398.00	173.71	-0.26	0.17
30/70	19.22	12.68	-1.37	-0.95	1.88	0.900	1.300	243.71	369.41	160.78	-2.57	3.52
20/80	18.85	11.80	-1.74	-1.83	3.03	3.350	3.180	222.43	355.32	139.24	-5.27	9.17
10/90	18.10	11.20	-2.49	-2.43	6.20	5.900	6.050	202.72	327.61	125.44	-15.44	38.04
0/100	17.63	10.90	-2.96	-2.73	6.20	7.450	8.080	192.17	310.82	118.81	-25.93	76.77
Total	226.57	149.89	0.11	-0.04	46.72	34.970	40.540	3127.86	4715.96	2077.44	57.22	530.34

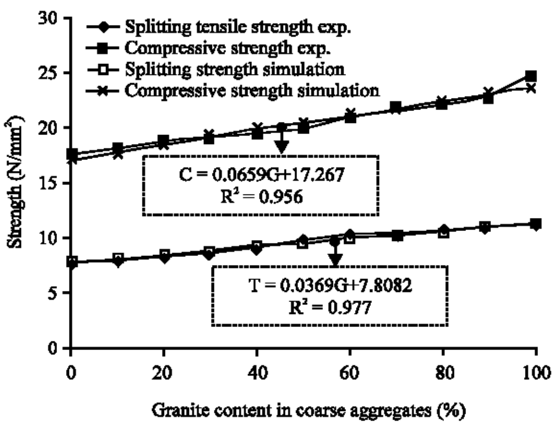

Fig. 7: Plots of splitting tensile and compressive strengths against granite content in coarse aggregates for 1:2:4 concrete mix

tensile strength as presented in Table 4 with corresponding correlation coefficients (R^2) of 0.956 and 0.977. These show a good sense of reliability in the mathematical expression of their linear behaviors.

Reliability analysis results: The reliability of structure was determined using the results obtained from Table 5 from the following equations; using Eq. 3 the sample mean determined were 20.59 N/mm^2 for 1:2:4 mix ratio and 13.63 N/mm^2 for 1:3:6, respectively. The concrete cubes compressive strength mode is 19.95 N/mm^2 from Eq. 4 and 5 variance and standard deviation was gotten to be 4.24 N/mm^2 and 2.06, respectively. As a means of comparison between dispersion of different data sets the dimensionless sample coefficient of variation is convenient, referring to Eq. 6 the concrete compressive strength sample coefficient of variation was determined to be 0.10 for 1:2:4 mix ratio. The coefficient of skewness which was used to determine the degree of symmetry of data set which is a simple logical extension of the sample variance was determined using Eq. 7 with the value 0.595. Using Eq. 8, the characteristic indicating the tendency toward high-high pairing and low-low pairing which a measure is of the correlation between the observed data sets the sample covariance was determined to be -4×10^{-4}. Equation 9 gives 0.99 as sample correlation coefficient this was as a results of sample covariance x_i are $>\bar{x}$ and $\bar{y}$ and these make most of the sum and sample covariance to be positive. This shows that the pairs are perfectly correlated. Equation 11 gives 0.1298 as reliability index while Eq. 10 was used to estimate the failure probability with sufficient accuracy of 0.44836 the positive value indicated that the structure component is safe using gravel and granite combination in concrete production. Comparing the result of the probability of failure obtained with the ISO 2394:1998 (E) standard it was found that $g(\underline{x})>0$ limit state is satisfied which indicated that the structure is safe.

CONCLUSION

From the findings in this study the following conclusions were arrived at: increase in the percentage of gravel content increases the workability of concrete. As the proportion of gravel increases, the compressive strength of concrete produced from the combination of granite and gravel as coarse aggregates decreases. The ratios of granite content that satisfied the British standard requirements at 28 days compressive strength for 1:2:4 and 1:3:6 mix ratios are 60 and 70 up to 100%, respectively. The split tensile strength of concrete produced from the combination of granite and gravel as coarse aggregates decreases as the proportion of gravel increases. The reliable percentages of granite/gravel combination satisfying the minimum strength requirement at 28 days for 1:2:4 and 1:3:6 mix ratios are 60 up to 100% for both mixes. The linear relationship between strength and granite or gravel content for compressive strength and splitting tensile strength with corresponding correlation coefficients (R^2) of 0.956 and 0.977. Show a good sense of reliability in the mathematical expression of their linear behaviors. The compressive strength of concrete made of 40% gravel as partial replacement of coarse aggregates is reliable for structural application for reinforced concrete.

The structural strength properties of the reinforced concrete are in good conformity to the specification following international standard BS 882 (1992); BS 1881 (1990); BS 812 (1990) and EN 206 (2000). The reliability index of the reinforced granite and gravel combination concrete is highly sensitive to bending forces; hence these forces should be investigated to establish the degree of reliability.

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