

## Synthesising Phospho Silicate Rapid Hardening High Strength Mortar



### Engineering

KEYWORDS :

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### ABSTRACT

*Deterioration of reinforced concrete structures has become a serious problem all around the world. In earlier days, these deteriorated concretes were removed and repaired with again the same mixture proportioned materials. But in recent years many new repair materials are developed and used for structural protection. One such newer repair material is based on phospho-silicate mortars and concrete. Various combinations were prepared and best one was selected and optimized with various compositions for structural repair work. The optimized compositions are tested for mechanical strength and durability test. The results are discussed.*

### INTRODUCTION

The deterioration of many structures like pavements, airport runway, bridge decks, marine structures and industrial structures are seriously viewed from structural safety and serviceability point of view. Currently, the repair works are carried out with ordinary Portland cement mixtures and concrete. As a further development from various types of failures, modified cement materials were used and still further many polymer materials based on epoxy, acrylic, and latex and epoxy silicone were used successfully. But they are not economical and restricted pot and shelf life.

Liyue and Chen Bing [1] developed super light weight magnesium phosphate cement formed concrete whose density ranges from 400 to 600Kg/m<sup>3</sup>. A previous researcher developed phosphate cement with magnesia and ammonium di-hydrogen phosphate. As this material liberated ammonia gas which lead to corrosion and create unpleasant environmental odor. To overcome these drawback Liyue and Chen Bing [1] developed magnesium phosphate cement with dead burned magnesium oxide and potassium di-hydrogen phosphate and some retarders as used in Portland cement and used here for flowability of fresh magnesium phosphate cement.

T.Sugama and L.E.Kukacka [2] developed phosphate cement with di ammonium phosphate solution mixing with calcined magnesium oxide powder. They developed a ceramic like magnesium compound for rapid repair and fire proofing structural elements in construction industry. Arun et, al [3] developed chemically bonded phosphor-silicate ceramics and made U.S. Patent. They developed phospho-silicate ceramic with monovalent alkali metal phosphate and sparsely soluble oxide with sparsely soluble silicate in an aqueous solution.

Though all the previous researchers developed materials with very rapid setting, high early strength, ability to set and harden at room temperature and high bonding strength, they all are used only in laboratory grade materials which are costly and emit green house gases.

Therefore, a new generation of phosphor-silicate materials are attempted to develop with commercially available raw materials, namely super phosphate with fly ash, sand and baby chips. The phosphor-silicate concrete is a concrete chemically reacting with phosphate and oxide with soluble silicate in an aqueous solution. This reaction develops a strong bond between silicates and gives very good strength in short time and no water curing

requires. Since the sodium silicate is a solution based, the reaction will be faster and forms quick setting. This, this new generation phosphor-silicate concrete can absolutely be used as repair materials and precast construction materials.

### Experimental Part

#### Materials used

Stone chips of 600mm grade washed in tap water and used. River sand passing through 600micron was used. Super phosphate purchased from fertilizer shop and of commercial grade. Sodium silicate purchased from Coimbatore of commercial grade. Fly ash was obtained from Neyveli Lignite Cooperation. MgO and ZnO are purchased from HIMEDIA chemical laboratory, Bombay.

#### Casting of Specimens

Cylinder specimens of size 75mm diameter and 150mm long were used for casting. Initially 38 formulations were cast as shown in Table 1. Casting process of cylinder specimens are shown in Fig. 1 and Fig. 2. PVC moulds are used for casting the specimens.

**Table 1 Material Composition for Trial Mix**

S i . No.	Compositions	Remarks
1	Water +Feldspar +Magnesium phosphate + Sand + Al <sub>2</sub> O <sub>3</sub> + Borax	Sets and Hardens
2	Sand+ CaO + MgO +Feldspar +MgCl <sub>2</sub>	Sets and Hardens
3	Stone Chips + Micro Silica +MgO + Magnesium phosphate + Sand	Not Set
4	Stone Chips +Magnesium Chloride +ZnO + Fly Ash +Sand	Not Set
5	Sand +Fly Ash + Stone Chips + Super Phosphate + MgO	Just set
6	Stone Chips + Fly Ash + Micro Silca + Super Phosphate + Orthophosphoric Acid +Sand	Not Set
7	Fly Ash + Super Phosphate + MgO + Sand	Just Set
8	SiO <sub>2</sub> + Boric Acid + Fly Ash + Super Phosphate + Stone Chips + Sand	Sets and Hardens
9	Sand + Stone Chips + Zinc Phosphate + ZnO + Fly Ash	Sets and Hardens
10	Sand + Orthophosphoric acid + Feldspar + MgO + Al <sub>2</sub> O <sub>3</sub>	Not set

11	Sand + Orthophosphoric acid + Feldspar + MgO + Al <sub>2</sub> O <sub>3</sub> + CaO	Not set
12	MgO + Magnesium Phosphate + Fly Ash + Stone Chips + Sand	Just Set
13	Sand + Stone Chips + Fly Ash + MgO + Super Phosphate	Sets and Hardens
14	ZnO + Super Phosphate + Fly Ash + Stone Chips + Sand	Sets and Hardens
15	ZnO + Super phosphate + Fly Ash + Stone Chips + Sand	Just set
16	ZnO + Super Phosphate + Sand + Stone Chips	Just set
17	ZnO + Super Phosphate + Sand + Stone Chips	Just set
18	ZnO + Super Phosphate + Sand + Fly Ash	Just set
19	Al <sub>2</sub> O <sub>3</sub> + Super Phosphate + Sand + Stone Chips + Fly Ash	Just set
20	Fly Ash + Sand + Sodium Silicate + Phosphoric Acid + Baby Chips	Not Set
21	Fly Ash + Sand + Sand Chips + Mg Phosphate + Sodium Silicate	Just Set
22	Fly Ash + Sand + Sand Chips + Zn Phosphate + Sodium Silicate	Just Set
23	Fly Ash + Sand + Sand Chips + Na Phosphate + Sodium Silicate	Not Set
24	Fly Ash + Sand + Sand Chips + Mg Phosphate + Sodium Silicate + MgO	Just Set
25	Fly Ash + Sand + Sand Chips + Super Phosphate + Sodium Silicate	Just Set
26	Feldspar + Mg Phosphate + Sand + Al <sub>2</sub> O <sub>3</sub> + Borax + Sand Chips + Sodium Silicate	Just Set
27	Zn Phosphate + Zn Oxide + Fly Ash + Sand + Sand Chips + Sodium Silicate	Just Set
28	Fly Ash + Sand + Sand Chips + Super Phosphate + Sodium Silicate + MgO	Just Set
29	Fly Ash + Sand + Sand Chips + Super Phosphate + Sodium Silicate + ZnO	Sets and Hardens
30	Fly Ash + Sand + Sand Chips + Super Phosphate + Sodium Silicate + SiO <sub>2</sub>	Sets and Hardens
31	Fly Ash + Sand + Sand Chips + Super Phosphate + Sodium Silicate + MgO + CaO + MgCl <sub>2</sub>	Not Set
32	Sand + Fly Ash + Clay + DAP	Just Set
33	Sand + Fly Ash + Clay + DAP + NaOH	Just Set
34	Sand + Fly Ash + Red Soil + DAP + NaOH	Just Set
35	Sand + Clay + Red Soil + Sodium Silicate + NaOH	Sets and Hardens
36	Sand + Fly Ash + DAP + NaOH	Just Set
37	Sand + Fly Ash + Super Phosphate	Just Set
38	Sand + Fly Ash + Red Soil + Super Phosphate	Just Set



Fig.1 Casting of Specimens



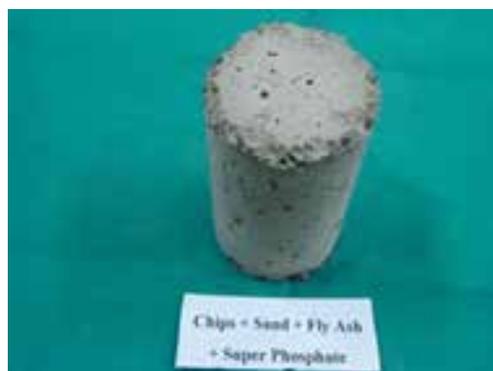
Fig.2 Hand Vibration for Consolidation

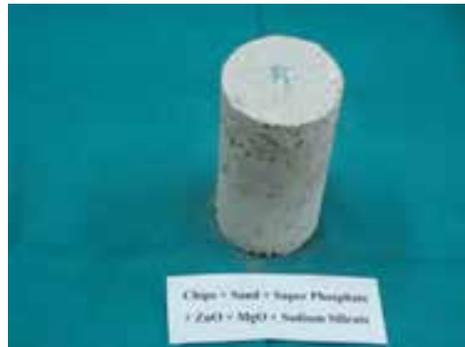
From the 38 preliminary formulations, the S.No. 1, 8, 9, 13, 14, 29, and 30 has got good results of setting and hardening process. Based on this selection again 18 formulations were prepared as indicated in Table 2 and the cast specimens of phosphor-silicate mixtures are shown in Fig.3.

Table 2 Material Compositions Selected Based on Table 1

Si No.	Mix ID	Composition	Remarks
1	P <sub>1</sub>	Sand Chips + Sand + Fly Ash + Super Phosphate	Not Set
2	P <sub>2</sub>	Sand Chips + Sand + Fly Ash + Super Phosphate + Sodium Silicate	Sets and Hardens
3	P <sub>3</sub>	Sand Chips + Sand + Fly Ash - 190g + Super Phosphate	Not Set
4	P <sub>4</sub>	Sand Chips + Sand + Fly Ash - 190g + Super Phosphate + Sodium Silicate	Sets and Hardens
5	P <sub>5</sub>	Sand Chips + Sand-190g + Fly Ash - 190g + Super Phosphate + Sodium Silicate	Sets and Hardens
6	P <sub>6</sub>	Sand Chips + Sand + Fly Ash - 190g + Super Phosphate + Sodium Silicate + MgO	Sets and Hardens
7	P <sub>7</sub>	Sand Chips - 375g + Sand + Fly Ash - 190g + Super Phosphate + Sodium Silicate + MgO	Sets and Hardens
8	P <sub>8</sub>	Sand Chips + Sand - 190g + Fly Ash - 190g + Super Phosphate + Sodium Silicate + MgO	Sets and Hardens

9	P <sub>9</sub>	Sand Chips + Sand + Fly Ash + Super Phosphate + Sodium Silicate + ZnO	Sets and Hardens
10	P <sub>10</sub>	Sand Chips - 375g + Sand + Fly Ash + Super Phosphate + Sodium Silicate + ZnO	Sets and Hardens
11	P <sub>11</sub>	Sand Chips + Sand - 190g+ Fly Ash + Super Phosphate + Sodium Silicate + ZnO	Sets and Hardens
12	P <sub>12</sub>	Sand + Super Phosphate + Sodium Silicate	Just Set
13	P <sub>13</sub>	Sand Chips + Sand + Clay + Super Phosphate + Sodium Silicate + ZnO	Just Set
14	P <sub>14</sub>	Sand Chips - 375g + Sand + Clay + Super Phosphate + Sodium Silicate + ZnO	Just Set
15	P <sub>15</sub>	Sand Chips + Sand - 190g+ Clay + Super Phosphate + Sodium Silicate + ZnO	Just Set
16	P <sub>16</sub>	Chips + Sand + Super Phosphate + ZnO + MgO + Sodium Silicate	Just Set
17	P <sub>17</sub>	Chips + Sand - 190g + Super Phosphate + ZnO + MgO + Sodium Silicate	Just Set
18	P <sub>18</sub>	Chips + Sand + Fly Ash + Super Phosphate + ZnO + MgO + Sodium Silicate	Sets and Hardens





**Fig.3 Cast Specimens of Phospho-Silicate Mixtures**

From this Table 2, one best formulation has been selected as a final composition for the product.

**Experiments**

Cylinder compressive strength has been carried out along with split tensile strength using cylinder specimens of size 75mm diameter x 150mm long. The results of compressive strength and split tensile strength are given in Table 3 for preliminary 38 samples. And Table 4 shows the values of compression and split tensile strength for the selected 18 samples. In this it is found that the formulations made out of fly ash, super phosphate, sand and sodium silicate found to be the best composition. For the selected 18 composition dry density and saturated density and percentage of water absorption are shown in Table 4. Sorptivity test has been carried for the selected specimens and results of water absorption through capillaries at various time interval up to 60 minutes in Table 5.

The coefficient of water absorption also computed using the formula.

$$k = \left(\frac{Q}{A}\right)^2 \times \frac{1}{t}$$

where

Q = the quantity of water absorbed for 60 minutes

A = area of specimens permitted to absorb water

t = duration in second = 3600 seconds

k = coefficient of water absorption

**Table 3 Mechanical Strength of Preliminary Mix Compositions**

S.No.	Cylinder Compression Strength $f_{cu}$	Split Tensile Strength $f_{ct}$	S.No.	Cylinder Compression Strength $f_{cu}$	Split Tensile Strength $f_{ct}$
1	22.16	2.34	20	-	-
2	21.71	2.84	21	-	-
3	-	-	22	-	-
4	-	-	23	-	-
5	-	-	24	-	-
6	-	-	25	-	-

**Table 5 Results of Sorptivity Test**

S i No.	M i x ID	Initial Weight (g)	Weight(g) (Time in Minutes)											Q Value	K Value (x 10 <sup>-4</sup> )
			1	3	5	7	10	15	20	30	40	50	60		
1	P <sub>1</sub>	258.62	-	-	-	-	-	-	-	-	-	-	-	-	-
2	P <sub>2</sub>	294.16	297.57	297.74	298.20	299.04	300.09	301.58	302.91	305.13	307.01	308.66	310.23	16.07	2.84
3	P <sub>3</sub>	267.78	-	-	-	-	-	-	-	-	-	-	-	-	-
4	P <sub>4</sub>	290.70	291.98	292.96	293.48	293.46	294.41	294.85	295.30	295.88	296.26	296.61	296.94	6.24	0.428
5	P <sub>5</sub>	287.69	289.28	290.63	291.36	292.01	292.72	293.55	294.23	295.23	296.07	296.80	297.45	9.76	1.047
6	P <sub>6</sub>	282.97	284.24	284.89	285.36	285.62	286.04	286.64	287.09	287.93	288.64	289.22	289.79	6.82	0.511
7	P <sub>7</sub>	250.17	251.27	251.68	252.34	253.02	253.04	254	254.59	255.58	256.55	257.49	258.22	8.05	0.319

7	-	-	26	-	-
8	24.86	2.59	27	-	-
9	22.62	2.32	28	-	-
10	-	-	29	20.16	2.18
11	-	-	30	22.73	2.32
12	-	-	31	-	-
13	22.31	2.42	32	-	-
14	23.14	2.31	33	-	-
15	-	-	34	-	-
16	-	-	35	16.12	1.83
17	-	-	36	-	-
18	-	-	37	-	-
19	-	-	38	-	-

**Table 4 Physical and Mechanical Properties of Selected Formulations**

Si. No.	Mix ID	Dry Density ( $\rho_{dry}$ ) ( $\times 10^3$ )	Saturated Density ( $\rho_{sat}$ ) ( $\times 10^3$ )	Water Absorption (%)	Cylinder Compressive Strength ( $f_{cy}$ ) MPa	Split Tensile Strength ( $f_{ct}$ ) MPa	Remarks
1	P <sub>1</sub>	-	-	-	-	-	Not Set
2	P <sub>2</sub>	2.311	2.464	6.60	18.73	1.97	Sets and Hardens
3	P <sub>3</sub>	-	-	-	-	-	Not Set
4	P <sub>4</sub>	2.284	2.403	5.197	19.02	2.03	Sets and Hardens
5	P <sub>5</sub>	2.261	2.380	5.179	18.34	1.98	Sets and Hardens
6	P <sub>6</sub>	2.224	2.359	6.10	18.64	2.01	Sets and Hardens
7	P <sub>7</sub>	1.755	1.855	5.712	19.11	2.11	Sets and Hardens
8	P <sub>8</sub>	1.954	2.103	7.623	17.98	1.93	Sets and Hardens
9	P <sub>9</sub>	1.669	2.060	23.436	22.18	2.34	Sets and Hardens
10	P <sub>10</sub>	2.105	2.201	4.54	23.43	2.41	Sets and Hardens
11	P <sub>11</sub>	1.967	2.059	4.678	19.36	2.03	Sets and Hardens
12	P <sub>12</sub>	1.092	1.502	9.411	18.63	2.00	Just Set
13	P <sub>13</sub>	1.732	1.892	9.23	18.99	2.03	Just Set
14	P <sub>14</sub>	1.830	1.974	7.88	17.98	1.93	Just Set
15	P <sub>15</sub>	1.630	1.766	8.37	16.68	1.84	Just Set
16	P <sub>16</sub>	1.945	2.069	6.380	17.34	1.86	Just Set
17	P <sub>17</sub>	1.795	1.920	6.941	9.84	1.20	Just Set
18	P <sub>18</sub>	2.075	2.211	6.546	22.94	2.21	Sets and Hardens

8	P <sub>8</sub>	278.61	280.01	280.65	281.10	281.67	281.87	282.45	282.91	283.78	284.63	285.36	285.95	7.34	0.858
9	P <sub>9</sub>	237.96	239.15	239.76	240.25	240.57	240.87	241.41	241.85	242.46	242.99	243.43	243.85	5.89	0.170
10	P <sub>10</sub>	300.17	301.85	302.76	203.43	303.99	304.64	305.53	306.25	307.48	308.60	309.46	310.33	10.16	1.188
11	P <sub>11</sub>	280.50	282.24	283.34	284.06	284.76	285.61	286.67	287.65	289.23	290.43	291.55	292.51	12.01	7.105
12	P <sub>12</sub>	195.72	208.75	214.07	216.59	213.91	217.08	217.09	217.15	217.20	217.21	217.22	217.24	21.46	2.510
13	P <sub>13</sub>	246.89	253.76	256.15	257.89	259.15	260.54	262.26	263.60	265.89	267.32	268.12	268.15	21.56	2.289
14	P <sub>14</sub>	260.90	263.71	265.94	267.48	268.70	270.08	271.90	273.46	276.47	279.59	281.79	283.64	22.74	2.547
15	P <sub>15</sub>	232.38	237.43	239.61	241.02	241.39	243.07	245.07	246.77	249.48	251.89	254.64	256.31	23.93	2.820
16	P <sub>16</sub>	277.26	280.25	282.41	283.21	283.58	285.74	288.47	290.82	294.62	296.02	296.07	296.13	18.87	2.207
17	P <sub>17</sub>	255.99	262.34	265.92	268.41	270.58	273.25	273.48	273.62	274.38	284.49	274.55	274.60	18.61	2.175
18	P <sub>18</sub>	295.90	297.74	298.92	299.68	300.23	301.11	302.13	303.03	304.51	305.99	307.15	308.31	12.41	0.758

**Results and Discussions**

From 38 preliminary formulations, 8 formulations found to set and harden by overnight and rest of the 30 specimens did not set and harden. From the 8 selected compositions the phosphate components reacts with the oxides present in the composition and started setting. The mix is made out of phosphoric acid with fly ash did not give good results. But the phosphate components and silicate components reacts with each other and gives best results and selected for next 18 compositions. From this 18 composition (Table 2) it is found that the formulation made out of super phosphate, sodium silicate, fly ash, sand and stone chips found as the best composition.

The mechanism can be explained for the best results that the super phosphate when mixed with water in the composition becomes acidic and reacts with the silicate phase particularly it is easy to react with sodium silicate. At the surface of silicates, the binding reaction takes place between phosphates and silicates. This fact attributes for greater strength in nature cooling.

From the compressive strength results of 38 samples, sample No. 8, 9, 13, 14, 29 and 30 found to be the best since there compressive strength is greater than 20MPa. Corresponding split tensile strength is around 12% of cylinder strength. The selected 18 samples from Table 4, P<sub>9</sub>, P<sub>10</sub> and P<sub>18</sub> found to be the best material with cylinder compressive strength more than 22.18MPa.

The average density of phospho-silicate concrete is around 2261Kg/m<sup>3</sup> and the saturated density is around 2359Kg/m<sup>3</sup>. The percentage of water absorption ranges from a minimum value of 9.41% and exceptional value of 23.46% has obtained due to very high porosity of the specimen. The coefficient of water absorption computed from sorptivity test is found much lesser than normal concrete.

**Conclusions**

The combination of super phosphate and sodium silicate along with fly ash and sand found to offer much higher strength in 8 hours in open air curing.

When laboratory grade magnesium phosphate and ZnO are mixed with fly ash and sand do not form hard mass when reacts with silicates present in fly ash.

This combination is found to be cheaper and eco-friendly since the cost of super phosphate is very cheap and the cost of sodium silicate of commercial grade is also a cheaper material and they do not produce any green house gases. Therefore, this phospho-silicate material found to be a greener, eco-friendly and cheaper construction material without water curing.

These formulations set in 8 hours time and therefore it is a best repair material both in industrial and other structures.

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