Experimental investigations on Elastic Properties of Concrete containing Steel fibre

K.Anbuvelan [#1], Dr.K.Subramanian [*2]
[#] Research Scholar, Anna University
Chennai – 600025, India.
[1] ksanbuvelan@yahoo.co.in
[*] Professor & Head, Department of Civil Engineering
Coimbatore Institute of Technology, Coimbatore – 641014, India.

Abstract - **this paper presents the relationship between modulus of elasticity and, modulus of rupture relationship with compressive strength of M60 concrete incorporating Steel fibre. Comparing the experimentally obtained result with the mechanical properties calculated using the recommend relationship from the various design codes. A new empirical relationship between elastic modulus, modulus of rupture and compressive strength for Steel fibre based M60 concrete is proposed.**

Keywords - Steel fibre, Modulus Of Elasticity, Modulus Of Rupture, Compressive strength, High Performance Concrete

I. Introduction

The static modulus of elasticity, modulus of rupture and compressive strength are important properties of concrete. These are the basic parameters for computing deflection in reinforced concrete structures. Various countries have been established their design codes based on this empirical relationship between static modulus of elasticity, modulus of rupture and compressive strength of plain concrete at 28 days of curing.

The Indian code of practice (IS 456) recommends the empirical relation between the static modulus of elasticity and cube compressive strength of concrete as,

$$Ec = 5000\sqrt{fck} \qquad \text{.... (1)}$$

The ACI code (ACI -318) defines the relationship between elastic modulus of concrete and cylinder compressive strength for calculating deflection as,

$$Ec = 4734\sqrt{fck'} \qquad \text{... (2)}$$

The New Zealand Code (NZS – 3101) defines elastic modulus for normal strength concrete as,

$$Ec = 4734\sqrt{fck'} + 6900 \qquad \text{... (3)}$$

The Euro-code recommends the following equation for static modulus of elasticity of concrete from its cube compressive strength of concrete as,

$$Ec = 9500\,(\sqrt{fck'} + 8)\,0.3 \text{... (4)}$$

The British Code of practice (BS – 8110) recommends the following expression for static modulus of elasticity with cube compressive strength of concrete as,

$$Ec = 20000 + 0.2\,fck \qquad \text{... (5)}$$

Where Ec is the static modulus of elasticity at 28 days in Mpa, fck is cube compressive strength at 28days in Mpa, fck' is cylinder compressive strength at 28days in Mpa.

Also, the Indian code of practice (IS 456) recommends the empirical relation between the static modulus of rupture and cube compressive strength of concrete as,

$$fr = 0.7\sqrt{fck} \qquad \text{.......(6)}$$

The ACI Code (ACI -318), defines the flexural tensile or modulus of rupture of concrete as,

$$fr = 0.62\sqrt{fck'} \qquad \text{......(7)}$$

The New Zealand Code (NZS – 3101) defines flexural tensile or modulus of rupture for normal strength concrete as,

$$fr = 0.60\sqrt{fck'} \qquad \text{.......(8)}$$

The Euro-code (EC-02) recommends the relationship between flexural tensile or modulus of rupture of concrete and cube compressive strength of concrete as,

$$fr = 0.3\,(fck)\,0.67 \qquad \text{....... (9)}$$

The Canadian Code of Practice (CSA) defines the flexural tensile or modulus of rupture of concrete from its cylinder compressive strength of concrete as,

$$fr = 0.60 \sqrt{fck'} \qquad \text{.......(10)}$$

Where fr is flexural tensile or modulus of rupture of concrete in Mpa, fck is cube compressive strength at 28days in Mpa, fck' is cylinder compressive strength at 28days in Mpa,

All the above empirical relationship is only for plain concretes. In the literature, only few relationships of this kind are available 1-19. Therefore, these experiments focused on establishing an empirical relationship between static modulus of elasticity and modulus of rupture based on the compressive strength of concrete containing Steel fibre.

II. RESEARCH SIGNIFICANCE

This paper provides information on the relationship between experimentally obtained modulus of elasticity, modulus of rupture and compressive strength of concrete and steel fibre concrete at 28 days. From the experimental results, the comparison of mechanical properties of concrete are derived from the codes of various countries. An attempt is made to form an empirical relationship between elastic modulus, modulus of rupture using compressive strength of concrete containing steel fibre up to 2.0%.

III.OBJECTIVES

For localized materials and conditions the effect of Steel fibre on the relationships between static modulus of elasticity, modulus of rupture and compressive strength of concrete containing steel fibre has not been clearly established.

1. To study the design codes of various countries for understanding the static modulus of elasticity, modulus of rupture and compressive strength relationships and compared with the relationships to concrete containing Steel fibre.
2. To propose new relationships linking static elastic modulus, modulus of rupture and compressive strength of Steel fibre based concreted with experimentally obtained results.

IV. EXPERIMENTAL PROGRAM – MATERIAL PROPERTIES

The materials consisted of 53-grade Ordinary Portland Cement, Natural River Sand, Crushed Granite Coarse Aggregate of maximum size 12.5mm, Ordinary portable water for mixing and curing and a Super Plasticizing admixture. Steel fibre used in this investigation was procured from Beakart, Belgium. Figure – 1 shows the experimental setup, Table –I show the Properties of Steel fibre and Table – II shows the Concrete mix design details.

TABLE – I
Properties of Steel fibre

Sl. No.	Description	Details
1.	Dramix -60	Dramix® fibres are filaments of wire, deformed and cut to lengths, for reinforcement of concrete, mortar and other composite materials. Dramix® RC-65/60-BN is a cold drawn wire fibre, with hooked ends, and glued in bundles.
2.	Geometry	Performance class: 65, Aspect ratio 45 (= l/d): 67, 3200 fibres / kg
3	Tensile strength	on the wire: 1000 N/mm2

Details from BEAKERT Belgium

TABLE - II
Concrete Mix design details

Sl. No.	Mix Identification	Addition of Steel fibre in concrete,%	Cement quantity in Kg/m^3	Addition of Steel fibre in concrete, Kg/m^3	F.A. in Kg/m^3	C.A. in Kg/m^3	W/C ratio	fck in Mpa	fck' in Mpa
1	Mix-I	0.0	504.21	0.0	683.20	1108.13	0.28	62.44	49.95
2	Mix-II	1.0	504.21	60.0	683.20	1108.13	0.28	61.58	49.42
3	Mix-III	1.5	504.21	90.0	683.20	1108.13	0.28	65.93	52.74
4	Mix-IV	2.0	504.21	120.0	683.20	1108.13	0.28	57.33	45.86

Figure – 1 shows the experimental setup

V. RESULTS AND DISCUSSION –STATIC MODULUS OF ELASTICITY

A comparison of static modulus of elasticity obtained experimentally and that obtained from the empirical expressions given by the various design codes for both plain concrete and steel fibre concrete is presented in Figures 2 & 3.

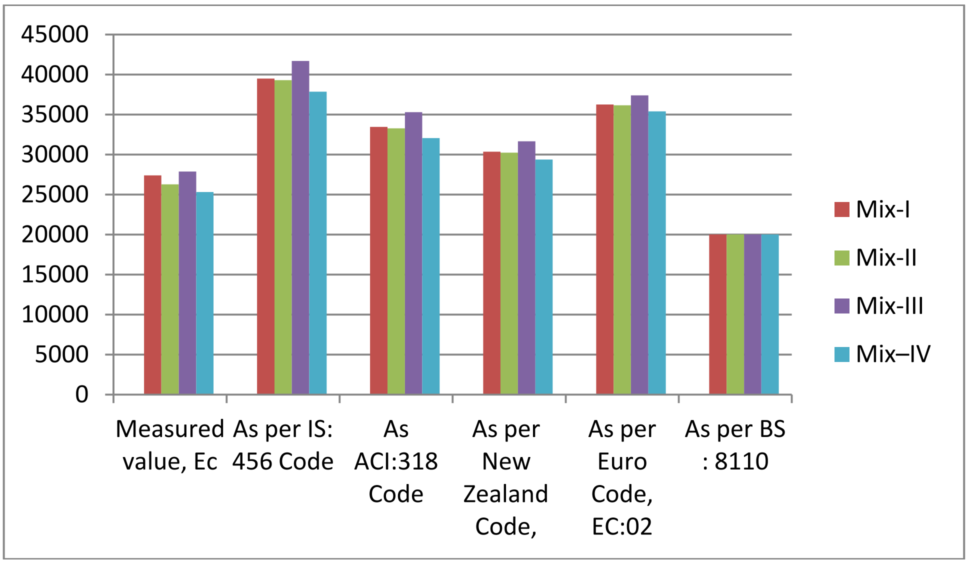

Figure – 2 Comparison of codal provisions for static modulus of elasticity

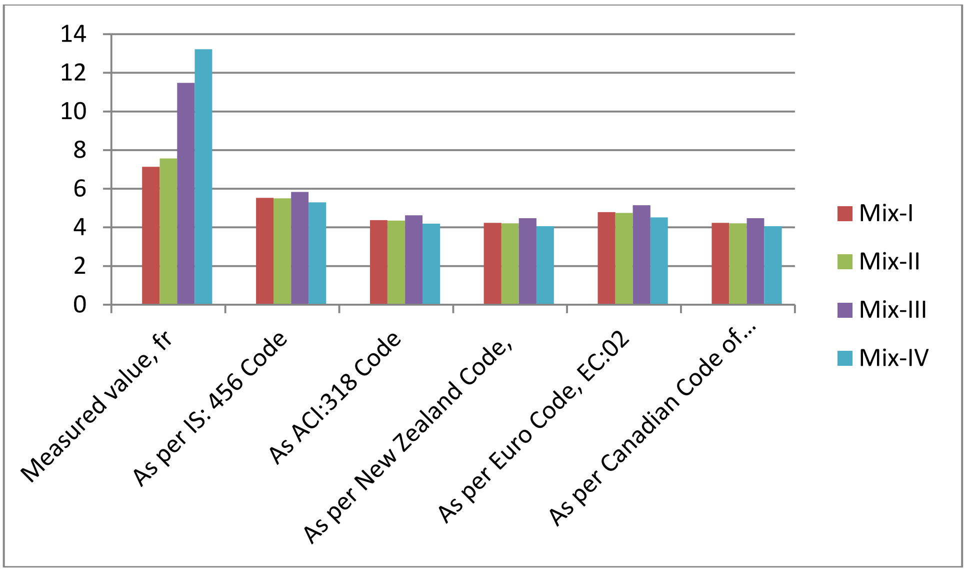

Figure – 3 Comparison of codal provisions for flexural tensile strength concrete

The figures show the modulus of elasticity predicted by IS: 456-2000 and EC:02 are higher than those predicted by BS:8110,ACI:318 and NZS:3101. The figures also show that the experimentally obtained modulus of elasticity is lower than the corresponding modulus of elasticity calculated from the codes.

The figure 2 shows the Modulus Of Elasticity predicted by IS: 456-2000 & EC-02-1995 are higher than compare to other code prediction. From the figure-2 it is concluded that the measured value of Modulus Of Elasticity (MOE) is lower side compare with other code predictions. As the compressive strength of concrete varies, the measured and predicted values of concrete also varying.

Table-II shows the details of cube and cylinder strength of M60 concrete with addition of different percentage steel fibre. As the incorporation percentage of steel fibre increases the strength properties increases up to 1.5% and further addition the values are decreasing.

From the literature, it is reported that the, static modulus of elasticity is a little higher than the bending elastic modulus[12]. With reference to Prashant.Y.Pawade.etal, the incorporation of steel fibers and silica fume in concrete composites shows better performance in improving ductility and strength prior to failure. Also the percentage of fiber increases at 28 and 90 days of curing[14].

TABLE - III
Comparison of codal provisions for static modulus of elasticity

Sl. No.	Mixes Identification	E_c value					
		As per Measured value	As per IS: 456 Code	As per ACI:318 Code	As per New Zealand Code, NZS :3101	As per Euro Code, EC:02	As per BS: 8110
1	Mix-I	27405.07	39509.49	33458.36	30364.67	36269.05	20012.48
2	Mix-II	26287.83	39300.12	33281.06	30240.33	36159.66	20012.35
3	Mix-III	27887.97	41692.32	35306.88	31660.56	37404.04	20013.90
4	Mix–IV	25325.06	37858.28	32060.05	29384.02	35403.98	20011.46

Mix-I – Plain Concrete, Mix – II – Plain Concrete + Addition of 1.0% Steel fibre , Mix – III – Plain Concrete + Addition of 1.5% Steel fibre, Mix – IV – Plain Concrete + Addition of 2.0% Steel fibre

TABLE - IV

Empirical relationships between static modulus of elasticity and compressive strength for constant, C1

Sl. No.	Mixes Identification	C1 for cube compressive strength					
		As per measured value	As per IS:456 Code	As per ACI:318 Code	As per New Zealand Code, NZS :3101	As per Euro Code, EC:02	As per BS : 8110 code
1	Mix-I	3469.00	5001.20	4235.23	3843.62	4591.01	2533.22
2	Mix-II	3344.50	5000.01	4234.23	3847.37	4600.46	2546.10
3	Mix-III	3434.50	5005.08	4238.52	3800.78	4490.28	2402.62
4	Mix–IV	3345.45	5001.09	4235.14	3881.64	4676.87	2643.52

TABLE - V

Empirical relationships between static modulus of elasticity and compressive strength for constant, C2

Sl. No.	Mixes Identification	C2 for cylinder compressive strength					
		As per measured value	As per IS:456 Code	As per ACI:318 Code	As per New Zealand Code, NZS :3101	As per Euro Code, EC:02	As per BS : 8110 code
1	Mix-I	3881.73	5596.24	4739.14	4300.94	5128.76	2834.62
2	Mix-II	3739.37	5590.34	4734.14	4301.61	5143.62	2846.70
3	Mix-III	3841.31	5596.28	4739.17	4249.73	5020.67	2686.42
4	Mix–IV	3740.77	5592.06	4735.60	4340.32	5229.53	2955.90

Based on the regression analysis of the experimentally obtained tests results, the proposed correlations of the modulus of elasticity and compressive strength of cube and cylinder for plain and steel fibre based concrete are given below:

For cube compressive strength

$$Ec = C1\sqrt{fck} \quad \ldots\ldots\ldots \quad (11)$$

For cylinder compressive strength

$$Ec = C2\sqrt{fck'} \quad \ldots\ldots\ldots\ldots \quad (12)$$

Where E_c is the static modulus of elasticity at 28 days in Mpa, fck is cube compressive strength at 28days in Mpa, fck' is cylinder compressive strength at 28days in Mpa and C1 & C2are constants given in the Table no.IV and V.

VI. MODULUS OF RUPTURE

A comparison of static modulus of rupture obtained experimentally and that obtained from the empirical expressions given by the various design codes for both plain concrete and steel fibre concrete is presented in Table -VI.

TABLE - VI

Comparison of codal provisions for flexural tensile strength concrete (fr)

Sl. No.	Mixes	As Per Measured value	As per IS: 456 Code	As per ACI:318 Code	As per New Zealand Code, NZS :3101	As per Euro Code, EC:02	As per Canadian Code of Practice(CSA)
1	Mix-I	7.14	5.531	4.377	4.236	4.787	4.236
2	Mix-II	7.57	5.500	4.350	4.210	4.750	4.210
3	Mix-III	11.48	5.836	4.623	4.474	5.144	4.474
4	Mix-IV	13.22	5.300	4.190	4.060	4.520	4.060

TABLE - VII
Empirical relationships between flexural tensile strength and compressive strength for constants, C1

Sl. No.	Mixes	C1 for cube compressive strength					
		As per measured value	As per IS:456 Code	As per ACI:318 Code	As per New Zealand Code, NZS :3101	As per Euro Code, EC:02	As per Canadian Code of Practice(CSA)
1	Mix-I	0.903	0.700	0.554	0.536	0.605	0.536
2	Mix-II	0.963	0.699	0.553	0.535	0.575	0.535
3	Mix-III	1.413	0.700	0.554	0.537	0.617	0.537
4	Mix–IV	1.746	0.700	0.553	0.536	0.597	0.536

TABLE - VIII
Empirical relationships between flexural tensile strength and compressive strength for constants, C2

Sl. No.	Mixes	C2 for cylinder compressive strength					
		As per measured value	As per IS:456 Code	As per ACI:318 Code	As per New Zealand Code, NZS :3101	As per Euro Code, EC:02	As per Canadian Code of Practice(CSA)
1	Mix-I	1.011	0.783	0.619	0.600	0.678	0.600
2	Mix-II	1.076	0.782	0.618	0.598	0.642	0.598
3	Mix-III	1.581	0.722	0.620	0.600	0.690	0.600
4	Mix–IV	1.952	0.782	0.618	0.599	0.667	0.599

From the Table- VI, the flexural tensile strength of experimental values of concrete is in higher side compare to other code provisions. Table VII & VIII are showing the details of empirical relationships between flexural tensile strength vs cube compressive strength and flexural tensile strength vs cylindrical compressive strength respectively. The IS code predicted values are high compare to other code provision and the value is low to the experimental measured values. The values of constant C1 and C2 are high for Mix-IV due to higher percentage incorporation of fibre in plain concrete and low for Mix-I i.e., plain concrete.

Based on the regression analysis of the experimentally obtained tests results, the proposed correlations between flexural tensile strength and compressive strength of cube and cylinder for plain and steel fibre based concrete are given below:

For cube compressive strength

$$\mathrm{fr} = \mathrm{C1}\sqrt{\mathrm{fck}} \qquad \ldots\ldots (13)$$

For cylinder compressive strength

$$\mathrm{fr} = \mathrm{C2}\sqrt{\mathrm{fck}'} \qquad \ldots\ldots (14)$$

Where f_r is the flexural tensile strength in Mpa, fck is cube compressive strength at 28days in Mpa, fck' is cylinder compressive strength at 28days in Mpa and C_1 & C_2 are constants given in the Table no.VII and VIII.

VII.CONCLUSIONS

This study of the experimentally obtained elastic modulus, modulus of rupture of plain concrete and steel fibre concrete at 28 days and the corresponding codal provisions of select countries, led to the following conclusions:

1. The experimental measured value of static modulus of elasticity of steel fibre reinforced concrete are lower side compare to IS:456-2000 Code, ACI:318 code & NZS:3101 code provisions. The prediction of BS:8110 code values are in lower side compare with measured values.
2. IS:456-2000 and EC:02 predict higher modulus of elasticity than BS:8110,ACI:318 and NZS:3101.
3. The experimental flexural tensile strength was higher than the code based flexural tensile strengths for all the mixes and for all the percentage of addition of steel fibre in plain concrete.
4. The new empirical relations for elastic modulus, modulus of rupture and compressive strength of concrete containing different dosage of steel fibre are proposed.

ACKNOWLEDGMENT

The authors are thankful to the authorities of Coimbatore Institute of Technology for extending their help and the facilities for carrying out the above work in Structural Engineering Laboratory of the Institution.

REFERENCES

[1] Alendar.M.G., An Experimental critique of the BS 8110 Method of estimating concrete elastic modulus, Magazine of Concrete Research, vol.43,pp.291-303,2001.

[2] Andrew Logan, Wonchang Choi, Amir Mirmiran, Sami Rizkalla, and Paul Zia, Short-Term Mechanical Properties of High-Strength Concrete, ACI Materials Journal, pp.1-7,September-October 2009.

[3] Bakht.B. Jaegger, L.G. and Mufti,A.A. , Elastic modulus of concrete from compression tests, ACI Material Journal, Vol.86,pp.220-224,1989.

[4] Beeby, A.W. and Narayanan.R.S. Designers, Handbook to Euro-code 2 Part1.1: Design of concrete Structures, Thomas Telford Services Ltd, London, 1995.

[5] Building code requirements for structural concrete and commentary, ACI Committee: 318-2000, American concrete Institute, Farmington Hills, Michigan.

[6] Design of concrete structures, CSA A 23.3:1994, Technical Committee, Canadian Standards Association, Rexdale, Ontario.

[7] Indian standard specification for coarse and fine aggregates from natural sources for concrete IS: 383-1970, Bureau of Indian Standard, New Delhi.

[8] Indian standard methods of physical tests for hydraulic cement (part 1to 15), IS: 4031-1999, Bureau of Indian Standard, New Delhi.

[9] Indian standard code for plain and reinforced concrete for general building constructions IS: 456-2000, Bureau of Indian Standard, New Delhi.

[10] Legeron,F and Paultre.P,, Prediction of modulus of concrete, ACI Materials Journal, vol.97,pp.193-200, 2000.

[11] Oluokon.F.A.,Burdette.E.G. and Deatherage,J.H., Elastic modulus, poisson's ratio, and compressive strength relationship at early ages, ACI Material Journal, vol.83,pp.302-309,1991.

[12] The Mechanical Properties of Steel Fiber-Reinforced Concrete at Low Fiber content, Engineering Science Research, pp.176, March 4, 2012.

[13] P. Balaguru, Properties of Normal- and High-Strength Concrete Containing Metakaolin, SP199-42, vol.199, pp.737-756, 2001.

[14] Prashant Y.Pawade, Nagarnaik.P.B.Pande.A.M., Performance of steel fiber on standard strength concrete in compression, International Journal of Civil and Structural Engineering, Vol.2,No.2,pp.483-492,2011.

[15] Recommended guidelines for concrete mix design, IS: 10262-1982, Bureau of Indian Standard, New Delhi.

[16] Structural use of concrete-code of practice for design and construction (part2), BS 8110: 1997, British Standard Institution, London.

[17] Standard test method for static modulus of elasticity and Poisson's ratio of concrete in compression, ASTMC: 469 – 2002, ASTM Standards, United states.

[18] The design of concrete structures (part-1) and commentary on the design of concrete structures (part2), NZS:1995, Wellington, New Zealand.

[19] Vinod B,Shikhave, L.G.Kalukar, Combine effectof Metakolin, Flyash and Steel fibre on Mechanical Properties of High Strength Concrete, ISOR Journal of Mechanical and Civil Engineering, Volume 7, Issue 1 (May – June 2013),pp.01-04.