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Constitutive Behaviour of Flyash Concretes with Steel Fibres in Ordinary Grades

N R D Murthy, *Member*

Dr D Rama Seshu, *Non-member*

Dr M V S Rao, *Fellow*

Construction activity is increasing all over the world today. To minimise the construction cost and to increase the performance of structural concrete without losing its original properties is a big challenge before the construction industry. To some extent this can be achieved using pozolanas and fibres in concrete production. The present paper discusses the stress-strain behaviour of such flyash concrete with steel fibres in ordinary grade. M30 grade of concrete was designed using the IS mix design code 10262-1982. Cylinders were cast with conventional concrete and flyash with random steel fibres. The cement was replaced by flyash up to 40% at regular intervals of 10%. The split tensile strength of conventional concrete with 1% steel fibres and steel fibred flyash concrete were evaluated. Concrete with flyash and steel showed an improvement in ductile behaviour. This paper presents a complete stress-strain behaviour of such concretes. An empirical equation has been proposed to predict the behaviour of such concrete under compression. The static moduli of elasticity of concrete at various percentage replacements of flyash are reported. The energy absorption capacity of steel fibred flyash concretes was evaluated. The percentage of steel fibres added is kept constant at 1% and aspect ratio as 75 for all replacements of flyash. The normalised stress-strain curves were plotted and are reported. The proposed equation showed a good correlation with experimental values.

Keywords : Concrete; Flyash; Steel fibres; Stress-strain behaviour; Compressive strength

INTRODUCTION

Concrete is one of the widely used common construction material. Every year concrete consumes 13 billion tonne of raw materials[1]. This huge consumption of raw materials is creating several ecological problems. The cement industry in India has contributed immensely to the infrastructure development of the country. Currently, India is the second largest cement producer in the world. Around 116 Mt of cement is being produced every year[2]. However, the per capita cement consumption in the country is among the lowest in the world. The safe disposal of huge amounts of flyash produced as a result of burning of Indian coal is a cause of natural concern. At the sametime, the acceptance of flyash in construction industry is gaining popularity, but at very slow rate in India due to various reasons.

N R D Murthy is with the Department of Civil Engineering, Kakatiya Institute of Technology and Sciences, Warangal 506 015; Dr D Rama Seshu is with the Department of Civil Engineering, National Institute of Technology, Warangal 506 004; and Dr M V S Rao is with the Department of Civil Engineering, Jawaharlal Nehru Technological University, Hyderabad 500 072.

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Limited research work has been reported in India on flyash structural concrete[3-4]. Utilisation of flyash in concrete may solve the problem of disposal of flyash on one hand and meeting the demand of raw materials on the other hand.

During the last decade, high performance concrete has become popular. High performance concrete is not a synonym of high strength concrete, It concentrates on the other properties in addition to strength. These may be ductility, density, durability, or resistance of the concrete to some forms of attack (Papworth and Ratcliffe,1994). Therefore, a complete stress-strain curve is needed for rational design and analysis of concrete structure. Especially, concrete structures built in severe environment need durable concrete because of high construction costs and difficulty in concrete repairs. Thus, a well defined stress-strain curve is needed for design and rehabilitation.

Many authors[5-10] have carried out extensive research work on high volume flyash concretes. It is reported that the concretes with flyash shows a better performance over conventional concrete.

Tikalsky, *et al*[11], examined concretes containing both class *C* and class *F* flyashes ranging from 0% to 35%

by weight of portland cement. It is reported from studies that compressive strength and flexural strengths of flyash concretes were slightly lower at the early ages than control concrete, but exceed those of control concrete at later ages.

Fibre Reinforced Flyash Concrete

Fibre reinforced flyash concrete or cement is a relatively new composite material in which fibres are introduced in the matrix as micro reinforcement so as to improve the cracking and other properties of concrete. Steel fibres are mainly used for structural purposes, *ie*, to improve the structural performance (ductility).

High-performance fibre-reinforced concrete (HPFRC) results from the addition of either short discrete fibres or continuous long fibres to the cement based matrix. Due to the superior performance characteristics of this category of HPC, its use by the construction industry has significantly increased in the last five years.

EXPERIMENTAL INVESTIGATION

Cylindrical specimens (150 mm Φ × 300 mm long) were cast for stress-strain behaviour. The mix was designed according to IS 10262-1982. M30 grade of concrete was designed and cement was replaced by flyash at regular interval of 10% up to 40%. The percentage of steel fibres was kept constant at 1 % by weight. The aspect ratio of the steel fibres was kept as 75. The diameter of the steel fibres used in the experiment was 0.5 mm. The design mix was 1 : 1.42 : 3.90 : 0.46. The experimental programme is given in Table 1. The flyash was obtained from Vijayawada Thermal Power Station of Andhra Pradesh. The physical and chemical properties of flyash were tested and all the results were compared with IS 3812-1981 and found satisfactory. Table 2 shows the chemical properties of the flyash. The specific gravity of flyash was found to be 2.12. The fine aggregate used was locally available river sand belonging to Zone II. Specific gravity of fine aggregate was 2.62. The fineness modulus of fine aggregate was 2.8.

Table 1 Details of experimental programme

Designation	Percentage of flyash+1% steel fibres	Number of cylinder tested	Workability (compaction factor)
PL0	0	6	0.89
PL10	10	6	0.90
PL20	20	6	0.91
PL30	30	6	0.92
PL40	40	6	0.91

Table 2 Chemical composition of VTPS flyash

Criteria	Values
Specific surface, cm^2/gm	5840
Specific gravity	2.3
Silica, weight %	58.14
Alumina, weight %	28.98
Ferric oxide, weight %	4.90
Calcium oxide, weight %	5.68
Magnesium oxide, weight %	1.04
Sulphur trioxide, weight %	0.64
Loss on ignition, weight %	0.54
Insoluble residue, %	84.44

The coarse aggregate was obtained from a local crusher. The 20 mm graded size granite was used whose specific gravity was 2.6 and fineness modulus was 6.2. All the ingredients including steel fibres were mixed according to mix design. After confirming that the mix was uniform, the concrete is filled in cylindrical moulds in three layers. The compaction was done with tamping rod. The specimens were removed from the moulds demoulded after 24 h and cured under water for 28 days. The cylinders were removed from water after 28 days and the surface was dried.

Testing Procedure

The cylinders was cured under water for 28 days and tested on 1810 kN Tinus Olsen Testing Machine (TOTM). A total number of 30 specimens were cast and tested. The cured specimens were capped with a paste of plaster of paris to provide smooth loading surface.

The specimens were fitted with three compressometers, The capped specimen with compressometers attached was placed on the movable cross head of the testing machine and tested under strain rate control. The readings were taken as the average of the three-dial gauges. Strain rate control was adopted to get the complete stress-strain curve including the post ultimate descending portion. The load - deflection curves were plotted.

The stress-strain curves at various loading were developed till the load reached about 85% of the ultimate load on the descending portion. The modulus of elasticity was computed from the stress-strain curve obtained.

The area obtained under the stress-strain curve was also calculated.

Analytical Stress-strain Curve

A number of empirical equations have been proposed to represent uniaxial stress-strain behaviour of concrete (Popovics –1973), but most of them can be used for only ascending portion of the curve. In 1985 Carriera and Chu extended the empirical equation proposed by Popovics (1973) to include both ascending and descending branches of complete stress-strain curve. Recently, Hsu and Hsu proposed an empirical equation which includes the effects of steel fibres with flyash concrete.

This paper proposes an equation in the form of

$$Y = \frac{Ax}{1 + Bx^2}$$

where x is the normalised strain; Y, normalised stress; A, B, constants for ascending portion; and A^1, B^1, constants for descending portion.

The boundary conditions are

(i) The strain ratio and stress ratio at the peak of the nondimensional stress-strain curve is unity.

$$\frac{\in}{\in_u} = 1 \; ; \; \frac{f}{f_u} = 1$$

where $\in_u$ is the strain at ultimate stress; $\in$, strain at any point; f_u, ultimate stress; and f, stress at any point.

(ii) The slope of non- dimensional stress-strain curve at the peak is zero.

$$\text{at} \frac{\in}{\in_u} = 1 \; ; \frac{d(f_u)}{d\left(\frac{\in}{\in_u}\right)} = 0$$

The area under stress-strain curve is obtained using trapezoidal method.

RESULTS AND DISCUSSIONS

Tables 3-7 give the stress-strain values for the various mixes of concrete tested. Table 8 gives normalised stress-strain values obtained and Table 9 gives the summary of results. Table 10 gives the initial tangent modulus of flyash concrete.

Discussions

The area under the stress-strain curve was observed

Table 3 Stress-strain values of 0% flyash +1% steel fibres in ordinary grade concrete

Load, N	Stress, MPa	Strain
0	0	0
22.25	2.8294	0.000125
44.50	4.6588	0.000185
66.75	7.4882	0.000262
89.00	10.1576	0.000350
111.25	13.1471	0.000495
133.50	15.9765	0.000595
155.75	18.8059	0.000710
178.00	21.6353	0.00088
200.25	26.8647	0.001245
222.50	30.2942	0.001575
244.75	32.1236	0.001855
267.00	33.4100	0.002455
244.75	30.5631	0.002800
222.50	26.3256	0.003100
200.25	18.3642	0.003500

Table 4 Stress-strain values of 10% flyash +1% steel fibres in ordinary grade concrete

Load, N	Stress, MPa	Strain
0	0	0
22.25	1.8294	0.000050
44.50	3.8800	0.000115
66.75	5.4882	0.000160
89.00	8.1576	0.000255
111.25	11.1471	0.000390
133.50	13.1765	0.000465
155.75	15.8059	0.000575
178.00	17.8530	0.000695
200.25	21.8647	0.000982
222.50	28.2942	0.001465
244.75	32.1236	0.001870
267.00	34.836	0.002290
275.90	35.4200	0.002690
244.75	32.3256	0.003010
222.50	27.8642	0.003280
200.25	20.2361	0.003620

Table 5 Stress-strain values of 20% flyash+1% steel fibres in ordinary grade concrete

Load, N	Stress, MPa	Strain
0	0	0
22.25	3.2194	0.0000945
44.50	5.6588	0.00016
66.75	7.8820	0.000280
89.00	10.1576	0.000355
111.25	12.4710	0.000455
133.50	14.7650	0.000580
155.75	19.6590	0.000840
178.00	22.6353	0.000995
200.25	25.8647	0.001220
222.50	31.1420	0.001600
244.75	33.6360	0.001850
267.00	36.6360	0.002210
289.25	38.1200	0.002730
267.00	34.3256	0.003100
241.75	29.8642	0.003400
222.50	22.2361	0.003730

Table 6 Stress-strain values of 30% flyash +1% steel fibres in ordinary grade concrete

Load, N	Stress, MPa	Strain
0	0	0
22.25	3.5940	0.000110
44.50	5.5800	0.000180
66.75	9.4820	0.000315
89.00	12.7600	0.000453
111.25	15.9710	0.000585
133.50	17.9650	0.000675
155.75	19.8590	0.000750
178 00	24.6350	0.000980
200.25	31.2640	0.001350
222.50	35.6420	0.001650
244.75	38.9860	0.001950
267.00	40.9000	0.002350
244.75	32.5540	0.002850
222.50	23.3256	0.003240
200.25	13.8620	0.003620

Table 7 Stress-strain values of 40% flyash+1% steel fibres in ordinary grade concrete

Load, N	Stress, MPa	Strain
0	0	0
22.25	4.294	0.000140
44.50	7.858	0.000287
66.75	10.582	0.000405
89.00	13.576	0.000550
111.25	16.171	0.000678
133.50	19.465	0.000860
155.70	23.359	0.001085
178.00	28.335	0.001390
200.25	32.474	0.001680
222.50	35.394	0.001910
245.75	37.500	0.002280
222.50	32.624	0.002610
200.25	25.554	0.002920
178.00	16.3256	0.003300

increasing up to 10 % replacement of cement by flyash, indicating the energy absorption capacity of the specimen. Even at 30 % replacement of cement by flyash the energy absorbing capacity was more than the controlled mix indicating that the toughness of the mix was more than control mix. The strain at the ultimate stress increased up to 20% replacement and then started decreasing. The strain at the ultimate stress at 40 % replacement of cement by flyash was comparable with control mix. Even at 40 % replacement of cement by flyash the ultimate stress was more than the control mix. The workabilities for various percentages of flyash concretes are given in the Table 1.

An empirical equation has been proposed to study the stress-strain behaviour of flyash concrete in the form of

$Y = \dfrac{Ax}{1 + Bx^2}$. The same empirical is valid for descending portion of the curve with modified values of constants, *ie*, A^1, B^1. The proposed empirical equation also studies the effects of flyash in concrete and can be found useful in designing modern flyash concrete structures. Once, the ultimate strength and concrete strain are known only two parameters are needed to study the ascending and descending behaviour of concrete. The proposed equation has shown a good correlation with experimental values.

Table 8 Summary of results

Designation	Cement content, kg/m^3	Flyash, kg/m^3	Fine aggregate, kg/m^3	1% steel fibres, g	Coarse aggregate, kg/m^3	Water/ cementious ratio	Ultimate stress	Strain at ultimate stress	Area under stress-strain curve
PL0 1	425.0	0	603.5	415	1657.5	0.46	33.41	0.0024	0.6064
PL0 2	425.0	0	603.5	415	1657.5	0.46	33.41	0.0024	0.6064
PL0 3	425.0	0	603.5	415	1657.5	0.46	33.41	0.0024	0.6064
PL10 1	382.5	42.5	603.5	415	1657.5	0.46	35.42	0.0026	0.6832
PL10 2	382.5	42.5	603.5	415	1657.5	0.46	35.42	0.0026	0.6832
PL10 3	382.5	42.5	603.5	415	1657.5	0.46	35.42	0.0026	0.6832
PL20 1	340.0	85.0	603.5	415	1657.5	0.46	38.12	0.0027	0.6600
PL20 2	340.0	85.0	603.5	415	1657.5	0.46	38.12	0.0027	0.6600
PL20 3	340.0	85.0	603.5	415	1657.5	0.46	38.12	0.0027	0.6600
PL30 1	297.5	127.5	603.5	415	1657.5	0.46	40.90	0.0023	0.6290
PL30 2	297.5	127.5	603.5	415	1657.5	0.46	40.90	0.0023	0.6290
PL30 3	297.5	127.5	603.5	415	1657.5	0.46	40.90	0.0023	0.6290
PL40 1	255.0	170.0	603.5	415	1657.5	0.46	37.50	0.0022	0.6070
PL40 2	255.0	170.0	603.5	415	1657.5	0.46	37.50	0.0022	0.6070
PL40 3	255.0	170.0	603.5	415	1657.5	0.46	37.50	0.0022	0.6070

Table 9 Normalised stress-strain values of flyash + 1% steel fibres in ordinary grade concrete

Normalised strain, σL_{max}	$\in / \in_u$				
	σL_0	σL_{10}	σL_{20}	σL_{30}	σL_{40}
0.1	0.2185	0.2369	0.2030	0.1760	0.1691
0.2	0.3992	0.4270	0.3808	0.3227	0.3121
0.3	0.5827	0.5510	0.5077	0.4577	0.4422
0.4	0.6964	0.6612	0.6397	0.5867	0.5463
0.5	0.8042	0.7714	0.7362	0.6894	0.6504
0.6	0.8887	0.8403	0.8631	0.7775	0.7544
0.7	0.9470	0.9147	0.9088	0.8655	0.8351
0.8	0.9790	0.9643	0.9773	0.9330	0.9287
0.9	0.9907	0.9973	0.9951	0.9828	0.9886
1.0	1.0000	1.0000	1.0000	1.0000	1.0000
1.1	0.947	0.9588	0.9393	0.9447	0.9125
1.2	0.8741	0.8155	0.8504	0.8508	0.7984
1.3	0.7284	0.6612	0.6981	0.7100	0.7700

Table 10 Initial tangent modulus of flyash concrete

Specimen	Initial tangent modulus, × 10^5, N/mm^2	Splitting tensile strength, N/mm^2
PL0	0.265	4.67
PL10	0.330	5.09
PL20	0.396	5.37
PL20	0.369	4.24
PL30	0.330	3.96

CONCLUSIONS

Simple empirical equation here is proposed to depict the complete stress-strain behaviour of steel fibred flyash concrete under compression. The equation is valid for ordinary grade of concrete (M30 grade).

- With increase in the replacement of cement by flyash the workability increases up to 30%, but at 40% replacement, the workability has decreased.

- The splitting tensile strength of concrete increased up to 20% replacement of cement by flyash.

◆ Even at 40% replacement of cement by flyash, workability of concrete is comparable with conventional concrete.

◆ Strain at ultimate stress has increased at 10% replacement of flyash by cement.

◆ At 30% replacement of cement by flyash the ductility was not affected.

◆ The initial tangent modulus is increasing continuously up to 20% replacement of cement by flyash. Even at 40% of cement by flyash the initial tangent modulus is more when compared with conventional concrete.

◆ The energy absorption capacity is also increasing up to 30% replacement of cement by flyash.

◆ The addition of steel fibres has contributed to the ductility of concrete.

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