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Empirical Relationship between Compressive, Flexural and Splitting Tensile Strengths of Concrete Containing Kuta Gravel as Coarse Aggregate

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Flexural and tensile strengths of concrete are of great importance in structural engineering. Understanding the flexural strength of concrete helps designers prevent and control development of cracks in concrete elements, ensuring durability. In addition to serviceability, shear, bond failure

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and flexural capacity in concrete members are directly linked to the tensile strength of the concrete. When compared to flexural and tensile strengths, determination of the compressive strength of concrete is easier to carry out in the field. It is therefore, customary to determine the compressive strength and correlate it to other strength properties. In this study, empirical relationships have been developed to relate the compressive strength to the flexural and splitting tensile strengths of concrete using Kuta river gravel as coarse aggregate. Using varying total aggregate to cement, coarse aggregate to total aggregate and water to cement ratios, 20 mixes were generated using Central Composite Design (CCD) in Minitab 21. The compressive, flexural and splitting tensile strengths of concrete samples from these mixes were determined at 28 days of age. From the strength data obtained, regression equations were developed that relate the strength properties with the aid of regression analysis tool in Microsoft Excel. The empirical models developed to predict the flexural and splitting tensile strengths of concrete from the compressive strength recorded R^2 values of 1 for both models, P-values of 5.23×10^{-29} and 4.47×10^{-30}, and standard errors of 0.21 and 0.06 respectively. Furthermore, residuals from the values of predicted strength properties show that there is very slight deviation between the experimental and predicted values. It was concluded that the empirical equations developed are significant, have high predictive capabilities and can be used in predicting the flexural and splitting tensile strengths of concrete.

Keywords: Empirical relationship; compressive strength; flexural strength; splitting tensile strength; Kuta gravel.

1. INTRODUCTION

Concrete as a conventional construction material is designed majorly to resist compressive stresses. For this reason, the compressive strength of concrete can be regarded as the most important property of concrete (Ajagbe et al., 2018). Compressive strength is a property that measures the capability of a concrete mix and so, constituent concrete materials are mostly proportioned in terms of compressive strength (Akorli et al., 2021).

Flexural and tensile strengths of concrete are also of great importance in structural engineering. To ensure durability of structures, understanding the flexural strength of concrete helps designers prevent and control development of cracks in concrete elements (Elinwa & Kabir, 2019). Cracking of concrete elements in service is an indication of tensile failure. Apart from the role of tensile strength in serviceability, shear, bond failure and flexural capacity in concrete members are directly linked to the tensile strength of the concrete (Slowik & Akram, 2021).

In the field, determination of the compressive strength of concrete is easier and more convenient when compared to other concrete properties. It is, therefore, traditional to measure the compressive strength and correlate it to other mechanical concrete properties (Shetty, 2005; Marin-Uribe & Navarro-Gaete, 2021).

Evidences suggest close relationships between compressive and tensile (flexural and direct tension) strengths of concrete. Nonetheless, the relationship between these strength properties is not directly proportional (Shetty, 2005; Neville & Brooks, 2010; Li, 2011). For low strength concrete, the tensile/compressive strength ratio runs between 10 to 11%, 8 to 9% for medium strength concrete, and 5 to 7% for high strength concrete (Li, 2011). It follows therefore, that higher grades of concrete are associated with lower tensile/compressive strength ratios and vice versa. Several factors affect the relationship between tensile and compressive strength of concrete. Some of these factors include the water/cement ratio, aggregate type and use of admixtures (Li, 2011).

This study is aimed at establishing empirical relationships between compressive and flexural strength, and compressive and splitting tensile strength of concrete using Kuta river gravel as coarse aggregate. Kuta river gravel is a natural deposit of aggregate obtained from the Kuta area of Niger State, Nigeria. The use of this aggregate in producing concrete has gained popularity among the locals. There is however, limited data on the characteristics of this aggregate and the properties of concrete produced from it.

2. LITERATURE REVIEW

Several studies have been carried out that have developed empirical relationships that relate the compressive strength and other properties of concrete. According to Neville and Brooks (Neville & Brooks, 2010), majority of these empirical equations that relates tensile and compressive strength are in the form presented in Equation 1.

$$f_t = kf_c^n \quad (1)$$

The value of the coefficient, k varies from 6.2 for gravels to 10.4 for crushed rocks while n may vary from $\frac{1}{2}$ to $\frac{3}{4}$ (Shetty, 2005).

Marin-Uribe and Navarro-Gaete, (2021) developed empirical relationships between compressive and flexural strengths of concrete using reclaimed asphalt. Reclaimed asphalt was incorporated into the concrete mix at 0, 20, 50 and 100%. The study developed linear, logarithmic and power relationships that relate concrete cube compressive strength (f_{cu}) and concrete beam flexural strength (f_s). These relationships are presented as Equations 2, 3 and 4.

$$f_s = 0.00524f_{cu} + 1.3894 \quad (2)$$

$$f_s = 0.9948 \ln f_{cu} - 0.4438 \quad (3)$$

$$f_s = 0.6647(f_{cu})^{0.4417} \quad (4)$$

Franklin and Kangootui, (2020) developed empirical relationships relating compressive strength and flexural strength, and compressive strength and splitting tensile strength. These were achieved using Kgale aggregates with botchem as a binding agent. Equations 5 and 6 were developed as empirical relationships between compressive strength and flexural strength, and compressive strength and splitting tensile strength respectively.

$$f_r = 0.234(f_c')^{2/3} \quad (5)$$

$$f_t = 0.533(f_c')^{0.5} \quad (6)$$

Juki et al., (2013) developed empirical relationship between compressive, flexural and splitting tensile strength of concrete using laboratory results from properties of concrete containing granulated waste Polyethylene Terephthalate (PET) bottles as fine aggregate. Fine aggregate was replaced at 25, 50 and 75%. Equations 7 and 8 shows the relationship between flexural and compressive strength, and splitting tensile and compressive strength respectively.

$$f_{fs} = 0.466(f_c)^{0.703} \quad \ldots\ldots(7)$$

$$f_t = 0.634(f_c)^{0.5} \quad \ldots\ldots(8)$$

According to Marin-Uribe and Navarro-Gaete, (2021), the Indian Standard, European Code and ACI postulates equations 9, 10, and 11 respectively as the equations that relate the flexural strength (f_s) and the compressive strength (f_{cu}) of concrete.

$$f_s = 0.7\sqrt{f_{cu}} \quad (9)$$

$$f_s = 0.201f_{cu} \quad (10)$$

$$f_s = 0.554\sqrt{f_{cu}} \quad (11)$$

3. MATERIALS AND METHODS

3.1 Materials

42.5N grade of Portland Limestone Cement (PLC) obtained from a cement distributor in Minna, Sand (fine aggregate) dredged from a river at the Gidan Mangoro area of Minna, Kuta gravel (coarse aggregate) sourced from Kuta in Niger state, and potable water from the Federal University of Technology, Minna were the materials used in carrying out this study. The properties of the aggregates used for this study are shown in Table 1.

3.2 Methods

3.2.1 Factor setting and design of concrete mixes

Twenty (20) mix points were generated using Central Composite Design in Minitab (2021). These mix points are different combinations of three design variables: water to cement ratio (W/C) = 0.36, 0.4, 0.5, 0.6 and 0.64; Coarse Aggregate to Total Aggregate ratio (CA/TA) = 0.53, 0.55, 0.6, 0.65 and 0.67; and Total Aggregate to Cement ratio (TA/C) = 2.38, 3, 4.5, 6 and 6.62.

A modified absolute volume equation that incorporates these design variables was then used to compute the weights of individual constituent material required per cubic meter of concrete. Equation 12 shows the modified absolute volume equation that computes the weight of cement per cubic meter of concrete. The weights of water, fine aggregate and coarse aggregate are then computed using equations 13, 14 and 15 respectively.

$$W_c = \frac{1 - AV}{\frac{\left(\frac{W_w}{W_c}\right)}{1000} + \frac{1}{1000SG_c} + \frac{\left(1 - \frac{W_{CA}}{W_{TA}}\right)\left(\frac{W_{TA}}{W_c}\right)}{1000SG_{FA}} + \frac{\left(\frac{W_{TA}}{W_c}\right)\left(\frac{W_{CA}}{W_{TA}}\right)}{1000SG_{CA}}} \quad (12)$$

$$W_w = W_c \times \left(\frac{W_w}{W_c}\right) \quad (13)$$

$$W_{FA} = \left(\frac{W_{TA}}{W_c}\right) \times \left(1 - \frac{W_{CA}}{W_{TA}}\right) \times W_c \quad (14)$$

$$W_{CA} = \left(\frac{W_{TA}}{W_c}\right)\left(\frac{W_{CA}}{W_{TA}}\right) W_c \quad (15)$$

Where:
W_C= cement weight, AV= percentage air void=2%=0.02, W_W=Weight of water, W_{CA}=Weight of Kuta gravel, W_{FA}=Weight of river sand, SG_C=Specific gravity of cement, SG_{FA}=specific gravity of river sand and SG_{CA}=Specific gravity of Kuta gravel.

Table 1. Properties of constituent materials

Material	Properties
River sand	Specific gravity:2.64 Water absorption: 0.79% Loose bulk density: 1588.83kg/m^3 Loose bulk density: 1697.56kg/m^3 Fineness Modulus: 2.2 Grading: falls within limit of graded fine aggregates
Kuta gravel	Specific gravity:2.67 Water absorption:0.6% Loose bulk density: 1523.47kg/m^3 Compacted bulk density: 1640.52 kg/m^3 Aggregate Impact Value (AIV): 16.45% Flakiness Index: 26% Elongation Index: 29% Grading: falls within limit of graded coarse aggregates

The proportions of the different constituent materials are presented in Table 2.

Table 2. Proportions of concrete constituents required per cubic meter of concrete mix

Run Order	W/C(x_1)	CA/TA(x_2)	TA/C(x_3)	Water (kg/m^3)	Cement (kg/m^3)	Fine Aggregates (kg/m^3)	Coarse Aggregates (kg/m^3)
1	0.5	0.6	4.5	195.18	390.36	702.64	1053.97
2	0.6	0.55	3	287.28	478.80	646.37	790.01
3	0.6	0.65	3	287.46	479.09	503.05	934.23
4	0.35858	0.6	4.5	148.33	413.66	744.59	1116.88
5	0.5	0.67071	4.5	195.28	390.57	578.75	1178.81
6	0.5	0.52929	4.5	195.07	390.15	826.41	929.26
7	0.5	0.6	2.3787	286.15	572.29	544.53	816.79
8	0.6	0.65	6	185.28	308.80	648.48	1204.31
9	0.4	0.55	3	212.26	530.65	716.37	875.57
10	0.4	0.65	6	131.83	329.57	692.09	1285.32
11	0.5	0.6	4.5	195.18	390.36	702.64	1053.97
12	0.5	0.6	6.6213	148.10	296.20	784.48	1176.72
13	0.5	0.6	4.5	195.18	390.36	702.64	1053.97
14	0.4	0.65	3	212.41	531.01	557.57	1035.48
15	0.64142	0.6	4.5	237.03	369.54	665.17	997.76
16	0.4	0.55	6	131.71	329.29	889.07	1086.64
17	0.5	0.6	4.5	195.18	390.36	702.64	1053.97

Run Order	W/C(x_1)	CA/TA(x_2)	TA/C(x_3)	Water (kg/m^3)	Cement (kg/m^3)	Fine Aggregates (kg/m^3)	Coarse Aggregates (kg/m^3)
18	0.5	0.6	4.5	195.18	390.36	702.64	1053.97
19	0.6	0.55	6	185.13	308.55	833.09	1018.22
20	0.5	0.6	4.5	195.18	390.36	702.64	1053.97

3.2.2 Casting of concrete samples and curing

According to dimension and shape requirements of BS EN 12390-1 (BS EN 12390-1, 2000), 150mm×150mm×150mm (cube samples), 100mm×100mm×500mm (beam samples), and 200mm×100mm (cylinder samples) were cast to test the compressive, flexural and splitting tensile strengths of the concrete respectively. Three samples were cast per sample point per mechanical property test. One hundred and eighty (180) concrete samples were cast in all. The concrete specimens were cured using total immersion method in accordance with BS EN 12390-2 (BS EN 12390-2, 2000).

3.2.3 Mechanical property tests

The concrete cubes, prisms and cylinders were tested for compressive, flexural and splitting tensile strengths in accordance to methods described in BS EN 12390-3 (BS EN 12390-3, 2002), BS EN 12390-5 (BS EN 12390-5, 2000) and BS EN 12390-6 (BS EN 12390-6, 2000), respectively at 28 days of age.

3.2.4 Developing empirical models that relates the mechanical properties

Relationships between compressive and splitting tensile strength, and compressive and flexural strengths were developed. The relationships between these mechanical properties of concrete in this study were developed using the regression analysis tool pack in excel. For each pair of relationship, three forms of empirical equations were developed. These equations are in the form $f_t = kf_{cu}^n$. The values for n were preassigned as 1, ½ and 2/3 to ensure adequate comparison to existing empirical equations while k, the coefficient of compressive strength is generated using excel regression tool pack.

4. RESULTS AND DISCUSSION

4.1 Mechanical Properties of Concrete

Table 3 shows the 28-day compressive, flexural and splitting tensile strengths of the concrete. These strength values are the data used in developing the empirical relationships between the concrete strength properties in excel.

Table 3. 28-days mechanical properties of the concrete

Mix No.	W/C (x_1)	CA/TA (x_2)	TA/C (x_3)	Compressive Strength (N/mm^2)	Flexural Strength (N/mm^2)	Splitting Tensile Strength (N/mm^2)
1	0.5	0.6	4.5	21.72	6.25	1.85
2	0.6	0.55	3	20.59	5.4	1.72
3	0.6	0.65	3	18.70	5.05	1.63
4	0.35858	0.6	4.5	20.34	5.35	1.70
5	0.5	0.67071	4.5	19.29	5.1	1.64
6	0.5	0.52929	4.5	22.31	6.3	1.87
7	0.5	0.6	2.3787	20.09	5.25	1.68
8	0.6	0.65	6	13.48	3.75	1.17
9	0.4	0.55	3	27.47	7.95	2.44
10	0.4	0.65	6	17.39	4.75	1.51
11	0.5	0.6	4.5	21.87	6.25	1.80
12	0.5	0.6	6.6213	16.77	4.65	1.49
13	0.5	0.6	4.5	21.99	6.3	1.78
14	0.4	0.65	3	24.36	6.95	2.14
15	0.64142	0.6	4.5	13.82	3.8	1.25
16	0.4	0.55	6	20.62	5.55	1.72
17	0.5	0.6	4.5	21.42	6.1	1.82
18	0.5	0.6	4.5	22.04	6.3	1.76
19	0.6	0.55	6	15.82	4.25	1.34
20	0.5	0.6	4.5	21.51	6.2	1.80

Table 4. Regression analysis for relationship between compressive strength (f_{cu}) and flexural strength (f_s)

Equation form	$f_s = kf_{cu}$		$f_s = k\sqrt{f_{cu}}$		$f_s = kf_{cu}^{2/3}$	
	R^2	1.00	R^2	0.99	R^2	0.99
	Adj R^2	0.95	Adj R^2	0.94	Adj R^2	0.94
	Std. Error	0.21	Std. Error	0.59	Std. Error	0.45
	P-value	5.23E-29	P-value	2.43E-20	P-value	1.16E-22
Mix	Predicted	Residual	Predicted	Residual	Predicted	Residual
1	6.05	0.20	5.87	0.38	5.94	0.31
2	5.73	-0.33	5.71	-0.31	5.73	-0.33
3	5.21	-0.16	5.44	-0.39	5.37	-0.32
4	5.66	-0.31	5.68	-0.33	5.68	-0.33
5	5.37	-0.27	5.53	-0.43	5.49	-0.39
6	6.21	0.09	5.94	0.36	6.05	0.25
7	5.59	-0.34	5.64	-0.39	5.64	-0.39
8	3.75	0.00	4.62	-0.87	4.32	-0.57
9	7.65	0.30	6.60	1.35	6.94	1.01
10	4.84	-0.09	5.25	-0.50	5.12	-0.37
11	6.09	0.16	5.89	0.36	5.97	0.28
12	4.67	-0.02	5.15	-0.50	5.00	-0.35
13	6.12	0.18	5.90	0.40	5.99	0.31
14	6.78	0.17	6.21	0.74	6.41	0.54
15	3.85	-0.05	4.68	-0.88	4.39	-0.59
16	5.74	-0.19	5.72	-0.17	5.74	-0.19
17	5.96	0.14	5.82	0.28	5.88	0.22
18	6.14	0.16	5.91	0.39	6.00	0.30
19	4.40	-0.15	5.01	-0.76	4.81	-0.56
20	5.99	0.21	5.84	0.36	5.90	0.30

4.2 Empirical Relationships between the Mechanical Properties of Concrete

4.2.1 Empirical relationship between flexural strength (f_s) and compressive strength(f_{cu})

Empirical equations relating compressive strength (fcu) and flexural strength (fs) of concrete developed in this study are presented as equations 16, 17 and 18.

$$f_s = 0.2784f_{cu} \quad (16)$$

$$f_s = 1.2586\sqrt{f_{cu}} \quad (17)$$

$$f_s = 0.7628f_{cu}^{2/3} \quad (18)$$

The results of the regression analysis and the trendline plot of the relationship between the two concrete strength properties are presented in Table 4 and Fig. 1 respectively.

The coefficient of determination (R^2) for all the empirical relationships are very high. This is an indication that all the models interpret the experimental data adequately. R^2 values of 1, 0.99 and 0.99 were recorded for equations 16, 17 and 18 respectively, implying that 100, 99 and 99% of the variability in the flexural strengths are explained by compressive strength for equations 16, 17 and 18 respectively.

All the equations developed for flexural strength as a function of the compressive strength are statistically significant. This is measured by the P-values as shown in Table 4. P-values of 5.23×10^{-29}, 2.43×10^{-20} and 1.16×10^{-22} are recorded for equations 16, 17 and 18 respectively. These P-values are far less than 0.005, indicating high statistical significance of the model's independent variable.

The standard errors of 0.21, 0.59 and 0.45 are observed for equations 16, 17 and 18 respectively as shown in Table 4. The errors can be seen to be very minimal and hence, insignificant. This further validates the capability of the equations in predicting flexural strength of Kuta gravel concrete from the compressive strength. Furthermore, residuals from the values of flexural strength predicted shows that there is very slight deviation between the experimental and predicted values.

By comparing the three equations, equation 16 is observed to have the highest R^2 (1.00), highest adjusted R^2 (0.95), lowest standard error (0.21), lowest P-value (5.23×10^{-29}), and lowest range of residual (-0.34 to +0.3). Therefore, the equation that best predicts the flexural strength of Kuta gravel concrete from the compressive strength is:

$$f_s = 0.2784 f_{cu} \quad (16)$$

Equation 19 compares closely to Equation 10 suggested by European code to relate flexural strength to compressive strength of concrete.

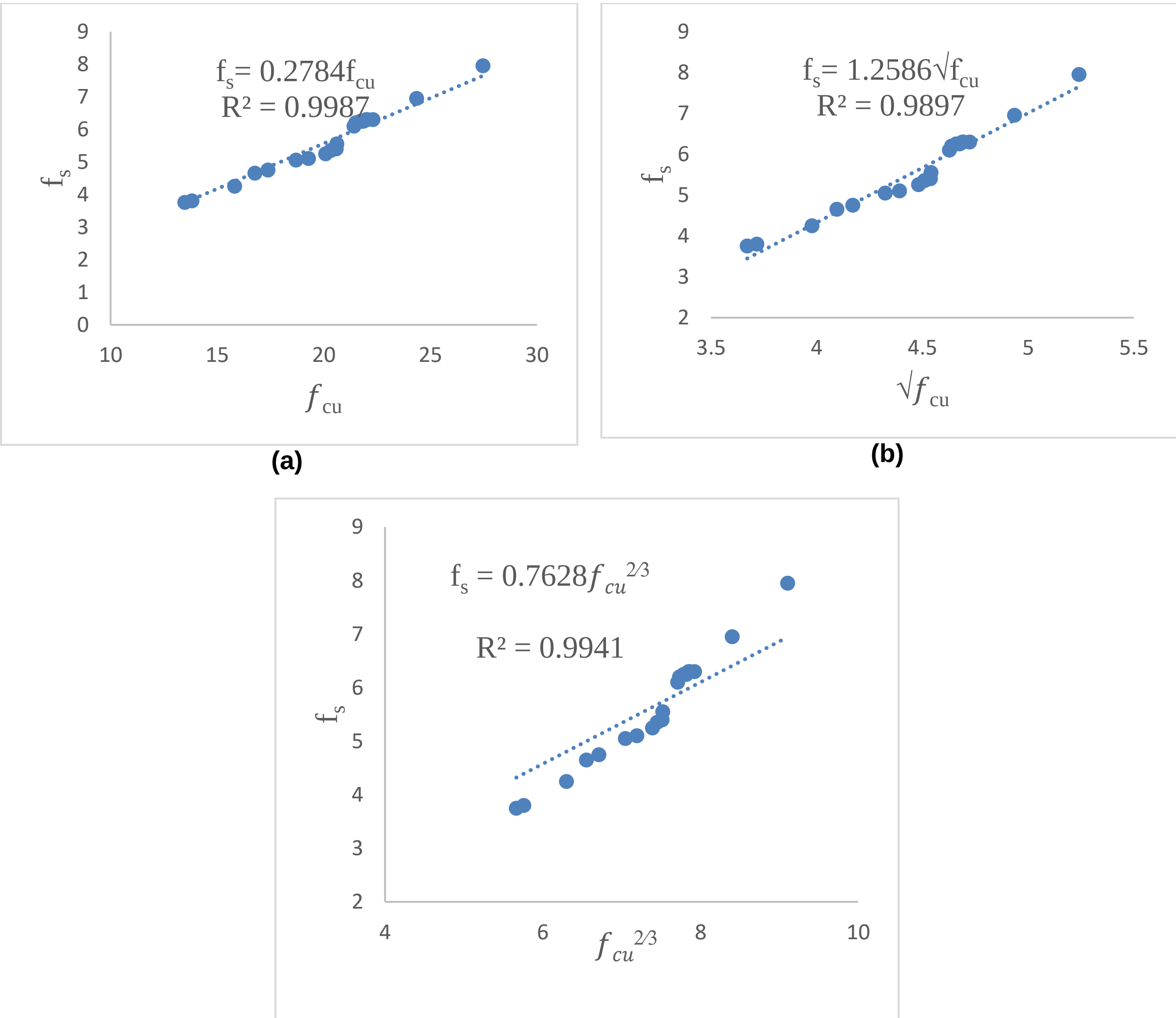
4.2.2 Empirical Relationship between splitting tensile strength (f_{st}) and compressive strength(f_{cu})

The models developed for splitting tensile strength (f_{st}) as a function of the 28-day compressive strength (f_{cu}) are represented as Equations 19, 20 and 21.

$$f_{st} = 0.0849 f_{cu} \quad (19)$$

$$f_{st} = 0.3843\sqrt{f_{cu}} \quad (20)$$

$$f_{st} = 0.2328 f_{cu}^{2/3} \quad (21)$$



(a) (b) (c)

Fig. 1. Trendline plots for the relationship between compressive strength (f_{cu}) and flexural strength (f_s) of kuta gravel concrete

Table 5. Regression analysis for relationship between compressive strength (f_{cu}) and splitting tensile strength (f_{st})

Equation form	$f_{st} = kf_{cu}$		$f_{st} = k\sqrt{f_{cu}}$		$f_{st} = kf_{cu}^{2/3}$	
	R^2	1.00	R^2	0.99	R^2	1.00
	Adj R^2	0.95	Adj R^2	0.94	Adj R^2	0.94
	Std. Error	0.06	Std. Error	0.15	Std. Error	0.10
	P-value	4.47E-30	P-value	4.02E-22	P-value	6.41E-25
Mix	Predicted	Residual	Predicted	Residual	Predicted	Residual
1	1.84	0.01	1.79	0.06	1.81	0.04
2	1.75	-0.03	1.74	-0.02	1.75	-0.03
3	1.59	0.04	1.66	-0.03	1.64	-0.01
4	1.73	-0.03	1.73	-0.03	1.73	-0.03
5	1.64	0.00	1.69	-0.05	1.67	-0.03
6	1.89	-0.02	1.82	0.05	1.84	0.03
7	1.71	-0.03	1.72	-0.04	1.72	-0.04
8	1.14	0.03	1.41	-0.24	1.32	-0.15
9	2.33	0.11	2.01	0.43	2.12	0.32
10	1.48	0.03	1.60	-0.09	1.56	-0.05
11	1.86	-0.06	1.80	0.00	1.82	-0.02
12	1.42	0.07	1.57	-0.08	1.53	-0.04
13	1.87	-0.09	1.80	-0.02	1.83	-0.05
14	2.07	0.07	1.90	0.24	1.96	0.18
15	1.17	0.08	1.43	-0.18	1.34	-0.09
16	1.75	-0.03	1.75	-0.03	1.75	-0.03
17	1.82	0.00	1.78	0.04	1.80	0.02
18	1.87	-0.11	1.80	-0.04	1.83	-0.07
19	1.34	0.00	1.53	-0.19	1.47	-0.13
20	1.83	-0.03	1.78	0.02	1.80	0.00

Table 5 presents a summary of the regression analysis for the three models while the plots in Fig. 2 show the trendline plots of the relationship between the compressive strength and splitting tensile strength.

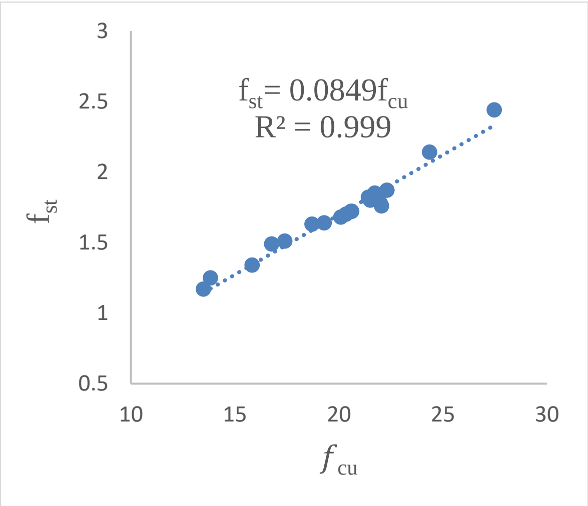
Like in the case of the flexural strength equations, the empirical equations developed for splitting tensile strength as functions of the compressive strength have high R^2 values, implying the adequacy of the equations in interpreting the experimental data. R^2 values of 1.00, 0.99 and 1.00 were recorded for Equations 19, 20 and 21 respectively. By this, for Equations 19, 20 and 21, 100, 99 and 100% of the variability in the splitting tensile strength (dependent variable) are explained by the compressive strength (independent variable) respectively.

The P-values for the splitting tensile strength equations are shown in Table 5. The equations are observed to be statistically significant. P-values of 4.47×10^{-30} , 4.02×10^{-22} and 6.41×10^{-25} are observed for Equations 19, 20 and 21 respectively. The P-values for all the empirical equations developed are far less than 0.005, implying high significance of the independent variable in the equations.

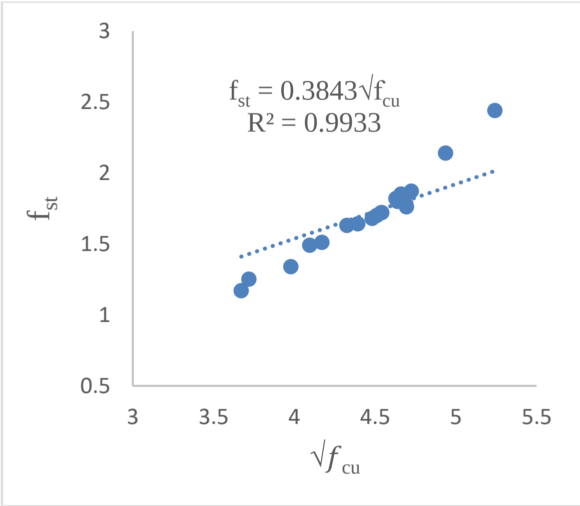
Table 5 also shows standard error for the relationships developed. Standard error of 0.06, 0.15 and 0.10 are observed for Equations 19, 20 and 21 respectively. The low values of standard errors imply insignificant errors for the three empirical models. The residuals arising from predicted values of splitting tensile strength also show very slight deviations between the predicted and experimental values for splitting tensile strength.

When the three empirical equations for splitting tensile strength are compared, Equation 19 has the highest R^2 (1.00), highest adjusted R^2 (0.95), lowest standard error (0.06), lowest P-value (4.47×10^{-30}), and the lowest range of residual value (-0.11 to +0.11). Consequently, the model that best predicts the splitting tensile strength of Kuta gravel concrete is:

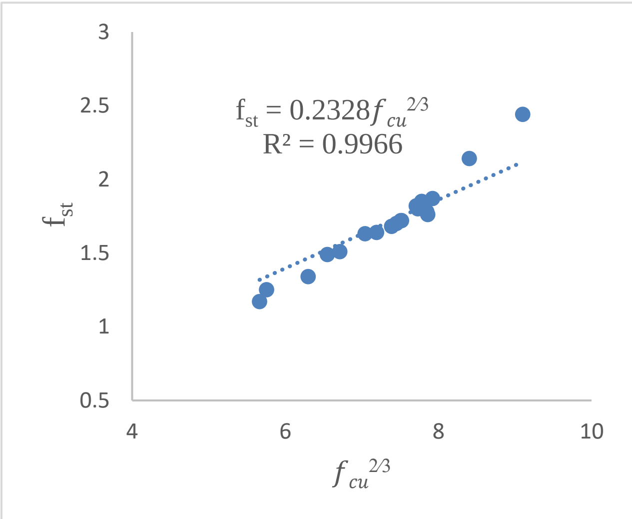
$$f_{st} = 0.0849 f_{cu} \qquad (19)$$



(a)



(b)



(c)

Fig. 2. Trendline plots for the relationship between compressive strength (f_{cu}) and splitting tensile strength (f_{st}) of kuta gravel concrete

The tensile/compressive strength ratio of Equation 19 is 8.49%. This agrees closely with the assertion made by Li (Li, 2011), that for medium strength concrete, the tensile/compressive strength ratio ranges between 8 to 9%. Equation 21 however, compares closely to Equation 5 developed by Franklin and Kangootui (Franklin & Kangootui, 2020) for predicting splitting tensile strength of concrete made from Kgale aggregates.

5. CONCLUSION

The empirical relationships between compressive and flexural strengths, and compressive and splitting tensile strengths of concrete using Kuta river gravel as coarse aggregate have been developed.

The relationship between the flexural strength and the compressive strength is expressed as $f_s = 0.2784 f_{cu}$.

The relationship between the splitting tensile strength and the compressive strength is expressed as $f_{st} = 0.0849 f_{cu}$.

The empirical equations developed are significant, have high predictive capabilities and can be used in predicting the flexural and splitting tensile strengths of concrete.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models

(ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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