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Flexural Behaviour of Reinforced Fly Ash Concrete Beams

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Abstract . This paper deals with an experimental study on the properties of concrete containing fly ash .The flexural behaviour of fly ash concrete beams with and without reinforcement was conducted in this study. The addition of fly ash content used was 10% and 20% of mass basis. All beams had the same dimensions tested under two point load. The experiment results showed that addition of fly ash into Portland cement improves the tensile strength and improves the cracking behaviour in terms of significant increase in first crack load and the formation of large number of finer cracks. However, only marginal improvement was observed in the case of ultimate load.

Keywords: Fly ash concrete, Reinforced concrete beams, Plain concrete beams, Flexural strength, Crack

1 Introduction

Fly ash is the fine powder produced as a product from the combustion of pulverized coal. The disposal of fly ash is one of the major issues as dumping of fly ash as a waste material may cause severe environmental problems. Therefore, the utilization of fly ash as an admixture in concrete instead of dumping it as a waste material can have great beneficial effects of lowering the water demand of concrete for similar workability, reduced bleeding and lowering evolution of heat. The use of fly ash in concrete is found to affect strength characteristics adversely. Arivalagan et al (2009) studied an experiments for fly ash concrete beams in filled with SHS beams, from this concluded that adding of flyash increase the moment carrying capacity. The experiments conducted by the composition and properties of HVFA concrete is adapted from Malhotra and Mehta's book on HVFA concrete (2002). From theoretical considerations and practical experience the authors have determined that, with 50% or more cement replacement by fly ash, it is possible to produce sustainable, high-performance concrete mixtures that show high workability, high ultimate strength, and high durability. Crouch et al(2007) studied on high volume fly ash concrete, from this study they concluded that HVFA mixtures would be ideal for warm weather placements when compared with ordinary concrete. Also HVFA exhibits comparable costs, increased compressive strength and enhanced durability properties. Falah M.Wegian et al(2011) aim of this study was to measure compressive and tensile strengths of concrete with different steel fibre and fly ash percentages. Concrete specimens with fibre contents of 0.50, 1.0 and 1.50% by volume were tested. Fly ash contents in mixes ranged between 0 and 30% by weight.Steel fibre and fly ash are common cement additives that can improve concrete performance. Swamy et al(1984) tests are reported on the flexural behaviour of reinforced concrete beams made with fly ash coarse aggregates and sand. The results show that fly ash aggregate concrete beams can satisfy the serviceability requirements of deflection and cracking, and that they possess adequate ductility and load factor against flexural failure. Also it is shown that fly ash aggregate concrete beams can give satisfactory structural performance according to British and American Codes. Bressan et al (2004) Present work investigates the replacement of 10% in mass of cement with fly ash in the concrete mixture. The mechanical properties as compressive strength, flexural strength and fracture toughness are experimentally determined for this concrete composition. From the experimental results shown in the present work it is possible to add class F fly ash to concrete. Fracture in concrete is due to rupture of the interface paste and aggregate, and the presence of pores.

2 Experimental Program

2.1 Materials

2.1.1 Cement

Locally available ordinary Portland Cement (OPC) 43 Grade was used in the present investigation. This Cement satisfied nearly all the requirements of the IS 8112 and IS 1489. The different properties of the Cement tested in the laboratory are listed in Table 1.

Table 1: Properties of Cement

Type	Standard Consistency	Specific gravity	Initial setting time in minutes	Final setting time in minutes	Compressive strength of (1:3) standard cement sand mixture
OPC	32.5%	3.02	72	340	28 days=29.7 Mpa

2.1.2 Fine and Coarse aggregates

Locally available river sand was used as Fine Aggregate. Sieve Analysis of the fine aggregate was carried out in the laboratory as per IS 383 and tested as per IS 2386 as shown in Table 2. Locally available crushed coarse aggregate was used. Sieve Analysis of the coarse aggregate was carried out in the laboratory as per IS 383 and tested as per IS2386 as shown in Table 2.

Table 2: Physical properties of Fine and Coarse Aggregate

Sl.No	Property	Value
Fine aggregate		
1	Fineness	2
2	Specific gravity (loose)	2.68
3	Density (kN/m^2)	16.9
4	Density/Compacted (kN/m^2)	18.4
Coarse aggregate		
1	Fineness Modulus	7.8
2	Unit weight (loose state) (kN/m^2)	16.8
3	Unit weight (dense state) (kN/m^2)	19.0

Table 3: Physical and Chemical properties of Fly ash

Physical Properties		
Sl.No	Characteristics	Properties
1	Colour	Whitish grey to grey with slight black
2	Bulk density, kg/m^2	1490
3	Specific gravity	2.3
4	Fineness, cm^2/gm	3200
Chemical Properties		
Sl.No	Characteristics	Properties
1	Silica(SiO_2}	45 to 89%
2	Alumina ($Al_2 O_2$)	23 to 33%
3	Feric Oxide ($Fe_2 O_3$)	0.6 to 0.4%
4	Titanium(Ti O_2)	0.5 to 16
5	Calcium Oxide(CaO)	5 to 16%
6	Magnesia(MgO)	1.5 to 5%
7	Sulphuric Anhydride as SO_3	2.5%
8	Loss of ignition	1.0 to 2.0%

2.1.3 Water

According to IS 3025, water to be used for mixing and curing should be free from injurious or deleterious materials. Potable water is generally considered satisfactory. In the present investigation, tap water was used for both mixing and curing purposes.

2.1.4 Fly Ash

Fly ash used in the experiments is taken from Ennore Thermal Plant, Chennai, Tamil Nadu. Physical properties are checked in laboratory and the chemical properties are reported here for ready reference as obtained from Thermal Plant. The physical and chemical properties of fly ash are given in Table 3.

2.1.5 Mixing and preparation of beams

A conventional rotary concrete mixer was used. The dry coarse aggregate, cement and sand were first mixed for about one minute before adding half of the mixing water. The fly ash was added slowly to the running mixer, after three minutes, to avoid clumping. Mixing was continued for another two minutes to achieve uniform distribution of mix.
The nominal water to cement ratio was 0.50.Workability of the fresh concrete was assessed using the slump test according to IS 10262-1982. After casting, the concrete was compacted using a vibrating table. From each mix, a beam section was cast in addition to three 150-mm cubes and two150dia, 300mm height cylinders for compressive and split tensile strength. The results of tested specimens are shown in Table 4.The beams and the cubes were cured in a room temperature environmental humidity until testing at 30 days.

2.2 Test procedure and measurements

The size of the test beams are 900mm length, 150mm breath and 150mm depth. The test beams were total length of 900 mm and an effective span length of 800 mm between supports. The dimensions details for the test beams are shown in Figure 1, and testing arrangements are shown in Figure 2. All beams were same dimensions and longitudinal reinforcement, loaded by two point load up to failure using a 400 kN UTM (Universal Testing Machine).The initiation of the cracks was detected using a magnifying lenses. Deflection of the beams during test at the mid-span and under the concentrated loads was measured using deflectometers.

Table 4: Properties of Test Beams

Beam Specimen	f_{ck} (Mpa)	Ast	f_y (Mpa)	Asc	f_{yc} (Mpa)	Stirrups	Percentage Fly ash
FAC-1	30.0	----	415	----	370	----	10
FAC-2	30.0	---		---		----	20
RCC-1	28.0	2T10		2T8		1φ8/180mm	---
RCC-2	28.0	2T10		2T8		1φ8/180mm	---
FARC-1	30.0	2T10		2T8		1φ8/180mm	10
FARC-2	30.0	2T10		2T8		1φ8/180mm	20

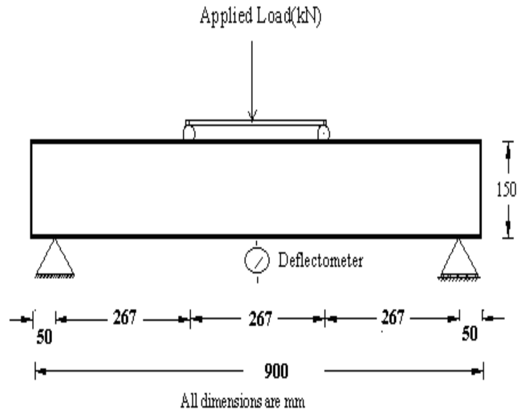

Figure 1: Details of test beams

Figure 2: Experimental set up

3 Results and Discussion:

3.1 Ultimate flexural and Cracking strength

Fly ash reinforced concrete beams fails in flexure remaining beams failed in shear. While in the case of beams with reinforcement, the addition of fly ash slightly increased its ultimate flexural strength. However, the FARC increased the shear strength and changed the failure pattern of the beam.

Actual cracking moment for the tested beams as shown in Table 5. The presence of the Fly ash slightly reduced the flexural cracking resistance, this was observed in case of beams with or without reinforcement. This is because the volume ratio of Fly ash reduced the mix workability and a higher water/cement ratio was required to obtain the required workability, which results in lower concrete strength, and hence, lower flexural tensile strength.

Table 5: Cracking, Yield & Ultimate Moments of Tested Beams

Beam Specimen	M_{cr}(kN m)	M_y(kN m)	M_{ult} (kN m)	Mode of Failure
FAC-1	1.90	3.35	4.50	Shear
FAC-2	1.85	3.40	4.65	Shear
RCC-1	1.75	3.35	5.00	Shear
RCC-2	1.92	3.50	5.20	Flexure
FARC-1	1.95	3.77	5.10	Flexure
FARC-2	1.98	3.80	5.15	Flexure

3.2 Load-deflection behaviour

Table 6 shows the deflection of the tested beams at the mid span at different load stages. In Reinforced concrete Beams (without fly ash-RCC1 and RCC2) show higher flexural rigidity before cracking. After cracking, its rigidity dropped to about 57% relative to that before cracking, due to the rapid progress of cracks through the section height. For FAC beams, the slope of load-deflection relation in the uncracked stage was less than that of RCC beam. However, after cracking the drop was smaller than that of RCC beams.As shown in Figure 3 the relation between load-deflection of beams without reinforcement(FAC1 and FAC2) show two stages, and while the failure of both beams were due to shear, the deflection at ultimate of beam FARC2 was higher than that of RCC1 and RCC2 (about 14% higher). This gave an adequate warning before failure. In case of beams with reinforcement, the relation between load and deflection shows three stages (Figure 3). Before cracking the difference between the load-deflection relation was negligible. At yield, beam FARC2 had the least deflection while at ultimate it had the maximum deflection among the tested beams.

Table 6: Deflection at Different Load Levels

Beam Specimen	Deflection(mm)			Max. Crack Width(mm)
	Cracking	Yield	Ultimate	
FAC-1	1.0	6.0	9.00	3.75
FAC-2	2.0	4.0	7.00	4.10
RCC-1	2.5	3.0	6.75	3.10
RCC-2	2.5	2.5	7.00	3.25
FARC-1	2.7	3.0	7.50	3.00
FARC-2	2.0	2.0	8.00	2.30

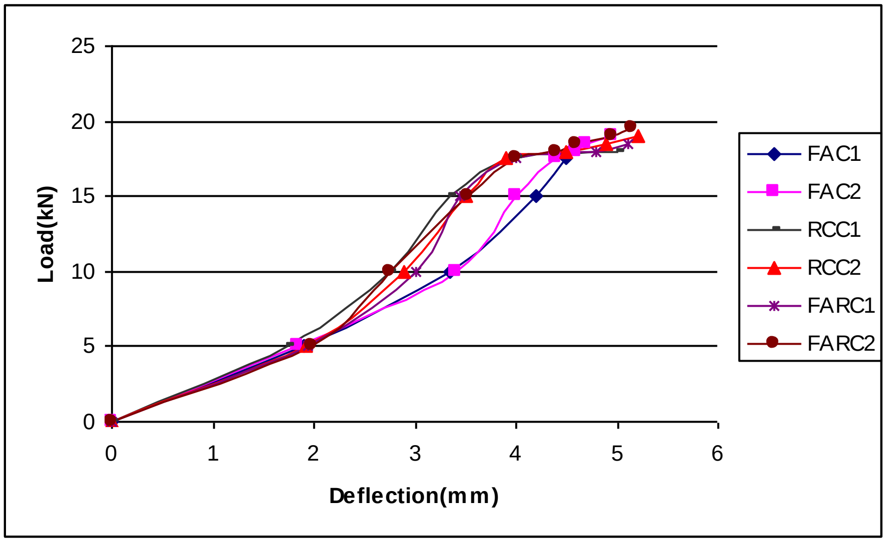

Figure 3: Relation between Load and Deflection of Beams

3.3 Flexural Ductility and Stiffness behaviour

The term ductility is defined as the ability of the material/member to sustain deformation beyond the elastic limit while maintaining the reasonable load carrying capacity until total failure. In reinforced concrete beam the deformation most suited for measurement of ductility is the curvature of the beam. As an alternative the deflection of the beams which is generally easier to measure, is used. When evaluating ductility, the most important parameter to be considered is the maximum deformation that the member can sustain prior to failure. The ductility factor can be expressed in dimensionless term "μ", as defined below .The μ values given in Table 7

$$\mu = \frac{\Delta u}{\Delta y} \quad \text{------------------ (1)}$$

Where
Δu is the maximum deformation at failure
and
Δy is the deformation when material or member yields.

Table 7: Ductility factor

Sl.No	Beam	Yield deflection	Ultimate deflection	Ductility factor

	Specimen	Δy	Δu	μ= Δu/ Δy
1	FAC-1	3.40	4.50	0.76
2	FAC-2	4.44	4.95	0.90
3	RCC-1	4.00	5.15	1.29
4	RCC-2	3.90	5.20	1.33
5	FARC-1	3.53	5.10	1.44
6	FARC-2	3.44	5.15	1.50

The gradient of the load-deflection relationship is an indication of beam stiffness. It may be seen in Figure 3 that prior to cracking, the stiffness of the beams remained practically the same for the entire set of parameters and their ranges considered in this study. FARC beam, demonstrated slightly smaller post-cracking stiffness than the corresponding FAC beam. The post cracking stiffness has been found to decreases in FAC beam specimens and with an increase in the amount of tension reinforcement with FARC. The effect of the amount of compression reinforcement or the spacing of stirrups in the flexural zone has practically no influence on beam stiffness. The maximum (mid span) deflection,(δs) obtained experimentally at the assumed service load, are presented in Table 7. It ranges from about 4.50 mm to about 5.20.

4 Conclusions

To study the effect of Fly ash reinforced concrete beams with or without reinforcement, six full scale beams with the same dimensions were loaded up to failure. Based on the test results the following conclusions were obtained:

1.Fly ash replacement (up to 20%) in concrete has shown good improvement in flexural strength.
2. The crack width under service load was within the permissible limit as per IS 456:2000.
3. Load deflection study gave similar post crack behaviour in comparison to Control beams (RCC beams).
4. Displacement ductility vales are found to increase in case of FlyAsh concrete beams.
5. While the inclusion of Fly ash had a minor effect on the beam stiffness.

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Notation

Ast = Area of tensile steel
Asc = Area of compressive steel
fy = yield strength of tensile steel
fyc = yield strength of compression steel
FAC = Fly Ash concrete
RCC = Reinforced Cement Concrete
FARC = Fly Ash Reinforced cement concrete

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