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Development of statistical models for prediction of mechanical properties of plain concrete

Desarrollo de modelos estadísticos para la predicción de propiedades mecánicas del hormigón simple

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ABSTRACT

Compressive strength of concrete is considered as an index property of the concrete and therefore other mechanical properties of concrete such as flexural strength and modulus of elasticity are correlated with it. The standard code practices of different nations provide empirical corelations between compressive strength and mechanical properties. However, it is observed that these correlations yield deviating results. Present paper aims on developing statistical models for accurately estimating these properties based on experimental results. Plain concrete cube, cylinder, and beam specimens are cast with varying water-cement ratio and aggregate-cement ratio. Based on experimental results, the prediction models for compressive strength, flexural strength, and modulus of elastic are developed. Experimental results are compared with the results obtained from generated statistical models as well as with the results available from literature. It is found that the present models accurately predict the mechanical properties of concretes.

Keywords: compressive strength; mechanical properties; concrete.

RESUMEN

La resistencia a la compresión del hormigón se considera una propiedad índice del hormigón y, por lo tanto, otras propiedades mecánicas del hormigón, como la resistencia a la flexión y el módulo de elasticidad, están correlacionadas con ella. Las prácticas del código estándar de diferentes países proporcionan correlaciones empíricas entre la resistencia a la compresión y las propiedades mecánicas. Sin embargo, se observa que estas correlaciones arrojan resultados desviados. El presente artículo tiene como objetivo desarrollar modelos estadísticos para estimar con precisión estas propiedades en base a resultados experimentales. Las muestras de cubos, cilindros y vigas de concreto simple se moldean con una relación agua-cemento y una relación agregado-cemento variables. Con base en los resultados experimentales, se desarrollan los modelos de predicción de la resistencia a la compresión, la resistencia a la flexión y el módulo de elasticidad. Los resultados experimentales se comparan con los resultados obtenidos a partir de modelos estadísticos generados, así como con los resultados disponibles de la literatura. Se encuentra que los modelos actuales predicen con precisión las propiedades mecánicas de los hormigones.

Palabras clave: *resistencia a la compresión; propiedades mecánicas; hormigón.*

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1. INTRODUCTION

Concrete, one of the most extensively used construction materials pan world, is under the lens due to the rapid pace at which construction is being undertaken. However, the present spurt of construction activity indicates that adequate care needs to be taken in order to maintain material quality which can sustain the above said growth. The quality of concrete is determined by the mechanical properties it exhibits, therefore in order to ensure product efficacy, the mechanical properties of concrete need to be evaluated with accuracy. Among these, compressive strength (), flexural strength () (modulus of rupture), and modulus of elasticity () are important properties of concrete. In the analysis and design of any type of concrete structures viz., plain, reinforced, or pre-stressed, these properties need to be well evaluated and incorporated.

Practical assessment of these mechanical properties with accuracy requires a prolonged duration. However, with emerging demand for rapid construction, it is the need of hour to have models for estimating these properties at early stages with accuracy. The standard guidelines of various countries give the correlation of compressive strength with the modulus of elasticity and flexural strength. Table 1 presents the correlations recommended by the design codes of various nations (1-7). However, the values obtained from these correlations are found to be deviating from the experimental values (8,9). This may be due to the development of technology and extensive improvement in the quality of ingredients of concrete, especially cement. Further, the commercially available design software uses the default values of elastic modulus and flexural strength as stipulated in standard codes. This leads to incorrect usage of materials, especially for relatively high strength concrete.

Initially, Li (10) developed the four-phase sphere model for the theoretical estimation of effective modulus of elasticity. Tomosawa (11) has proposed a practical and universal equation for estimating the modulus of elasticity, considering the unit weight and type of aggregates. The mathematical equations for modulus of elasticity with consideration to different types of aggregates were also developed (12). Some researchers gave equations for different mechanical properties of concrete containing mineral admixtures such as fly ash, silica fume, metakaolin, and palm kernel shell (7, 8, 13-14). Liu (15) reported that the micro-cracks formed during the curing period have a significant effect on the elastic modulus. The empirical equation was proposed to estimate the elastic modulus considering the micro-cracking pattern and moisture content. Ahmed (16) studied factors like level of stress, age, and confinement ratio, which have a significant effect on the flexural tensile strength. Advancements are also made for the development of empirical equations for freshly compacted concrete (17).

Further, a study of elastic modulus for sprayed concrete is conducted. It has been observed that there is a significant difference between the elastic modulus of plain concrete and sprayed concrete (18). Equations for mechanical properties of high strength concrete with admixture are also reported (13, 19). However, the models for predicting different mechanical properties for various mix proportions constituting different commercial grades of concrete have not been found as reported. In the present study, extensive experimentation is carried out to determine compressive strength on cube specimens and cylinder specimens, flexural strength on beam specimens and modulus of elasticity of concrete. The present experimental results for flexural strength and modulus of elasticity are compared with the results obtained using correlations given by different national codes. Further, the statistical models are developed using the experimental results to predict the mechanical properties of concrete. The efficacy of these models is established with some experimental results as well as the results from the available literature.

2. EXPERIMENTAL PROCEDURE

Eight basic concrete mixes of varying varieties are used in the present study. Table 2 illustrates the above said mix proportions and corresponding water to cement ratio and aggregate to cement ratio. For different water-cement ratios ranging from 0.6 to 0.33, the aggregate-cement ratio ranges from 6.9 to 4.9, respectively. Cement content varied from 300 kg/m^3 [0.0108 lbs/in^3] to 420 kg/m^3 [0.0151 lbs/in^3] for different mix proportions.

2.1 Materials

The locally available ingredient materials viz., cement, fine aggregates (river sand), and coarse aggregate are used for casting

Table 1. Correlations recommended by standard codes of various nations.

Country	Code of Reference	Modulus of Elasticity	Flexural Strength	Remarks
American Code	ACI- 318	$Ec = 4700\sqrt{fc'}$	$fr = 0.7\sqrt{fc'}$	fc' specified 28 days cylinder comp strength
New Zealand code	NZS 3101	$Ec = 3320\sqrt{fc'} + 6900$	$fcr = 0.6\sqrt{fc'}$	fc' specified 28 days cylinder comp strength
Euro Code	EN1992 -1-1	$Ecm = 22000\,(0.1 * fcm)^{0.3}$	$fctm = 2.2 * \ln\,(1 + 0.1\,fcm$	fcm Mean value of 28 days concrete cylinder compressive strength
British Code	BS 8110	$Ec = 20000 + 0.2 * fcu$	$fcr = 0.6\sqrt{fcu}$	fcu is the characteristic cube strength at 28 days
Canadian Code	CSA A23.3-04	$Ec = 4500\sqrt{fc'}$	$fr = 0.6\sqrt{fc'}$	fc' specified 28 days cylinder comp strength
Turkish Code	TS 500-2003	$Ec = 3250\sqrt{fck} + 14000$	$fr = 0.7\sqrt{fck}$	fck characteristic 28 days cylinder compressive strength
Indian Code	IS 456	$Ec = 5000\sqrt{fck}$	$fcr = 0.7\sqrt{fck}$	fck characteristic 28 days cube compressive strength

of concrete specimens. Ordinary Portland Cement (OPC) 53 grade, as stipulated in IS 12269 (20), is used. The consistency, soundness, and setting time properties of OPC are assessed as per IS 4031 (21). Similarly, the physical properties of fine and coarse aggregates such as sieve analysis, water absorption, and specific gravity are determined following IS 2386 (22). Table 3 shows the test results obtained while determining the physical properties of the ingredient materials.

2.2 Specimen

The concrete specimens are prepared following IS 10086 and IS 516 (23, 24). The cube specimens (150 mm [5.90 in.]) and cylinder specimens (300 x 150 Φ mm [11.811 x 5.90 in.]) are cast for compressive strength testing. Beam specimens (150 x 150 x 700 mm [5.90 x 5.90 x 27.56 in.]) are prepared for flexural testing and an additional set of cylindrical specimens (300 x 150 Φ mm [11.811 x 5.90 in.]) are cast for determining the modulus of elasticity. All the above specimens are prepared in each of the eight mixes. The specimens after casting are kept for initial setting at room temperature of 28° C [82.4° F] and relative humidity of 90%. The specimens are demoulded after 24 hours, and then the specimens are moist cured by ponding in a curing tank for 28 days.

2.3 Testing of specimen

The testing program for all the specimens is conducted as per IS 516 (24). All the specimens are tested in Multi-function control console (MCC-8) machine for compression, flexure strength, and modulus of elasticity following IS 516 (clause 5) (24). All the readings of load and deformation are recorded by a calibrated electronic control system attached to a host PC. Digital linear variable displacement transducer (LVDT) and extensometer are used to measure the deformation. The machine is kept in the load control mechanism throughout the testing program. Care is taken that the vertical axis of the machine platen coincides with the axis of the specimen.

The testing surfaces are milled before tests. The specimens are tested in saturated surface dry conditions. The cube specimens used for compressive testing are subjected to load on the adjacent side of casting. However, in the case of cylinder compression testing, the cylinders are necessarily kept vertical. The load rate used is kept at 0.233 MPa/sec (140 kg/sq.cm/min [1991.27 lbs/sq. in/min]) as recommended by IS 516 (24). The specimens are tested until failure. Four specimens of both cube and cylinders are tested for a period of 28 days, per mix.

In the flexural testing of concrete beams, the four-point loading mechanism is used. Two LVDT's are used for measuring the deflection of the beams. All the contact surfaces are cleaned to remove loose materials. The supports are 600 mm [23.62 in.] apart, and loading rollers are 200 mm [7.874 in.] apart, thereby dividing the beam into three parts of 200 mm [7.874 in.] each. Figure 1 shows the beam and LVDT arrangement for the flexural test. The load is applied at the rate of

Table 2. Mix proportions.

Mix	Water-cement ratio	Aggregate -cement ratio	Quantities 1 cu.m of concrete (kg#)				
			Cement content	F.A.	C.A. 10 mm (0.393 in)	C.A. 20 mm (0.787 in)	Water Content
M-1	0.60	6.89	300	684.0	414.0	969.0	180.0
M-2	0.55	6.72	310	688.2	418.5	976.5	170.5
M-3	0.52	6.57	320	694.4	423.0	985.6	166.4
M-4	0.50	6.34	340	707.2	431.1	1016.6	170.0
M-5	0.50	6.07	355	710.0	505.9	939.7	177.5
M-6	0.45	5.85	365	698.6	575.6	861.4	164.3
M-7	0.33	5.08	410	681.0	421.1	982.4	135.3
M-8	0.33	4.96	420	697.6	554.4	831.6	138.6

*F.A. – Fine Aggregate, C.A. – Coarse Aggregate#1kg = 2.204 lbs

Table 3. Material properties.

Material	Parameter Assessed	I.S. Code	Test Performed	Result
Cement	Soundness	IS 4031	Le-Chatelier Method	5 mm
	Standard Consistency		Vicats Plunger Test	33%
	Initial Setting Time			33 min
	Final Setting Time			10 hours
Fine Aggregate	Fineness Modulus	IS 2386	Sieve Analysis	3.01
	Specific Gravity		Pycnometer Bottle Test	2.699
	Water Absorption		Oven Dry Method	1.20%
Coarse Aggregate	Fineness Modulus	IS 2386	Sieve Analysis	3.62
	Specific Gravity		Wire basket Method	2.99
	Water Absorption		Oven Dry Method	2%

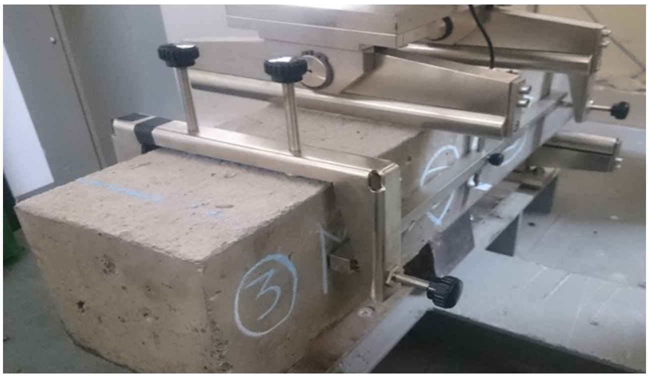

Figure. 1. Flexural testing on beam.

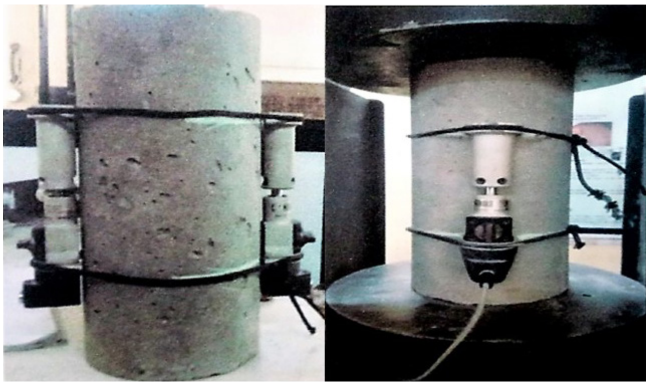

Figure 2. Modulus of elasticity test on cylinder.

0.0114 MPa/sec (7 kg/sq.cm/mm) as per IS 516 (24). The load is increased until the failure of specimens. For every mix, three specimens are tested for the period of 28 days.

Standard cylinders (300 x 150Φmm [11.811 x 5.90 in.]) are used for measuring the modulus of elasticity of concrete. The load is continuously applied at the rate of 0.233 MPa/sec (140 kg/sq.cm/mm [1991.27 lbs/sq. in/min]) as per the guidelines of IS 516 until the average stress of (C+5) kg/sq.cm is obtained, where, C is one-third of the average compressive strength. The load is maintained at this stress value for at least a minute and then gradually unloaded to reach an average stress of 1.5 kg/sq.cm [21.94 lbs/sq.in]. The load is again applied for the second time at the same rate until the average stress of (C+1.5) kg/sq.cm is reached, and unloading is carried out in the same way. The load is further applied for the third time and in ten approximately equal increments of stress reaching up to an average stress of (C+1.5) kg/sq.cm. Two extensometers are diagonally attached to the vertical surface of the specimen for measuring the deformation of specimens at every load change. Figure 2 presents the arrangement of extensometers and the specimen arrangement for the determination of modulus of elasticity test. Three specimens are tested for a period of 28 days per mix proportion.

3. EXPERIMENTAL RESULTS

The testing of concrete specimens is conducted at the age of 28 days after curing. IS 456 (clause 6.2.1) recommends 28 days strength as the characteristic compressive strength to be used

Table 4. Test results.

Cube compressive strength (MPa)								
Specimen	M1	M2	M3	M4	M5	M6	M7	M8
#1	28.21	35.99	40.31	48.83	51.59	58.40	61.30	63.91
#2	28.03	39.19	39.25	44.31	54.69	49.93	58.93	67.98
#3	29.52	36.67	41.95	47.54	52.60	54.83	60.68	65.24
#4	29.33	38.75	41.35	46.67	54.39	58.06	60.24	65.07
Average	**28.77**	**37.65**	**40.71**	**46.83**	**53.31**	**55.30**	**60.28**	**65.55**
C.O.V. (%)	3%	4%	3%	4%	3%	7%	2%	3%
Cylinder compressive strength (MPa)								
	M1	M2	M3	M4	M5	M6	M7	M8
#1	20.43	23.83	30.76	34.51	40.18	41.25	46.47	49.02
#2	21.36	26.53	32.25	36.89	36.99	45.23	47.10	55.78
#3	21.02	25.25	31.22	35.67	38.60	42.45	44.02	51.10
#4	20.52	24.51	31.70	36.25	39.54	44.35	46.29	53.41
Average	**20.83**	**25.03**	**31.48**	**35.83**	**38.83**	**43.32**	**45.97**	**52.33**
C.O.V. (%)	2%	5%	2%	3%	4%	4%	3%	6%
Flexural Strength (MPa)								
	M1	M2	M3	M4	M5	M6	M7	M8
#1	3.69	4.05	4.58	4.41	5.12	5.50	5.66	6.45
#2	3.72	4.39	4.65	4.68	4.96	5.185	5.78	5.91
#3	3.76	4.55	4.71	4.77	5.09	5.21	5.68	6.31
Average	**3.72**	**4.33**	**4.65**	**4.62**	**5.06**	**5.30**	**5.71**	**6.22**
C.O.V. (%)	1%	6%	1%	4%	2%	3%	1%	5%
Modulus of Elasticity (MPa)								
	M1	M2	M3	M4	M5	M6	M7	M8
#1	27349.37	26997.30	34814.22	35813.57	38952.44	37388.81	43701.64	45885.27
#2	24458.12	30964.60	32594.59	34694.70	35837.58	38952.44	42287.62	48733.77
#3	25889.93	28743.32	33861.41	34744.69	37043.47	38426.51	43034.65	46757.12
Average	**25899.14**	**28901.74**	**33756.74**	**35084.32**	**37277.83**	**38255.92**	**43007.97**	**47125.39**
C.O.V. (%)	6%	7%	3%	2%	4%	2%	2%	3%

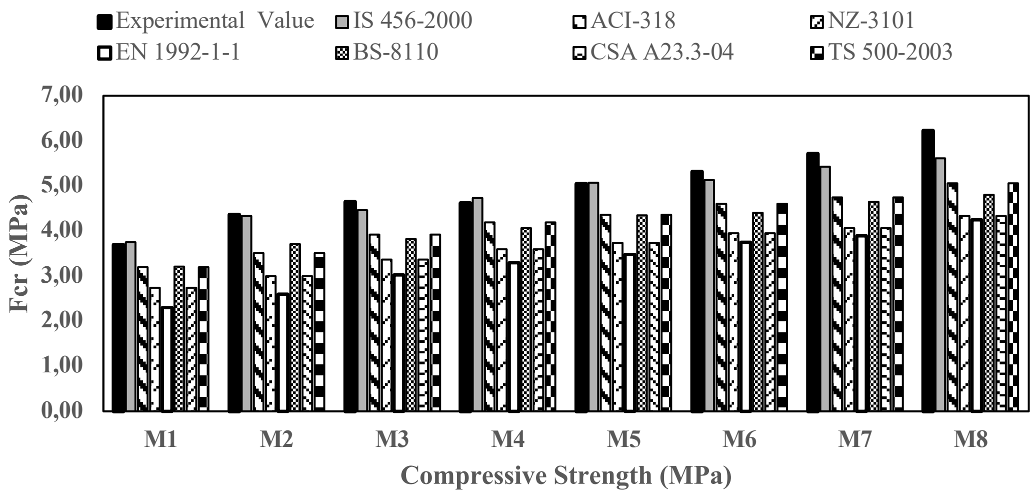

Figure 3. Comparison of flexural strength.

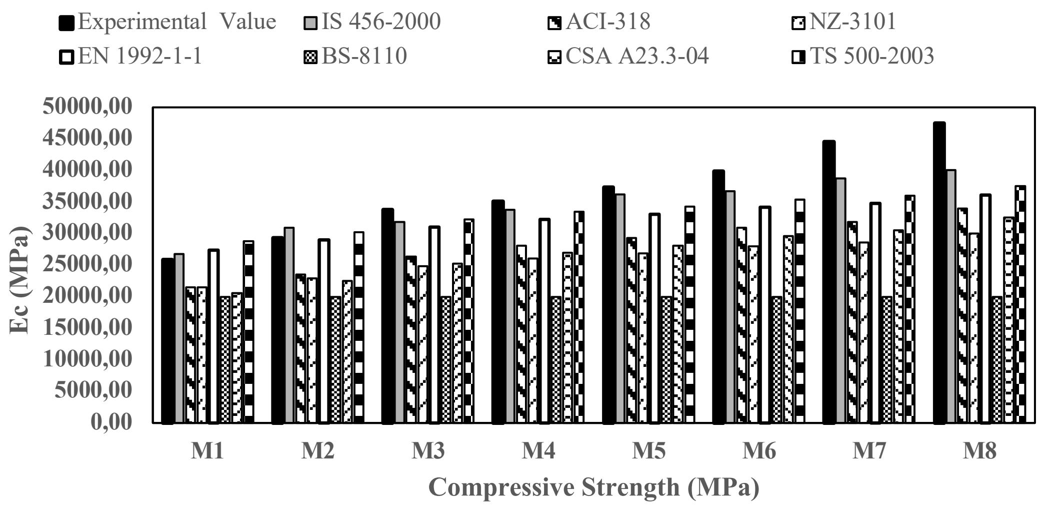

Figure 4. Comparison of Modulus of Elasticity.

for design purposes. Table 4 presents the experimental results for characteristic compressive strength, flexural strength, and modulus of elasticity for all concrete mixes used.

The compressive strength, flexural strength and modulus of elasticity are important parameters considered in designing the structural concrete members. It is necessary to validate the correlation proposed by various codes with experimental results. Figure 3 compares the experimental value of flexural strength of concrete mixes tested after 28 days with the empirical correlation given by standard codes of different countries. Figure 4 similarly compares the modulus of elasticity of the eight concrete mixtures to correlation stipulated by standard codes. Regardless of the type of concrete, the modulus of rupture at 28 days has a variation of more than 15% in most of the cases. The ACI-318 and EN 1992-1-1, regardless of the compressive strength of concrete, conservatively estimates the modulus of rupture almost by 20%. Similar observations were made for modulus of elasticity at 28 days. The ACI-318 regardless of concretes underestimates the modulus of elasticity by 20%.

4. ANALYTICAL INVESTIGATION

In the present investigation, multiple linear regression analysis of experimental data is performed to develop predictive models for the estimation of compressive strength, flexural strength, and modulus of elasticity. For statistical modeling, multiple linear regression analysis was carried out using IBM-SPSS Statistics (version 23). The coefficient of correlation, i.e., Pearson's R, a parameter indicating the strength of correlation of dependent and independent variables, is also obtained for all the proposed models. Pearson's R-value in the proximity of unity signifies the efficiency of the prediction model.

Further, the linear curve fit is plotted between the predicted value and the experimental value. The R^2 value, i.e., the coefficient of determination, is obtained for this linear curve. R^2 value approaching closer to unity is indicative of a higher efficacy of the predictive model.

4.1 Prediction of cube compressive strength

In developing a model through SPSS, compressive strength is used as a dependent, and the quantity of cement, fine aggregate, coarse aggregate, and water in 1 cu.m of concrete are used as variables. The model is developed with SPSS software (version 23) using the experimental data generated during testing of cube compressive strength as presented by Eq. 1. Out of the available 32 strength values, 17 have been used to

Table 5. Comparison of predicted cube compressive strength with experimental values.

Author	Experimental Values (MPa*)	Predicted Values (MPa)	Deviation (%)
Present Study	29.33	29.48	0.51
	28.13	29.48	4.80
	36.37	34.61	4.83
	38.45	34.61	9.98
	41.35	39.62	4.17
	40.54	39.62	2.26
	47.54	48.64	2.32
	46.67	48.64	4.23
	52.60	51.64	1.82
	54.35	51.64	4.98
	54.83	52.25	4.71
	58.04	52.25	9.98
	60.68	60.08	0.99
	60.24	60.08	0.27
	59.26	60.08	1.38
Anbuvelan (2014) (8)	62.44	68.77	10.15
Shelke N. (2006) (25)	50.46	44.66	11.49
	52.47	46.07	12.20
	56.07	50.05	10.75

*1MPa = 145.04 lbs/sq.in

generate the model, while the remaining 15 strength values have been used to validate the proposed model.

$$[1]\quad fck = 0.223 * C + 0.269 * FA + 0.041 * CA - 0.135 * W - 253.819$$

where fck is the compressive strength of cube specimen (MPa) at the age of 28 days, C, FA, CA, and W are the quantities of the cement, fine aggregate, coarse aggregate, and water respectively in kg/m^3 of concrete mix.

Pearson's R for the above-proposed model is found as 0.98, indicating the effectiveness of the proposed model. It is worth noting here that the coefficient of water quantity is obtained to be negative, indicating that compressive strength is inversely proportional to the quantity of water added to the concrete mix. The generated predictive models from the available test data, as detailed in the previous section, are validated from the remaining test results. Table 5 presents actual experimental values of the compressive strength of cube that are obtained from a test program conducted and the predicted values that are obtained from the proposed model [1]. The table also depicts the percentage deviation in the predicted values of compressive strength. It can be seen that in all cases, the percentage deviation is less than 5% except for one value, which is deviating by 9.98%, still less than 10%, and hence well acceptable. These show the effectiveness of the proposed model in predicting the cube compressive strength of the concrete. The efficacy of the present model is further checked with the results available in literature (8, 25). It can be seen that these experimental values are also in good agreement with the results obtained from the models.

Additionally, to assess the efficacy of the proposed model [1], predicted values are plotted against experimental values, as shown in Figure 5, for which the R^2 value is found to be 0.97. It is observed that linear fit of the predicted values plotted against experimental values obtained from available literature lies within the 95% prediction band. This indicates that predicted values are in consonance with experimental values. All the predicted values obtained from the model lies in the 95% prediction band.

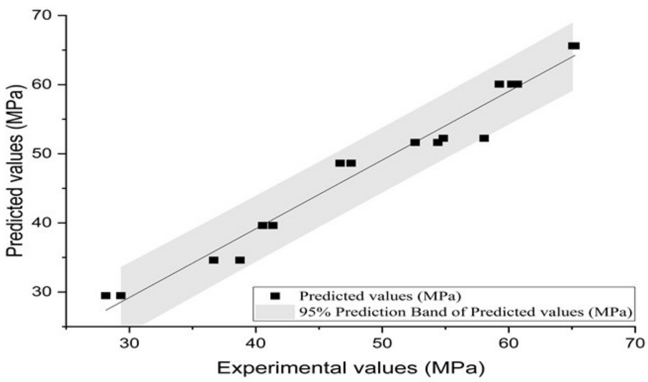

Figure 5. Comparison of cube compressive strength.

4.2 Prediction of cylinder compressive strength

According to the standard code guidelines of some of the nations such as America (ACI318), New Zealand (NZS3101), and Europe (EN 199211), the compressive strength is measured on cylindrical specimens of standard size, generally 300 mm x 150 mm for the purpose of designing. Hence, a model for prediction of cylinder compressive strength is also developed on the same lines as cube compressive strength as stated in [2].

$$[2]\ fck' = 0.180 * C + 0.217 * FA + 0.037 * CA - 0.152 * W - 205.185$$

Where fck' is the compressive strength of cylinder (MPa) at the age of 28 days.

For the above model, the correlating coefficient is obtained as 0.98, which alludes to the effectiveness of the model. The comparison of the compressive strength of the cylinder across different mixes is as shown in Table 6. From the testing program, experimental values are obtained and the proposed model [2] is used to predict the corresponding values. The percentage deviation in predicted value from experimental value is also shown in Table 6. In no case, the percentage deviation is more than 5% except in one instance where it is 9.09%. These figures clearly indicate the closeness of the proposed model to the experimental results. The efficiency of the developed model is further checked with the results available in literature (8, 16, 26). These experimental values imply to be in good agreement with the results obtained from the models.

Moreover, when plotted, the R^2 value for predicted values against experimental values is 0.97. This indicates the higher efficacy of the prediction model. Also, as seen in Figure 6, almost all values lie in the 95% prediction band. The linear fit of the predicted values plotted against experimental values obtained from available literature lies close to prediction band. This signifies the effectiveness of the proposed model.

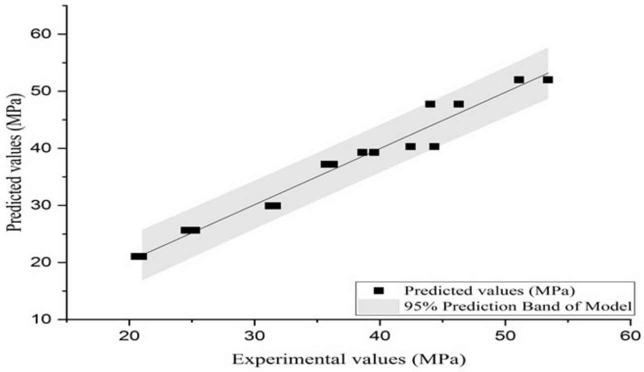

Figure 6. Comparison of cylinder compressive strength.

4.3 Prediction of flexural strength

The tensile strength of concrete is most commonly attributed to flexural strength (modulus of rupture). Almost all structural components are subjected to significant flexure stresses. Several structural components viz., slabs, beams, road pavements are designed basically for the flexural loads. In the investigation of flexural strength according to standard codes, it is revealed that the process involves tedious experimentation. Therefore, the standard guidelines of different countries have given an empirical equation for

Table 6. Comparison of predicted cylinder compressive strength with experimental values.

Author	Experimental Values (MPa)	Predicted Values (MPa)	Deviation (%)
Present Study	21.02	21.05	0.16
	20.52	21.05	2.60
	25.25	25.65	1.60
	24.51	25.65	4.67
	31.22	29.93	4.14
	31.49	29.93	4.96
	35.67	37.20	4.30
	36.25	37.20	2.63
	38.60	39.29	1.79
	39.54	39.29	0.63
	42.42	40.32	4.96
	44.35	40.32	9.09
	44.02	47.76	8.49
	46.29	47.76	3.17
	51.10	52.01	1.79
	53.41	52.01	2.61
Anbuvelan (2014) (8)	49.95	53.37	6.84
Ahmed (2016) (16)	31.80	36.42	14.15
	78.2	76.06	2.73
Ashour (2000) (26)	48.00	43.67	9.02
	78.00	77.13	1.12

estimating the flexural strength of concrete correlating to compressive strength. However, compressive strength also needs aout 28 days of experimentation. Hence, for estimating the flexural strength at an early age with accuracy, a predictive model is developed as given in [3].

$$[3]\ fcr = 0.011 * C + 0.020 * FA - 0.001 * CA - 0.020 * W - 8.359$$

where, fcr is the flexural tensile strength of concrete (MPa).

Pearson's R, obtained after multiple regression analyses for the above mentioned model, is 0.96. Table 7 shows the deviation of experimental values acquired from the test program for flexural tensile strength and predicted values obtained from the proposed model [3]. It is witnessed that the predicted values have a percentage deviation of less than 9%. These indicate that the proposed model gives value in the vicinity of experimental values. The effectiveness of the developed model is further validated by comparing it to reported results (27). The results obtained from the models are consistent with these experimental values.

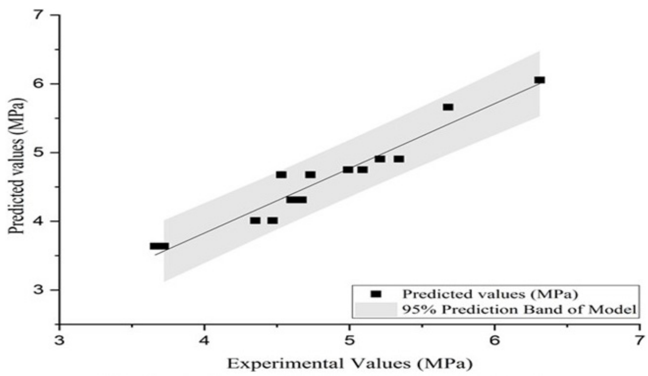

Figure 7. Comparison of flexural strength.

Figure 7 shows the curve fit obtained from the linear regression analysis. The R^2 value or coefficient of determination is obtained as 0.94. In addition to this, it can be seen from the curve that all experimental values are in the 95% prediction band. The predicted values plotted against experimental values obtained from available literature lies in to prediction band. This indicates the efficiency of the proposed model.

4.4 Prediction of modulus of elasticity

The modulus of elasticity is the valuable mechanical property used in the analysis and designing of concrete structures. The modulus of elasticity is the measure of flexibility of the material. The deflection pattern of materials is governed by its modulus of elasticity and hence defines the serviceability of the material. The existing standard guidelines give the correlation of modulus of elasticity with compressive strength. In addition to this, standard experimental procedures are also prescribed for its determination. However, this process requires a longer duration of time. Hence for prompt analysis of elastic property of the designed concrete, the predictive model is articulated. [4] gives the prediction model for modulus of elasticity of concrete.

$$[4]\ Ec = 92.66 * C + 230.36 * FA - 8.90 * CA - 171.16 * W - 116125.37$$

where, Ec is the modulus of elasticity of concrete (MPa).

Also, after performing statistical analysis, Pearson's R-value obtained is 0.976. The predicted values obtained from the proposed model [4] are compared with the experimental values of modulus of elasticity. It is apparent that none of the predicted values have a percentage deviation of more than 4.5%, as shown in Table 8. This indicates that the proposed model give values, which are very close to the experimental values. The effectiveness of the devel-

Table 7. Comparison of predicted flexural strength with the experimental values.

Author	Experimental Values (MPa)	Predicted Values (MPa)	Deviation (%)
Present Study	3.72	3.63	2.20
	3.66	3.63	0.60
	4.35	4.01	7.82
	4.37	4.01	8.24
	4.60	4.31	6.25
	4.67	4.31	7.66
	4.53	4.67	3.25
	4.73	4.67	1.11
	5.09	4.75	6.67
	4.99	4.75	4.80
	5.21	4.90	5.83
	5.34	4.90	8.12
	5.68	5.66	0.32
	6.31	6.05	4.03
Khayat (2015) (27)	5.5	6.21	12.84

Table 8. Comparison of predicted modulus of elasticity with experimental values.

Author	42,898 mm	Predicted Values (MPa)	Deviation (%)
Present Study	25889.93	26114.25	0.87
	28743.32	29527.52	2.73
	30723.71	29527.52	3.89
	33861.41	32462.65	4.13
	34744.69	36300.24	4.48
	37043.47	37070.69	0.07
	37423.2	37070.69	0.94
	38426.51	37717.53	1.85
	43034.65	43086.99	0.12
	46757.12	47430.35	1.44
	48439.49	47430.35	2.08
Vijaylaxmi (2014) (9)	25998.43	27818.96	7.00
Ashour (2000) (26)	24612.00	27489.00	11.69

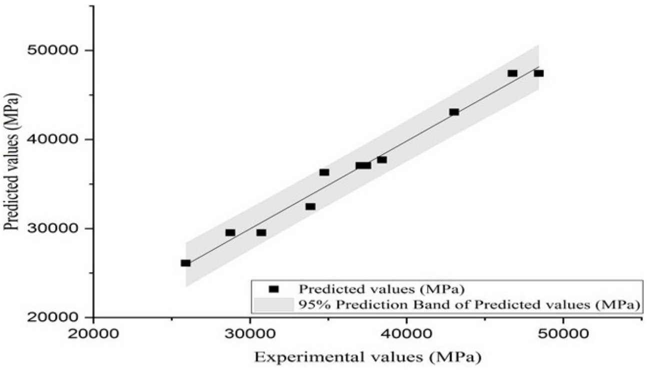

Figure 8. Comparison of modulus of elasticity.

oped model is further examined with the results available in literature (9, 26). It is apparent that these experimental values are also in good agreement with the results obtained from the models.

Additionally, a curve fit with a 95% prediction band is also developed, as shown in Figure 8. The efficacy of the above model can be seen from the R^2 value, which is obtained as 0.98. The predicted values plotted against experimental values obtained from available literature fall within the prediction band. This demonstrate the efficacy of the proposed model.

5. CONCLUSION

In this study, mechanical properties of concrete are investigated for eight commercial concrete mixes. The models are proposed for predicting compressive strength of cube and cylinder specimens, flexural strength, and modulus of elasticity. It can be concluded that

1. The predicted values obtained from the proposed models are closer to the experimental values. Hence, the present approach provides a practical and generalized tool that can be adopted by the industry. This tool can be used to give results at a very early stage without much delay.
2. The developed models shows a negative coefficient of water quantity, which indicates that the mechanical properties are inversely related to the quantity of water added to the concrete mix.

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