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Strength Gain Properties of Low Calcium Fly Ash Based Cementitious System

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Abstract: Fly ash ash (FA) has been widely used as a supplementary cementitious material due to its pozzolanic strength gain properties. It is realized that high cementing efficiency from fly ash is due to the silicieous content which favourably reacts with the hydration product. This paper presents a comprehensive and a detailed insight on the hardened properties of cement concrete blended with class F fly ash. A comprehensive study on concrete made with fly ash as a partial cement substituted at 10% to 70% by weight of cement with the effect of steel fibres on the compressive properties for various mixture proportions of concrete were investigated. It has been observed that low calcium fly ash replacement upto 50% of the Portland cement resulted on the improvement on the variation of strength properties. However, the effect of steam curing for high volume fly ash is realized when the intital steam curing for 18 hours is adopted and the remaining curing is kept in water. This increase was on par as that of 30% fly ash concrete specimens kept for normal water curing. The test results on the compressive strength of concrete for normal curing containing 30% of fly ash, 1% accelerator and 1% addition of steel fibres showed marginal strength increase than reference concrete upto 36.70 MPa at 28 days, when compared to reference concrete the strength was 31.50 MPa, whereas the effect of steam curing along with normal curing there was a significant increase in compressive strength of concrete containing 50% fly ash with 1% steel fibres which apparently showed maximum strength of 36.10 MPa at 28 days.

Key words: Fly ash · Setting properties · Superplasticizer · Strength and steam curing

INTRODUCTION

It is well demonstrated that the use of fly ash in construction increased to a maximum of 50% replacement in cement concrete. The use is well augumented depending upon the large scale production of fly ash from thermal power station. Different types of fly ash with low and high calcium varieties are prodcued from different source material. FA is generated on an average of 30% to the rate by weight of the fly ash that is processed. Most of the fly ash is burned or dumped as waste materials and now days widely used for fly ash based materials in concrete. It has been used either as a partial replacement for cement or as an additive when special properties are desired. The rapid increase in the use of fly ash is attributed to its positive effects on the mechanical properties of cementitious composites. Though added strength and low permeability are the two reasons that fly ash is added to concrete, there are other properties that are favorably improved which includes: high modulus of elasticity, higher strength at later ages, less sodium sulfate attack due to low permeability to water and chloride ions. It is well documented that the use of fly ash as a partial replacement for cement in combination with super plasticizers provides a significant increase in the strength of concrete. During the last two decades concrete technology has undergone rapid development to produce high strength concrete [1]. Apart from strength, durability properties have also been improved as a result of enhanced microstructure. Some of the research studies have reported generally large amount of cement quantities were used with 28 days curing in larboratory work to achieve the target high strength but in the case of low calcium class 'F' fly ash which contribute to high strength to incorporating the OPC. The utilization of fly ash in high strength concrete is to reduce the heat of hydration and consume the calcium hydroxide to obtain the better durability properties for various mixture proportions of concrete [2-4]. However, concrete has typically 50 to 60% low calcium fly ash as the total cementitious materials content with required high range water reducing admixtures to obtain a high degree of workability.

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It seems that lower water to binder ratio and normal amount of fly ash does not reduce the temperature rise due to heat of hydration. Fly ash based concrete requires special curing much more than reference Portland cement concrete needs [5]. The replacement level of fly ash based concrete with superplasticizers those being combination of concrete mixture, fresh concrete workability is increased with adequate strength gain. However, the shrinkage of hardened concrete os reduced and chloride ion permeability is decreased due to the effect of pore filling effect of the micropores of concrete. The addition of fibres showed better improvement on the mechanical properties such as compressive strength, tensile strength, flexural strength, tensile stress, toughness and impact resistance [6-8]. Good number of research studies has been carried out in fly ash which showed the consistent improvement on the properties of concrete strength and lead to high strength. The further explorations on the pozzolanic reaction of fly ash in cement concrete can slead to durable concrete.

Research Significance: The experimental studies focused in this studies showed that the optimum addition of fly ash is restricted upto 30% of (by weight of cement) due to its high fineness and with the increased dosage the water demand increases. Also, the increased performance levels of fly ash are achieved only with the addition of high range water reducers that can suitably compensate the workability. The present study is aimed at to evaluate the effect of partial replacement of cement by fly ash on strength properties of concrete for fixed water to binder ratio and fine to aggregate ratio. It can be noted that both mechanical properties and ultrasonic pulse velocity for various mixture proportions of concrete was recorded due to increased level of fly ash.

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

Cement: Ordinary Portland cement of 53 grade having 28 days compressive strength of 49.4 MPa, satisfying the requirements of IS: 12269–1987 [9].

Fine Aggregates: River sand obtained from locally available source passing through 4.75 mm maximum size, complying with zone-II as per IS: 383-1970 [10] were used with fineness modulus of 2.41, a specific gravity of 2.58 and water absorption of 0.68 % at 24 hours.

Table 1: Physical properties of class F fly ash and Portland cement

Parameters	Fly ash Class-F	Cement
Specific gravity	2.41	3.18
Specific surface area (blaine) (m^2/kg)	320	354

Table 2: Chemical components of raw materials (weight %)

Properties (%)	Fly ash Class-F	Cement
SiO_2	59.5	20.81
Al_2O_3	34.7	4.79
Fe_2O_3	5.87	3.2
CaO	<1	63.9
MgO	<1	2.61
SO_3	0.1	1.39
Na_2O	0.6	0.18
K_2O	1.4	0.79
Cl^-	0.49	0.002
Loss on ignition	1.2	0.92
Insoluble residue	-	0.12
Moisture content	0.73	-

Table 3: Properties of Glued steel fibres (GSF)

Material	Glued steel fibres
Relative Density	7.65 kN/m^3
Length	35 mm
l/d ratio	70
Thickness	0.5 mm
Width	1.25 mm
Tensile strength	1700 MPa
Failure strain	3 to 5 %

Coarse Aggregates: Crushed blue granite stone well graded aggregate with 12.5 mm maximum size, conforming to IS: 383-1970 [10] was used. The specific gravity was found to be 2.70, fineness modulus of 7.10 and water absorption is 0.60 % at 24 hours.

Fly Ash: Fly ash is obtained from ennure power plant in chennai and contains large proportion of silica. The physical and chemical properties are given in Tables 1 and 2.

Chemical Admixture: A polycarboxylate ether based super-plasticizer admixture at 1.5% by weight of cement was used to obtain the desired workability.

Glued Steel Fibres: Glued steel fibres (as shown in Figure 1) were used in the present study and the various material properties are given in Tables 3. The both ends hooked were present in the glued steel fibres improve the bond strength, anchorages and lead to increase in the reinforcing efficiency.

Fig. 1: Snapshot for glued steel fibres (GSF) used in study

Fig. 2: Test setup for compressive testing machine

Conceptual Mix Design: In this experiemental research paper a total of eight different type of mixes were cast using a constant water to binder ratio of 0.30 and fixed dosage of polycarboxlyic ether based superplasticizers. The concrete mixture proportions were prepared which consists of a reference concrete mix without fly ash was proportioned and the other 7 mixes containing different replacement level of fly ash (10, 20, 30, 40, 50, 60 and 70%) by weight of cement. The detailed of mix design are given in Table 4.

Casting of Specimen: All the fresh concrete mixtures were designed using a conceptual mix proportioning method. The ingredients were mixed in a rotating type drum mixer of capacity 35 kg. A superplasticizer dosage of 1.5% then mixed thoroughly with the calculated mix water and added to the drum mixer for a period of 3 minutes. Fresh concrete is then cast in steel moulds of standard size for different mixture proportions and compacted on a table vibrator. The surface finishing was done very carefully to obtain a uniform surface on the top of the fresh concrete with the help of trowel and detailed specimen size is presented in Table 5. Series 1 stands for normal water curing for different mixture proportions of concrete specimens and series 2 stands for initial steam curing (temperature upto 75°C for 18 hours) followed by normal water curing of all the concrete specimens and the snapshot for steam curing is shown in Figure 2.

Table 4: Mixture proportions of concrete

Mix Id	w/b ratio	F/c ratio	Cement	Fly ash	Fine aggregate content	Coarse aggregate	Water	Steel Fibres (%) V_f	Accel erator (%)	Super plasticizer (%)
			(kg/m^3)							
R	0.3	0.6	473	0	672	1113	142	0	1	1.50
FA1	0.3	0.6	426	47	672	1113	142	1	1	1.50
FA2	0.3	0.6	378	95	672	1113	142	1	1	1.50
FA3	0.3	0.6	331	142	672	1113	142	1	1	1.50
FA4	0.3	0.6	285	188	672	1113	142	1	1	1.50
FA5	0.3	0.6	237	236	672	1113	142	1	1	1.50
FA6	0.3	0.6	190	283	672	1113	142	1	1	1.50
FA7	0.3	0.6	142	331	672	1113	142	1	1	1.50

Note: w/b – water to binder ratio; F/c – fine to coarse aggregate ratio; V_f – volume fraction;

Table 5: Concrete specimen parameters details

Shape	Size of the concrete specimens	Tested
Cubes	100 X 100 X 100 mm	Compression
Cylinder	100 mm diameter and 150 mm height	Split Tensile strength
prism moulds	100 X 100 X 500 mm (third point loading).	Flexural strength for third point loading

Fig. 3: Test setup for compressive testing machine

Fig. 4: Test setup for flexural testing machine

Evaluation of Mechanical Properties of Concrete: The mechanical properties of concrete such as compressive, splite tensile strength of concrete were conducted on the compression testing machine capacity 2000 kN. The pressure gauge indicating the load per least count of 1 kN and load applied on the specimens at a constant rate up to the failure and the snapshot of the compression testing machine is shown in Figure 3. The splitting tensile strength is calculated from Equation 1 and the experimental test results on the various mixture proportions of concrete were evaluated based on IS 516-1959 [11]. A flexural testing machine of capacity 100 kN was used to study the flexural tensile properties of hardened concrete using a third point bending test. The beam element is simply supported on rollers for a span length of 450 mm and the flexural tensile stress is calculated from the Equation 2 and snapshot of flexural test setup is shown in Figure 4.

Split tensile strength (MPa) = $\frac{2p}{\pi DL}$ (1)

Where-P, D and L are Load, diameter and length of cylinder specimen.

Flexural tensile strength (MPa) = f_{cr} = $f_{cr}\frac{pL}{bd^2}$ (2)
where,
f_{cr} – flexural tensile stress (N/mm^2)
P – load (kN)
L – length of concrete specimen (mm)
b – width of concrete specimen (mm)
d – depth of specimen (mm)

RESULTS AND DISCUSSION

The experimental test results are presented in Tables 6 and 7 and all the values are provided graphically in Figures 5 to 12 and have been discussed under various categories.

Fresh Concrete Properties: The reference concrete mixtures at low water to binder ratio showed a good workability with the addition of 1.5% of superplasticizer however; with the addition of fly ash as the binder volume increases there was a reduction in the consistency.

Table 6: Compressive strength of concrete for different mixture proportions – series 1

			Compressive strength (Mpa)					Split tensile strength (Mpa)			Flexural strength (Mpa)		
Mix Id	Steel fibre (%)	Fly ash (%)	3 days	7 days	28 days	56 days	90 days	120 days	28 days	90 days	28 days	56 days	90 days
R	0	0	21.4	24.7	31.5	34.50	36.70	38.50	3.56	3.87	3.41	3.78	4.76
MFA1	1	10	19.5	23.4	33.4	37.30	41.40	42.50	3.73	3.95	3.67	3.91	4.84
MFA2	1	20	17.4	19.9	35.3	38.54	42.80	44.30	3.81	4.12	3.99	4.74	4.99
MFA3	1	30	16.3	18.4	36.7	38.90	41.20	42.80	3.96	4.34	4.12	4.81	5.12
MFA4	1	40	15.4	16.3	21.5	24.30	28.90	31.50	3.67	3.98	4.01	4.35	4.73
MFA5	1	50	13.9	14.5	18.5	21.50	25.40	27.30	2.93	3.74	3.41	3.76	3.98
MFA6	1	60	12.5	13.7	15.3	19.80	23.60	24.50	2.21	2.43	2.21	2.33	2.45
MFA7	1	70	10.4	11.9	13.2	16.50	21.78	23.10	1.54	1.98	1.67	1.82	1.95

Table 7: Variation of strength for different mixture proportions of concrete – series 11

Mix Id	Steel fibre (%)	Fly ash (%)	Compressive strength (Mpa)					Split tensile strength (Mpa)			Flexural strength (Mpa)		
			3 days	7 days	28 days	56 days	90 days	120 days	28 days	90 days	28 days	56 days	90 days
R	0	0	32.1	34.5	40.1	42.40	43.90	45.10	3.67	3.92	3.75	4.21	4.76
MFA1	1	10	32.5	36.4	45.2	47.10	49.43	50.40	3.81	3.95	3.99	4.56	4.84
MFA2	1	20	31.2	34.5	41.3	43.10	47.89	48.31	3.94	4.12	4.98	5.12	5.41
MFA3	1	30	30.9	31.2	39	40.30	45.90	46.50	4.01	4.24	4.45	5.01	5.1
MFA4	1	40	25.7	27.4	40.5	39.90	44.10	45.32	4.13	4.35	4.31	4.99	4.73
MFA5	1	50	21.4	24.5	39.1	37.50	41.50	43.20	4.22	4.51	4.19	4.93	5.23
MFA6	1	60	17.9	19.5	21.3	22.90	26.10	28.40	3.2	3.31	2.39	2.45	2.64
MFA7	1	70	12.4	16.3	21.9	23.40	24.80	25.50	1.62	2.21	1.75	1.99	2.01

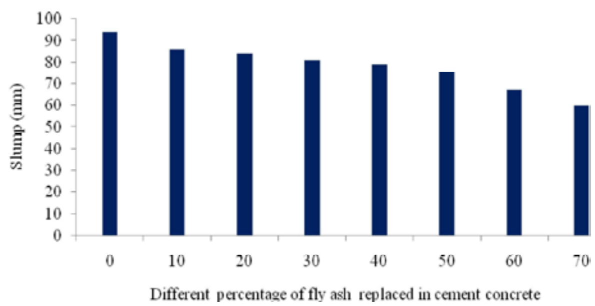

Fig. 5: Slump test for various mixture proportion of fresh concrete

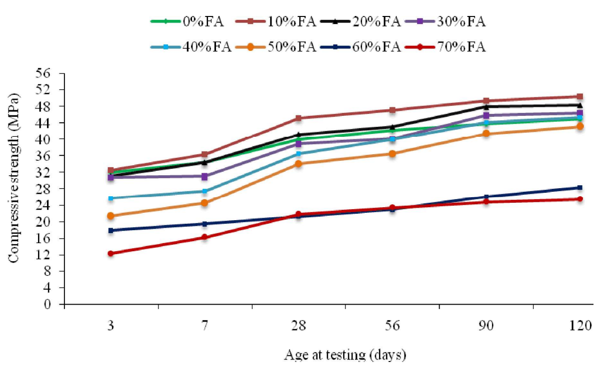

Fig. 6: Compressive strength of concrete with normal curing

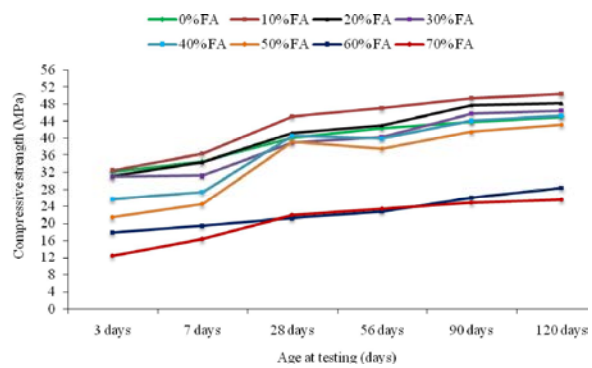

Fig. 7: Compressive strength of concrete specimens subjected to steam curing and normal water curing

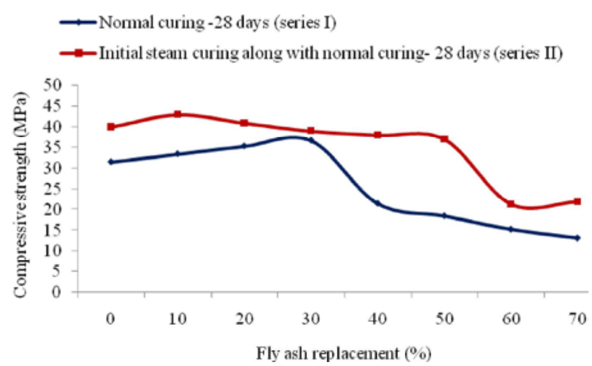

Fig. 8: Trend of the compressive strength when fly ash replaces OPC

The loss in workability was because of the fineness of the fly ash and the addition of high range water reducing admixtures at higher dosage becomes mandatory to obtain the required workability as shown in Figure 5. The water demand needed for the various replacement levels of fly ash and this was primarily due to high surface area of the fly ash which also showed significant bleeding during compaction. This increase in water demand was due to more surface area of the fly ash and requires more wetting for saturating the surface area. with the addition of high range water reducers the consistency of fly ash concrete mixes was reinstated.

Compressive Strength of Concrete: The experimental test results for compressive strength of concrete with and without fly ash are summarized for normal curing as given in Table 6 and Table 7 for steam as well as normal curing. The maximum strength of concrete was noted for fly ash substitution at 30% with a strength value of 36.70 MPa at 28 days as shown in Figure 6. Whereas, in the case of high volume fly ash susbsittuion the improvements on the strength gain was appreciable with the effect of steam curing as the reaction proceeds faster at higher

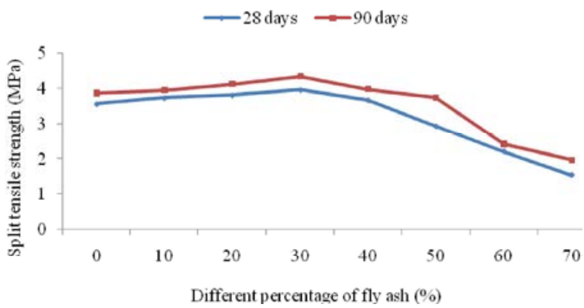

Fig. 9: Split tensile strength of concrete with normal curing

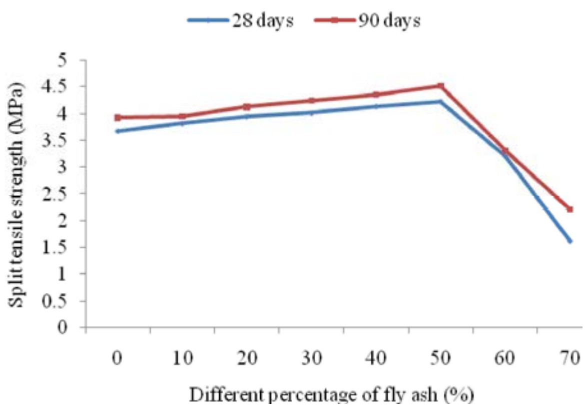

Fig. 10: Split tensile strength of concrete specimens subjected to steam curing and normal water curing

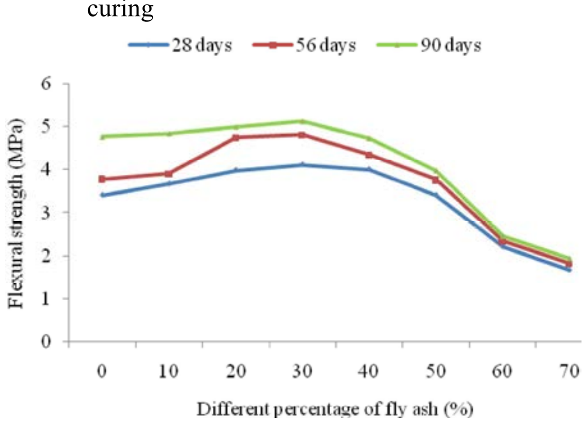

Fig. 11: Flexural strength of concrete with normal curing

temperature. As a result there was an increasing trend noted for concrete mixtures containing 50% fly ash reported an increase in strength value of 10.47 % (44.30 MPa at 28 days) compared to reference concrete which was around 40.10 MPa at 28 days as shown in Figure 7. It was also noticed that the compressive strength were found to be marginally increased upto 50% with steam curing as the further addition of fly ash did not improved the strength proeprties. This specific trend was observed in the case of all fly ash concretes with different

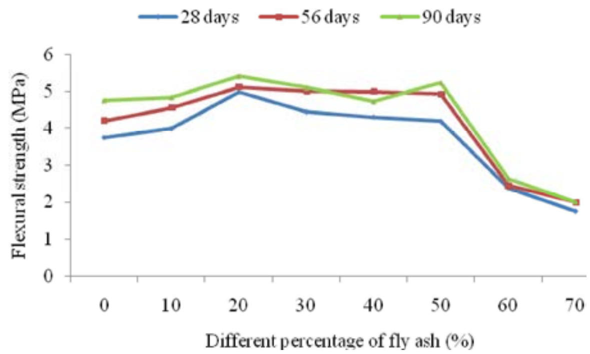

Fig. 12: Flexural strength of concrete specimens subjected to steam curing and normal water curing

Fig. 13: Effective fibre bridging – pullout resistance

percentage of fly ash replacement in ordinary Portland cement as shown Figrue 8.

Split Tensile Strength of Concrete: The experimental test results was graphically plotted from Figure 9 (series I) showed that the normal curing for various concrete mixes were maximum compared to reference concrete at all steel fibre dosages upto 1% by volume fraction. The percentage gain in strength was increased to 11.24% at 28 days and 12.14% at 90 days of MFA3 mix containing 30% fly ash with 1% steel fibres as compared to that of reference concrete mix (M).

From the Figure 10 (series II), it can be observed that MFA5 mixes showed a maximum tensile strength due to the effect of steam curing, in which there was an appreciable increase upto 14.98% at 28 days and 15.05% at 90 days, when compared to reference concrete and the minimum strength recorded by MFA6 and MFA7 mixes at different curing days. The increase in split tensile strength trend was influenced with the addition of steel fibres, type of accelerated curing technique, selection of fine to coarse aggregate ratio and dosage of superplasticizers which is expected to arrest the crack and reduce the crack width.

Flexural Strength of Concrete: The flexural strength results of the various concrete specimens are given in Table 6. Maximum strength of 4.12 MPa was recorded for concretes containing 30% of fly ash with 1% of glued steel fibres strength tested at 28 days. It can be also noted that the later age pozzolanic reaction of fly ash was found to be effective as it was seen that the flexural strength was increased to 4.81MPa at 56 days and 5.10 Mpa at 90 days (series I). This increase was phenomenal as compared to that of reference concrete as shown in Figure 11. Similarly the increase in strength properties with higher susbstitution of 50% fly ash was notably improved at higher replacement of glued steel fibres accompanied by steam curing (as seen in series II) which is given in Table 7. As an illustration, the variation of increase in flexural strength of MFA5 mixes at 1% of glued steel fibre volume fractions, the strength was increased 4.14 MPa at 28 days, 4.93 MPa at 56 days and 5.23 MPa at 90 days when compared to reference concrete and it is graphically presented in Figure 12. The post crack performance of fibres can be observed with the result of fibre bridging effect as seen in Figure 13. The above results justifies that the composite improvement in fly ash concretes depends on the optimal fly ash susbsitution, type of accelerated steam curing temperature and additional reinforcement mechanism. It is well demonstrated that high volum fly ash susbsitution is effective at higher suring temperatures sue to improved pozzolanic reaction and better formation of internal micorstructure.

CONCLUSIONS

Based on the experimental investigation always be acknowledged that there is the limitations of the test results.

- The proper selection of various ingredients such as water to binder ratio (0.3) and fine to coarse aggregate ratio of 0.6 had significant effect on the micro-structural alterations in concrete, which results in improvements in the mechanical properties.
- Strength enhancement was reported for fly ash addition at 10% replacement of cement in reference concrete. Also, at low w/b ratio the strength increase was insignificant at higher substitution for 50% replacement due to decreased reactivity.
- Rate of strength gain was appreciable at different curing ages with effect of w/b ratio of 0.30 due to pore filling effect of fly ash particles and improve the pozzolanic properties based on the fineness of fly ash.
- Strength obtained in concrete is a major role of low water binder ratio, F/C ratio, superplasticizer dosage, fly ash and steel fibres showed greater improvement on the considerable strength gain than reference concrete.
- Concrete mixes containing fly ash can be used upto 50% to produce the high strength concrete at 7 days without affecting the durability properties.
- The results demonstrated that a maximum strength of 36.70 MPa at 28 days can be achieved with the 30% of fly ash. Whereas for the 50% of fly ash replacement the initial steam curing for 18 hours is required for faster strength gain and later cured in normal curing.
- The split tensile strength of concrete with fly ash replacement upto 30% and 1% steel fibres addition showed better split tensile strength for normal curing than reference concrete.
- The addition of 50% fly ash with 1% glued steel fibres attained maximum tensile stress of concrete with the effect of steam curing upto 18 hours along with normal curing at 7 days than reference concrete.

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