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Compressive Strength Development of Fly Ash Concrete for Different Cement Replacement Levels

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Abstract*— Compressive strength tests were conducted on design mixes M30, M40 and M50 for cement replacement levels (CRLs) of 20%, 35% and 50% for different curing periods of 3, 7, 28, 56 and 91 days. Three water binder (w/b) ratios for each CRL were considered for the study, so that the optimum w/b ratio could be chosen for further study, the optimum w/b ratio being that ratio, which gives a compressive strength equal to that of normal concrete for curing period of 28 days. Tabulated the test results of compressive strength of Fly ash concrete (FAC) and normal concrete (NC) for grades M30, M40 and M50 respectively. The test results of compressive strength development of Fly ash concrete for different cement replacement levels with different curing periods and of normal concrete all of grades M30, M40 and M50 are discussed in this paper.

Index Terms*—Compressive strength, Cement replacement level, Fly ash concrete.

I. INTRODUCTION

Most of the early research work has been conducted on the compressive strength and durability aspects of Fly ash concrete either by using Fly ash as an additive or by replacing a fraction of cement by Fly ash. These studies are successful in bringing out the advantages of use of Fly ash in concrete in terms of enhancement in long-term strength and durability. It is invariably recommended as an ingredient in high performance concrete and self-compacting concrete [1,4].

However, concrete can never be used in isolation as a structural material, without incorporating reinforcing steel, because of its low tensile strength. Though tension is induced due to several structural actions in a structural member, the important structural action where in tensile stresses are encountered is flexure or bending [5]. The suitability of Fly ash concrete as a structural material can be established only when its behavior along with embedded reinforcement when subjected to bending proves to be satisfactory [3]. Hence, the present investigations is taken up with a view to compare 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.

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II. OPTIMUM WATER BINDER RATIO

From results for each CRL and grade, the optimum water binder ratio was chosen for these mixes. The compressive strength achieved at different curing periods of 3, 7, 28, 56 and 91 days are given in Tables 4 to 6 for grades M30, M40 and M50. These are graphically represented in Figures 1 to 12 and for selected w/b ratios for all three grades of concrete in Figure 13. In case of FAC, for any given CRL, the compressive strength largely depends on the w/b ratio. For any given CRL, the appropriate w/b ratio, which will give the same strength as normal concrete at 28 days, can be found.

Thus, in M30 concrete, for CRLs of 20%, 35% and 50%, the w/b ratio that gives very nearly the same target strength as that of NC (w/b 0.47) at 28 days is found to be 0.45, 0.45 and 0.40 respectively. In M40 concrete for each CRL, the w/b ratios found to give the same strength as that of NC at 28 days, for 20% CRL (FC-A-1), 35% CRL (FC-B-3) and 50% CRL (FC-C-1); are found to be 0.41, 0.34 and 0.38 respectively. In M50 concrete for each CRL, from Table 3 one w/b ratio can be found to give the same strength as that of NC at 28 days, thus for 20% CRL (FC-A-1) 35% CRL (FC-B-2) and for 50% CRL (FC-C-2), these w/b ratios are found to be 0.33, 0.32 and 0.31 respectively.

A. Fly ash concrete and Normal concrete M30

Compressive strength achieved by different grades of FAC and NC at different ages as a ratio of strength at 28 days is reported in Tables 4 to 6 and shown in Figures 1 to 4. On an average, 3 day strength of M30 FAC is found to be 0.42 times that of 28 day strength of M30 FAC, while 3 day strength of M30 NC is found to be 0.48 times that of 28 day strength of M30 NC. Similarly, the 7 day strength of M30 FAC is found to be 0.59 times that of 28 day strength of M30 FAC while 7 day strength of M30 NC is found to be 0.67 times that of 28 day strength of M30 NC. It is also observed that the compressive strengths of M30 FAC

for all three CRLs are lesser than that of NC for curing periods of 3 and 7 days. The 56 day strength of M30 FAC is found to be 1.22 times that of 28 day strength of M30 FAC and for 91 days, it is found to be 1.34 times that of 28-day strength of M30 FAC. While the 56 day strength of M30 NC is found to be 1.15 times that of 28 day strength of M30 NC and for 91 days, it is found to be 1.19 times that of 28 day strength of M30 NC. As in the case of NC, strength development is low for initial periods up to 3 to 7 days and 7 to 28 days for all CRLs. It is also observed that the compressive strengths of M30 FAC for all three CRLs are lesser than that of NC for curing periods of 3 and 7 days. At 28 days, strength of FAC at all w/b ratios is close to the strength of NC as it was planned to be so At curing periods of 56 and 91 days, higher gain of strength is observed in M30 FAC for all three CRLs at all w/b ratios than in NC.

B. Fly ash concrete and Normal concrete M40

For M40 concrete, it is seen from Table 2 and Figures 5 to 7, that strength development in FAC with replacement level of 50% is lower than that of NC, while it is more in the case of 20% and 35% CRL as compared to NC at 3 and 7 days curing period. On an average, 3 day strength of M40 FAC is found to be 0.50 times that of 28-day strength of M40 FAC, while 3 day strength of M40 NC is found to be 0.48 times that of 28 day strength of M40 NC. Similarly, 7 day strength of M40 FAC is found to be 0.65 times that of 28-day strength of M40 FAC, while 7 day strength of M40 NC is found to be 0.68 times that of 28 day strength of M40 NC. The 56 and 91 days strength are found to be 1.24 and 1.30 times that of 28 day strength of M40 FAC, while 56 and 91 days strength are found to be 1.20 and 1.24 times that of 28 day strength of M40 NC. It is seen that M40 FAC can be proportioned to achieve target compressive strength equal to that of NC as shown in Table 6.5. At curing periods of 56 and 91 days, higher gain of strength may be observed for FAC for all three CRLs than in NC.

C. Fly ash concrete and Normal concrete M50

For M50 concrete, it is clearly seen from Figures 9 to 11, that the strength development in FAC is slightly lower for initial periods from 7 to 28 days for all CRLs as compared to strength development in NC for 7 to 28 days. On average, 3 day strength of M50 FAC is found to be 0.42 times that of 28 day strength of FAC while 3 day strength of M50 NC is found to be 0.51 times that of 28 day strength of NC. Similarly, the 7 day strength of M50 FAC is found to be 0.67 times that of 28 day strength of M50 FAC, while 7 day strength of M50 NC is found to be 0.66 times that of 28 day strength of M50 FAC. The 56 day strength is found to be 1.20 times that of 28 day strength of M50 FAC and the 91 day strength is found to be 1.26 times that of 28 day strength, while, 56 day strength is found to be 1.12 times that of 28 day strength of M50 NC and the 91 day strength is found to be 1.18 times that of 28 day strength of M50 NC. It is seen that M50 FAC can be proportioned to achieve target compressive strength equal to or close to that of NC as shown in Table 6.

III. COMPARISON OF FLY ASH CONCRETE WITH NORMAL CONCRETE

On an average, for all the grades of FAC concrete under consideration, 3 day strength is found to be 0.45 times that of 28 day strength, 7 day strength is found to be 0.64 times that of 28 day strength, 56 day strength is found to be 1.22 times that of 28 day strength and for 91 days it is found to be 1.30 times that of 28 day strength of NC.

It is seen from Figure 12 that compressive strength of FAC for all three CRLs is less than that of NC for curing periods of 3 and 7 days. However, at 28 days, strength of M50 FAC at all w/b ratios are close to the values of NC at 28 days. At curing periods of 56 and 91 days, higher gain of strength may be observed for FAC for all three CRLs at all w/b ratios than in NC. However, at 28 days, strength of FAC of 20% CRL is equal to that of NC while the compressive strengths of FAC with 35% and 50% CRL are slightly lower than that of NC.

For any given w/b ratio, CRL largely affects the compressive strength. Referring to Table 1, it can be seen that for the common w/b ratio of 0.4, the early age strength at 3 and 7 days of both 35% and 50% CRL gives strength only about 50% to 60% of that of 20% CRL. At 28 days, there is an improvement in strength. The strength of 35% and 50% CRL came closer to that of 20% CRL. At 56 days, the strength was about 75% and at 91 days, it was about 80% that of strength of concrete with 20% CRL. Between 35% and 50% CRL, strength reduction for higher percentage of CRL was only around 15% at early ages that reduces to 6% at 91 days.

Strength of M30 grade FAC with the mix design shown in Table 1 and Figures 1 to 6.4 has the same strength as that of NC at 28 days. It has slightly lower strength at 3 and 7 days, but has higher strength at higher curing periods of 56 and 91 days. At 56 and 91 days the strength of M30 FAC are found to be 1.25 and 1.40 times that of NC at 28 days. Strength of M40 grade FAC with the mix design shown in Table 2 and Figures 5 to 6.8 has the same strength as that of NC at 28 days. It has slightly lower strength at 3 and 7 days, but has higher strength at higher curing periods of 56 and 91 days. At 56 and 91 days the strength of M40 FAC are found to be 1.13 and 1.27 times that of NC at 28 days. Strength of M50 grade FAC with the mix design shown in Table 3 and Figures 9 to 6.12 has the same strength as that of NC at 28 days. It has slightly lower strength at 3 and 7 days, but has higher strength at higher curing periods of 56 and 91 days. At 56 and 91 days the strength of M50 FAC are found to be 1.13 and 1.20 times that of NC at 28 days. On an average, at 56 and 91 days the strength of M30, M40 and M50 NC is found to be 1.12 and 1.18 times that of NC at 28 days.

Table 1: Test Results of cube compressive strengths M30

Designation		NC-40	FC-A-1	FC-A-2	FC-A-3	FC-B-1	FC-B-2	FC-B-3	FC-C-1	FC-C-2	FC-C-3
Mix proportions		1: 1.03: 3.26									
% CRL		0	20	20	20	35	35	35	50	50	50
w/b ratio		0.41	0.41	0.38	0.37	0.38	0.36	0.34	0.38	0.36	0.34
Superplasticizer % total binder		0.50	0.25	0.50	0.75	--	0.25	0.75	0.25	0.50	1.00
Slump, mm		71	70	66	71	75	70	69	73	70	73
Compressive Strength, MPa	3 days	22.88	27.50	30.79	23.55	15.06	19.90	26.48	16.35	15.02	12.07
	7 days	32.13	34.47	39.71	30.66	19.24	25.95	34.93	23.30	20.88	15.82
	28 days	48.86	47.48	55.72	46.13	35.81	41.86	47.85	42.22	40.26	27.99
	56 days	54.54	59.39	66.66	54.54	45.14	56.66	58.66	57.29	46.36	39.02
	91 days	58.48	63.62	74.22	62.42	53.23	62.11	64.66	59.09	52.72	47.87

Table 2: Test Results of cube compressive strengths M40

Designation		NC-40	FC-A-1	FC-A-2	FC-A-3	FC-B-1	FC-B-2	FC-B-3	FC-C-1	FC-C-2	FC-C-3
Mix proportions		1: 1.03: 3.26									
% CRL		0	20	20	20	35	35	35	50	50	50
w/b ratio		0.41	0.41	0.38	0.37	0.38	0.36	0.34	0.38	0.36	0.34
Superplasticizer % total binder		0.50	0.25	0.50	0.75	--	0.25	0.75	0.25	0.50	1.00
Slump, mm		71	70	66	71	75	70	69	73	70	73
Compressive Strength, MPa	3 days	22.88	27.50	30.79	23.55	15.06	19.90	26.48	16.35	15.02	12.07
	7 days	32.13	34.47	39.71	30.66	19.24	25.95	34.93	23.30	20.88	15.82
	28 days	48.86	47.48	55.72	46.13	35.81	41.86	47.85	42.22	40.26	27.99
	56 days	54.54	59.39	66.66	54.54	45.14	56.66	58.66	57.29	46.36	39.02
	91 days	58.48	63.62	74.22	62.42	53.23	62.11	64.66	59.09	52.72	47.87

Table 3: Test Results of cube compressive strengths M50

Designation		NC-50	FC-A-1	FC-A-2	FC-A-3	FC-B-1	FC-B-2	FC-B-3	FC-C-1	FC-C-2	FC-C-3
Mix proportions		1: 1.04: 3.05									
% CRL		0	20	20	20	35	35	35	50	50	50
w/b ratio		0.33	0.33	0.32	0.31	0.33	0.32	0.31	0.33	0.32	0.31
Superplasticizer , % total binder		0.75	0. 5	0.65	0.75	0.25	0.65	0.8	0.25	0.35	0.65
Slump, mm		70	70	65	62	63	58	65	60	62	65
Compressive Strength, MPa	3 days	30.13	26.77	29.41	31.02	21.42	23.99	26.75	18.12	20.57	22.44
	7 days	39.15	39.99	43.82	44.52	26.92	37.51	38.93	24.18	26.04	38.26
	28 days	59.16	59.46	67.50	67.10	49.86	57.24	61.86	38.66	49.94	57.06
	56 days	66.05	71.81	76.36	75.0	59.39	69.08	72.11	52.12	56.66	69.68
	91 days	69.54	73.50	78.90	77.50	64.80	72.60	73.90	60.80	64.80	73.20

Table 4: Test results of selected cube compressive strengths M30

Designation		NC-30		FC-A-1		FC-B-1		FC-C-2	
Mix proportions		1: 1.61: 3.75							
% CRL		0		20		35		50	
w/b ratio		0.47		0.45		0.45		0.40	
Superplasticizer, % of total binder		-		-		-		1	
Slump, mm		70		70		70		68	
Compressive Strength, MPa	3 days	19.16	0.48	17.44	0.43	15.62	0.38	17.82	0.45
	7 days	26.94	0.67	25.66	0.64	20.93	0.51	24.88	0.63
	28 days	40.26	1.00	40.35	1.00	41.06	1.00	39.28	1.00
	56 days	46.06	1.15	46.66	1.16	49.63	1.21	50.90	1.30
	91 days	47.72	1.19	49.69	1.23	54.67	1.33	57.27	1.45

CompStrength age/ CompStrength 28 days

Table 5: Test Results of selected cube compressive strengths M40

Designation		NC-40			FC-A-1		FC-B-3		FC-C-1	
Mix proportions		1: 1.03: 3.26								
% CRL		0			20		35		50	
w/b ratio		0.41			0.41		0.34		0.38	
Superplasticizer, % of total binder		0.5			0.25		0.75		0.25	
Slump, mm		70			70		69		73	
Compressive Strength MPa	3 days	22.88	CompStrength age/ CompStrength 28 days	0.47	27.5	0.58	26.48	0.55	17.82	0.40
	7 days	32.13		0.66	34.47	0.73	34.93	0.73	23.3	0.53
	28 days	48.86		1.00	47.48	1.00	47.85	1.00	44.30	1.00
	56 days	54.54		1.12	59.39	1.25	58.66	1.23	57.29	1.30
	91 days	58.48		1.19	63.62	1.34	64.66	1.35	59.09	1.34

Table 6: Test Results of selected cube compressive strengths M50

Designation		NC-50			FC-A-1		FC-B-2		FC-C-3	
Mix proportions		1: 1.04: 3.05								
% CRL		0			20		35		50	
w/b ratio		0.33			0.33		0.32		0.31	
Superplasticizer, % of total binder		0.75			0. 5		0.65		0.65	
Slump, mm		70			70		58		65	
Compressive Strength MPa	3 days	30.13	CompStrength age/ CompStrength 28 days	0.51	26.7	0.45	23.99	0.42	22.44	0.39
	7 days	39.15		0.66	39.99	0.67	37.51	0.66	38.26	0.67
	28 days	59.16		1.00	59.46	1.00	57.24	1.00	57.06	1.00
	56 days	66.05		1.12	71.81	1.21	69.08	1.21	69.68	1.22
	91 days	69.54		1.18	73.5	1.24	72.6	1.27	73.20	1.28

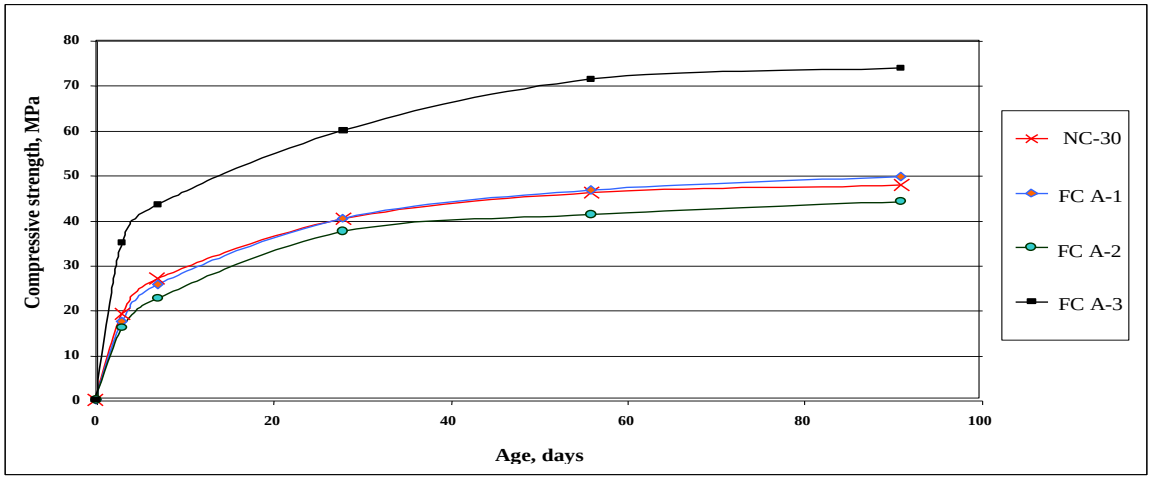

Figure 1: Variation of compressive strength with curing period for different w/b ratios for M30, NC and FAC 20% CRL

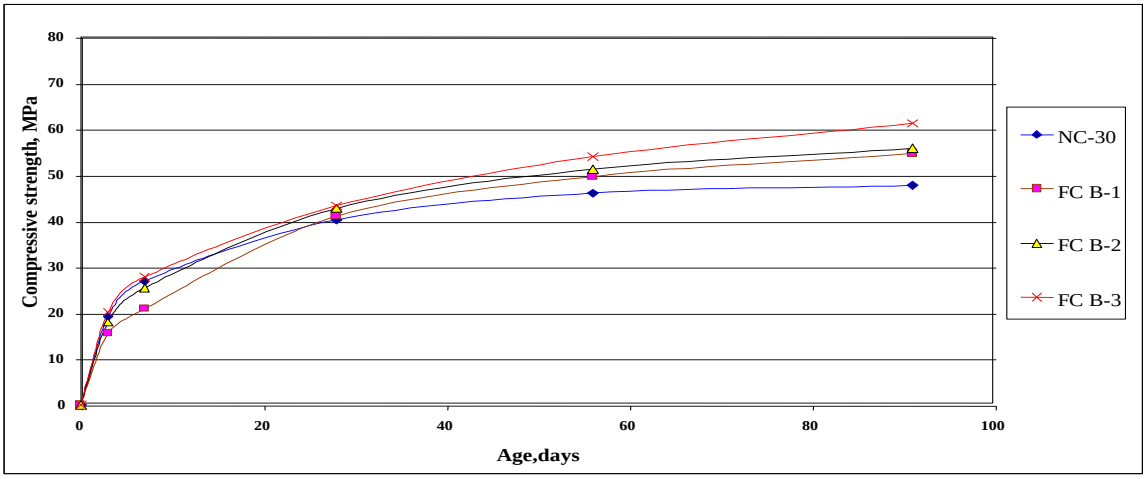

Figure 2: Variation of compressive strength with curing period for different w/b ratios for M30, NC and FAC 35% CRL

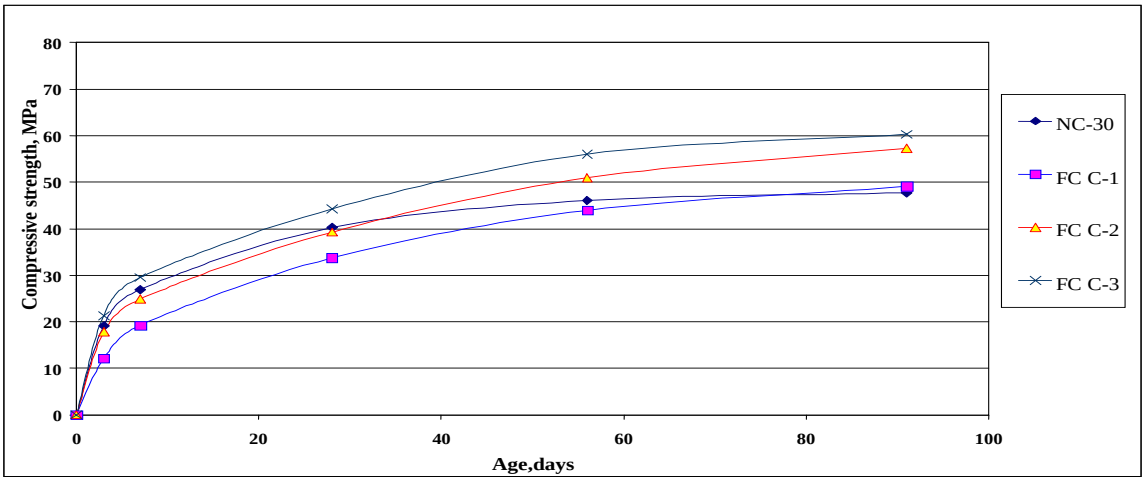

Figure 3: Variation of compressive strength with curing period for different w/b ratios for M30, NC and FAC 50% CRL

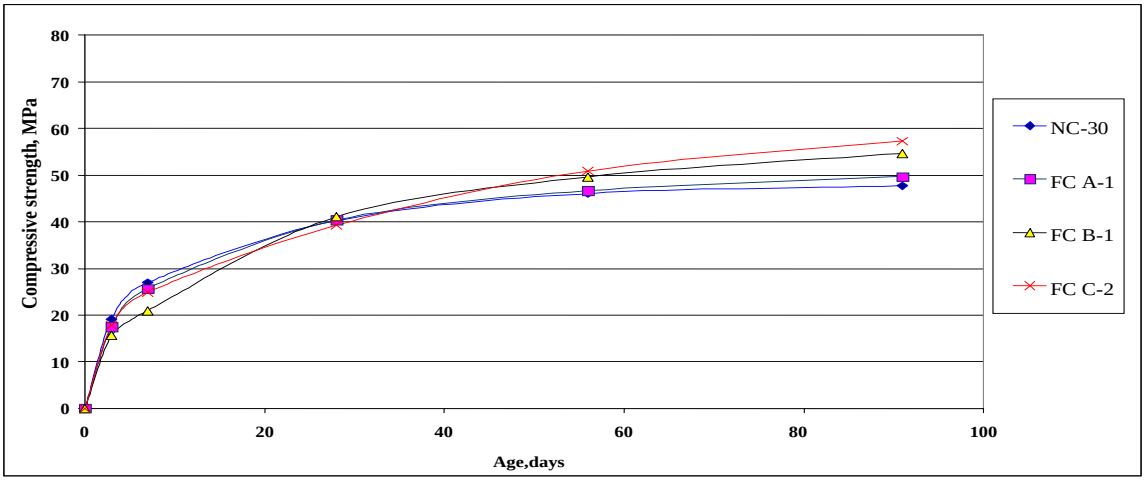

Figure 4: Variation of compressive strength with curing period for selected w/b ratios for different CRLs M30

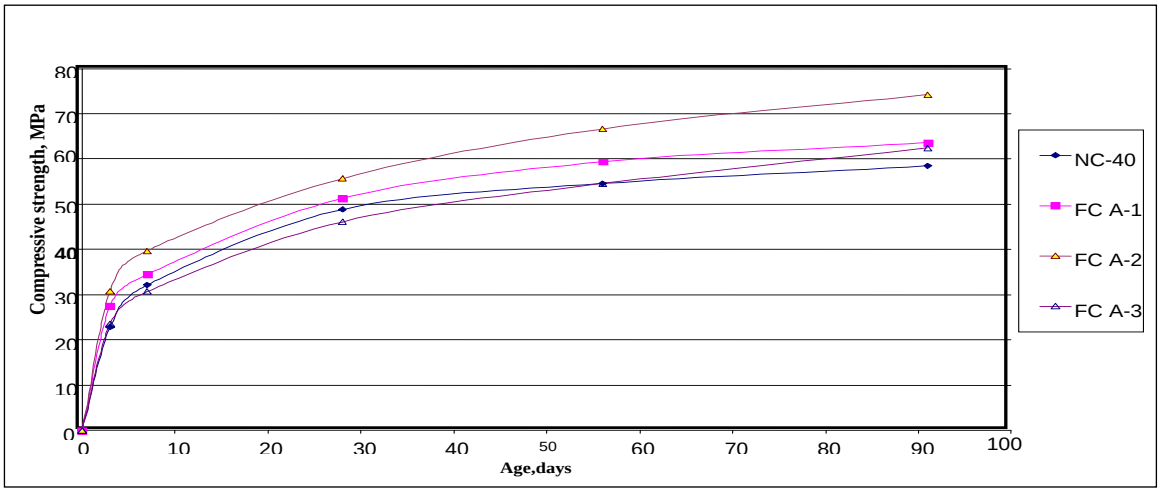

Figure 5: Variation of compressive strength with curing period for varying w/b ratios for M40 NC and FAC 20% CRL

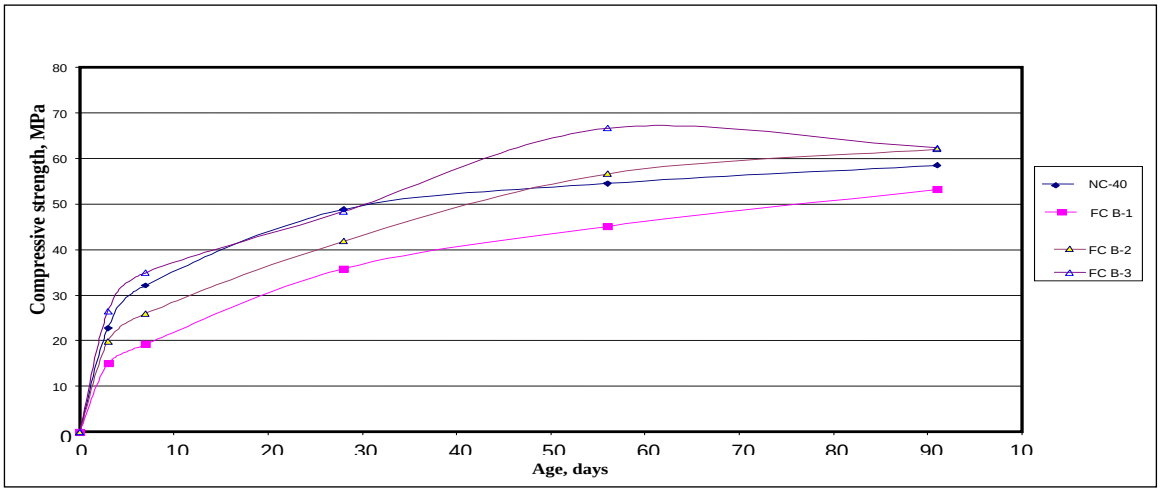

Figure6: Variation of compressive strength with curing period for varying w/b ratios for M40 NC and FAC 35% CRL

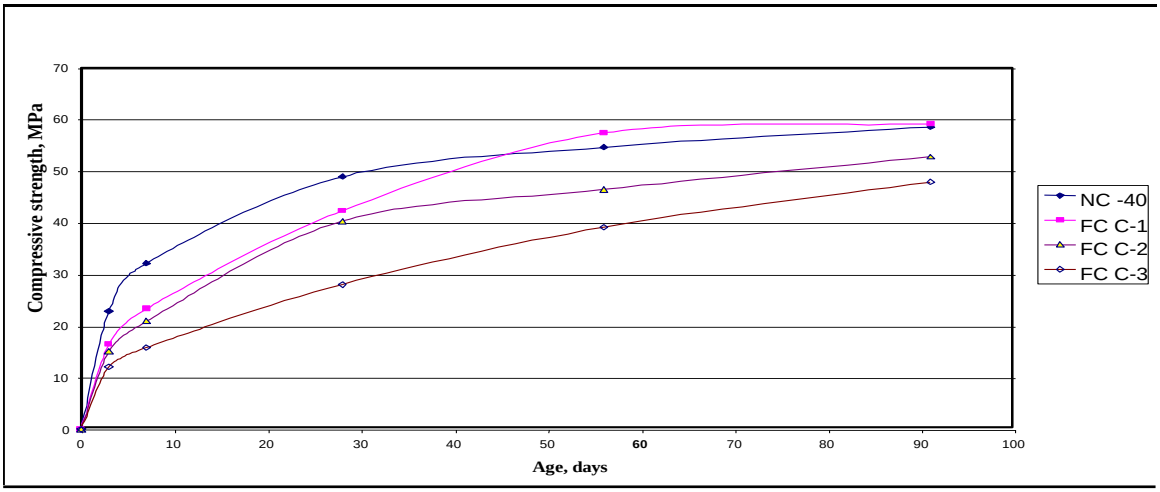

Figure 7 Variation of compressive strength with curing period for varying w/b ratios for M40 NC and FAC 50% CRL

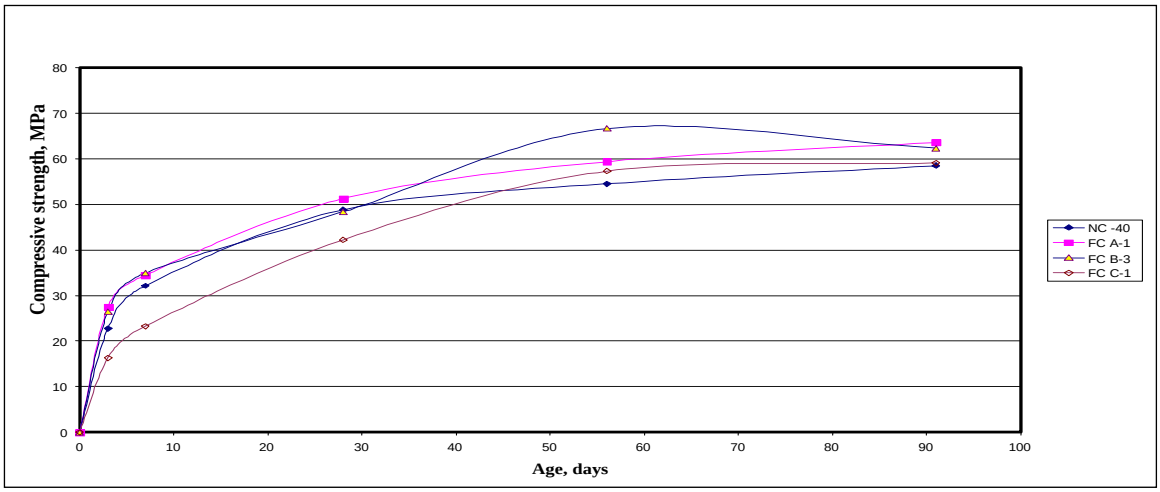

Figure 8: Variation of compressive strength with curing period for selected w/b ratios for different CRLs M40

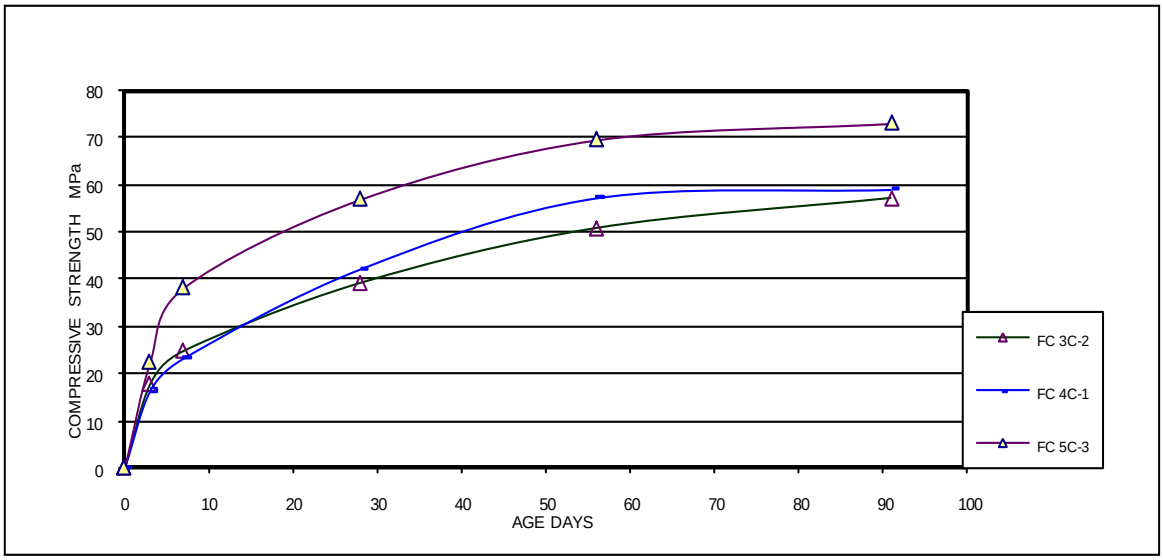

Figure 9: Variation of compressive strength with curing period for varying w/b ratios for M50 NC and FAC 20% CRL

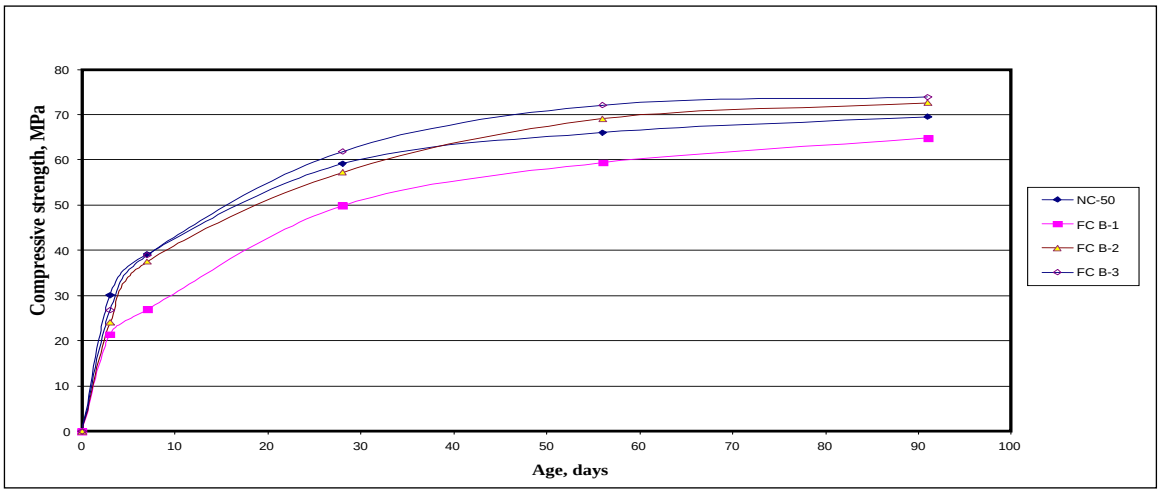

Figure 10: Variation of compressive strength with curing period for varying w/b ratios for M50, NC and FAC 35% CRL

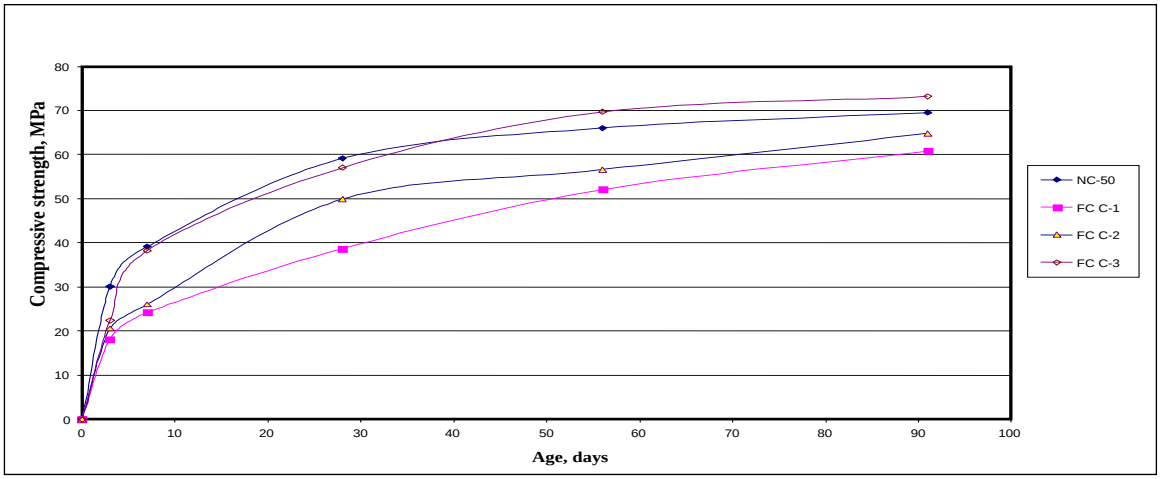

Figure 11: Variation of compressive strength with curing period for varying w/b ratios for M50, NC and FAC 50% CRL

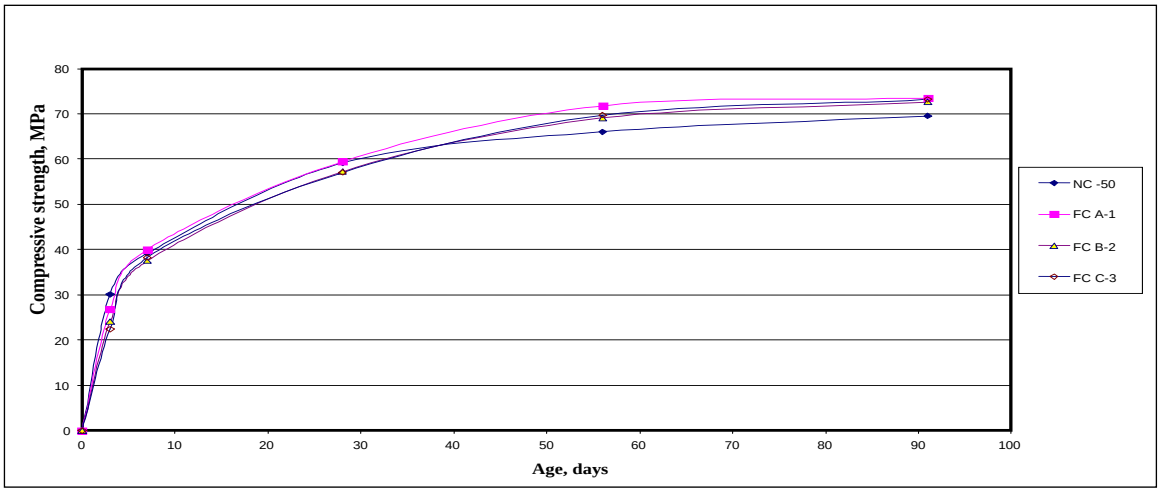

Figure 12: Variation of compressive strength with curing period for selected w/b ratios for different CRLs M50

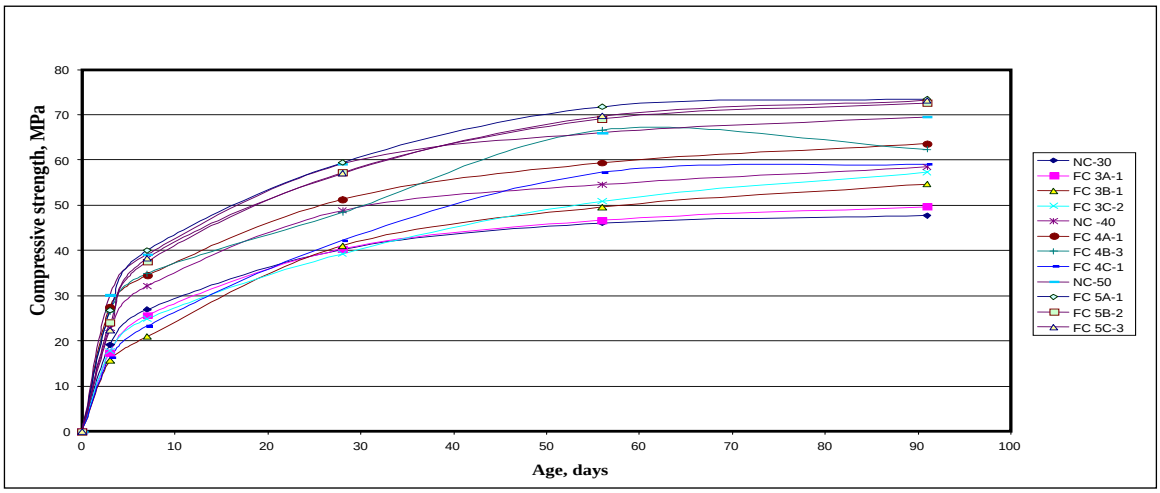

Figure 13: Variation of compressive strength with curing period for selected w/b ratios for different CRLs for all three grades of concrete

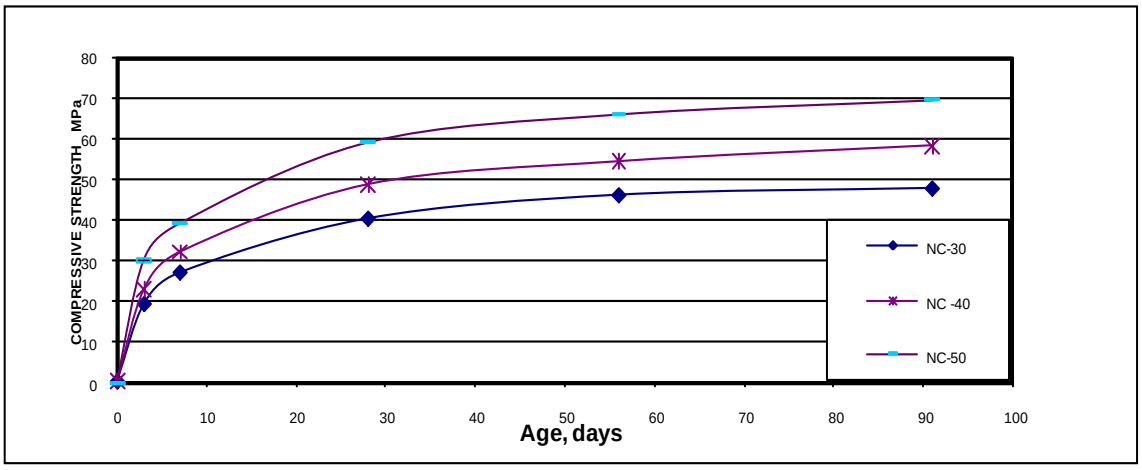

Figure 14: Variation of compressive strength with curing period for all three grades of normal concrete

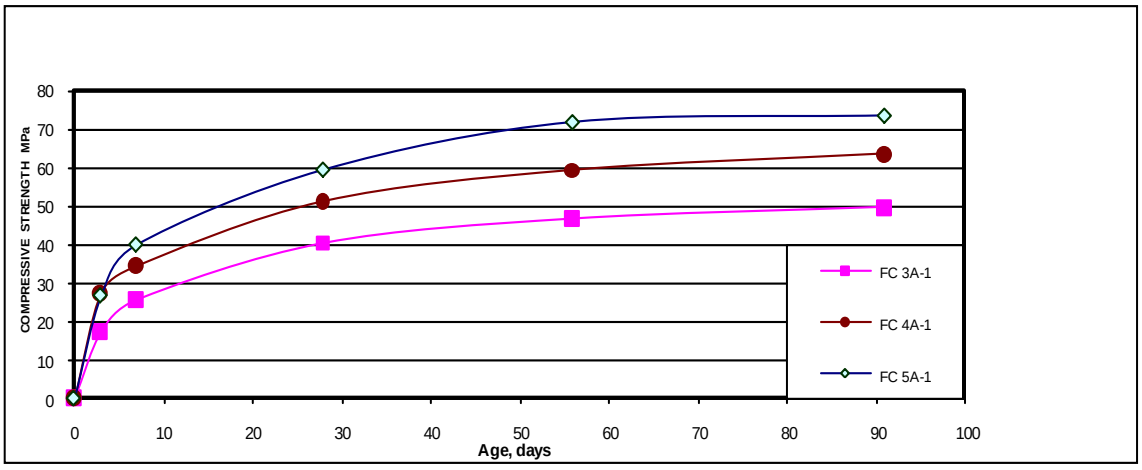

Figure 15: Variation of compressive strength with curing period for all three grades of Fly ash concrete 20% CRL

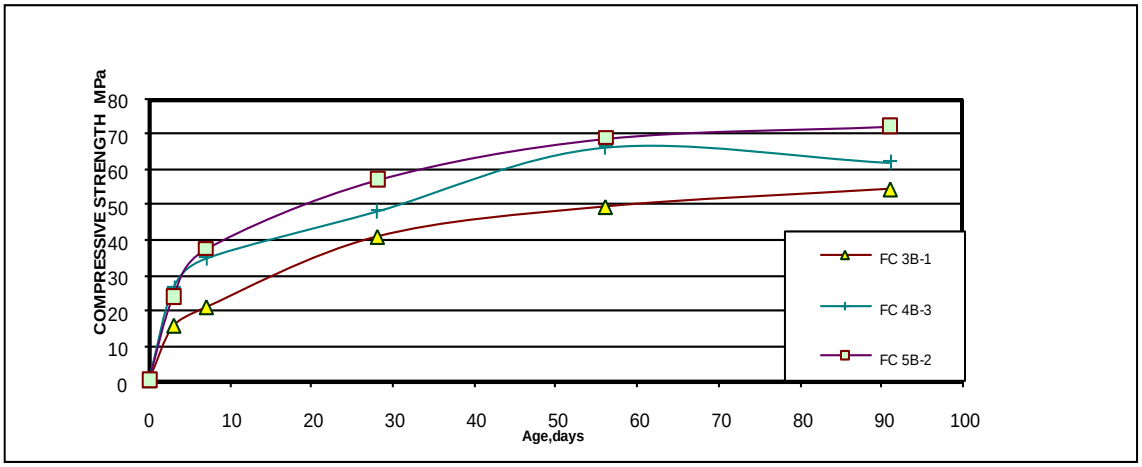

Figure 16: Variation of compressive strength with curing period for all three grades of Fly ash concrete 35% CRL

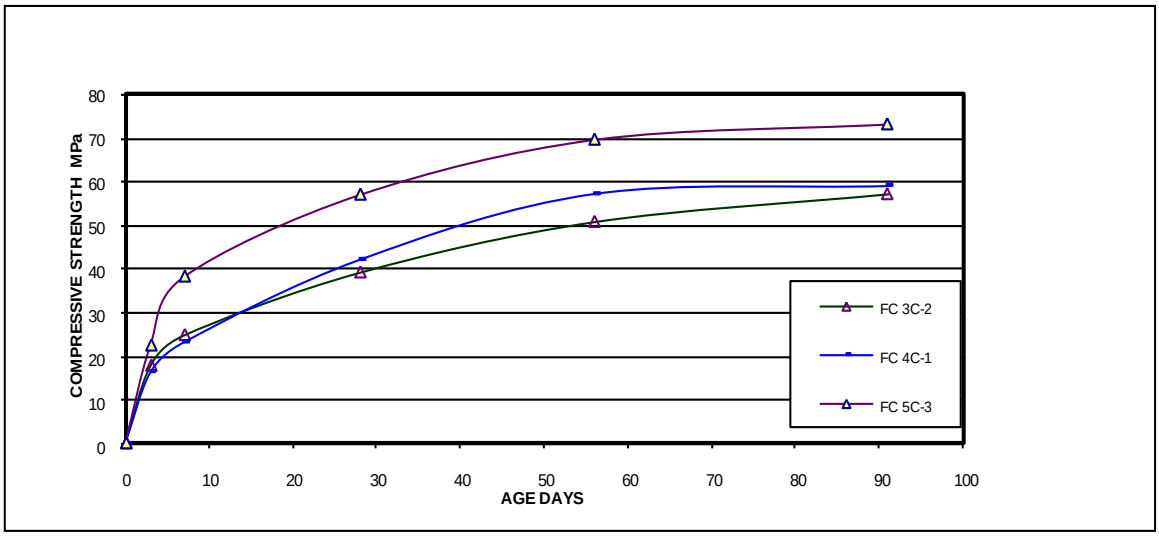

Figure 17: Variation of compressive strength with curing period for all three grades of Fly ash concrete 50% CRL

I. CONCLUSION

It is clear from the discussions on FACs and NC of M30, M40 and M50 that

(i) As curing period advances the strength of FAC and NC increase in all three grades of concrete as seen in Figures 1 to 17.

(ii) The addition of Fly ash is found to reduce the compressive strength in comparison to NC at early ages (3 and 7 days) in all three grades of concrete as observed in Figures 4, 8, 12, 13 and 17. These results are in agreement with the findings of several investigators like [5,6], who have also concluded that partial replacement of cement by Fly ash results in lower early age strengths of FAC. In the present study, there is marked increase of compressive strength between 28 and 56 days and a slight increase there after up to 91 days. These findings are in close agreement with those of investigators like [2,3,7,8], concluded that FAC gains strength subsequently from 28 days to 56 days.

(iii) In the present study, at 56 days the strength of M30 FAC is found to be 1.25 times that of M30 FAC at 28 days. Similarly, at 56 days the strength of M40 FAC is found to be 1.24 times that of M40 FAC at 28 days and at 56 days the strength of M50 FAC is found to be 1.20 times that of M50 FAC at 28 days.At 56 days the strength of M30 NC is found to be 1.15 times that of M30 NC at 28 days. Similarly, at 56 days the strength of M40 NC is found to be 1.20 times that of M40 NC at 28 days and at 56 days the strength of M50 NC is found to be 1.12 times that of M50 NC at 28 days.

REFERENCES

[1] Ganesh Babu. K., Siva Nageshwara Rao., "Efficiency of Fly Ash Concrete with Age", Cement and Concrete Research, Vol. 26, No. 3, 1996, pp.465-474.

[2] Mullick. A. K., "Use of Fly ash in Structural Concrete: Part I - Why?", The Indian Concrete Journal, Vol. 79, 2005, pp.13-22.

[3] Mullick. A. K., "Use of Fly ash in Structural Concrete: Part II - How Much?", The Indian Concrete Journal, Vol. 79, 2005, pp. 10-14.

[4] Nataraja. M. C., Ramalinga Reddy. B. M., Bhavanishankar. S., and Bharathraj Y. B., "Mix Design and Some Properties of Cement Replacement by Large Volumes of Fly ash", Proceedings of the Second International Symposium as Concrete Technology for Sustainable Development, February - March 2005.

[5] Sivasundaram. V., "Evaluation of Indian Fly ashes for Use in HVFA Concrete-Part II: Behavior in Concrete", The Indian Concrete Journal, 78 (11), 2004, pp.41- 50.

[6] Sivasundaram. V., Carette. G. G., and Malhotra. V. M., "Long-Term Strength Development of High-Volume Fly Ash Concrete", Cement and Concrete Research, September 1990, pp.263-270.

[7] Tarun R. Naik., Shiw S. Singh., and Mohammad M. Hossain., "Permeability of Concrete containing Large Amounts of Fly ash", Cement and Concrete Research, Vol. 24, No.05, April 1994, pp.913-922.

[8] Torben C. Hansen., "Long-Term Strength of High Fly ash Concretes", Journal of Cement and Concrete Composite, April 1990, pp. 193-196.