An Experimental Investigation on Structural Properties of Polymer Modified Fiber Reinforced Concrete

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Abstract - *This paper aims to study the stress-strain behavior of polymer modified fiber reinforced concrete in flexure, compression, single shear. Crimped shaped flat steel fibers were used in this investigation. Fiber content varies from 0.5% to 9.5% by weight of cement considering polymer percentage constant as 5% by weight of cement. Polymer in the form of emulsified styrene butadiene rubber latex was used. The M-40 grade of concrete was used. 36 cubes of size 150 mm x 150 mm x150mm were cast for compression, 36 flexure beams of size 150 mm x150 mm x700 mm, 36 push off specimens of size 150mm x150 mm x 450mm were cast for single shear strength test was conducted. All specimens were air cured up to 28 days to form proper bond between polymer layer and concrete ingredients while normal concrete specimens were water cured for 28 days and tested subsequently. All the beam specimens for flexural strength were tested under two point loading up to failure, and all push off specimens were tested by direct shear. Workability of wet mix was found to be increased due to polymer initially and found to be reduced with increase in fiber content. Ductility of polymer modified steel fiber reinforced concrete (PMFRC) was found to be increased as observed from the study of load deflection behavior. A significant improvement in the various strengths is observed due to inclusion of polymers and fibers in the concrete. Optimum fiber content is found to be the strength dependent.*

Key Words: *Polymer (SBR latex), aspect ratio of fiber, volume fraction of fibers, PMFRC workability.*

1. INTRODUCTION

Cement concretes containing short randomly distributed steel fibers are structural materials that are gaining importance quite rapidly due to the increasing demand of superior structural properties. These composites exhibit attractive tensile and compressive strengths, low drying shrinkage, high toughness, high energy absorption and durability. Flexural strength and compressive strength of concrete increases with addition of fibers. However compressive strength of concrete decreases with addition of SBR. Overall porosity of concrete increases with increase in dosage of SBR [1]. Ductility in latex modified concrete (LMC) and latex modified fiber reinforced concrete (LMFRC) is increased by 45.94% and 50.27% respectively as compared to plain concrete. The cracking pattern in LMFRC began from the middle region of the beam and it propagates toward the both sides of support the plain concrete beam sample have wider crack compared to LMC and very thin crack width is seen in case of LMFRC beams [2]. A linear co relation is observed between micro mechanical properties and macroscopic properties of cementitious composites. The encountered linear relation between the microscopic and macroscopic strength properties highlights the finer scale origin of the performance of SBR latex modified mortar. The toughness of SBR latex modified mortars is improved significantly at latex/cement ratio of 10%. When P/C ratio is higher than 10% the beneficial additional effect of SBR latex on both the micro and macro mechanical properties is not significant [3]. While justifying potencies of acrylic styrene and latex polymer we can say that Acrylic styrene is proved superior over latex polymer because of its fine particle size and relatively less viscosity [4].It is observed that SBR modified cement mortar possess very good water penetration as well as SBR bonding agent possesses good tensile strength compared to cement slurry [5]. The polymer modified mortar and concretes could be employed in various techniques of repair, restoration and strengthening of concrete and masonry structures depending upon the type and extent of damage caused by earthquake[6]. The influence of steel fibers on flexural strength of concrete is much greater than for direct tension and compression. Two flexural strength values are commonly reported, one termed the first-crack flexural strength, corresponds to the load at which the load-deformation curve departs from linearity. Other corresponds to the maximum load achieved, commonly called the ultimate flexural strength or modulus of rupture [7]. Latex modification of cement mortar and concrete is governed by both cement hydration and polymer film formation processes in their binder phase. The cement hydration process generally precedes the polymer formation process & In due course, a co-matrix phase is formed by both cement hydration and polymer film formation processes. It is important to understand the mechanism of the co-matrix phase formation [8]. The proper addition of polymer can fill the holes, micro-cracks inside the concrete and enhance the connection with the cement hydrates and aggregates. But cementitious properties of cement will be weakened by the thick polymer film if the addition of latex is too much [9].

2. SYSTEM MODELLING

For preparation of polymer modified concrete (PMC) and polymer modified steel fiber reinforced concrete (PMSFRC), materials used were cement, fine aggregate, coarse aggregate (20mm), coarse aggregate (10mm), crimped shaped steel fibers, polymer latex, and water.

2.1 Cement

In this experimental work Ultratech-53grade ordinary Portland cement is used within one month of its arrival in the laboratory. All properties of cement are tested according to I.S.12269:1987[10] specification for 53 grade ordinary Portland cement.

2.2 Fine Aggregate

Locally available natural sand passing through 4.75 mm sieve confirming to (zone II) IS: 383-1970[11] was used. To know the quality and grading of fine aggregates, various tests were performed and the results are shown in Table 1.

Table -1: Physical properties of fine aggregate (sand)

Sr. no	Properties	Result
1	Particle shape	Rounded
2	Size	4.75mm (down to 150 micron)
3	Silt content	2%
4	Specific gravity	2.8
5	Water absorption	1.2%
6	Surface moisture	Nil
7	Fineness modulus	2.76

2.3 Coarse Aggregate

Coarse aggregates are originated from basalt rocks. Two different size of coarse aggregates (CA) were used in this experimental work. Locally available coarse aggregate having maximum size 20 mm down to 10 mm were used for present work. Testing of coarse aggregate was confirmed from IS 383-1970[11].

Table -2: Physical properties of Coarse aggregate (20 mm)

Sr no	Properties	Result
1	Particle shape	Angular
2	Particle size	20 mm
3	Surface moisture	Nil
4	Fineness modulus	7.25

Table -3: Physical properties of Coarse aggregate (10mm)

Sr. no	Property	Result
1	Particle shape	Angular
2	Particle size	10 mm
3	Surface moisture	Nil
4	Fineness modulus	6.87

2.4 Physical Properties of Steel Fiber.

I.S.O. 9001:2008 certified crimped steel fiber conforming to ASTM A820 M04 Type-I [12] Standard is used for experimental work.

Fig -1: Crimped Shaped steel fibers.

Table 4. Physical properties of crimped with crescent cross section steel fiber.

Sr. no	Properties	Result
1	Thickness of fiber(T_f)	1mm
2	Length of fiber (L_f)	50 mm
3	Equivalent diameter (D_f)	1.66 mm
4	Aspect ratio (L_f) /(D_f)	30
5	Modulus of elasticity	200 GPa
6	Tensile strength	>1100 MPa
7	Deformation	6 undulation

2.5 Polymer

Polymer latex additive 'Monobond' is used as a polymer in this experimental work. This polymer is available in liquid form containing 44% solids and 56 % 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.

Table 5. Physical properties of Polymer.

Sr. no	Properties	Result
1	Name	Styrene Butadiene rubber latex (synthetic emulsified rubber)
2	Appearance	Milk white
3	Particle size	0.22 μm
4	Total solid	44%
5	Water	56%

6	Specific gravity (20 ⁰ c)	1.01
7	pH	11
8	Viscosity (20 ⁰ c)	20 Cp

2.6 Mix Proportion.

Mix design of concrete for grade M40 was done by using I.S. 10262-2009 [13]. All material shall be brought to room temperature, preferably 270c ± 30c before commencing the concrete mix. Then all ingredients are weighed separately on digital electronic weighing machine as per the mix details. The concrete was mixed in transit mixer. The uniformity of concrete and proper distribution of fibers mainly depends on the mixing procedure. Cement and aggregates are mixed thoroughly and then fibers are added manually. At the end to ensure that proper fiber dispersion was achieved and that fiber clumping and balling did not occur. While the mixing operation is in progress, 70% of water with polymer is added first and mixed for about 3 minutes. Then the remaining 30% water is added and mixed thoroughly. Then specimen vibrated on table vibrator for a few seconds for proper compaction and the surfaces are finished with trowel.

3. RESULTS AND DISCUSSION.

The results of testing of normal concrete mix, polymer modified concrete mix and polymer modified steel fiber reinforced concrete (PMSFRC) mix specimens for all parameters at 28 days age have been tabulated. Compression test, flexure test, and shear tests, have been performed on hardened concrete in the laboratory. These tests have been carried out as per the relevant standards and experimental test procedures. Workability of concrete has been carried out on fresh (wet) concrete and all other tests have been carried out on hardened (dry) concrete at 28 days of curing.

3.1 Workability of Concrete.

Workability of fresh normal concrete mix, polymer modified concrete mix and polymer modified steel fiber reinforced concrete mix was determined by using slump cone test. Workability is measured in terms of slump by using slump cone apparatus as per IS: 1199-1959[14]. The results have been tabulated in Table 6. Graph of variation of slump with respect to fiber content (V_f %) has plotted and shown in Chart 1.

Table 6. Slump and Slump Loss of PMSFRC.

Mix designation	Workability by slump test (mm)	% Increase in workability	Slump loss w.r.t. PMC (%)
M	25	-	-
M_p	130	80.46	-
M0.5	127	80.31	2.30
M1.5	123	79.67	5.38
M2.5	120	79.16	7.69
M3.5	115	78.26	11.53
M4.5	106	76.41	18.46
M5.5	103	75.72	20.77
M6.5	101	75.24	22.30
M7.5	99	74.74	23.84
M8.5	86	70.93	33.85
M9.5	75	66.66	42.30

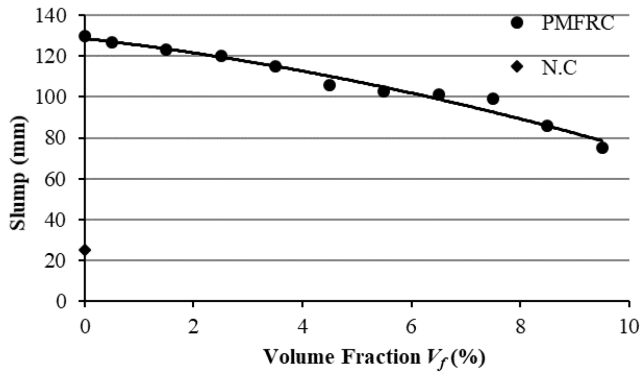

Chart-1 Variation of Slump with respect to Fibre Content (V_f%)

3.2 Compressive Strength.

The compression test was performed to find out compressive strength of normal concrete, polymer modified concrete and polymer modified steel fiber reinforced concrete on test specimens cubical in shape of size 150mm ×150mm × 150mm, confirming to IS:10086-1982[15]. All specimens of cube compression were air dried prior to testing. The results have mentioned in Table 7. Graph of compressive strength with respect to fiber content has plotted as shown in chart 2.

Table 7. Effect of fiber volume fraction on Compressive Strength (f_{cu}) of PMSFRC.

Mix designation	Compressive strength in (MPa)	% Increase in compressive strength
M	49.7	-
M_p	46.5	-6.43
M0.5	53.8	8.24
M1.5	55.26	11.18
M2.5	54.12	8.89
M3.5	52.20	5.03
M4.5	52.26	5.15
M5.5	50.53	1.67
M6.5	50.10	0.80

M7.5	48.57	-2.27
M8.5	46.63	-6.17
M9.5	44.10	-11.27

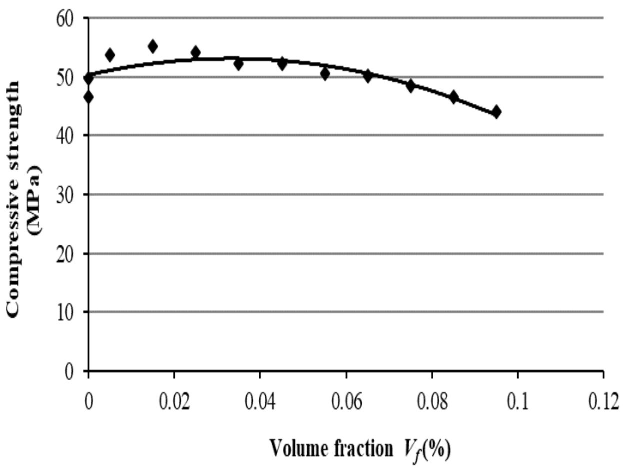

Chart 2. Variation of Compressive Strength (f_{cu}) with respect to Fibre Content.

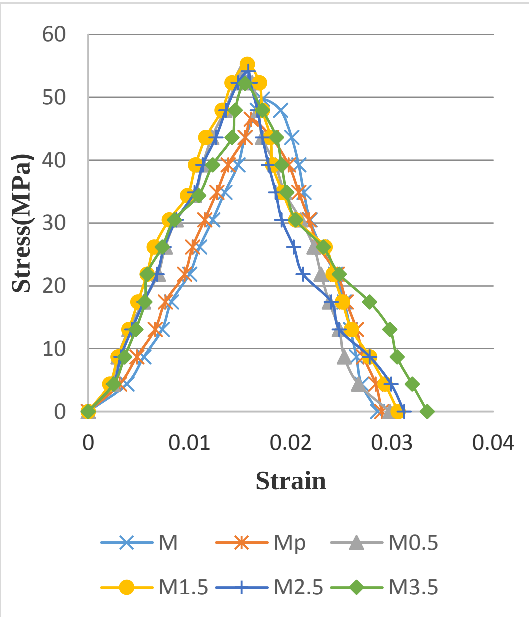

Chart 3 Stress (MPa) and strain variation of Normal Concrete, PMC and PMFRC under compression from M to M3.5.

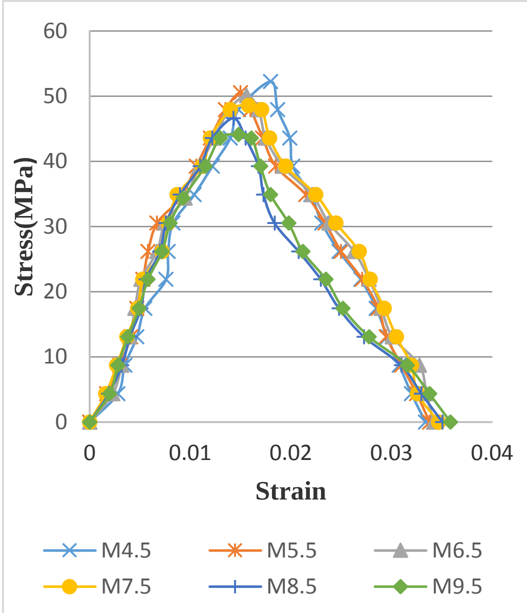

Chart 4. Stress (MPa) and strain variation of PMFRC under compression from M4.5 to M9.5.

3.3 Flexural Strength.

To find out flexural strength of concrete, prism specimens of size 150mm ×150mm ×700mm were used. 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 results of flexural failure load, flexural strength and percentage increase in flexural strength over normal mix are mentioned in Table 8.

Table 8. Flexural load at failure (P), Flexural Strength (f_{cr}) and Percentage Increase in Flexural Strength of PMSFRC.

Mix designation	Flexural load at failure (kN)	Flexural strength (MPa)	%Increase in Flexural Strength
M	25.54	4.54	-
M_p	26.04	4.63	1.94
M0.5	27.9	4.96	9.25
M1.5	28.92	5.14	13.21
M2.5	29.36	5.22	14.97
M3.5	29.64	5.27	16.07
M4.5	29.92	5.32	17.18
M5.5	30.37	5.40	18.94
M6.5	31.16	5.54	22.02
M7.5	31.72	5.64	24.22

M8.5	32.23	5.73	26.21
M9.5	33.43	5.94	30.83

3.4 Shear Strength

For this test, specimens (push off type or double 'L' type) were cast in laboratory by using mould. The specimen was designed to fail in shear with a shear plane length of 150mm. Load was applied continuously and without impact at a shearing stress rate of 0.1 MPa per second as per JSCE-SF6 [16]. This is a single shear test as the failure is at one plane only. The results of maximum shear load (Ps), Shear strength (τs) and percentage increase in shear strength over normal mix of concrete are shown in Table 9.

Table 9. Max. Shear Load (P_s), Shear Strength (τ_s) and Percentage Increase in Shear Strength over Normal Mix of PMSFRC.

Mix designation	Shear load (kN)	Direct shear strength (MPa)	% Increase in shear stress (MPa)
M	73	3.24	-
M_p	77.75	3.45	6.48
M0.5	81	3.6	11.11
M1.5	85.30	3.79	16.97
M2.5	89	3.95	21.91
M3.5	96.80	4.30	32.71
M4.5	93	4.13	27.46
M5.5	90	4	23.45
M6.5	88.75	3.94	21.60
M7.5	85	3.78	16.66
M8.5	84.83	3.77	16.35
M9.5	82.12	3.65	12.65

4. CONCLUSIONS

An experimental study of effectiveness of polymer and steel fibers in concrete has been carried out in the laboratory. On the basis of results obtained from experimental work, observations made during casting and testing of specimens, and results of the behaviour of fiber reinforced concrete and normal concrete, the following conclusions are drawn.

1) In polymer modified mixes, workability of concrete mix increases with the addition of polymer, while inclusion of steel fibers leads in reduction of slump. Slump loss calculated for variable fiber percentage shows increase in slump loss as the percentage of fiber dosage increases.
2) The maximum cube compressive strength, flexural strength and direct shear strength achieved are 55.26MPa, 5.94MPa and 4.30MPa at 1.5%, 9.5% and 3.5% of fiber volume fraction along with constant polymer dose of 5% respectively at the age of 28 days. The percentage increase in strength over normal concrete is 11.18%, 30.83% and 32.71% for compressive strength, flexural strength and direct shear strength respectively.
3) Due to inclusion of polymer to the normal mix the compressive strength does not show any increment, while 2% increment in flexural strength over normal concrete and 6.48% increment in shear strength over normal concrete is observed. Whereas 18.84%, 28.29% and 24.64% increment in compressive strength, flexure strength and single shear strength of PMSFRC is observed over PMC.
4) The increase in deflection with increase in load carrying capacity due to inclusion of fibers volume fraction over normal concrete is observed. Hence, mode of failure observed to be changed from brittle to ductile with the increase in fiber content, when subjected to compression, bending and shear loads.

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