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Flexural behavior of Reinforced Fly Ash Concrete in Comparison to Reinforced Normal Concrete Beams in Terms of Ductility Index

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Abstract— ***Ductility is a measure of the ability of a material section, structural element or structural system to sustain inelastic deformation prior to collapse, without significant loss in resistance. The ductility index describes the inelastic deformation capacity of the structural member. The ductility index in case of flexural members like beam is generally defined in terms of deflection ductility, since it can be measured in test more easily. The ductility indices of RFAC beams with 20%, 35% and 50% CRLs are 0.86, 0.75 and 0.63 times the ductility index of RNC beam respectively. There is considerable difference in the ductility indices between the different CRLs considered and the values range between 1.68 to 2.30.The cracking behaviour observed for RFAC beams clearly shows that performance of RFAC beams is satisfactory when compared to RNC beams with respect to crack widths. In design, the theory applied for strength prediction of RNC beams is equally valid for RFAC beams.The experimental investigation clearly demonstrates that the there was no major difference in the strength, deformations and structural performances between the RFAC beams with different CRLs and RNC beams.***

Index Terms— ***Fly ash, cement replacement material, concrete beams, flexural behaviour of reinforced Fly ash concrete, ductility index.***

I. INTRODUCTION

The deflection ductility index is given by the ratio of deflection at ultimate load to deflection at yield load. The yield point for the beams is taken as yield of tensile reinforcement given by the strain equal to $0.87f_y / E_s$. The load corresponding to this strain is taken as the yield load. The deflection corresponding to this load is taken as the deflection at yield. The ductility index is calculated from measured values of deflection for all the beams and summarized in Tab le 1.

II. COMPARISON BETWEEN RFAC AND RNC BEAMS

The ductility indices from Table 1 shows that RFAC beams possess sufficient ductility, the ductility indices varying from 2.13 to 2.68, though these values are less than those of RNC beams. The ductility indices of RFAC beams with 20%, 35% and 50% CRL are 0.66, 0.61 and 0.55 times the ductility index of RNC beam respectively. With the increase in CRL, the ductility index decreases for RFAC beams.

For beams of M40 concrete the ductility index lies between 2.28 and 3.00. The ductility index for RNC beam is 2.78 and value is least for RFAC beam with 50% CRL (2.28). From Table 2, it can be observed that there is no significant variation in the values for ductility indices between RFAC beams and RNC beam. The ductility indices of RFAC beams with 20%, 35% and 50% CRL are 1.08, 0.93 and 0.82 times the ductility index of RNC beam respectively.

From Table 1, it can be seen that the ductility indices for M50 beams varies between 1.68 to 2.68, the ductility index being least for the RFAC beam with 50% cement replacement (1.68). In this grade of concrete also the ductility indices increase with decrease in cement replacement with Fly ash [2.30 (20%), 2.00 (35%), 1.68 (50%)]. The ductility indices of RFAC beams with 20%, 35% and 50% CRLs are 0.86, 0.75 and 0.63 times the ductility index of RNC beam respectively. There is considerable difference in the ductility indices between the different CRLs considered and the values range between 1.68 to 2.30.

Table.1: Ductility index for RFAC and RNC beams

Beam	% CRL by Fly ash	Grade	Ductility index $\mu = \Delta_U / \Delta_Y$
FC-3A-28	20	M30	2.57
FC-3B-28	35		2.36
FC-3C-28	50		2.13
NC-30-28	0		3.85
FC-4A-28	20	M40	3.0
FC-4B-28	35		2.6
FC-4C-28	50		2.28
NC-40-28	0		2.78
FC-5A-28	20	M50	2.30
FC-5B-28	35		2.00
FC-5C-28	50		1.68
NC-50-28	0		2.68

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Table 2: Test Results of Crack Spacing and Crack Width

Sl. No.	Grade	Beam Notation	Total No. of Cracks	No. of Flexural Zone Cracks	Average Crack Spacing in mm	Maximum Crack Spacing in mm	Crack width at service load in mm	Maximum Crack width in mm
1	M30	FC-3A-28	17	7	110	160	0.22	0.4
2		FC-3B-28	15	7	130	180	0.22	0.4
3		FC-3C-28	19	9	80	140	0.21	0.4
4		NC-30-28	15	7	110	170	0.19	0.3
5	M40	FC-4A-28	18	9	110	175	0.18	0.35
6		FC-4B-28	16	9	130	195	0.16	0.38
7		FC-4C-28	16	11	120	180	0.19	0.4
8		NC-40-28	19	10	105	160	0.19	0.3
9	M50	FC-5A-28	18	12	125	145	0.18	0.32
10		FC-5B-28	17	11	132	160	0.16	0.39
11		FC-5C-28	17	10	132	175	0.15	0.41
12		NC-50-28	18	10	125	140	0.16	0.30

A. Summary and Discussion:

- Referring Figure 1, wherein variations of ductility indices with CRL of M30, M40 and M50 concrete are represented it is observed that in all three grades of concrete, that though RFAC beams with different CRLs do not possess as much ductility as RNC beams, they do possess considerable ductility.
- The second inference is that with an increase in CRL, the ductility index decreases in RFAC beams.
- Referring to Figure 6.76,where in variations of ductility indices with ultimate moment between RFAC and RNC beams for M30, M40 and M50 concrete are represented, it is seen that with an increase in grade of concrete there is a decrease in ductility indices, both in case of RFAC and RNC beams. This needs to be accounted for during designs by adopting appropriate reinforcement detailing

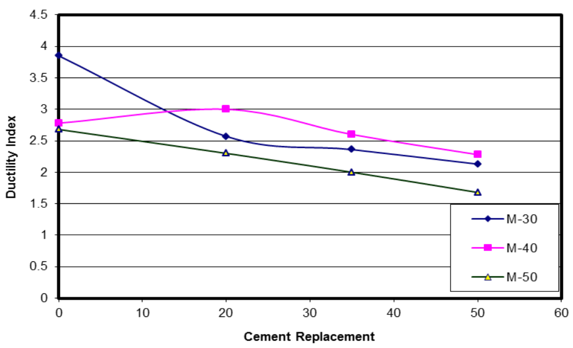

Figure 1: Variation of ductility indices with CRLs of all 3 grades of concrete.

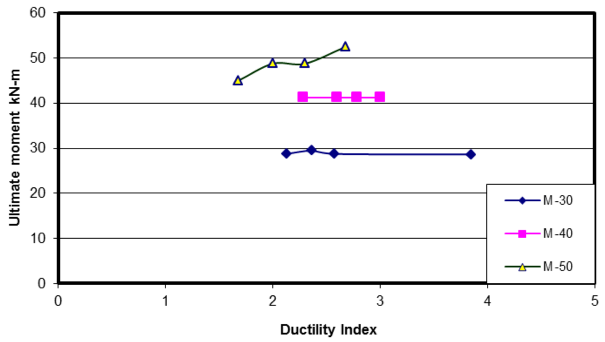

Figure 2: Variation of ductility indices with ultimate moment between RFAC and RNC beams for all three grades of concrete (all balanced section; 28 days curing period).

III. CRACK PATTERN AND MODE OF FAILURE

Plain concrete is weak in tension, though it is a versatile and strong material in compression. It cracks at an early stage of loading history when the tensile strain is of the order of 0.0002 to 0.0005. In fact the tensile reinforcement becomes effective only when the concrete cracks. Large scale cracking is not acceptable, as it is aesthetically not appreciable and also promotes moisture ingress, resulting in corrosion. Cracking is considered to be an important limit state of serviceability. Crack width is an important factor from the durability point of view. On the other hand, cracks have a major influence on structural performance including bending stiffness, energy absorption capacity, ductility and corrosion resistance of reinforcement.

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For a member exposed to aggressive environment IS: 456-2000 specifies the width of surface cracks as explained earlier.

The propagation of cracks was observed and marked during each increment of load up to failure and final crack patterns are presented for each beam separately in Figures 1 to 2. The cracks started at the bottom fibres of the beam in tension zone and gradually extended upwards and widened as the load increased. It was observed in all the beams that 3 to 4 cracks appeared simultaneously at the first crack load. As the load increased cracks entered the compression zone and reached close to extreme compression fiber. Later on few of the cracks appeared outside the pure bending zone and flexural cracks seemed to be temporarily stabilized with secondary crack formation gaining ground. At still higher loads a steady growth was observed.

Figure 3 show that the cracks are well distributed and symmetrical about the center. The cracks in the pure bending region are predominantly vertical and parallel as expected.

All the beams of different series failed in flexure zone only and coincided with expected failure pattern as can be seen from crack pattern of all the beams reported.

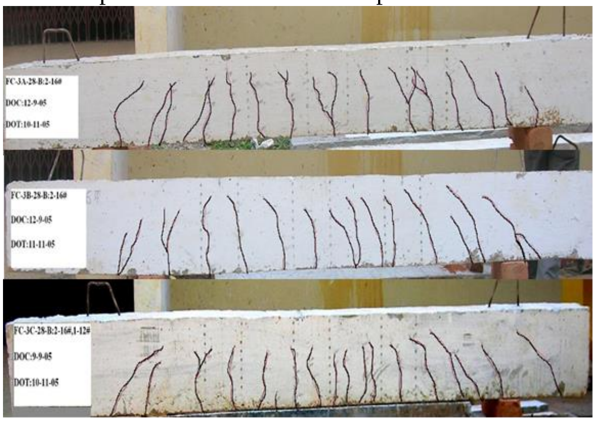

Figure 3: Crack pattern of RFAC beams (all 28 days balanced section; 28 days curing period and different CRLs) M30

The total number of cracks and number of cracks in flexural zone observed are tabulated in Table 2. The average crack spacing, maximum crack spacing as well as crack width at ultimate load are also shown in Table 2. In M30 grade of concrete, the mean crack spacing was found to be less in RFAC beams as compared to RNC beams But in M40 and M50grades of concrete the mean crack spacing was found to be slightly more in RFAC beams than in RNC beams. The crack widths exhibited at service loads varied between 0.1 to 0.3 mm in beams of all three grades of concrete. At ultimate loads, the crack widths varied between 0.3 to 0.4 mm in beams of all three grades of concrete.

In beams of all three grades of concrete considered, RFAC beams exhibited higher crack width than RNC beams. It is also observed from Table 2 that the numbers of cracks in RFAC beams of M30 are less than in RFAC beams of M40 and M50. The crack spacing was found to be slightly more in the case of RFAC beam specimens of M30 resulting in marginally higher crack width when compared to RFAC beam specimens of M40 and M50.

In RFAC beams the flexural cracks came very close to compression fiber but crushing of concrete was not observed typically demonstrating tension failure. In case of RNC beams few cracks reach the top compression fibre and additional cracks were formed and already developed cracks extended upwards and widened causing collapse accompanied by yielding of steel demonstrating a classical balanced failure.

Depth of cracks exhibited by RFAC beams was larger than RNC beams (particularly for 35% and 50% CRLs) and number of cracks in flexure zone was considerably more in RNC beams.

The above cracking behavior observed for RFAC beams clearly shows that performance of RFAC beams is satisfactory when compared to RNC beams with respect to crack widths. In design, the theory applied for strength prediction of RNC beams is equally valid for RFAC beams.

The experimental investigation clearly demonstrates that the there was no major difference in the strength, deformations and structural performances between the RFAC beams with different CRLs and RNC beams.

Figure 4: Comparison of crack pattern between RFAC and RNC beams (all 28 days balance section; 28 days curing period and different CRLs) M40

IV. 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 loads 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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