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Interaction of Non-Chloride Hardening Accelerator with Type of Cement and Method of Curing in the Strength Development of Pavement Concrete

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ABSTRACT

This paper explains the interaction of commercial non-chloride hardening accelerator with type of cement and method of curing in the strength development of pavement concrete. Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC) were the two cements used to produce concrete mixtures. Concrete mixtures were designed as per the new guidelines of IS 10262:2009. Accelerator dosage was varied from 2 liters to 5 liters per cubic meter of concrete in seven equal intervals. Compressive strength of standard cube specimens (150 mm) at early and later age cured with water and alternatively with commercial wax based membrane forming curing compound, was studied. Performance of accelerator at a given age of concrete was assessed based on the maximum percentage increase in the compressive strength, measured with reference to the strength of control mixture (without accelerator), at the corresponding age. Average efficiency of the curing compound at a given age, calculated as the ratio of average compressive strength of concrete cured with it to that cured with water, was also studied. The test results revealed that the type of curing affected the optimum performance of accelerator in OPC mixtures but not in PPC mixtures. Curing compound was more effective in PPC mixtures.

***Keywords* - Accelerator, Blended cements, Compressive strength, Curing, Fast-track**

1. INTRODUCTION

Capacity enhancement of National Highways qualitatively and quantitatively initiated by National Highway Development Project (NHDP) under the aegis National Highway Authority of India (NHAI) is an ambitious plan which involves design and construction of high speed corridors including concrete roads. With continuous increase in the traffic of heavy vehicles, repair and rehabilitation of these roads is imminent due to the fact that most of our infrastructure deteriorates at unacceptable rates. New vistas need to be explored to extend the needful life of distressed structures cost-effectively, especially in developing countries like India. 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 particularly for concrete roads has overcome this problem [1]. Fast-track paving typically does not require any special equipment or newly developed technique [2]. Design of suitable concrete mixtures is the most important aspect in the fast-track pavement technology and with conventional ingredients it is possible to design reasonably good fast-track concrete mixtures by incorporating 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 construction projects in India are made to suffer from the non-availability of cement [3]. Hence need for supplementary cementitious materials, which can replace OPC partially or completely has increased substantially [4]. Two industrial by products, namely Fly Ash and Blast Furnace Slag if used appropriately in cement concrete as supplementary cementitious materials, can enhance the durability of concrete. [5].

Research on the use of these 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 Portland Pozzolana Cement (PPC) is one such blended cement used widely in various construction works but has very limited application in pavement construction in India.

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 can be achieved by using mineral admixtures and blended cements [3]. Further, concrete containing Fly Ash has shown improved workability, less segregation and bleeding, increased water tightness and reduced tendency of time to leach out [5]. For same water to cementitious materials ratio and cementitious materials content, the plain cement concrete has found to exhibit more chloride permeability than blended cement concrete. [7]. It is further investigated that resistance of concrete against long-term environmental conditions such as chloride attacks and freeze-thaw cycles can be improved with the use of blended cements.

Many state departments of transportation (DOTs) are allowing the use of blended cements as the construction material in transportation structures instead of typically disposing them off to landfills [8]. In India, IS 456:2000, Code of Practice for Plain and Reinforced Concrete permits use of PPC but 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.

There are many methods that can be used in the production of concrete to accelerate rate of hydration. Accelerators, especially 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]. Production of concrete should be followed by effective curing to get the desired strength and durability. There are various methods of curing; each one has its own merits and demerits. In the recent times, curing compounds and high early-strength concrete have become the key features of the fast-track construction for rigid pavements, especially in the regions that suffer from the scarcity of water [1, 2]. Heat treatment is one of the methods employed to get early strength in concrete but there is a possibility of decline in strength at full maturity [12]. Curing compounds namely, acrylic and water based are effective in decreasing plastic and drying shrinkage strain for both ordinary and blended cements. [13].

Experimental findings in the past have modeled concrete by varying admixtures, cement and curing method qualitatively and quantitatively. Zhang and Zhang[14] demonstrated effect of moist curing in tropical regions at different temperatures on the strength and other properties of concrete produced with Portland Cement(ASTM Type I) and found strength of concrete cured at higher temperature to be higher. Buch et al. [15] in their work on high early- strength of plain cement concrete mixtures concluded that these mixtures could be prepared but interactions between various constituents could result in durability problems, moreover their work did not take into account the method of curing. Khokhar et al. [16] have used high content of mineral additions to improve early age strength of concrete without chemical admixture. Al-Gahatani [13] has studied properties of concrete with blended cement and acrylic based curing compound and experimentally found the curing efficiency of such compounds with respect to compressive strength to be typically in the range of 84 to 96 percent. In their study on the impact of admixture on the hydration kinetics of Portland cement concrete, Cheung et al.[9] have concluded that a number of specific requirements like type of cement, type of aggregate , climatic conditions, type of curing etc. were needed to model the behavior of accelerators. Yilmaz and Turken [17] have studied the effect of various curing materials on the compressive strength of concrete produced with multiple chemical admixtures excluding accelerators and concluded that laboratory preliminary tests were required to check the compatibility of curing material and chemical admixture to get favorable results for concrete.

Going through the literature in the form of experimental findings and reviews, the authors are of the opinion that independent effects of type accelerator, type of cement and method of curing on the property of concrete are assessed but interaction of a non-chloride hardening accelerator with type of cement and method of curing in the strength properties of concrete at early and later age is hitherto not assessed in the tropical environments like India, particularly with the revised guidelines for mix proportioning as given by IS 10262:2009[18]. The present experimental task is an effort in this direction.

The objective of the present experimental program is to give initial guidelines based on the compressive strength of concrete towards accelerated construction and rehabilitation of concrete roads in India, particularly by exploring the feasibility of PPC and membrane curing as possible alternatives to OPC and conventional water curing respectively.

2. MATERIALS AND METHODS

2.1 Materials

Two types of cements manufactured in India, namely Ordinary Portland Cement (OPC), conforming to IS 8112-1989 and fly ash based Portland Pozzolana Cement (PPC), conforming to IS 1489-1991(Part1) were used to prepare concrete mixtures, whose physical and chemical characteristics are given in Tables 1 and 2 respectively. Oven dried river sand conforming to grading zone IV of IS 383:1970[19] was used as fine aggregate. Saturated surface dry angular aggregates (Crushed Granite) of size 20 mm and 10 mm, mixed in the ratio of 60:40 were used as coarse aggregates such that the combined gradation conformed to IS 383:1970[19] grading limits for graded coarse aggregates. Table 3 shows the physical properties of aggregates. Ordinary tap water was used for mixing the concrete mixtures of the experimental study. Commercial non-chloride hardening accelerator conforming to ASTM C- 494 Type C and IS 9103: 1999 standards**,** in the form of colorless free flowing liquid having relative density 1.2 ±0.02 at 25^{o} C, pH ≥6 and chloride ion content < 0.2%, manufactured by BASF Construction Chemicals (India) Private Limited with brand name Pozzolith 100 HE, was used to accelerate hardening process of the concrete mixtures.

Table 1. Physical characteristics of OPC and PPC

Cement	Fineness (m^2/kg)	Soundness Autoclave (%)	Setting Time (Min.)		Compressive Strength-28 Day (MPa)	Specific Gravity
			Initial	Final		
OPC	230	0.8	95	230	45.2	3.15
PPC	305	0.7	105	240	37.50	2.90

Table 2. Chemical characteristics of OPC and PPC

Cement	Lime Saturation Factor (%)	MgO (%)	Ignition Loss
OPC	0.80	1.20	1.45
PPC	0.85	1.30	1.40

Table 3. Test results on aggregates

Aggregate	Specific Gravity	Bulk unit weight (kN/m^3)
Fine	2.60	15.77
Coarse	2.71	15.49

2.2. Concrete Mix Proportioning

Concrete mixtures of grade M 40 were designed for pavement concrete using revised guidelines of IS 10262:2009[19]. Table 4 shows ingredients of control mixtures (without accelerators), produced with OPC and PPC.

Table 4. Ingredients per cubic meter of concrete (Control mixtures)

Mixture	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (liters)
OPC0	432.56	609.03	1199.87	186
PPC0	442.85	591.20	1175.10	186

The control mixtures were modified with accelerator dosage from 2 liters to 5 liters per cubic meter of concrete as per the instructions of the manufacturer, i.e. 0.583 to 1.456 and 0.569 to 1.422 percent by weight of cement, in seven equal intervals for OPC and PPC mixtures respectively. Laboratory Drum-type, electrically operated mixer was used for mixing the ingredients and table vibrator was used for the purpose of compaction.

2.3 Curing

Cast concrete cube specimens (150 mm) were cured with water by immersing specimens in water tank at room temperature and alternatively with wax based membrane forming curing compound (Compliance-ASTM C309 Type II Class A, BS 7542: 1992) of brand name Mastercure, manufactured by BASF Construction Chemicals (India) Private Limited. Curing compound was applied after six hours of casting to all the surfaces of specimen by ordinary paint brush.

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2.4. Tests

Workability tests were conducted on the mixtures by slump test. 288 cube specimens of 16 different mixtures(8 each with OPC and PPC) were tested (Figure.1) at different age of curing by compressive strength test in accordance with IS 516:1959 [20] to evaluate the interaction of accelerator with type of cement and method of curing in the compressive strength development of concrete, as often compressive strength of concrete is deemed as the sole criterion to approve any concrete mixture and moreover it is possible to relate compressive strength to other strength and durability parameters using customary empirical equations.

Fig 1.Section of tested cube specimens in Compression Testing Machine

3. RESULTS AND DISCUSSION

The range of slump values for all the mixtures was 5 to 10 mm. The mixtures with higher dosage of accelerator recorded lower slump as the increased dosage of accelerator targeted aluminate phase resulting in rapid workability loss hence all the mixtures were insensitive to the Slump test [9]. Increase in compressive strength of a given concrete mixture at a given curing age in presence of accelerator, assessed with respect to the compressive strength of control mix at the corresponding curing age, was taken as the performance indicator of accelerator. With a view of early strength requirement in fast-track construction and rehabilitation , compressive strength of all the sixteen mixtures was tested at one, two, three, five, seven and twenty-eight day of curing. The strength results are tabulated in tables 5 to 8. Figures 2 to 5 show the percentage gain in compressive strength of the mixtures, measured with reference to compressive strength of control mixtures for different periods of curing, different accelerator dosage, type of cement and method of curing.
Efficiency of curing compound at a given age of concrete and for a given dosage of accelerator, defined as the ratio of compressive strength of the given mixture, cured with it to the compressive strength of the mixture cured with water, expressed as percentage was assessed for all the mixtures. Average efficiency of curing compound for OPC and PPC mixtures (for varied dosage of accelerator) for different periods of curing is as shown in figures 6 and 7 respectively.

Table 5. Compressive strength of OPC mixtures (Cured with water)

Mixture	% Accelerator	Compressive strength (MPa)					
		1 day	2 day	3 day	5 day	7 day	28 day
OPC0	0	24.67	26.50	28.40	30.20	37.20	49.96
OPC1	0.583	26.36	28.40	30.40	32.99	38.20	50.45
OPC2	0.728	26.77	30.50	34.37	36.55	38.38	51.85
OPC3	0.874	26.80	31.20	35.20	38.56	39.16	52.30
OPC4	1.019	27.20	31.67	35.80	39.53	40.10	53.40
OPC5	1.165	29.96	31.90	36.10	40.20	43.74	53.40
OPC6	1.31	30.20	31.50	37.20	41.56	42.96	52.96
OPC7	1.456	30.40	31.50	39.56	42.20	43.10	53.10

Table 6. Compressive strength of OPC mixtures (Cured with curing compound)

Mixture	% accelerator	Compressive strength (MPa)					
		1 day	2 day	3 day	5 day	7 day	28 day
OPC0	0	17.95	26.45	27.22	28.24	30.37	37.92
OPC1	0.583	18.20	27.32	27.92	30.16	33.86	38.46
OPC2	0.728	19.50	28.15	28.16	31.45	33.92	38.46
OPC3	0.874	20.45	28.20	28.27	31.82	34.29	38.67
OPC4	1.019	22.36	28.20	28.98	32.45	34.86	38.12
OPC5	1.165	22.10	28.92	29.12	32.38	34.92	38.93
OPC6	1.31	23.32	28.92	29.45	32.96	34.76	38.67
OPC7	1.456	23.80	29.12	30.16	33.12	34.92	39.12

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Table 7. Compressive strength of PPC mixtures (Cured with water)

Mixture	% accelerator	Compressive strength (MPa)					
		1 day	2 day	3 day	5 day	7 day	28 day
PPC0	0	17.49	19.62	24.852	30.084	33.572	48.652
PPC1	0.5690	19.184	24.852	28.34	31.828	34.444	48.652
PPC2	0.7213	20.056	25.288	29.12	32.264	35.28	49.289
PPC3	0.8535	21.215	28.34	30.084	33.185	36.124	51.012
PPC4	0.9950	22.316	29.324	31.125	34.285	36.85	51.012
PPC5	1.1380	23.428	30.212	32.43	35.18	37.125	51.448
PPC6	1.2800	24.852	31.645	33.185	35.28	38.28	50.704
PPC7	1.4220	25.12	31.645	34.285	36.78	38.98	50.928

Table 8. Compressive strength of PPC mixtures (Cured with curing compound)

Mixture	% accelerator	Compressive strength (MPa)					
		1 day	2 day	3 day	5 day	7 day	28 day
PPC0	0	14.75	17.51	23.78	24.82	25.30	35.46
PPC1	0.5690	15.62	19.91	26.38	27.38	27.58	36.42
PPC2	0.7213	16.20	24.56	27.83	29.96	30.31	36.92
PPC3	0.8535	16.80	25.00	27.83	30.31	31.16	37.12
PPC4	0.9950	18.16	25.62	28.21	31.46	32.45	37.12
PPC5	1.1380	19.24	26.12	28.25	32.12	32.28	38.20
PPC6	1.2800	19.96	26.76	28.45	32.12	32.92	38.46
PPC7	1.4220	18.78	26.76	28.96	32.72	33.42	38.92

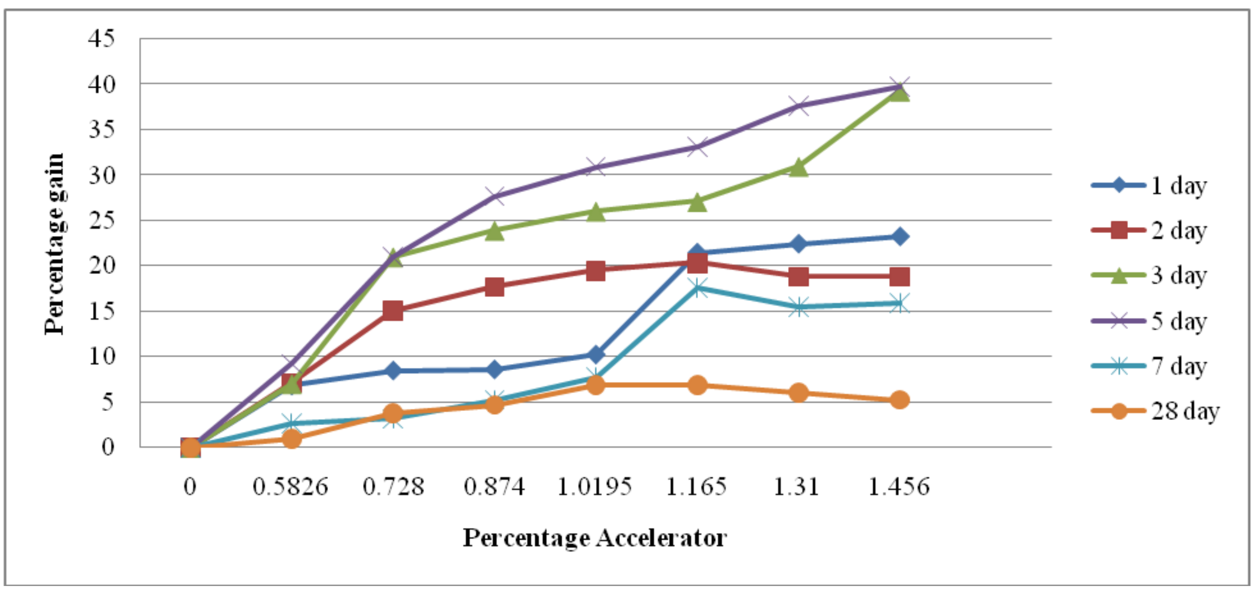

Fig 2. Percentage gain in compressive strength of OPC mixtures cured with water for varied dosage of accelerator

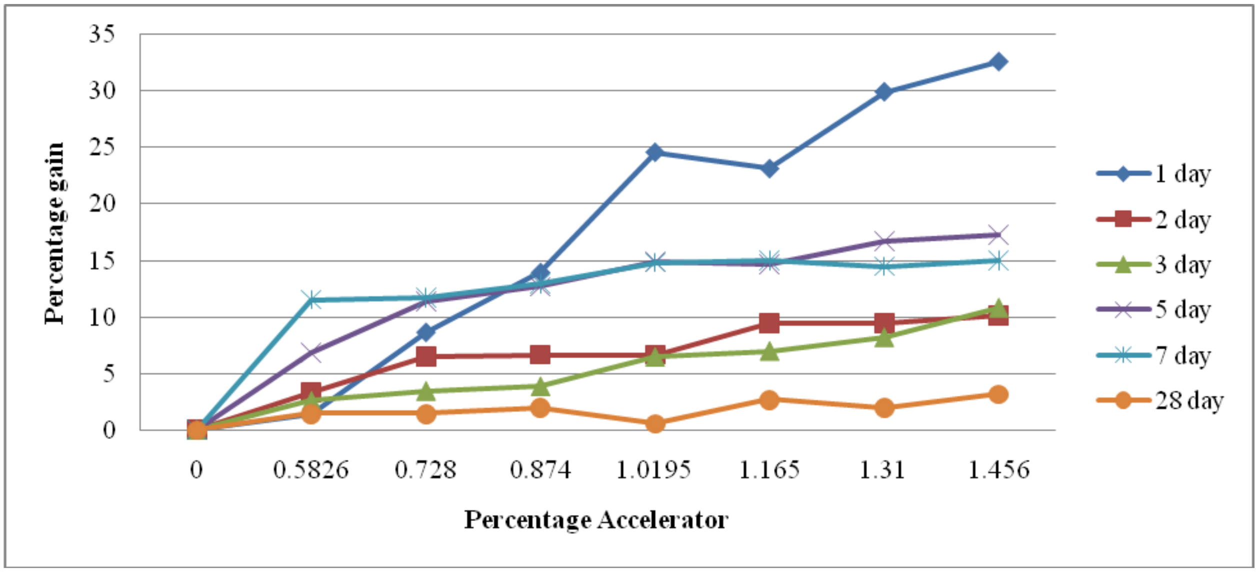

Fig 3. Percentage gain in compressive strength of OPC mixtures, cured with curing compound for varied dosage of accelerator

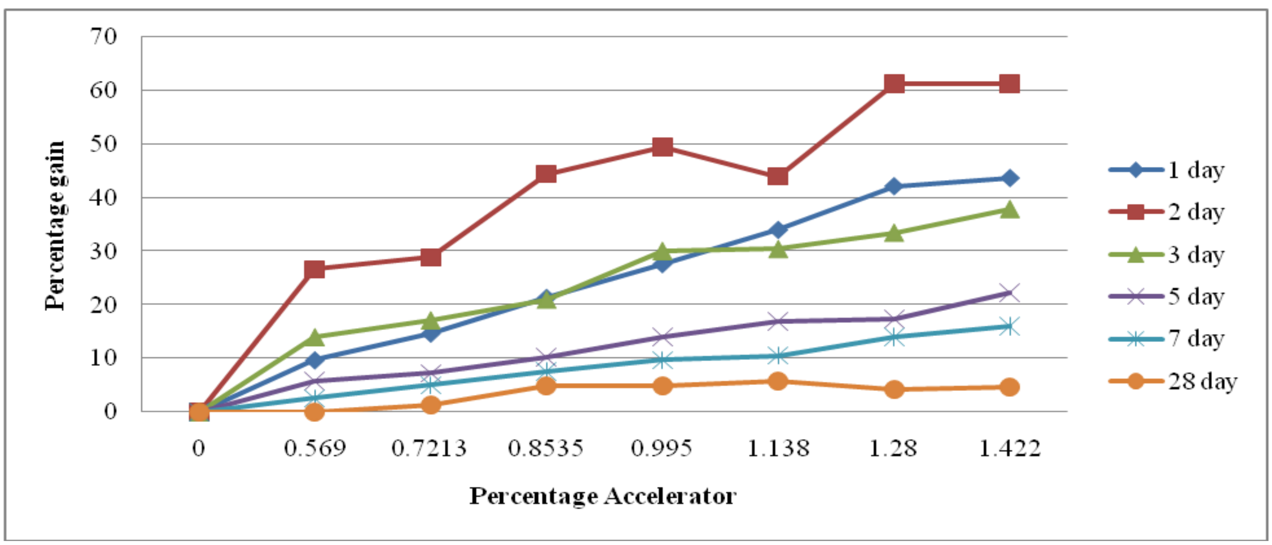

Fig 4. Percentage gain in compressive strength of PPC mixtures cured with water for varied dosage of accelerator

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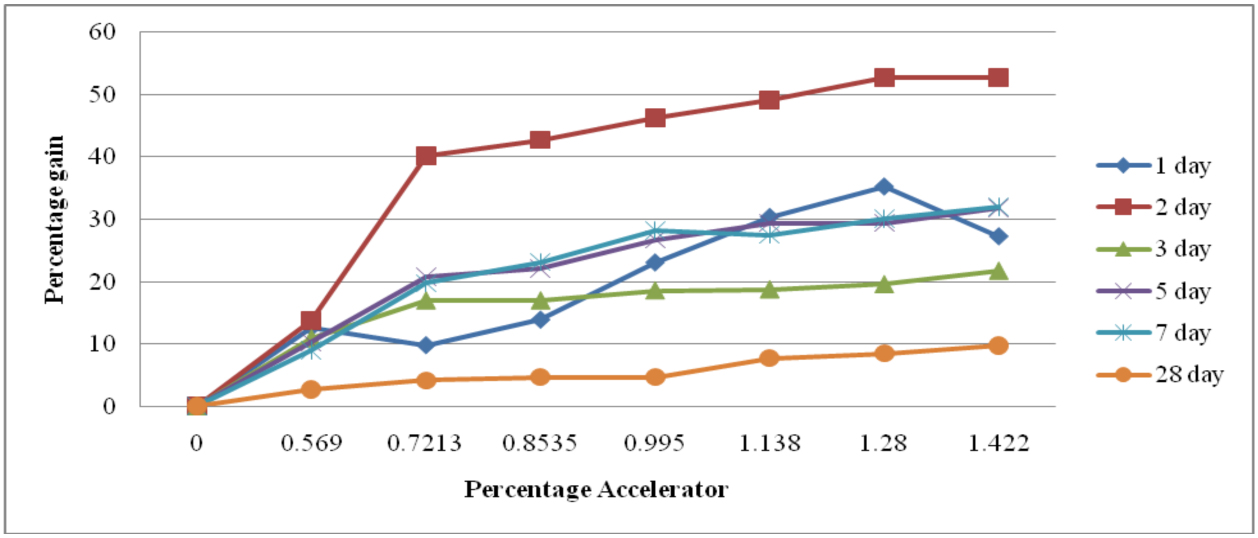

Fig 5. Percentage gain in compressive strength of PPC mixtures, cured with curing compound for varied dosage of accelerator

For a given dosage of accelerator and for a given period and type of curing, the compressive strength of OPC mixtures was more than that of PPC mixtures and the mixtures cured with curing compound failed to attain the stipulated design strength. The rate of strength gain in PPC mixtures, cured with water and with curing compound was slow at early age as hydration process of these mixtures was slow due to presence fly ash which is known to be less pozzolanic but the strength at twenty-eight day of all the PPC mixtures was on par with that of OPC mixtures for a given dosage of accelerator. Accelerator could not influence greatly to the twenty-eight day strength of all the mixtures. All the mixtures of OPC and PPC responded well to the addition of accelerator and there was gradual increase in the strength at early age.

In case of water-cured OPC mixtures, the uppermost maximum percentage gain in strength was 39.73, recorded at five day, by the mixture with maximum dosage (1.456 percent) of accelerator. The maximum percentage gain in strength at three day was close to that of five day with a value of 39.29, observed by the mixture with maximum dosage of accelerator. The maximum percentage gain in strength at one day was moderate with a value of 23.23, recorded by the mixture with maximum dosage of accelerator. With increase in the dosage of accelerator, the percentage gain in strength at two day increased gradually with a maximum value of 20.38 for the mixture with 1.165 percent accelerator and then attained a constant value of 18.87 for the mixtures with further dosages of accelerator. The seven day strength too increased gradually with the addition of accelerator and attained a maximum percentage hike of 17.58 for the mixture with 1.165 percent accelerator before attaining a percentage gain of 15.86 for the mixture with maximum dosage of accelerator. There was marginal hike of 5 to 6 percent in twenty-eight day strength recorded by the mixtures with greater dosage (above 1 percent) of accelerator.

The OPC mixtures cured with curing compound had moderate to low percentage gain in strength. The maximum percentage gain in strength observed at one day was 32.59. The maximum percentage hike was low with the values of 10.09 and 10.8 respectively at two and three day , moderate with the values of 17.28 and 14.98 respectively at five and seven day and negligible with a value of 3.16 at twenty-eight day. The maximum percentage gain in strength for all the days of curing was recorded by the mixtures with maximum dosage of accelerator.

In case of PPC mixtures cured with water, the uppermost maximum percentage gain in strength was 61.28 percent, recorded at two day by the mixture with maximum dosage (1.422 percent) of accelerator. The mixtures showed reasonably good gain in strength at one and three day of curing. The maximum percentage hike was 43. 625 and 37.956 percent at one and three day respectively, again recorded by the mixtures with maximum dosage of accelerator. The maximum percentage gain in strength at five and seven day was marginal with the values of 22.26 and 16.109, recorded with maximum dosage of accelerator. The percentage gain in twenty-eight day strength was low with a maximum increase of 4.678 percent, observed by the mixture with maximum dosage of accelerator.

The PPC mixtures cured with curing compound recorded lesser strength in comparison to that cured with water, but performed better in recording maximum percentage gain in strength. The uppermost maximum percentage gain in strength in these mixtures was observed at two day with a value of 52.83 percent in the mixture with maximum dosage of accelerator. The one day strength also gradually peaked with increase in the dosage of accelerator with maximum percentage hike of 35.32, recorded for the mixture with 1.28 percent of accelerator and then slipped to a lower value of 27.32, observed for the mixture with maximum dosage of accelerator. After peaking to a percentage increase of 17.03 for the mixture with accelerator dosage of 0.721 percent, the percentage gain in three day strength had a narrow range with further increase in the dosage of accelerator. The trend in percentage hike for five and seven day was almost similar to that of three day, with maximum percentage increase of 31.83 and 32.09, respectively recorded by the mixtures with maximum dosage of accelerator. The peaking of twenty-eight day strength was marginal with increase in the dosage of accelerator; a maximum of 9.76 percentage gain was recorded by the mixture with maximum dosage of accelerator.

Interaction of accelerator was better at three and five day of curing in the OPC mixtures cured with water and at one day in the same mixtures cured with curing compound. This could be attributed to the fact that OPC mixtures due to type of cement and accelerator, though generated more heat of hydration (in OPC half of the total heat of hydration is liberated within three day of curing), moist curing kept the heat under control and prevented drying of the surfaces of the specimens which resulted in effective hydration and high increase in strength at early age. With absence of this condition in membrane curing, rapid drying of the surfaces of the specimens, coupled with more heat of hydration, resulting in lessee gain in strength after one day. In case of PPC mixtures the optimum performance of accelerator was recorded at two day irrespective of type of curing. Lesser heat of hydration due to presence of fly ash could be the reason for such consistent performance of accelerator at early age. The optimum performance of accelerator in OPC mixtures was affected by type of curing.

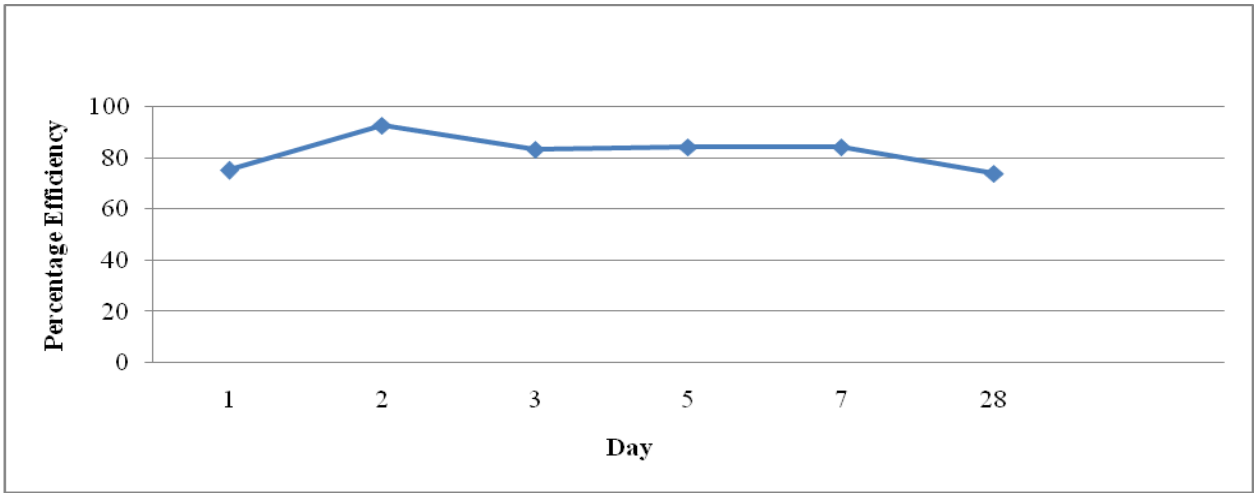

Fig. 6. Average efficiency of curing compound for OPC mixtures at different days of curing

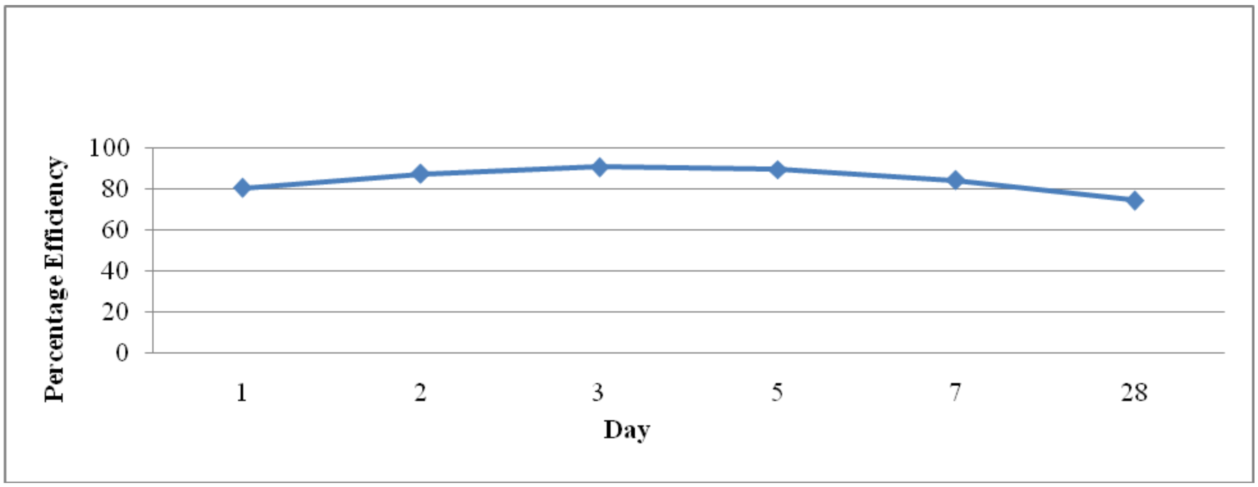

Fig.7. Average efficiency of curing compound for PPC mixtures at different days of curing

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Average efficiency of curing compound for OPC mixtures attained a moderate value of 75.27 at one day of curing, peaked to 92.83 at two day and gradually decreased for subsequent days of curing before settling for a lowest value of 73.9 at twenty-eight day. For PPC mixtures it increased gradually from 80.488 percent at one day, peaked to 90.59 percent for three day and then decreased gradually at five and seven day before attaining a lowest value of 74.36 at twenty- eight day. Average efficiency of the curing compound at a given age, was found to be more for PPC mixtures than for OPC mixtures. Further, Efficiency was found to be more at early age for both OPC and PPC mixtures, as decline in the quality of protective curing membrane due to variation in day and night room temperature could be the reason for the lower efficiency at later age.

4. CONCLUSIONS

Following are the conclusions from the outcome of the experimental program. Accelerator was effective in increasing the compressive strength of all the concrete mixtures. Performance of accelerator at a given age of concrete was assessed based on the maximum percentage increase in the compressive strength, measured with reference to the strength of the control mixture (without accelerator) at the corresponding age. Interaction of accelerator was better at three and five day in the OPC mixtures cured with water and at one day in the same mixtures cured with curing compound. In the PPC mixtures the optimum performance of accelerator, recorded at two day was not affected by type of curing. Average efficiency of the curing compound at a given age, calculated as the ratio of average compressive strength of concrete cured with it to that cured with the water was found to be more for PPC mixtures than for OPC mixtures. Efficiency was found to be more at early age for both OPC and PPC mixtures.

The present findings can serve as initial guidelines towards accelerated construction and rehabilitation of concrete roads in India, especially by exploring the feasibility of PPC and membrane curing as possible alternatives to OPC and conventional water curing respectively.

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