

A Study on Replacement of Phosphogypsum in Conventional Cement Concrete

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ABSTRACT: The rapid increase in construction activities leads to massive shortage of conventional construction materials such as cement, fine aggregate and coarse aggregate. Phosphogypsum is a by-product of phosphate fertilizer plants and chemical industries. As it is contaminated with the impurities that impair the strength development of calcined products, it can be used as partial replacement of cement. The present paper deals with the experimental investigation on mechanical properties of partially cement replaced phosphogypsum concrete using 0%, 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5% and 20% replacement with M₂₅ grade concrete with water-binder ratio of 0.48. The strength characteristics are studied by casting and testing specimens for 28 and 56 days. Cubes of 150mm x 150mm size, Cylinders of 150 mm diameter and 300mm height, and prisms of 100 mm x 100mm x 500mm are cast for conventional concrete and test was conducted to study the mechanical properties of concrete, such as compressive strength, split tensile strength and flexural strength. It is shown that a part of ordinary Portland cement can be replaced with phosphogypsum to develop a good and hardened concrete to achieve economy above 10% replacement of phosphogypsum in concrete leads to drastic reduction not only in the compressive strength, but also flexural, split tensile strength.

KEYWORDS: Phosphogypsum, Flexural Strength, Compressive Strength, Split Tensile strength.

I. INTRODUCTION

Concrete as is well known heterogeneous mix of cement, water and aggregates. The admixtures may be added in concrete in order to enhance some of the properties desired specially. In its simplest form, concrete is a mixture of paste and aggregates. The growth in infrastructure sector leads to scarcity of cement because of which the cost of cement increased incrementally. In India, demand for cement is more. Due to this construction cost of the structure increases. The phosphogypsum is an industrial waste by-product produced in various industries like fertilizer industry, phosphate ore and phosphoric chemical industry. Among them Over 6 million tons of PG is produced per annum in India. Which causes various environmental and storage problems. In today's world, there is an ever increasing demand for construction due to population expansion and shortage of building materials. The growth in infrastructure sector led to scarcity of cement because of which the cost of cement increased incrementally. In India, the cost of cement during 1995 was around Rs. 1.25/kg and in now day 2014 the price increased approximately six times and increasing day to day. Demand of cement is more. Due to this construction cost of the structure increases. In order to overcome the scarcity of cement and decrease the cost of concrete under these circumstances the use of solid wastes, agricultural wastes, and industrial by-products like fly ash, blast furnace slag, silica fume, rice husk, phosphogypsum, etc. came into use. Utilization of industrial waste such as phosphogypsum not only solves environmental problems but also provides a new resource for construction industry. This paper tries to focus on the use of phosphogypsum in partial replacement of cement in concrete. The use of above mentioned waste products with concrete in partial amounts replacing cement paved a role for

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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- 1) Modifying the properties of the concrete,
- 2) Controlling the concrete production cost,
- 3) To overcome the scarcity of cement,
- 4) The advantageous disposal of industrial wastes,
- 5) Solve the problem of environmental pollution.

The use of particular waste product will be economically advantageous usually at the place of abundant availability and production. Much of the literature is available on the use of fly ash, blast furnace slag, silica fume, rice husk, etc. In manufacture of cement concrete. However, the literature on the use of phosphogypsum in partial replacement of cement in concrete shows more application in construction area. The paper focuses on the use of phosphogypsum as a replacement material in cement.

II. LITERATURE REVIEW

Ong, Metcalf, Seals and Taha (2014) studied unconfined compressive strength of various cement stabilized Phosphogypsum (CSPG) and it was shown that the mix behaves like cement-stabilized soil. The strength and its relation between parameters were studied for different curing conditions. It was concluded phosphogypsum could be stabilized with cement to produce an adequate material for road base construction to the requirement of the local codes.

Yun Yan (2013) In order to make clear the role of phosphogypsum in cement–PG–slag–lime system, the following scheme was established: kept the proportion of cement–slag–lime invariant, added phosphogypsum whose content was 0–50% multiply by the total amount of cement, slag and lime, at the same time, the ratio of water to raw materials was also consistent. Effect of phosphogypsum content on compressive strength increases with phosphogypsum content increasing from 0% to 10%, however, which decreases when phosphogypsum content exceeds 10%. This shows that a part of phosphogypsum plays the role of activator in the system, besides, redundant phosphogypsum plays the role of filler. When phosphogypsum content exceeds 10%, the compressive strength goes down due to the relative volume of binder reduce with phosphogypsum content increasing.

Lin Yang, Zhihua Hu (2013) Phosphogypsum (PG) was used as raw material for the preparation of non autoclaved aerated concrete, a series of technological parameters, such as water to solid ratio (W/S), quick lime content, steam temperature, and chemical activators, were investigated based on the density and compressive strength of specimens in this paper and the performances of products were also tested. The optimal mix proportion for preparing PG non-autoclaved aerated concrete (about 700 kg/m³) is as follows: cement 15%, Ground Granulated Blast Furnace Slag (GGBFS) 30%, PG 55%, quick lime 7%, Na₂SO₄ 1.6%, aluminium powder 0.074%, W/S 0.45. The best steam temperature used for curing the specimens is 90 C. The compressive strength, frost-resistance and thermal conductivity of products meet the requirements of Chinese autoclaved aerated concrete blocks standard, however, the shrinking of non-autoclaved aerated concrete is still a challenge and the durability also must be observed in the next work. The results also show that phosphogypsum not only plays the role of filler but also plays the role of activator.

In recent years, a great deal of researchers devoted themselves to the utilization of PG and have gained positive results. Sunil Kumar utilized PG as raw material for manufacturing of hollow blocks. **Shen et al.** prepared a new type of lime–fly ash–phosphogypsum binder to improve the performances of lime–fly ash binder, the PG content was 18–23%. In the study of **Degirmenci (2012)**, the utilization of PG was divided into two aspects, one was used as raw material directly, the other was calcined. PG can be used for preparing binder, building block, and so on, however, the report of utilization of PG for manufacturing non-autoclaved aerated concrete is little known.

Ouyang, Nanni and Chang (2010) studied sulphate attack resistance of Portland cement mixture containing phosphogypsum and conventional aggregate. A wide range of SO₃ and C₃A contents were investigated with respect to linear expansion and compressive strength development for specimen submerged in fresh and seawater. The cement contents were varied between 10% - 30% by weight, whereas phosphogypsum varied from 0 – 50%, lime rock

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aggregate was used. The results indicated that, the optimum C_3A content, which corresponds to minimum expansion, is about 1.1% for Portland cement having C_3A content less than 7%. And phosphogypsum contents directly proportional to expansion in cement mixes. Seawater immersion decreases the strength development rate of cylinders and increases linear expansion of bars.

ZongShou Lin (2009) investigated a cementitious material by utilizing two industrial wastes, phosphogypsum (PG) and steel slag (SS), combined with another industrial byproduct ground granulated blast-furnace slag (GGBFS) and limestone (LS). The 28days compressive strength of a mixture of 45% PG, 10% SS, 35% GGBFS and 10% LS exceeded 40 MPa. XRD and SEM analyses showed that the main hydration products were ettringite and C–S–H gel. Part of PG reacted with GGBFS and SS to form ettringite, the residual PG was wrapped by hydration products. SS in the cement acted as an alkalinity activator. Over dosage of SS may cause unsoundness.

Chang, Chin and Ho (2006) have published state of art report on phosphogypsum for secondary road construction. It was concluded phosphogypsum when subjected to compaction could be transformed into a solid of valuable strength. It could be used very effectively as binder to stabilized soil, replace shell or clay in secondary road and aggregate and water. A base course was built by spreading 5 inch of loose phosphogypsum on existing soil, over which the concrete was laid. This pavement was tested for abrasion, durability, shrinkage, compensation, onsite deflection and radiation monitoring. The project demonstrated that PG based RCC was suitable for construction of parking facilities. PG without was detrimental to strength contributed to good mix and surface finish because of fine grinding.

In the study of **Smadi et al. (2003)** the setting times increased with using PG for calcined and unclaimed samples. Heat treatment of PG has resulted in the highest improvement in latter's flexural strengths and the lowest improvement in compressive strengths. Also, the curing method was found to greatly affect the strengths. The samples, which were cured in damp room, showed lower strength as compared to those cured in air.

Roy, Kalvakaalava and Seals (1996) were studied micro structural and phase characteristics of phosphogypsum cement mixtures. The effect of tricalcium aluminate (C_3A) content of the stabilizing cement (with two different C_3A percentage), curing time (7, 28, 45 and 90 days), proportion of phosphogypsum (5% to 60%), grain size, impurities in phosphogypsum on microstructure (SEM) and phase properties of mix was studied. Derivative thermo gravitometric analysis (DTA) was used in this study for hydrated products of these mixes. The study was concluded the addition of phosphogypsum to Portland cement produced large amount of ettringite. Phosphogypsum increased the degree of hydration of cement in the mixtures in the long term. The amount of carbonation in phosphogypsum based mixture was found relatively low.

III. EXPERIMENTAL PROGRAMM

MATERIALS USED

Cement

Grade 53 Ultratech cement was used for casting cubes for all concrete mixes. The cement is free from lumps and colour is uniform. Results of various tests on cement conducted are summarised in table 1.

Sand

The sand used for this experimental investigation was locally obtained and confirmed to Indian Standard Specifications IS: 383-1970. The sand was primarily sieved through 4.75 mm sieve to separate any particles greater than 4.75 mm.

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Aggregates

Crushed granite was used as coarse aggregate. The coarse aggregate according to IS: 383-1970 was used. Maximum size of coarse aggregate in the present study was 20 mm. The properties of fine aggregate and coarse aggregate are shown in table 2.

Table 1 Properties of Cement

S. No.	Characteristics	Values obtained	Standard values
1	Normal Consistency	35%	-
2	Initial Setting time	48 min	Not less than 30 min
3	Final Setting time	240 min	Not greater than 600 min
4	Fineness	4%	Less than 10%
5	Specific Gravity	3.1	3.1-3.15

Table 2 Properties of Fine Aggregate and Coarse Aggregate

S. No.	Characteristics	Fine Aggregate	Coarse Aggregate
1	Specific Gravity	2.66	2.86
2	Fineness Modulus	3.1	6.29
3	Grading Zone	II	-

PHOSPHOGYPSUM (PG)

Phosphate, in the form P_2O_5 is a nutrient for plants and a building bloc in food production. Agriculture sector uses large amount of chemical fertilizers to replenish and supplement the nutrients that growing plants take up from the soil. Modern intensive agriculture boosts natural phosphate levels in the soil through the addition of the phosphate Fertilizers. Rock phosphate is the naturally occurring source for P_2O_5 . The phosphogypsum is generated from the phosphoric acid plants. If the phosphogypsum is disposed in open yards or disposal in phosphogypsum stack yards, it may pose threat to the environment. Handling and management of phosphogypsum is a major problem in phosphoric acid plants because of the large volumes and large area required and the potential for release of dust, fluoride and heavy metals in seepage. Phosphogypsum (PG) is a byproduct generated by phosphorus fertilizer industry. It consists mainly of $CaSO_4 \cdot 2H_2O$ and contains some impurities such as P_2O_5 , F, and organic substances. The quantity of PG is large: about 5 tons of PG is produced for each ton phosphate acid. The annual production of this material in China is 40 million tons at present and only 10% is utilized. Over 400 million tons of PG has been accumulating as wastes in China.



Fig.1. Phosphogypsum

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Gypsum has been used in several forms since the beginning of civilization. At the present time, natural gypsum is utilized as building material (gypsum board, plaster ingredient, component of Portland cement, binder in Fast-Dry tennis court clay), in medicine (surgical splints), as fertilizer and soil conditioner, in hygienic products (foot creams, shampoos and hair products). The shortage of this product, its price or the non-existence of gypsum ores in several countries, have obliged to look for alternatives for the construction industry. One of these alternatives is to replace gypsum by phosphogypsum which would have the additional advantage of resolving partially the environmental problems created by fertilizer industries. Phosphogypsum can replace some of the natural components of building materials. The phosphogypsum with pale yellow colour is collected from fertilizer industries at Balanagar, Hyderabad.

APPLICATIONS OF PHOSPHOGYPSUM

The phosphogypsum for different applications which include

1. For use as soil conditioning (for alkaline soil) or as fertilizer in agriculture
2. In cement manufacturing to control the setting time of cement (as a retardant) and
3. Small quantity is used in the production of plaster, plaster boards, gypsum fiber boards, and gypsum blocks.

The utilization of phosphogypsum depends on the degree of impurities such as fluoride, phosphoric acid and radio-activity which depends on type of raw material used process adopted or pre-treatment given to phosphogypsum.

Preparation and casting of specimens

The standard size of specimens such as cubes (150 mm × 150 mm × 150 mm) to determine compressive strength, cylinders (150 mm diameter and 300 mm length) to determine split tensile strength and beams (100 mm × 100 mm × 500 mm) to determine flexural strength were casted. All the inner surfaces and base plates of moulds were coated with oil for easy removal of form and smooth finish. At-most care was taken while batching, mixing and casting operations were done. The specimens were de-moulded after 24 hours and kept in water for curing for 28 days and 56 days .

Experimental procedure

Experimental investigation was carried out with reference to the nominal concrete mix M₂₅. Phosphogypsum, Grade 53 Ultratech cement, sand, aggregates are the materials used as replacement of cement in this study .

Mix Proportions of Concrete (Kg/m³)

Mix	Cement	Fine Aggregate	Coarse Aggregate	Water(litres)
M ₂₅	399.125	679.778	1208	191.58

IV. EXPERIMENTAL RESULTS

RESULTS:

% of Phospho gypsume In concrete	Compressive strength(Mpa)		Split tensile strength(Mpa)		Flexural strength(Mpa)	
	28 days	56 days	28 days	56 days	28 days	56 days
0%	34.59	36.29	3.05	3.28	2.97	3.16
2.5%	36.58	39.20	3.23	3.36	3.15	3.20
5%	39.10	41.10	3.32	3.47	3.43	3.50

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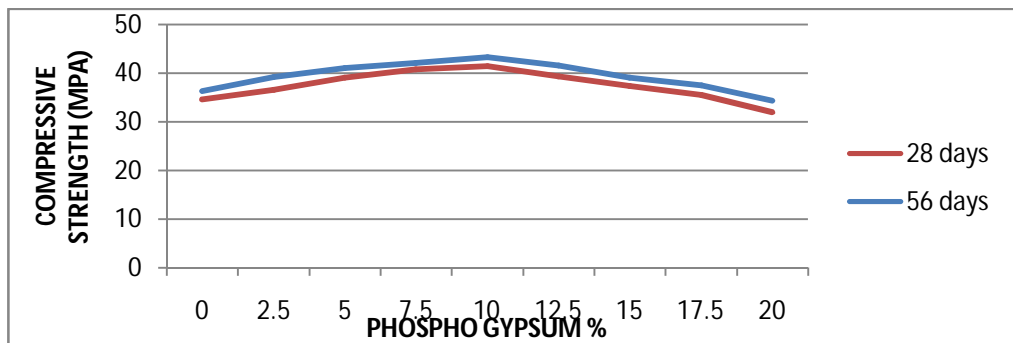
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7.5%	40.74	42.07	3.42	3.87	3.70	3.70
10%	41.48	43.29	3.67	4.41	3.76	3.85
12.5%	39.33	41.51	3.30	3.83	3.66	3.77
15%	37.33	39.03	3.25	3.53	3.59	3.71
17.5%	35.48	37.51	2.83	3.33	3.10	3.31
20%	31.99	34.33	2.62	3.27	2.65	2.79

GRAPHS:

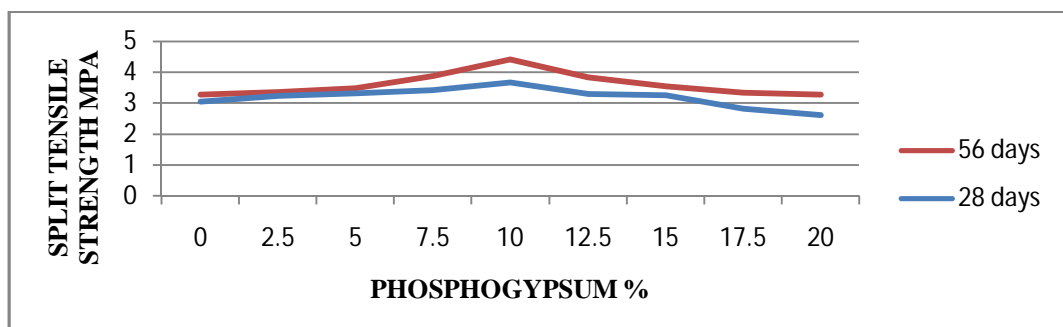
COMPRESSIVE STRENGTH:

Compressive strength test was carried out for the cubes after 28 days and 56 days with reference to M₂₅ grade concrete. Compressive strength at 28 days increases by 19.92% and Compressive strength at 56 days increases by 18.44% with 10% replacement of phosphogypsum. The variation of compressive strength is shown in graph 1



SPLIT TENSILE STRENGTH:

Split tensile strength test for 28 days and 56 days was carried for the cylinders with reference to the nominal concrete mix M₂₅. The split tensile strength of concrete with phosphogypsum showed an increase in Split tensile strength at 28 days increases by 16.28% and Split tensile strength at 56 days increases by 16.88% with 10% replacement of phosphogypsum with reference to conventional concrete. The variation of split tensile strength is shown in graph 2.



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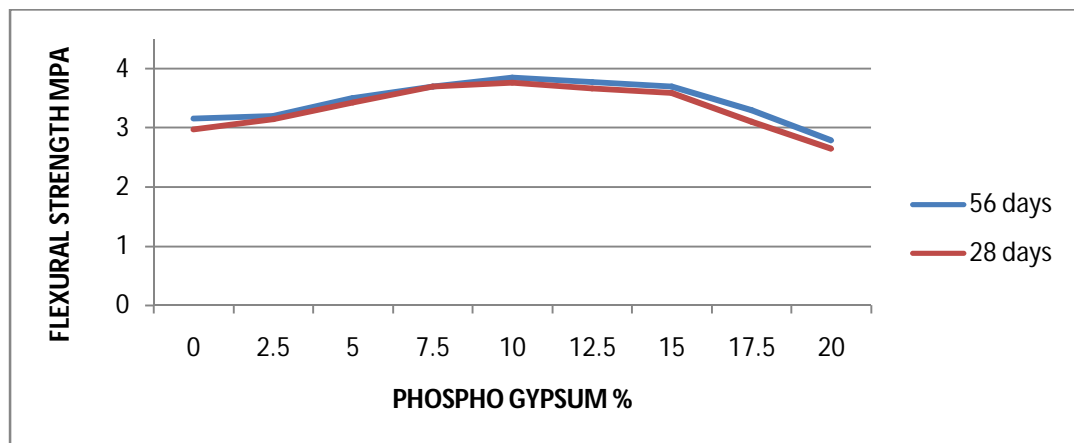
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FLEXURAL STRENGTH:

Flexural tensile strength test for 28 days and 56 days was carried for beams with reference to the nominal concrete mix M₂₅. The flexural strength of concrete with phosphogypsum showed an increase in flexural tensile strength at 28 days increases by 26.6% and at 56 days increases by 17.92% with 10% replacement of phosphogypsum with reference to conventional concrete. The variation of split tensile strength is shown in graph 3.



V. CONCLUSIONS

1. By replacements cement in concrete by phosphogypsum, reduces the consumption of cement.
2. Compressive strength at 28 days increases by 19.92% and 56 days increases by 18.44% with optimum value of 10% replacement of phosphogypsum.
3. Split tensile strength at 28 days increases by 16.28% and 56 days increases by 16.88% with optimum value of 10% replacement of phosphogypsum.
4. Flexural strength at 28 days increases by 26.6% and 56 days increases by 17.92% with optimum value of 10% replacement of phosphogypsum.
5. Environmental effects from wastes and residual amount of cement manufacturing can be reduced through this low cost concrete.
6. Helps to some extent in preserving the environment as its application reduces the requirement of cement's raw material.
- 7.

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ISSN(Online) : 2319-8753
ISSN (Print) : 2347-6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 1, January 2017

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