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Effect of Method of Curing on the Compressive Strength of Pavement Concrete produced with Blended Cement and Hardening Accelerator

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ABSTRACT

The present experimental study explains the effect of method of curing on the compressive strength of Pavement Concrete produced with Blended cement and non-chloride hardening Accelerator. Portland Pozzolana Cement (PPC) was used in the production of 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 age and at full maturity cured with water and alternatively with 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 did not affect optimum performance of accelerator. Average efficiency of the curing compound was found to be more at early age than at later age.

Introduction

Under the aegis of National Highway Authority of India (NHAI), National Highway Development Project (NHDP) is an ambitious plan for the capacity enhancement of National highways qualitatively and quantitatively 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 impending due to the fact that most of our infrastructure deteriorates at unacceptable rates. New possibilities 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 cause several days of traffic interruption, more so in heavy-traffic areas. Further, such methods incur high replacement cost. Fast-track pavement technology, especially for concrete roads has overcome this problem [1]. Special equipment or newly developed technique is not always necessary for fast-track road construction [2]. Design of suitable concrete mixtures is the most important facet in the fast-track pavement technology and it is possible to design reasonably good fast-track concrete mixtures with conventional native ingredients and admixtures. Ordinary Portland Cement (OPC) is generally used for construction and rehabilitation of concrete roads. But acute shortage of OPC has hampered all the government projects of construction in India. [3]. Hence there is urgent need for supplementary cementitious materials, which can replace OPC partially or completely [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].

Study on the use of these supplementary cementitious materials in cement concrete suggests 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.

Heat of hydration is one of the niggling problems associated with concrete pavements, especially in the tropical regions. Heat of hydration is considered 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]. It has been recognized that concrete produced with Fly Ash has 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, experimental findings advocate that chloride permeability of the plain cement concrete to be more than that of the concrete produced with blended cements [7]. It is further investigated that resistance of concrete against long-term environmental conditions such as chloride attacks, 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 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 whereas Ministry of Road Transport and Highway (MORT&H) specification

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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 and cost-effective admixtures for this purpose. 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 indicates 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 having its own merits and demerits. Curing by membrane forming curing compounds is becoming increasingly popular, especially for mass concreting like pavement construction in the areas that suffer from paucity of water. Of late curing compounds and high early- strength concrete have become the key features of fast-track construction for rigid pavements [1, 2]. Heat treatment is another method 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, Van Dam, Peterson and Sutter [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 method of curing. Khokhar, Roziere, Turcry, Grondin and Loukili [16] have used high content of mineral additions to improve strength of concrete at early age 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, Jeknavorian, Roberts and Silva[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. Ulku and Hakan[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 and method of curing on the property of concrete are assessed but interaction of a non-chloride hardening accelerator with method of curing in the strength properties of concrete at early and later age, produced with blended cement is yet to be studied in the tropical regions 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 by exploring the feasibility of PPC and membrane curing as possible alternatives to OPC and conventional water curing respectively.

Materials and Methods

Materials

Fly ash based PPC; conforming to IS 1489-1991(Part1) was 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.

Concrete Mix Proportioning

Concrete mixtures of grade M 40 were designed for pavement concrete using revised guidelines of IS 10262:2009[18]. Table 4 shows ingredients of control mixture (without accelerator) produced with PPC.

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

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 Masterkure107i, 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.

Tests

Workability tests were conducted on the mixtures by slump test.144 cube specimens of 8 different mixtures were tested at different age of curing by compressive strength test in accordance with IS 516:1959 [20] to evaluate the interaction of accelerator with blended 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.

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 increased dosage of accelerator targeted aluminate phase resulting in rapid workability loss [9]. Hence all the mixtures were insensitive to the Slump test. Increase in compressive strength of a given concrete mixture at a given curing age for a given dosage of accelerator, assessed with respect to the strength of control mixture 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 eight mixtures was tested at one, two, three, five, seven and twenty-eight day of curing. The strength results are tabulated in Tables 5 and 6. Figures 1 and 2 show the percentage gain in compressive strength of mixtures, measured with reference to the strength of control mixtures for different periods of curing and different accelerator dosage, for water and membrane curing respectively.

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 varied dosage of accelerator) for different periods of curing is as shown in Figure 3.

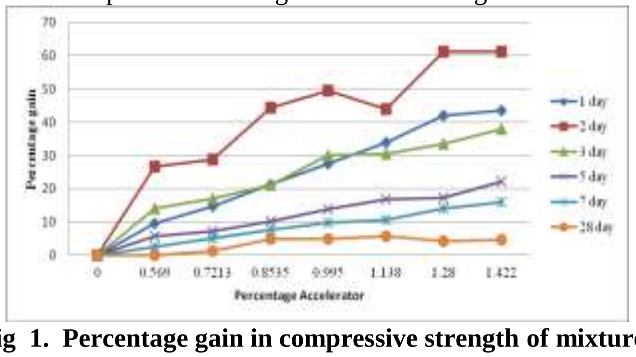

Fig 1. Percentage gain in compressive strength of mixtures cured with water for varied dosage of accelerator

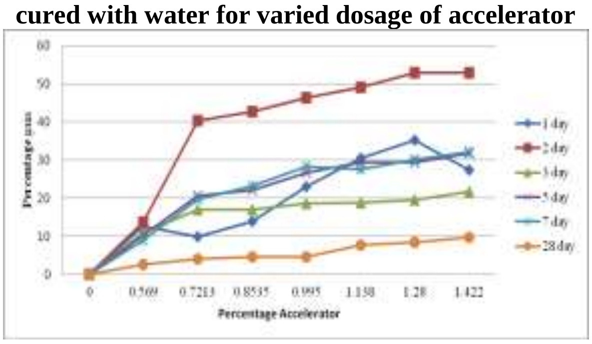

Fig 2. Percentage gain in compressive strength of mixtures, cured with curing compound for varied dosage of accelerator

All the mixtures cured with water attained stipulated design strength whereas none of the mixtures cured with curing compound could attain the same. The rate of strength gain in the mixtures, cured with water and with curing compound was slow at early age as hydration process was slow due to presence fly ash which is known to be less pozzolanic. Accelerator could not influence greatly to the twenty-eight day strength of all the mixtures. All the mixtures responded well to the addition of accelerator and there was gradual increase in the strength at early age.

In case of 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. 62 and 37.96 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 16.11, 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 mixtures cured with curing compound recorded lesser strength in comparison to that cured with water, but performed satisfactorily 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 0.7213 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.

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 consistent performance of accelerator at early age.

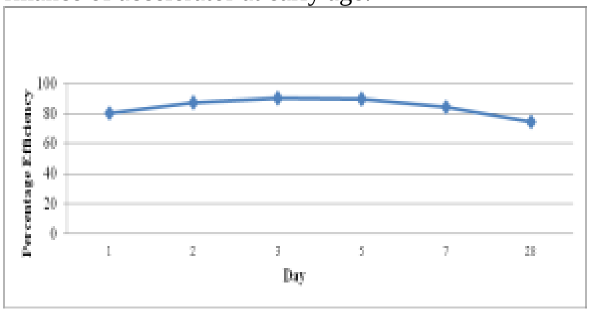

Fig 3. Average efficiency of curing compound for mixtures at different days of curing

Efficiency of curing compound increased gradually from 80.49 percent for one day, peaked at 90.59 percent for three day and then decreased gradually for five and seven day before attaining a lowest value of 74.36 for twenty- eight day. Efficiency was found to be more at early age as the quality of protective membrane at later age deteriorated due to variation in day and night room temperature thereby lowering the efficiency.

Conclusions

Following are the conclusions from the outcome of the experimental program. Accelerator was effective in increasing the compressive strength of concrete mixtures but 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. Accelerator was more effective at early age in water-cured mixtures (up to 3 day) and at later age in the mixtures cured with curing compound. 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 at early age than at later age.

The present findings can serve as initial guidelines towards fast-track construction and rehabilitation of concrete roads in India by considering blended cement as possible alternative to Ordinary Portland Cement in the concrete mixtures, cured with two different methods.

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Table 1. Physical characteristics of cement

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

Table 2. Chemical characteristics of cement

Lime Saturation Factor (%)	MgO(%)	Ignition Loss
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

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

Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate(kg)	Water (liter)
442.85	591.20	1175.10	186

Table 5. Compressive strength of 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 6. Compressive strength of 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