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Effect of Non-Chloride Hardening Accelerator on the Compressive and Flexural Strengths at Early and Later Age of Pavement Concrete Produced with Pozzolana Cement

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Abstract

This paper explains the experimental findings on the role of non-chloride hardening accelerator on the mechanical properties of pavement concrete at early and later age, produced with Portland Pozzolana Cement (PPC) as cementitious material. Concrete mixtures were designed as per revised guidelines of Indian Standards IS 10262: 2009 with varied dosage of accelerator. Fresh concrete properties were studied by Slump test. Compressive and flexural strengths of standard laboratory specimens, cured with water were assessed at early age and at full maturity.

Keywords: Fast-track; Accelerator; Blended cements; Compressive strength; Flexural strength

INTRODUCTION

Repair and rehabilitation of concrete roads shall be an on-going priority as concrete roads which are designed for a specific projected traffic volume may have to sustain greater traffic in future. Traditional methods of rehabilitation of rigid pavements are time consuming and cause several days of traffic interruption, more so in heavy-traffic areas. Further, these methods incur high replacement cost. Emergence of fast-track pavement technology for concrete roads has overcome this problem [1]. Fast-track paving typically does not require any special equipment or newly developed technique [2]. With conventional ingredients it is possible to design reasonably good fast-track concrete mixtures with the help of mineral and chemical admixtures. Concrete roads are typically built and rehabilitated with Ordinary Portland Cement (OPC). But due to acute shortage of OPC, all government projects in India are made to suffer from non-availability of cement [3].Hence need for supplementary cementitious materials, which can replace OPC partially or completely has increased substantially [4]. The two industrial by products, namely Fly Ash and Blast Furnace Slag, if used appropriately in cement concrete, will not only mitigate the problem of their disposal (which otherwise are deemed as waste) but also concrete produced will be durable[5].

Research on the use of supplementary cementitious materials in cement concrete hints at the limitation of their blending with cement at site due to lack of testing facility to check their pozzolanic characteristics and due to other practical reasons[3].Hence blending of cementitious materials during the production of cement under strict quality control is prudent to reap the benefits. Fly ash based PPC is one such blended cement used widely in various construction works but has very limited application in pavement construction.

One of the nagging problems associated with concrete pavements in the tropical regions is the evolution of heat of hydration and its undesirable effects on their performance. Heat of hydration is seen as an aging parameter in concrete [6]. The objective of reducing heat of hydration in concrete can be achieved by using mineral admixtures and blended cements [3]. Further, concrete produced with Fly Ash has improved workability, less segregation and bleeding, increased water tightness and reduced tendency of time to leach out [5]. Experimental findings suggest that chloride permeability of plain cement concrete is more than fly ash concrete for same water to cementitious materials ratio and cementitious materials content[7]. Experimental investigations further suggest that resistance against long-term environmental conditions such as chloride attacks, freeze-thaw cycles can be improved with blended cements.

Many state departments of transportation (DOTs) are allowing the use of blended cements as construction material in transportation structures instead of typically disposing them off to landfills [8]. In India, though IS 456:2000, Code of Practice for Plain and Reinforced Concrete permits use of PPC, Ministry of Road Transport and Highway(MORT&H) specification clause 602 and 1000 do not permit its use. Further, IS 15:2002, Code of Practice for Construction of Concrete Roads allows PPC conforming to IS 1489. Other organizations like Central Public Works Department (CPWD), Military Engineering Services (MES) and Indian Railways permit the use of PPC in the construction works.

Accelerators, particularly hardening accelerators are desirable admixtures in the fast-track paving mixtures. They increase the rate of hydration, thereby giving high early strength for concrete. They primarily target aluminate phase resulting in rapid workability loss [9]. Study on accelerators suggests that they help in improving the resistance to wear, depending on the curing age [2].They also play a vital role in reducing chloride attack on concrete [10].Limited application of accelerator is seen in fast-track construction and generally only calcium chloride is tried as accelerator [2]. Non-chloride accelerators are now being tried in place of calcium chloride in order to minimize potential of steel corrosion [11].

EXPERIMENTAL PROGRAM

Scope

Often the 28-day compressive strength is considered as the sole criterion for approving a concrete mix by the construction industry. But for concrete pavements flexural strength is considered as design criterion. Hence correlation between compressive and flexural strengths of pavement concrete at early and later age, produced with non-chloride hardening accelerator assumes greater importance in Indian construction scenario in the light of revised guidelines for concrete mix proportioning as given by IS 10262-2009, especially for fast-track pavement concrete when PPC is used as cementitious material in place of OPC.

Materials

River sand was used as fine aggregate along with 20 mm and 10 mm crushed granite coarse aggregate. PPC(fly ash based) conforming to IS 1489-1991 (Part 1), commercial non-chloride hardening accelerator(ASTM C- 494 Type C and IS 9103: 1999 standard , colorless free flowing liquid , relative density 1.2 ±0.02 at 25^{o}C , pH ≥6, chloride ion content < 0.2%) and ordinary tap water were used in the production of concrete. The properties of the materials are listed in table 1 and table.

Concrete mix design for grade M40 was carried out using revised guidelines of IS 10262:2009. The quantities by weight per cubic meter of concrete, of cement and water were kept constant at 442.85 kg and 186 kg respectively throughout the investigation. According to the revised guidelines of IS 10262:2009, volume of all in aggregate depends not only on volumes of cement, water but also on the volume of admixture, further, mass of coarse aggregate and fine aggregate depends on volume of all-in aggregate. Hence as the dosage of admixture is varied in a mixture, the quantities (mass) of aggregates also vary. The dosage of admixture was varied from 0 to 1.422 percent by weight of cement (2 liter to 5 liter per cubic meter of fresh concrete) in seven equal intervals. Table 2 shows the ingredients of pavement concrete for different dosages of accelerator, produced with PPC.

Tests

All mixtures were subjected to tests that examined fresh and hardened properties of concrete. The fresh concrete properties were tested by Slump test. Compression tests on laboratory cube specimens of size 150 mm and Third-point loading flexural strength tests on laboratory beam specimens of size 100 mm x 100 mm x 700 mm were carried out to assess the hardened properties in accordance with IS 516:1959.

RESULTS AND DISCUSSION

Fresh Concrete Properties

Fresh concrete properties are recorded in table 3. The range of slump values for all the mixtures was 5 to 10 mm and the mixtures with higher dosage of accelerator recorded lower slumps. The workability of all the mixtures was very low and with the increased dosage of accelerator it was still on the lower side. No distinct behavior was observed by the mixtures in the workability results.

Hardened Concrete Properties

Hardened concrete properties at early age and at full maturity (twenty-eight day) were assessed by both compressive and flexural strength tests for the mixtures with varied dosage of accelerator from 0 to 1.422 percent by weight of cement.

It is not only the strength at full maturity, but the strength at early age is equally important in fast- track pavement construction and rehabilitation. Hence, both compressive and flexural strength (modulus of rupture) at one, two, three, five, seven and twenty-eight day of curing for the mixtures, with varied dosage of accelerator were studied. The values are shown in tables 4 and 5. Percentage gain in strength of these mixtures with varied dosage of accelerator, with reference to the strength of control mix, i.e. with no accelerator was calculated.

Table.1. Specific gravity

Cement PPC	2.90
Fine aggregate*	2.60
Coarse aggregate**	2.71

*Conforming to grading zone IV of IS 383:1970. ** 20mm and 10mm aggregates in the ratio of 60:40, combined gradation conforming to IS 383:1970 grading limits for coarse aggregate, for graded aggregates.

Table.2. Accelerator dosage and mix proportions of mixtures

Accelerator (%)	Cement	Fine aggregate	Coarse aggregate	w/c ratio	Mixture name
0	1	1.335	2.653	0.42	PPC0
0.5826	1	1.331	2.647	0.42	PPC1
0.728	1	1.330	2.645	0.42	PPC2
874	1	1.329	2.643	0.42	PPC3
1.0195	1	1.328	2.640	0.42	PPC4
1.165	1	1.327	2.639	0.42	PPC5
1.310	1	1.326	2.637	0.42	PPC6
1.456	1	1.325	2.635	0.42	PPC7

Almost all the mixtures invariably showed increase in compressive and flexural strengths with increase in the dosage of accelerator at early age and the twenty-eight day compressive strength was least affected by increase in the dosage of accelerator. The results are recorded in tables 4 and 5 for compressive and flexural strengths respectively. Maximum compressive strengths recorded at one, two, three, five, seven and twenty-eight days of curing were 25.120, 31.645, 34.285, 36.780, 38.980 and 50.928 respectively in MPa. All these values peaked for the maximum dosage (1.422 percent) of accelerator. Maximum flexural strengths at one, two, three, five, seven and twenty-eight days of curing were 2.685, 2.904, 4.969, 5.377, 5.512 and 7.120 respectively in MPa. Again all these values recorded for the maximum dosage of accelerator.

Percentage gain in compressive and flexural strength for given dosage of accelerator and for given period of curing, expressed with reference to that of control mix(with no accelerator) was calculated and is shown in figures 1 and 2 respectively. The maximum percentage gain in compressive and flexural strengths at all the days of curing was recorded at the maximum dosage of accelerator. The maximum percentage gain in compressive strength at two day was 61.289 which is the peak value recorded for any period of curing. The maximum percentage gain in compressive strength was moderate at 43.625 and 37.956 for one and three days of curing respectively. The percentage gain in compressive strength at five and seven days was marginal with increase in the dosage of accelerator. The maximum increase in the percentage gain for seven day compressive strength was found to be less in comparison to that for five day compressive strength. The maximum percentage gain in compressive strength at five and seven days was 22.257 and 16.109 respectively. The percentage gain in twenty-eight day compressive strength was low and a maximum of only 4.678 percent was recorded. All the mixtures were able to attain design strength in twenty-eight day of curing.

The maximum percentage gain in flexural strength was

Table.3. Workability of mixtures

Mixture	PPC0	PPC1	PPC2	PPC3	PPC4	PPC5	PPC6	PPC7
Slump (mm)	10	10	10	10	5	5	5	5

Table.4. Compressive strength of mixtures

Mixture	Accelerator (%)	Compressive strength (MPa)					
		1 day	2 day	3 day	5 day	7 day	28 day
PPC0	0	17.490	19.620	24.852	30.084	33.572	48.652
PPC1	0.5690	19.184	24.852	28.340	31.828	34.444	48.652
PPC2	0.7213	20.056	25.288	29.120	32.264	35.280	49.289
PPC3	0.8535	21.215	28.340	30.084	33.185	36.124	51.012
PPC4	0.9950	22.316	29.324	31.125	34.285	36.850	51.012
PPC5	1.1380	23.428	30.212	32.430	35.180	37.125	51.448
PPC6	1.2800	24.852	31.645	33.185	35.280	38.280	50.704
PPC7	1.4220	25.120	31.645	34.285	36.780	38.980	50.928

Table.5. Flexural strength (modulus of rupture) of mixtures

Mixture	Accelerator (%)	Flexural strength (MPa)					
		1 day	2 day	3 day	5 day	7 day	28 day
PPC0	0	1.844	2.197	2.689	3.215	4.795	6.592
PPC1	0.5690	1.903	2.217	2.786	3.410	4.925	6.611
PPC2	0.7213	2.001	2.511	3.590	4.159	5.102	6.670
PPC3	0.8535	2.197	2.59	4.100	4.296	5.18	6.788
PPC4	0.9950	2.237	2.688	4.473	4.689	5.18	6.827
PPC5	1.1380	2.589	2.825	4.924	5.180	5.356	6.847
PPC6	1.2800	2.610	2.845	4.855	5.282	5.411	7.004
PPC7	1.4220	2.685	2.904	4.969	5.377	5.512	7.120

moderate at one and two day, high at three and five day and low at seven and twenty-eight day of curing. With 84.789 percent the maximum percentage gain in flexural strength was the uppermost value recorded for any period of curing. The maximum percentage gain in flexural strength at one and two days of curing was moderate at 45.607 and 32.180 respectively. The maximum of 67.247 percentage gain in flexural strength was recorded at five day of curing. The peaking of flexural strength at seven and twenty-eight day of curing was low with maximum percentage gain of 14.953 and 8.009 respectively.

Flexural strength expressed as percentage of compressive strength for all the days of curing and for all the dosages of accelerator is shown in figure 3. From the figure it is evident that at early age of concrete it is lower and higher for the later age of concrete. The average of flexural strength for all the seven mixtures (for varied dosage of accelerator) for a given age of concrete, again expressed as percentage of average compressive strength is shown in fig. 4. It recorded lower values of around 10 percent at early (one and two day) age of curing. The average flexural strength increased to 13.156 percent at three day of curing and there after remained almost constant in the range of 13 to 14 percent.

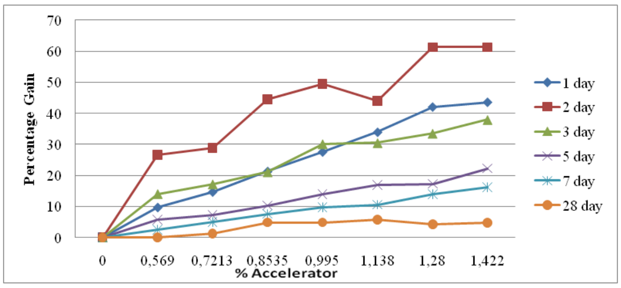

Fig.1. Percentage gain in compressive strength for varied dosage of accelerator and at different age of curing.

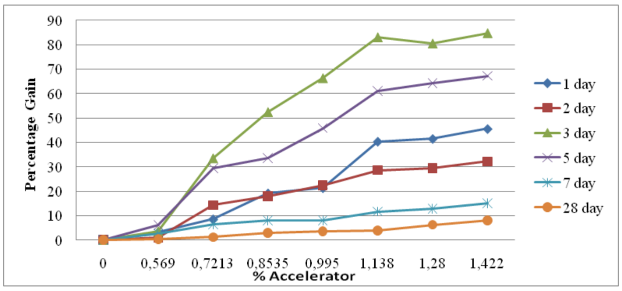

Fig. 2. Percentage gain in flexural strength (modulus of rupture) for varied dosage of accelerator and at different age of curing.

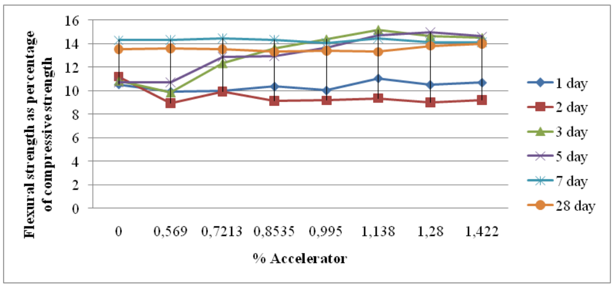

Fig.3. Flexural strength (modulus of rupture), expressed as percentage of compressive strength for varied dosage of accelerator and at different age of curing.

CONCLUSIONS

Following conclusions can be drawn from the outcome of this experimental program.

1. Accelerator was more effective in increasing the flexural strength than compressive strength of the designed concrete mixtures.
2. Maximum percentage gain in compressive strength was more than sixty percent, recorded at two day of curing with maximum dosage of accelerator.
3. In attaining maximum percentage gain in compressive strength, mixtures performed better at early age (one two and three days of curing); whereas their performance was lower for five and seven days of curing. The accelerator had negligible effect on the percentage gain in compressive strength of mixtures at twenty-eight day of curing.
4. Accelerator was most effective at three day of curing in recording maximum percentage gain in flexural strength and the hike was above eighty percent. Maximum percentage gain in flexural strength was moderate at one and two days, high at five days and low at seven and twenty-eight days of curing.

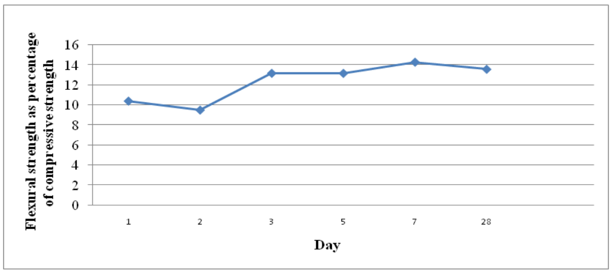

Fig.4. Average flexural strength (modulus of rupture), expressed as percentage of compressive strength, at different age of cuing.

5. The average flexural strength for all the dosage of accelerator, expressed as percentage of average compressive strength was found to be around ten percent for one and two days of curing whereas it was higher in the range of thirteen to fourteen percent for other days of curing.

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