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EFFECT OF CALCINED PHOSPHOGYPSUM IN PORTLAND POZZOLANA CEMENT CONCRETE

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Abstract - *Phosphogypsum (PG) is a solid by-product of the production of phosphoric acid, a major constituent of many fertilizers, chemical industry materials. As it is contaminated with the impurities that impair the strength development of calcined products, it can be used as partial replacement of cement PG could be used as a substitute of natural gypsum in the production of Portland cement to control the hydration reaction rate of cement. Besides, the industrial and urban management systems are generating solid wastes, and most often dumping them in open fields. The disposal of PG is a serious environmental problem. This problem along with scarcity of cement, environmental pollution associated with the manufacture of cement and its increased cost can be solved to some extent by replacing certain quantity of cement in concrete with PG. This project deals with the experimental investigation on mortar mix and compressive strength, splitting tensile strength, flexural strength and water permeability of PG concrete. The study aims to determine the optimum amount of PG that can give maximum strength to concrete.*

Key Words: Phosphogypsum concrete, Environmental pollution, Compressive Strength, Split Tensile, Flexural Strength, and Water Permeability

1. INTRODUCTION

With the advancement of technology and increased field application of concrete and mortars the strength, workability, durability and other characteristics of the ordinary concrete is continually undergoing modification to make it more suitable for any situation. The growth in infrastructure sector led to scarcity of cement because of which, the cost of cement increase incrementally. In India, the cost of cement during 1993 was around Rs 1.25/kg, in 2005 the price increased approximately 3 times and in 2017 price reaches to Rs. 7-8/kg. In order to combat the scarcity of cement and the increase in the cost of concrete under these circumstances the use of recycled agricultural solid wastes and industrial by products like fly ash, blast furnace slag, silica fumes, rise husk, phosphogypsum came into use. The use of above mentioned waste products in concrete in partial amount replacing cement paved a role for

a) Controlling the concrete production cost
b) Modifying the properties of the concrete
c) To overcome the scarcity of the cement
d) The advantageous disposal of wastes

The use of particular waste product will be economically advantageous usually at the place of abundant availability and production. PG is a by-product of the chemical reaction called the wet process whereby sulphuric acid is reacted with phosphate rock to produce phosphoric acid, needed for fertilizer production. Approximately five tons of PG is produced for every ton of phosphoric acid manufactured. Through the wet process, some impurities naturally present in the phosphate rock become concentrated in PG, including fluoride, sulfate, phosphates, organic matter, heavy metals, radionuclides, and residual acidity. Approximately 58% of the worldwide PG by-product is stockpiled, 14% is reprocessed and 28% is dumped into water bodies. Therefore, attempts were made to use PG in concrete.

1.1 Phosphogypsum

World manufacturing consists of approximately 25 million tons per year of phosphoric acid. Most common industrial process is wet process operation (95%) for producing phosphoric acid from phosphate rock. In all process ground phosphate rock is combined with sulphuric acid in a series of mixing tanks. Finally PG is either slurries with water or pumped sedimentation ponds (wet stacking) or transported to large stocks by truck or belt conveyers (dry stacking). It is largely calcium sulphate and has been given the name PG (gypsum is the common name for hydrated calcium sulphate, a common building material.).For each ton of wet phosphoric acid, approximately 5 tons of PG are produced. An increasing demand for phosphate fertilizers has subsequently increased PG production and stockpiling throughout world. The worldwide production of PG is approximately 120 million tons per year. Depending upon the nature of phosphate rock and industrial operation, chemical composition of PG may vary.

1.2 Characteristics of Calcined PG

The primary reason PG was not used for construction products in India was because it contained small quantities of silica, fluorine and phosphate (P_20_5) as impurities and fuel was required to dry it before it could be processed for some applications as a substitute for natural gypsum, which is a material of higher purity. These impurities impair the strength development of calcined products.

The phosphorus, sulfate, fluoride, and organic impurities contained in PG interfere in an unpredictable way to delay the setting time, and decrease the mechanical strength development of cement (Singh et al., 2002). It is, thus, clear that PG may not always be suitable for direct use in OPC. Some way has to be found to counteract the harmful influence of impurities, before it can be considered by the cement industry. To solve this problem it is required to produce PG containing few or no impurities.

The usage of the PG as a retarder replacement of NG (Natural Gypsum) provides both economic and ecological profits. PG was calcined at 135°C for 3hr to obtain hemihydrate calcium sulfate. The calcination process was carried in a Treatment Plant and later calcined PG was milled in a roller mill.

2. MATERIALS AND PROPERTIES

Cement

Portland Pozzolana Cement (ACC Brand) confirming to IS 1489 (Part 1): 1991 was used for all the concrete mixtures. The cement was tested according to IS 4031:1988. It confirmed to IS 12269:1987. Its Properties is given in Table 1.

Table -1: Properties of Cement

S.no.	Properties	Values	Codal limits IS 1489 (Part1): 1991
1	Specific Gravity	2.87	-
2	Standard Consistency	31%	26 - 33%
3	Initial Setting Time	110 mins	> 30 mins
4	Final Setting Time	210 Mins	< 600 mins
5	Average Compressive Strength (MPa)	35.12 N/mm²	≥ 33 N/mm²

Fine Aggregate

Natural fine aggregate used is manufactured sand. Fine aggregate under saturated surface dry condition was used for casting. The tests were conducted according to IS: 2386 (Part I) - 1963 provisions. The sieve analysis and physical properties of fine aggregate is as shown in the table below.

Table -2: Physical Properties of fine aggregate

S.no	Properties	Test results	IS : 383 - 1970
1	Water absorption	1.2%	<12%
2	Specific gravity	2.702	2.6 – 2.8
3	Zone	II	-

Coarse Aggregate

The maximum size of coarse aggregate used in the concrete mixture is 20mm.Tests were conducted according to IS 2386 – 1963. The sieve analysis and physical properties of coarse aggregate is as shown in the table below.

Table -3: Physical Properties of coarse aggregate

S.no	Properties	Test results	IS : 383 - 1970
1	Water absorption	0.57%	0.4-1%
2	Specific gravity	2.725	2.4 – 2.9

Superplasticizer

The super plasticizer used was Conplast SP430 a product of Fosroc. Conplast SP430 is a chloride free, superplasticising admixture based on sulphonated naphthalene polymer.

Water

Portable water which is available at the laboratory premises was used for mixing of concrete ingredients. Water from sources like industrial plants, sewage and other contaminated should not be used for concrete making.

Calcined Phosphogypsum

Phosphogypsum is a light grey coloured, fine grained powder, silt or silty-sand material with a maximum size range between 0.5 mm and 1.0 mm and majority of the particles are finer than 0.040 mm. The specific gravity of phosphogypsum ranges from 2.3 to 2.6. The maximum dry bulk density is likely to range from 1470 to 1670 kg/m³, based on Standard Proctor Compaction.

3. PRELIMINARY STUDY

3.1 Cement-PG Mix Test Results

Normal Consistency (IS: 4031(part 4)-1988)

It was observed that phosphogypsum provides additional stiffness to the paste and therefore it was required to add water for desired penetration of Vicats plunger.

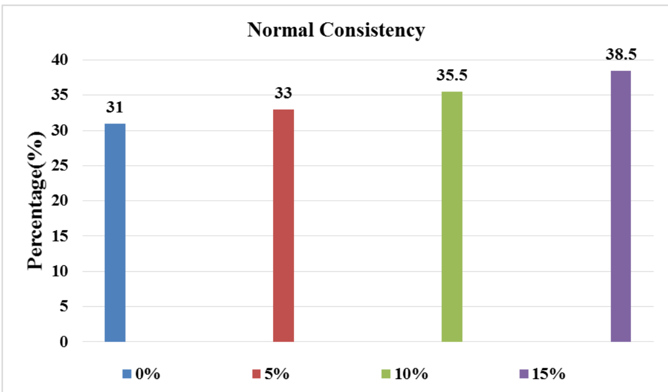

Fig -1: Normal consistency of cement – PG mixes

Setting Time (IS: 4031-1988)

It was observed that even for five percent replacement of cement with treated phosphogypsum the initial and final time was increased beyond standard value for Portland Pozzolana Cement.

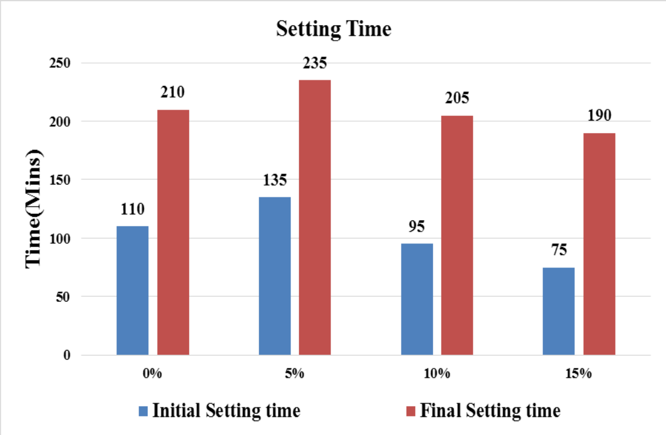

Fig -2: Setting time of cement – PG mixes

Cement – PG Mortar Mix (IS 4031: Part 6-1988)

The standard mix proportion of 1:3 by weight was considered for the test. The proportions of phosphogypsum were varied from 0%, 5%, 10%and 15% of cement by dry weight. The strength was found to decrease at 15% replacement.

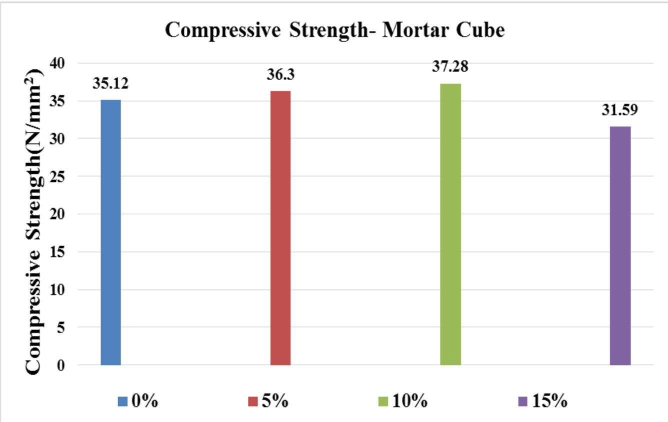

Fig -3: Compressive Strength- Mortar Cube

3.2 Mix Design (IS 10262:2009)

In this investigation concrete mix design M25 was designed based on IS 10262 – 2009. This code presents a generally applicable method for selecting mixture proportion. The quantity of material used in this study details are given below in table 4.

Table -4: Mix for Various Phosphogypsum Mixes

Component	CM-1 (0%)	CM-2 (5%)	CM-3 (10%)	CM-4 (15%)
Cement(kg)	330	313.5	297	280.5
PG (kg)	0	16.5	33	49.5
Fine aggregate (kg)	795.5	795.5	795.5	795.5
Coarse aggregate (kg)	1203.4	1203.4	1203.4	1203.4
Admixture (%)	0.3	0.4	0.5	0.6
Water (litres)	164.9	164.9	164.9	164.9

4. ANALYSIS AND TEST RESULT

4.1 Hardened Concrete

Compressive strength test (IS 516:1959)

The compressive strength of concrete is found to increase with the addition of phosphogypsum up to 10% replacement of cement with phosphogypsum. The percentage increase in compressive strength at 10% phosphogypsum content, when compared with plain concrete is more than 17%. There is a significant reduction in the compressive strength beyond 10% phosphogypsum content. Thus the optimum amount of phosphogypsum in concrete is found to be 10%.

The results of compression tests of various samples are given in Table 5

Table -5: Compressive Strength Test Results

S.no	Compressive strength	CM-1 (0%)	CM- 2 (5%)	CM-3 (10%)	CM-4 (15%)
1	7th day (MPa)	20.08	23.09	24.08	14.36
2	28th day (MPa)	31.75	34.97	36.74	26.32
3	56th day (MPa)	33.36	36.26	38.76	27.82

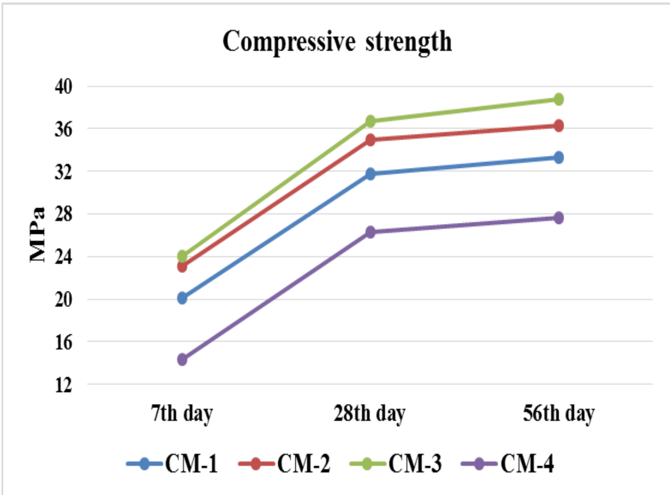

Fig -4: Compressive strength at various ages

Split Tensile Strength (IS 5816:1999)

The split tensile strength of concrete is found to increase with the addition of phosphogypsum up to 10 % replacement of cement with phosphogypsum. The percentage increase in split tensile strength at 10% phosphogypsum content, when compared with plain concrete is around 16%. There is a significant reduction in the split tensile strength at 15% phosphogypsum content. Thus the optimum amount of phosphogypsum in concrete is found to be 10%.

The results of Split Tensile strength of various samples are given in Table 6

Table -6: Split Tensile Strength Test Results

Mix Type	Split Tensile strength(N/mm²)
CM-1	3.227
CM-2	3.401
CM-3	3.712
CM-4	2.978

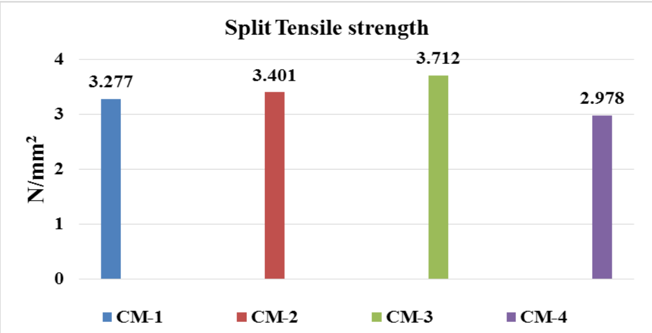

Fig -5: Split tensile strength at 28 days

Flexural strength test (IS 516:1959)

The Flexural strength of concrete is found to increase with the addition of phosphogypsum up to 10 % replacement of cement with phosphogypsum. The percentage increase in Flexural strength at 10% phosphogypsum content, when compared with plain concrete is around 9%. There is a significant reduction in the Flexural strength at 15% phosphogypsum content. Thus the optimum amount of phosphogypsum in concrete is found to be 10%.

Table -7: Flexural Strength Test Results

Mix Type	Flexural Strength(N/mm²)
CM-1	6.48
CM-2	6.80
CM-3	7.04
CM-4	5.92

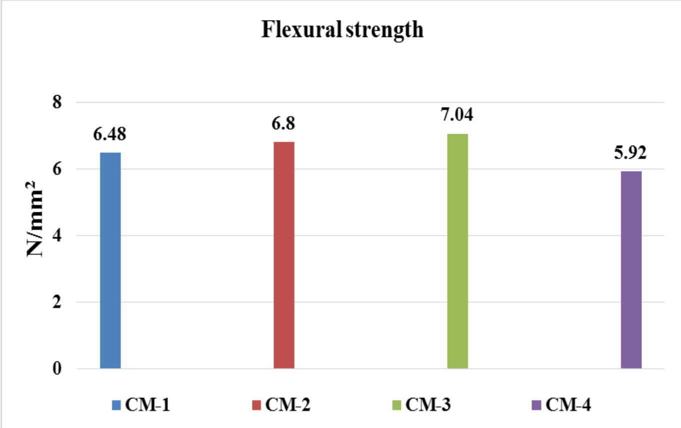

Fig -6: Flexural strength test at 28 days

Permeability of Concrete (IS: 3085 - 1965)

The coefficient of permeability shall be calculated as follows:

$$K = \frac{Q}{AT\frac{H}{L}}$$

Where,

K = coefficient of permeability in cm/sec;

Q = quantity of water in millilitres percolating over the entire period of test after the steady state has been reached;

A = area of the specimen face in cm²;

T = time in seconds over which Q is measured; and

H/L= ratio of the pressure head to thickness of specimen, both expressed in the same units.

A=100cm²

T=360000sec

L=10cm

The coefficient of permeability was calculated by using Darcy's formula, which is applicable at steady state flow conditions. The steady state flow condition was deemed to be achieved when the discharge through the sample became constant for 24 hours. The discharge measurements were taken for about 100 hours. The coefficient of permeability of the concrete mixes incorporating 5%, 10% and 15 % weight fractions of phosphogypsum after 28 days of curing have been listed in Table 8

Table -8: Permeability Test Details

Mix	Quantity of Water (Q) ml	Pressure Head (H) m	Coefficient of Permeability (K) cm/sec
CM-1	2380	75	8.815×10^{-8}
CM-2	2030	75	7.518×10^{-8}
CM-3	1610	75	5.963×10^{-8}
CM-4	2105	75	7.796×10^{-8}

5. CONCLUSIONS

The experimental results have shown the use of calcined phosphogypsum in making concrete/mortar can provide an alternative solution to minimize the environmental impact due to unscientific disposal of raw phosphogypsum. The following conclusions were drawn:

- Compressive strength of concrete is found to increase with the addition of phosphogypsum up to 10% replacement of cement but there is a significant reduction in the compressive strength beyond 10% phosphogypsum content.
- The percentage increase in Flexural strength at 10% phosphogypsum content, when compared with plain concrete is around 9%. There is a significant reduction in the Flexural strength at 15% phosphogypsum content.
- Split tensile strength of concrete is found to increase with the addition of phosphogypsum up to 10 % replacement of cement. There is a significant reduction in the split tensile strength at 15% phosphogypsum content.
- With the increase in phosphogypsum dosage, the permeability of concrete specimen is found to be decreasing. As compared to control mix, phosphogypsum concrete showed a 32.35% decrease in coefficient of permeability.

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