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A study of factors affecting the flexural tensile strength of concrete

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KEYWORDS

Compressive strength;
Flexural tensile strength;
Modulus of rupture;
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Concrete confinement;
Age of concrete

Abstract The deflection and cracking behavior of concrete structure depend on the flexural tensile strength of concrete. Many factors have been shown to influence the flexural tensile strength of concrete, particularly the level of stress, size, age and confinement to concrete flexure member, etc. The concrete members, in general, are of large continuous size and have at least minimum reinforcement introducing a confining effect to the concrete. The confining reinforcement increases ductility and large deflections in structures provide a good warning of failure prior to complete failure of the flexure member and also for efficient use of constructional material, it is desirable to take full advantage of long-term strength gain. Therefore, the effect of the factors like level of stress, age and confinement of concrete member should be given prime importance while studying the flexure tensile strength of concrete. This paper presents an experimental study done to predict the flexural tensile strength considering the confinement conditions and age of concrete for a wide range of concrete strengths (from 30 to 85 MPa). It is concluded that the factors like confinement conditions and age of concrete should be given due consideration in deriving the flexural tensile strength and compressive strength proportionality equations.

1. Introduction

The cracking and deflection behavior of concrete structure under flexure and minimum flexural reinforcement of concrete members depends upon the flexural tensile strength or modulus of rupture of concrete in addition to other factors. The equations proposed to determine the flexural tensile strength are of the power equation type: flexural tensile strength, $f_r = bf_c^n$ where f_c is the compressive strength of the concrete and, b (varies from 0.33 to 0.94) and n (1/2 or 2/3) are coefficients which depend on factors such as strength levels, aggregate properties and mineralogy, admixtures types, moisture content of specimen, compaction and curing conditions, specimen geometry and confinement, age of concrete, etc. The value reported for the flexural tensile strength by various investigators and standards in square root form ($n = 1/2$) ranges from 0.3 to 1.0 $f_c^{0.5}$ MPa (Ahmed et al., 2008). Légeron and Paultre (2000) have derived equations for flexural tensile strength using published database as $f_{r,\min} = 0.68\ f_c^{0.5}$, $f_{r,\text{avg}} = 0.94\ f_c^{0.5}$ $f_{r,\max} = 1.2\, f_c^{0.5}$, where $f_{r,\min}$, $f_{r,\text{avg}}$ and $f_{r,\max}$ are the min-

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imum, average and maximum values of the modulus of rupture. They also recommended to use $f_{r,\min}$ for deflection and crack control and $f_{r,\max}$ to behave as flexure member in a ductile manner. Raphael (1984) was the first to use power equation (n = 2/3) for predicting the flexural tensile strength of high strength concrete based on its compressive strength. One of the reasons for variation in reported flexural tensile strength, explained by Raphael (1984), is that the co-relating equations are derived from elastic theory, which assumes elastic behavior of concrete to the point of failure. Abdul Razak and Wong (2004) have conducted a test on high performance concrete to evaluate the strength relationship and concluded that the square-root function recommended by most codes of practice is inadequate when applied to concretes of higher strength, particularly in the case for tensile strength prediction. The flexural strength co-relation studied for manufactured sand in self compacting concrete is mentioned by Kothai and Malathy (2012). Ahmed et al. (2014) have assessed the square root (n = 1/2) and power model (n = 2/3) proportionality equations relating flexural tensile strength and compressive strength reliability and concluded that power model is more reliable and applicable to a large range of concrete strength level.

The researchers have also devoted their work to study the factors causing variability in flexural tensile strength of concrete. The effect of curing of concrete member on flexural tensile strength, cured under standard testing conditions and cured under site conditions, is studied by Légeron and Paultre (2000). They found significant differences between the modulus of rupture of concrete specimens and this difference is varied from 35% to 100% for HPC. The effect of admixtures of the concrete on flexural tensile strength is studied by Siddiqui (2011) and Amudhavalli and Mathew (2012). They concluded that optimum amount of silica fume is 10–15% and of fly ash is about 15% for maximum compressive and flexural strength. Gonen and Yazicioglu (2009) carried out research work on the influence of mineral admixtures on the short and long term performance of concrete and concluded that silica fume contributed to both short and long term properties of concrete, where as fly ash shows its beneficial effect in a relatively longer time. Koksal et al. (2008) have conducted the flexural strength testing of concrete incorporating hooked steel fibers and silica fume. They found greater flexural strengths of concretes containing 1% steel fiber than those of the concrete with 0.5% steel fiber with various silica fume contents. The standard test method for the flexural tensile strength of concrete with its size dependence is proposed by Bazant and Novak (2001). They concluded that the flexural tensile strength decreases with increase of structural element size. Ahmed et al. (2014) have studied the effect of the size of specimen on the flexural tensile strength of concrete. They concluded that the concrete member size has a significant effect and proposed an equation incorporating the effect of size of concrete for predicting the flexural tensile strength of concrete given as, $f_r = \frac{0.827}{h^{0.1}} f_c^{2/3}$, where f_c is compressive strength and h is depth of beam in mm. NCHRP (2004) has proposed an equation to determine the flexural tensile strength (MOR) at different age, if 28-day flexural tensile strength of concrete is given, as

$$\mathrm{MOR}(t)\left[1+\log_{10}\left(\frac{t}{0.0767}\right)-0.01566\log_{10}\left(\frac{t}{0.0767}\right)^2\times \mathrm{MOR}_{28d}\right]$$

where $\mathrm{MOR}(t)$ is the flexural tensile strength at any given time (t, in days), t is the age of concrete (day), and MOR_{28d} is flexural tensile strength at 28 days.

A review of past studies indicates that in spite of numerous works reported on flexural tensile strength, little attention has been paid to study the parameters affecting the flexural tensile strength of concrete. The effect of the factors like age and confinement of concrete on flexural strength has not been investigated properly and proper inter-dependency of various factors that affect the flexural strength has not been co-related. The effect of confinement on flexural tensile strength is an interesting issue as most of the concrete members are of large continuous size and other smaller size members have at least minimum reinforcement giving the confining effect to the concrete members. The confining reinforcement increases ductility and large deflections in structures, providing a good warning of failure in the form of tensile cracks prior to complete failure of the flexure member. In the available literature, the relationship for predicting flexural tensile strength of low strength and high strength concrete has been reported separately. The combined effect of low and high strength including the transition from normal strength to high strength of concrete on flexural tensile strength may also be investigated. For efficient use of constructional material, it is desirable to take full advantage of long-term strength gain. Therefore, the flexural tensile strength of concrete should be further investigated for a wider range of concrete strengths considering the long term and confinement conditions of members. The present study is devoted to investigate the flexural tensile behavior under concrete confinement using four concrete mixes having 28-days compressive strength ranges from 30 MPa to 85 MPa. The flexural tensile behavior of concrete at 7 days and 56 days concrete strength has also been studied at different confinement conditions of concrete.

2. Materials and methodology

An experimental program was carried out in the present work to investigate the flexural tensile strength of concrete taking into consideration the level of compressive strength of concrete, age of concrete and confinement of concrete specimen.

2.1. Cement and aggregates

Type- I Ordinary Portland cement with specific gravity 3.15 was used. The initial and final setting times were found as 60 min and 300 min respectively. Fine aggregate used is ordinary siliceous sand with a fineness modulus and the specific gravity of 2.61 and 2.45 respectively. Crushed Basalt of nominal maximum size of 10 mm was used as coarse aggregate. The specific gravity of coarse aggregate is found to be 2.75. The coarse aggregates have water absorption of 1.01% in SSD condition.

2.2. Admixture

Super plasticizer is used to obtain a constant slump of 10 cm for all concrete mix. Silica fume is used as a partial replacement for cement on equal weight basis.

2.3. Mix proportion

In this study, four different concrete mixes were used. Mix proportion for each mix is given in Table 1. These mixes were designed to achieve different concrete compressive strength.

2.4. Concrete properties

Slump test according to ASTM C143 (1978) was done on the fresh concrete while tests for compressive strength and flexural tensile strength, were carried out on hardened concrete.

2.4.1. Compressive strength test

Compression test on the 150 mm diameter × 300 mm height cylinder specimens was conducted on the 1000 kN universal testing machine. The specimens were cured in water for 7-days, 28-days and 56-days. The cube compressive strength is calculated as crushing load per unit area and is presented in Table 2. For each mix three specimens were tested and average values are reported. The compression test set-up is shown in Fig. 1.

2.4.2. Flexural tensile strength test

The Three-Point bending test is conducted on a loading frame to determine the flexural tensile strength on standard beam specimens of size 750 × 150 × 150 mm. The specimens were cured in water for 7-days, 28-days and 56-days. The minimum reinforcement is provided for confined beam specimen tests. The reinforcement details for confined beam specimen are given in Fig. 2. The beam specimen is simply supported on two rollers of 4.5 cm diameter. The flexural tensile strength is calculated as the ratio of the calculated bending moment and section modulus of the beam specimen and is presented in Tables 2 and 3. Table 4 show the flexural tensile strength after deducting the flexural tensile strength (approximate) of provided reinforcement. The flexure test set-up is shown in Fig. 3.

3. Result and discussion

The results of flexural tensile strength experimental study are given in Tables 2–4 for different concrete mixes at 7-days, 28-days and 56-days and specimens under different confinement. Table 5 depicts the level of concrete strength effect on the flexural tensile strength without confining conditions of concrete. It is clear that the flexural tensile strength increases when the compressive strength and age of the concrete increase. Moreover, the increase in the flexural strength is lower than the corresponding increase in the compressive strength at same age of concrete. The percentage increase in flexural tensile strength decreases with the increase of level of concrete strength. For compressive strength of 24.1 MPa,

Table 1 Mix ingredients for different mixes.

Mix	Cement content (kg/m^3)	Sand (kg/m^3)	Basalt (kg/m^3)	Silica fume (%)	$w/(c+s)$
I	350	757	1135	0	0.52
II	450	700	1200	10	0.33
III	520	777	1070	0	0.26
IV	520	777	1070	10	0.26

Table 2 Compressive and flexural tensile Strength (without confining reinforcement).

Mix	Compressive strength (MPa)			Flexural strength (MPa)		
	7-days	28-days	56-days	7-days	28-days	56-days
I	24.1	31.8	37.7	3.17	4.85	5.35
II	30.9	44.95	58.5	4.55	6.12	7.08
III	58.5	78.2	89.0	5.44	6.84	8.15
IV	58.7	81.2	98.6	5.6	6.96	8.29

Figure 1 Compression test set-up.

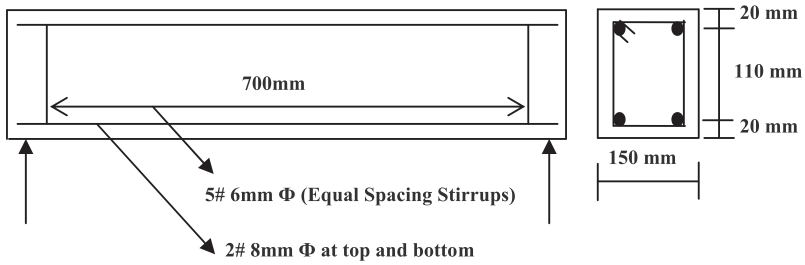

Figure 2 Confined beam specimen detail.

Table 3 Compressive and flexural tensile strength (with confining reinforcement).

Mix	Compressive strength (MPa)			Flexural strength (MPa)		
	7-days	28-days	56-days	7-days	28-days	56-days
I	24.1	31.8	37.7	5.29	7.92	8.65
II	30.9	44.95	58.5	8.74	13.38	15,91
III	58.5	78.2	89.0	13.38	20.07	24.02
IV	58.7	81.2	98.6	16.96	22.87	27.53

Table 4 Compressive and flexural tensile strength (with confining condition after deducting reinforcement strength).

Mix	Compressive Strength (MPa), 28-days	Flexural Strength (MPa), 28-days
I	31.8	4.17
II	44.95	9.63
III	78.2	16.32
IV	81.2	19.12

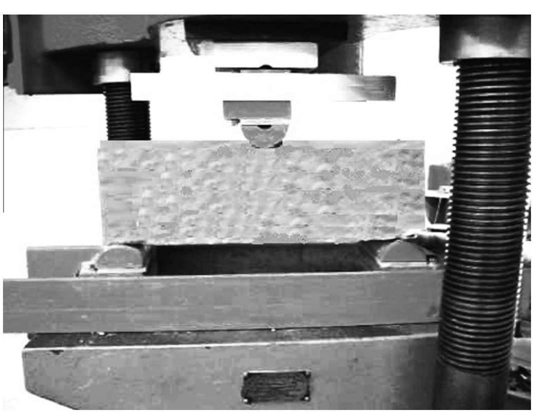

Figure 3 Flexure test set-up.

31.8 MPa and 37.7 MPa, the flexural strength are 3.17 MPa, 4.85 MPa and 5.35 MPa at 7-days, 28-days and 56-days respectively whereas for compressive strength of 58.7 MPa, 81.2 MPa and 98.6 MPa, the flexural tensile strength are 5.6 MPa, 6.96 MPa and 8.29 MPa respectively on same corresponding ages. It is due to the different concrete compression and flexure failure mechanism of low and high strength concrete. The crack began in the interface region due to tensile strain produced by the compressive load and then micro crack extended into the mortar matrix. Under the flexure loading, the cracks are initiated in the interfacial zone at low stresses and extend into the mortar matrix at high stresses and the resistant to cracks results from the cement paste only.

Table 6 and Fig. 4 show the effect of confinement conditions on flexural tensile strength of concrete with different level of concrete strength. The flexural tensile strength increases under confinement at different level of strength and the increase in flexural tensile strength decreases with the increase of level of concrete strength under the confining condition of concrete.

Table 7 shows the effect of confinement conditions on flexural tensile strength of unconfined concrete. The percentage increase remains more or less the same with the increase of age of concrete at same level of strength of concrete but with the increase of level of stress, the flexural tensile strength increases many fold. This is attributed to the behavior of compression and tension zone of flexure concrete member under confining condition at different age of concrete. The initiated cracks in tension zone are arrested and whole compression zone is also divided into smaller component zones due the presence of confinement reinforcement. For compressive strength of 24.1 MPa, 31.8 MPa and 37.7 MPa at 7-days, 28-days and 56-days, corresponding percentage increase of the confined flexural tensile strength over unconfined flexural tensile strength are respectively 66.9%, 46.8% and 61.7%. For compressive strength of 58.7 MPa, 81.2 MPa and 98.6 MPa, the confined flexural tensile strength percentage increase to 202.9%, 228.6% and 231.3% at 7-days, 28-days and 56-days respectively. Table 7 also shows the confined flexural tensile strength after deducting the flexural tensile strength of provided reinforcement simulating the large continuous concrete member. The maximum increase in the flexural tensile strength is still 175% over the unconfined flexural tensile strength even after deducting the flexural tensile strength of reinforcement.

Table 8 presents the effect of age of concrete on flexure tensile strength under different confining conditions of concrete. It is inferred from the table that the flexural tensile strength increases with the age of concrete. There is no clear relation-

Table 5 Effect of level of concrete strength on flexural tensile strength (unconfined).

Mix	Compressive Strength, f_c (MPa)			Flexural strength, f_r (MPa)		
	7-days (% increase in level of stress)	28-days (% increase in level of stress)	56-days (% increase in level of stress)	7-days	28-days	56-days
I	24.1	31.8	37.7	3.17	4.85	5.35
II	30.9 (28.2%)	44.95 (41.4%)	58.5 (55.2%)	4.55 (43.5%)	6.12 (26.2%)	7.08 (32.3%)
III	58.5 (89.3%)	78.2 (74.0%)	89.0 (52.1%)	5.44 (19.6%)	6.84 (11.8%)	8.15 (15.1%)
IV	58.7 (0.34%)	81.2 (3.8%)	98.6 (10.8%)	5.6 (2.9%)	6. 96 (1.7%)	8.29 (1.7%)

Table 6 Effect of level of concrete strength on confined flexural tensile strength.

Mix	Flexural Strength			
	Confined flexural strength, f_r (MPa)			Confined flexural strength after deducting the reinforcement strength (at 28-days age)
	7-days	28-days	56-days	
I	5.29	7.92	8.65	4.17
II	8.74 (65.2%)	13.38 (68.9%)	15.91 (83.9%)	9.63 (130.9%)
III	13.38 (53.1%)	20.07 (50%)	24.02 (50.1%)	16.32 (69.5%)
IV	16.96 (26.8%)	22.87 (13.95%)	27.53 (14.6%)	19.12 (17.2%)

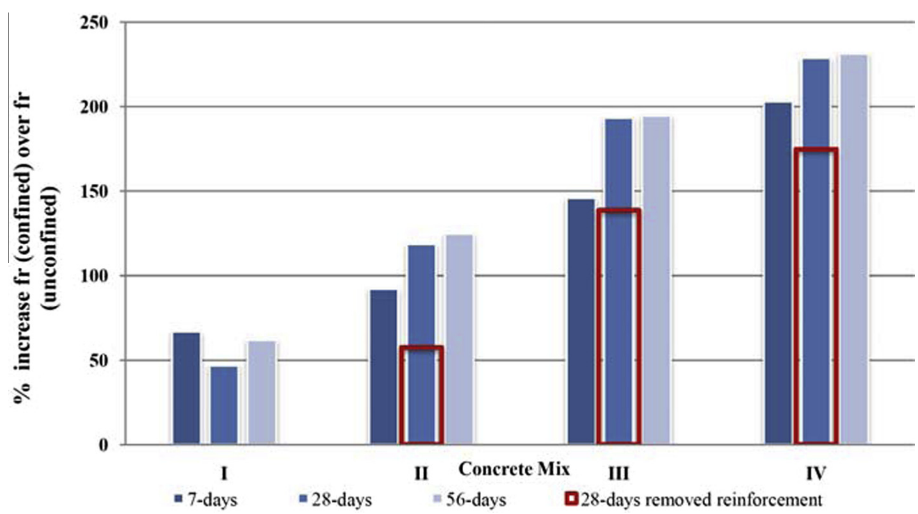

Figure 4 Effect of confinement on Flexural Tensile Strength of unconfined concrete.

Table 7 Effect of confinement over Flexural Tensile Strength of UNCONFINED concrete.

Mix	Flexural Strength			
	Percentage increase in confined f_r over without confinement f_r			Percentage increase in confined f_r over without confinement after deducting the reinforcement flexural strength (at 28-days age)
	7-days	28-days	56-days	
I	66.9	46.8	61.7	0.0
II	92.1	118.6	124.7	57.4
III	146.0	193.4	194.7	138.6
IV	202.9	228.6	231.3	174.7

ship between the increase in level of compressive strength and increase in flexural tensile strength of concrete with increase of age of concrete under different confining conditions. The percentage increase in flexural tensile strength at lower age is more than the percentage increase at higher age of concrete under with and without confined conditions. The percentage increase

Table 8 Effect of age on unconfined flexural tensile strength.

Mix	Compressive Strength, f_c (MPa)		Flexural Strength, f_r (MPa)			
	Percentage increase in f_c (7-days to 28-days)	Percentage increase in f_c (28-days to 56-days)	Percentage increase in f_r (7-days to 28-days)		Percentage increase in f_r (28-days to 56-days)	
			Unconfined	Confined	Unconfined	Confined
I	32.0	18.6	53.0	34.6	10.3	21.5
II	45.5	30.2	29.6	53.1	15.7	18.9
III	33.7	13.8	25.7	50.0	19.2	19.7
IV	38.3	21.4	24.3	34.9	19.4	20.4

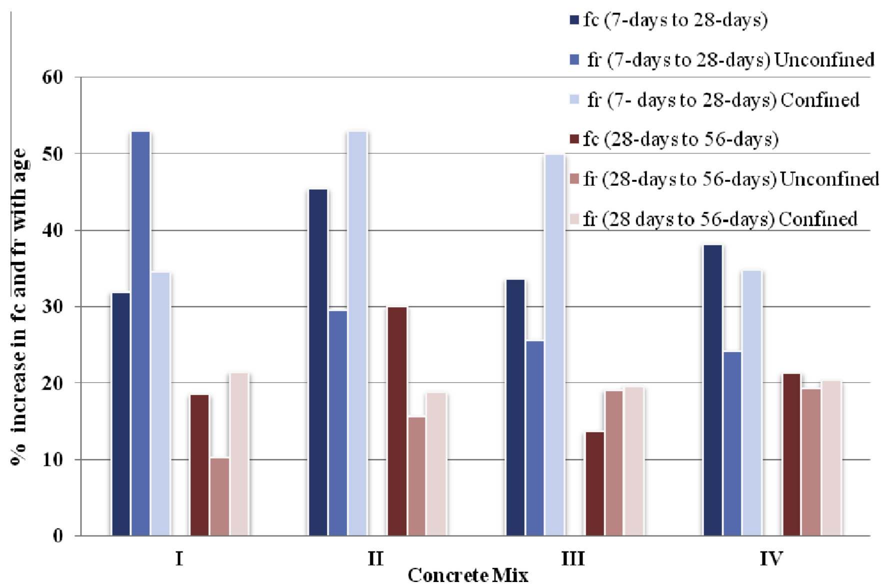

Figure 5 Effect of age on flexural tensile strength of concrete.

Table 9 Value of b_1 and b_2 under different age and confinement conditions.

Eqn. model	Value of b_1 and b_2		Flexural strength (MPa)	Compressive strength (MPa)
	Unconfined	Confined	Age (days)	Age (days)
Square Root (1/2) model	0.763	1.677	7	7
	0.830	2.069	28	28
	–	1.58 (deducting reinf.)	28	28
	0.880	2.28	56	56
	0.618	1.444	7	28
	0.955	2.489	56	28
	0.841	2.197	28 + 56	28 + 56
	0.810	1.990	7 + 28 + 56	7 + 28 + 56
(2/3) model	0.390	0.892	7	7
	0.420	1.040	28	28
	–	0.791 (deducting reinf.)	28	28
	0.430	1.113	56	56
	0.313	0.726	7	28
	0.484	1.252	56	28
	0.41	1.087	28 + 56	28 + 56
	0.412	1.010	7 + 28 + 56	7 + 28 + 56

in flexure tensile strength at different level of concrete strength is 53%, 29.6%, 25.7% and 24.3% when age of concrete increases from 7-days to 28-days while at similar level of concrete strength, percentage increase in flexure tensile strength is 10.3%, 15.7%, 19.2% and 19.4% when age of concrete increase from 28-days to 56-days. The percentage increase in flexural tensile strength of confined concrete at higher age is constant on various levels of concrete strength while it is

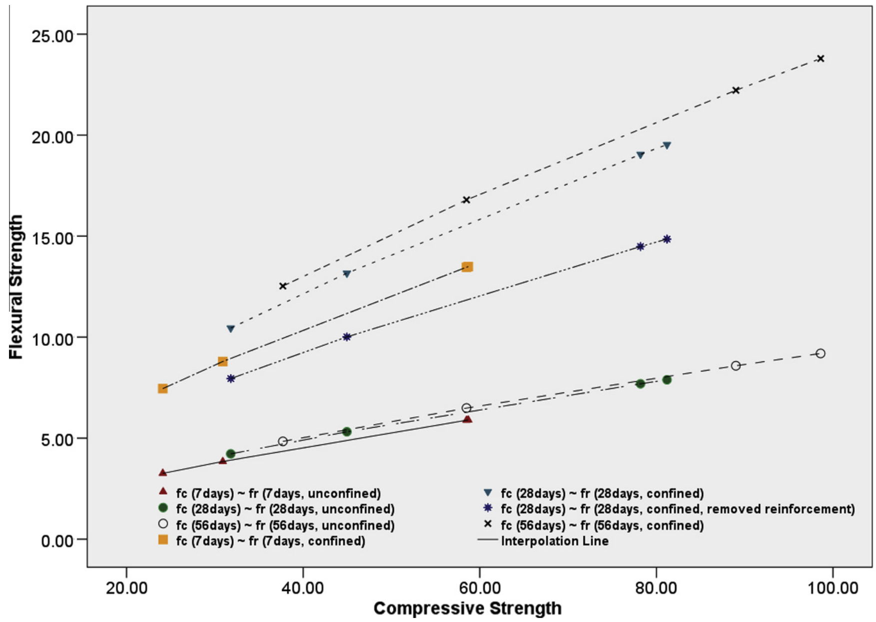

Figure 6 Comparative analysis of predicted flexure strength of different age and confining conditions using square root model equations.

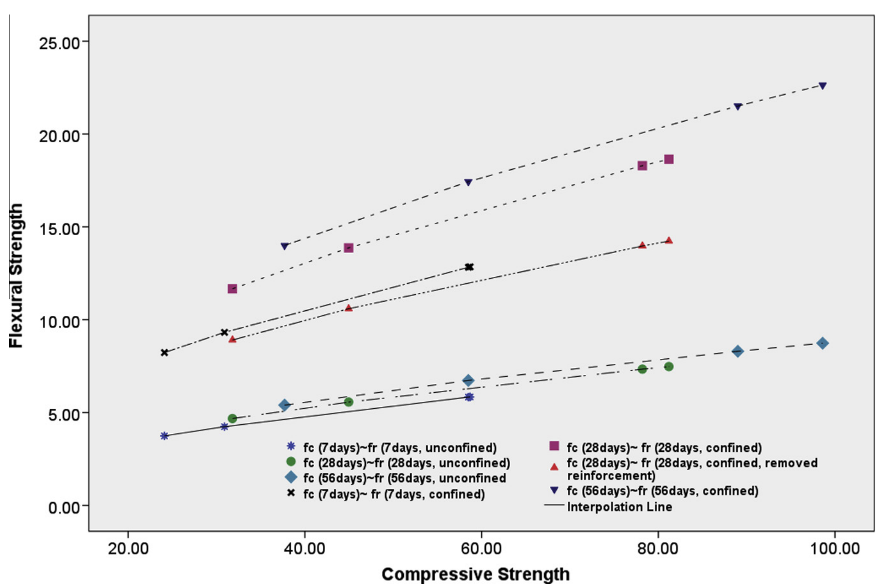

Figure 7 Comparative analysis of predicted flexure strength of different age and confining conditions using (2/3) power model equations.

increasing under unconfined condition. It increases about 20% when age of concrete is increased from 28-days to 56-days. The percentage increase in graphical form is depicted in Fig. 5.

The experimental study presented above is also analyzed by using linear regression analysis to derive proportionality equations to relate concrete flexure tensile strength (f_r) to compressive strength (f_c) in the standard form of square root and (2/3) models. Numbers of equation have been developed for predicting the flexure tensile strength for different age and confinement conditions of concrete having linear correlation coefficients (R^2) of about 0.90 in two standard models namely $f_r = b_1 f_c^{1/2}$, or $b_2 f_c^{2/3}$. The coefficients of equations i.e. b_1 and b_2 are presented in Table 9.

The derived equations in square root and (2/3) models are plotted in Figs. 6–9. It is clear from the derived proportionality equations for flexural tensile strength that the there is a wide variability in proportionality coefficient of square root model than the coefficient in 2/3rd power model. This means that the 2/3rd power model is better choice to incorporate the effect of affecting parameters in the co-relation equations for flexural tensile strength.

The following equation for standard strength of concrete at 28 days is also proposed considering the combined effect of concrete with no confinement, with confinement and age of concrete in power model because of its more reliability and

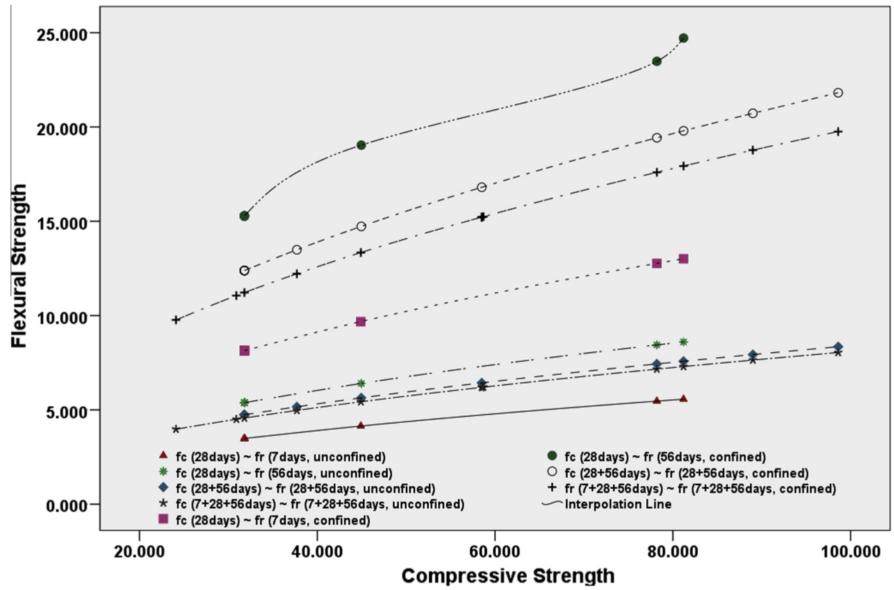

Figure 8 Comparative analysis of predicted flexure strength of combined age and confining conditions using square root model equations.

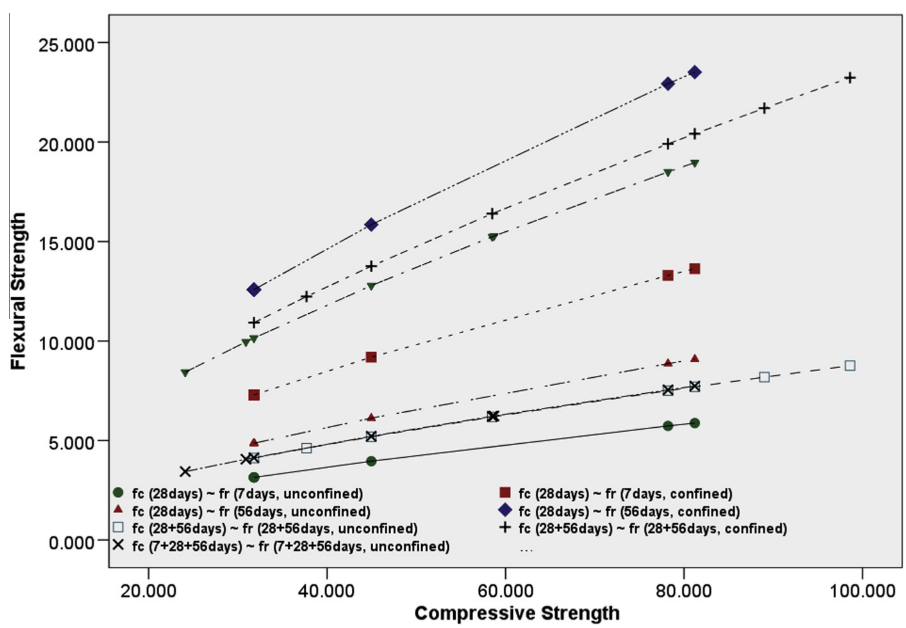

Figure 9 Comparative analysis of predicted flexure strength of combined age and confining conditions using (2/3) power model equations.

suitability to accommodate the affecting parameters of flexure tensile strength.

$$f_r = \lambda_1.\lambda_2.0.45.f_c^{2/3} \tag{1}$$

where λ_1 and λ_2 are multiplying factors for age of the concrete and confinement condition of concrete. The values of λ_1 and λ_2 are 1 for 28 days and for plain concrete without reinforced members. $\lambda_1 = 0.95$ and 1.05 for 7 days and 56 days of concrete, and $\lambda_2 = 1.45$ for confined conditions.

The reliability of proposed equation is assessed using the statistical procedures. Pearson's coefficient (R), linear correlation coefficient (R^2), standard deviation (SD), mean and coefficient of variation (COV) have been estimated for the flexural tensile strength values obtained using the proposed equation. An error parameter, relative predictive error (RPE), used by others (Hueste et al., 2004) to know the goodness of fit of predictive equations, is also determined. The RPE is evaluated as follows

$$\text{RPE} = \frac{1}{n}\sum_{k=0}^{n}\left(\frac{f'}{f} - 1\right)^2$$

where f is experimental value of flexural tensile strength and f' is predictive value of flexural tensile strength. The proposed

Table 10 Statistical comparison of predicted values from derived equation and code equations.

Equations	R	R^2	SD	Mean	COV	RPE
Saudi Arabia code[a] (0.5 power model)	0.939	0.918	1.155	5.285	0.219	0.027
ACI code 1[b] (0.5 power model)	0.939	0.918	0.853	3.903	0.219	0.142
ACI code 2[c] (0.5 power model)	0.939	0.918	1.552	7.097	0.219	0.026
Proposed equation (2/3 power model)	0.933	0.917	1.931	6.728	0.287	0.0243

[a] Saudi Building Code-SBC-304, (2007).
[b] ACI 318 (2005).
[c] ACI 363 (1992).

equation provides a good correlation with the experimental values. The comparative analysis of statistical parameters for proposed equation, Saudi code and ACI codes equations for compressive and flexural tensile strength of concrete are given in Table 10.

4. Conclusion

The flexural tensile strength of concrete is an important parameter for designing the flexure members. The confining conditions and age of concrete will influence the mechanical properties of concrete including its flexural tensile strength. The study presents the experimental investigation of flexural tensile strength of concrete for wider range of concrete strength with its affecting parameters namely, level of concrete strength, confining and age of concrete. The results of experimental observation on flexural tensile of concrete are discussed. The empirical relations between flexural tensile strength and compressive strength of concrete considering affecting parameters are derived in standard i.e. square root and 2/3rd power, form. By using linear regression analysis, the following equation for flexural tensile strength is proposed in terms of affecting parameters.

$$f_r = \lambda_1.\lambda_2.0.45.f_c^{2/3}$$

where λ_1 and λ_2 are multiplying factors for age of the concrete and confinement condition of concrete. The values of λ_1 and λ_2 are 1 for 28 days and for plain concrete without reinforced members. $\lambda_1 = 0.95$ and 1.05 for 7 days and 56 days of concrete, and $\lambda_2 = 1.45$ for confined conditions. The numerical factors in the above relationship between flexural tensile and compressive strength are based on the limited experimental data results. Additional experimental investigations and test data are required for definite recommendations about the numerical factors for empirical relationship of flexural tensile and compressive strength of concrete that include the various levels of strength and confinement, larger sizes of members and ages of concrete.

Further, the following conclusions may be drawn based on results of the limited experimental program reported in the present study.

- The empirical relationships for flexural tensile strength and compressive strength of concrete proposed in the literature and standards have low validity range of compressive strength. The flexural tensile strength affecting parameters has been not integrated in the earlier proposed proportionality equations.
- The (2/3) power model for proportionality relationship for flexural tensile strength and compressive strength is more suitable to include the wider range of level of concrete strength.
- The confinement conditions and age of concrete member have a remarkable effect on flexure strength of concrete, so correlation equations should include the factors to incorporate the effect of such parameters.
- The presented proportionality equation in (2/3) power model is applicable to a wider range of levels of concrete strength and includes the factors for parameters affecting the flexural tensile strength.
- The flexural tensile strength increases with increase of age and strength of concrete. The proportional increase in the flexural tensile strength at same age of concrete goes on decreasing with increase of level of concrete strength.
- The flexural tensile strength increases many folds under confinement confining condition of concrete. The percentage increase in flexural tensile strength with the increase of age of concrete under confining condition of concrete is constant at different level of compressive strength.

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References

Abdul Razak, H., Wong, H.S., 2004. Re-evaluation of strength and stiffness relationships for high-strength concrete. Asian J. Civil Eng. (Build. Hous.) 5 (1–2), 85–99.

ACI Committee 318, 2005. Building Code Requirements for Structural Concrete (ACI 318–05) and Commentary (318R–05). ACI, Farmington Hills, MI, p. 430.

ACI Committee 363, 1992. Report on High-Strength Concrete (ACI 363R–92). American Concrete Institute, Farmington Hills, MI, p. 56.

Ahmed, M., Dad Khan, M.K., Wamiq, M., 2008. Effect of concrete cracking on the lateral response of RCC buildings. Asian J. Civil Eng. (Build. Hous.) 9 (1), 25–34.

Ahmed, M., El Hadi, K.M., Abul Hasan, M., Mallick J. Ahmed, A., 2014. Evaluating the co-relationship between concrete flexural tensile strength and compressive strength, Int. J. Struct. Eng. 5 (2).

Amudhavalli, N.K., Mathew, J., 2012. Effect of silica fume on strength and durability parameters of concrete. Int. J. Eng. Sci. Emerg. Technol. 3 (1), 28–35.

Bazant, Z.P., Novak, D., 2001. Proposal for standard test of modulus of rupture of concrete with its size dependence. Am. Concrete Instit. Mater. J. 98 (1), 79–87.

Gonen, T., Yazicioglu, S., 2009. The Influence of Mineral Admixtures on the Short and Long Term Performances of Concrete. Department Of Construction Education, Firat University, Elazig 23119, Turkey.

Hueste, M.B., Chompreda, P., Trejo, D., Cline, D.B.H., Keating, P.B., 2004. Mechanical properties of high strength concrete for prestressed member. Am. Concrete Instit. Struct. J. 101 (4), 457–465.

Koksal, F., Altun, F., Yigit, I., Sahin, Y., 2008. Combined effect of silica fume and steel fibre on the mechanical properties of high strength concretes. Construct. Build. Mater. 22 (8), 1874–1880.

Kothai, L., Malathy, R., 2012. Strength studies on self compacting concrete with manufactured sand as partial replacement of natural sand. Eur. J. Sci. Res. 89 (3), 490–496.

Légeron, F., Paultre, P., 2000. Prediction of modulus of rupture of concrete. Am. Concrete Instit. Mater. J. 97, 193–200.

NCHRP, 2004. Guide for Mechanistic-Empirical design – of new and rehabilitated pavement structures, Final Report. National Cooperative Highway Research Program, ARA Inc, ERES Consultants Division, 505 West University Avenue, Champaign, IL.

Raphael, J.M., 1984. Tensile strength of concrete. Am. Concrete Instit. J. 81, 158–165.

Saudi Building Code-SBC-304, 2007. Structural-Concrete Structures, The Saudi Building Code, Structural Technical Committee (SBC–STC), pp. 5/2.

Siddiqui, S., 2011. Utilization of silica fume in concrete: review of hardened properties. Resour. Conserv. Recycl. 55, 923–932.