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Flexural behavior of Reinforced Fly Ash Concrete in Comparison to Reinforced Normal Concrete beams in Terms of Cracking Load and Ultimate Load Carrying Capacity

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Abstract— ***Fly ash or pulverized fuel ash is the residue of the combustion of finely ground coal used in thermal power plants. It is removed by the dust collection system as fine particle residue from the flue gases before they are discharged into the atmosphere. Use of Fly ash in concrete will not only solve the problem of disposal, but will also reduce the consumption of cement, which is a material whose production is energy intensive. Fly ash concrete has found extensive application in mass concrete, pre-cast concrete, concrete used for pavements, structural concrete and roller compacted concrete with the added advantages of increased workability, impermeability, resistance to chemical attack and increased durability in comparison to ordinary Portland cement concrete. Hence, this paper present the investigation of comparison between the flexural behavior of reinforced Fly ash concrete beams with that of reinforced normal concrete beams and increase the confidence levels of designers and other beneficiaries in using reinforced Fly ash concrete as a structural material. The flexural behavior of reinforced Fly ash concrete beams with different cement replacement levels (20%, 35% and 50%) are compared with reinforced normal concrete beams (without containing Fly ash) under similar conditions. All the beams are reinforced as balanced sections, cured and tested at 28 days. These investigations were conducted with three grades of concrete i.e. M30, M40 and M50. The flexural behaviour of these beams is discussed in terms of its cracking load and ultimate load carrying capacity.***

Index Terms— ***Fly ash, cement replacement material, concrete beams, flexural behavior of reinforced Fly ash concrete, cracking load capacity and ultimate load capacity.***

I. INTRODUCTION

Fly ash is defined as finely divided residue that results from the combustion of ground and powdered coal that is transported by flue gases. The word “Fly ash” is commonly used as generic terminology for the by-product due to burning of coal in the boiler of a thermal power plant. The generic terminology for such a by-product, as per IS: 3812-2003 is pulverized fuel ash [2]. It is defined as ash generated by burning of ground or pulverized or crushed coal or lignite in boilers. Pulverized fuel ash can be Fly ash, pond ash extracted from the flue gases by any suitable process such as by cyclone separation or electrostatic precipitation [9].

During the combustion of pulverized coal in suspension fixed furnaces of thermal power plants, the volatile matter is vaporized and the majority of carbon is burnt off. The mineral matter associated with coal such as clay, quartz and feldspar disintegrate to varying degree. The disintegrated particles and un-burnt carbon are collected as ash. The coarse particles fall in the bottom of the furnace and are collected as boiler ash or boiler slag. The finer particles that escape with the flue gases are collected as Fly ash using cyclone separators and electrostatic precipitators. Depending on the collection system and fabric filters about 85% to 98% of the ash from the flue gases is retrieved in the form of Fly ash. Fly ash accounts for 76% to 86% of the total coal and remainder is collected as bottom ash [3,4]. Thus, it is important to recognize that all ash is not Fly ash. Fly ash generated in coal burning plants is a variable material due to several factors. Among these, the type and mineralogical composition of coal, degree of coal pulverization, type of furnace, oxidation conditions, manner of Fly ash collection, handling and storing before use are important. Fly ashes from various power plants are likely to be different, since no two plants may have all factors in common. The physical and mineralogical compositions of Fly ashes are highly variable but these by themselves should not hinder the efficient and effective use of Fly ash in concrete. It is the abundant availability virtually all over India, of vast amounts of Fly ash as an industrial by-product that has refocused and rekindled interests of engineers on the material and structural implication of incorporating it as essential cementitious component of concrete. Fly ash is an excellent cement replacement material, either for blending during manufacturing of cement or as a separate addition at the batching plant during the manufacture of concrete at site or at ready mixed concrete facility. IS: 456-2000 specifies that “Fly ash conforming to Grade I of IS: 3812-2003 may be used as part replacement of Portland cement provided uniform blending with cement is ensured” [2].The 85 thermal power stations in India generate a huge quantity of Fly ash every year (140 million tonnes per year) as a by-product almost matching the annual production of cement. Now it is universally recognized that with the limited reserves of oil and gas and the questions of reliability and safety of nuclear power plants, coal will be the major source of fuel for the generation of electricity for some more decades.

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The dumping of Fly ash in open fields results in ecological and environmental problems. In such a situation, three factors – environmental protection, energy savings and the inherent advantages arising from the use of Fly ash demand that the construction industry examine closely the implication of the incorporation of Fly ash in concrete construction [5]. Thus, there is worldwide interest in Fly ash utilization in concrete and this is reflected in the development currently taking place in the concrete industry.

II. Flexural Behavior of Reinforced Fly Ash Concrete Beams For Different CRLs

Tests were conducted on twelve beams of rectangular cross section (150 x 250 mm and length 2550 mm), out of which nine beams were of reinforced Fly ash concrete (RFAC) and three beams were of reinforced normal concrete (RNC). To understand the flexural behavior of RFAC beams, three CRLs by Fly ash namely 20%, 35% and 50% were considered and compared with RNC beams (without Fly ash). Three grades of concrete M30, M40 and M50 were also considered, such that the 28 days cube compressive strength of both Fly ash concrete and normal concrete are same. All the beams were reinforced as balanced sections. The details of the beams tested are given in Table 1 and 2. All the beams are tested under pure bending over middle third region loads were applied incrementally up to failure and at each increment of load, deflections at center of the beam and under load points.

Table 1: Beam Designation and test details

Sl. No.	Grade	Beam notation	% CRL by Fly ash	% Tensile reinforcement	Reinforcement provided	Age at testing, days	Standard Age, days
1	M30	FC-3A-28	20	1.24	2 - 16 #	58	28
2		FC-3B-28	35	1.24	2 - 16 #	59	28
3		FC-3C-28	50	1.24	2 - 16 #	61	28
4		NC-30-28	0	1.24	2 - 16 #	60	28
5	M40	FC-4A-28	20	1.582	2 - 16 # & 1 - 12 #	28	28
6		FC-4B-28	35	1.582	2 – 16 # & 1 - 12 #	28	28
7		FC-4C-28	50	1.582	2 – 16 # & 1 - 12 #	28	28
8		NC-40-28	0	1.582	2 - 16 # & 1 - 12 #	28	28
9	M50	FC-5A-28	20	1.948	2 - 20 #	28	28
10		FC-5B-28	35	1.948	2 - 20 #	28	28
11		FC-5C-28	50	1.948	2 - 20 #	28	28
12		NC-50-28	0	1.948	2 - 20 #	28	28

The test observations and results are presented in the form of tables.

In the above, the notations used to represent each beam are as follows:

NC - Normal concrete FC - Fly ash concrete A - 20% CRL B - 35% CRL C - 50% CRL 30 & 3 – M30 Grade of concrete 40 & 4 – M40 Grade of concrete 50 & 5 – M50 Grade of concrete

Cross section of beam 150 mm X 250mm, clear cover to reinforcement 25mm

Table 2: Details of RFAC and RNC beams considered

Beam notation	Compressive strength, MPa	Normalization Factor	
		For load	For deflection
FC-3A-28	34.85*	1.160	1.077
FC-3B-28	33.74*	1.120	1.060
FC-3C-28	34.78*	1.159	1.070
NC-30-28	35.00*	1.160	1.080
FC-4A-28	39.28	-	-
FC-4B-28	39.60	-	-
FC-4C-28	36.05	-	-
NC-40-28	39.01	-	-
FC-5A-28	48.41	-	-
FC-5B-28	47.16	-	-
FC-5C-28	43.75	-	-
NC-50-28	49.01	-	-

Considerations

Before discussing the test results, following points are noted:

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All the beams are designed as balanced sections. Stirrups provided (8#-2legged @ 125c/c) are closer than theoretically needed to ensure safety against shear.

The measured values are subjected to the following conditions:

1. Recording of loads was done with a least count of 10.0 kN.
2. Instead of local strains, average strains over a length of 150 mm were measured using a Demec gauge.

3. The theoretical calculations are in accordance with IS: 456-2000. Other equations as per references mentioned are utilized whenever required.
4. Wherever age of testing are higher than standard age (only in case of M30), the recorded values of load and deformations are normalized using appropriate normalization factors.
5. Discussion is mainly carried out at two load levels, service load and ultimate load, wherever necessary cracking loads are also considered.

Flexural behavior of RFAC beams with 20%, 35% and 50% replacement of cement by Fly ash in comparison with RNC beam reinforced as balanced section cured for 28 days for three grades of concrete (M30, M40 and M50) is discussed. Discussions carried out are in terms of Cracking load and Ultimate load, which is presented in the next section.

I. Cracking Loads of RFAC and RNC Beams of M30, M40 and M50

During the flexural test the load at which the first crack appears is recorded as the experimental cracking load. Table 3 represents the experimental and theoretical cracking loads of the beams tested. Comparison of cracking loads between RFAC beams with 20%, 35% and 50% replacement of cement by Fly ash (CRL) and RNC beams both of grades M30, M40 and M50 is done in this section. Theoretical cracking loads are calculated on the basis of modulus of rupture and detailed specimen [1].

Table 3: Experimental and Theoretical Cracking and Ultimate loads (failure loads)

Beam Designation	Grade	% CRL	% Tensile Reinforcement	Exp Cracking Load kN P_{crExp}	Theo Cracking Load kN P_{crTheo}	Ratio P_{crExp}/P_{crTheo}	Exp Ultimate Load kN P_{uExp}	Theo Ultimate Load kN P_{uTheo}	Ratio P_{uExp}/P_{uTheo}
FC-3A-28	M30	20	1.24	13.92*	15.63	0.90	76.66	78.00	0.98
FC-3B-28		35	1.24	14.20*	15.36	0.93	78.62	77.45	1.02
FC-3C-28		50	1.24	13.94*	15.62	0.90	76.70	77.97	0.98
NC-30-28		0	1.24	13.87*	15.67	0.89	76.33	78.01	0.98
FC-4A-28	M40	20	1.582	20	16.60	1.19	110	97.67	1.13
FC-4B-28		35	1.582	30	16.77	1.78	110	97.87	1.12
FC-4C-28		50	1.582	20	15.93	1.25	110	95.48	1.15
NC-40-28		0	1.582	20	16.63	1.20	110	97.50	1.13
FC-5A-28	M50	20	1.948	30	18.70	1.60	130	118.54	1.09
FC-5B-28		35	1.948	30	18.54	1.61	130	118.04	1.10
FC-5C-28		50	1.948	20	17.74	1.13	120	118.46	1.04
NC-50-28		0	1.948	30	18.83	1.59	140	118.90	1.17

* - Normalized values

FC - Fly ash Reinforced Concrete beams NC - Normal Reinforced Concrete beams

Both RFAC beams and RNC beams designed as balanced section and cured for 28 days of M30 cracked at loads around 14 kN. Both RFAC and RNC beams of M40 cracked at loads of around 20 kN, while those of M50 cracked at loads around 30 kN. When cracking loads of different CRLs are compared, generally the cracking load exhibited by RFAC beams of all CRLs is found to be almost same and equal to that of RNC beams in all three grades of concrete considered with small variations for one CRL in each grade, which could be attributed to least count of loading gauge which is 10 kN.

Comparison of experimental and theoretical cracking loads of RFAC and RNC beams for all three grades of concrete shows that for all the beams tested the value of experimental first crack load is more than the respective theoretical first crack load except in RFAC and RNC beams of M30, where in the value of experimental first crack load is around 10% lesser than that of theoretical first crack load. In most of the beams tested, the ratio between experimental and theoretical cracking loads is around 1.19 and for a few beams the ratio is around 1.60 showing that theoretical values are little conservative, as they have to be.

I. Comparison Of Ultimate Loads Of RFAC Beams (With 20%, 35% And 50% Replacement Of Cement By Fly Ash) With RNC Beam Designed As Balanced Section

In the Limit State Theory of reinforced concrete, failure is defined in terms of limiting strain in concrete and steel making use of the complete stress-strain relationship and a functional failure criterion. Ultimate stage of failure is defined as the loading condition at which a section reaches its maximum capacity.

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In the present experimental programme, the functional failure to carry any more load, rather than the limiting strain values is recorded as ultimate load for each beam tested theoretical ultimate load is based on the criterion of Limit state theory [6].

Table 3 reports the experimental and theoretical ultimate loads [Pu(exp) and Pu (theo)] and ratio Pu(exp)/Pu (theo) of the beams tested for all three grades of concrete and in each grade for different CRLs and normal concrete.From Table 3 it is observed that in M30 and M40 concretes, for a particular compressive strength and reinforcement ratio, the ultimate load almost remains unaltered between RFAC beams having different CRLs and RNC beams. In M50 concrete, also the ultimate strengths of RFAC beams with different CRLs and RNC beams do not differ by more than 10% on the average. This shows that when designed for a particular grade of concrete, the inclusion of Fly ash and the extent of inclusion (up to 50%) do not significantly affect the ultimate loads. Higher the grade, higher is the ultimate load as expected.

When experimental ultimate loads are compared with theoretical loads, it is observed that except in RFAC and RNC beams of M30, where in the value of experimental ultimate loads are lesser than that of theoretical ultimate loads, in all the other beams the values of experimental ultimate loads are higher than that of theoretical ultimate loads and the ratios of Pu(exp) to Pu (theo) for RFAC and RNC beams varies from 1.19 to 1.25 and for a few beams the ratio is around 1.60 showing that the theoretical values are little conservative.

II. Conclusion

For beams with a particular compressive strength and reinforcement content, the first crack load is unaffected by CRLs in case of RFAC beams and almost remains unaltered between RFAC beams and RNC beams, mainly because both RFAC and RNC beams are designed to have the same compressive strength for a particular grade of concrete.

The ultimate loads carried by all the beams are also reported in Table 3. When cracking load as a percentage of ultimate load is calculated, it is found that the onset of cracking in RFAC and RNC beams in M30 concrete beams started at a magnitude of 18% of the ultimate load. The cracking load of RFAC and RNC beams in M40 and M50 concrete was 21% and 23% of the ultimate loads. From the experimental data obtained, it may be inferred that the onset of cracking starts at around 20% of the ultimate load in both RFAC and RNC beams of all grades of concrete. These findings are in tandem with the findings of other investigators, [7,8] also found that the first crack loads were of the order of 20% of the ultimate loads.

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