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Evaluation of relationship between split tensile strength and compressive strength for geopolymer concrete of varying grades and molarity

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Abstract

This paper presents the experimental and analytical results of high calcium flyash based geopolymer concrete to investigate the relationship between tensile strength and compressive strength based on the split cylinder test ASTM C496 and compressive strength test ASTM C39. Experimental studies were performed on cube specimens of 150 mm and cylinder specimens of 100 mm diameter and 200 mm height with varying molarity and grades at age of 28 days. The experimental data have been used to obtain the relationship between tensile strength and compressive strength. A representative non linear equation is proposed for the relationship between tensile strength and compressive strength of class C flyash based geopolymer concrete cured at ambient temperature. There is a good agreement between the average experimental results and those calculated from the proposed equation. Also the reliability of the proposed equation and other empirical relationships were assessed by means of Integral Absolute Error (IAE), Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and Normal Efficiency (EF).

Keywords: geopolymer, class C flyash, ambient curing, split tensile strength, compressive strength, error analysis

INTRODUCTION

Fly ash, a waste combustion by product from thermal power plant has fine particles of silicon, aluminum and calcium oxides in an amorphous, glassy form that is more reactive similar to ordinary cement [1]. Utilization of waste materials such as fly ash in construction industry reduces the environmental problems. Geopolymers are the binders which could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminium in source materials of geological origin or by product materials such as fly ash [2].

Compressive strength and splitting tensile strength are both important parameters that are utilized for design of concrete members. Tensile strength of concrete can be estimated by three methods viz direct tension test, modulus of rupture test and split cylinder test. It is widely known that the split cylinder test is simpler and provide reliable data under uniform stress [3].

However, this is not always easy from an experimental point of view. To avoid the demand and time consuming direct measurements of the splitting tensile strength, researchers have tried to predict the splitting tensile strength using theoretical and empirical approaches based on compressive strength [4]. Generally, square root function was probably chosen as a matter of convenience for predicting tensile strength from compressive strength. But recent researchers found that square root relationship between splitting tensile strength and compressive strength is not the most appropriate relationship for maturing concrete and the power of compressive strength varies between 0.6 and 0.8 [5].

Hence, considering the gap in the existing literature, an attempt has been made to obtain a relationship between the splitting tensile strength and compressive strength of high calcium flyash based geopolymer concrete. The Integral Absolute Error (IAE), Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and Normal Efficiency (EF) were used as the criteria to compare the performance of proposed model and other models.

RESEARCH SIGNIFICANCE

Most of the researches were published on the behaviour of geopolymer concrete. There is no relationship available in the literature for the geopolymer concrete cured at ambient temperature. The present study deals with the relationship between the splitting tensile strength and compressive strength of Class C based geopolymer concrete for the age of 28 days.

EXPERIMENTAL PROGRAMME

Flyash used in this experimental work was obtained from Neyveli Lignite Corporation (NLC Ltd), Neyveli, India. The chemical compositions of the flyash determined by X - Ray Fluorescence (XRF) analysis are given in Table 1 is approximately equal to the maximum specified ASTM values.

Table 1 Chemical Composition of Class C flyash

Elements	Silicon dioxide (SiO_2)	Aluminium oxide (Al_2O_3)	Ferric oxide (Fe_2O_3)	Calcium oxide (CaO)	Magnesium oxide (MgO)	Sodium oxide (Na_2O_3)	Sulphur trioxide (SO_3)	Loss of Ignition (LOI)
Composition, % Tested	25.69	17.10	9.43	24.54	4.06	1.62	4.25	0.5
Specified as per ASTM	25 - 42	15 - 21	5 - 10	17 - 32	4 - 12.5	0.8 - 6.0	0.4 - 5.0	0.1 - 1.0

The specific gravity, fineness modulus, specific surface area and density of flyash are 2.80, 2.7%, 310 m^2/kg and 2293 kg/m^3 respectively. Locally available river sand having fineness modulus 3.1%, specific gravity 2.6 and conforming to grading zone - III as per I.S: 383 – 1970 was used. Coarse aggregate is of angular shaped with maximum size 20mm and its fineness modulus and specific gravity are 6.7% and 2.88 respectively. Water with pH value 7was used for the geopolymer concrete. The sodium hydroxide solids were of commercial grade in pellet form with 97% purity. Sodium silicate solution (Vitrosol D - A53) has the chemical composition Na_2O=14.7%, SiO_2=29.4%, and water 55.9% by mass was purchased from local supplier.

All geopolymer concrete mixes were designed using IS 10262 - 2009 [6]. Table 2 shows mix designs of geopolymer concrete. The mix of grade M20, M25, M30 and M35 were designed to have the same sodium silicate /sodium hydroxide ratio of 2.5 [7] and the molarity of 8M, 10M, 12M, 14M, and 16M.

Table 2 Mix proportions of high calcium geopolymer concrete

Materials, kg/m^3					
Grade	Coarse aggregate (20 mm)	Fine aggregate (sand)	Flyash	Alkaline solution	
				Na_2SiO_3	NaOH
M20	1195	567	383	136.87	54.74
M25	1226	549	425	132.86	53.14
M30	1254	536	479	132.86	53.14
M35	1280	525	530	132.86	53.14

Sodium hydroxide pellets of 320 gm, 400 gm, 480 gm, 560 gm, 640 gm were dissolved in water to get 8M, 10 M, 12M, 14 M and 16M respectively. The sodium hydroxide solution is mixed with sodium silicate solution to get the desired alkaline solution one day before making the geopolymer concrete [8]. Mixes were developed for the cubes of 150 mm x150 mm x150 mm, cylinders of diameter of 100 mm x height 200 mm to study the 28th day compressive and split tensile strength of each mix. The demoulded specimens were left in room temperature for curing. The cube specimens were tested under compression in accordance with the ASTM Test C - 39. The cylinder specimens were loaded in compression along the diameter in accordance to ASTM C - 496.

DISCUSSION OF RESULTS

An analytical work of 28 days split tensile strength and corresponding compressive strength of high calcium flyash based geopolymer concrete with different molarity and different grades has been carried out. The ratio of splitting tensile strength to compressive strength f_t/f_c was evaluated by means of regression analysis regardless of grades and molarity. The regression analyses were carried out on several statistical models and the results are compiled in table 3.

Table 3 Results of several statistical models used in regression analysis

Eq.No	Statistical Model	a	b	R
1.	$f_t = a\, f_c^{b}$	0.249	0.772	0.92
2.	$f_t = a\, f_c + b$	0.087	0.764	0.92
3.	$f_t = a\ln(f_c) - b$	1.933	3.198	0.93
4.	$f_t = ae^{b\, fc}$	1.239	0.033	0.88

Note: a, b are constants, R is the regression co efficient

According to many researchers, splitting tensile strength of concrete is closely related to that of compressive strength. The relationship between tensile strength and compressive strength of concrete can be represented by nonlinear equations, because the tensile strength of concrete increases with an increase in compressive strength and the ratio of tensile strength to compressive strength decreases as the compressive strength increase [9]. This implies that equation I can be adopted for the non linear relationship between split tensile strength and compressive strength. Also equations proposed by many researchers for f_c - f_t relationship were accepted in the form of equation I. The tensile strength values computed by current model and other models are shown in table 4. As seen from the figure 1, the predicted data from the current model were sufficiently close to the experimental data.

The coefficient of determination R^2 was obtained between experimental data and regression equation. The value of R^2 = 0.84 was obtained which explains that 84% of experimental data was correlated to the regression equation. The coefficient of correlation R that measures the strength of the proposed relationship should be large. It is important to note that even when the correlation is significant, the variability can still be large, and the proposed equation may not be reliable. The accuracy of the relationship should be as high as possible. In other words, the errors associated with the proposed equation should be as small as possible [10].

Table 4 Predicted Split tensile strength for several relationships

Experimental Data		Predicted Data												
Source		ACI363R - 92 [11]	ACI 318 - 99 [12]	CEB - FIB [13]	Mokhtarzadeh et al [14]	Carino et al [15]	Raphael [9]	Ahmad et al [16]	Gardner et al [17]	Gardner [18]	Oluokun et al [3]	Arioglu [19]	Neville [20]	current study [A]
Compressive Strength N/mm^2	Split Tensile Strength N/mm^2	$f_t = 0.59 f_c^{0.5}$	f_t = 0.56 f_c 0^{5}	$f_t = 0.3 f_c^{0.66}$	$f_t = 0.56 f_c^{0.5}$	$f_t = 0.272 f_c^{0.71}$	$f_t = 0.313 f_c^{0.667}$	$f_t = 0.462 f_c^{0.55}$	$f_t = 0.47 f_c^{0.59}$	$f_t = 0.34 f_c^{0.66}$	$f_t = 0.294 f_c^{0.69}$	$f_t = 0.321 f_c^{0.661}$	$f_t = 0.23 f_c^{0.67}$	$f_t = 0.249 f_c^{0.772}$
11.45	1.4	2.0	1.9	1.6	1.9	1.5	1.6	1.8	2.0	1.7	1.6	1.6	1.2	1.6
18.33	2.43	2.5	2.4	2.2	2.4	2.1	2.2	2.3	2.6	2.3	2.2	2.2	1.6	2.4
29.33	3.01	3.2	3.0	3.0	3.0	3.0	3.0	3.0	3.4	3.2	3.0	3.0	2.2	3.4
20.00	2.10	2.6	2.5	2.3	2.5	2.3	2.3	2.4	2.8	2.5	2.3	2.3	1.7	2.5
18.71	2.00	2.6	2.4	2.2	2.4	2.2	2.2	2.3	2.6	2.3	2.2	2.2	1.6	2.4
12.65	1.65	2.1	2.0	1.7	2.0	1.6	1.7	1.9	2.1	1.8	1.7	1.7	1.3	1.8
19.45	2.67	2.6	2.5	2.3	2.5	2.2	2.3	2.4	2.7	2.4	2.3	2.3	1.7	2.5
31.25	3.32	3.3	3.1	3.1	3.1	3.1	3.1	3.1	3.6	3.3	3.2	3.1	2.3	3.5
19.78	2.64	2.6	2.5	2.3	2.5	2.3	2.3	2.4	2.7	2.4	2.3	2.3	1.7	2.5
17.70	2.52	2.5	2.4	2.1	2.4	2.1	2.1	2.2	2.6	2.3	2.1	2.1	1.6	2.3
13.70	2.00	2.2	2.1	1.8	2.1	1.7	1.8	1.9	2.2	1.9	1.8	1.8	1.3	1.9
20.65	2.78	2.7	2.5	2.4	2.5	2.3	2.4	2.4	2.8	2.5	2.4	2.4	1.7	2.6
33.00	3.65	3.4	3.2	3.2	3.2	3.3	3.2	3.2	3.7	3.4	3.3	3.2	2.4	3.7
19.94	2.89	2.6	2.5	2.3	2.5	2.3	2.3	2.4	2.7	2.5	2.3	2.3	1.7	2.5
18.53	2.76	2.5	2.4	2.2	2.4	2.2	2.2	2.3	2.6	2.3	2.2	2.2	1.6	2.4
15	2.00	2.3	2.2	1.9	2.2	1.9	1.9	2.0	2.3	2.0	1.9	1.9	1.4	2.0
22.33	2.75	2.8	2.6	2.5	2.6	2.5	2.5	2.5	2.9	2.6	2.5	2.5	1.8	2.7
35	3.87	3.5	3.3	3.3	3.3	3.4	3.4	3.3	3.8	3.6	3.4	3.4	2.5	3.9
20.21	2.8	2.7	2.5	2.3	2.5	2.3	2.3	2.4	2.8	2.5	2.3	2.3	1.7	2.5
19.55	2.5	2.6	2.5	2.3	2.5	2.2	2.3	2.4	2.7	2.4	2.3	2.3	1.7	2.5

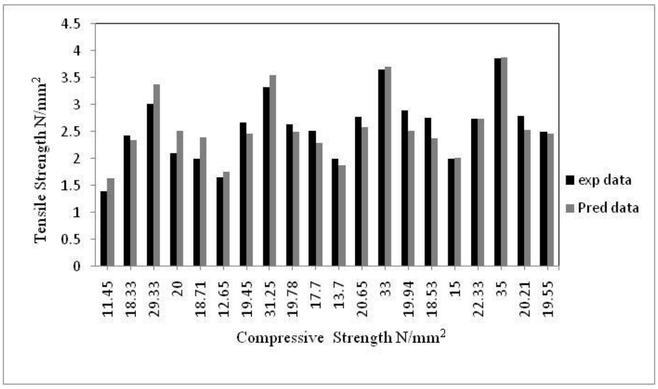

Figure 1 Compressive strength Vs tensile strength

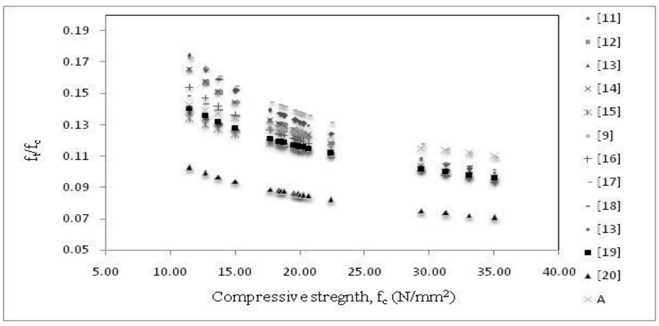

Figure 2 Ratio of Split tensile strength to Compressive strength Vs Compressive strength

There is a little information in the literature concerning the accuracy and validity of the equations used for the purpose of estimating splitting tensile strength from compressive strength. The accuracy of the proposed model and other power function relationships obtained from literature were assessed by four popular statistical parameters like, Integral Absolute Error (IAE), Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and Normal Efficiency (EF); their expressions are given below.

$$IAE = \sum_{i=0}^{n} \frac{[(O_i - P_i)^2]^{1/2}}{\sum O_i} . 100 \quad (1)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n} |P_i - O_i| \quad (2)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2} \quad (3)$$

$$EF = \left(1 - \frac{1}{n}\sum_{i=1}^{n}\frac{|P_i - O_i|}{O_i}\right)100\% \quad (4)$$

Where P_i is the predicted value and O_i is the observed value

Table 5 Results of statistical parameters

S.No	Source	Relationship	IAE	MAE	RMSE	EF
1.	ACI363R - 92 [11]	$f_t = 0.59 f_c^{0.5}$	9	0.23	0.29	89
2.	ACI 318 - 99 [12]	$f_t = 0.56\ f_c^{0.5}$	10	0.25	0.30	89
3.	CEB - FIB [13]	$f_t = 0.3\ f_c^{0.66}$	12	0.30	0.34	88
4.	Mokhtarzadeh et al [14]	$f_t = 0.56\ f_c^{0.5}$	10	0.25	0.30	89
5.	Carino et al [15]	$f_t = 0.272\ f_c^{0.71}$	12	0.31	0.35	88
6.	Raphael [9]	$f_t = 0.313\ f_c^{0.667}$	12	0.30	0.34	88
7.	Ahmad et al [16]	$f_t = 0.462\ f_c^{0.55}$	11	0.28	0.32	89
8.	Gardner et al [17]	$f_t = 0.47\ f_c^{0.59}$	9	0.24	0.31	89
9.	Gardner [18]	$f_t = 0.34\ f_c^{0.66}$	9	0.22	0.26	91
10.	Oluokun et al [3]	$f_t = 0.294\ f_c^{0.69}$	11	0.29	0.33	89
11.	Arioglu [19]	$f_t = 0.321\ f_c^{0.661}$	11	0.29	0.33	89
12.	Neville [20]	$f_t = 0.23\ f_c^{0.67}$	33	0.85	0.90	68
13.	current study	$f_t = 0.249\ f_c^{0.772}$	8	0.19	0.24	92

It was found that the splitting tensile strength obtained from the proposed model is more accurate than those obtained from design codes and several empirical equations, when a comparison is made on the basis of the experimental data. The commonly accepted square root relationship between the splitting tensile strength and cylinder compressive strength was not determined to be realistic. This is in agreement with many researchers. As seen in fig 2, the ratio of splitting tensile strength and compressive strength decreases with increases in compressive strength. The ratio of f_t/f_c varies between 0.07 and 0.17. Statistical parameters of the predicted model and other models are presented in Table 5. The statistical parameters of IAE, MAE, RMSE and EF showed that the proposed model has the best accuracy and can predict splitting tensile strength very close to experiment results. A range of the IAE from 0 to 10% may be regarded as the limits for an acceptable regression equation [10]. Based on the values of IAE calculated, the proposed model has lowest error of 8% which can be considered to be reasonably accurate and applicable to the geopolymer concrete of compressive strength upto 33 N/mm^2. The model having the smallest IAE, MAE, RMSE and EF can be regarded to be the best model. Observed IAE, MAE, RMSE and EF of predicted model for geopolymer concrete are 8, 0.19, 0.24, and 92 respectively. Hence, the use of the proposed model is very advantageous for the prediction of the splitting tensile strength of geopolymer concrete from compression strength because it can perform nonlinear regression efficiently.

CONCLUSIONS

A non linear mathematical model was developed to determine the relationship between tensile strength and compressive strength of concrete at 28 days curing. The ratio of tensile strength to compressive strength decreases as the compressive strength increases. The relationship between splitting tensile strength and compressive strength are not in accordance with power's law. A simple power function $f_t = 0.249 f_c^{0.772}$ was proposed to evaluate the splitting tensile strength from compressive strength regardless of grades and molarity of geopolymer concrete. The predicted results of the proposed model and other models were compared with the experimental data and their performances were evaluated with statistical parameters. Based on the error analysis, the proposed equation was reasonably accurate with minimum error of IAE (8), MAE (0.19), RMSE (0.24), and E (92 %).

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