Evaluation of correlation between compressive and splitting tensile strength of concrete using alccofine and nano silica

K Ashwini and P Srinivasa Rao

K Ashwini, Research scholar, Department of civil engineering, Jawaharlal Nehru Technological University Hyderabad, (Telangana State) - 500085, India

P Srinivasa Rao, Professor, Department of civil engineering, Jawaharlal Nehru Technological University Hyderabad, (Telangana State) - 500085, India

Abstract. In the present study correlation between compressive and splitting tensile strength of concrete was studied using both experimental and analytically predicted results. Three grades of concrete M40, M50, and M60 were considered by replacing its cement content with alccofine and nano-silica. Experimental results of compressive and splitting tensile strength were evaluated using 150mm cubes and cylinders of diameter 150mm and height 300mm for 28 days of curing in water. An equation was proposed for correlation between compressive and splitting tensile strength from experimental data using regression analysis and analytical results were predicted. Accuracy of empirical equations reported by researchers and the proposed equation was analyzed employing Root Mean Square Error, Integral Absolute Error, Normal Efficiency and Mean Absolute Error statistical parameters. Good compliance between experimental and analytical results was observed.

Key words: alccofine, cement, concrete, mechanical properties, nano silica,

1. Introduction

Concrete is one of the utmost versatile and durable construction materials as it is strong and economical. High-performance concrete (HPC) is found to be cost-effective, regardless of its high initial cost as compared to conventional concrete as it increases the service life of the structure and thereby reduces overall costs. HPC produced by replacing cement with one or more additives like GGBS, flyash, microsilica, etc. improves the fresh, mechanical, and durability properties to a large extent. Nowadays researchers taking a keen interest in producing high-performance concrete using micro and nano particular size additives.

Alccofine is an ultrafine material showing high reactivity and controlled particle size distribution [11] is being used as an additive to produce high-performance concrete. Use of alccofine in concrete results in denser pore structure and high strength because maximum SiO$_2$ and CaO content in it enables it to react both in the pozzolanic and hydraulic manner [10,12]. It enhances the mechanical properties like split tensile strength, compressive strength, and flexural strength [13] and durable against acidic environment [14] and also chloride penetration, chances of corrosion [15]. Nano particular sized nano-silica is progressively attracting the consideration of researchers to boost the strength and durability of high-performance concrete. The compressive strength and bond strength of concrete using nano-
silica is much greater than control concrete mixes [16]. Nano silica fills up the pores and increases the hydration process [18].

Compressive and split tensile strength is the most essential properties of concrete. As the direct tensile test is difficult to execute, therefore indirect tensile strength tests namely split and flexural strength are performed [7]. Split tensile strength is one of the crucial properties of concrete and is used to design structural elements of concrete subjected to transverse shear, torsion, shrinkage, etc. [21]. As a matter of comport, square root functions are used mostly to find tensile strength from compressive strength ($f_{ck}$) [2]. But many research studies were conducted to determine the correlation between compressive and splitting tensile strength for conventional concrete, geopolymer concrete, self-compacting concrete, roller-compacted concrete, etc. using power-type equations and found that the power of compressive strength varies [1-6]. Error analysis using statistical parameters of Root Mean Square Error, Integral Absolute Error, Normal Efficiency, and Mean Absolute Error are used to determine the accuracy of these power-type equations developed from experimental results [2, 9].

Hence in this research, an effort is made to determine a correlation between the compressive and splitting tensile strength of alccofine and nano silica-based concrete.

2. Research significance

Mostly many researches investigated the behavior of concrete and very few researches are there on the correlation between split tensile and compressive strength of concrete. Therefore the present study investigates the correlation between split tensile and compressive strength of concrete using alccofine and nano-silica by considering analytical and experimental results for 28 days of curing.

3. Experimental Programme

Alccofine and Nano silica was procured from Ambuja cement Pvt. Ltd. and Astra Chemicals Chennai. The particular size, fineness, and specific gravity of Alccofine and Nano silica are 4-6µm, 12000 cm²/gm, 2.86 and 17nm, 202 m²/g, 2.2-2.4 as provided by suppliers. KPC cement grade 53 conforming to IS 12269-1987 used for the study was obtained from local suppliers. Locally available sand having the density of 1520 Kg/m³, confirming to Zone-II, having fineness modulus 3.18 was used. Coarse aggregate of density 1416 Kg/m³ having fineness modulus 7.6 and size 20mm was used. Locally available tap water was used.

All the concrete mixes of grade M40, M50, and M60 were designed as per IS10262:2019 and IS 456:2005. In the present research, all the grades of concrete were partially replaced by 15% Alccofine (Al) and 15+3% (Al) Alccofine and nano-silica (Ns) by weight of cement. Mix proportions for all the grades of concrete are given in table 1.

| Concrete grades | Cement | Fine aggregate (FA) | Coarse aggregate (CA) | w/c |
|-----------------|--------|---------------------|-----------------------|-----|
| M40             | 400    | 667                 | 1248                  | 0.4 |
| M50             | 440    | 642                 | 1243                  | 0.36|
| M60             | 527    | 596                 | 1218                  | 0.3 |

Evaluation of experimental results of compressive strength was done using 150mm cubes and split tensile strength using cylinders of diameter 150mm and height 300mm for 28 days of curing in water using standard test methods confirming to IS:516-1959 and IS:5816-1999. Regression analysis was used to develop a proposed power-type equation to determine the correlation between
compressive and splitting tensile strength. The predicted results of split tensile strength from the proposed power-type equation are compared with experimental results. A proposed power-type equation was compared with the equations developed by other researchers and the accuracy of the equations was measured using statistical parameters of Root Mean Square Error, Integral Absolute Error, Normal Efficiency, and Mean Absolute Error.

| Concrete grade | Additives | Compressive strength (fck) | Split tensile strength (ft) |
|----------------|-----------|----------------------------|-----------------------------|
| M40            | 0         | 51.2                       | 4.18                        |
|                | Al        | 62.7                       | 5.26                        |
|                | Al+Ns     | 66                         | 5.65                        |
| M50            | 0         | 58.7                       | 4.91                        |
|                | Al        | 67.6                       | 6.05                        |
|                | Al+Ns     | 70.7                       | 6.43                        |
| M60            | 0         | 68.5                       | 5.61                        |
|                | Al        | 80.1                       | 6.68                        |
|                | Al+Ns     | 82.69                      | 7.08                        |

4. Results and discussions

Experimental results of compressive and splitting tensile strength of concrete using alcocofine and alcocofine + nano-silica as additives for concrete grades of M40, M50, and M60 are given in table 2. Experimental results given in the table are average values of three specimens tested. It was observed that compressive and splitting tensile results using (Al+Ns) were greater than control mixes for all the grades of concrete. Using regression analysis a power-type equation was developed to determine the correlation between compressive and splitting tensile strength considering all the grades of concrete. From figure 1 it was observed that split tensile strength for all grades of concrete increases with an increase in compressive strength.

![Figure 1](image1.png)  
**Figure 1** Correlation between compressive and splitting tensile strength

![Figure 2](image2.png)  
**Figure 2** Compressive strength Vs Experimental & Predicted results of split tensile strength
Equation 1 given below is the proposed power-type equation adopted for the correlation between compressive and splitting tensile strength of concrete considering all the grades of concrete at 28 days of curing obtained from figure 1 using regression analysis. $R^2=0.9545$ acquired from experimental results and power-type regression equation justifies that 95.45% of experimental results were correlated to the power-type regression equation and a good relation between compressive and splitting tensile strength was observed.

$$f_t = 0.059f_{ck}^{1.087}$$ .................................................................1

$\quad f_t = \text{Split tensile strength}$

$f_{ck} = \text{Compressive strength}$

Table 3. Split tensile strength calculated from different equations

| Experimental results | Predicted values |
|----------------------|------------------|
|                      | Proposed Equation| ACI318-14[1] | Selim et al. [6] | Lavanya et al. [2] | Smadi et al. [5] | Carino et al. [3] | Oluokun et al. [4] |
| Comp. strength (fck) | Split tensile strength (ft) | $0.059f_{ck}^{1.087}$ | $0.56\sqrt{f_{ck}}$ | $0.106f_{ck}^{0.948}$ | $0.249f_{ck}^{0.772}$ | $0.46\sqrt{f_{ck}}$ | $0.272f_{ck}^{0.71}$ | $0.294f_{ck}^{0.69}$ |
| 51.2                 | E1               | 4.18          | 4.25          | 4.01          | 4.42          | 5.20          | 3.29          | 4.45          | 4.44   |
| 58.7                 | Pi               | 4.91          | 4.94          | 4.29          | 5.03          | 5.78          | 3.52          | 4.90          | 4.88   |
| 62.7                 | E2               | 5.26          | 5.30          | 4.43          | 5.36          | 6.08          | 3.64          | 5.14          | 5.11   |
| 66.0                 | E3               | 5.65          | 5.61          | 4.55          | 5.63          | 6.32          | 3.74          | 5.33          | 5.29   |
| 67.6                 | E4               | 6.05          | 5.75          | 4.60          | 5.76          | 6.44          | 3.78          | 5.42          | 5.38   |
| 68.5                 | E5               | 6.61          | 5.84          | 4.63          | 5.83          | 6.51          | 3.81          | 5.47          | 5.43   |
| 70.7                 | E6               | 6.43          | 6.04          | 4.71          | 6.01          | 6.67          | 3.87          | 5.59          | 5.55   |
| 80.1                 |                   | 6.68          | 6.92          | 5.01          | 6.76          | 7.34          | 4.12          | 6.11          | 6.05   |
| 82.69                |                   | 7.08          | 7.16          | 5.09          | 6.97          | 7.52          | 4.18          | 6.25          | 6.19   |

Split tensile strength values calculated from the proposed power-type equation and other equations are given in table 3. From figure 2 it can be concluded that experimental results and results predicted from the proposed equation are almost similar. Not much information regarding the validity and accuracy of the equations utilized for determining split tensile strength from compressive strength is available in the literature [2]. Error analysis was done using statistical parameters of Root Mean Square Error, Integral Absolute Error, Normal Efficiency, and Mean Absolute Error [2, 9, 19] to analyze the accuracy of the proposed power-type equation as compared to the equations developed by other researchers are given below.
Root Mean Square Error (RMSE) = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (E_i - P_i)^2}  \…………………………………….2

Integral Absolute Error (IAE) = \sum_{i=0}^{n} \frac{\sqrt{(E_i-P_i)^2}}{\sum E_i} \times 100  \…………………………………….3

Normal Efficiency (NEF) = \left(1 - \frac{1}{n} \sum_{i=1}^{n} \frac{|P_i-E_i|}{E_i}\right) \times 100  \……………………………………...4

Mean Absolute Error (MAE) = \frac{1}{n} \sum_{i=1}^{n} |P_i - E_i|  \……………………………………….……..5

E_i = Experimental results  
P_i = Predicted results from proposed equations

| Source               | Equations              | RMSE  | IAE   | NEF   | MAE   |
|----------------------|------------------------|-------|-------|-------|-------|
| Proposed Equation    | 0.059f_{ck}^{1.087}    | 0.201 | 2.74  | 99.77 | 0.158 |
| ACI318-14[1]         | 0.56\sqrt{f_{ck}}     | 1.29  | 20.28 | 98.35 | 0.158 |
| Selim et al. [6]     | 0.106f_{ck}^{0.948}    | 0.215 | 3.12  | 99.75 | 0.18  |
| Lavanya et al. [2]   | 0.249f_{ck}^{0.772}    | 0.711 | 11.57 | 98.96 | 0.667 |
| Smadi et al. [5]     | 0.46\sqrt{f_{ck}}     | 2.07  | 34.51 | 97.12 | 1.988 |
| Carino et al. [3]    | 0.272f_{ck}^{0.71}     | 0.507 | 7.196 | 99.42 | 0.414 |
| Oluokun et al. [4]   | 0.294f_{ck}^{0.69}     | 0.544 | 7.79  | 99.37 | 0.449 |

From the error analysis values shown in table 4 split tensile strength calculated from the proposed equation based on experimental results is much accurate compared to those calculated using design codes and other equations obtained by researchers. The split tensile results calculated from the equation obtained from Selim et al. [6] were almost similar to predicted results. It can be concluded that the equation having power other than square root can also be used to calculate split tensile strength from compressive strength and this is in agreement with many other researchers [2-7]. As the regression equation is acceptable if the IAE value ranges within the limit of 0 to 10% [20], the proposed equation showed the lowest value of IAE i.e. 2.74 as compared to other equations. Equations showing the least value of Root Mean Square Error, Integral Absolute Error, Normal Efficiency, and Mean Absolute Error can be considered as best [2, 9, 19]. From table 4 RMSE, IAE, NEF, MAE values of proposed equation are 0.201, 2.74, 99.77, 0.158. Hence proposed equation can be used to predicted split tensile results from compressive strength results.

5. Conclusion

- Good compliance between experimental and analytical results was observed.
- $R^2=0.9545$ acquired from experimental results and power-type regression equation justifies that 95.45% of experimental results were correlated to the power-type regression equation
- The split tensile results calculated from the equation obtained from Selim Pul [6] were almost similar to predicted results.
- Equation having power other than square root can also be used to calculate split tensile strength from compressive strength.
From error analysis using statistical parameters the proposed equation \( f_t = 0.059f_{ck}^{1.087} \) is accurate, as it showed least value as compared to other equations and can be used to calculate split tensile results from compressive strength results.

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**Conflict of Interest**

The authors declare that there is no conflict of interest regarding the publication of this paper.

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**AUTHORS PROFILE**

**K Ashwini** is currently pursuing Ph.D in Structural Engineering from Jawaharlal Nehru Technological University Hyderabad, Telangana, India. She completed her M.E in Structural Engineering from AISSM Scoe Pune. She has published three research articles in international journals.

**Dr. P Srinivasa Rao** is currently working as a Professor in the department of civil engineering at JNTUH college of engineering Hyderabad, Telangana, India. He has been associated with number of design projects, for numbers of organizations and involved as a key person in quality control and mix designs. He has guided 8 Ph.D students, guiding 10 Ph.D students and guided more than 200 M. tech projects. He is the member of ISTE, ICI and Institute of Engineers and has delivered invite lectures in many organizations and institutions. He was recipient of best teacher award of 2015 govt. of Telangana and also outstanding concrete engineer of Telangana-2015 (ICI). He specialized in structural engineering and his research interest are concrete technology, structural design, high performance concrete, prefabricating structures, special concretes and use of micro silica, fly ash building materials.