Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 4, No. 11, November, 2018

Experimental and Numerical Study to Determine the Relationship between Tensile Strength and Compressive Strength of Concrete

Baitollah Badarloo [a*], Amir Kari [a], Faezeh Jafari [b]

[a] *Department of Civil Engineering, Qom University of Technology (QUT), Qom, Iran.*

[b] *Department of Civil Engineering, Malayer University, Malayer 65719-95863, Iran.*

Received 18 April 2018; Accepted 19 September 2018

Abstract

As one of the most widely used materials in different structures, concrete is a material evaluated and categorized based on compressive strength criterion. In addition, national and international codes (INBC- part 9) and standards determine the tensile strength of concrete based on its compressive strength. The purpose of this research is to determine the relationship between compressive strength and tensile strength of C20, C30 and C40 grades. In this laboratory research, a total of 42 cubic specimens of 150 × 150 × 150 mm and 42 cylindrical specimens of 300 × 150 mm were assessed under compressive and tensile tests, respectively. Based on the results of this study, the relationships presented in Ninth Article of Iranian National Building Codes, ACI-318 and Euro Code 2 have been evaluated.

Keywords: Concrete; Compressive Strength; Tensile Strength; Relationship.

---

1. Introduction

Despite its abundant use in building industry due to its considerable advantages, concrete has some disadvantages; so that low tensile strength is considered as the greatest deficient for concrete. According to Codes for design of concrete structures, tensile strength of concrete is ignored in the design of concrete elements. Therefore, concrete tensile strength and its effective factors are of minor importance to researchers; hence, comprehensive and extensive researches are not done in this subject. According to the American Concrete Institute (ACI-318), the tensile strength of concrete is proportional to square root of its compressive strength [1]. Recent research on the relationship between tensile and compressive strengths of concrete indicates that the tensile strength of concrete is proportional with a 0.6 to 0.8 power of its compressive strength; thus, the proposed relation in ACI-318 Code is an inappropriate relation [2-5]. In addition, the results of conducted researches show that the ratio of tensile strength to compressive strength of concrete is decreased by increasing the compressive strength of concrete. In 2007, Öttl et al. studied the correlation between tensile, flexural and compressive strength of autoclaved aerated concrete to evaluate prEN 12602 standards. The result of this research includes statistical evaluation and provides a proposal for standardization of prEN 12602 guideline [6]. In 2011, Anuradha studied the relationship between compressive and tensile strength in the geopolymer. This relationship investigated for different mixture between grade of geopolymer and the result showed that the relationship in conventional meaning was not valid for GPCs and some current relationships should use to predict tensile strength [7]. In 2013, Yan predicted the correlation between tensile and compressive strength by using SVM method. In this research, SVM and experimental method were employed to obtain compressive and tensile strength and then predict split strength [8]. In 2017, Yao investigated the relationship between compressive and splitting tensile strength of old concrete existing

---

* Corresponding author: badarloo@qut.ac.ir

http://dx.doi.org/10.28991/cej-03091198

under marine environment. The result of this research showed that the tensile strength has positive relationship with compressive strength and the researchers claimed that the value of tensile strength could be predicted by using compressive strength [9]. In 2017, Akinpelu used analytical and experimental method to obtain the relationship between compressive and tensile strength for vibrated concrete (VC) and self-compacting concrete. Experimental research showed that the ratio of the splitting tensile to compressive strengths decrease with increasing compressive strength [10]. In 2018, Chhorn investigated the relationship between compressive and tensile strength for RCC conventional concrete; to this end, the directed tensile strength and compressive strength were obtained by experimental test [11]. In 2018, Zhang studied the correlation between compressive strength and flexural strength of pavement geopolymer; 20 groups of samples were made for this research. Mechanical test were employed for determining compressive and fractural strength; ultimately, the linear relationship between compressive and flexural strength were calculated in this research [12].Using RMSE, MSE and R^2 to obtain the accuracy of relationship in predicting method is common in different researches for example: Badarloo et al studied the effect of position and number of openings on the Performance of composite steel shear walls and in this study , authors used RMSE and R^2 to evaluate neural network method [13]. Khotbehsara et al. used ANFIS to predict physical concrete property and its durability with nanoparticle; in this study, the author used neural network and some statistical value such as RMSE, R^2 to evaluate the accuracy of neural network [14]. In 2018, Ghanei et al. studied the impact of Nanoparticle on the concrete; they used ANFIS and SVM to predict concrete property [15]. Naseri et al. used SVM method to predict physical concrete and its durability with Nano. In this research, authors used RMSE and R2 to evaluate the accuracy of neural network method [16].

Different researcher in the world studied the relationship between compressive and tensile strength in some guidelines such as ACI [1] and EURO Code [17]. Increasing the number of research in this field is necessary because the designer and engineering must be able to trust guideline's equation more than ever and these researches help them to design better than ever. It is obvious that, the relationship between compressive and tensile strength in different guideline could be improved or changed by changing the grade of concert, material and age of concrete in different countries.

The purpose of this research is to determine the relationship between compressive strength and tensile strength of concrete; and the possibility of using compressive strength to estimate tensile strength was discussed. Besides it, ACI guideline, European and Iranian National Code (INBC- part 9) [18] compared with experimental result and the accuracy of guideline's relationships were investigated in different guidelines. Experimental test and numerical approach are used in this study in two steps. Firstly, in order to prepare concrete mix designs for C20, C30 and C40 grades, cylindrical 300 × 150 mm specimens and cubic 150 × 150 × 150 mm specimens were prepared and tested after 7-days and 28-days curing periods. Cylindrical specimens have been used to determine tensile strength (Brazilian Tensile test for concrete); while cubic specimens have been used to determine compressive strength of concrete (compressive failure test). Secondly, all data were entered to Excel and Easy Fit Software for obtaining the best relationship between experimental tests. Some statistical parameters such as fit distribution, RMSE and R^2 were employed to evaluate different relationship.

2. Method and Material

2.1. Materials

Cement: Cement used in this research includes cement type two produced in Tehran Cement Factory. According to the catalog provided by the factory, the properties of the used cements are in accordance with the characteristics specified in National Iranian Standard No. 389 [19].

Water: In this study, based on the considerations described in Section 9.10.4.2 by Ninth Article of National Building Codes [20], clean and smooth drinking water (urban drinking water) has been used.

Gravel: The sand used in this research is a river gravel with a maximum fracture percentage and a maximum diameter of 25 mm. Gradation test was performed according to Iranian National Standard No. 302 [21] and the gradation curve is shown in Fig. 1.

Sand: The sand used in this research is river sand and its corners are slightly rounded. Gradation test was conducted according to Iranian National Standard No. 302 [8]; gradation curve is shown in Figures 1 and 2.

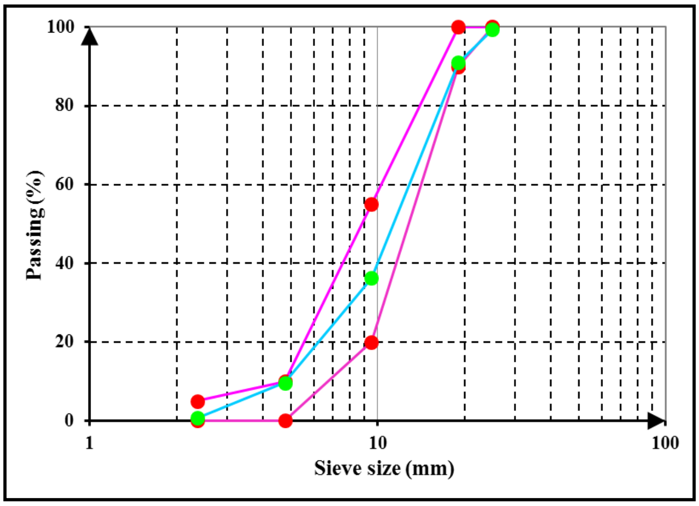

Figure 1. Gradation curve of coarse aggregate along with the upper and lower limits of Iranian National Standard No. 302

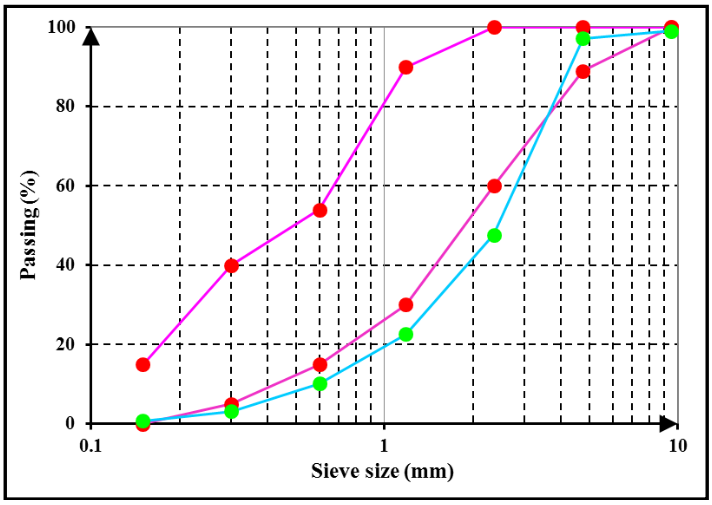

Figure 2. Gradation curve of fine aggregate along with the upper and lower limits of Iranian National Standard No. 302

1.1. Concrete Mix Design

Concrete mix design used in this study is based on a weighting method and according to provisions of 479-Z Issue (The National Method for Concrete Mix Design). Three mix designs are prepared based on the average strength of 20, 30 and 40 MPa corresponding to the C20, C30 and C40 grades, the components of each of which are presented in Table 1. In this study, the mix designs of A, B and C are corresponding to C20, C30, and C40 grades, respectively

Table 1. Mix proportions for C20, C30 and C40 concrete

Mix. Design	Water	Cement	Sand	Gravel
A	204	322	696	1139
B	203	357	666	1139
C	203	460	580	1139

1.2. Specimens

In this research, as described in Table 2 and Figure 3, 84 specimens, including both cubic (150 × 150 × 150 mm) and cylindrical (150 × 300) mm ones were prepared. They have been tested at the age of 7 and 28 days under compressive strength tests. All specimens were cured 24 hours after casting and striking of formworks in a water pond at 25-22 ° C temperature up to the desired ages (7 and 28 days) [22].

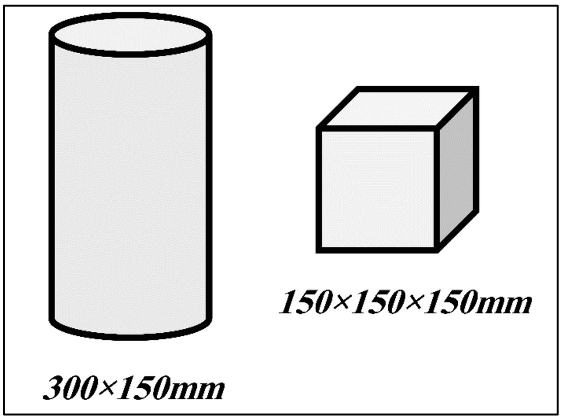

Figure 3. Dimension for cylinder and cubic specimens

Table 2. Specifications of concrete specimens

Specimen Age	Mix A		Mix B		Mix C	
	Cu	Cy	Cu	Cy	Cu	Cy
7	7	7	7	7	7	7
28	7	7	7	7	7	7

2. Testing Procedure

Test for determining the compressive strength of concrete on cubic specimens and test for determining tensile strength by Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens were done according to ASTM C496-90 [23] and ASTM C-39 [24] standards, respectively. In this study, specimens were taken out of the water in the desired ages, loaded in wet conditions using a 200-ton hydraulic jack, and then tested. A sample image of how to test the specimens is shown in Figure 4.

Figure 4. Compressive, tensile samples and mechanical instruments

3. Experimental Results

The results obtained from the compressive and tensile strength tests on the cubic and cylindrical specimens are shown in Table 3. It should be noted that, in this study, seven similar samples were prepared for each series of specimens; then, the values of compressive and tensile strengths presented in Table 3 were based on an average amount of 7 specimens. In this table, Cu and Cy represent cubic (150 × 150 × 150 mm) and cylindrical (150 × 300 mm) specimens, respectively.

Table 3. Mean compressive and tensile strength results of specimens (MPa)

Specimen Age	Mix A		Mix B		Mix C	
	Cu	Cy	Cu	Cy	Cu	Cy
7	29.61	2.62	23.98	2.28	15.08	1.76
28	42.34	4.14	35.24	3.78	23.80	3.01

Figures 5 and 6 show the stress – strain curve for compressive strength in different grade. The manner of different grade for 27 and 7 days are similar and the maximum point indicates the average of compressive strength for concrete.

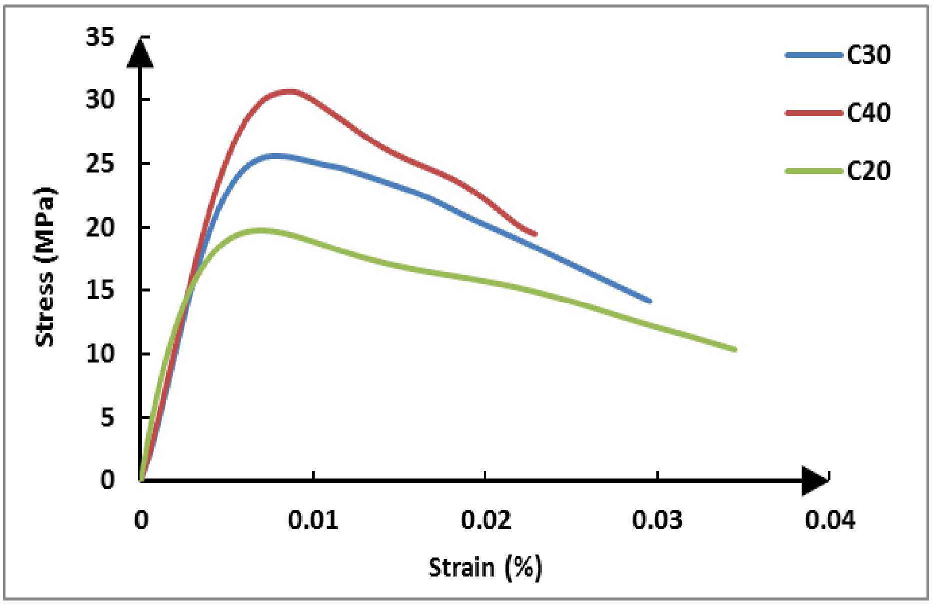

Figure 5. Stress – strain curve for samples at 7 days

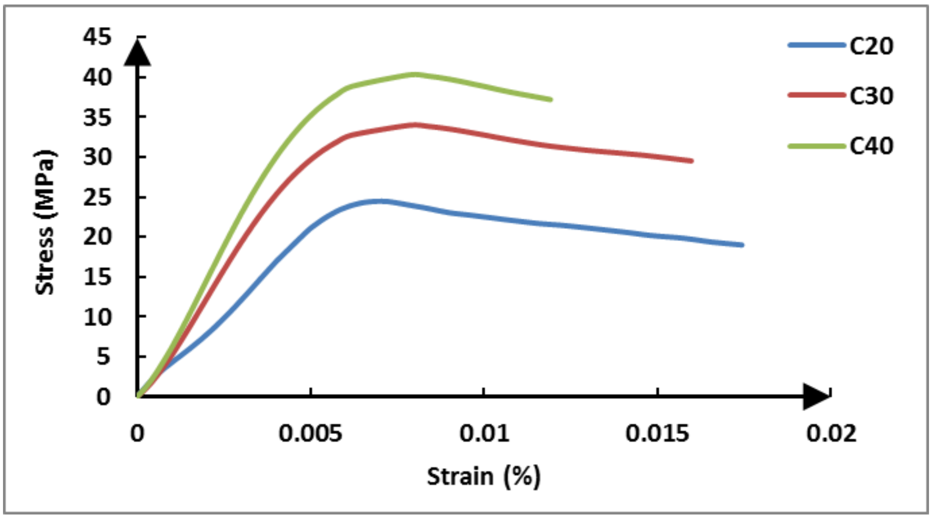

Figure6. Stress – strain curve for samples at 28 day

4. Numerical Part

4.1. Guide Line Formulae

This research examines the relationships between the regulations and compares them with the actual data. Different regulations have suggested different relationships for estimating the tensile strength based on the compressive strength; moreover, Equations 1 to 3 show the value of tensile strength based on the compressive strength for the Euro Code, ACI-318 and the Iranian National Building Code (INBC-part 9), respectively.

$$f_t = \frac{0.3}{0.9\times(f_c^{\frac{2}{3}})} \tag{1}$$

$$f_t = 0.56 \times \sqrt{f_c} \tag{2}$$

$$f_t = 0.6 \times \sqrt{f_c} \tag{3}$$

4.2. Accuracy of Guide Line Formulae

To this end, first, the guideline predicted the tensile strength. Next, these values were compared with the experimental results, and it is presented in Figures 9 to 12. It is expected that the predictions of guideline were very close to the experimental values. The prediction accuracy of this method is evaluated based on the relative root–mean–squared–error (RRMSE) and the absolute fraction of variance R^2: In equation 1, y and $\bar{y}$ are experimental result and guideline result; and (n) represents the number of data. The prediction accuracy was the highest value among models when the value of RRMSE is near to zero and the value of R^2 is near to 1.

$$\text{RRMSE}=\sqrt{\frac{n_t \sum_{i=1}^{n_t}(y_i-\overline{y_i^2})}{(n_t-1)\sum_{i=1}^{n_t} y_i^2}} \tag{4}$$

$$R^2 = 1-\left(\frac{\sum_{i=1}^{n_t}(y_i-\bar{y}_i)^2}{\sum_{i=1}^{n_t}\bar{y}_i^2}\right) \tag{5}$$

In Equation 4, y and $\bar{y}$ are experimental result and guide line result; and (n) is the number of data. The prediction accuracy was the highest value among models when the value of RRMSE is near to zero and the value of R^2 is near to 1.

4.3. Probabilistic Part

It is common to estimate the probability and frequency functions in concrete research to represent the mean, data variance and statistical distribution in concrete reliability research. In the research, after finding the statistical distributions, the safety factor is estimated for different relations in the regulations. This part of the research aims to estimate the statistical function and other statistical parameters of the samples tested in the laboratory in the field of compressive strength and tensile strength. In this part of the study, in order to compare the results, the statistical analysis of the data extracted from the laboratory is conducted to determine which statistical function they follow. Previous research has proposed different functions for concrete compressive and tensile strength data. In the present study, after the laboratory studies, the results were given to the Easy Fit software [25] and the software plotted the best statistical function on the data. It could be stated that among the known statistical functions, the software suggested the lognormal function for the compressive strength data and the normal function for the tensile strength. In previous studies such as [26, 27], which carried out statistical investigations on concrete data, it has been shown that laboratory data usually follow the normal or lognormal functions for the compressive and tensile strength, which are variable in various investigations. On the other hand, the results show that there is a close distribution between the compressive and tensile strength data and the frequency around the mean point, indicating a good correlation between the compressive and tensile data. In fact, two following figures (Figures 7 and 8) show the dispersion of the data for the compressive strength in the range (12-43), as well as the results of tensile strength in the range (1.47-4.45), which shows the frequency of data in the vertical axis. In the lower quartile of the compressive strength (24-26), the frequency of compressive strength data further differs from the frequency of tensile strength data. Therefore, it could be stated that in this range, the estimate of tensile strength from the compressive strength values can contain some errors (due to the high dispersion of the data); however, in other parts, it is almost possible to estimate the tensile strength data with an appropriate approximation. According to Table 4, 75% of the data have the compressive strength less than 37, which has the same relative frequency as the tensile strength of their samples.

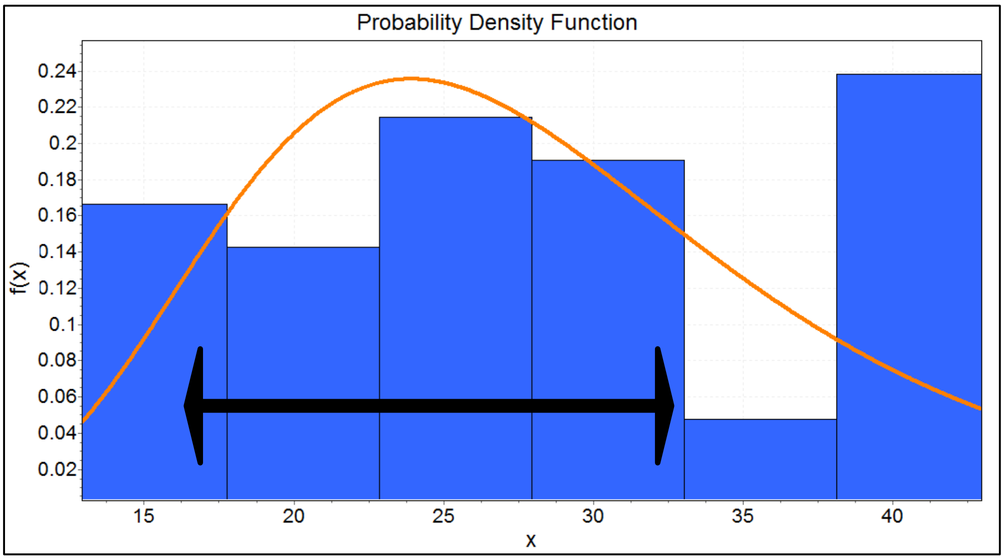

Figure 7. Probable density function for compressive strength result

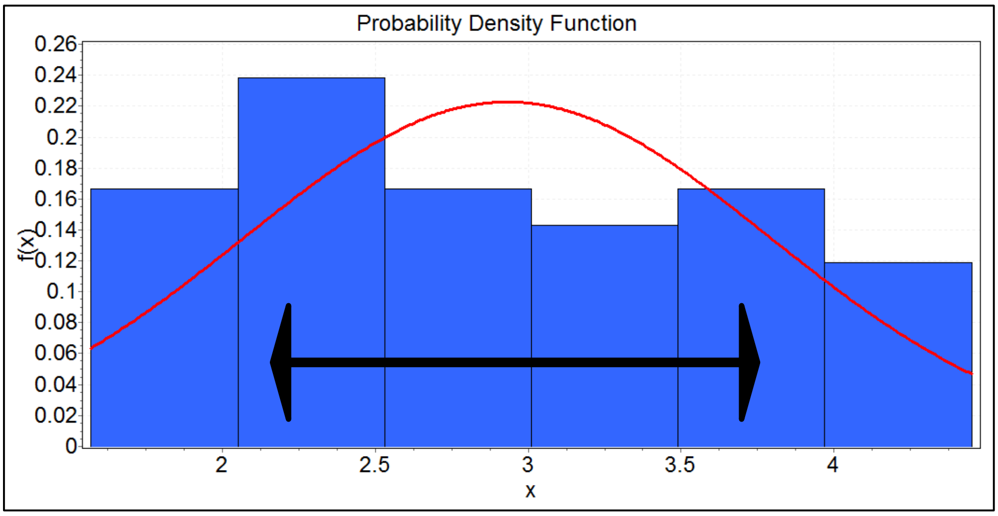

Figure 8. Probable density function for tensile strength result

The closeness of the fitted distributions to the experimental data suggests that the behavior of concrete in tension and compression for the same mix design imitates each other. In other words, the growth of compressive strength leads to an increase in the tensile strength (with a given ratio). A summary of the statistical parameters such as standard deviation, mean, data range, etc. is obtained from the Easy Fit software; and it is shown in Table 4 for better statistical understanding of the numerical nature of the samples.

Table 4. Specifications of concrete specimens

Compressive strength				Tensile strength			
Statistic	**Value**	**Percentile**	**Value**	**Statistic**	**Value**	**Percentile**	**Value**
Sample Size	42	Min	12.69	Sample Size	42	Min	1.57
Range	30.51	5%	13.77	Range	2.88	0.05	1.6745
Mean	28.342	10%	15.99	Mean	2.9317	0.1	1.722
Coef. of Var	0.32186	25% (Q1)	21.933	Coef. of Var	0.29319	25% (Q1)	2.255
Std. Error	1.4076	50% (Median)	27.24	Std. Error	0.13263	50% (Median)	2.755
Skewness	0.15052	75% (Q3)	36.832	Skewness	0.20676	75% (Q3)	3.6525
Excess Kurtosis	-0.95729	90%	42.563	Excess Kurtosis	-1.1156	0.9	4.298
		95%	43.037			0.95	4.387
		Max	43			**Max**	4.45

4.4. Numerical and Experimental Relationship

This part of the study estimates the relationship between the compressive strength and tensile strength among the actual data and the results are shown in Figures 9 and 10. The results of the two figures show that the data from the C30 grade have less distance to the regression line and this distance increases in the C20 grade. However, at the age of 7 and 28 days, there is a significant relationship between the compressive strength and the tensile strength of the concrete, so that the R^2coefficient is higher than 0.90 for all concrete grades at both ages. The correlation between the results shows that it is possible to estimate the tensile strength from the compressive strength. Figures 11 and 12 show the results of the tensile strength estimated by various equations in different guidelines and the tensile strength obtained from the laboratory test. Since the correlation coefficient for both concrete ages in the actual data (Figures 11 and 12) is higher than 0.90, but this coefficient is 0.84 in the estimated data of various equations with the actual values, as shown in Figure 12, it seems that by proposing separate relationships for both concrete ages, it would be possible to predict more accurate values. It is also possible to obtain a linear function for 7days concrete with respect to the high regression coefficient. Given that the samples were produced in Iran, as expected, the correlation coefficient between the actual and estimated data in the Iranian National Building Code was the highest at the ages of 7 and 28. The slope of the line in the ACI Regulation is lower than the rest of regulations and higher in the Iranian National Building Code than other data, which importantly indicates that the Iranian National Building Code estimates the values of tensile strength at the age of 7 days more than the actual value. However, with increasing the concrete age, the slope of the line decreases and the estimated values are closer to the laboratory data. The higher correlation of laboratory data in the C30 grade and the decrease in this value with the increase in the concrete grade indicates that the use of a single relationship for the estimation of all concrete grades leads to the errors, and it is possible through conducting more experiments to more accurately estimate the results for each grade and present a separate relationship for them.

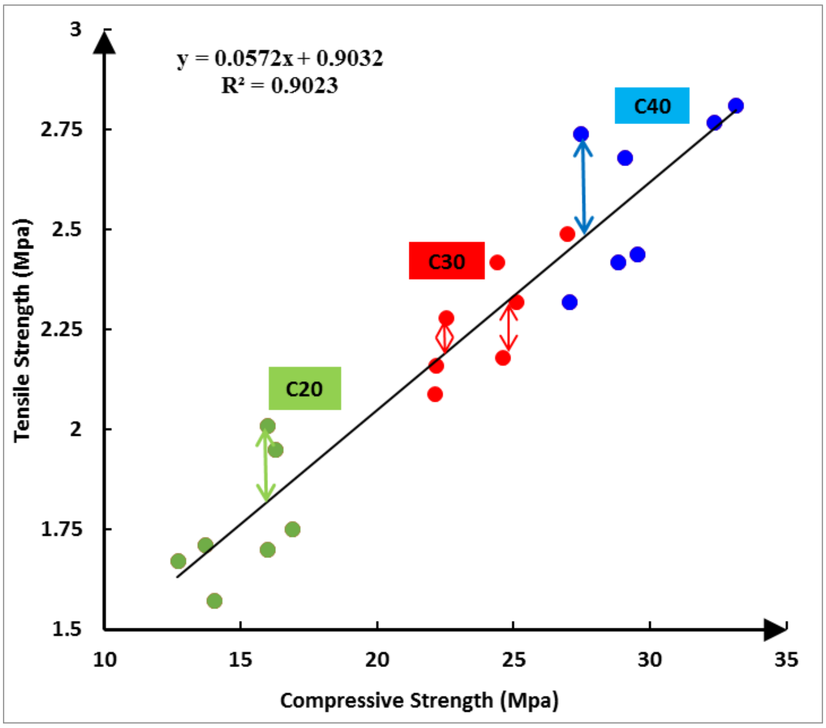

Figure 9. Experimental result for tensile and compressive strengths (7 days)

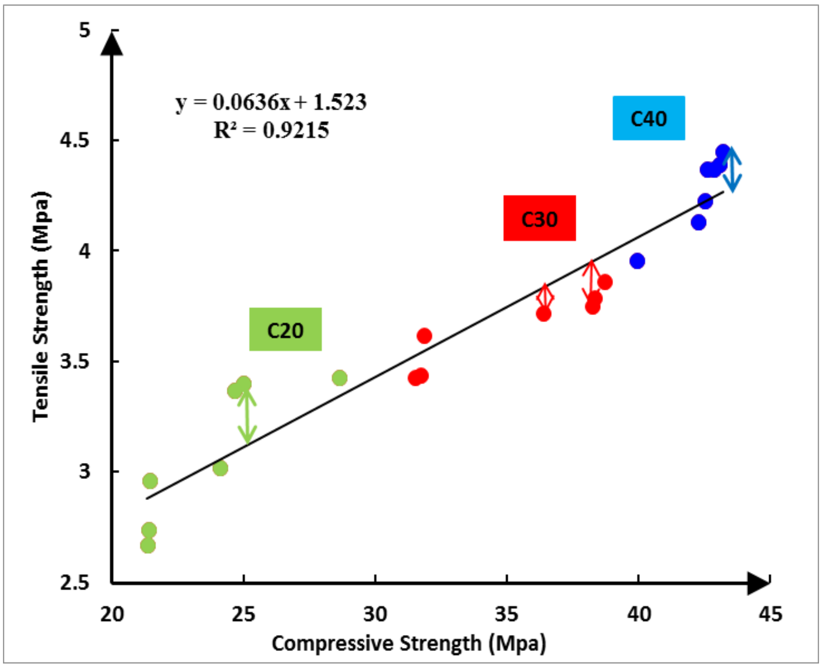

Figure 10. Experimental results for tensile and compressive strengths (28 days)

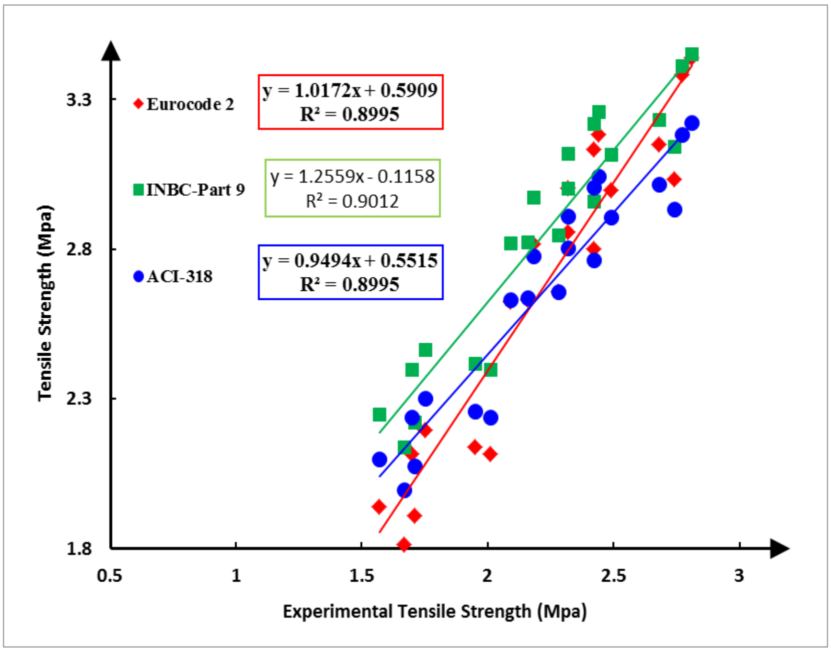

Figure 11. Experimental and guideline result for tensile strength (7 days)

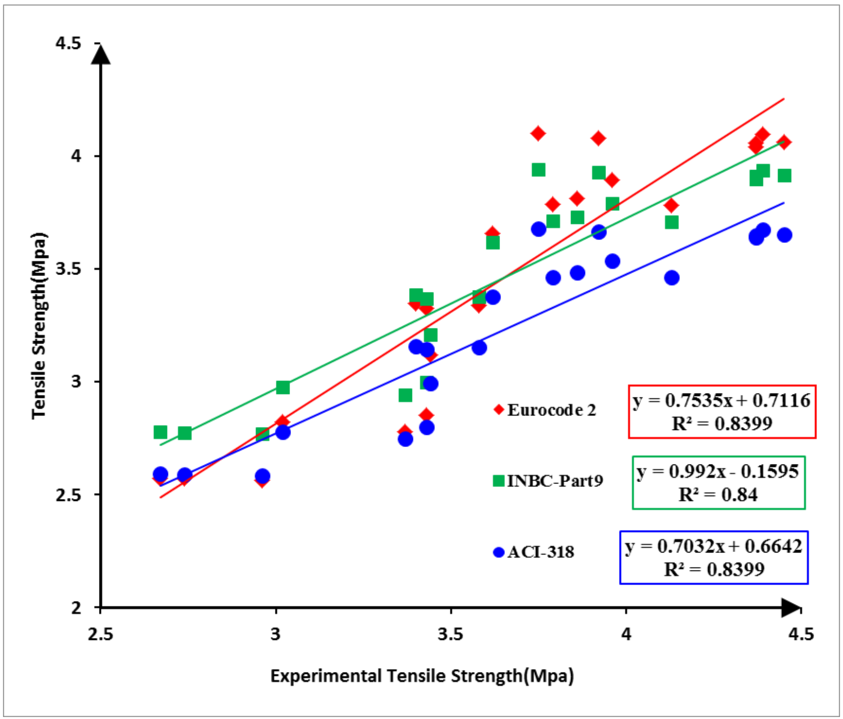

Figure12. Experimental and guideline result for tensile strength (28 days)

4.5. Growing Percentage

In this part of the study, the growth rates in different regulations are calculated through the numerical Equation 6.

$$growing\ percentage = \frac{guide\ line\ data - experimental\ data}{guide\ line\ data} \times 100 \tag{6}$$

It is investigated in the current study that how close is the estimated equation for the tensile strength at different ages to the actual values. The results show that in the C20 grade, the growth rate is about 41%, which is decreased by increasing the concrete grade; and the values obtained in the C30 grade for the 7-day concrete have the lowest growth rate (the closest value) to the actual values. Figure 13 shows that the relations in the regulations estimate the tensile strengths above the actual value for 7 days concrete (about 41%), while Figure 14 shows that, this value is negative for a 28 days concrete (-21%). In fact, the regulation proposes the values below the actual, because 28 days is the basis of designing; so that if the designer has to use the relations of the regulation, the issues such as material diversity, change in the concrete grade and the production process would not reduce the tensile strength of concrete and the 28 days and tensile strength would be safe for designing. In addition, the available relationship between the C20 and C30 intermediate grades in the regulation estimates the results closer to reality for both 7 and 28 days.

In fact, given that only a single relation is proposed for different ages of concrete in different grades by the equations, the results indicate that this relation is intended to estimate the 28 days strength with a lower and safer growth rate. Thus, using guideline to estimate tensile strength is more suitable for the age of 28 days. On the other hand, the estimated values in the middle grades (C30) are closer to reality. Therefore, based on the research results, it is suggested that the tensile strength is estimated from the 28-day concrete strength, and if the materials inside Iran are used, then the Equation 3 from the Iranian national building is used to estimate the tensile strength. The comparison of the three equations shows that the 7days tensile strength in the ACI and Euro code has less growth rate and offers a closer approximation to reality (grade C20); while in the Iranian National Building Code, the values for the 28days tensile strength are closer to reality for the C20 grade. Producing more samples and comparing them with the results of the regulations can help designers and engineers to more precisely estimate the tensile strength in different concrete grades and suggest the suitable regulations for different ages and grades of concrete. The results of this study show that the Euro Code used for the C20 grade gives the best results for the 7days. The Iranian National Building Code and Euro Code used at 28 days for the C30 grade have the best results, and these are so close to reality.

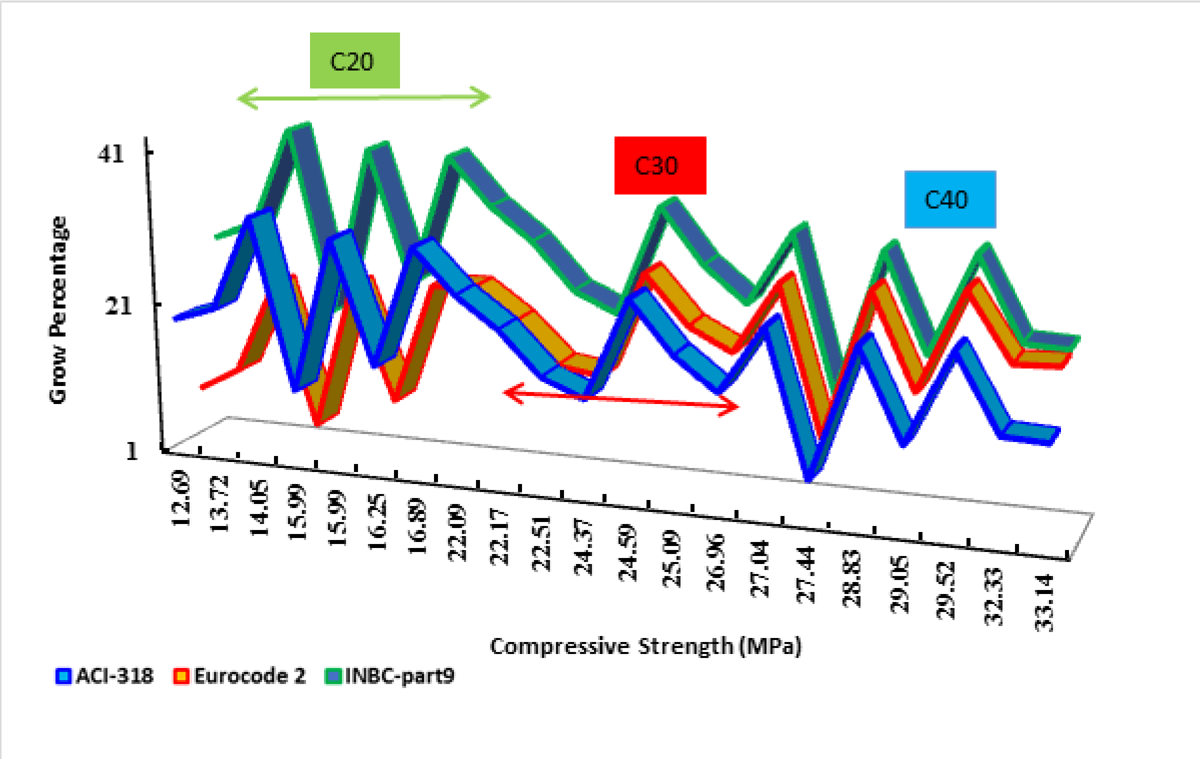

Figure 13. Growing percentage for specimens (7 days)

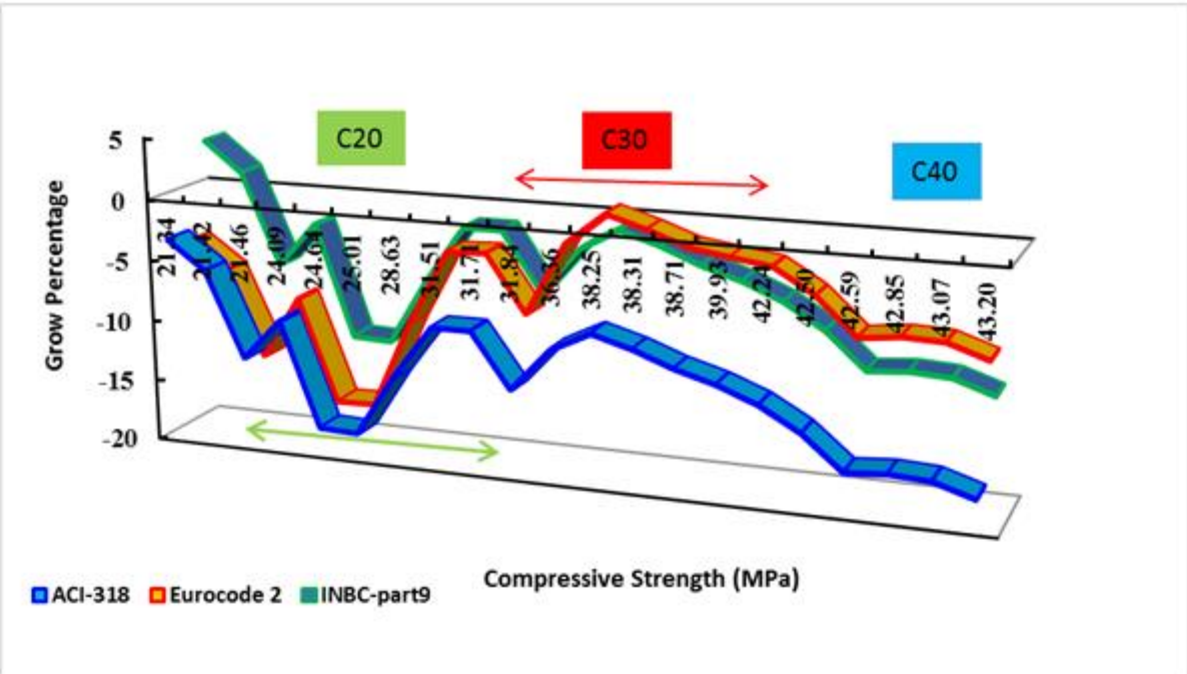

Figure 14. Growing percentage for specimens (28 days)

Figure 15 shows the values of the relationship between the compressive strength and the tensile strength for concrete, indicating the average results of the 7 and 28 days concrete grades. In general, the Iranian National Building Code suggests higher tensile strength with the shortest distance from the compressive strength of the 28 days concrete. In fact, by prioritizing the 28 days concrete's strength, the regulations try to consider the average tensile strength for 28 and 7 days by presenting a relation.

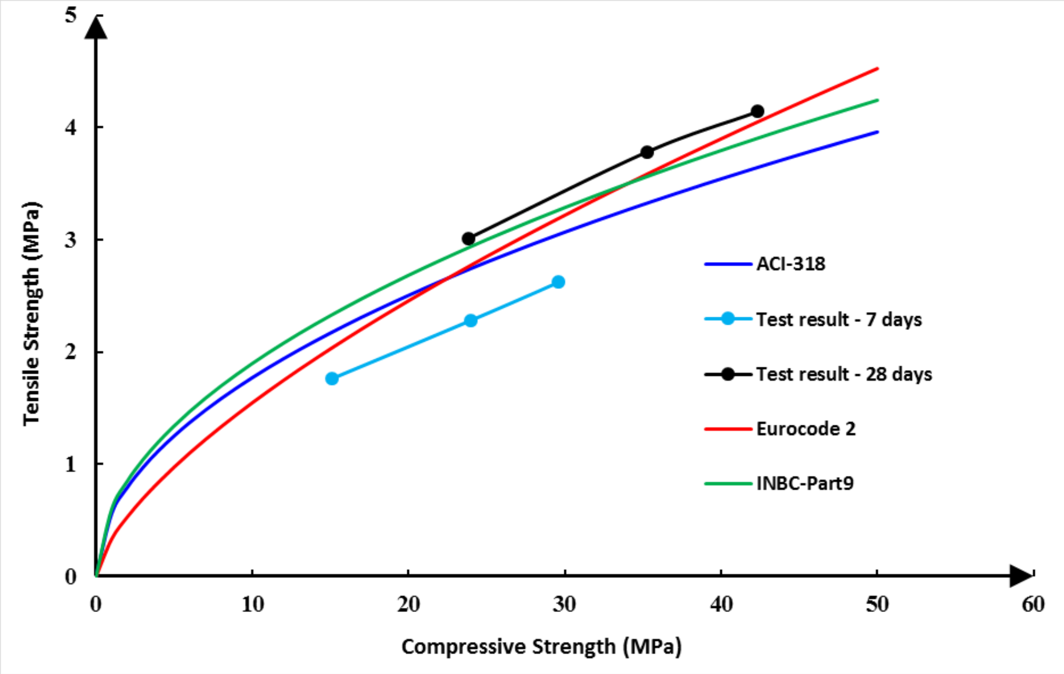

Figure 15. Result of the compressive strength of the specimens at 7 and 28 days

The overall results of the research are summarized in Tables 5 and 6. The lower RMSE and the lower absolute magnitude of the growth rate are, the closer the estimated data would be to the actual values. The average compressive and tensile strength for each grade of concrete at the age of 7 and 28 days is summarized in the table. The table suggests that to what extent one can trust the relationship between different and which regulation could report the results closer to reality for each grade of concrete at different ages. For example, the Euro Code estimates the best tensile strength for the 7 days C20 concrete.

Table 5. Result for 7-day concrete

Guide line	C20		C30		C40	
Euro cod	RRMSE	0.52	RRMSE	0.27	RRMSE	0.55
	% growing	15.52	%growing	21.73	%growing	21.86
	Tensile average	2	Tensile average	2.8	Tensile average	3.2
ACI	RRMSE	0.41	RRMSE	0.20	RRMSE	0.39
	%growing	23.55	%growing	20.45	%growing	16.34
	Tensile average	2.2	Tensile average	2.7	Tensile average	3
Iranian national building	RRMSE	0.44	RRMSE	0.22	RRMSE	0.42
	%growing	32.37	%growing	29.05	% growing	24.75
	Tensile average	2.3	Tensile average	2.9	Tensile average	3.3
Compressive average	15.48		24.29		29.62	

Table 6. Result for 28-day concrete

Guide line	C20		C30		C40	
Euro cod	RRMSE	0.51	RRMSE	0.23	RRMSE	0.016
	% growing	-10.47	%growing	-3.03	%growing	-1.77
	Tensile average	2.8	Tensile average	3.6	Tensile average	4
ACI	RRMSE	0.38	RRMSE	0.16	RRMSE	0.011
	%growing	-11.21	%growing	-11.71	%growing	-11.61
	Tensile average	2.7	Tensile average	3.3	Tensile average	3.6
Iranian national building	RRMSE	0.4	RRMSE	0.17	RRMSE	0.012
	%growing	-4.87	%growing	-5.41	% growing	-5.29
	Tensile average	2.9	Tensile average	3.6	Tensile average	3.9
Compressive average	24.18		35.86		42.25	

5. Discussion

The obtained results of compressive strength and tensile strength tests for specimens of all three studied mix designs at the ages of 3 and 7 days have been shown in Figures and compared with the relationships provided by the ACI-318[1], EC2 [17] and the Ninth Article of Iranian National Building Code [18]. According to the presented diagrams, it can be seen that the amounts of tensile strength of the specimens increase as the compressive strengths increase. In addition, the results show that the percentage of increase in tensile strength of concrete at 28days compared to the 7days age is higher than that of in compressive strength. Comparing the results with the relationships provided by the ACI-318, EC2 and the Ninth Article of National Building Code, show that using these relationships to estimate concrete tensile strength at 7days age does not provide reliable results. Furthermore, comparing the obtained results with the relationships provided by the ACI-318, EC2, and the Iranian National Building Code revealed that ACI-318 provides the most conservative estimation on tensile strength of concrete compared to EC2 and the Ninth Article of the National Building Code. The results of the tensile strength test at the age of 28 days are the most consistent with the curve derived from the relationship provided by the Iranian National Building Code.

6. Conclusions

In this study, the relationship between tensile strength and compressive strength of concrete at ages of 7 and 28 days has been studied and analyzed by conducting compressive and tensile strength tests on 84 cylindrical and cubic specimens prepared using three mix designs corresponding to three strengths of C20, C30 and C40 grades. The results of this research are:

- The amounts of tensile strength of the specimens have increased by increasing their compressive strengths.
- The increase percentage in tensile strength of concrete at 28days compared to 7days is higher than that of compressive strength in experimental test.
- Comparing the obtained results with the relationships provided by the ACI-318, EC2 and the Iranian National Building Code shows that using these relationships to estimate the tensile strength of concrete does not provide reliable results at the age of 7 days.
- Comparing the obtained results with the relationships provided by the ACI-318, EC2 and the Iranian National Building Code shows that ACI-318 provides the most conservative estimations on concrete tensile strength of compared to EC2 and the Ninth Article of the National Building Code.
- The results of the tensile strength test at the age of 28 days are the most consistent with the curve derived from the relationship provided by Iranian National Building Code and EC2.

7. Conflicts of Interest

The authors declare no conflict of interest.

8. References

[1] ACI Committee, American Concrete Institute, and International Organization for Standardization. "Building code requirements for structural concrete (ACI 318-08) and commentary." American Concrete Institute, (2008).

[2] Phani, S. S., T. S. Sekhar, and S. Rao. "Sravana. Evaluation of relationship between mechanical properties of high strength self compacting concrete." Am J Eng Res 2 (2013): 67-71.

[3] Arıoglu, Nihal, Z. Canan Girgin, and Ergin Arıoglu. "Evaluation of ratio between splitting tensile strength and compressive strength for concretes up to 120 MPa and its application in strength criterion." ACI Materials Journal 103, no. 1 (2006): 18-24.

[4] Lavanya, G., and J. Jegan. "Evaluation of relationship between split tensile strength and compressive strength for geopolymer concrete of varying grades and molarity." Int. J. Appl. Eng. Res 10, no. 15 (2015): 35523-27.

[5] Gajendran, K.A., Anuradha, R., Venkatasubramani, G.S., Studies on relationship between compressive and splitting tensile strength of high performance concrete. ARPN J. Eng. Appl. Sci. 10 (14), (2015): 6151–6156.

[6] Öttl, Christian, and Hans Schellhorn. "Examination of the Relation between Tensile/flexural Strength and Compressive Strength of Autoclaved Aerated Concrete According to prEN 12602." Advances in Construction Materials 2007 (n.d.): 749–756. doi:10.1007/978-3-540-72448-3_76.

[7] Anuradha, R., V. Sreevidya, R. Venkatasubramani, and B. Vijaya Rangan. "Relationship between compressive and splitting tensile strength of geopolymer concrete." The Indian Concrete Journal 85, no. 11 (2011): 18-24.

[8] Yan, Kezhen, Hongbing Xu, Guanghui Shen, and Pei Liu. "Prediction of Splitting Tensile Strength from Cylinder Compressive Strength of Concrete by Support Vector Machine." Advances in Materials Science and Engineering 2013 (2013): 1–13. doi:10.1155/2013/597257.

[9] Yao, Weilai, Shiyong Jiang, Wei Fei, and Tao Cai. "Correlation Between the Compressive, Tensile Strength of Old Concrete Under Marine Environment and Prediction of Long-Term Strength." Advances in Materials Science and Engineering 2017 (2017): 1–12. doi:10.1155/2017/8251842.

[10] Akinpelu, Mutiu A., Samson O. Odeyemi, Oladipupo S. Olafusi, and Fatimah Z. Muhammed. "Evaluation of Splitting Tensile and Compressive Strength Relationship of Self-Compacting Concrete." Journal of King Saud University - Engineering Sciences (January 2017). doi:10.1016/j.jksues.2017.01.002.

[11] Chhorn, Chamroeun, Seong Jae Hong, and Seung Woo Lee. "Relationship between Compressive and Tensile Strengths of Roller-Compacted Concrete." Journal of Traffic and Transportation Engineering (English Edition) 5, no. 3 (June 2018): 215–223. doi:10.1016/j.jtte.2017.09.002.

[12] Zhang, L, X X Han, J Ge, and C H Wang. "The Relationship between Compressive Strength and Flexural Strength of Pavement Geopolymer Grouting Material." IOP Conference Series: Materials Science and Engineering 292 (January 2018): 012114. doi:10.1088/1757-899x/292/1/012114.

[13] Badarloo, Baitollah, and Faezeh Jafari. "A Numerical Study on the Effect of Position and Number of Openings on the Performance of Composite Steel Shear Walls." Buildings 8, no. 9 (September 1, 2018): 121. doi:10.3390/buildings8090121.

[14] Khotbehsara, Mojdeh Mehrinejad, Bahareh Mehdizadeh Miyandehi, Farzad Naseri, Togay Ozbakkaloglu, Faezeh Jafari, and Ehsan Mohseni. "Effect of SnO 2 , ZrO 2 , and CaCO 3 Nanoparticles on Water Transport and Durability Properties of Self-Compacting Mortar Containing Fly Ash: Experimental Observations and ANFIS Predictions." Construction and Building Materials 158 (January 2018): 823–834. doi:10.1016/j.conbuildmat.2017.10.067.

[15] Ghanei, Amir, Faezeh Jafari, Mojdeh Mehrinejad Khotbehsara, Ehsan Mohseni, Waiching Tang, and Hongzhi Cui. "Effect of Nano-CuO on Engineering and Microstructure Properties of Fibre-Reinforced Mortars Incorporating Metakaolin: Experimental and Numerical Studies." Materials 10, no. 10 (October 23, 2017): 1215. doi:10.3390/ma10101215.

[16] Naseri, Farzad, Faezeh Jafari, Ehsan Mohseni, Waiching Tang, Abdosattar Feizbakhsh, and Mohsen Khatibinia. "Experimental Observations and SVM-Based Prediction of Properties of Polypropylene Fibres Reinforced Self-Compacting Composites Incorporating Nano-CuO." Construction and Building Materials 143 (July 2017): 589–598. doi:10.1016/j.conbuildmat.2017.03.124.

[17] Eurocode 2, Design of Concrete Structures, Part 1: General Rules and Rules for Buildings, prEN 1992-1 CEN, (2005).

[18] Iranian National Building Codes Compilation Office. Iranian National Building Code, Part 9: Reinforced Concrete Buildings Design, Ministry of Housing and Urban Development (MHUD), (2014).

[19] Iranian National Standardization Organization , Specification for Portland cement, No. 389, 3rd Revision. (1999),

[20] Iranian National Building Codes Compilation Office. Iranian National Building Code, Part 9: Reinforced Concrete Buildings Design, Ministry of Housing and Urban Development (MHUD), (2014).

[21] Iranian National Standardization Organization , concrete aggregates-Specifications, No. 302, 3rd. Revision. (2015),

[22] Badarlou, B., A. A. Tasnimi, and M. S. Mohammadi. "Failure criteria of unreinforced grouted brick masonry based on a biaxial compression test." (2009): 502-511.

[23] ASTM C 496/C 496M-04, Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, American Standard Test Method, West Conshohocken, Penn, USA, (2004).

[24] ASTM Standards. Standard test method for compressive strength of cylindrical concrete specimens. In: Annual Book of ASTM Standards (ASTM C 39-01). American Society for Testing and Materials, Philadelphia, 5 pp. (2001).

[25] Schittkowski, K. "EASY-FIT: a Software System for Data Fitting in Dynamical Systems." Structural and Multidisciplinary Optimization 23, no. 2 (March 2002): 153–169. doi:10.1007/s00158-002-0174-6.

[26] Jafari, Faeze, Jalal Akbari, and Alireza Jahanpour. "Evaluation of Safety Index and Calibration of Load and Resistance Factors for Reinforced Concrete Beams under Bending, Shear and Torsion Demands." Journal of Structural and Construction Engineering 3, no. 4 (2017): 49-64. doi: 10.22065/jsce.2016.41237.

[27] Akbari, Jala, and Faezeh Jafari. "Calibration of Load and Resistance Factors for Reinforced Concrete." Civil Engineering Infrastructures Journal 51, no. 1 (2018): 217-227. doi: 10.7508/ceij.2018.01.012.