The Asian Review of Civil Engineering
ISSN: 2249 - 6203 Vol. 3 No. 2, 2014, pp.27-40

Elastic Constants of Polymer Modified Fiber Reinforced Concrete

Uttam B. Kalwane[1], Yuwaraj M. Ghugal[2], and Ajay G. Dahake[3]
[1]Principal, Dr. D Y Patil School of Engineering and Technology, Pune (MS), India
[2]Professor, Government College of Engineering, Karad (MS), India
[3]Associate Professor, Marathwada Institute of Technology, Aurangabad (MS), India
E-mail: ajaydahake@gmail.com, ghugal@rediffmail.com

***Abstract* - The results of an experimental investigation to study the effects of hooked steel fibers with varying dosage and polymer latex with fixed dosage in concrete are studied. In this experimental study, varying volume fraction of hooked steel fibers from 0% to 7% by weight of cement at the interval of 1% of fiber and SBR latex polymer of fixed volume of 15% by weight of cement were used. All specimens of only fiber content were water cured and specimens of polymer with fiber content were air cured. At the end of 28 days of curing period, destructive tests were carried out on concrete specimens to determine the elastic constants of fiber reinforced concrete and polymer modified steel fiber reinforced concrete. For the analysis of structures, the elastic constants are very important. The elastic constants are static modulus of elasticity (E_s), dynamic modulus of elasticity (E_d), Poisson's ratio (μ) and modulus of rigidity (G), etc.**

***Keywords:* Polymer modified fiber reinforced concrete, modulus of elasticity, modulus of rigidity, Poisson's ratio**

I. INTRODUCTION

Concrete is one of the most widely used construction material all over the world in view of its strength, high mould ability, structural stability and relative low cost. Rapid advances in Construction materials technology have enabled civil and structural engineers to achieve impressive gains in the safety, economy, and functionality of structure built to serve the common needs of society. There are clear indications that the use of fibers in concrete will increasingly continue to be the preferred choice for many repair and rehabilitation projects involving construction of bridges, Industrial floors, airport pavements, overlays, high rise buildings, TV towers, parking garages, offshore structures, historic monuments etc.

The greatest benefit of using fiber reinforcement is improved long-term serviceability of the structure. By the use of fibers in concrete, substantial time and cost savings can be attained by reducing the cost intensive labors to prepare, place and control ordinary reinforcement. Hence fiber reinforced concrete has been modern and cost efficient construction material [1]. Fiber reinforcement has been shown to improve the ductility, toughness, flexural strength and shear strength of cementitious materials, to reduce shrinkage cracking and permeability and to enhance fatigue and impact resistance. Fiber reinforcement is used to improve the brittle nature of cementitious composites [2]. Fibers are discontinuous and are generally distributed randomly throughout concrete matrix. Fibers are being used in structural applications with conventional reinforcement [3]. Because of the flexibility in methods of fabrication, fiber reinforced concrete can be an economic and useful construction material [4]. In slabs on grade, mining, tunneling, an excavation support applications, steel and synthetic fiber reinforced concrete and shotcrete have been used in lieu of welded wire fabric reinforcement [5]. Polymers being organic in nature have coefficients of thermal expansion several times higher than those of inorganic materials such as concrete or steel. Therefore, when a polymer concrete overlay is subjected to temperature changes, it undergoes greater volumetric changes than the substrate, creating stresses at the bond line. The cumulative effect of these stresses, particularly at very low temperatures, may cause deboning due to adhesive failure at the interface or shear failure in either the polymer concrete or the substrate [6]. It is also known as polymer Portland cement concrete. Polymer modified concrete mixtures are normal Portland cement concrete mixtures to which a water soluble or emulsified polymer has been added during the mixing process. As the concrete cures, hardening of the polymer also occurs, forming a continuous matrix of polymer throughout the concrete. A wide variety of polymers have been investigated for the use in polymer modified concrete [7]. Of these, the latex polymers have been most widely used and accepted. Styrene butadiene is excellent for exterior exposure or environments where moisture is present.

Anupam Singh et al [8] has carried out the study of polymer modified concrete and reported that concrete polymer materials with their increased strength, stiffness and durability properties appear to provide the answer to age-old problem of cracking and deterioration of concrete under adverse environmental conditions. James S. Davidson et al [9] have demonstrated an innovative use of thin-membrane elastomeric polymers to prevent breaching and collapse of unreinforced masonry walls subjected to blast. ACI committee 548 [10] has given standard specifications for latex modified concrete overlays. Semisi Yazici et. al [11] have investigated the effects of aspect ratio and volume fraction of steel fiber on the compressive strength, split tensile strength, flexural strength and ultrasonic pulse velocity of steel fiber reinforced concrete. Christopher K. Y. Leung et al [12] have reported that the flexural strength of fiber reinforced shotcrete is slightly higher than that for fiber reinforced concrete in most cases, but the residual load carrying capacity in post cracking regime can be significantly lower. Due to addition of fibers in concrete, the increase in compressive strength is up to 23% and tensile strength increases up to 60% [13]. Moncef Nehdi et al [14] have used fiber- reinforced self consolidating concrete (FRSCC) for the research work and concluded that some steel fiber combinations seemed to increase the compressive strength of FRSCC beyond what could be achieved by single type steel fibers. Synthetic macro fibers tended to decrease compressive strength but this effect could be reduced when such fibers were used in hybrid blends along with steel fibers, likely due to a better control of micro-macro cracking and the higher stiffness of steel fibers. Charles Nutter et al [15] have performed the experimental investigation to determine the performance characteristics of concretes reinforced with a polypropylene structural fiber. They reported that, in all fiber reinforced concretes the mode of failure was changed from a brittle to a ductile failure when subjected to compression or bending. The average residual strength increased with increase in the fiber content. The modulus of elasticity of fiber reinforced concrete increased up to 30% to 80% higher than that of plain concrete [16]. The modulus of elasticity of concrete is largely controlled by the volume and modulus of the aggregate. Small addition of steel fibers would not be expected to greatly alert the modulus of the composites.

Sedat Kurugol et.al [17] have studied the effect of steel fiber reinforcement and polymer modification on the young's modulus of lightweight concrete aggregates. They concluded that, the young's modulus of elasticity of the concrete decreases with the change of coarse aggregate fraction with lightweight aggregate and by increasing its volume fraction. The same trend can be observed in steel fiber reinforced lightweight concrete mixtures. The rate of decrease depends strongly on the aggregate volume fraction. The effect of the polymer on modulus of elasticity is that for lower polymer volume ratio it has a positive effect. Modulus of elasticity of the polymer concrete, increases by approximately 13%. V. Bhikshma and L. Jail Singh [18] have reported that, the increase in modulus of elasticity for M30 grade concrete with addition of 0.25%, 0.5% and 1.0% of steel fibers was observed to be 16%, 41% and 50% respectively when compared with plain concrete. Similarly for M35 grade concrete the increase in strength with addition of steel fibers was observed to be 25%, 43% and 55% respectively when compared to plain concrete. The modulus of elasticity of recycled aggregate concrete with addition of 1.0% of steel fibers to be 50% more compared to plain concrete.

Job Thomas and Ananth Ramaswamy [19] have carried out the experimental study and an analytical assessment of the influence of addition of fibers on mechanical properties of concrete. They reported that the maximum increase in the compressive strength, modulus of elasticity and Poisson's ratio due to the addition of steel fibers was found to be quite small (less than 10%) in various grades of concrete (M35, M65 and M85). The maximum increase in the tensile strength, namely, split tensile strength and modulus of rupture due to the addition of steel fibers, was found to be about 40% in various grades of concrete and is the primary justification for using fibers in concrete. The post- cracking response is significantly enhanced with fiber dosages across the different concrete grades. The modulus of elasticity of fiber reinforced concrete increased up to 30% to 80% higher than that of plain concrete [4]. The modulus of elasticity of concrete is largely controlled by the volume and modulus of the aggregate. Small addition of steel fibers would not be expected to greatly alert the modulus of the composites.

In this paper, effect of polymer modified fiber reinforced concrete on modulus of elasticity, modulus of rigidity and Poisson's ratio over plain concrete is studied.

II.EXPERIMENTAL PROGRAMME

Experimental work was aimed to study the effect of polymer modification along with hooked steel fibers on various properties of concrete and its feasibility in the actual field of construction, especially flexural strength, compressive strength, modulus of elasticity, etc of modified high strength concrete after some preliminary trials.

For preparation of steel fiber reinforced concrete (SFRC) and polymer modified steel fiber reinforced concrete (PMSFRC), materials used were cement, fine aggregate, coarse aggregate (20mm), coarse aggregate (10mm), hooked end steel fibers, polymer latex, super plasticizer and water. The cement used in this experimental work was 53 grade Ordinary Portland Cement (OPC) conforming to IS: 12269-1987, the fineness moduli of fine and coarse agreegates were 2.872 and 6.97 respectively. Bekaert–Dramix® high tensile steel fibers with hooked ends are made from prime quality high carbon steel wire were used. They had hooked ends and were collated into clips of about10 individual fibers using water soluble adhesive as shown in Figure 1. The collation reduces the tendency for balling of fibers during the mixing process. The adhesive dissolved in the mixing water in about one minute, facilitating the distribution of individual fibers. A hooked end which slowly deforms during pull-out is generally considered as the best form of anchorage. These fibers are manufactured by the BEKAERT, a Belgium based company with the trade name of Dramix® and type RC80/60 BN. These fibers are supplied by M/s Shakti Commodities Pvt. Ltd., New Delhi.

Fig. 1 Hooked End Steel Fibers

Physical properties of fibers used for the experimental work are shown in Table I.

TABLE I PHYSICAL PROPERTIES OF FIBER

Description	Value
Type of fiber	Hooked end steel fiber
Length of fiber (*l*)	60 mm
Thickness (diameter) of fiber (d)	0.75 mm
Aspect ratio (*l*/d)	80
Tensile Strength	2000 N/mm^2
Specific gravity	7.8
Modulus of Elasticity	200 Gpa

Polymer latex additive ‘Monobond’ is used as a polymer. This polymer is available in liquid form containing 40% solids and 60 % water. The water contained in the polymer has included in the total water content of the mix i.e. reduce the amount of water contained in polymer from the quantity of w/c ratio while adding the water to the concrete mix. This is a non-epoxy thermosetting polymer. It is a latex emulsion manufactured and marketed by a Mumbai based company M/s Krishna Conchem products Pvt. Ltd. under the trade name ‘Monobond®’. Properties of this polymer are shown in Table II.

TABLE II PROPERTIES OF POLYMER

Property	Description
Polymer system	Polymer Latex additive (Monobond)
Type	Latex
Base	Polymer Latex
Appearance	Milky White
Setting characteristics	Slow
Viscosity at 270c (± 2)	15 sec
Specific Gravity at 270c (± 2)	1.08
pH	10.40

Roff Super plast 320 have been used as super plasticizer to improve the workability of concrete. Dosage used in this experimental work was 1.75% by weight of cement. This Super plasticizer is added to mixing water first and then this mixture is added to the dry mix concrete.

III.SYSTEM DEVELOPMENT

A. Compression test

The compression test was performed to find out compressive strength of steel fiber reinforced concrete and polymer modified steel fiber reinforced concrete on test specimens cubical in shape of size 150mm, confirming to IS: 10086-1982. Compression testing machine of capacity 3000 kN was used.

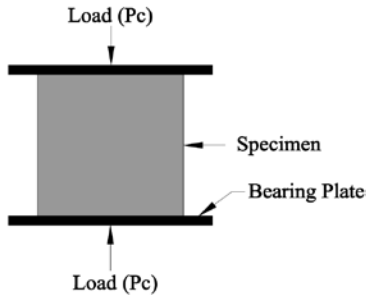

Fig. 2 Compression test setup

The compressive strength of the specimen is calculated by using the formula,

$$f_{cu} = \frac{P_c}{A} \tag{1}$$

where, f_{cu} = Compressive strength of concrete in MPa
P_c = Maximum applied load in N
A = Cross sectional area in mm^2

B. Flexure test

To find out flexural strength of concrete, prism specimens of size 150mm $\times$150mm $\times$700mm were used. The arrangement for loading of flexure test specimen is shown in Figure 3. The prism specimen shall be placed in the machine in such a manner that the load shall be applied to the uppermost surface as cast in the mould, along two lines spaced 200mm apart i.e. two point load. The axis of the specimen shall be carefully aligned with the axis of the loading device. The load was applied without shock and increasing continuously at a rate of 400 kg/min. The appearance of the fractured faces of concrete and any unusual features in the type of failure was noted.

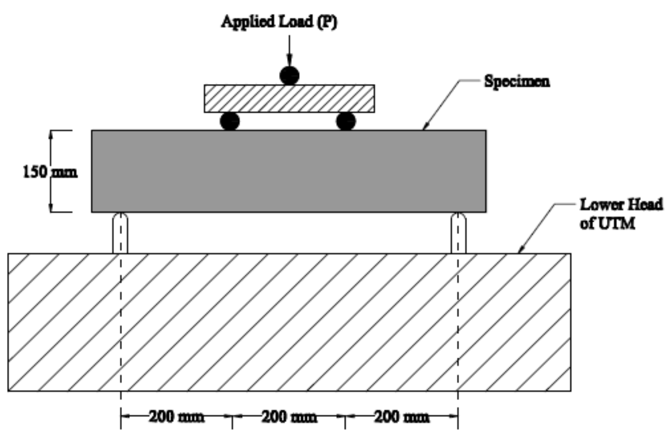

Fig. 3 Loading Arrangement for Flexure Test

The flexural strength of the specimen shall be expressed as the modulus of rupture (*fb*) and calculated by using following expression

$$f_b = \frac{Pl}{bd^2} \tag{2}$$

when ‘a’ is greater than 200 mm, or

$$f_b = \frac{3Pa}{bd^2} \tag{3}$$

when ‘a’ is less than 200 mm but greater than 170 mm.
where,
P = Maximum applied load to the specimen in kN
a = the distance from the line of fracture to the nearer support, measured on the center line of the tensile side of the specimen in mm (Note: if ‘a’ is less than 170mm then the results of the test shall be discarded

b = measured width of the specimen in mm.
d = measured depth of the specimen at the point of failure in mm.
l = length of the span on which the specimen is supported in mm.

The results of compressive strength (f_{cu}) and flexural tensile strength (f_b) of concrete are shown in Table 3.

C. Modulus of elasticity

The modulus of elasticity (E) is primarily influenced by the elastic properties of the aggregate, age of the concrete, conditions of curing, the type of cement and mix proportions. Small additions of steel fibers would not be expected to greatly alter the modulus of composite. The modulus of elasticity is normally related to the compressive strength of concrete. The static modulus of elasticity of steel fiber reinforced concrete and polymer modified steel fiber reinforced concrete can be determined by using formulae given by Indian code IS 456: 2000 and British code BS: 8110 depending upon compressive strength of concrete. It is given by the following expressions

Using IS 456:2000, $$E_s = 5.0\sqrt{f_{cu}} \qquad (4)$$

Using BS 8110 :(Part2)-1985, $$E_s = 9.1\,(f_{cu})^{0.33} \qquad (5)$$

where, E_s = Static modulus of elasticity in GPa
f_{cu} = Cube compressive strength of concrete in N/mm^2

Dynamic modulus of elasticity is obtained according to BS 8110: (Part2)-1985 by the following expression

$$E_d = 7.6\,(f_{cu})^{0.33} + 14 \qquad (6)$$

where, E_d = Dynamic modulus of elasticity of the PMSFRC in GPa
f_{cu} = Cube compressive strength of PMSFRC in N/mm^2

The relation between static modulus of Elasticity (Es) and dynamic modulus of Elasticity (E_d) (from Eqn. 5) of concrete as per BS: 8110 (Part-2)–1985 is given below

$$E_s = 1.25E_d - 19 \qquad (7)$$

D. Poisson's ratio

At the point of initial cracking the strain on the tension face of a beam in flexure and the lateral tensile strain in compression specimen in uniaxial compression are of the same magnitude. Based on this research finding and using stress strain relation of solid mechanics Neville has derived the formula for Poisson's ratio as follows

Poisson's ratio, $$\mu = \frac{f_b}{f_{cu}} \qquad (8)$$

where, μ = Static Poisson's ratio
f_b = Tensile stress at cracking in flexure in MPa
f_{cu} = Compressive stress at cracking in a compression specimen in MPa

E. Modulus of rigidity

The modulus of rigidity (G) of steel fiber reinforcement concrete and polymer modified steel fiber reinforced concrete is obtained from following equation

$$G = \frac{E}{2(1+\mu)} \qquad (9)$$

where, E = Modulus of elasticity
μ = Poisson's ratio

Results of the static modulus of elasticity, dynamic modulus of elasticity, Poisson's ratio of the composite and modulus of rigidity from the above expressions are presented in tables and graphically also.

IV. RESULTS AND DISCUSSION

A. Compression strength and flexural / tensile strength

Results of compressive strength and flexural / tensile strength are shown in Table III.

TABLE III COMPRESSIVE STRENGTH AND FLEXURAL / TENSILE STRENGTH

Sr. No.	Mix Designation	Fiber Content (*Vf*) %	Polymer Content %	Compressive Strength (f_{cu}) MPa	Flexural/Tensile Strength (f_b) MPa
1	M0	0	0	44.59	3.17
2	M1	1		46.67	4.17
3	M2	2		47.02	5.37
4	M3	3		49.51	5.46
5	M4	4		54.22	5.08
6	M5	5		54.13	4.71
7	M6	6		51.56	4.63
8	M7	7		48.09	4.48
9	M8	0	15	47.88	3.87
10	M9	1		49.88	4.60
11	M10	2		50.52	5.44
12	M11	3		52.89	5.56
13	M12	4		56.36	5.17
14	M13	5		55.73	4.76
15	M14	6		52.53	4.65
16	M15	7		49.35	4.62

B. Modulus of elasticity

The results of static modulus of elasticity (*Es*) obtained from Eqn. (4) and Eqn. (5) and dynamic modulus of Elasticity (E_d) obtained from Eqn. (6) for steel fiber reinforced concrete (SFRC) and polymer modified steel fiber reinforced concrete (PMSFRC) are shown in Table 4.

Variations of modulus of elasticity (E_s) from IS: 456-2000, BS: 8110, variation of dynamic modulus of elasticity (E_d) with respect to fiber content (*Vf*) are plotted as shown in Figure 4, Figure 5 and Figure 6 respectively. Also variation of modulus of elasticity (E_s) from IS: 456-2000 and BS: 8110 with respect to compressive strength (f_{cu}) are plotted as shown in Figure 6 and Figure 7.

TABLE IV EXPERIMENTAL RESULTS AND RESULTS OF REGRESSION ANALYSIS OF MODULUS OF ELASTICITY (E) OF SFRC AND PMSFRC

Sr. No.	Mix Designation	Fiber Content (Vf) %	Polymer Content %	Modulus of Elasticity (E) MPa					
				Es (GPa) using IS: 456 Eqn. (4)	From Eqn. (10) and (11)	Es (GPa) using BS: 8110 Eqn. (5)	From Eqn. (12) and (13)	Ed (GPa) using Eqn.(6)	From Eqn. (14) and (15)
1	M0	0	0	33.39	33.500	31.86	31.930	40.61	40.670
2	M1	1		34.16	33.769	32.35	32.102	41.01	40.814
3	M2	2		34.29	34.564	32.43	32.592	41.08	41.226
4	M3	3		35.18	35.555	32.98	33.196	41.55	41.738
5	M4	4		36.82	36.412	33.99	33.710	42.39	42.182
6	M5	5		36.79	36.805	33.97	33.930	42.37	42.390
7	M6	6		35.90	36.404	33.43	33.652	41.92	42.194
8	M7	7		34.67	34.879	32.67	32.672	41.28	41.426
9	M8	0	15	34.60	34.650	32.62	32.650	41.24	41.270
10	M9	1		35.31	35.072	33.06	32.911	41.61	41.489
11	M10	2		35.54	35.804	33.20	33.356	41.73	41.866
12	M11	3		36.36	36.594	33.71	33.829	42.15	42.275
13	M12	4		37.54	37.190	34.42	34.174	42.75	42.590
14	M13	5		37.33	37.340	34.30	34.235	42.64	42.685
15	M14	6		36.24	36.792	33.63	33.856	42.09	42.434
16	M15	7		35.12	35.294	32.95	32.881	41.52	41.711

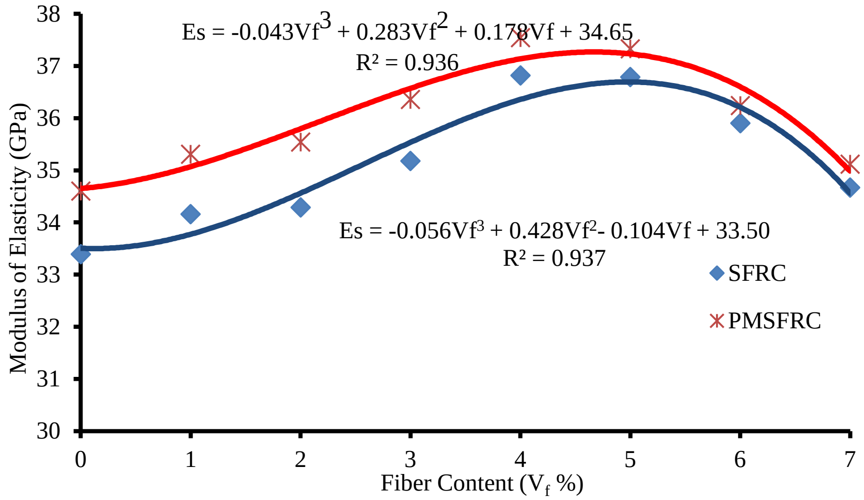

Fig.4 Variation of modulus of elasticity (Es) (IS: 456-2000) with respect to fiber content.

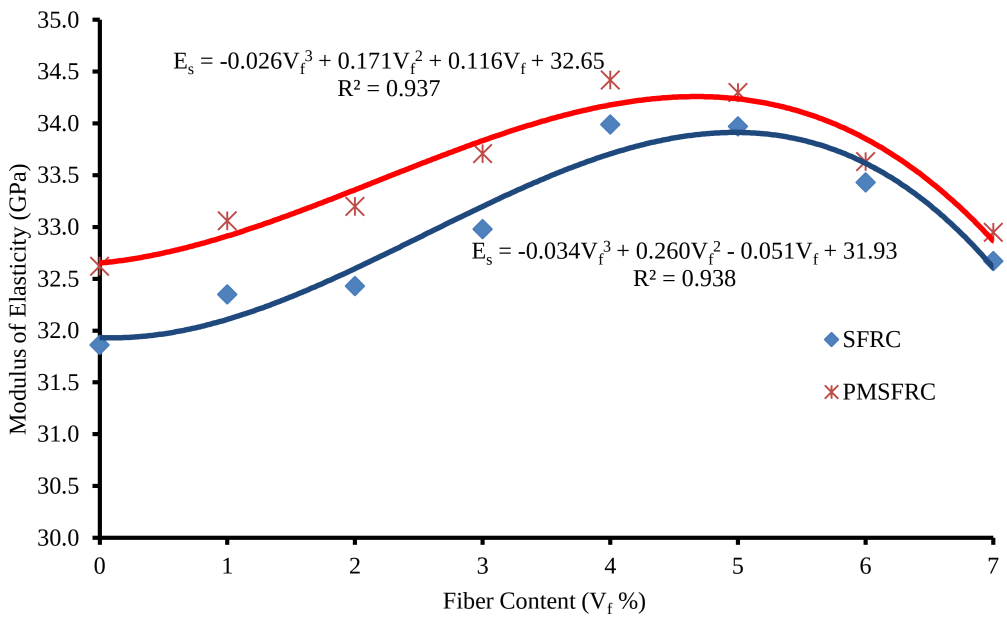

Fig.5 Variation of modulus of elasticity (Es) (BS:8110) with respect to fiber content (Vf).

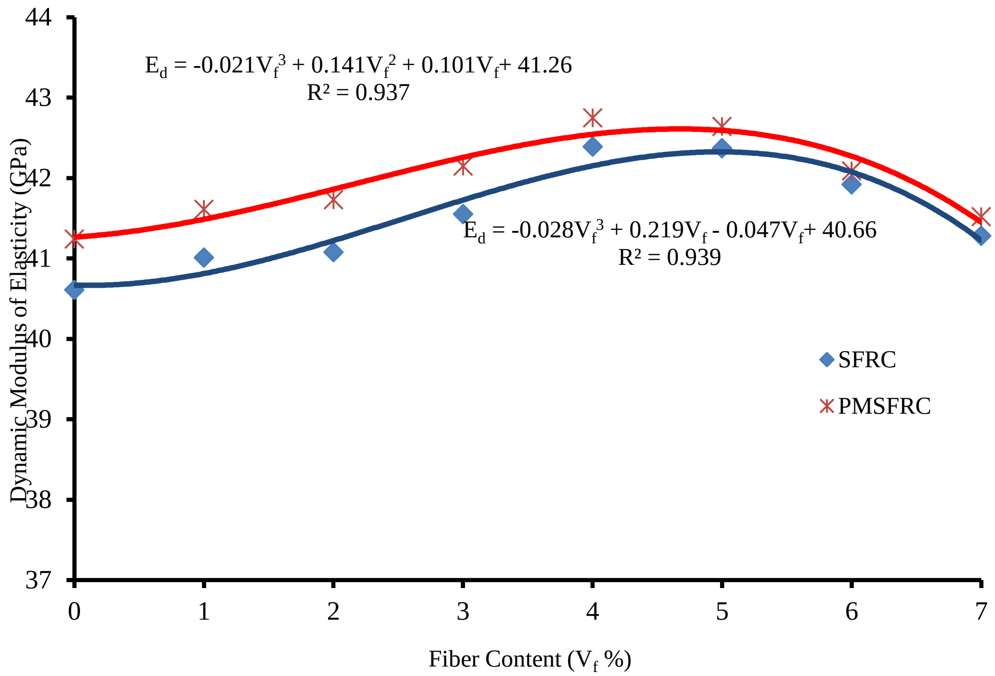

Fig.6 Variation of dynamic modulus of elasticity (Ed) with respect to fiber content (Vf).

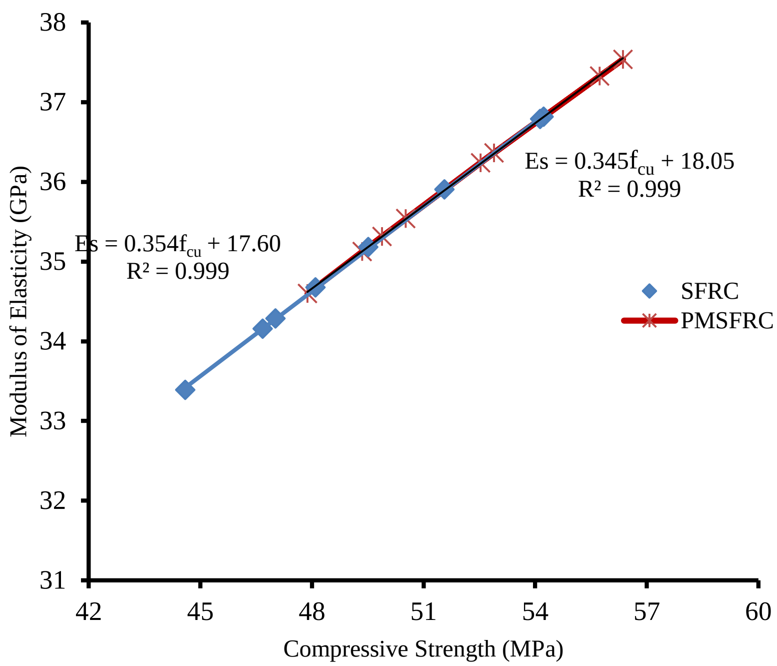

Fig.7 Variation of modulus of elasticity (Es) (IS: 456-2000) with respect to compressive strength (fcu).

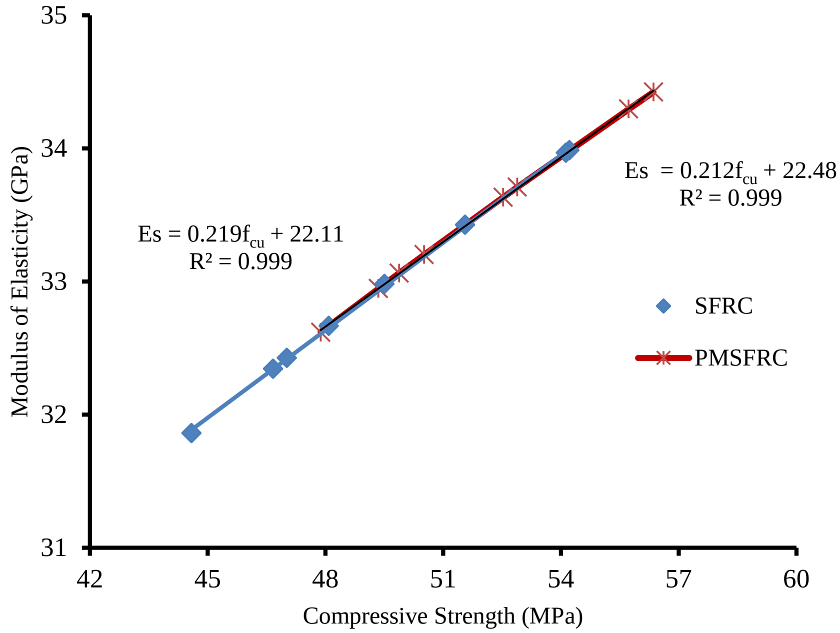

Fig. 8 Variation of modulus of elasticity (Es) (BS: 8110) with respect to compressive strength (fcu).

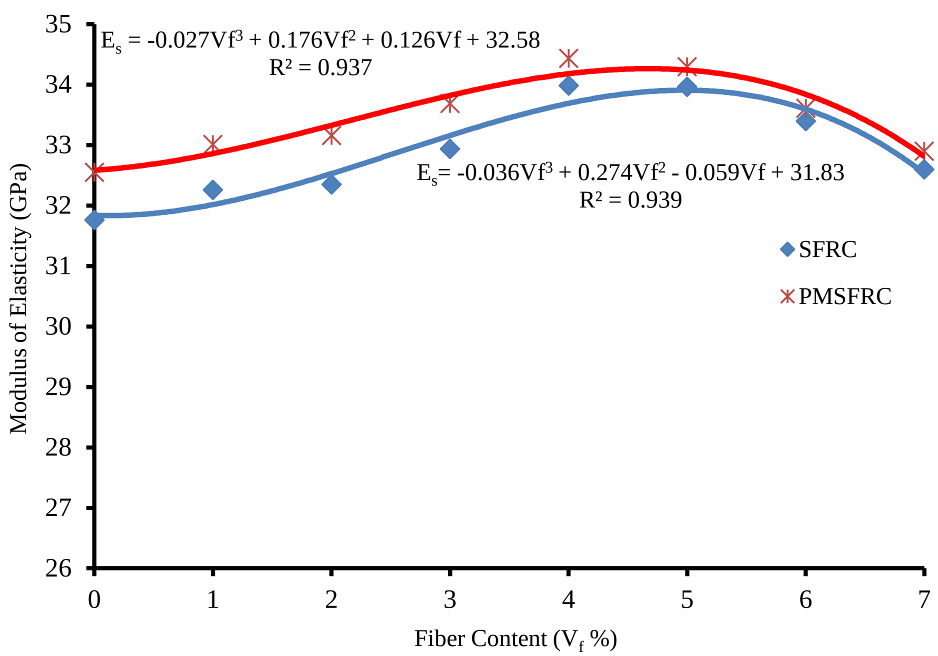

Fig. 9 Variation of modulus of elasticity (Es) from dynamic modulus of elasticity (Ed) with respect to fiber content.

Mathematical analysis of the test results is done by using regression analysis. Regression analysis is the dependence of a variable on one or more variables. Results obtained in this experimental research work are compared by regression analysis and are presented in the tables.

Expressions for static modulus of Elasticity (Es) (using IS 456:2000) in 3rd degree polynomial in terms of fiber content (Vf) are obtained from the Figure 2 and are given below

For SFRC, $Es = -0.055\ Vf^{3} + 0.428\ Vf^{2} - 0.104\ Vf + 33.50$ (10)

For PMSFRC, $Es = -0.042\ Vf^{3} + 0.281\ Vf^{2} + 0.183\ Vf + 34.65$ (11)

Expressions for static modulus of Elasticity (Es) (using BS 8110: (Part 2)-1985) in 3rd degree polynomial in terms of fiber content (Vf) are obtained from the Figure 2 and are given below

For SFRC, $Es = -0.034\ Vf^3 + 0.261\ Vf^2 - 0.055\ Vf + 31.93$ (12)
For PMSFRC, $Es = -0.026\ Vf^3 + 0.170\ Vf^2 + 0.117\ Vf + 32.65$ (13)

Expressions for dynamic modulus of Elasticity (Ed) (using BS: 8110 Part2-1985) in 3rd degree polynomial in terms of fiber content (Vf) are obtained from the Figure 4 as below

For SFRC, $Ed = -0.028\ Vf^3 + 0.218\ Vf^2 - 0.046\ Vf + 40.67$ (14)
For PMSFRC, $Ed = -0.021\ Vf^3 + 0.142\ Vf^2 + 0.098\ Vf + 41.27$ (15)

Graphs have plotted for static modulus of Elasticity (Es) (using IS; 456-2000) versus compressive strength (fcu) and static modulus of Elasticity (Es) (using BS: 8110 Part 2-1985) versus compressive strength (fcu) are as shown in Figure 5 and Figure 6.

For SFRC, $Es = -0.036\ Vf^3 + 0.274\ Vf^2 - 0.059\ Vf + 31.83$ (16)
For PMSFRC, $Es = -0.027\ Vf^3 + 0.176\ Vf^2 + 0.126\ Vf + 32.58$ (17)

It is observed from the results shown in Table V, Figure 3, Figure 4 and Figure 5 that, the modulus of elasticity of the specimens containing fibers only (SFRC) have increased up to 4% of fiber content as compared to the normal mix and then it is reduced with the increase in fiber content. Also the modulus of elasticity of the specimens containing fibers with polymer (PMSFRC) have increased up to 4% of fibers with polymer content and then it is reduces with the increase in fiber content. It is also observed that the values of dynamic modulus of elasticity are slightly more as compared to the values of static modulus of elasticity.

C. Poisson's ratio

The results of Poisson's ratio (μ) obtained from Eqn. (8) and results of regression analysis obtained via Eqn. (18,19) for steel fiber reinforced concrete (SFRC) and polymer modified steel fiber reinforced concrete (PMSFRC) are shown in Table 5 and variations of Poisson's ratio (μ) with respect to fiber content (Vf) are plotted as shown in Figure 10.

TABLE V EXPERIMENTAL RESULTS AND RESULTS OF REGRESSION ANALYSIS FOR POISSON'S RATIO (μ) OF SFRC AND PMSFRC.

Sr. No.	Mix Designation	Fiber Content (Vf) %	Polymer Content %	Poisson's Ratio (μ)	
				Experimental Value from Eqn. (8)	From Eqn. (18) and (19)
1	M0	0	0	0.071	0.068
2	M1	1		0.089	0.097
3	M2	2		0.114	0.108
4	M3	3		0.110	0.107
5	M4	4		0.094	0.100
6	M5	5		0.087	0.093
7	M6	6		0.090	0.092
8	M7	7		0.093	0.103
9	M8	0	15	0.081	0.078
10	M9	1		0.092	0.096
11	M10	2		0.108	0.096
12	M11	3		0.105	0.078
13	M12	4		0.092	0.042
14	M13	5		0.085	-0.012
15	M14	6		0.089	-0.084
16	M15	7		0.094	-0.174

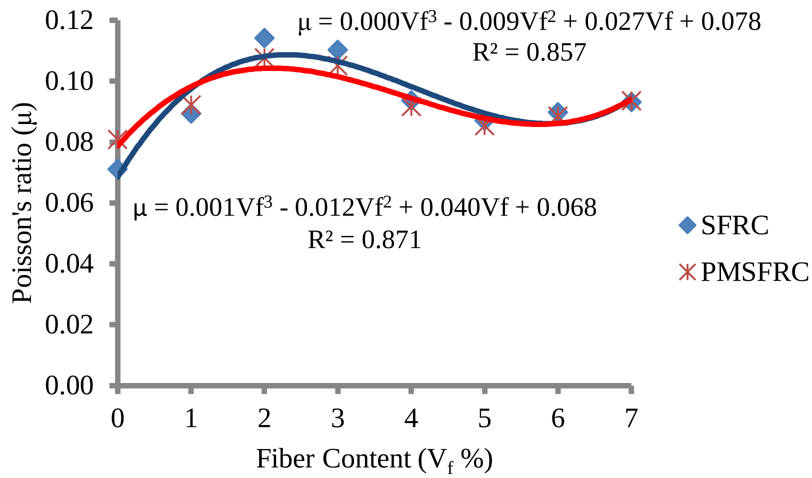

Fig.10 Variation of Poisson's ratio (μ) with respect to fiber content (Vf).

Experimental results and results of regression analysis for Poisson's ratio (μ) of SFRC and PMSFRC are presented in Table V.

For SFRC, $\mu = 0.001\ Vf^3 - 0.012\ Vf^2 + 0.040\ Vf + 0.068$ (18)

For PMSFRC, $\mu = 0.000\ Vf^3 - 0.009\ Vf^2 + 0.027Vf + 0.078$ (19)

It is observed from the results shown in Table 5 and Figure 9 that, the Poisson's ratio of the specimens containing fibers only (SFRC) have increased up to 3% of fiber content as compared to the normal mix and then it is reduced with the increase in fiber content. Also the Poisson's ratio of the specimens containing fibers with polymer (PMSFRC) have increased up to 2% of fibers with polymer content and then it is reduces with the increase in fiber content.

D. Modulus of rigidity

The of modulus of rigidity (G) has been find out by using Eqn. (9) and the results obtained from regression analysis are presented in Table 6 and graphically shown in Figure 11-13.

TABLE VI EXPERIMENTAL RESULTS AND RESULTS OF REGRESSION ANALYSIS FOR MODULUS OF RIGIDITY (G) OF SFRC AND PMSFRC

Sr. No.	Mix Designation	Fiber Content (Vf) %	Polymer Content %	Modulus of Rigidity (G) MPa					
				Experimental Result *Gs* (GPa) From Eqn. (9)	From Eqn. (20) and (21)	Experi-mental Result *Gs* (GPa)	From Eqn. (22) and (23)	Experime-ntal Result *Gd* (GPa)	From Eqn. (24) and (25)
1	M0	0	0	15.88	15.94	15.16	15.19	19.32	19.35
2	M1	1		15.68	15.45	14.85	14.70	18.83	18.68
3	M2	2		15.39	15.58	14.56	14.69	18.44	18.58
4	M3	3		15.85	16.04	14.86	14.99	18.72	18.82
5	M4	4		16.83	16.58	15.53	15.38	19.37	19.18
6	M5	5		16.92	16.94	15.63	15.68	19.49	19.46
7	M6	6		16.47	16.85	15.33	15.67	19.23	19.43
8	M7	7		15.86	16.04	14.95	15.17	18.88	18.89
9	M8	0	15	16.11	16.17	15.19	15.14	19.20	19.26
10	M9	1		16.27	16.02	15.24	14.94	19.18	18.96
11	M10	2		16.04	16.23	14.98	15.03	18.83	18.98
12	M11	3		16.45	16.62	15.25	15.27	19.07	19.19
13	M12	4		17.19	17.01	15.76	15.52	19.57	19.43
14	M13	5		17.20	17.20	15.81	15.66	19.65	19.57
15	M14	6		16.64	17.01	15.44	15.52	19.33	19.45
16	M15	7		16.05	16.254	15.06	14.99	18.98	18.95

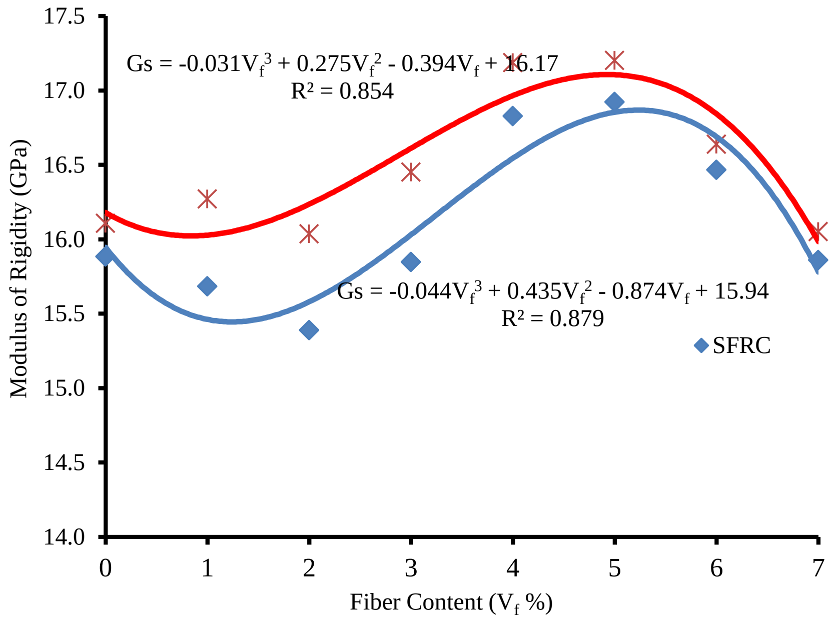

Fig. 11 Variation of modulus of rigidity (Gs) (IS: 456-2000) with respect to fiber content.

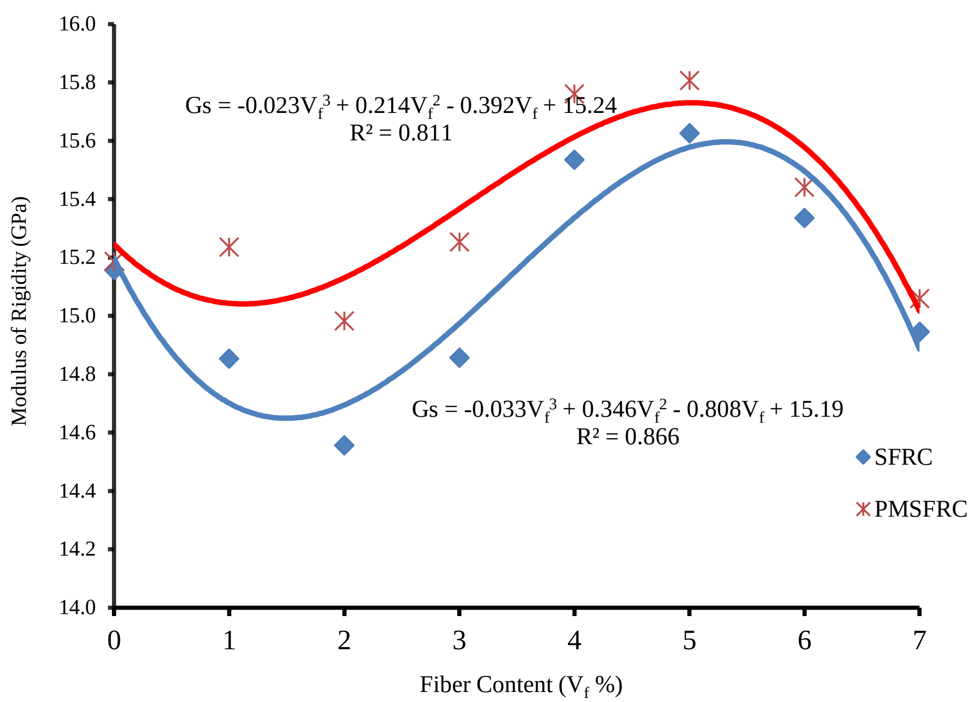

Fig. 12 Variation of modulus of rigidity (Gs) (BS: 8110) with respect to fiber content (Vf).

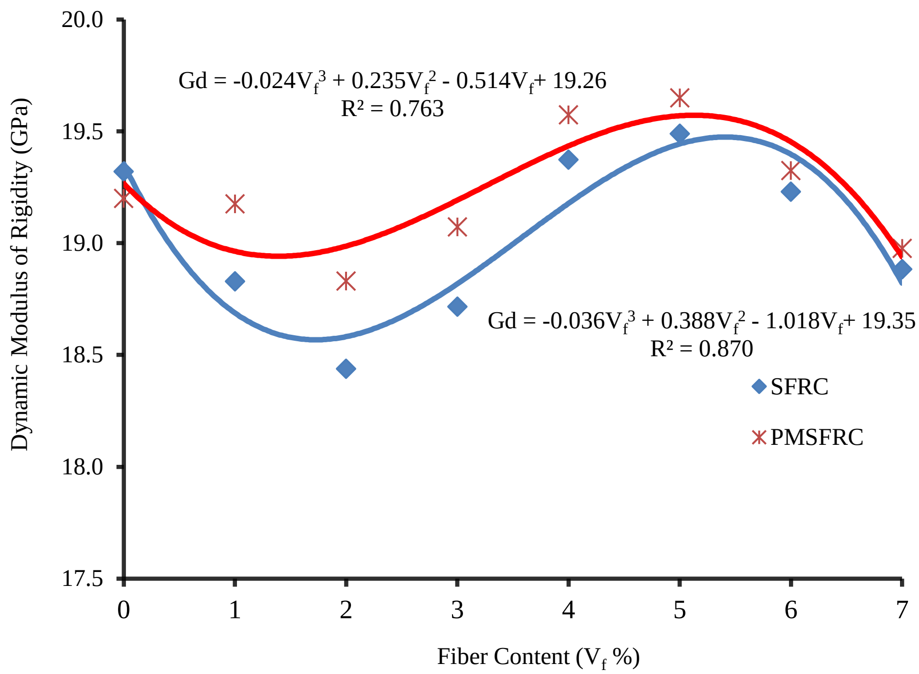

Fig.13 Variation of dynamic modulus of rigidity (Gd) with respect to fiber content (Vf).

For SFRC, $G_s = -0.044\ Vf^{3} + 0.435\ Vf^{2} - 0.874\ Vf + 15.94$ (20)

For PMSFRC, $G_s = -0.031\ Vf^{3} + 0.275\ Vf^{2} - 0.394\ Vf + 16.17$ (21)

Expressions for static modulus of rigidity (Gd) in 3rd degree polynomial using BS: 8110 in terms of fiber content (Vf) are obtained from the Figure 11 and are mentioned below

For SFRC, $G_s = -0.033\ Vf^{3} + 0.346\ Vf^{2} - 0.808\ Vf + 15.19$ (22)

For PMSFRC, $G_s = -0.023\ Vf^{3} + 0.214\ Vf^{2} - 0.392\ Vf + 15.24$ (23)

Expressions for dynamic modulus of rigidity (Gd) in 3rd degree polynomial in terms of fiber content (Vf) are obtained from the Figure 12 and are mentioned below

For SFRC, $G_d = -0.036\ Vf^{3} + 0.388\ Vf^{2} - 1.018\ Vf + 19.35$ (24)

For PMSFRC, $G_d = -0.024\ Vf^{3} + 0.235\ Vf^{2} - 0.514\ Vf + 19.26$ (25)

It is observed from the results shown in Table 6 and Figure 10-12 that, the modulus of rigidity of the specimens containing fibers only (SFRC) and that of with polymer (PMSFRC) have increased up to 5% of fiber content as compared to the normal mix and then it is reduced with the increase in fiber content.

V. CONCLUSION

On the basis of results obtained from experimental work, observations made during casting and testing of specimens, and results of the behavior of fiber reinforced concrete and normal concrete. For the analysis of structures, the elastic constants are very important. The elastic constants are static modulus of elasticity (Es), dynamic modulus of elasticity (Ed), Poisson's ratio (μ) and modulus of rigidity (G), etc. Experimental results and results obtained by regression analysis are in excellent agreement with each other.

REFERENCES

[1] Winterberg Ralf "Fibre Reinforced Concrete – A Modern Cost-efficient Construction Material", *ICI Journal*, Vol. 11, Issue 3, pp. 34-45, 2010.

[2] Kuder Katherine, G. Ozyurt, Nilufer, E. B. Mu, S. P. Shah "Rheology of Fiber- Reinforced Cementitious Materials", *Cement and Concrete Research*, Vol. 37, Issue 2, pp. 191-199, 2007.

[3] Balaguru P. and Najm H. "High-Performance Fiber-Reinforced Concrete Mixture Proportions With High Fiber Volume Fractions", *ACI Materials Journal*, 101, Vol. 4, pp. 281-286, 2004.

[4] Balaguru P. and Foden Andrew, "Properties of Fiber Reinforced Structural Lightweight Concrete", *ACI Structural Journal*, Vol. 93, Issue 1, pp. 62-78, 1996.

[5] Parameswaran V. S. "High- Performance Fibre Reinforced Concretes", *The Indian Concrete Journal*, pp. 621-627, 1996.

[6] ACI Committee 548 (ACI 548.5R), "Guide for Polymer Concrete Overlays", ACI Materials Journal, pp. 499-522, 1993.

[7] ACI Committee 548 (ACI 548.1 R.86), "Guide for the Use of Polymers in Concrete", *ACI Journal*, Vol. 83, pp. 798-829, 1986.

[8] Singh Anupam, Lakhani Rajni, et al, "A Review on Polymer Modified Cementitious System for Building Applications", *Civil Engineering and Construction Review*, Vol. 19, Issue 10 (CE & CR), pp. 33-39, 2006.

[9] Davidson James S., et al, "Failure Mechanisms of Polymer-Reinforced Concrete Masonry Walls Subjected to Blast", *Journal*

of Structural Engineering, ASCE, Vol. 131, Issue 8, pp. 1194-1205, 2005.

[10] ACI Committee 548 (ACI 548.4), "Standard Specification for Latex-Modified Concrete (LMC) Over Lays", *ACI Materials Journal*, Vol. 89, Issue 5, pp. 521-526, 1992.

[11] Yazici Semsi, Inan Gozde, et al, (2007) Effect of aspect ratio and volume fraction of steel fiber on the mechanical properties of SFRC," *Construction and Building Materials*, Vol. 21, pp. 1250-1253, 2007.

[12] Christopher K.Y. Leung, Raymond Lai, et al, "Properties of Wet- Mixed Fiber Reinforced Shotcrete and Fiber Reinforced Concrete with Similar Composition", *Cement and Concrete Research*, Vol. 35, pp. 788-795, 2005.

[13] Ghugal Y. M. "Effect of Steel Fibers on Various Strengths of Concrete", *ICI Journal*, pp. 23-29, 2003.

[14] Nehdi Moncef and Ladanchuk Jennifer Duquette, "Fiber Synergy in Fiber- Reinforced Self- Consolidating Concrete", *ACI Materials Journal*, pp. 508-517, 2004.

[15] Nutter Charles, Kalahasti Srikanth, Panchalan Ramesh K. and Ramakrishna V. "International Centre for Fibre Reinforced Concrete Composite (ICFRC)", *Technical Manual*, TM 9, pp. 1-8, 2005.

[16] Kurugol Sedat, Tanacan Leyla, Halit Ersoy, Yasa, "Young's modulus of fiber- reinforced and polymer- modified light weight concrete composites", *Construction and Building Materials*, pp. 1-10, 2007.

[17] Bhikshma V. and Singh L., Jail, "Investigations on Mechanical Properties of Recycled Aggregate concrete containing steel fibers", *ICI Journal*, Vol. 10, Issue 4, pp. 15-19, 2010.

[18] Job Thomas and Ananth Ramaswamy, "Mechanical Properties of Fiber – Reinforced Concrete", *Journal of Materials in Civil Engineering, ASCE*, Vol. 19,Issue 5, pp. 385-392, 2007.

[19] Sedat Kurugol, Leyla Tanacan, Halit Yasa Ersoy, "Young's modulus of fiber- reinforced and polymer- modified light weight concrete composites," *Construction and Building Materials* , Accepted 19th March 2007, pp. 1-10, 2007.