Performance Evaluation of Metallic Fibres on the Low and high Volume Class F Flyash based Cement Concrete

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***Abstract* - Flyash based concrete attracts more attention owing to huge cost savings, reduction in the heat of hydration and longer durability. This research study presents the experimental investigation that was carried out to evaluate the performance characteristics of flyash addition in concrete. The concrete mixtures were prepared with different dosages of steel fibres and different replacement level of Class F flyash. The test results on mechanical properties indicated that the addition of flyash at 30% and 50% showed an initial reduction in compressive strength. However, at longer curing periods there was a subsequent gain in strength. Also, the addition of steel fibres at 1% volume fraction showed a consistent improvement in the concrete strength of 45.50 MPa and 59.80 MPa at 7 and 28 days respectively. It can be concluded that the addition of 30% of flyash with 1% steel fibre based concrete showed a marginal improvement in compressive strength and significant increase in flexural strength than conventional concrete.**

Keywords - Sieve analysis; Fly ash, steel fibres, Superplasticizer, Strength, Ultrasonic pulse velocity, Modulus of elasticity.

I. INTRODUCTION

The large scale potential applications of flyash utilization in construction industry depends on more reliable research results that envisages the beneficial effects of flyash in concrete. Low early age strength gain properties and the poor pozzolanic reaction restrict the large scale utilization in concrete. However, numerous studies had been carried out in the recent past for beneficiation of flyash in cement concrete. On the other context, the poor tensile response of cementitious system requires the addition of steel fibres for improving the compressive, tensile and flexural strength of conventional concrete. Generally steel fibre concrete is composite materials have excellent resistance to tension, toughness and fracture, fibres as the additional ingredients, dispersed uniformly at random. The energy required for mixing, conveying, placing and finishing of SFRC is slightly higher. Steel fibres are added to concrete to improve the structural properties, particularly tensile and flexural strength. It improves the strength of concrete and reduces the crack width and enhancements in terms of moment of resistance and ductility. The extent of improvement in the mechanical properties achieved with SFRC over those of plain concrete depends on several factors, such as shape, size, volume, percentage and distribution of fibres. [1] Showed that various percentage of fly ash treated as supplementary cementitious materials such as pozzolanic material incorporated with ordinary Portland cement showed strength enhancement and improved durability properties at various levels of low calcium fly ash after 28 days. [2] Studied different types of fibres containing low modulus and high modulus fibres with respect to fibres types and dosage of fibres and concluded that addition of fibers to cement pastes containing large amounts of fly ash can restrain the expansion and also low modulus of fibres does not contribute the expansion of specimens improve the composite toughness. However, efficiency of hybrid fibres showed higher toughness than that of mono fibers [3], investigated using ultrasonic pulse velocity for different fly ash mixed steel fibre concretes and developed the appropriate calibration curve for different curing days and concluded that the dynamic modulus of elasticity was found to be improved upto 8% compared to that determined by the full destructive test. [4-6] demonstrated that high volume fly ash based concrete with ordinary Portland cement was designed to increase the compressive strength upto 80 N/mm^2 at decreased water to cementitious materials. It was also concluded that 15% of fly ash exhibited increased compressive strength test with different curing days. [7] in their research studies concluded that the addition of steel fibres improved the concrete matrix in all aspects of concrete such as compressive strength, spilt tensile strength, flexural strength, fracture and toughness.[8], in their research studies showed that addition of fly ash at optimum level provided early strength and improved durability properties of concrete. [9-11] carried out research on high volume fly ash blended cements containing ground fly ash can result in substantial increase in the compressive strength of the mortars. The improvement in the strength was increased noticed with the increase in the fineness of fly ash and improved the strength gain properties of concrete.[12-14], has studied the mechanical properties of concrete by replacing cement with fly ash upto optimum level of 30% and the strength was found to be consistent all ages compared to plain concrete. [15, 16], in their studies showed that the effect of steel fiber content 0 to 80 Kg/m^3 with two types of steel fibres with l/d ratio of 40 and 80. The specimens were subjected to pullout test and concluded that pullout load of the deformed steel bars embedded into the concrete upto 18% when the concrete cover of the steel fiber concretes, it is also concluded that compressive strength was increased when compared to concretes without fibers[17].

Several research work had been concluded that the steel fibres with high volume of class F fly ash based concreted was greatly improved in terms of the mechanical and durability properties of concrete depending upon the proper mix selection and material selection.

The purposes of this study was to investigate the strength enhancement of class F fly ash at low and high volume additions in concrete and the effect of glued steel fibres addition. Also, the relative performance levels of flyash at various fibre dosages were compared systematically for different concrete mixture proportions at constant water to binder ratio.

II. EXPERIMENTAL INVESTIGATION

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

A. Cement [18]

Ordinary Portland cement of 53 grade 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.

Table I
Physical properties of cement

Sl. No.	Name of the test	Value
1	Consistency	31%
2	Initial setting time	95 minutes
3	Final setting time	260 minutes
4	Specific gravity	3.25
5	Fineness of cement	3%
6.	Soundness	2 mm
7	Compressive strength age of 7 days age of 28 days	 25.37 N/mm^2 47.02 N/mm^2

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.

Table II
Chemical composition of Class F fly ash

Properties (%)	Fly ash Class F
SiO_2	58.9
Al_2O_3	33.4
Fe_2O_3	5.86
CaO	1.02
MgO	0.38
SO_3	0.12
Na_2O	1.28
K_2O	0.01
Cl^-	0.49
Loss on ignition	2.2
Insoluble residue	-
Moisture content	0.73
Specific gravity	2.48

C. Fineness of fly ash by wet sieving

Fineness of flyash was determined by wet sieving as this provides a reliable estimate on the percentage of particles passing through the sieve. The values are given in Table III and Fig 1 show the wet sieving method carried out for determining the fineness of flyash.

Table III
Fineness of fly ash

Trial	Empty weight of 45µ sieve	Sample taken	Weight of dry sieve+ sample	Dry weight of sample retained in 45µ sieve	Percentage of retained	Fineness of fly ash
1	361	50	381	20	40	0.40
2	361	50	382	21	42	0.42
3	361	50	380	19	38	0.38
Average value of Fineness of fly ash =						0.40

Fig. 1. Wet sieving for fineness of fly ash

D. 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 observed values are presented in Table IV and plotted the graph by percentage of passing as shown in Fig 2. The fineness modulus value is 2.97, specific gravity of 2.71 and water absorption of 0.67 % at 24 hours.

Table IV
Sieve analysis of Fine aggregate

Is sieve	Weight retained (gms)	Cumulative Weight Retained (gms)	Cumulative % retained	Cumulative % Passing
4.75mm	78	78	3.9	96.1
2.36mm	70	148	7.4	92.6
1.18mm	375	523	26	74
600µ	819	1342	67	33
300µ	541	1883	94	6
150µ	104	1987	99	1
Fineness modulus of fine aggregate = ∑ cumulative % retained /100 = 2.97				

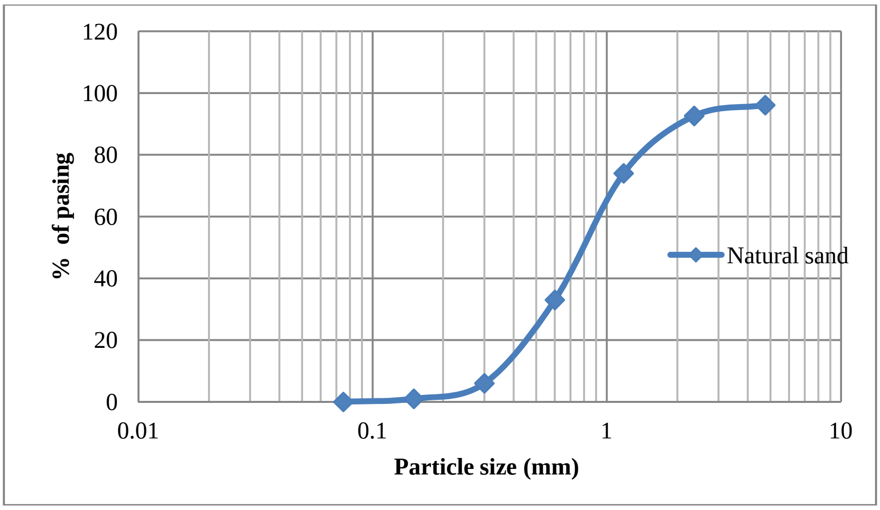

Fig. 2. Gradation chart for sieve analysis of fine aggregate

E. 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 for experimental values are shown in Table V and observed values are presented in the graphically plotted as shown in Fig 3, 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.

Table V
Sieve analysis of coarse aggregate

Is sieve	Weight retained (gms)	Cumulative Weight Retained (gms)	Cumulative % Retained	Cumulative % Passing
80mm	0	0	0	100
50mm	0	0	0	100
40mm	0	0	0	100
25mm	0	0	0	100
20mm	138	138	2.7	97.3
12.5	1986	2124	42.4	57.6
10	1476	3600	72	28
6.35	1388	4938	98.7	1.3
4.35	1	4939	98.7	1.3
3.35	4940	4940	98.7	1.2
Fineness modulus of fine aggregate = ∑ cumulative % retained /100 = 4.133				

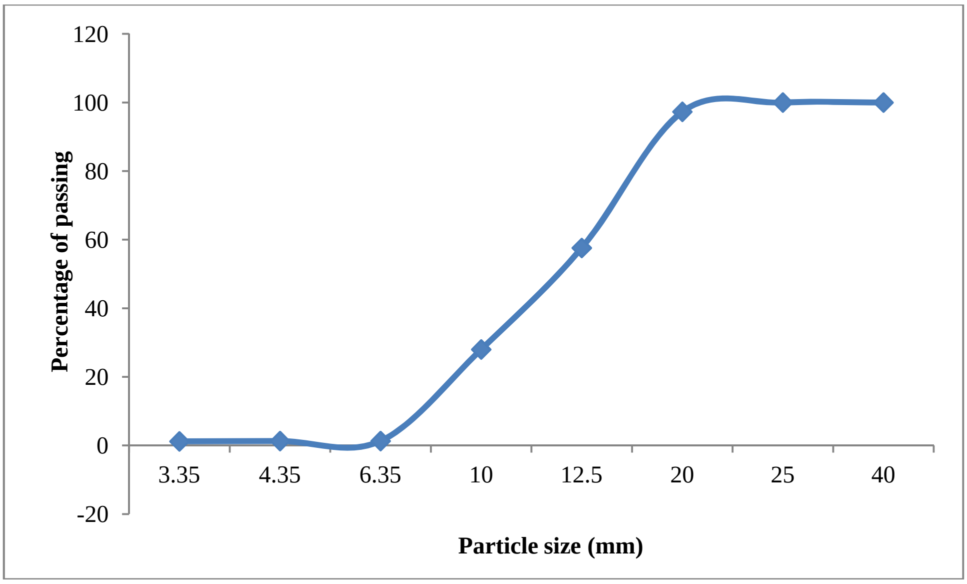

Figure 3: Particle Size Distribution curve of Coarse Aggregate.

F. Chemical admixture

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

G. Steel fibres

Both end hooked glued steel fibres was used in the study and the dimension of the steel fibre is 60 mm longer and 0.5 mm diameter with l/d ratio of 80 with different dosage level (0.5 to 1.0 % by volume fraction) was used.

H. Proportioning of Ingredients

In this experimental work a total of 12 different concrete mixture proportions were studied. Plain concrete mix without flyash and steel fibres and concrete with fly ash, superplasticizer and steel fibres) was proportioned as per conceptual mix design method by keeping the fine aggregate to coarse aggregate ratio of 0.7 and w/b (cement +fly ash) as shown in Table VI.

I. Mixing, casting, curing and testing the specimen

First the coarse aggregate and fine aggregate are added into the drum mixer with capacity 30 Kg of mixing machine. Then the binder content and steel fibres are added and dry mixed separately on the metal plate for about 3 minutes until the uniform composition is obtained. Then the required amount of water is added to the mixer and rotates till it obtains the uniform mixture. The whole mixture is mixed well for about approximately 4 minutes before casting into the moulds. After casting, the concrete specimens were covered with wet burlap and polyethylene sheets and kept in the laboratory at room temperature for 24 hours. After demolding, the concrete specimens were kept for curing to achieve the desired compressive strength at respective ages. Compression testing of concrete as per IS 516: 1959, 100 mm x 100 mm size cubes were employed. All the cubes were tested in saturated surface dried condition. For each mix, a minimum of three specimens were tested using a Concrete Compression Testing machine of 1000 tone Capacity. The tests were carried out at a uniform stress rate, after the specimen was center in the testing machine. The loading was continued till the specimen reaches its ultimate load. The concrete mixture is then casted in cubes of size 100 × 100 x 100 mm used for compressive strength, cylinder of diameter 100 mm and height 200 mm used for split tensile strength and prism of 500 × 100 × 100 mm used for flexural strength of concrete using flexural testing machine as shown in **Fig 4** . The mixture is poured in the mould in three layers and each layer is compacted under vibrating table to avoid the air pockets, honeycomb voids, increased the density of concrete and finally top surface should be leveled by using travel..

Table VI
Various mixture proportions

Mix Id	w/b ratio	Cement	Fly ash	water	Fine aggregate	Coarse aggregate		Sp	Steel Fibres (%)	F/C ratio
						10 mm	20 mm			
		Kg/m^3								
M	0.4	400	0	180	752	502	502	1.28	0.00	0.7
M1	0.4	400	0	180	752	502	502	1.28	0.5	0.7
M2	0.4	400	0	180	752	502	502	1.28	0.75	0.7
M3	0.4	400	0	180	752	502	502	1.28	1.00	0.7
M4	0.4	400	120	180	752	502	524	1.28	0.00	0.7
M5	0.4	400	120	180	752	524	524	1.28	0.50	0.7
M6	0.4	280	120	180	735	524	524	1.28	0.75	0.7
M7	0.4	280	120	180	735	524	524	1.28	1.00	0.7
M8	0.4	200	200	180	720	518	518	1.28	0.00	0.7
M9	0.4	200	200	180	720	518	518	1.28	0.50	0.7
M10	0.4	200	200	180	720	518	518	1.28	0.75	0.7
M11	0.4	200	200	180	720	518	518	1.28	1.00	0.7

Fig. 4. Test set up for flexural strength testing machine

III. EXPERIMENTAL TEST RESULTS AND DISCUSSION

The obtained experimental results reveal the influence of the flyash and steel fibres on the behavior of hardened concrete

J. Compressive strength

The compressive test results of different concrete mixtures are given in Table VII. It can be observed that plain concrete at F/C ratio of 0.7 without fly ash and steel fibres showed strength was 38.60 MPa for 7days, 53.60 MPa for 28 days and 54.20 MPa for 56 days. It can also be noted that the variables such as fine to coarse aggregate ratio with 1.0% of steel fibres obtained the compressive strength properties was greatly improved when the w/b ratio is 0.4 showed increasing trend upto 11.19% for 28 days and 16.24% for 56 days that is M3 mix as shown in Fig 5. Similarly it can be noted that 30 % of fly ash with 1.0% steel fibres strength was marginally decreased upto 9.14% for 28 days when compared to plain concrete but in the case of 56 days strength was increased upto 3.14% (M7 mix) as shown in Fig 6. Also, a similar trend was observed for w/c of 0.4, F/C ratio of 0.7 with 1.0% of steel fibres and 50% of fly ash based concrete mix, which resulted in marginal decrease in the strength upto 36.43% and 24.16 % for 28 days and 56 days respectively and shown in Fig 7. Finally compared with different curing ages and compressive strength results with different percentage of fly ash, higher replacement level of flyash showed delayed strength gain; however, with the addition of steel fibres the strength was compensated which is shown in Fig 8 and eventually fibres can delay the cracking in concrete upon loading.

Table VII
Various mixture proportions of compressive strength of concrete at different curing ages

Mix Id	**w/b ratio**	**Average Compressive strength (MPa)**	**Average Compressive strength (MPa)**	**Average Compressive strength (MPa)**
		7 days	**28 days**	**56 days**
M	0.4	38.60	53.60	54.20
M1	0.4	40.90	56.20	61.50
M2	0.4	45.50	57.30	62.80
M3	0.4	44.30	59.60	63.10
M4	0.4	27.40	42.50	53.80
M5	0.4	31.60	48.50	55.20
M6	0.4	30.90	45.40	53.90
M7	0.4	30.60	48.70	55.90
M8	0.4	18.50	31.50	39.70
M9	0.4	20.50	33.80	36.50
M10	0.4	19.90	33.85	41.40
M11	0.4	20.40	34.40	43.10

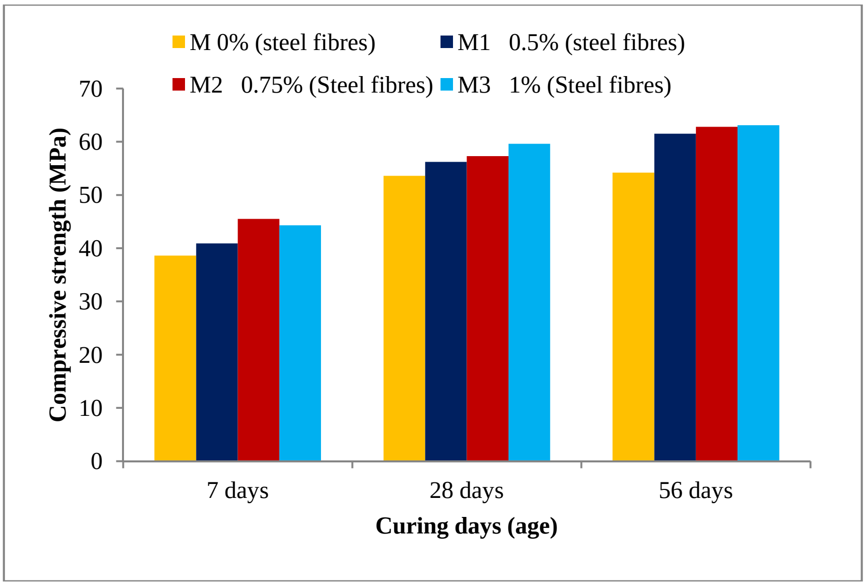

Fig. 5. The compressive strength of concrete at different dosage of steel fibres

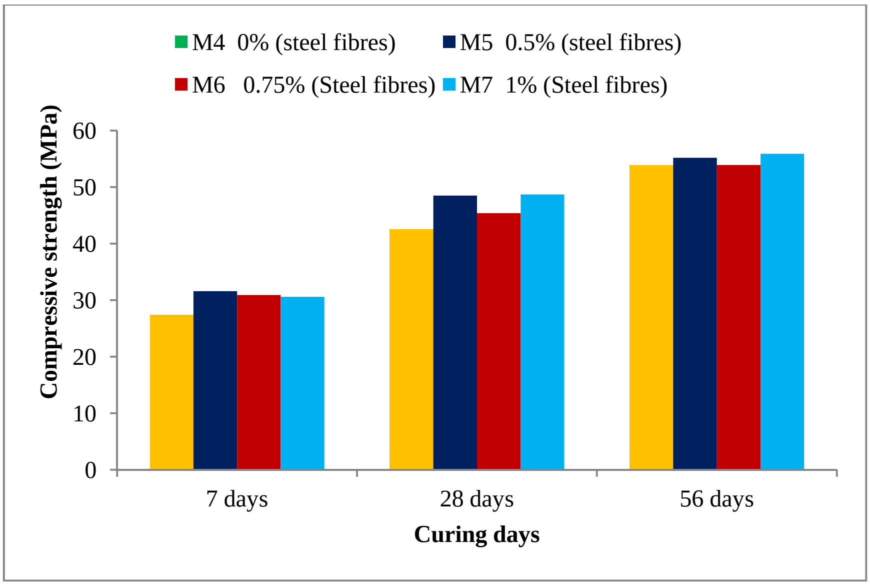

Fig. 6. Compressive strength of concrete for 30% fly ash at different dosage of steel fibres

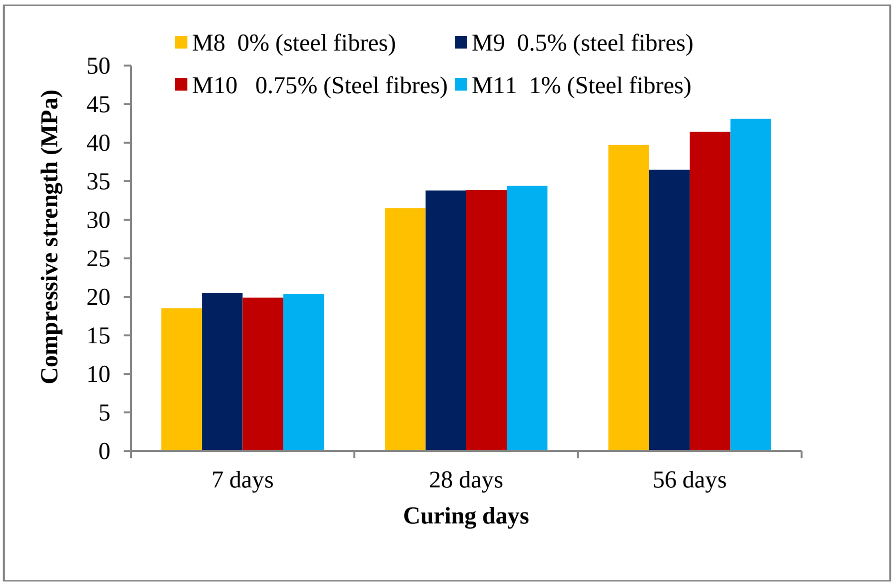

Fig. 7. Compressive strength of concrete for 50% fly ash at different dosage of steel fibres

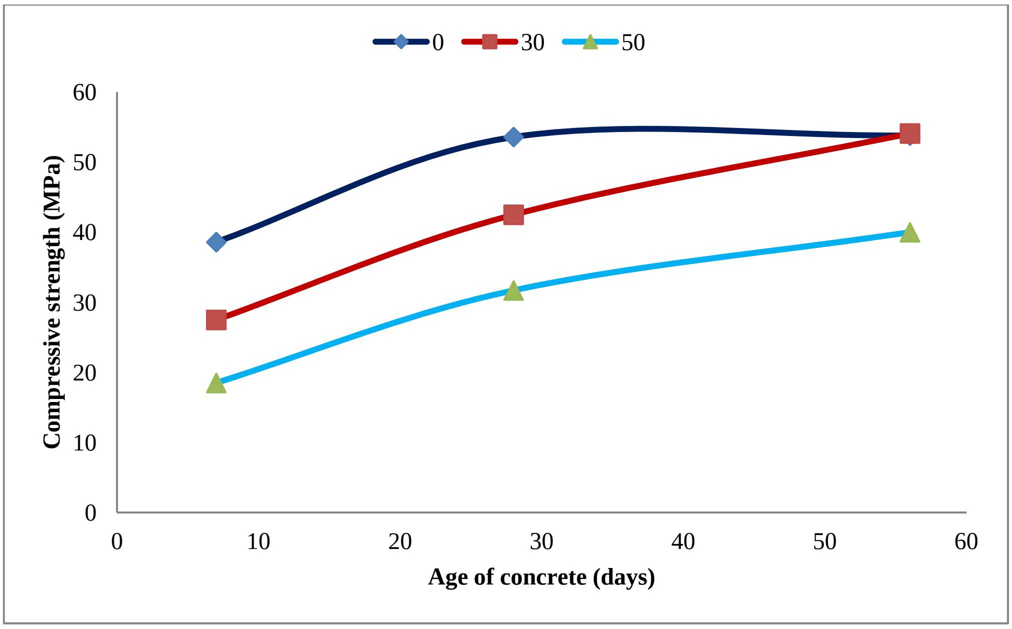

Fig. 8. Various percentage of flyash for compressive strength of concrete Vs Age of concrete

K. Split tensile strength

Split Tensile Test is an indirect tension test method as per IS 5816: 1999 and the specimens were placed horizontally between the loading surfaces of a compression testing machine and the load is applied until failure of the cylinder, along the vertical diameter. When load is applied along the element on the vertical diameter of the cylinder is subjected to a horizontal stress of the specimen and shows the splitting tensile resistance the test result is shown in Table VIII and plotted in Fig 9. It can be noted that the variables such as fine to coarse aggregate ratio with out steel fibres showed improved split tensile strength was higher 5.18 MPa that is plain concrete. Also, a better improvement is observed when the w/b ratio is 0.4 with an increase upto 10.81% for 28 days that is M3 mix. Similarly it can be noted that 20 % and 50% of fly ash showed an increase upto 14.09% and 12.36% for 28 days respectively. Steel fibres in flyash based concrete mixes suitably improved the tensile properties even though there was a reduced strength gain property.

Table VIII
Average Split tensile strength of concrete at various mixture proportions at 28 days.

Mix Id	w/b ratio	Average split tensile strength (MPa)
		28 days
M	0.4	5.18
M1	0.4	5.18
M2	0.4	5.27
M3	0.4	5.74
M4	0.4	3.60
M5	0.4	4.54
M6	0.4	4.25
M7	0.4	4.45
M8	0.4	3.28
M9	0.4	4.00
M10	0.4	3.95
M11	0.4	4.54

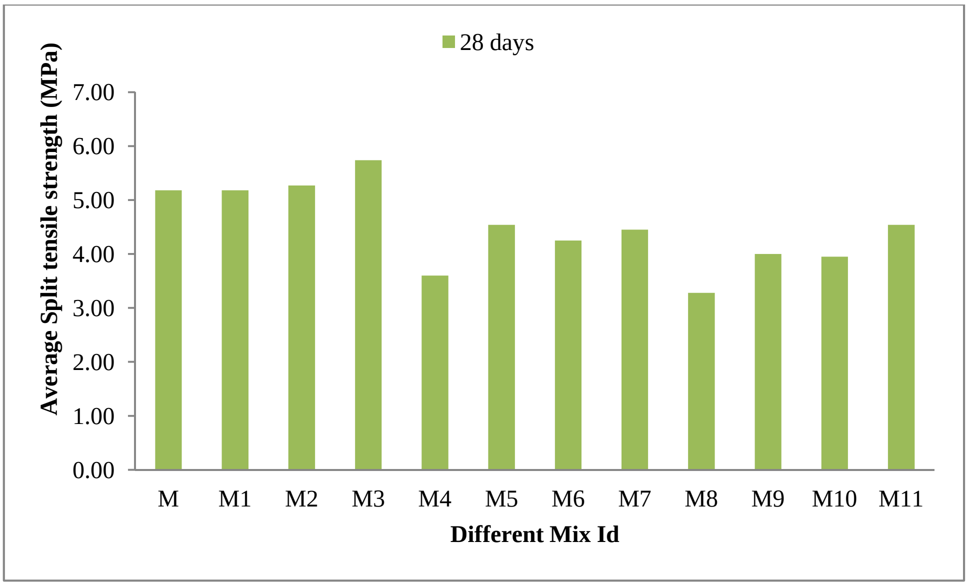

Fig. 9. Split tensile strength at 28 days

L. Flexural test

The flexural test results of different concrete mixtures are given in Table IX. Tensile resistance of fibre concretes can be realized only in flexural direction as the failure is primarily due to fracture and a third point loading arrangement was considered to be appropriate since it maximizes the bending area and the real effects of fibre distribution is encountered. Plain concrete specimens showed a sudden failure in flexure as the cracks propagated much faster whereas; all fibre concretes with high volume flyash concretes showed a controlled failure anticipated with steady growth of cracks and resulted in fibre pullout near the crack tip. The influence of steel fibre concretes with maximum dosage level of steel fibres of 1.0% by volume fraction showed the flexural strength of 7.2 N/mm^2 at 28 days (M3 mix). It can also be noted that 20% fly ash with 1.0% of steel fibres showed a strength decrease upto18.75% when compared to M3 mix and also noted that 50% fly ash based concrete with higher dosage level of steel fibres the flexural strength was decreased upto 36%, when compared to M3 mix as shown in Fig 10.

Table IX
Flexural Strength of concrete for various mixture proportions at 28 days

Mix	Load KN	Modulus of rupture N/mm^2
M	18.57	5.5
M1	20.7	6.21
M2	22.24	6.67
M3	24.06	7.2
M4	15.84	4.7
M5	17.19	5.15
M6	18.9	5.6
M7	19.52	5.85
M8	12.65	3.7
M9	15.1	4.5
M10	15.32	4.5
M11	15.0	4.5

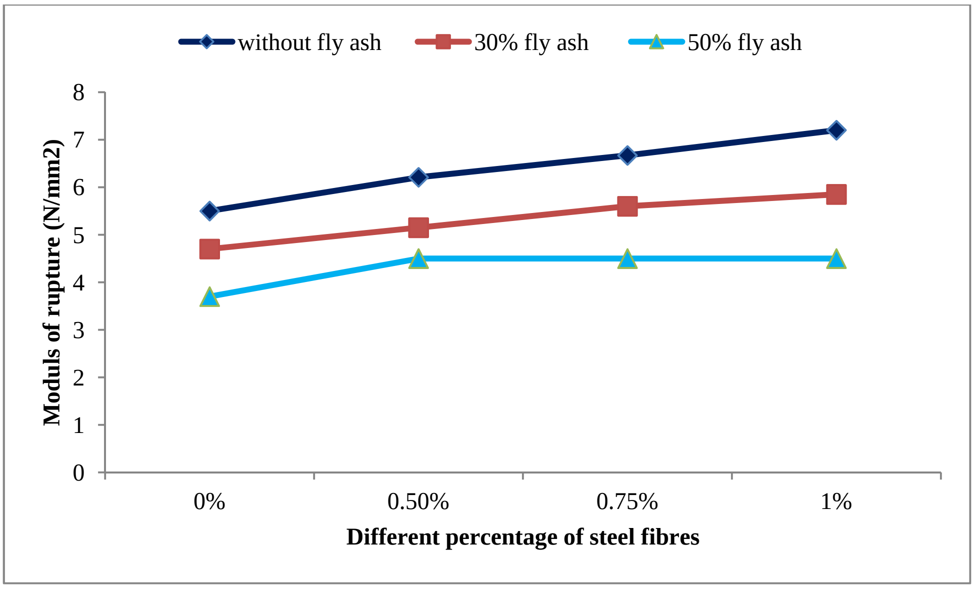

Fig. 10. Flexural strength with different mixture proportion of concrete at 28 days

M. Ultra sonic Pulse Velocity Test (UPV)

The experimental test results showed that higher enhancement of the strength as tested using ultrasonic pulse velocity as given in Figure 11. The UPV values revealed an increasing trend for different concrete mixes with the pulse velocity values ranging from 3.1 to 4.75 Km/sec. However, the higher value of ultrasonic pulse velocity value (4.13 km/sec) was obtained at 28 days, when fly ash up to 30% and F/C ratio of 0.7 with w/c of 0.4. In general all the concrete mixes showed a good strength gain as recorded in the ultrasonic pulse velocity test and satisfies the codal provision as per Indian Standard 13311.

Fig. 11. Ultrasonic pulse velocity test set up

N. Dynamic modulus of elasticity

The ultrasonic pulse velocity and dynamic modulus of elasticity values for different mix ingredients of concrete with respect to different curing ages are presented in the Table X.

Dynamic modulus of elasticity can also be found out from the following equation

$$E = \rho V^2 (1+\mu)(1-2\mu)/\,(1+\mu)$$

$where\ V\ is\ the\ pulse\ velocity$ (Km/sec)

$\rho\ is\ the\ density\ of\ concrete\ \left(\frac{Kg}{m^3}\right)\ and\ \mu\ is\ the\ poisson's\ ratio$ (0.2)

The value 'E' calculated using ultrasonic pulse velocity frequency is referred to as dynamic modulus of elasticity. This provides a valuable estimate on the dynamic modulus of elasticity of concrete as shown in Figs. 12 to 14 and also to predict the quality of concrete by using ultrasonic pulse velocity technique.

Table X
Dynamic modulus of concrete at various mixture proportions at different curing ages.

Mix Id	M	M1	M2	M3	M4	M5	M6	M7	M8	M8	M9	M10	M11
UPV (Km/s)	3.83	3.75	3.50	3.14	3.20	3.67	3.79	3.90	3.73	4.38	4.01	4.11	4.12
7 days (GPa)	31.70	30.30	24.50	21.30	22.10	29.09	31.03	32.85	30.05	41.40	34.73	36.49	36.66
UPV (Km/s)	4.34	4.20	4.13	4.10	4.04	4.34	4.46	4.46	4.41	4.90	4.20	4.75	4.21
28 days (GPa)	40.70	38.10	36.84	36.30	35.25	40.70	42.97	42.01	42.00	51.86	38.10	48.74	38.28
UPV (Km/s)	4.46	4.55	4.59	4.57	4.20	4.46	4.30	4.20	4.16	4.32	3.91	3.97	3.82
56 days (GPa)	42.97	44.71	45.50	45.11	38.10	42.97	39.93	38.10	37.38	40.31	33.02	34.04	31.52

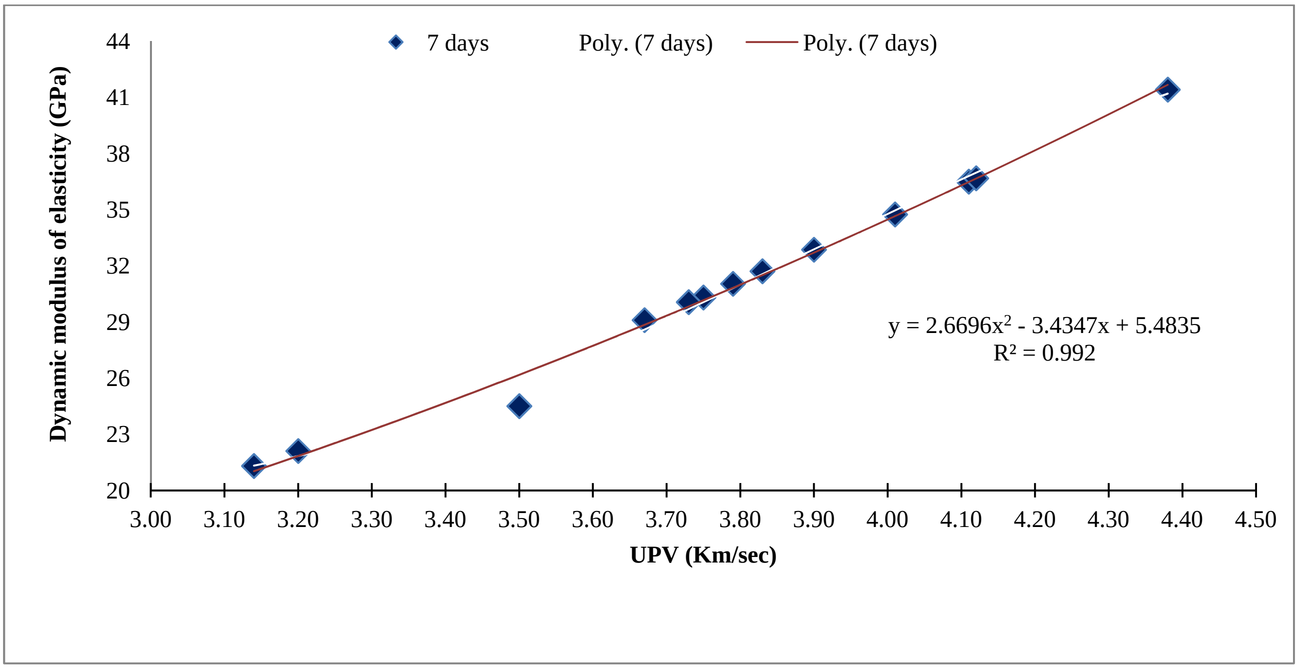

Fig. 12. Dynamic modulus of elasticity of concrete at various mixture proportions at 7 days

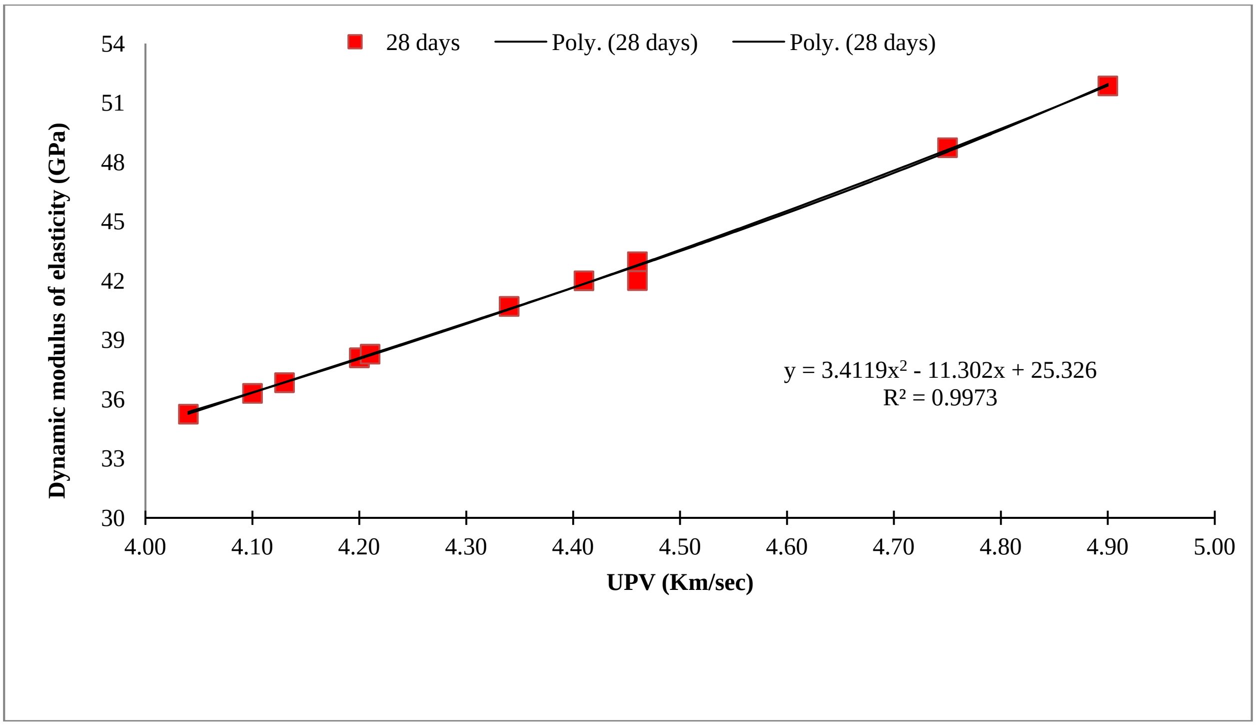

Fig. 13. Dynamic modulus of elasticity of concrete at various mixture proportions at 28 days

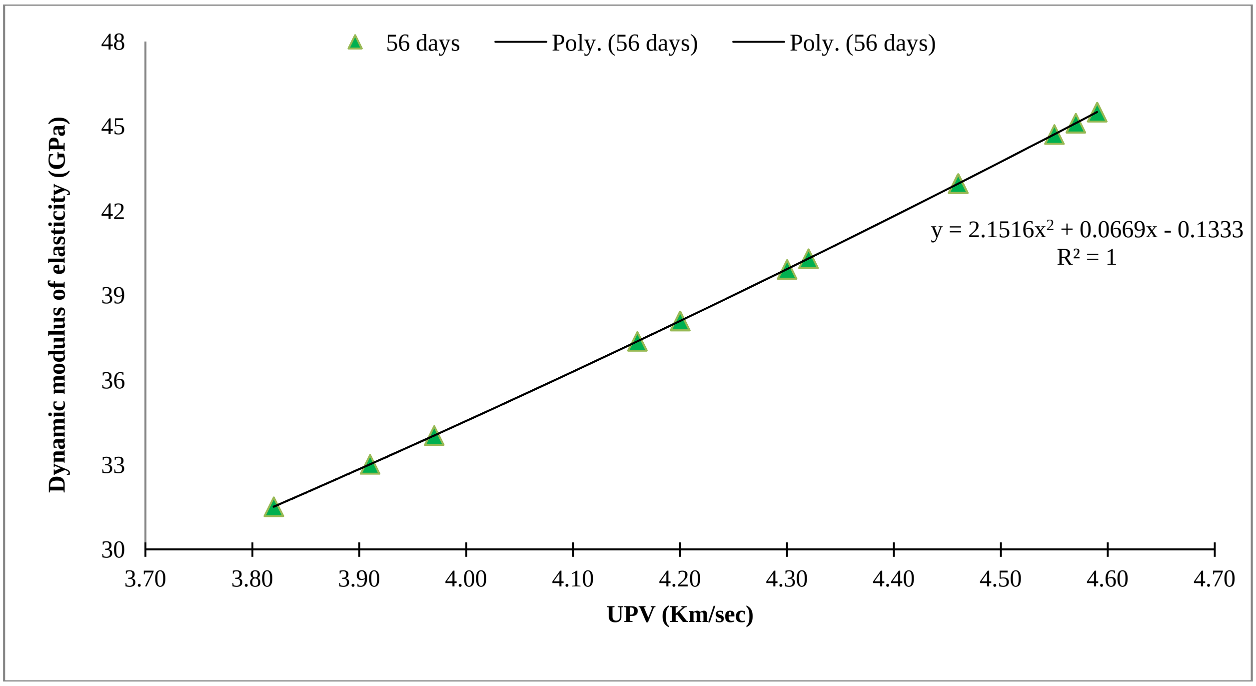

Fig. 14. Dynamic modulus of elasticity of concrete at various mixture proportions at 56 days

IV. CONCLUSION

The important conclusions can be drawn from the study as given below:

- ✓ The cement content in the concrete can be reduced with the use of fly ash in different proportions. It can be possible to produce structural grade concrete even with the use of high volume of fly ash.
- ✓ Based on the experimental results it can be concluded that the compressive strength for conventional concrete varies from 38.06 N/mm^2 to 61.50 N/mm^2 with the addition of fibres at 1% Volume fraction.

- ✓ Fibre reinforcement with fly ash replaced concrete showed a marginal increase on the compressive strength with increase in fibres volume fraction.
- ✓ Fly ash based concrete shows delayed pozzolanic reaction however; after 56 days of curing fly ash concrete can produce the 28 days compressive strength as that of conventional concrete.
- ✓ Steel fibres provide an increase in the tensile strength of the concrete providing a maximum of 5.74 N/mm^2.
- ✓ Flexural strength of the concrete increased with the increase in fibres volume fraction. All fibre concrete mixes attains a maximum strength at 1% fibre volume fraction and a maximum flexural strength of 6.67 N/mm^2 was obtained**.**
- ✓ Dynamic modulus of elasticity of concrete can be obtained from the pulse velocity values, which can be of useful estimate for predicting the stiffness of concrete developed.

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