Effect of Fly Ash and Steel Fibre on Portland Pozzolana Cement Concrete

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Abstract— **This paper presents the result of an experimental investigation carried out to evaluate the mechanical properties of concrete with steel fibre and steel fibre fly ash in which portland pozzolana cement was partially replaced with fly ash by weight. The experimental investigation carried out on steel fibres concrete up to a total fibre volume fraction of 0.5%, 1% and 1.5% and fly ash in which portland pozzolana cement (PPC) was partially replaced with 30% fly ash. The mechanical properties, compressive strength and splitting tensile strength were studied for concrete prepared. Compressive strength and splitting tensile strength were determined at 7, 28 and, 56 days. The laboratory results showed that addition of steel fibres reinforced fly ash into PPC concrete decreases the strength properties. While the results showed that steel fibres addition into PPC concrete improve the strength properties.**

Keywords—**Portland pozzolana cement, Fly ash, Steel fibre, Compressive strength, Split tensile strength.**

I. Introduction

The quantity of fly ash produced from thermal power plants in India is approximately 80 million tons each year. During the last few years, some cement companies have started using fly ash in manufacturing cement, known as 'Portland pozzolana cement'

The use of fly ash in concrete is found to affect strength characteristics adversely at early age. One of the ways to compensate for the early-age strength loss associated with the usage of fly ash is by incorporating fibres, which have been proved very efficient in enhancing the strength characteristics of concrete [1]. The addition of fibres to concrete considerably improves its structural characteristics such as static flexural strength, impact strength, tensile strength, ductility and flexural toughness [2]. For long term, strength and toughness and high stress resistance, steel fibre reinforced concrete (SFRC) is increasingly being used in structures such as flooring, housing, precast, tunnelling, heavy duty pavement and mining. Generally, aspect ratios of steel fibres used in concrete mix are varied between 50 and 100. The most suitable volume fraction values for concrete mixes are between 0.5% and 2.5% by volume of concrete [3]. In general, the character and performance of fiber reinforced concrete changes with varying concrete formulation as well as the fiber material type, fiber geometry, fiber distribution, fiber orientation and fiber concentration [4].

Although, there were numerous studies carried out on the influence of fiber addition in concrete mixture on mechanical and durability properties of concrete limited research work has been carried out concerning the influence of fibre addition in concrete with pozzolans.

Topcu and Canbaz [5] studied the effect of steel and polypropylene fibres on the mechanical properties of concrete containing fly ash. According to the results of the study, addition of fibres provide better performance for the concrete, while fly ash in the mixture may adjust the workability and strength-loss caused by fibres, and improve strength gain.

Qian and Stroeven [6] investigated the optimization of fibre size, fibre content, and fly ash content in hybrid polypropylene-steel fibre concrete with low fibre content based on general mechanical properties. The results show that a certain content of fine particles such as those found in fly ash is necessary to evenly disperse fibres. Gutierrez et al. [7] studied the effects of the pozzolans on the performance of fibre reinforced mortars. They reported that in general, pozzolanic materials, especially silica fume and metakaolin, improve the mechanical performance and the durability of fibre-reinforced materials. The fly ash addition had a low performance, which was attributed to its low degree of pozzolanicity.

An area that has not been extensively examined previously is the effect of steel fibre additions on the mechanical properties of partial replaced of fly ash on PPC concrete.

The purpose of this research is to study the effects of steel fibres on compressive strength, and splitting tensile strength of partial replaced of fly ash with Portland pozzolana cement (PPC).

II. Experimental Program

A. Materials

1) Cement:

Portland Pozzolana Cement (PPC) (Fly ash based) of Birla Gold brand (Maihar cement) obtained from a single batches throughout the investigation was used for all concrete mixes. The cement satisfies the requirements of IS 1489 (Part 1) [8]. The physical properties of PPC as determined are shown in Table 1.

Table 1: Physical properties of cement (As provided by manufacturer).

S. No.	Physical Properties	Experimental
1	Normal consistency	31.5
2	Initial setting time (min)	250
3	Final setting time (min)	315
4	Soundness of cement (autoclave %)	0.13
5	Fineness (retained on 90 µ IS sieve)	352
6	Specific Gravity	2.92
7	Compressive Strength (MPa)	
8	3 days	24
9	7 days	34
10	28 days	45.5
11	Pozzolana used (Fly ash) %	32.1

2) Fly ash:

Fly ash obtained from NTPC thermal power plant at Unchahar, Raibareli in India was used in this investigation. Fly ash was satisfied the IS: 3812 Specification [9]. Specific gravity and Blaine specific surface area were 2.30 and 268 m^2/kg, respectively. Chemical oxide composition of fly ash was given in Table 2.

Table 2: Chemical composition of fly ash (As provided by manufacturer).

Chemical composition (%)	
Silicon dioxide (SiO_2)	60.5
Aluminum oxide (Al_2O_3	22.80
Iron oxide (Fe_2O_3)	8.80
Calcium oxide (CaO)	2.38
Magnesium oxide (MgO)	0.6
Loss on ignition	1.1
Chlorides (Cl)	0.01
Sodium oxide (Na_2O)	0.1

3) Aggregate:

The Fine Aggregate used in this study was locally available river sand which was passed through IS 4.75 mm sieve. The fine aggregate was tested as per Indian standard specification IS: 383 [10]. The specific gravity and fineness modulus of fine aggregate were 2.0 and 2.268 respectively. The coarse aggregate used was locally available quarry having two different sizes; one fraction is passing through 20 mm sieve and another fraction passing through 10 mm sieve. The coarse aggregate was tested as per Indian standard specification IS: 383 [10]. The specific gravity of 20mm and 10mm aggregates are 3.08 and 2.66 respectively. The water absorption of 20 mm and 10 mm aggregates are 0.37% and 0.56% respectively. The proportion of 20 mm and 10 mm size were 60% and 40% respectively.

4) Fibres:

Crimped steel fibre was used with aspect ratio of 41.7. The steel fibre is obtained from Bakul casting company at Dewas in India. Volume fractions of steel fibres were 0.5%, 1.0% and 1.5% (i.e. 39.5, 78.5 and 117.75 kg respectively). Properties of the steel fibre are shown in Table 3.

B. Mixture composition and preparation

M20 grade of concrete was used in this investigation. The proportion of cement, fine aggregate and coarse aggregate were taken as (1: 2.08: 3.86) with water cement ratio 0.50 by weight and the quantity of cement was 380 kg/m^3. Concrete mix has been designed based on Indian Standard IS: 10262 [11]. Details of mixture for cubical and cylindrical specimens shown in Table 4(a) and 4(b) respectively.

Table 3: Properties of the steel fibre (As provided by manufacturer).

Property	Value
Density of steel fibre (kg/m^3)	7850
Length (mm)	25
Diameter (mm)	0.6
Aspect ratio (L/D)	41.7
Grade of steel fibre	I
Type of steel fibre	Carbon

In present study, the concrete mixture was prepared by hand mixing. The procedures for mixing the fibre-reinforced concrete involved the following. First, the gravel and sand were placed and dry mixed. Second, the cement and fibre were spread and dry mixed. Third, the mixing water (60%) was added and mixed for approximately 2 min. Fourth, the remaining mixing water (40%) was added and mixed. Finally, the freshly mixed fibre-reinforced concrete was cast into specimens mould and vibrated simultaneously to remove any air remained entrapped. After casting, each of the specimens was allowed to stand for 24h in laboratory before de-moulding. All the specimens were cured in water tank curing.

Table 4(a). Detail of mixture for cubical specimen.

Mix no.	FA (%)	ST (%)	FA (gm)	ST (gm)	Cement (gm)	Aggregates (gm)
A1	-	-	-	-	1425	8465.25
A2	30	0.5	427.5	129.5	997.5	8465.25
A3	30	1.0	427.5	259.1	997.5	8465.25
A4	-	1.0	-	259.1	1425	8465.25
A5	30	1.5	427.5	388.6	997.5	8465.25

Table 4(b). Detail of mixture for cylindrical specimen.

Mix no.	FA (%)	ST (%)	FA (gm)	ST (gm)	Cement (gm)	Aggregates (gm)
C1	-	-	-	-	3776.3	22431.6
C2	30	0.5	1133	343.4	2643.4	22431.6
C3	30	1.0	1133	687	2643.4	22431.6
C4	-	1.0	-	687	3776.3	22431.6
C5	30	1.5	1133	1030	2643.4	22431.6

The compression tests were performed in accordance with IS: 516 [12]. Cubes having dimensions of 100mm×100mm ×100mm have been cast in the laboratory to investigate compressive strength. All the cubical samples have been cured for 7, 28 and 56 days and they been subjected to compression test on a 200T AIMIL compression testing machine (Fig. 1).

Cylinder specimens were tested for split tensile strength according to IS: 5816 [13]. Cylinders having dimensions of 150mm dia., 150mm length have been cast in the laboratory (Fig. 2).

Fig. 1: Compressive strength test

Fig. 2: Split tensile test

III. RESULTS AND DISCUSSION

A. Compressive Strength

Compressive strength of concrete mixtures was measured at the ages of 7, 28 and 56 days and shown in Table 5. There was an increase in compressive strength of cube concrete specimens produced with steel fibres. The presence of fly ash, when compared with plain concrete, decreased the average compressive strength for 30% fly ash replacement ratio. It is observed that steel fibres did not recover the compressive strength loss of fly ash.

Table 5: Compressive strength test results at 7, 28 and 56 days age.

Mixture no.	Steel fibre (%)	Fly ash (%)	Compressive strength (Mpa)		
			7 days	28 days	56 days
A1	0	0	16.1	28.4	28.7
A2	0.5	30	10.95	19.5	19.7
A3	1.0	30	11.75	21.3	22.7
A4	1.0	-	16.77	32.53	36.87
A5	1.5	30	12.15	19.8	22.25

At all ages, compared to plain concrete, there was reduction in compressive strength of cube concrete specimens produced with steel fibres and 30% of fly ash (Fig. 3). The presence of fly ash, when compared with plain concrete, decreased the average compressive strength. It is evident from (Fig. 3) that the compressive strength of steel fibre fly ash concrete continued to decrease with the age.

The compressive strength increases up to 28.5% with 1.5% of steel fibres and without of fly ash (Fig. 3).

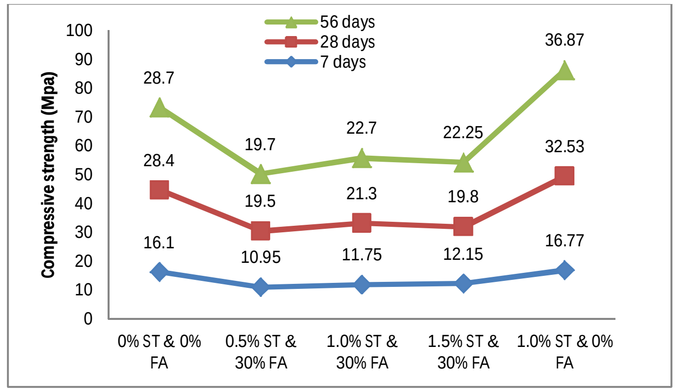

Fig. 3: Effect of steel fibre and fly ash on compressive strength at different ages.

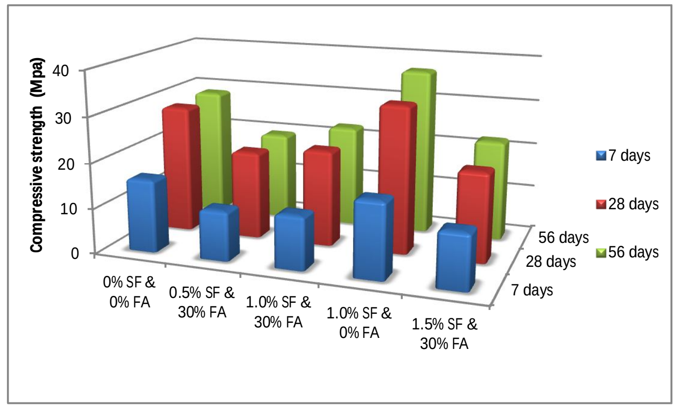

Fig. 4: Variation of compressive strength at different ages.

B. Splitting Tensile Strength

Split tensile strength of concrete mixtures was measured at the ages of 7, 28 and 56 days and shown in Table 6. The results show that in general, there is an increase in splitting tensile strength of cylinder concrete specimens with the addition of fibres to the concrete at 28 days age.

Table 6: Split tensile strength test results at 7, 28 and 56 days age

Mixture no.	Steel fibre (%)	Fly ash (%)	Split tensile strength (Mpa)		
			7 days	28 days	56 days
C1	0	0	1.1638	2.746	2.9713
C2	0.5	30	0.6231	1.7122	2.3365
C3	1.0	30	0.8965	1.668	2.905
C4	1.0	-	1.4785	3.0715	3.229
C5	1.5	30	0.936	1.685	2.4175

The presence of fly ash, when compared with plain concrete, decreased the average splitting tensile strength for 30% fly ash replacement ratio. At all ages, compared to plain concrete, there was reduction in splitting tensile strength of cylinder concrete specimens produced with steel fibres and 30% of fly ash (Fig. 5). It is evident from (Fig. 5) that the splitting tensile strength of steel fibre fly ash concrete continued to decrease with the age. The split tensile strength, compared with plain concrete, increases up to 11.85% with 1.0% of steel fibres and (0%) of fly ash at 28 days age (Fig. 5).

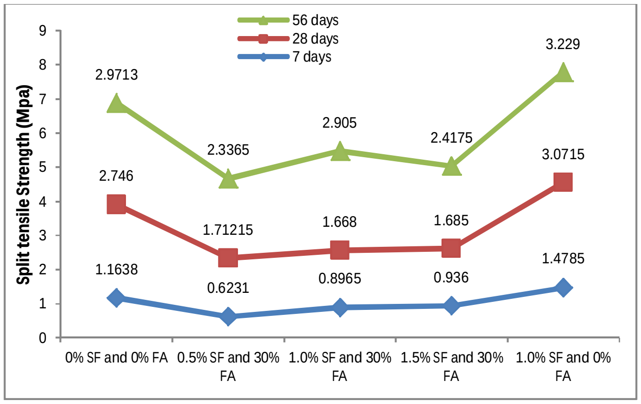

Fig. 5: Effect of steel fibre and fly ash on splitting tensile strength at different ages.

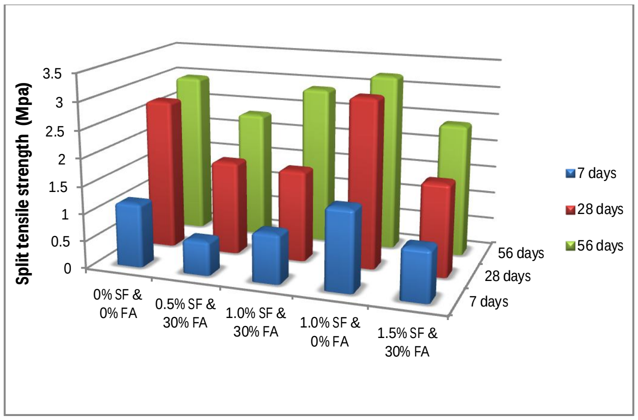

Fig. 6: Variation of splitting tensile strength at different ages.

IV. Conclusions

After investigation of obtained results of this study, following conclusions are derived.

1. Compressive strength and split tensile strength of portland pozzolana cement replaced fly ash concrete specimens were less than the plain concrete (control mix) specimens at all the ages.
2. Compressive strength and split tensile strength of cement replaced fly ash concrete specimens continued to decrease with the age.
3. At all the ages, the minimum reduction in compressive strength was 21% at 56 days age with 30% replaced fly ash and 1.0% steel fibres. While the maximum reduction was 31.4% with 30% replaced fly ash and 0.5% steel fibres at 28 days age.
4. At all the ages, the minimum reduction in splitting tensile strength was 2.2% at 56 days age with 30% replaced fly ash and 1.0% steel fibres. While the maximum reduction was 39% with 30% replaced fly ash and 1.0% steel fibres at 28 days age.
5.
6. Fibre inclusion increased compressive strength and split tensile strength of PPC concrete without fly ash.
7. Steel fibres significantly affect both splitting and compressive characteristic of PPC concrete. But, the effects on splitting characteristic are rather different from those on compressive behavior. Steel fibres significantly increase the compressive strength (up to about 28.5%) but they have much smaller effect on increasing the splitting tensile strength (up to about 11.85%).
8. Incorporation of steel fibres improved the splitting tensile strength of PPC concrete (up to 11.85%). the magnitude of strength improvement due to the incorporation of fibres is less than that in compressive strength (up to about 28.5%).
9. The addition of steel fibres into concrete mixtures significantly improved their bond strength. Increase in bond strength for all concrete mixtures has been observed as the percentage of fibres volume fraction increased.

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Notation

The following abbreviations are used in this paper:

ST = Steel fiber.

FA = Fly ash.