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International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-4 Issue-2, December 2014

Flexural behavior of Reinforced Fly Ash Concrete in Comparison to Reinforced Normal Concrete Beams in Terms of Load Deflection

B.K.Narendra, T.M.Mahadeviah

Abstract— ***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. 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. 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. 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. Hence, this paper present the investigation of comparison between the flexural behaviour 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 behaviour of reinforced Fly ash concrete beams with different cement replacement levels (20%, 35% and 50%) are compared with reinforced normal concrete beams (with out containing Fly ash) under similar conditions. These investigations were conducted with three grades of concrete i.e. M30, M40 and M50. Deflection is one of the important serviceability limit states to be satisfied in the design of concrete structures. So the flexural behaviour of these beams is discussed in terms of load deflection behavior.***

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

I. Introduction

Deflection is one of the important serviceability limit states to be satisfied in the design of concrete structures. Clause 23.2 of IS: 456 - 2000 recommends, in case of simply supported beams, a ratio of span to effective depth of less than or equal to 20 as generally sufficient to restrict the deflections to an allowable value of span/250 [3]. During each test, deflections were measured at midspan and at two load points. The comparative deflection responses to applied loads of RFAC beams and RNC beams are discussed separately for each grade of concrete considered. During discussions, theoretical (computed) deflections as per IS: 456-2000 are also considered and specimen calculation [2,4,7]. The flexural behaviour of reinforced Fly ash concrete beams with different cement replacement levels (20%, 35% and 50%) are compared with reinforced normal concrete beams (with out 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 load deflection behaviors and is presented in the next section.

Manuscript published on 30 December 2014.
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II. M30 Concrete

Measured mid span deflections of RFAC beams with three replacement levels and RNC beam considered are presented in Table 1. Three load levels namely cracking load Pcr, service load Ps, and ultimate load Pu and the corresponding midspan deflections, namely Δcr, Δs and Δu , both measured (experimental) and theoretically computed deflection values are tabulated here.

A. Deflection Profiles

Deflection measurements were made at center of span and at load points at all increments of loads. The measured deflections could therefore be plotted along the span of beam to obtain deflection profiles at different load levels for each beam and are shown in Figure 1 for RFAC beams with 20%, 35% and 50% CRLs respectively and RNC beam at cracking load, service load and ultimate load. The deflection profiles clearly indicate that all RFAC beams have lesser deflection in comparison to RNC beam at any load level.

Note: Experimental values of loads and deflections are normalized.

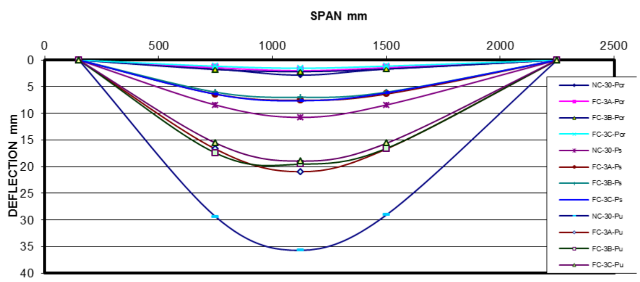

Figure 1: Deflection profile of all RFAC and RNC beams at different load levels for M30

Table 1: Results of deflection behaviour of RFAC and RNC beams at mid span M30

Beam Designation	Compressive strength MPa	Percentage CRL	Percentage Reinforcement	Experimental Values						Theoretical Values				
				P_{cr} kN	Δ_{cr} mm	P_s kN	Δ_s Mm	P_u kN	Δ_u mm	P_{cr} kN	Δ_{cr} mm	P_s kN	Δ_s mm	P_u kN
FC-3A-28	34.85	20	1.24	13.92	1.98	51.11	9.12	76.66	20.95	15.63	0.602	53.58	4.91	78.00
FC-3B-28	33.74	35	1.24	14.20	2.16	52.41	8.65	78.62	19.54	15.36	0.603	53.22	4.85	77.45
FC-3C-28	34.78	50	1.24	13.94	1.52	51.13	8.27	76.70	17.82	15.62	0.602	53.56	4.91	77.97
NC-30-28	35.00	0	1.24	13.87	2.83	50.88	11.28	76.23	35.71	15.67	0.602	53.63	4.92	78.01

B. Load - mid span deflection

Figure 2 compares the load vs measured mid span deflection variation of RFAC beams having different CRLs with that of RNC beam for M30 concrete. It is seen that as all beams were designed to be of M30 grade of concrete irrespective of CRLs the experimental ultimate load the beams carry is almost the same (76.33 to 78.62 kN). The deflection of RFAC beams is found to be lesser than that of RNC beam at all load levels, possibly because of the higher value of modulus of elasticity of Fly ash concrete as observed earlier, showing that RFAC beams are stiffer than RNC beams. The difference in deflection observed at cracking load level of RFAC beams expressed as a fraction of deflection of normal concrete beam at corresponding load for 20%, 35% and 50% CRLs respectively is found to be 0.70, 0.76 and 0.54 times the deflections of RNC beam. Similarly at service load level RFAC beams with 20%, 35% and 50% CRLs respectively have only 0.80, 0.77 and 0.73 times the deflections of RNC beam.

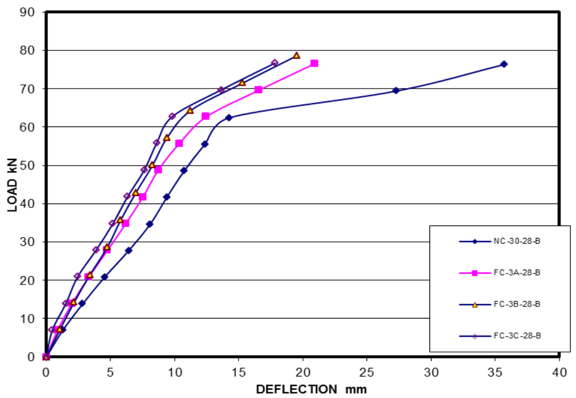

Figure 2: Comparison of load vs mid span deflection between RFAC and RNC beams for M30

The difference in deflection observed at ultimate load level, of the RFAC beams with 20%, 35% and 50% CRLs respectively are found to be 0.58, 0.54 and 0.50 times the deflections of RNC beam. Between the different CRLs considered, all the beams have almost same deflection but deflections slightly decrease as CRLs increase at any particular load level.

From Table 1, it is to be noted that deflection at service load for all RFAC beams and RNC beam satisfy the deflection criterion suggested by code IS: 456-2000 (Δ= span/250 = 9 mm). Comparison of theoretical and experimental mid span deflection values recorded in Table 1 shows that experimental deflection values are always higher than theoretically computed values, more so at first cracking load, showing that theoretical values underestimate the deflection even for RNC beam. The ratio of experimental deflection to theoretical deflection at service load for RFAC beams with 20%, 35% and 50% CRLs respectively are 1.85, 1.78 and 1.68 and for RNC beam this ratio is 2.29. At cracking load, the ratio of experimental deflection to theoretical deflection for RFAC beams with 20%, 35% and 50% CRLs are 3.3, 3.6 and 2.53 respectively and for RNC beam this ratio is 4.72.

C. Load -deflection at load point

Deflections were measured at two load points in addition to that at midspan and the average value is considered for study. Variations of load vs deflection at load point for RFAC beams and RNC beam is compared in Figure 3. The trend of variation of deflections at load point with load is similar to that of mid span deflection. At service load, the deflections of RFAC beams for 20%, 35% and 50% CRLs respectively are 0.80, 0.82 and 0.75 times the deflections of RNC beam.

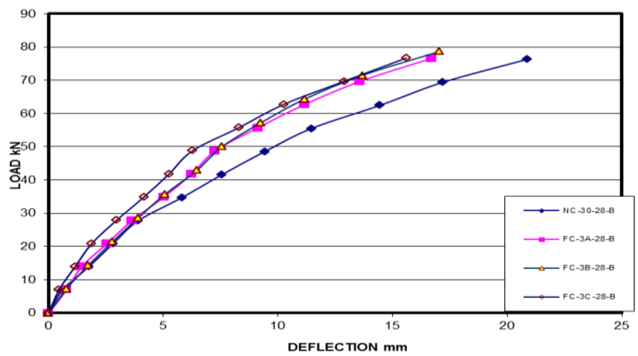

Figure 3: Comparison of load vs load point deflection between RFAC and RNC beams for M30

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Table 2 Results of deflection behaviour of RFAC and RNC beam at mid span for M40

Beam Designation	ssivestre ngth	Percent age	Percent age Reinforc	Experimental Values						Theoretical Values				
				P_{cr} kN	Δ_{cr} mm	P_s kN	Δ_s mm	P_u kN	Δ_u mm	P_{cr} kN	Δ_{cr} mm	P_s kN	Δ_s mm	P_u kN
FC-4A-28	39.28	20	1.582	20	1.18	73.33	6.28	110	13.74	16.69	0.602	66.69	4.94	97.67
FC-4B-28	39.60	35	1.582	30	1.14	73.33	4.89	110	13.23	16.77	0.603	66.82	4.97	97.87
FC-4C-28	36.05	50	1.582	20	0.88	73.33	4.5	110	12.56	15.93	0.602	65.23	4.62	95.48
NC-40-28	39.01	0	1.582	20	3.66	73.33	8.55	110	14.47	16.63	0.602	66.58	4.92	97.50

III. LOAD-DEFLECTION:M40 CONCRETE

Measured mid span deflections of RFAC beams with three cement replacement levels and RNC beam considered are presented in Table 2. Three load levels namely cracking load Pcr, service load Ps, and ultimate load Pu and the corresponding measured mid span deflections namely Δcr, Δs and Δu are tabulated. Corresponding theoretical deflections are also included here.

A. Deflection profiles

Deflection measurements were made at center of span and at load points at all increments of loads. The measured deflections are therefore plotted along the span of beam to obtain deflection profiles at different load levels for each beam and are shown in Figure 4 for RFAC beams with 20%, 35% and 50% CRLs respectively and RNC beam at cracking load, service load and ultimate load. The deflection profiles clearly indicate that RFAC beams have lesser deflection in comparison to RNC beam.

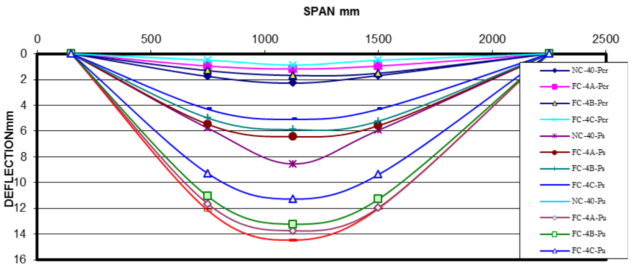

Figure 4: Comparison of deflection profile between RFAC and RNC beams at different loads for M40

B. Load - mid span deflection

Figure 5 compares the load vs measured mid span deflection variation of RFAC beams having different CRLs with that of RNC beam for M40 concrete. It is seen that as all beams were designed to be of M40 grade of concrete irrespective of CRLs, the experimental ultimate load the beams carry is same (110 kN).

The deflection of RFAC beams is found to be lesser than that of RNC beam at all load levels, possibly because of the higher value of E of Fly ash concrete, showing that RFAC beams are stiffer than RNC beams. The maximum difference in deflection is observed at cracking load level and not at ultimate loads as in the previous case. The RFAC beams for 20%, 35% and 50% CRLs respectively have 0.32, 0.31and 0.24 times the deflections of RNC beam at cracking loads. The RFAC beams for 20%, 35% and 50% CRLs respectively have 0.73, 0.57 and 0.52 times the deflections of RNC beam at service loads. The RFAC beams for 20%, 35% and 50% CRLs respectively have 0.95, 0.91 and 0.87 times the deflections of RNC beam at ultimate loads. Between the different CRLs considered, all the beams have almost same deflection but deflections slightly decrease as CRLs increase at any particular load level.

From Table 2, it is observed that deflection at service load for all RFAC beams and RNC beam satisfy the deflection criterion proposed by code IS: 456-2000 (Δ= span/250 = 9 mm). Comparison of theoretical and experimental mid span deflection values recorded in Table 2 shows that experimental deflection values are generally higher than theoretical computed values, at both cracking load and service load levels.

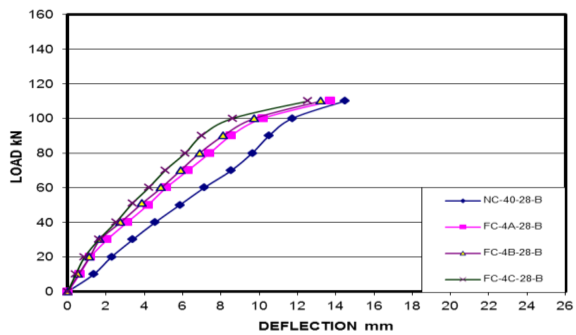

Figure 5: Comparison of load vs mid span deflection between RFAC and RNC beams for M40

C. Load - deflection at load point

Deflections were measured at two load points in addition to that at mid span and the average value is considered for study. Variations of load vs deflection at load point for RFAC beams and RNC beam is compared in Figure 6.

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The trend of variation of deflections at load point with load is similar to that of mid span deflection. At service load, the deflections of RFAC beams for 20%, 35% and 50% CRLs respectively are 0.92, 0.85 and 0.75 times the deflections of RNC beam.

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.

IV. LOAD-DEFLECTION:M50 CONCRETE

Measured mid span deflections of RFAC beams with three replacement levels and RNC beam considered are presented in Table 3. Three load levels namely cracking load Pcr, service load Ps, and ultimate load Pu and the corresponding measured midspan deflections as well as computed deflections, namely Δcr, Δs and Δu are tabulated.

A. Deflection profiles

Deflection measurements were made at center of span and at load points at all increments of loads.

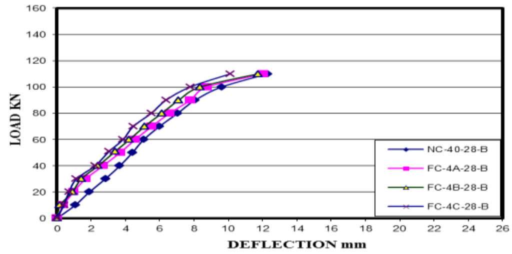

Figure 6: Comparison of load vs load point deflection between RFAC and RNC beams for M40

The measured deflections are therefore plotted along the span of beam to obtain deflection profiles at different load levels for each beam and are shown in Figure 6 for RFAC beams with 20%, 35% and 50% CRLs respectively and RNC beam at cracking load, service load and ultimate load. The deflection profiles clearly indicate that RFAC beams have lesser deflection in comparison to RNC beam.

B. Load - mid span deflection:M50

Figure 8 compares the load vs mid span deflection variation of RFAC beams with different CRLs with that of RNC beam for M50. The observations previously made for M30 and M40 concrete, that the deflection in RFAC beams is lesser than that in RNC beam at all load levels also holds good for M50 concrete, showing that RFAC beams are stiffer than RNC beams. The deflection observed at service load level for the RFAC beams with 20%, 35% and 50% CRLs respectively are 0.97, 0.79 and 0.63 times the deflections of RNC beam.

The maximum differences in deflection are observed at ultimate load level and for RFAC beams with 20%, 35% and 50% CRLs respectively are observed to be 0.87, 0.70 and 0.58 times the deflections of RNC beam.

Table 3 Results of deflection behaviour of M50 RFAC and RNC beams at mid span

Beam	Compressive Strength MPa	Percentage CRL	Percentage Reinforcement	Experimental Values						Theoretical Values				
				P_{cr} kN	Δ_{cr} mm	P_s kN	Δ_s mm	P_u kN	Δ_u mm	P_{cr} kN	Δ_{cr} mm	P_s kN	Δ_s mm	P_u kN
FC-5A-28	48.41	20	1.948	30	1.95	86.66	6.79	130	11.93	18.70	0.603	80.61	5.30	118.5
FC-5B-28	47.16	35	1.948	30	1.39	86.66	5.52	130	9.54	18.54	0.603	80.28	5.25	118.0
FC-5C-28	43.75	50	1.948	20	1.29	80.00	4.40	120	7.86	17.71	0.602	78.52	4.93	115.4
NC-50-28	49.01	0	1.948	30	2.47	93.33	6.96	140	13.63	18.83	0.603	80.85	5.33	118.9

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Between the different CRLs considered, all the beams have almost same deflection, but deflections slightly decrease as CRLs increase at any particular load level. The load vs midspan deflection and load vs loadpoint deflection of all RFAC and RNC beams are depicted in Figures 14 and 15 respectively.

From Table 3 it is noted that deflection at service load for all RFAC beams and RNC beam satisfy the deflection criterion proposed by code IS: 456-2000 (Δ = span/250 = 9 mm). Comparison of theoretical and experimental mid span deflection values recorded in Table 3 shows that experimental deflection values are always higher than theoretical computed values. The ratio of the experimental deflection value to that of theoretical value at cracking load is on an average 2.55 for RFAC beams and for RNC beam it is 4.10. The ratio of the experimental deflection value to that of theoretical deflection value at service load is on an average 1.08 for RFAC beams and for RNC beam it is 1.30.

C. Load - deflection at load point:M50

Deflections were measured at two load points in addition to that at mid span and the average value is considered for study. Variations of load vs deflection at load point for RFAC beams and RNC beam is compared in Figure 9. The trend of variation of deflections at load point with load is similar to that of mid span deflection, at service load the deflections of RFAC beams for 20%, 35% and 50% CRLs respectively are 0.96, 0.91 and 0.75 times the deflections of RNC beam. The deflection profiles for RFAC beams of M30, M40 and M50 are shown separately for 20%, 35% and 50% CRLs in Figures 10 to 12 respectively. The deflection profiles of all RAFC and RNC beams of all three grades of concrete are shown in Figure 13.

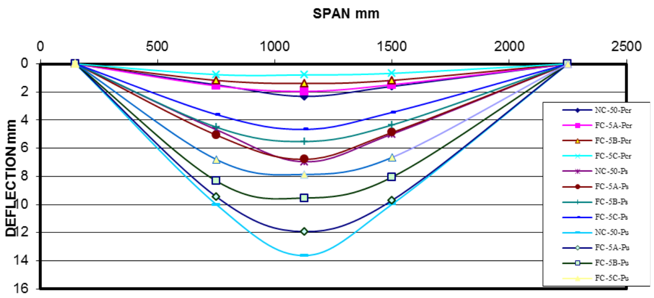

Figure 7: Deflection profile of RFAC and RNC beams combined at different load levels M50

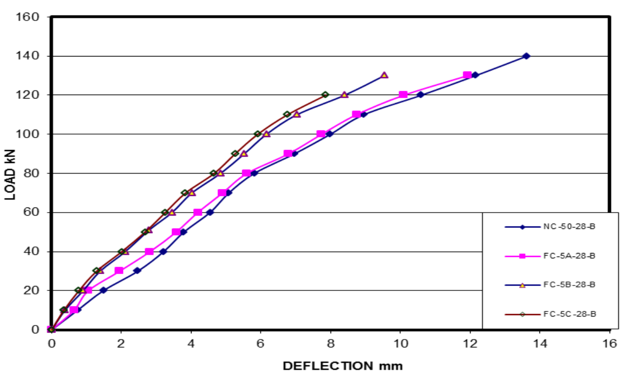

Figure 8: Comparison of load vs mid span deflection between RFAC and RNC beams for M50

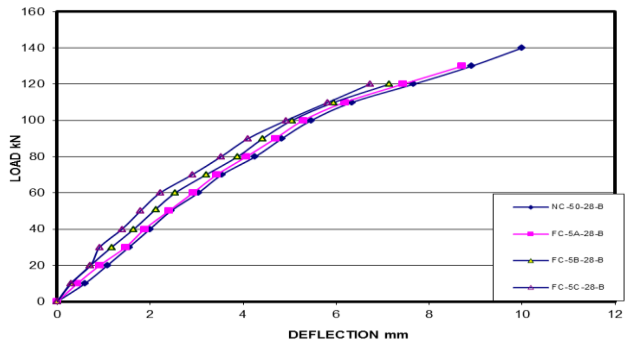

Figure 9 Comparison of load vs load point deflection between RFAC and RNC beams for M50

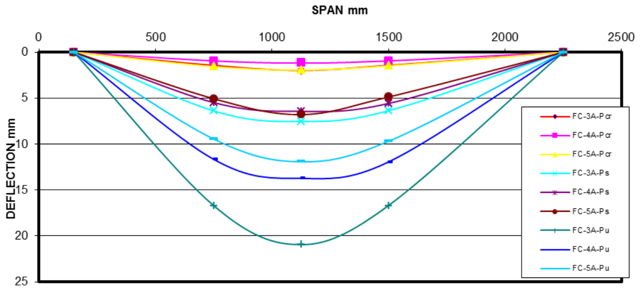

Figure 10: Deflection profiles of RFAC beams at P_{cr}, P_s and P_u M30, M40, M50

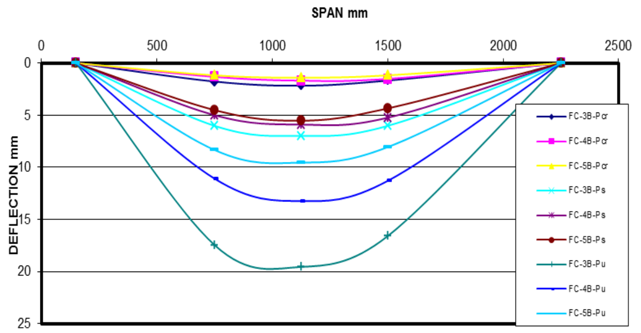

Figure 11: Deflection profiles of RFAC beams at P_{cr}, P_s and P_u M30, M40, M50

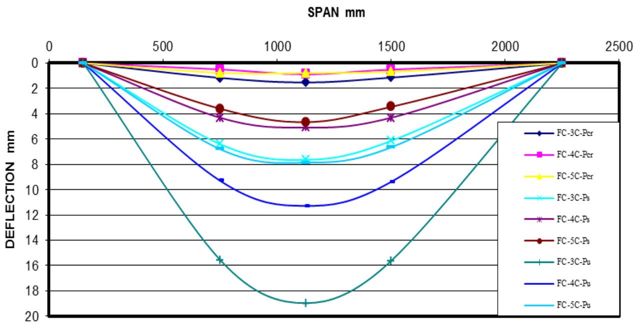

Figure 12: Deflection Profiles of RFAC beams at P_{cr}, P_s and P_u M30, M40, M50

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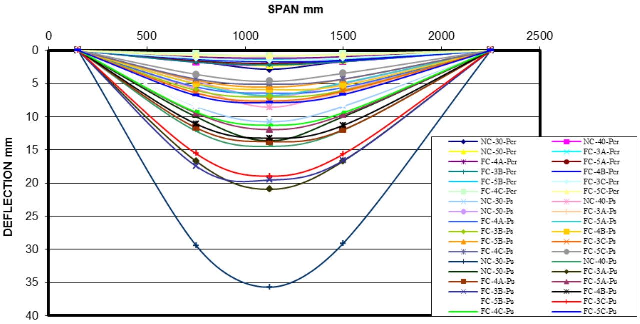

Figure 13: Deflection Profiles of RFAC and RNC beams at P_{cr}, P_s and P_u M30, M40, M50

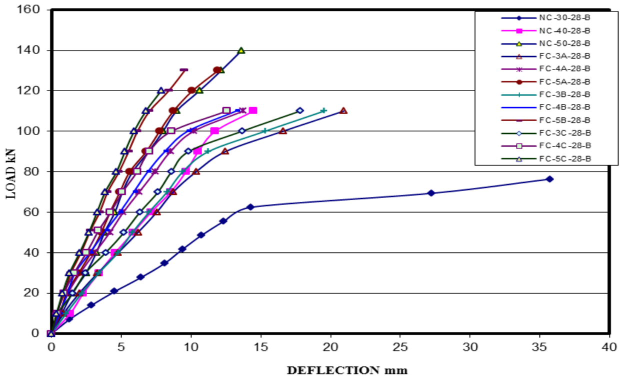

Figure 14: Comparison of load vs mid span deflection between RFAC and RNC beams of all three grades of concrete

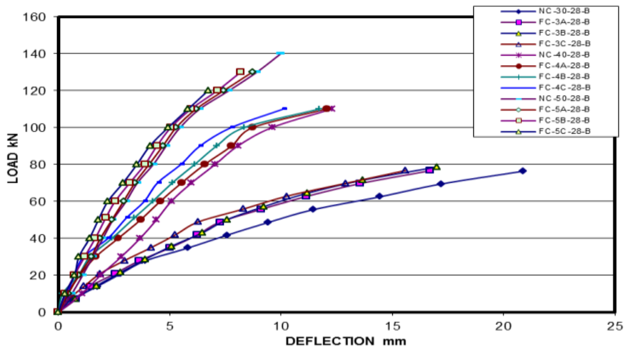

Figure 15: Comparison of load vs load point deflection between RFAC and RNC beams of all three grades of concrete

V. Summary and Discussion:

It may be inferred that

i) All the RFAC beams with varying CRLs of all three grades of concrete considered, i.e., M30, M40 and M50 undergo lower deflections as compared to corresponding RNC beams at all load levels as shown in Figures 16 to 18. On an average, the deflection of RFAC beams at service loads was 0.68 times that of RNC beams and at ultimate loads, this ratio was about 0.79.

ii) As the CRL of RFAC beams increases, in comparison to RNC beams, there is a reduction in magnitude of deflection at service load in all the three grades of concrete as seen in Figures 16 to 18. The reduction in deflection between any two beams with consecutive CRLs is in the range of 5% to 18%, being very small in M30(5%).

iii) The decrease in deflection of RFAC beams could be attributed to the increase in E in Fly ash concrete.

iv) [5,6] have conducted experimental studies on flexural behaviour of reinforced Fly ash concrete blocks by replacing cement by Fly ash and silica fume to an extent of 60%. Similarly [1] have conducted experimental investigation on the flexural behaviour of RC beams by replacing cement by slag and Fly ash and the mean target strength was kept at 40MPa. Both these investigators have observed that the load-deflection behaviour in flexure of RFAC beams are similar to that of RNC beams for the entire range of loads. The findings of the present experimental investigation are in agreement with those of earlier investigators.

The experimental deflection of RFAC beams at service loads varied between Span/246 to Span/272 for M30 concrete and for RNC beams it was span/200. The experimental deflection of RFAC beams at ultimate loads varied between Span/107 to Span/126 for M30 concrete and the deflection at ultimate load decreased by around 9% with each increase in CRL by 15% and for RNC beam it was span/63. All the RFAC beams with varying CRLs had lesser deflection than the RNC beam in M30 concrete. The maximum difference of 15% in the magnitude of deflection was between RFAC beam with 50% CRL and RNC beam in M30 concrete.

The experimental deflections of RFAC beams at service loads varied between Span/358 to Span/500 for M40 concrete and for RNC beams it was span/263. In M40 concrete, the experimental deflection of RFAC beams at ultimate loads varied between Span/164 to Span/180 and the deflection at ultimate load decreased marginally by around 4.5% with each increase in CRL by 15% and for RNC beam it was span /155. All the RFAC beams with varying CRLs had lesser deflection than the RNC beams.

The experimental deflections of RFAC beams at service loads varied between Span /331 to Span /511 for M50 concrete and for RNC beams it was span/323. In M50 concrete, the experimental deflection of RFAC beams at ultimate loads varied between Span /158 to Span/286 and the deflection at ultimate load decreased by 22% with an increase in cement replacement level by 15% and for RNC beam it was span /165. All the RFAC beams with varying CRLs had lesser deflection than the RNC beams. With the RFAC beam with 50% CRL having 0.75 times the deflection of RNC beam at service load.

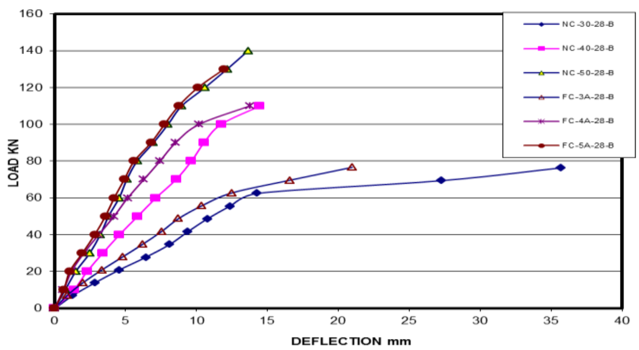

Figure 16: Comparison of load vs mid span deflection between RFAC and RNC beams of all three grades of concrete

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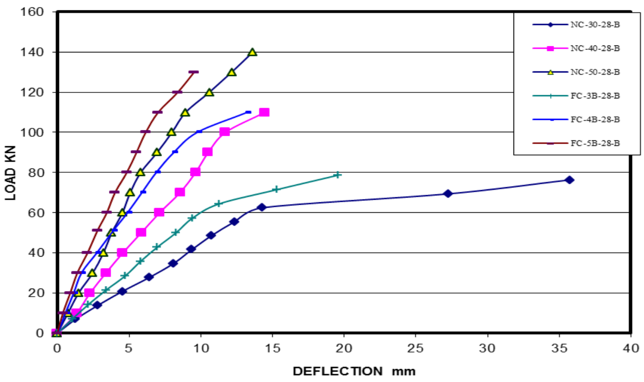

Figure 17: Comparison of load vs mid span deflection between RFAC and RNC beams of all three grades of concrete

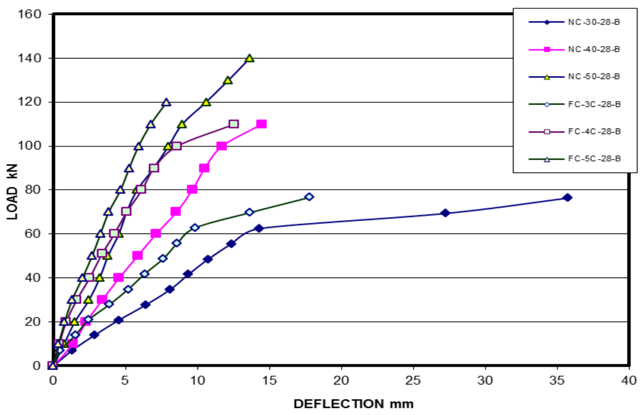

Figure 18: Comparison of load vs mid span deflection between RFAC and RNC beams of all three grades of concrete

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