STRAIN HARDENING PROPERTIES OF STEEL FIBRE REINFORCED LATEX CONCRETE COMPOSITE

V.M. Sounthararajan[1], Deependra Singh[2], Shreyansh Parakh, S. Thirumurugan and A. Sivakumar[3]
[1]soundar.vm@vit.ac.in,
[2]deependra_singh2010@vit.ac.in,
[3]sivakumara@vit.ac.in,
Structural Engineering Division,
School of Mechanical and Building Sciences,
VIT University, Vellore 632014, Tamilnadu, India

Abstract—**Steel fibre addition in concrete possesses high merits in terms of achieving homogeneity and tensile strength properties. Polymeric addition in concrete has high advantages in terms of pore filling effect and subsequent increase in durability index. The combined addition of steel and polymeric latex additions in concrete leads to increased strength, durability, toughness, resistance to cracking and crack propagation. Studies were conducted in the present study to analyse the properties of concrete that can be further improved with the addition of polymer styrene butadiene rubber emulsion (SBR) along with steel fibres. In this research analysis, styrene-butadiene rubber (SBR) latex as a polymeric admixture was used in steel fibre reinforced concrete. The effect of curing conditions on the strength gain properties of composite steel fibre latex matrix on the compressive, flexural strength, and split tensile test of polymer modified steel fibre reinforced concrete (PSFC) concrete was examined. Including SBR latex at a certain % of binder in the PSFC concrete improves the bonds within the cement matrix and steel fibres (SF). This is due to the SBR films formed in the matrix. By the comparison of properties of SFC and PSFC, it can be shown that a tremendous increase in compressive strength when 4% and 8% SBR is added along with 0.75% and 1.5% SF. The increase in flexural strength was noticed and post cracking ductility is imparted to concrete.**

Keywords-Steel fibre, SBR, Strength of concrete, Fibre Reinforced Concrete, Fly Ash, Super Plasticizer.

I. INTRODUCTION

Steel fibre concretes are growing concern in construction industry owing to increased fatigue resistance and long term durability aspects of concrete. It is vital to improve the brittle properties of plain concrete by increasing the ductility and toughness of the concrete. In this regard, different types of fibres are used for improving the tensile resistance of concrete. The various polymeric fibres and steel fibres were used in many research studies to improve the composite properties. Fibre addition provides increased tensile and compressive strengths, higher toughness, high energy absorption and durability. Many research studies exhibited that with the random fibre addition into the concrete flexural and tensile properties of the concrete are increased. This result in the inhibition of micro cracks and thereby resulting in the propagation cracks. Fibre-matrix interfacial bond is provided by the type of fibre surface either hooked or crimped fibres. Fibres provide post- cracking ductility (toughness) to concrete [3, 4]. In the present study the addition of polymer latex was tested and several studies investigated that polymeric admixtures used as a main ingredient for improving the mechanical behavior of concrete. Polymer admixtures are available as polymer latexes, water-soluble polymers and liquid polymer, used in cementitious composites such as mortar and concrete [5, 6]. It was observed that the hydration of cement and formation of polymer film in the hardened stage forms a bonding between cement phase and aggregate showed an improvement in strength over conventional concrete. Polymer latex modification of cement concrete is governed by both cement hydration and polymer film formation [7]. It can be concluded that the cement hydration process generally precedes the polymer film formation process formed a highly cohesive particle with the cement matrix [8]. This also resulted in the polymer-modified mortar and concrete have superior compressive and flexural strength, excellent adhesion, high water proof ness, high abrasion resistance and good durability, as compared to ordinary cement concrete [9,10]. Research studies also showed that the addition of styrene butadiene rubber latex-modified concrete has been widely used in the field of repair work patching, resurfacing works for damaged bridge decks, because of its ease of execution, excellent adhesion to the base concrete, high freeze-thaw resistance and resistance to chloride penetration [11-14]. It can be noted from the research studies that polymer steel fibre concrete have high flexural strength, good ductile behaviour and high toughness due to the formation of a three dimensional polymer network through the hardened cementitious matrices. The porosity is decreased as this network fills the void gap and virtually bridges the gap across the cracks [15]. In this study styrene butadiene rubber (SBR) has been incorporated to improve the ductility, flexural and compressive strength of steel fibre reinforced concrete (SFC). To broaden the scope of this investigation UPV, effect of different curing conditions, split tensile test, water absorption has been investigated and compared to plain cement concrete.

II.MATERIALS USED AND TESTING PROCEDURE

The details of materials used in the present experimental investigation are as follows.

A. Cement

Ordinary Portland cement of 53 grades having 28 days compressive strength of 47.02 MPa, satisfying the requirements of IS: 12269–1987. The physical properties of cement value are presented in Table I**.**

B. Fly ash

Class F fly ash obtained from the thermal power plant was used in the study and the fly ash contained less than 10% lime (CaO) as shown in Table II.

C. Fine aggregates

River sand obtained from locally available in the river bed, fine aggregate passing through IS sieve, conforming to grading zone-II as per IS: 383-1970. The fineness modulus value is 2.97, specific gravity of 2.71 and water absorption of 0.67 % at 24 hours.

D. Coarse aggregates

Machine crushed well graded angular blue granite stone of size 20 mm and 12.5 mm were used, for different size of sieve used as per standard , which is maintained with different proportion of coarse aggregate and conforming to IS: 383-1970. The specific gravity was found to be 2.75, fineness modulus is 7.2 and water absorption is 0.62 % at 24 hours.

E. Chemical admixtures

Polycarboxylate ether based super-plasticizer condensate as high range water reducing admixture (HRWR) to maintain a satisfactory of workability for different mixes with a constant w/b ratio throughout the experiment works. It has a specific gravity value of 1.18; pH value of 5.7 and solids content of 40%.

F. Steel fibres

Both ends hooked steel fibres was used in the study and the dimension of the steel fibre is 60 mm longer and 0.5 mm diameter with a l/d ratio of 80 with different dosage level (0.75 to 1.5 % by volume fraction) wasusedFig.1Properties of steel fibre is listed in Table III**.**

G. Polymer latex

Styrene based rubber latex (shown in Fig. 2) Was used for improving the hardening properties of concrete and the dosage was kept at 0.4 and 0.8% of the total binder.

H. Concrete Mixture Proportions and Casting of specimens

The concrete mixture proportions used in the study are provided in Table IV. A total of 9 different concrete mixtures were proportioned based on the water to binder ratio (w/b) 0.5 and fine to coarse aggregate ratio (F/C) 0.4. The concrete mixtures were mixed using a 30 liters capacity of the container with tilting drum type mixer and specimens were cast using steel mould, the standard cube 100 X 100 X 100 mm moulds, the size of the cylinders (100 mm diameter X 200 mm height) and size of prism beam mould 100 X 100 X 500.**.** The fresh concrete mixtures in moulds were compacted using table vibrator and the sspecimens were demoulded after 24 hours after casting and water ,dry cured at 27 ± 3^{o}C until the age of testing at 3,7 and 28 days.

Fig.1 Snap shot of glued steel fibre

Fig.2Snap shot of SBR latex liquid

TABLE I
Physical properties of cement

Sl.no	Name of the test	Value
1	Consistency	32%
2	Initial Setting Time	165 min
3	Final Setting Time	450 min
4	Specific Gravity	3.25
5	Fineness of cement	3%
6	Soundness	2 mm
7	Compressive Strength	
	7 days	25.37N/mm^2
	28 days	47.02N/mm^2

TABLE II
Chemical properties of Flyash

Properties (%)	**Fly ash Class F**
SiO2	58.9
Al2O3	33.4
Fe2O3	5.86
CaO	1.02
MgO	0.38
SO3	0.12
Na2O	1.28
K2O	0.01
Cl^{-}	0.49
Loss on ignition	2.2
Specific gravity	2.48

TABLE III
Properties of Glued steel fibres

Parameters	**Values**
Length	35 mm
Equivalent Diameter	0.5 mm
Tensile Strength	1100 MPa
Dosage	20-40 kg/m3

TABLE IV
Mix proportions

Mix Id	**Cement**	**Fly ash**	**Fine Aggregate**	**Coarse Aggregate**	**Water**	**F/C**	**w/b**	**Steel fibre (%)**	**SBR (%)**
	Kg/m3								
M1	300	75	579	1446	150	0.4	0.5	0	0
	300	75	579	1446	150	0.4	0.5	0	4
	300	75	579	1446	150	0.4	0.5	0	8
M1F1	300	75	579	1446	150	0.4	0.5	0.75	0
	300	75	579	1446	150	0.4	0.5	0.75	4
	300	75	579	1446	150	0.4	0.5	0.75	8
M1F2	300	75	579	1446	150	0.4	0.5	1.5	0
	300	75	579	1446	150	0.4	0.5	1.5	4
	300	75	579	1446	150	0.4	0.5	1.5	8

III. EXPERIMENTAL TEST RESULTS AND DISCUSSIONS

The test results obtained through this experimental study reveal the influence of the SBR and steel fibres on the behaviour of hardened concrete and are tabulated in Table V**.**

Table V
Experimental test results

Mix Id			M1	M1	M1	M1F1	MI1F1	M1F1	M1F2	M1F2	M1F2
w/c	**ratio**		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
F/C	**ratio**		0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Fly ash	**%**		25	25	25	25	25	25	25	25	25
SBR	**%**		0	4	8	0	4	8	0	4	8
Steel fibre	**%**		0	0.75	1.5	0	0.75	1.5	0	0.75	1.5
Compressive strength (MPa)	**1 day**	-	16.6	22.4	21	26.3	23.1	20.6	19.4	16.6	25.2
	3 days	**dry curing**	24.5	35.1	25.1	40.1	37.65	34.7	31.9	34.7	28.5
		water curing	27.4	33.2	22.6	37.1	28.1	33	37.1	34.7	21.1
	7 days	**dry curing**	32.2	34.2	38.6	47.2	41.3	48.5	36	46.5	27.8
		water curing	33.6	27.1	21.9	45.1	33.8	43	34.8	39.7	29.4
	28 days	**dry curing**	34.2	39.3	41.4	48.4	46.5	53.1	44.1	48.6	54.8
		water curing	38.4	35.5	35.4	51.6	41.2	46.5	39.9	47.4	47.3
Split tensile strength(MPa)	**28 days**	**dry curing**	2.95	3.25	3.14	3.23	3.71	3.41	3.31	4.1	3.6
		water curing	3.12	3.42	3.21	3.67	4.12	3.82	3.62	4.38	4.1
Flexural strength (MPa)	**7 days**	**dry curing**	6.32	6.56	7.12	7.28	6.96	8.48	6.44	7.28	7.64
		water curing	6.8	6.4	6.12	7.6	5.4	7.8	6.8	6.4	5.8
	28 days	**dry curing**	7.44	8.48	7.88	6.48	7.48	10.25	8.6	9.04	10.24
		water curing	8.2	7.6	7.36	8.48	6.6	9.6	8.84	8.6	8.04
UPV(m/s)	**1 day**		3450	3590	3610	3950	3430	3890	3587	4000	3950
		Rating	medium	good	Good	good	medium	Good	Good	Good	good
	3 days	**dry curing**	3620	3670	3740	4070	3510	3980	3830	3610	4120
		Rating	good	good	Good	good	good	Good	Good	Good	good
		water curing	3970	3750	3810	4020	3620	4050	3620	4100	4020
		Rating	good	good	Good	good	good	Good	Good	Good	good
ratings as per IS 13311 PART 1	**7 days**	**dry curing**	4010	3940	3980	4430	3740	4260	3710	3730	4350
		Rating	good	good	Good	good	good	Good	Good	Good	good
		water curing	4190	3980	4010	4370	3650	4200	3666	3910	4310
		Rating	good	good	Good	good	good	Good	Good	Good	good
	28 days	**dry curing**	4510	4390	4410	4200	3940	4170	3730	3940	4430
		Rating	excellent	good	Good	good	good	Good	Good	Good	good
		water curing	4460	4210	4390	4280	3600	4030	3560	3860	4240
		Rating	good	good	Good	good	good	Good	Good	Good	good

A. Effect of Steel Fibre sand SBR on Compressive Strength

Addition of steel fibre to normal concrete showed improvement in compressive strength at 3, 7 and 28 days compared to reference mix is given in Table V. The strength of various mixes containing various % of steel fibre was plotted against no. of days and type of curing as shown in Fig.4 to 6, it can be concluded that with addition 0.75% of steel fibres strength of concrete increases by as much as 63%,46% and 34% at 3,7 and 28 days respectively. However the gain in strength by addition of 1.5% steel fibres was 35%, 12% and 29%at 3, 7 and 28 day respectively. The gain in strength for dry curing was higher than that of water curing. From Fig.4 it is clear that 0.75% of steel fibre yields higher compression strength than 1.5%. Also the difference in compressive strength between dry and water cured specimen for 0.75% steel fibre was 8%, 4.6% and 6.2% suggesting that at higher days of curing the strength of dry cured specimen is less than that of water cured specimen. However for 1.5% of steel fibre these values where 14%, 3.4% and 10% respectively for 3, 7 and 28 days of curing. This suggests that for 1.5 % steel fibre, the strength of dry cured specimen is higher than water cured specimen.

Similarly from Fig.5**,** it can be observed that the maximum gain in strength over normal concrete ,for 0.75% SF is 7.2%,21% and 18 % for 3 , 7 and 28 days respectively. For 1.5% SF these values are 4.5%, 46.5% and 34% for 3, 7 and 28 days respectively. In both the cases the difference increases slowly from 3 to 7 days, maximum gain is reported on 7 day, the following values decrease marginally. However unlike in case of 0.75% SF the maximum gain in strength over normal concrete for 1.5% SF occurs for water curing. Moreover, the maximum values of compressive strength for various days are reported for 1.5% addition of SF. Hence addition of 4% SBR increases the strength of 1.5% (upto 18%for 28 days) SF but decreases the strength of 0.75% SF, as compared to the results plotted in Fig.6.With addition of SBR the strength of plain concrete decreases for water cured specimen as plotted in Fig.7. With 8% addition of SBR 7 day water cured strength decreases by as much as 48.6 % for 4% SBR the decrease is meagre 1.2%. However for dry cured specimen 8 % SBR addition resulted in increase in strength (21% and 19.8% for 28 and 7 day respectively). This increase is true for 4% SBR addition also, though the increase is less as compared to 8% addition. However if SF is present in combination with SBR, compressive strength increases considerably. From Fig.8it can observe that the maximum increase in 28 day cured strength is 31%, 34% for 0.75, 1.5% addition of SF. The rate of increase is marginally less for dry cured specimen but the strength is maximum for dry cured specimen and it increases with increase in SF and SBR. It can be inferred that 4% SBR addition results in gain of early strength. The increase in strength from 1st to 3rd day is 53%, 63%, 109% for 0%, 0.75%, 1.5% SF respectively for 4% SBR content. 4% SBR containing concrete attain 70-87% of their 28 day strength (dry cured), the % decreases with addition of steel fibres (87% for 0% SF, 71% for 1.5% SF).

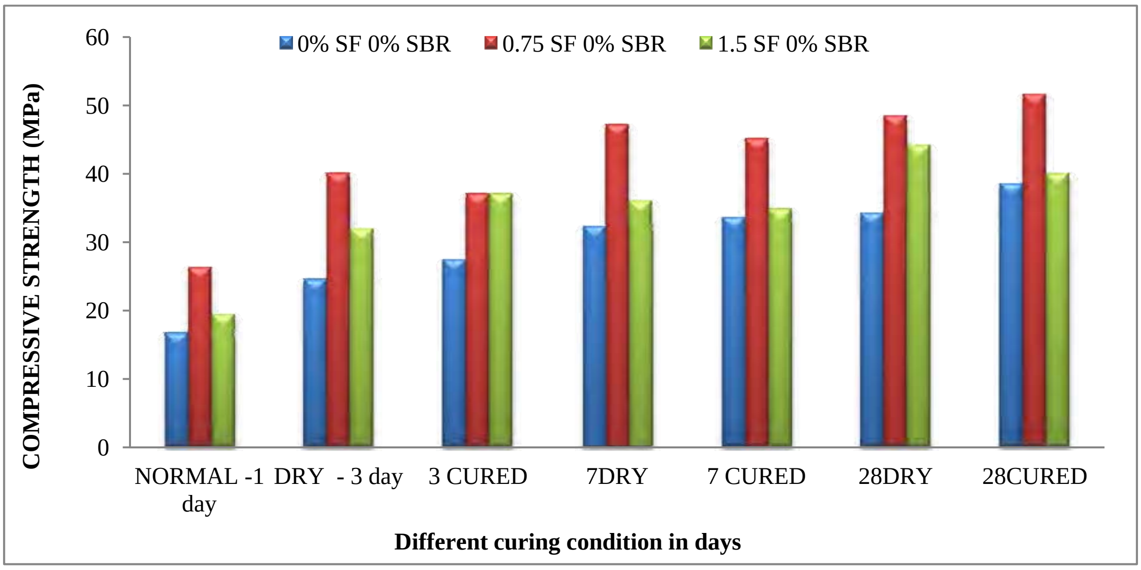

Fig. 3 Compressive strength with different percentage of steel fibre

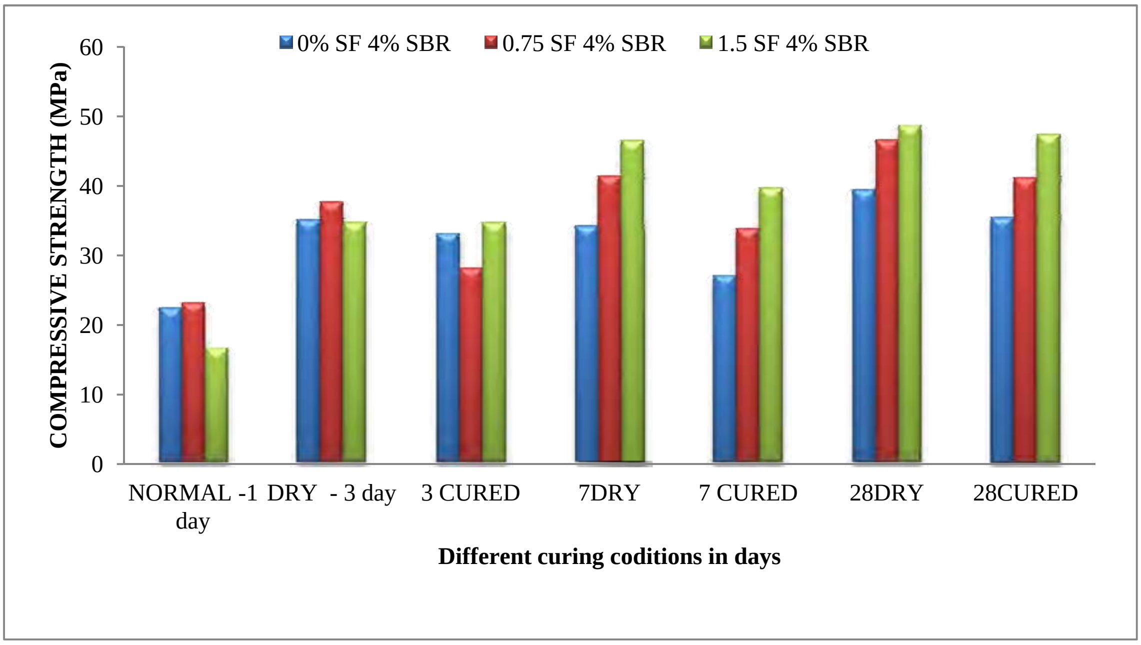

Fig. 4 Compressive strength with different percentage of SBR and steel fibre

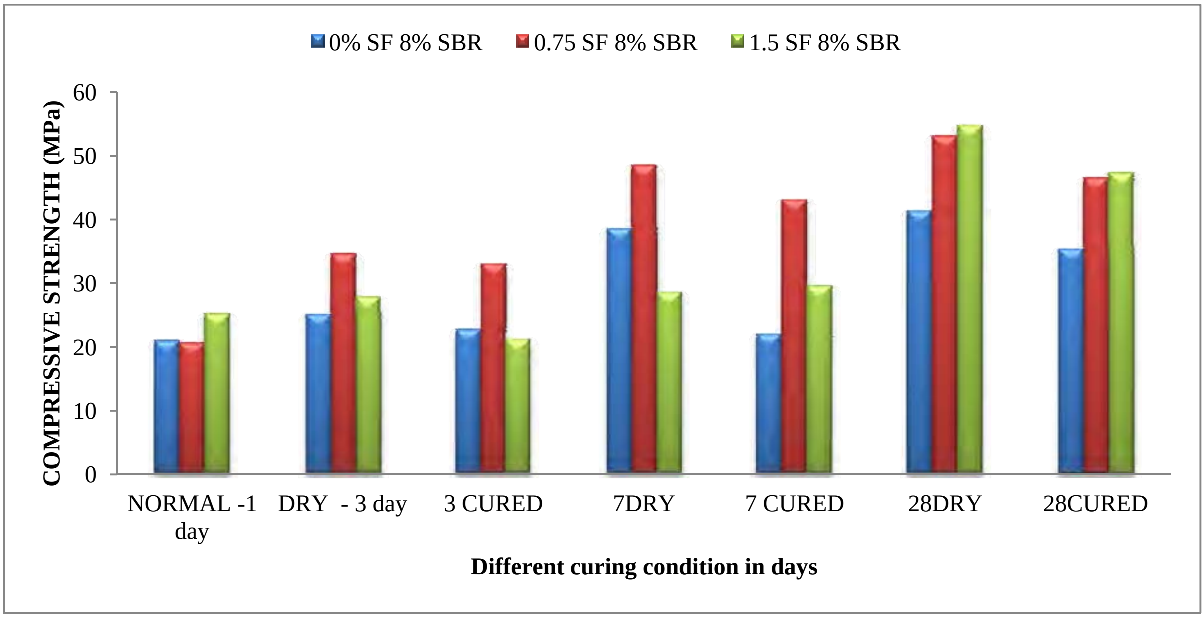

Fig.5 Compressive strength with different percentage of SBR and Steel fibres

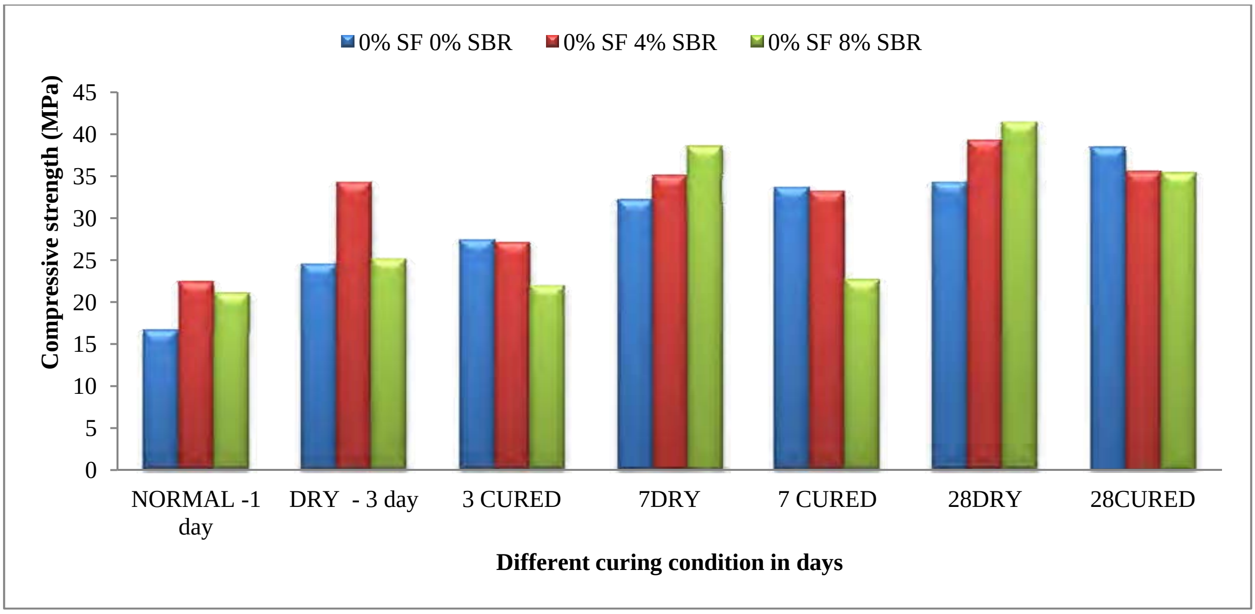

Fig. 6 Compressive strength of conventional and SBR concrete

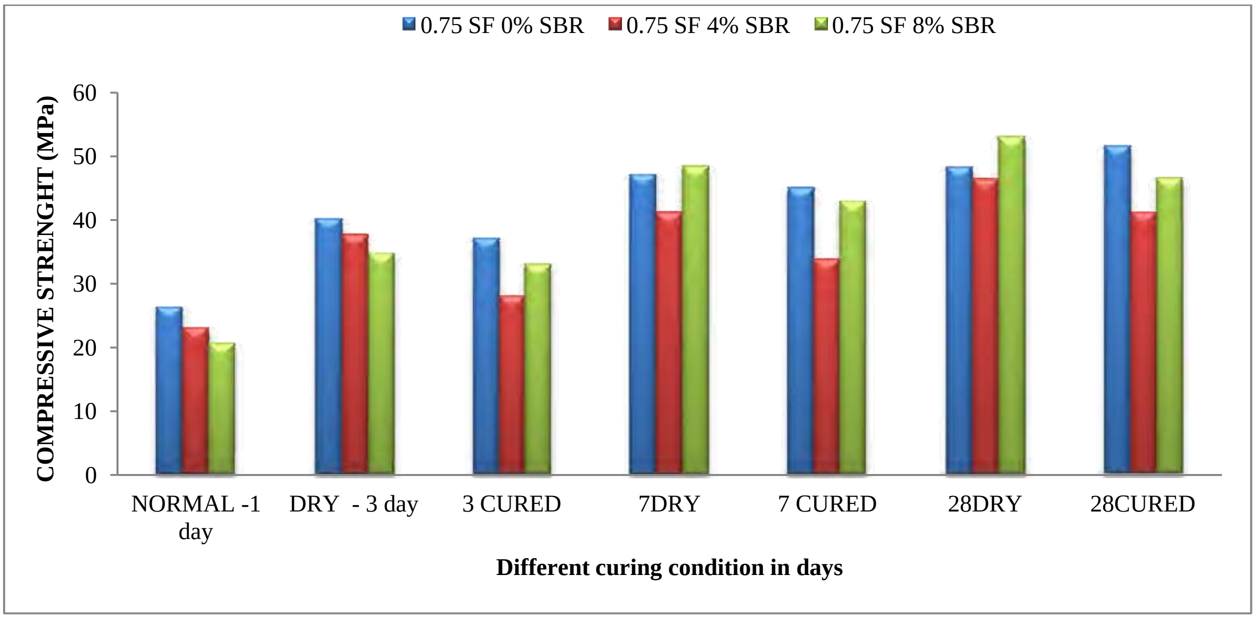

Fig.7 Compressive Strength for different percentage of fibres and SBR latex

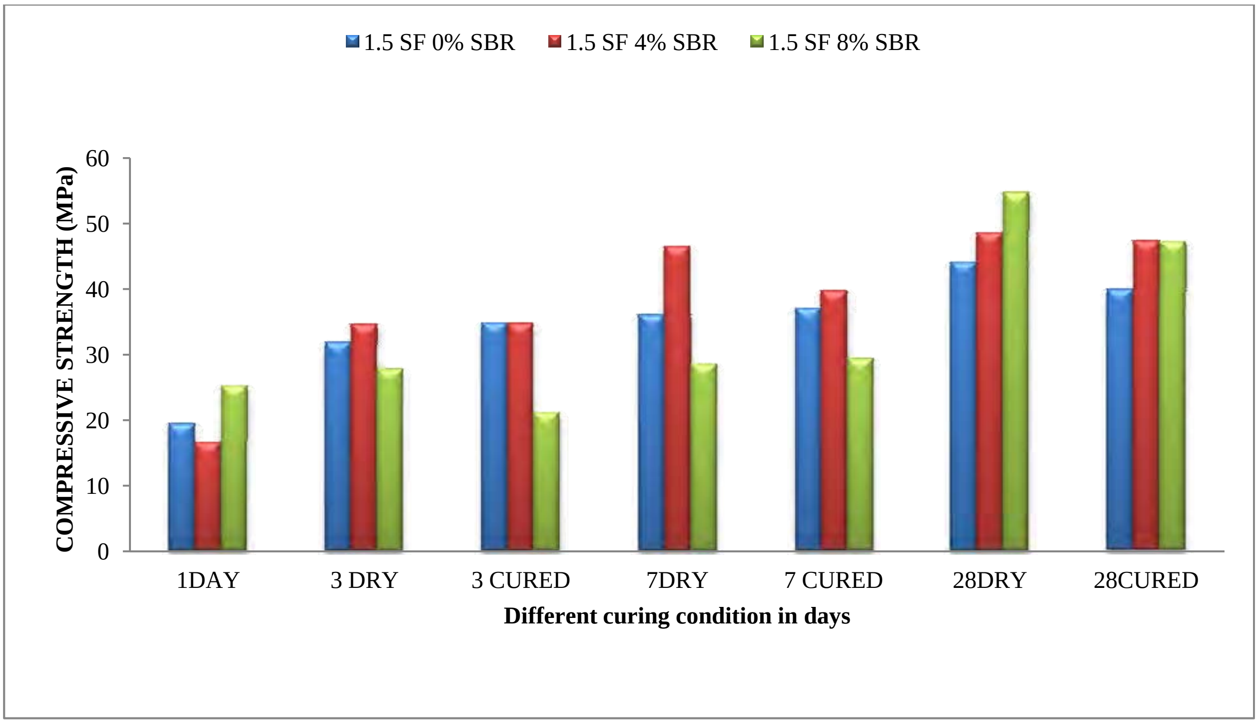

Fig.8 Compressive strength for different parentage of fibres and SBR latex

B. Effect of Steel Fibres and SBR on Flexural Strength

The flexural strength for various mixes is plotted in Fig.9 to 11. From the graphs it is clear that addition of SF increase the flexural strength. At 7 days curing 0.75% SF show higher strength but for 28 days 1.5% SF yields higher strength. 0.75% SF increases the flexural strength for 7 days of curing by 11-15% than that of plain concrete cured specimen. The increase in 1.5% SF samples is pronounced more in 28 days curing and for 7 day curing the strength increases marginally. With addition of SBR flexural strength increases, but only for dry curing and water cured samples show decrease in strength. This increase is independent of SF content. The increase is 5%, 13% for 4 and 8% SBR addition for 7 days of curing. When concrete is mixed with 0.75% SF and 4% SBR the strength obtained for 7 days of dry curing is higher than that of 28 days of water curing. But for 28 days of curing this mixture shows values lower than plain concrete. If the SBR content is increased from 4 to 8% the values obtained are highest of all i.e. 0.75% SF and 8% SBR has highest flexural strength for given days of curing. Also the strength obtained for 28 days of dry curing of 0.75% SF has increased by 58% when SBR content was increased from 0 to 8%.

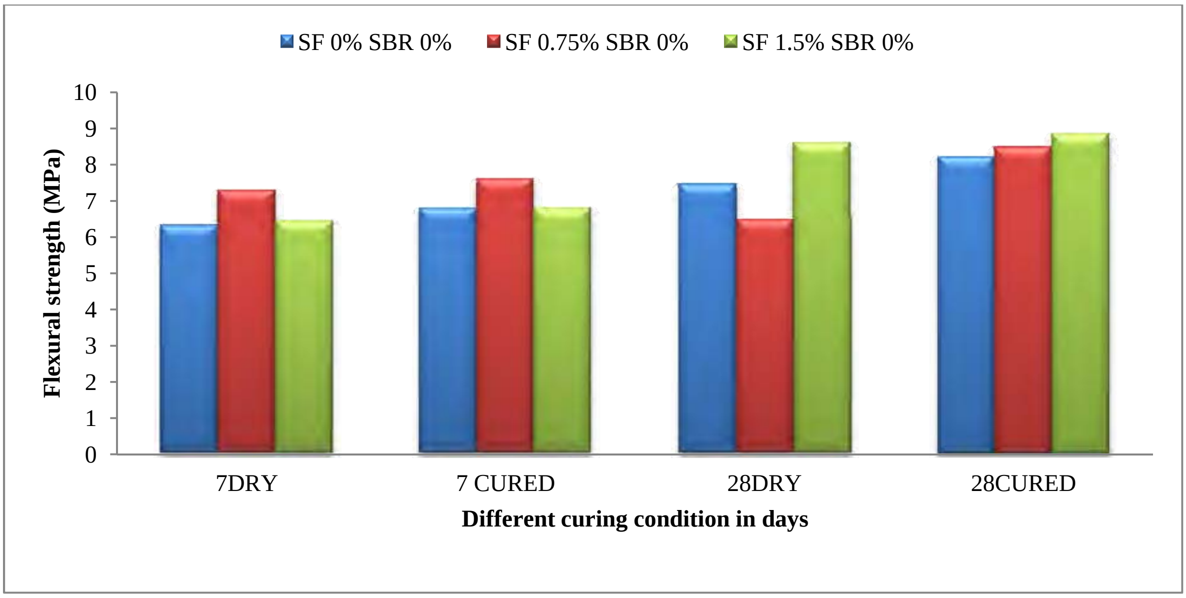

Fig. 9 Flexural strength with different percentage of steel fibres

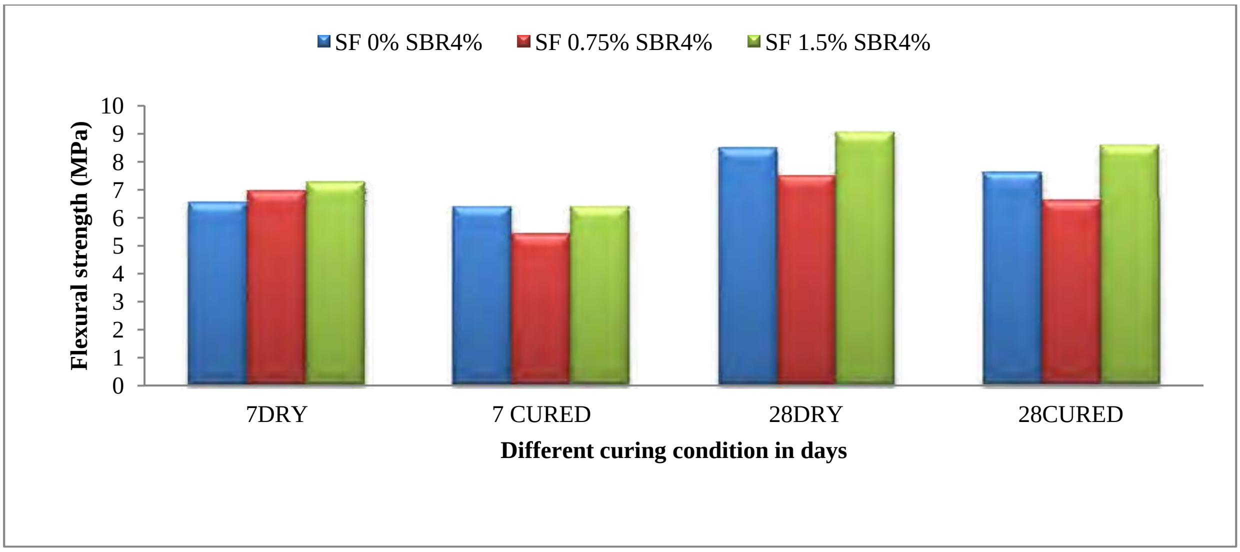

Fig. 10 Flexural strength for different percentage of fibres and latex

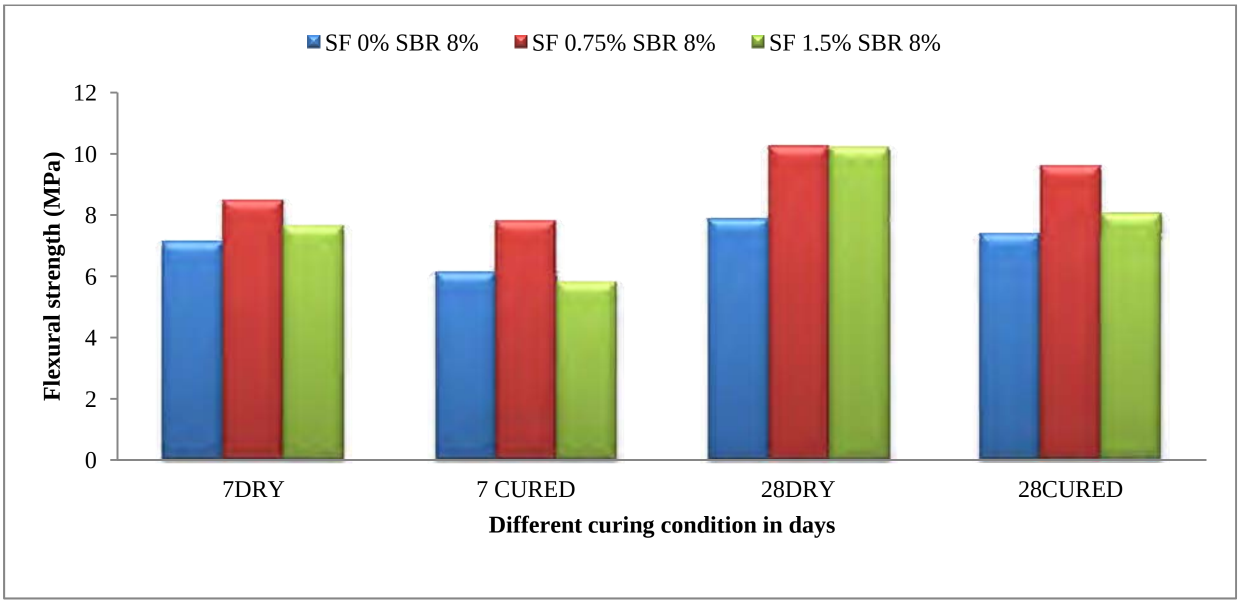

Fig. 11Flexural strength of different percentage of steel fibre and latex

C. *Effect of Steel Fibres and SBR on Split Tensile Test*

The values of split tensile test performed on various mixes are plotted in Fig. 12. SF has increased the split tensile values of plain concrete. Addition of 0.75, 1.5% SF increases the compression strength of plain concrete value from 2.95MPa to 3.23, 3.31MPa for 28 days dry curing. For water curing values obtained are higher than dry curing. SBR also increases the compression strength value, more for dry cured sample when compared with water cured sample. 4% SBR addition has shown the maximum values of compressive strength for both plain and SF reinforced concrete irrespective of the type of curing.

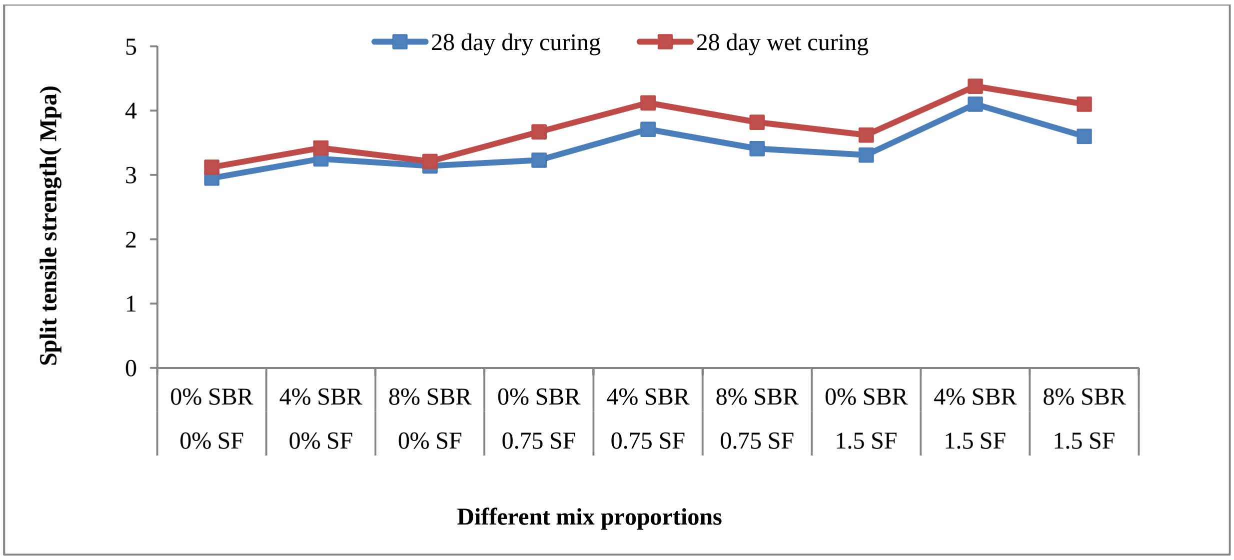

Fig. 12 Split tensile strength of different percentage of steel fibre and latex

D. Effect of Steel Fibres and SBR on Ultra-sonic Pulse Velocity (UPV)

The UPV values for different mix proportions for different curing days are tabulated in Table V along with the rankings as per IS 13311. The values for 7 and 28 days of curing are plotted as in Fig. 13 and 14. Test results on ultrasonic pulse velocity showed that there was a decrease in pulse velocity with addition of SBR when the curing days are more than 3.This was true for SF as well but decrease was noticed in 28 day cured specimen only; others showed increased values of UPV. A good prediction of the strength based on the UPV values can be drawn from the relationship and can be ideal estimate for estimating the quality of concrete.

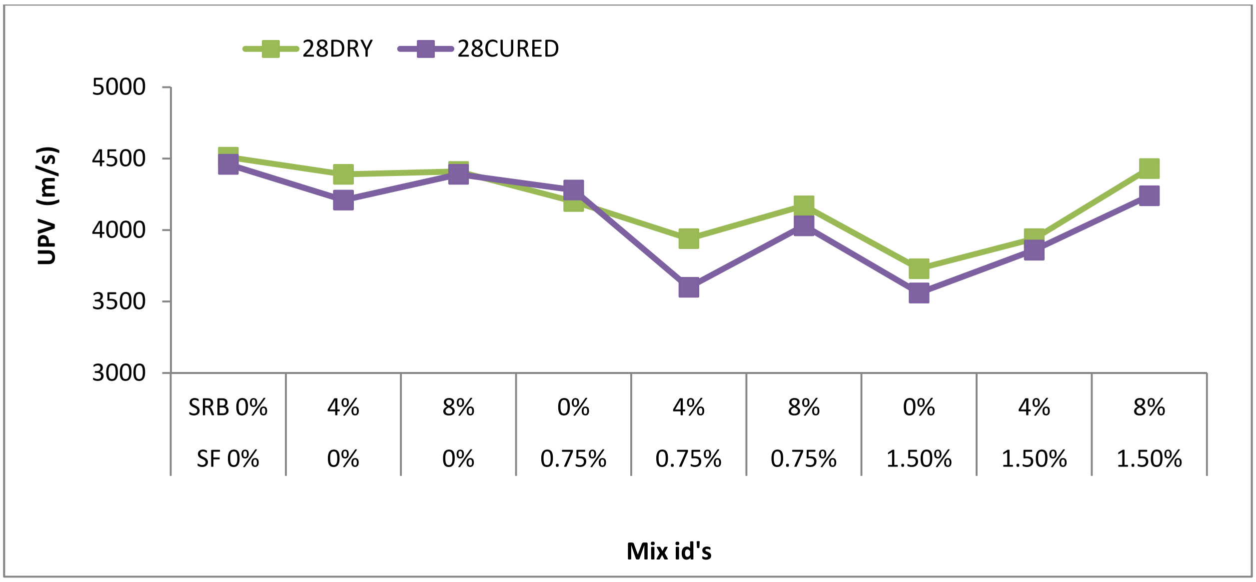

Fig. 13Ultrasonic pulse velocity for different percentage of fibre and SBR at 28 day

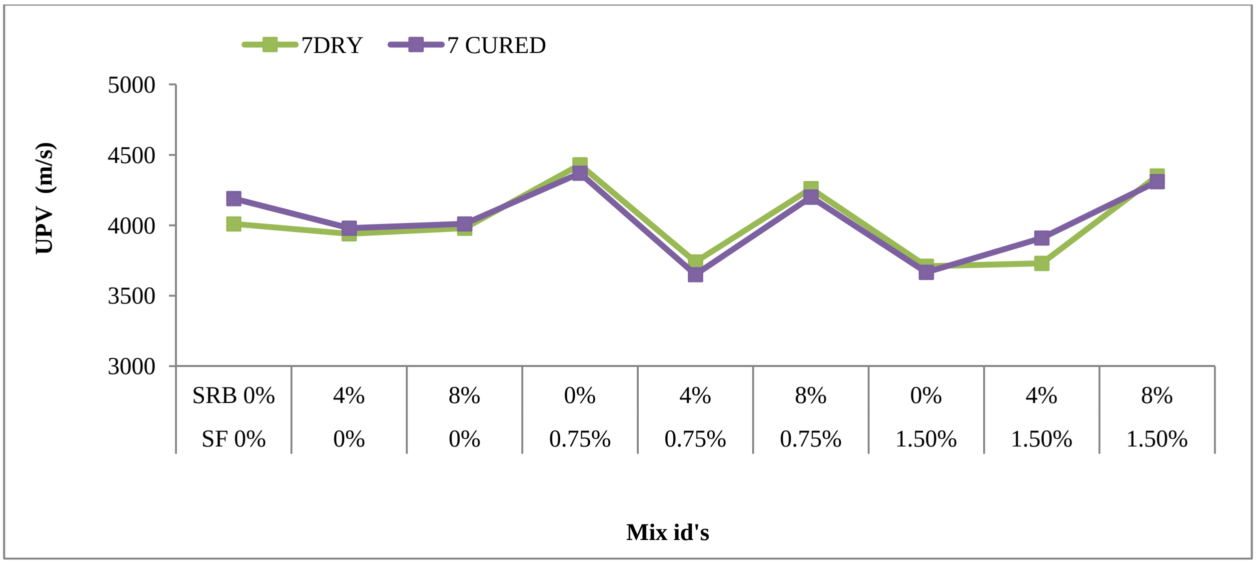

Fig. 14 Ultrasonic pulse velocity for different percentage of fibre and SBR at 7 day

IV. CONCLUSIONS

Mechanical properties of SBR modified concrete reinforced concrete were investigated and can be summarized as follows.

- Addition of SF increases the compressive and flexural strength value as compared to plain concrete.
- 0.75% steel fibres resulted in maximum increase of compressive strength (around 34 % for 28 day).
- The gain in strength was faster for 0.75% SF content, 63% for 3rd day as compared with 1.5% SF. SBR addition to normal concrete decreases its compressive and flexural strength if it is water cured; however dry curing increases the strength. 4% SBR and 0.75% SF resulted in early gain of compressive and flexural strength.
- Addition of SF decrease workability, on the other hand SBR imparts workability to the mix. Dry curing of SBR modified concrete yielded better results than water cured concrete.

REFERENCES

[1] Mangat P.S., 1976, “Tensile strength of steel fibre reinforced concrete”, Cement and Concrete Research, vol. 6, no. 2, pp. 45–52.
[2] Almansa E.M, and Cánovas M.F., 1999, “Behaviour of normal and steel fibre-reinforced concrete under impact of small projectiles” Cement Concrete Research, vol. 29, 18, 07–14.
[3] Choi O.C, and Lee C., 2003, “Flexural performance of ring-type steel fibre-reinforced concrete”. Cement Concrete Research, vol. 33, no. 84, pp. 1–9.
[4] Rami H.H. and Mohammed M.S., 2004, “Role of fibres in controlling unrestrained expansion and arresting cracking in Portland cement concrete undergoing alkali–silica reaction,” Cement and Concrete. Research, vol.34, pp.103–8.
[5] Colville J., Made A.M., and Miltenberger M., 1999, “Tensile bond strength of polymer modified mortar”, Journal of Material Civil Engineering. vol.11, no.1, pp. 1 – 5.
[6] Ray I., Gupta A.P. and Biswas M., 1994, “Effect of latex and super plasticiser on Portland cement mortar in the fresh state”, Cement and Concrete Composite, vol.16, pp. 309– 316.
[7] Ray I., Gupta A.P.and Biswas M., 2004, “Effect of latex and super plasticiser on LMM dynamic parameters for different percentages of latex”, Cement and Concrete Research vol. 34, pp. 527–535.
[8] Schulze J., 1999, “Influence of water-to-cement ratio and cement content on the properties of polymer-modified mortars”, Cement and Concrete. Research, vol. 29, pp. 909–915.
[9] Bureau L., Alliche A., Pilvin P.H., and Pascal S., 2001, “Mechanical characterization of a styrene – butadiene modified mortar,” Material and Science Engineering. A308, pp. 233–240.
[10] Southararajan V.M. and Sivakumar A., 2012, “Experimental studies on the effect of Fineness of flyash particles on the Accelerated Concrete Properties.”ARPN Journal of Engineering and Applied Sciences vol. 7, no.12, pp.1644-1651.
[11] Southararajan V.M. and Sivakumar A., 2013, “Accelerated Properties of Steel fibre Reinforced Concrete Containing Finer Sand.” ARPN Journal of Engineering and Applied Sciences vol. 8, no. 1, pp. 57-63.
[12] Southararajan V.M. and Sivakumar A., 2013, “Drying shrinkage properties of accelerated fly ash cement concrete reinforced with hooked steel fibres”. ARPN Journal of Engineering and Applied Sciences vol. 8, no.1, pp.77-85.
[13] Southararajan V.M. and Sivakumar A., 2013, “Strength Investigations of Processed High Volume Flyash Based Cement Concrete.” International Journal of Applied Engineering Research, vol. 8, no.2, pp. 143-155.
[14] Shaker F.A., El-Dieb A.S., and Reda M.M., 1997, “Durability of styrene – butadiene latex modified concrete”, Cement and Concrete. Research, vol. 27, no. 5, pp. 711 –720.
[15] Genying Li, Xiaohua Zhao and Chuiqiang Rong, 2010, Zhan Wang. “Properties of polymer modified steel fibre reinforced cement concretes”. Construction and Building Materials, vol. 24, no.7, pp.1201-1206.