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REGRESSION MODELS FOR PREDICTION OF COMPRESSIVE AND TENSILE CONCRETE STRENGTH

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ABSTRACT

Prediction of concrete strength helps to fast-track completion time of construction job and reduces waste of materials. This study was undertaken to determine linear regression models for the prediction of compressive and tensile strengths of concrete. Laboratory experimental methods were used to carry out the tests. Five concrete grades 20, 25, 30, 35, and 40 were adopted for the tests. Five model equations were developed using compressive and tensile strength results at 28-day with the aid of MATLAB Software. The specific gravity of river sand, granite, and river gravel were found to be 2.60, 2.61, and 2.72 respectively. The grading of the aggregates shows that, coefficient of uniformity (Cu) of river gravel and granite are 1.9 and 1.64 respectively. The slump for granite concrete varies from 50 to 59 mm and that of river gravel varies from 51 to 59 mm. Compressive strength of granite concrete are between 20.1 and 40.7 N/mm^2. The compressive strength of the river gravel concrete is between 19.3 and 38.8 N/mm^2. Compressive strength of the granite-admixture concrete is between 20.26 and 41.12 N/mm^2. The maximum compressive strengths of 40.2, 38.8, and 41.1N/mm^2 at 28-day of curing, was observed for granite-concrete, river-gravel, and granite-admixture grade 40 respectively. The tensile strength at 28-day for granite concrete is between 1.55 and 3.74 N/mm^2 while river-gravel concrete strength values are between 1.20 and 3.41 N/mm^2. The results revealed that, the tensile strength of concrete cylinders produced with granite are higher than the ones made with river gravel. The developed models can predict compressive and tensile strength of concrete with high degree of accuracy. The models were validated with concrete produced using randomly selected mix ratios. Statistical t-test shows that there is no significant difference between the observed and predicted strengths. It is recommended that the models could be used for prediction of concrete compressive and tensile strengths.

Keywords: *Linear Regression, Models, Prediction, Concrete Strength*

INTRODUCTION

Concrete is an extensively used construction material in the world, second to water as the most utilised substance on earth (Alhaji, 2016: Gupta et al., 2021). It is a composite material consisting cement, sand, aggregates, and water. Sometimes, chemical additives are added to raw ingredients or fresh concrete to enhance its specific properties (Building Research Establishment, 2010). It is widely used in construction due to its high compressive strength, availability, and economic viability (Skrzypczak and Slowk, 2019). However, concrete samples cured for the prescribed 28-day often exhibit variations in strength both within and between batches (American Concrete Institute, 2011). To account for these variations, modern concrete mix designs aim for a strength higher than the specified minimum characteristic strength (American Concrete Institute, 2019).
In construction industry, strength is a primary criterion in selecting concrete for a particular application. The concrete used for construction gains strength over a long period of time after casting the concrete. The characteristic strength of concrete is defined as the compressive strength of a sample that has been cured for 28 days. Neither waiting for such duration for such a test would serve the rapidity of construction, nor neglecting it would serve the quality control process on concrete in large construction sites (Daregholi and Hosseinzadeh**,** 2021).

According to Hamid-zadeh (2006), quality control of concrete involves monitoring the properties of its constituents, conducting tests on fresh concrete, and assessing its hardened state through compressive, tensile, and bending strength tests. Control tests are crucial prior to mass production of concrete, to ensure quality and efficiency. Timely availability of test results is essential to prevent material wastage, reduce production costs, and optimize labour utilization. It can also contribute to the timely completion and delivery of projects (Obam et al., 2023).

Concrete mix design involves selecting and proportioning the concrete ingredients to achieve the desired strength, durability, and workability in a cost-effective manner (Abdelkader et al., 2020). It is a complex task due to the varying properties of the constituent materials, site exposure conditions, and specific project requirements (Shetty and Jain, 2019). According to the British Standards Institution (2019), the proportions of concrete mixes should ensure the intended performance in both the fresh and hardened states with an appropriate safety margin. Therefore, successful mix design requires knowledge of the properties of the constituent materials, concreting experience, and site conditions (Shetty and Jain, 2019).

Various codes of practice, such as Building Research Establishment (2010), American Concrete Institute (2011), and Bureau of Indian Standards (2019), acknowledge that the strength of concrete typically follows a normal distribution pattern. Concrete mix designers target the mean strength, ensuring that no more than 5% of test results fall below the desired characteristic strength. Achieving the specified characteristic strength is crucial, but predicting the mean strength of concrete mixes is also important for reliable mix designs. The Bureau of Indian Standards (2019) suggests using consecutive strength test results of at least thirty samples to establish the appropriate mean strength for a concrete class. However, conducting such a large number of destructive tests for every new mix can be time-consuming and economically impractical. Various countries have developed their own models to simplify concrete mix design, tailored to local materials and conditions (Demissew, 2022). The use of regression models in concrete mix design has proven to be successful, reliable, accurate and scientific (Wilson et al., 2019). The use of soft computing tools in predicting concrete properties has shown promise in reducing material consumption and saving time, as reported by Obam et al. (2023). This research aims to develop linear regression models for the prediction of strength of concrete. The specific objectives are to; determine the grading of river sand, river gravel and crushed granite aggregates. Setting time of cement, specific gravity, and water absorption properties of the aggregates are to be determined, Other objectives are to determine slump, compressive strength, and tensile strength of the concretes, Finally, to develop mathematical models for predicting compressive and tensile strength of concrete

STATEMENT OF THE PROBLEM

Timely completion of project work is important in almost all spheres of life. The waste of materials during construction could lead to financial losses including labour costs. Predicting 28-day strength of concrete could help construction workers to avoid waiting for 28 days before the normal concrete strength could be accessed. The models predict strength values within 4 or 5 hours. Therefore, concrete can be mass-produced soon after with little fear of losing it.

MATERIALS AND METHOD

In this study, materials used for the concrete are:

i. Bua Cement of 43 grade: NIS 444-1: 2018-CEM II/A-L was used. It was obtained at North Bank market Makurdi, Nigeria.
ii. Aggregate used includes river sand, river gravel, obtained from River Benue Makurdi, Nigeria and granite. Granite was obtained from Makurdi. They were prepared to conform with BS 8110 (1997) recommendations for structural concrete. The granite has maximum size of 20 mm.
iii. The water used for the concrete was pipe-borne water obtained at the Civil Engineering Laboratory, Joseph Sarwuan Tarka University Makurdi, Nigeria.
iv. The water-reducing admixture (ADM) used was a powder-based modified polycarboxilic ether (Dr. Fixit Powder). The ADM conformed to Types A and F Admixtures of BS EN 934-2:2001.

Grading of the aggregates:

Grading tests were performed on the river sand and gravel as described in BS EN 933-1 (1997) and BS 812-103 (1990).

Water absorption test:

The water absorption tests of the aggregates were carried out according to the method described in BS EN 1097-6 (2013). The water absorption of the aggregate was calculated using equation (1).

$$\text{Water Absorption} = \frac{(\text{Weight of Oven}-\text{Dry Sample} - \text{Weight of SSD Sample})}{\text{Weight of SSD Sample}} \times 100 \qquad (1)$$

Specific gravity test:

The specific gravity test was carried out on the aggregates as described in BS EN 1097-6 (2013). The specific gravity was calculated using equation 2.

$$Gs = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \qquad (2)$$

Gs = specific gravity
M_1 = weight of empty flask (g)
M_2 = weight of empty flask + weight of the sample (g)
M_3= weight of empty flask + weight of the sample + water (g)
M_4 = weight of empty flask + water (g)

Preparation of the concrete:

Concrete of grades 20, 25, 30, 35, and 40 were adopted for the study. Concrete mixing was done manually. Concrete was cast in 150 mm cubes and 150 x 300 mm cylinders. Fifteen concrete cubes were produced for each grade and cured for 28 days. The same number was produced for the concrete with the admixture. A dosage of 1% by weight of cement of the admixture was added. Fifteen concrete cubes and cylinders were produced for each mix ratio for granite, river gravel, and granite-admixture concretes. Five arbitrary mix ratios 1:2:3.5, 1:2:3, 1:1.8:3, 1:1.5:2.5, and 1:1.5:2 were chosen for the design of concrete to verify the adequacy of the models.

Workability test:
The workability of the concrete was determined through slump test. Slump test was conducted in accordance with the provision of BS EN 12350: Part 2 (2000).

Compression test:
The compression test was conducted as specified in BS EN 12390-3 (2009). The compressive strength is given by equation 3.

$$\text{Compresive Strength } (\sigma \text{ in N/mm}^2) = \frac{\text{crushing load of cube (N)}}{\text{Area of cubes (mm}^2)} \quad (3)$$

Splitting tensile strength test:
Concrete cylinder specimens with dimensions 150 x 300 mm were used in the determination of the splitting tensile strength of the concrete samples. The splitting tensile strength test was conducted as described in BS 12390: Part 6 (2009). Tensile strength is given in equation 4.

$$Ts = \frac{2P}{\pi l d} \quad (4)$$

Where
Ts is the splitting tensile strength (N/mm^2),
P is the maximum applied load (in Newtons) by the testing machine,
l is the length of the specimen (mm), and
d is the diameter of the specimen (mm).

Model equations:
The general linear regression equations, for 4-component and 5-component independent variables are shown inequations 5 and 6 respectively (Murray and Larry, 2011).

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 \qquad (5)$$

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5 \qquad (6)$$

Y = Compressive strength or tensile strength of concrete at 28-day
X_1 = proportion of cement in the mix
a_i (i=0-4 and i=5) = constants of regression equation and they depend on concrete ingredients.

X_2 = proportion of fine aggregate in the mix
X_3 = proportion of coarse aggregate in the mix
X_4 = proportion of water/cement ratio
X_5 = proportion of water reducing admixture
Five model equations were developed; two model equations each for compressive strength and tensile strength, at 28-day, using equation (5). Equation (6) was used to develop a model with water reducing admixture-granite concrete for compressive strength, at 28-day. MATLAB Software was used to find the constant a_0 and coefficients a_i (i=1-5) of equations 5 and 6.

Results and Discussion

Sieve Analysis:

The results of grading (sieve analysis) of fine and river gravels used are shown in Figures 1 and 2. The river sand distribution curve falls within the overall limits for fine aggregates from natural sources for concrete as specified in BS 882 (1992). The granite aggregate is within the range prescribed for single-sized coarse aggregate of 20mm, according to BS 882 (1992). It is observed that coefficient of uniformity (Cu) and coefficient of curvature (Cc) of the river sand are 2.25 and 1.0 respectively. The coefficient of uniformity (Cu) and coefficient of curvature (Cc) of the river gravel are 1.9 and 1.0. These values agree with the results of Nwogu (2022). The soil particles with coefficient of curvature between 1 and 3 are said to be well-graded. The soil is poorly graded when it is less than 1 and uniformly graded at 1. The soil is uniformly graded when Cu is less than 4. All the aggregates used have Cc approximately 1and Cu less than 4. The aggregates are therefore, uniformly graded and suitable for making quality concrete.

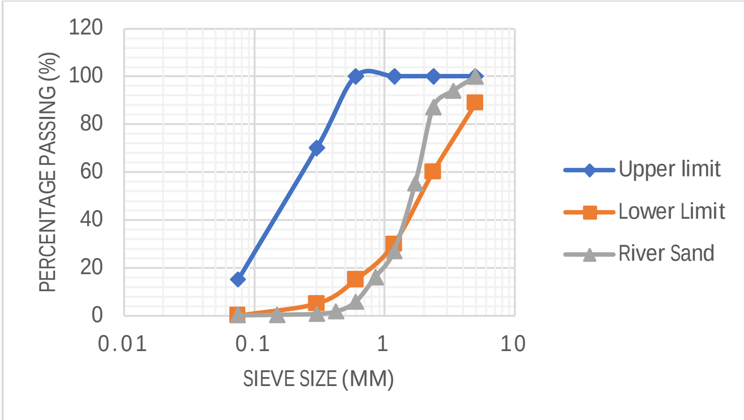

Figure 1: Grading curve for the river Sand

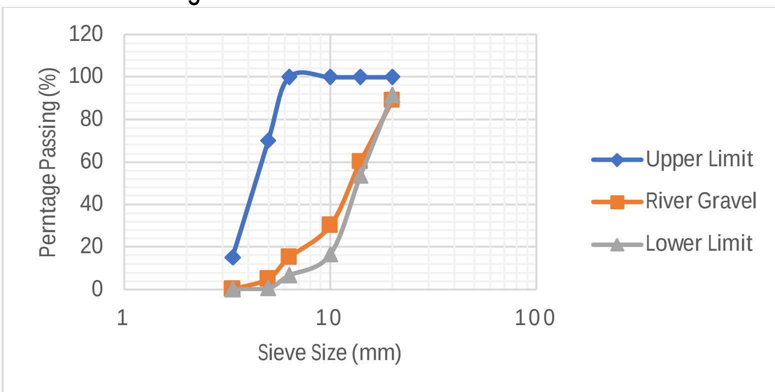

Figure 2: Grading curve for the River Gravel

Specific Gravity:

The specific gravity for river sand, granite and river sand are 2.60, 2.61 and 2.59 respectively as shown in Table 1. The specific gravity values obtained in this study are similar to the values obtained by Obam, et al, (2023). The results of this study fall within the 2.6-2.7 and 2.6-3.0 range for sand and granite (Neville,1997). The values also fall within the specifications of ASTM C33 (2003).

Table 1: Results of Specific Gravity of the Aggregates

Aggregate Type	Specific Gravity
River sand	2.60
River Gravel	2.61
Granite	2.72

Water Absorption of the Aggregates:

Table 2 shows the results of water absorption test of the aggregates. water absorption for river gravel, granite, and river sand are 1.06, 1.44, and 1.24 % respectively. Concrete quality is controlled by amount of water absorption by the aggregates (Gideon et al. 2019). The water absorption values obtained for all the samples are below 2% as recommended by ASTM C33 (2003). Neville (2011), reported that in concrete mix proportioning, additional water and cement will be needed by aggregates with considerable absorption to make workable fresh concrete and to meet the water-cement ratio requirement.

Table 2: Results of water absorption test of the Aggregates

Aggregate Type	Water Absorption (%)
River sand	1.06
River Gravel	1.24
Granite	1.44

Slump Values:

Figure 3 shows the results of slump test for concrete made with river gravel, granite and granite- admixture. The slump values for granite concrete varies from 50 to 59 mm. River gravel-concrete slump varies from 51 to 59 mm and the values for granite-admixture concrete are between 65 and 74 mm. The slump values indicated medium workability Neville (2011) and workability Class S1, according to BS EN 206 (2013). Sumadi and Lee (2008), reported that water reducing agent is to enhance workability of concrete and reduce the amount of water used. Besides, the voids ratio also can be reduced in order to increase the strength and decrease the porosity of concrete.

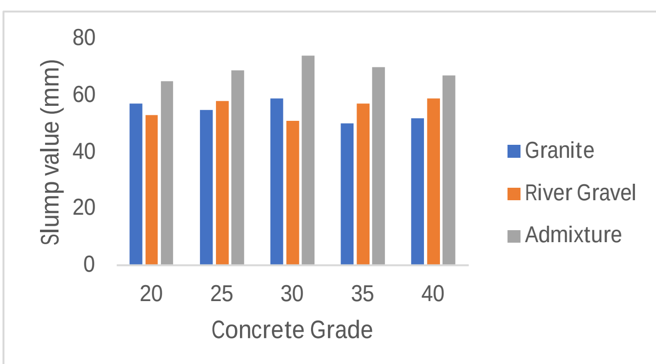

Figure 3: Slump Values vs grades of the Concrete

Compressive Strength Test:

Figures 4 shows the results of average compressive strength of the concretes at 28-day, for river gravel concrete, granite concrete, and granite-admixture concrete. The compressive strength of river gravel concrete at 28-day varies from 18.2 to 38.3 N/mm^2, while that of granite concrete are between 20.1 to 40.7 N/mm^2. The values for granite-admixture concrete varies from 20.3 to 41.1 N/mm^2. These results agree with the findings of Ignatius, et al. (2021), who reported that the compressive strength of concrete produced with granite were higher when compared with river gravel concrete. The results of concrete produced with water reducing agent are higher when compare with concrete produced from river gravel and granite. However, Sumadi and Lee (2008), reported that water-reducing agent reduced void ratio in order to increase the concrete strength and decrease the porosity of the concrete. The results obtained conform to the findings of Yunusa (2011). BS 8810 (1985), states that the minimum compressive strength required for concrete to be used for structural purpose at 28-day should be between 20 to 40 N/mm^2.

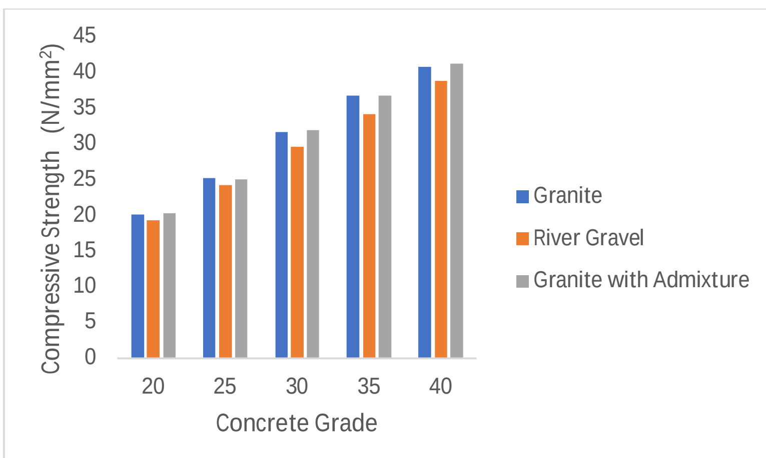

Figure 4: Compressive Strength Values vs Grades of the Concrete

Split tensile strength test results:

Figure 5 presents the results of split tensile strength at 28-day, for river gravel and granite concretes. The values are between 1.6 to 3.7 and 1.2 to 3.4 N/mm^2 for river gravel concrete and granite concrete respectively. The higher tensile values for the latter could be attributed to rough surfaces of the granite, providing better interlocking bond in the matrix. These results are in line with Christopher, et al. (2020), who obtained a split tensile strength between 0.55 to 3.23 N/mm^2.

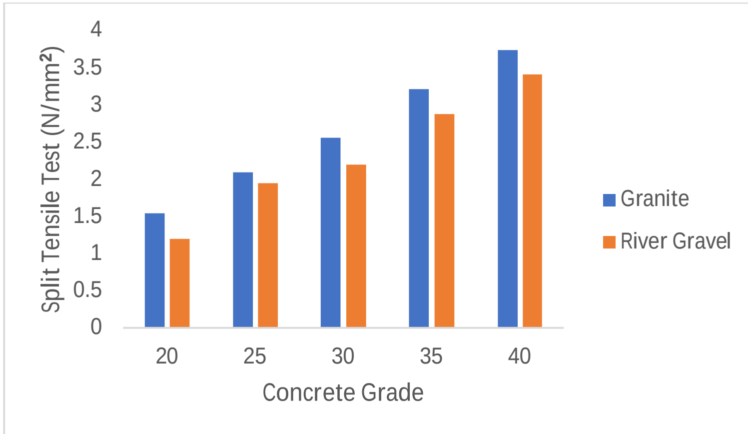

Figure 5: Tensile Strength Values vs grades of the Concrete

The model Equations:
Values of the constants in the regression equations (equations 5 and 6) are shown in Table 3. The five linear regression equation models are shown in equations 8 to 12.

Compressive strength model equation for granite concrete is
$$Y = 8.515 + 111.647X_1 + 0.009X_2 - 0.089X_3 - 0.199X_4 \quad (8)$$
Compressive strength model equation for river gravel concrete is
$$Y = 8.245 + 104.727X_1 - 0.004X_2 - 0.081X_3 + 0.283X_4 \quad (9)$$
Compressive strength model equation for granite-admixture concrete
$$Y = 8.317 - 9.540X_1 - 0.017X_2 + 0.139X_3 + 198.192X_4 + 0.183X_5 \quad (10)$$
Model equation for split tensile strength for granite concrete is
$$Y = 0.303 - 2.744X_1 + 0.059X_2 - 0.122X_3 + 20.407X_4 \quad (11)$$
Model equation for split tensile strength for river gravel concrete is
$$Y = 0.066 - 3.534X_1 + 0.058X_2 - 0.060X_3 + 19.807X_4 \quad (12)$$

Y = Strength of concrete at 28-day
X_1 = proportion of cement in the mix
X_2 = proportion of fine aggregate in the mix
X_3 = proportion of coarse aggregate in the mix
X_4 = proportion of water-cement
X_5 = proportion of water reducing admixture

Equations 8 to 12 were used to predict both the compressive and tensile strengths. Figures 6 and 7 show the relationship between the predicted and observed values of strength. The coefficient of determination R^2 specifies how accurate a model could predict strength. The value of adjusted R^2 is often used instead of R^2(Murray and Larry, 2011). The granite concrete model achieved a coefficient of determination (R^2) of 0.886 with an adjusted R^2 value of 0.884. This implies that the developed model can predict 28-day compressive strength with an accuracy of 88.4%. Here, Cement is the only component with a p-value less than the 5% (0.000) significance level, in the analysis of compressive strength. This indicates its importance in concrete strength development. Similarly, the river-gravel concrete and granite-admixture concrete models can predict compressive strength up to 91.1 and 90.0 % accuracy respectively. These findings are similar to those of Kolo and Enwongulu, (2022), with adjusted R^2 value of 95.2 %, for their model.

The granite concrete model for tensile strength has adjusted R^2 value of 0.903. This implies that the developed model can predict 28-day tensile strength with an accuracy of 93.2%. The p-values for cement and water are less 5%, significance level. The river-gravel concrete model for tensile strength could predict strength to 92.7 % accuracy.

The observed strength varies from 20.1 to 41.1 N/mm^2 and 1.2 to 3.7 N/mm^2, for the compressive and tensile strengths respectively. while the predicted tensile strength varies from 1.0 to 3.1 N/mm^2. The average percentage difference between the observed and predicted strengths are 6.5 and 7.3 for compressive and tensile strengths respectively (Appendix I). The statistical t-test shows that there is no significant difference between the observed and the predicted values of strength (Appendix II).

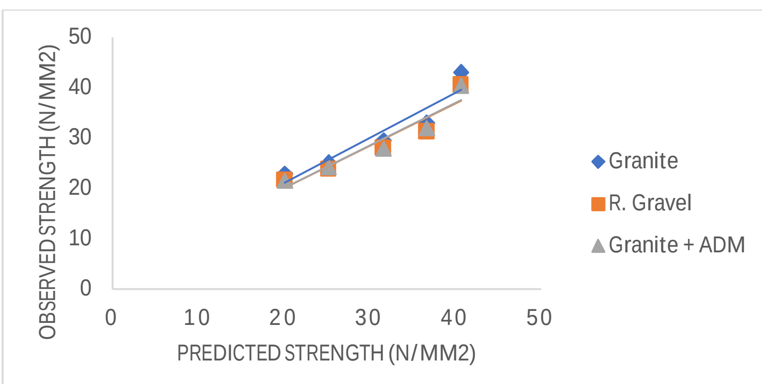

Figure 6. Observed vs Predicted Compressive Strength Values of the Concrete

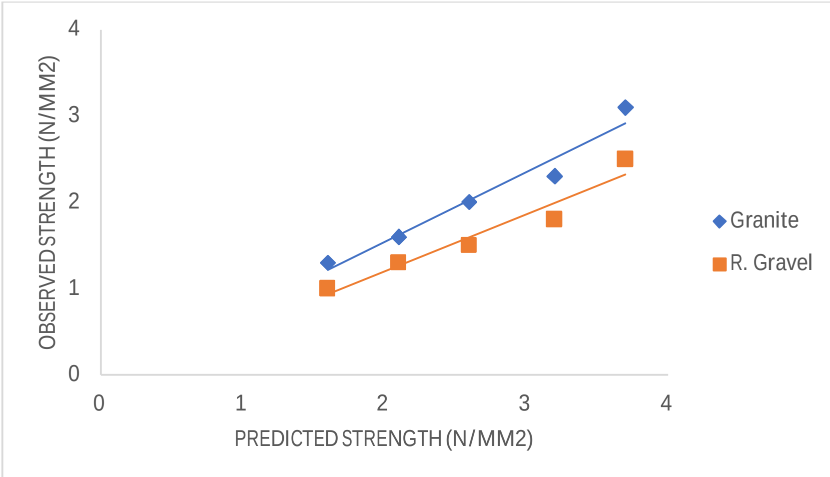

Figure 7. Observed vs Predicted Tensile Strength Values of the Concrete

Table 3: Values of model constants (as obtained from Matlab Software Analysis)

Coefficient (Symbol)	Values	p-value
Compressive Strength Model with Granite Concrete:		
Constant (a_0)	8.515	0.000
Cement (a_1)	111.647	0.000
Sand (a_2)	0.009	0.815
Gravel (a_3)	-0.089	0.713
Water (a_4)	0.199	0.523
R Square	0.886	-
Adjusted R Square	0.884	-
Compressive Strength Model with River Concrete		
Constant (a_0)	8.245	0.000
Cement (a_1)	104.727	0.000
Sand (a_2)	0.004	0.913
Gravel (a_3)	-0.081	0.698
Water (a_4)	0.283	0.296
R Square	0.914	-
Adjusted R Square	0.913	-
Split Tensile Strength Model with Granite Concrete		
Constant (a_0)	0.303	0.000
Cement (a_1)	-2.744	0.000
Sand (a_2)	0.059	0.054
Gravel (a_3)	-0.122	0.533
Water (a_4)	20.407	0.000
R Square	0.933	-
Adjusted R Square	0.932	-

Table 3. Values of model constants (as obtained from Matlab Software Analysis) Continued

Coefficient (Symbol)	Values	p-value
Split Tensile Strength Model with River Gravel Concrete		
Constant (a_0)	0.066	0.395
Cement (a_1)	-3.534	0.000
Sand (a_2)	0.058	0.066
Gravel (a_3)	-0.060	0.769
Water (a_4)	19.807	0.000
R Square	0.928	-
Adjusted R Square	0.927	-
Compressive Strength Model with Granite and Admixture Concrete		
Constant (a_0)	8.317	0.000
Cement (a_1)	-9.540	0.000
Sand (a_2)	-0.017	0.654
Gravel (a_3)	0.139	0.616
Water (a_4)	198.192	0.000
Admixture (a_5)	0.183	0.000
R Square	0.903	-
Adjusted R Square	0.901	-

CONCLUSION

Both client and contractor stand to lose when projects are delayed. The waste of materials on site might increase these losses. Predicting the 28-day strength of concrete could speed up construction work and reduce waste of materials. This is because concrete tests could no longer wait for the usual 28 days to evaluate its strength. Laboratory test methods were used to determine the 28-day strengths of the concrete. The average compressive strength of granite-concrete varies from 20.1 to 40.7 N/mm^2, and that of river gravel concrete from 19.3 to 38.8 N/mm^2. The values of the concrete regression constants were determined with Matlab Software. The average percentage difference between the observed and predicted strengths are 6.5 and 7.3 for compressive and tensile strengths respectively. The statistical t-test shows that there is no significant difference between the observed and the predicted values of strength.

RECOMMENDATIONS

Based on the findings, we make the following recommendations:

i. The use of water reducing agent admixture is recommended to improved quality of concrete.
ii. The developed models can be used to predict the 28-day strength of concrete produced from the same or similar materials.

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Appendix I: Differences between the Observed and the Predicted Strengths

Concrete Mix Ratio	Compressive Strength (Granite Concrete) (N/mm^2)			
	Observed Strength	**Verified Strength**	**Difference**	**Percentage Difference**
1:2:3.5	26.00	27.80	-1.80	-6.92
1:2:3	27.10	27.81	-0.71	-2.62
1:1.8:3	28.14	28.30	-0.16	-0.57
1:1.5:2.5	33.00	31.10	1.90	5.76
1:1.5:2	36.00	33.18	2.82	7.83
	Compressive Strength (River-Gravel Concrete) **(N/mm^2)**			
1:2:3.5	25.40	26.35	-0.95	-3.74
1:2:3	25.90	26.40	-0.50	-1.93
1:1.8:3	27.00	27.76	-0.76	-2.81
1:1.5:2.5	29.20	29.40	-0.20	-0.68
1:1.5:2	30.80	31.40	-0.60	-1.95
	Compressive Strength (Granite-Admixture Concrete) **(N/mm^2)**			
1:2:3.5	26.70	26.50	0.20	0.75
1:2:3	27.60	26.54	1.06	3.84
1:1.8:3	28.80	27.10	1.70	5.90
1:1.5:2.5	34.20	29.63	4.57	13.36
1:1.5:2	36.00	31.63	4.37	12.14
	Split Tensile Strength (Granite Concrete) **(N/mm^2)**			
1:2:3.5	1.76	1.72	0.04	2.27
1:2:3	1.80	1.83	-0.03	-1.67
1:1.8:3	1.95	1.88	0.07	3.59
1:1.5:2.5	2.10	2.05	0.05	2.38
1:1.5:2	2.40	2.28	0.12	5.00
	Split Tensile Strength (River Gravel Concrete) **(N/mm^2)**			
1:2:3.5	1.40	1.33	0.07	5.00
1:2:3	1.53	1.43	0.10	6.53
1:1.8:3	1.60	1.47	0.13	8.13
1:1.5:2.5	1.73	1.62	0.11	6.36
1:1.5:2	1.97	1.82	0.15	7.61

Appendix II: The T-test Results

A. T-Test for Granite Concrete

T-Test

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Observed	5	30.8420	8.37290	3.74447
predicted	5	30.8200	7.90550	3.53545

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Observed	8.237	4	.001	30.84200	20.4457	41.2383
predicted	8.717	4	.001	30.82000	21.0040	40.6360

B. T-Test for River Gravel Concrete

T-Test

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Observed	5	29.1840	7.73669	3.45995
predicted	5	29.1600	7.42819	3.32199

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Observed	8.435	4	.001	29.18400	19.5776	38.7904
predicted	8.778	4	.001	29.16000	19.9367	38.3833