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Experimental Investigation of Magnesium Phosphate Cement Based Concrete

S. Priyadarshika[1], M. Rajkannan[2]

[1]PG student (structural Engineering), [2]Assistant Professor,
[1,2]Civil Department, Paavai Engineering College, Pachal, Tamil Nadu, India

ABSTRACT
This project shows the results of an experimental study on the Magnesium phosphate cement for repair work in concrete mixed with coarse aggregate and fine aggregate. The percentage of Magnesium phosphate cement used in concrete and cement was replaced with 0%, 5% and 10%. The effects of curing for 7, 14 and 28 days on strength of concrete were studied. Experimental results indicate that the increase in the proportions of Mineral Admixtures resulted in an increase or decrease in the strength of concrete. The overall test performance revealed that Magnesium phosphate cement can be utilized as a partial replacement of cement in high strength concrete. The Mix Design for concrete M60 grade is being done as per the Indian Standard Code IS: 10262-2009.

KEYWORDS: *Magnesium phosphate cement, coarse aggregate, fine aggregate*

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1. INTRODUCTION
1.1. CONCRETE
Concrete is a composite material composed of fine and coarse aggregate bonded together with a fluid cement (cement paste) that hardens (cures) over time. In the past lime based cement binders were often used, such as lime putty, but sometimes with other hydraulic cements, such as a calcium aluminate cement or with Portland cement to form Portland cement concrete (for its visual resemblance to Portland stone) Many other non-cementitious types of concrete exist with different methods of binding aggregate together, including asphalt concrete with a bitumen binder, which is frequently used for road surfaces, and polymer concretes that use polymers as a binder.

Concrete structure may often suffer from an unexpected deterioration in terms of pop-out arising from physical/chemical delamination and corrosion of steel reinforcement. Moreover, internal cracking has still a potential risk of degradation of concrete properties, subsequently leading to structural failure. Thus, regular repair and rehabilitation would be required to secure a structural safety. However, unlike other civil infrastructures, the traffic restriction during the repair of pavement costs high; only a couple of hours are given for the repair treatment at night to avoid congestion of transportation. Additionally, the conventional repair materials such as Ordinary Portland Cement and hot-mix asphalt may face early degradation due to a debondment from the existing substrate.

1.2. MAGNESIUM PHOSPHATE CEMENT CONCRETE
Magnesium phosphate cement, also known as MPC, is a high performance, quick setting cement binder that has a multitude of beneficial properties when compared to Ordinary Portland Cement (OPC) binder systems.

MPC cement provides a fast-setting, strong and durable binder system for a wide variety of construction products applications for both external and internal use. The binder system bonds tenaciously to a wide variety of aggregates, fillers, and fibers allowing a broad choice of ingredients while maintaining sufficient compressive strength and integrity even at low binder ratios. The binder system also bonds with a wide variety of substrates such as itself, concrete, asphalt, metals, wood, and a variety of plastics thus providing a wide spectrum of potential applications. The main applications for MPC binder systems are for dry shotcrete mixes, for rapid setting and hardening patching mortar or dry-mix products, and protective coatings.

1.3. OBJECTIVE OF THE STUDY
The present study on magnesium phosphate cement concrete has the following objectives.

To find the optimum percentage of magnesium phosphate cement with OPC.

To find out the mix proportion of magnesium phosphate cement based on concrete.

To study the characteristics of magnesium phosphate cement based on concrete.

To carry out strength properties of magnesium phosphate cement based on concrete.

1.4. SCOPE OF THE STUDY

The MPC has high bond strength and low shrinkages rates, setting times are most common which may give an early strength development.

It is very fast setting material with low flow characteristics. This is an important development for the emergency repair of air fields, launching pads, road pavement suffering damage due to enemy bombing and missile attack.

2. LITERATURE REVIEW

Kyung Holeeet.al., (2017) conducted the test on magnesium potassium phosphate composite mortars with different water to binder ratio and molar ratio of magnesium to phosphate. A total of 25 mixes mortar is used The water to binder ratio is varying from 20 to 40% and M/P ratio is varying from 3.4 to 30.4The MgO and potassium phosphate ratio is 9:1 to 5:5 respectively. The compressive strength is achieved as 30 MPa, at 28 days .The flow of MKPC mortars tended to increase with an increase the M/P ratio of 7.9 beyond which the flow decreased gradually. The setting time of MKPC mortars were significantly delayed as the W/B increased from 25% to 30%. The 28 days compressive strength is inversely proportional to the macro- capillaries.

Sainan Xing and chengyonwu (2017) assessed the of magnesium phosphate cement for the application of concrete repairing work. There is an economical and environmentally friendly method that utilizing industrial waste residue to prepare magnesium phosphate cement. In order to apply it to the actual work of repairing concrete, the mass ratio of magnesium oxide to potassium phosphate di hydrogen phosphate should be 2:1; the water cement ratio is 0.2. The mass ratio of magnesium oxide and potassium di hydrogen phosphate was 1:1, 2:1, 2.5:1 and3:1 respectively. The mass ratio of 2:1 magnesium phosphate cement paste over the concrete rupture surface, reached flexural strength 7.11MPa at the age of 7 days.

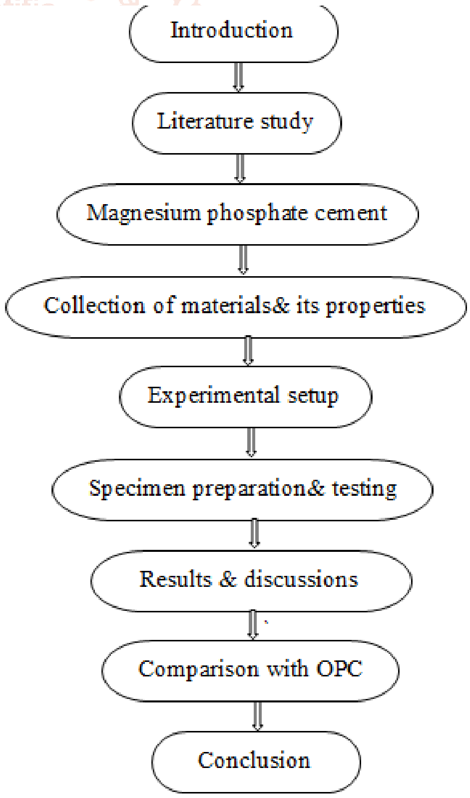
Xiaojiefuet.al., (2016) studied the magnesium phosphate cement with the zinc powder. When the zinc powder content is increased the early hydration temperature reduced gradually. The compressive strength of MPCPM is decreased from 13.23MPa. to 7.15 MPa, from 14.45MPa to 5.80 MPa and from 9.90MPa to 5.35 MPa, after hydration for 28 days as the zinc powder content increased from 0.3% to 0.8% respectively.

Nan yang et.al., (2014) made an attempt to study magnesium phosphate cement based materials, MPC is the phosphate bonded inorganic material derived from reactions between phosphate and magnesium oxide. The setting time and mechanical properties depend on the proportion and characteristics of raw materials, water to binder ratio, the addition of retarders and admixtures. The MPC is usually vibration mixed by MgO Powder, phosphate, retarder, and inert fillers in certain ratio. The prepared MPC mortars with w/b in range of 0.16 to 0.21.MPC demonstrated high compressive strength especially during early ages which developed to 40MPa in 3hrs.

Soudee and Pera (2000) explained the setting mechanism of Magnesia Phosphate cements which is obtained by mixing equal qualities of magnesia and monoammonium di hydrogen phosphate. The mixing proportions of mortars were MgO: $NH_4\,H_2\,PO_4$: S = 1:1:2. The liquid: solid ratio of 1:4 was employed. When magnesia phosphate cement is mixed with water an exothermic reaction occur leading to a hardened product within a few minutes. The setting time depends on the structure of MgO surface. The dissociation depends on both this wetting and the MAP concentration of the solution.

Sandorpopovics and Rajendran (2000) conducted a study on early age properties of magnesium phosphate based cement under various temperature condition. The mechanical and physico chemical tests were carried out by means of x-ray diffraction optical microscopy and infrared spectroscopy. The test was carried on the both hot and cold weathering conditions. The MPC mortar is prepared by the different series at 73^0F, 100 ^{0}F, and 32^0F at air cured condition. The MP mortars were surpassed by 14 MPa compressive strength at the age of 1hr.

3. METHODOLOGY



4. MATERIAL & PROPERTIES

4.1. CEMENT

Ordinary Portland cement (OPC) of 53 grade, satisfying the requirements of IS 12269-2013 has been used to produce control mix. The physical properties of the cement were measured as per BIS 4031- 1988 & 1999 and the results are summarized in Table 1.

Table 1 Properties of Cement

S. No	Description	Test Result
1	Specific gravity of cement	3.15
2	Fineness of cement	1.17
3	Standard consistency of cement	30%
4	Setting time Initial setting time Final setting time	 33 min 310 min
5	Soundness of cement	2.2 mm

4.2. MAGNESIUM PHOSPHATE CEMENT

Magnesium phosphate cement, also known as MPC, is a high performance, quick setting cement binder that has a multitude of beneficial properties when compared to Ordinary Portland Cement (OPC) binder systems. Magnesium phosphate cement (MPC) was obtained from Mumbai. The physical properties of MPC was measured using the procedure prescribed by IS: 4031-1988 and the results is presented in Table 2.

Table 2 Physical Properties of MPC

S. No	Description	Test Result
1	Specific gravity of cement	2.65
2	Fineness of cement	2%
3	Standard consistency of cement	33.4%
4	Setting time Initial setting time Final setting time	 25 min 28 min
5	Soundness of cement	2.3 mm

4.3. FINE AGGREGATE

Fine aggregate used in this work is crushed sand collected from local source. The physical properties of crushed sand were tested as per BIS 2386-1963 (reaffirmed 2002) and the results are presented in Table 3. Crushed sand is conforming to grading zone II as per BIS 383-1970 (reaffirmed 2011).

Table 3 Test Result of Fine Aggregate

S. No	Description	Test Result
1	Specific gravity of fine aggregate	2.63
2	Fineness modules of fine aggregate	2.53
3	Water absorption (%)	1.31
4	Bulking of fine aggregate	33.3
5	Density of fine aggregate Loose bulk density Rodded bulk density	 1452 kg/m^3 1550 kg/m^3

4.4. COARSE AGGREGATE

Locally available hard granite broken stones of 20 mm maximum size coarse aggregate were used in the present work. The physical properties of aggregates were conducted as per the procedure prescribed by BIS 2386-1963 (reaffirmed 2002) and results are presented in Table 4. The result shows that the characteristics of aggregates are in conformity with the requirements prescribed by BIS 383-1970 (reaffirmed 2011).

Table 4 Test Result of Coarse Aggregate

S. No	Description	Test Result
1	Specific gravity	2.91
2	fineness modules	7.419
3	water absorption (%)	1.56
4	Impact value	10.9
5	Crushing value	26.2
6	Abrasion value	35.24
7	Flakiness index Elongation index	11.84 16.92
8	Density of coarse aggregate Loose bulk density Rodded bulk density	 1413 kg/m^3 1450 kg/m^3

4.5. DESIGN OF M60 CONCRETE MIX AS PER IS 10262:2009

Mix proportions

Cement = 620 kg/ m^3
Water = 186 lit/ m^3
Fine aggregate = 584.36 kg/ m^3
Coarse aggregate = 1149.47kg/ m^3
W/C = 0.30

	Cement	Fine aggregate	Coarse aggregate	Water
By weight (kg/m^3)	620	584.36	1149.47	186
By ratio	1	0.94	1.85	0.30

5. RESULT AND DISCUSSION

5.1. COMPRESSION STRENGTH OF MPC CONCRETE

The compressive strength of MPC concrete of five mixes was determined at the age of 7 days, 14 days and 28 days the results are given in Table 5 and its variation is presented in Figure 1. It is evident from the results that 10% MPC higher compressive strength than other mixes. It is noticed that 10MP mix produced 65.7Mpa compressive strength at the age of 28 days.

Table 5 Compressive Strength of MPC Concrete

S. No	Mix ID	Compressive Strength (MPa)		
		7 days	14 days	28 days
1	CM	40.2	50.8	59.5
2	5MP	41.3	54.6	63.2
3	10MP	42.0	55.2	65.7

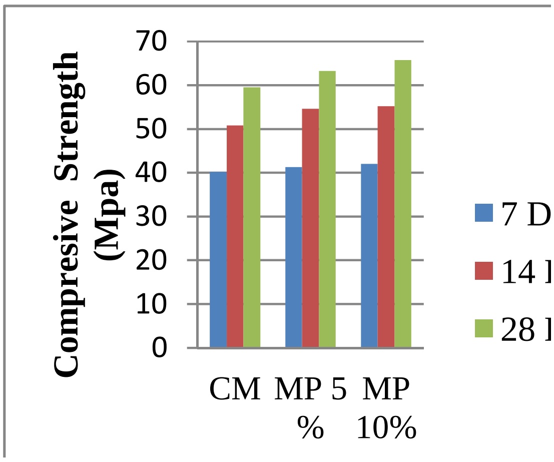


Fig 1 Compressive Strength of MPC Concrete

5.2. SPLIT TENSILE STRENGTH OF MPC CONCRETE

The split tensile strength of MPC concrete of five mixes was determined at the age of 7 days, 14 days and 28 days and the results are given in Table 6 and its variation is presented in Figure 2. It is evident from the results that 10% MPC higher split tensile strength than other mixes similar to compressive strength. It is noticed that 10MP mix produced 9.3Mpa split tensile strength at the age of 28 days.

Table 6Tensile Strength of MPC Concrete

S. No	Mix ID	Flexural strength (MPa)	
		7 days	28 days
1	CM	4.12	8.12
2	5MP	4.62	8.18
3	10MP	4.76	8.45

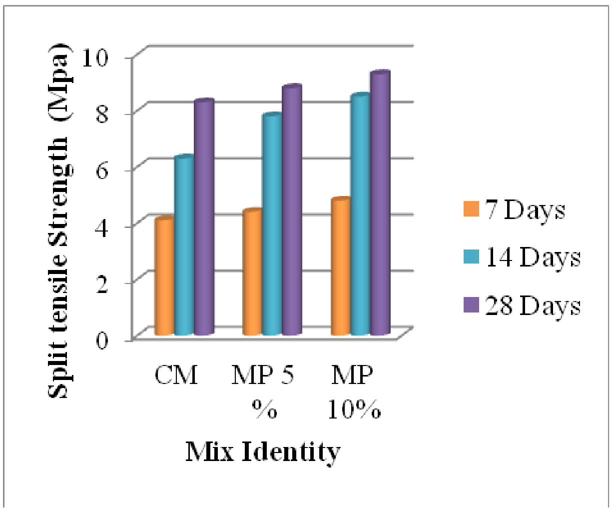


Fig 2Tensile Strength of MPC Concrete

5.3. FLEXURAL STRENGTH OF MPC CONCRETE

The flexural strength of MPC concrete of five mixes was determined at the age of 7 days and 28 days and the results are given in Table 7 and its variation is presented in Figure 3. It is obvious from the results that 10% MPC yielded higher flexural strength than other mixes. It is noticed that 10MP mix produced 8.45Mpa higher flexural strength than the control concrete at the age of 28 days.

Table 7 Flexural Strength ofMPC Concrete

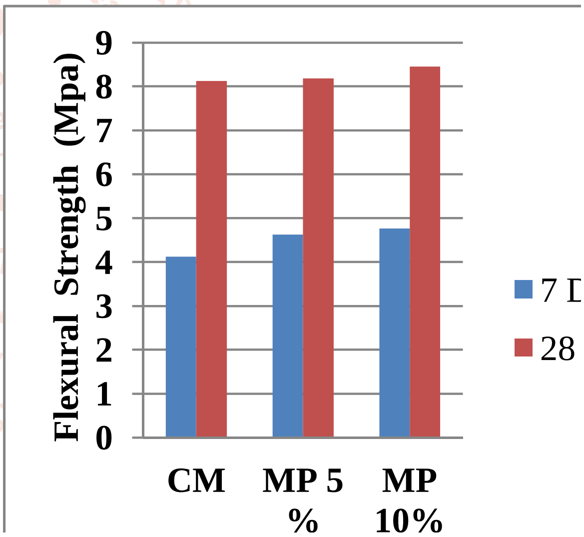


Fig 3 Flexural Strength of MPC Concrete

5.4. STRUCTURAL BEHAVIOUR OF MPC CONCRETE

5.4.1. Flexural Behavior

The control and MP RCC beam were tested using loading frame and result are presented in the Table 8 and 9. The values of first crack load and ultimate load with their respective deflection are tabulated (Table 8). The load deflection values noted, used to draw load deflection graph. The load deflection behaviour of beams is shown in Fig4 and 5.

From the load-deflection curves, it can be understood that MP RCC beams are stiffer than the control RCC beam. The ultimate load carrying capacity of the MP RCC beam was greater than RCC control beam. It was noticed that the ultimate load obtained in the MP RCC beam CM was70kN, while in the RCC control beam, it was 45kN. The maximum load of MP beams has presented two times higher load compared with CM RCC beam.

Table 8 Load Deflection of Control Rcc Beam

Load (kN)	Deflection(mm)
0	0
5.0	0.08
10.0	0.25
15.0	0.40
20.0	0.65
25	0.98
30.0	1.12
35.0	1.58
40.0	2.35
45.0	3.05

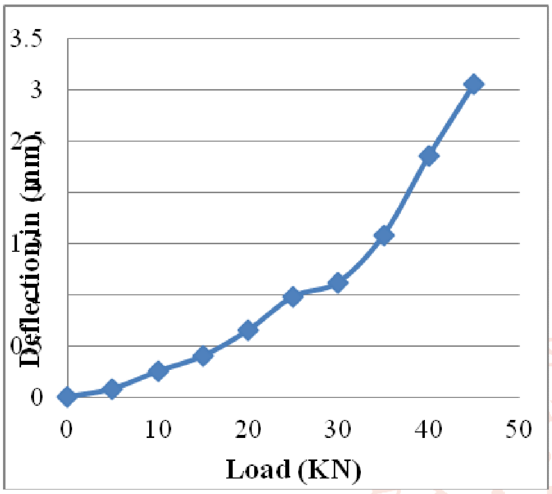


Fig 4 Load Deflection Behaviour of Control RCC Beam

Fig 5 Experimental testing of reinforced concrete beam

Table 9 Load Deflection of MPC 10Rcc Beam

Load (kN)	Deflection(mm)
0	0
5.0	0.02
10.0	0.15
15.0	0.30
20.0	0.52
25	0.64
30	0.85
35	0.97
40	1.02
45	1.10
50	1.18
55	1.30
60	1.35
65	1.72
70	2.40

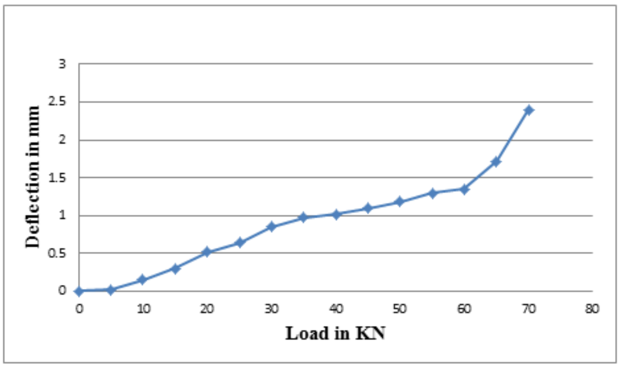


Fig 6 Load Deflection behaviour of MPC 10 Concrete Beam

Table 10 Flexural Performance of Cm and MPC 10Rcc Beam

Mix ID	Max. Load (kN)	Ultimate deflection (mm)	Moment M= wl/6 (kNm)	Load at first crack (kN)
CM	45	3.05	9.00	10
MPC 10	70	2.40	14.0	30

5.4.2. Flexural Ductility and Stiffness Behavior of CM and MPC 10 RCC Beam

The term ductility is defined as the capacity of the material/member to uphold the deformation beyond the elastic limit while maintaining a considerable load carrying capacity until total failure. When evaluating ductility, the most important parameter to be considered is the maximum deformation that the member can sustain, prior to failure. For calculating the ductility factor, deflections corresponding to the yield load point and the ultimate load point were noted from the load-deflection diagram. Then, the ductility factor was computed as the ratio of deflection at the ultimate load to that of the load at yielding. The ductility factor can be expressed in a dimensionless term "µ", whose values are given in Table 11. It can be seen that the MP RCC specimens produced higher ductility strength. These results showed the same trend of ductility value of the beam specimens.

Table 11Ductility Factor of Cm and MPC 10Rcc Beam

Beam Specimen id	Ultimate load (kN)	Yield deflection Δy (mm)	Ultimate deflection Δu (mm)	Ductility factor $\mu = \Delta u / \Delta y$
CM	45.0	1.58	3.05	1.93
MPC 10	70	1.30	2.40	1.84

6. CONCLUSION

In this present work, an attempt has been made to study the strength performance of the magnesium phosphate cement concrete. The material properties of ingredients were studied and found that all the properties are well with the prescribed standards. The control concrete mix design was made for M60 grade concrete. The compressive, split tensile strength and flexural strength of concrete was found. Based on strength properties of magnesium phosphate cement concrete, the following conclusion is drawn.

A. Among all MPC mixes, the 10% MPC concrete mix has highest compressive strength of 65.7 MPa at the age of 28 days.
B. The similar trend has been noticed in split tensile strength, and flexural strength of MPC concrete. The

split tensile strength of 10MPC is 9.3MPa at the age of 28 days.

C. Also, the flexural strength of 10MPC is 8.45MPa which is greater than control mix concrete.
D. Therefore, the optimum content of MPC is found as 10% in conventional concrete.
E. Reinforced MPC RC beams have shown greater ultimate load compared to CM RCC beams.
F. The initial crack is postponed for the MPC RC beams compared to CM specimen. The ultimate load carrying capacity of the MPC RC beams has shown two times higher than CM RC beam.

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