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# A STUDY ON STRENGTH CHARACTERISTICS OF PHOSPHOGYPSUM CONCRETE

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## ABSTRACT

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 compressive, tensile and flexural strength characteristics of partially cement replaced phosphogypsum concrete using 0%., 10%, 20%, 30% and 40% replacement with different water-binder ratios of 0.40, 0.45, 0.50, 0.55, 0.60 and 0.65. The strength characteristics are studied by casting and testing a total of 450 specimens, which consists of 270 cubes, 90 cylinders and 90 beams for 7, 28 and 90 days. It is shown that a part of Portland cement can be replaced with phosphogypsum to develop a good and hardened concrete to achieve economy; above 10% replacement of phosphogypsum in concrete lead to drastic reduction not only in the compressive strength but in the split-tensile strength also; the flexural strength decreases as width and number of cracks increases significantly at replacement above 10% of cement with phosphogypsum at different water-binder ratios.

**Keywords:** Phosphogypsum; partial replacement; water-binder ratio; compressive; tensile and flexural strengths.

## 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 modifications 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

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increased incrementally. In India, the cost of cement during 1995 was around Rs. 1.25/kg and in 2005 the price increased approximately three times [1]. In order to combat the scarcity of cement and the increase in cost of concrete under these circumstances the use of recycled solid wastes, agricultural wastes, and industrial by-products like fly ash, blast furnace slag, silica fume, rise husk, phosphogypsum, etc. came into use. The use of above-mentioned waste products with concrete in partial amounts replacing cement paved a role for (i) modifying the properties of the concrete, (ii) controlling the concrete production cost, (iii) to overcome the scarcity of cement, and finally (iv) the advantageous disposal of industrial wastes. 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, rise husk, etc. in manufacture of cement concrete. However, the literature on the use of phosphogypsum in construction industry is in the budding stage. This paper tries to focus on the use of phosphogypsum in partial replacement of cement in concrete.

*1.1 Phosphogypsum*

In India, about 6 million tons of waste gypsum such as phosphogypsum, flourogypsum etc., are being generated annually [2]. Phosphogypsum is a by-product in the wet process for manufacture of phosphoric acid (ammonium phosphate fertilizer) by the action of sulphuric acid on the rock phosphate. It is produced by various processes such as dihydrate, hemihydrate or anhydrite processes. In India the majority of phosphogypsum is produced by the dehydrate process due to its simplicity in operation and lower maintenance as compared to other processes. The other sources of phosphogypsum are by-products of hydrofluoric acid and boric acid industries.

Current worldwide production of phosphoric acid yields over 100 million tons of phosphogypsum per year. While most of the rest of the world looked at phosphogypsum as a valuable raw material and developed process to utilize it in chemical manufacture and building products, India blessed with abundant low-cost natural gypsum piled the phosphogypsum up rather than bear the additional expense of utilizing it as a raw material [3, 4]. It should be noted that during most of this time period the primary reason phosphogypsum 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 [5]. However, these impurities impair the strength development of calcined products [6]. It has only been in recent years that the question of radioactivity has been raised and this question now influences every decision relative to potential use in building products in this country [7, 8].

## 2. LITERATURE REVIEW

Some attempts have been made to utilize phosphogypsum as base and fill materials (in the form of cement-stabilized phosphogypsum mix) in the construction of highways, runways, etc. [9, 10]. In other attempts, phosphogypsum was recycled for manufacture of fibrous gypsum boards, blocks, gypsum plaster, composite mortars using Portland cement, masonry cement, and super-sulphate cement [2, 11, 12]. In some other attempts phosphogypsum was also used as a soil conditioner for calcium and sulphur deficient-soils as it has fertilizer value due to the presence of ammonium sulphate [13, 14]. Recently, the effect of phosphatic and fluoride impurities present in waste phosphogypsum on the setting time, strength development and morphology of selenite gypsum plaster have been studied [15]. Also, the techno-economic feasibility of beneficiating phosphogypsum has been studied wherein the beneficiated phosphogypsum was used for making Portland cement and Portland slag cement, and the results favoured use of phosphogypsum as an additive to cement clinker in place of natural gypsum [16]. However, a very few attempts have been made to study the usability of phosphogypsum as partial replacement to cement, whose use in cement and concrete will be a significant achievement in the development of concrete technology in the coming few decades [7, 16-23]. The present paper deals with the experimental investigation on compressive, tensile and flexural strength characteristics of partially cement replaced phosphogypsum concrete using 0%, 10%, 20%, 30% and 40% replacement with lower water-binder ratios of 0.40, 0.45 and 0.50, and higher water-binder ratios of 0.55, 0.60 and 0.65 respectively.

## 3. EXPERIMENTAL PROGRAMME

An experimental investigation is conducted to study the effect of partial replacement of cement by phosphogypsum in cement concrete. Absolute volume method is used in the present investigation. The test programme consisted of carrying out compressive strength test on cubes, split-tensile strength test on cylinders and flexural strength test on flexural beams.

### *3.1 Materials*

- Cement: Ordinary Portland cement (53 grade 'Priya' cement) confirming to IS 12269-1987 standards is used in the present investigation. The cement is tested for its various properties as per IS 4031-1988 and found to be confirming to the requirements as per IS 12269-1987. The different properties of cement are: specific gravity-3.05, normal consistency-29.5%, fineness - 6%, initial setting time - 35 minutes, and final setting time-190 minutes.
- Phosphogypsum: The phosphogypsum with pale yellow colour is collected from fertilizer industries at Balanagar, Hyderabad.
- Fine Aggregates: The locally available sand confirming to IS 383:1970 is used as fine aggregate in the present investigation. The sand is free from clay matter, silt and organic impurities. The sand has a specific gravity 2.69 in accordance with IS 2386-1963, and fineness modulus 2.9.
- Coarse Aggregates: Machine crushed 20 mm nominal size angular granite metal from local source confirming to IS 383:1970 is used as coarse aggregate. It is free from impurities such as dust, clay particles and organic matter, etc. The coarse aggregate has specific gravity 2.72, and fineness modulus 6.90.
- Water: The water used to prepare concrete is clean, and free of organic matter. The

locally available potable water conforming to IS 3025-1986, which is free from concentration of acids and organic substances, is used for mixing the concrete.

*3.2 Test programme*

- Quantities of Ingredients: Quantities of ingredients for concrete mix are calculated by absolute volume method conforming to IS 10262-1982. In this method, the absolute volume of the fully compacted concrete mixed freshly is equal to the sum of the absolute volumes of all the ingredients. The final quantities of these ingredients for 0%, 10%, 20%, 30% and 40% replacement of phosphogypsum with lower water-binder ratios of 0.40, 0.45 and 0.50, and higher water-binder ratios of 0.55, 0.60 and 0.65 respectively are arrived at. The strength characteristics are studied by casting and testing nine cubes of 150mm side, three cylinders of 150 mm diameter and 300 mm height, and three beams of 100mm×100mm×500mm in case of each water-binder ratio with a particular percentage replacement of phosphogypsum. The final quantities with 5% extra (i.e. total volume 0.064575 $m^3$), for example, for 10% replacement of phosphogypsum with lower water-binder ratio of 0.40 are: cement – 31.3 kg, phosphogypsum – 3.5 kg, water – 14.2 liters, coarse aggregate – 64.0 kg, and fine aggregate – 42.7 kg respectively.
- Weighing and Batching: Mixing operation was done in such a way so as to produce homogeneous, uniform cement mortar mix. The proportioning of cement, phosphogypsum, and aggregates for each batch was done by mass. For every batch quantity of mix was mixed in such a way that about 5% excess was left out after pouring concrete in moulds for the desired test specimens. All measuring equipments were maintained in a clean serviceable condition with their accuracy periodically checked.
- Mixing Concrete: After arriving at the quantities of ingredients, all the materials are weigh batched, and they are placed on non-porous platform. Cement and phosphogypsum are dry mixed to which fine aggregate and coarse aggregate are added and thoroughly mixed. Water measured exactly is added to it and mixed thoroughly until a homogeneous mix is achieved. This mix is then ready for casting.
- Placing Concrete in Moulds: All the test specimens are cast in removable standard (cast iron) moulds confirming to IS 10086-1982. The wet concrete mix is placed in moulds with proper care and tamped with a thin iron rod before keeping the moulds on the vibrating machine, and vibrated on a standard vibrating table confirming to IS 7246-1974 for one minute such that there will be no air voids and the concrete will compact properly. In total 450 specimens are cast in 30 batches, which consists of 270 cubes, 90 cylinders, 90 beams for different percentage replacement of phosphogypsum with different water-binder ratios. After 24 hours demoulding is done and the specimens are kept in water for curing.
- Curing: Curing is done till such a period that the specimens are tested for their strength characteristics at the end of 7, 28 and 90 days.
- Testing of Specimens: In this investigation, specimens are tested for compressive strength according to IS 516-1959 and results are noted at the end of 7, 28, and 90 days according to their schedule. Similarly the specimens are tested for split-tensile strength and flexure test as per the codal requirements at the end of 28 days and results are tabulated in Table 1.

Table 1: Test results showing compressive, split tensile and flexural strengths with different water-binder ratios with age

| **Water-binder ratio** | **Replacement of cement, %** | **Compressive strength, N/mm$^2$** | | | **Split tensile strength, N/mm$^2$** | **Flexural strength, N/mm$^2$** |
|---|---|---|---|---|---|---|
| | | **7 days** | **28 days** | **90 days** | **28 days** | **28 days** |
| 0.40 | 0 | 32.50 | 48.80 | 49.90 | 3.70 | 2.40 |
| | 10 | 33.20 | 49.30 | 53.20 | 4.05 | 2.40 |
| | 20 | 30.70 | 43.70 | 46.80 | 3.50 | 2.40 |
| | 30 | 24.00 | 31.20 | 35.40 | 2.86 | 1.60 |
| | 40 | 16.00 | 16.50 | 18.30 | 2.55 | 0.80 |
| 0.45 | 0 | 35.60 | 37.80 | 46.00 | 3.90 | 2.40 |
| | 10 | 35.90 | 47.10 | 47.90 | 4.10 | 2.40 |
| | 20 | 35.30 | 42.70 | 44.30 | 3.55 | 2.00 |
| | 30 | 27.00 | 31.60 | 37.80 | 2.96 | 1.20 |
| | 40 | 13.10 | 15.30 | 17.50 | 2.40 | 0.80 |
| 0.50 | 0 | 28.00 | 34.80 | 41.30 | 3.85 | 2.80 |
| | 10 | 33.50 | 36.00 | 42.20 | 4.15 | 2.40 |
| | 20 | 30.80 | 33.70 | 37.20 | 3.44 | 2.00 |
| | 30 | 23.50 | 29.40 | 31.50 | 2.92 | 1.20 |
| | 40 | 8.60 | 9.30 | 12.20 | 2.35 | 0.80 |
| 0.55 | 0 | 27.37 | 34.66 | 43.77 | 3.80 | 2.80 |
| | 10 | 29.42 | 33.60 | 44.40 | 4.10 | 2.40 |
| | 20 | 24.75 | 30.62 | 34.90 | 3.65 | 2.00 |
| | 30 | 16.08 | 23.06 | 26.48 | 2.96 | 1.20 |
| | 40 | 9.15 | 13.73 | 14.84 | 2.68 | 0.80 |
| 0.60 | 0 | 24.84 | 30.44 | 38.13 | 3.95 | 2.40 |
| | 10 | 27.46 | 30.66 | 42.00 | 4.05 | 2.40 |
| | 20 | 21.70 | 24.97 | 27.15 | 3.53 | 1.60 |
| | 30 | 14.10 | 18.71 | 21.02 | 3.10 | 0.80 |
| | 40 | 6.97 | 10.75 | 12.62 | 2.80 | 0.80 |
| 0.65 | 0 | 25.20 | 31.55 | 33.82 | 3.75 | 2.80 |
| | 10 | 25.82 | 32.20 | 40.08 | 4.15 | 2.00 |
| | 20 | 15.82 | 23.51 | 26.75 | 3.45 | 0.80 |
| | 30 | 10.17 | 17.55 | 18.40 | 2.80 | 0.80 |
| | 40 | 5.02 | 9.77 | 11.28 | 2.75 | 0.80 |

*3.3 Discussion of test results*

The variation of compressive strength of cubes and spit-tensile strength of cylinders versus age in days using different percentage replacements of phosphogypsum at lower water-binder ratios 0.40, 0.45 and 0.50 is presented in Figure 1, while the same variation at higher water-binder ratios 0.55, 0.60 and 0.65 is presented in Figure 2. A close look at these figures and Table 1 reveals that with 10% replacement of cement with phosphogypsum:

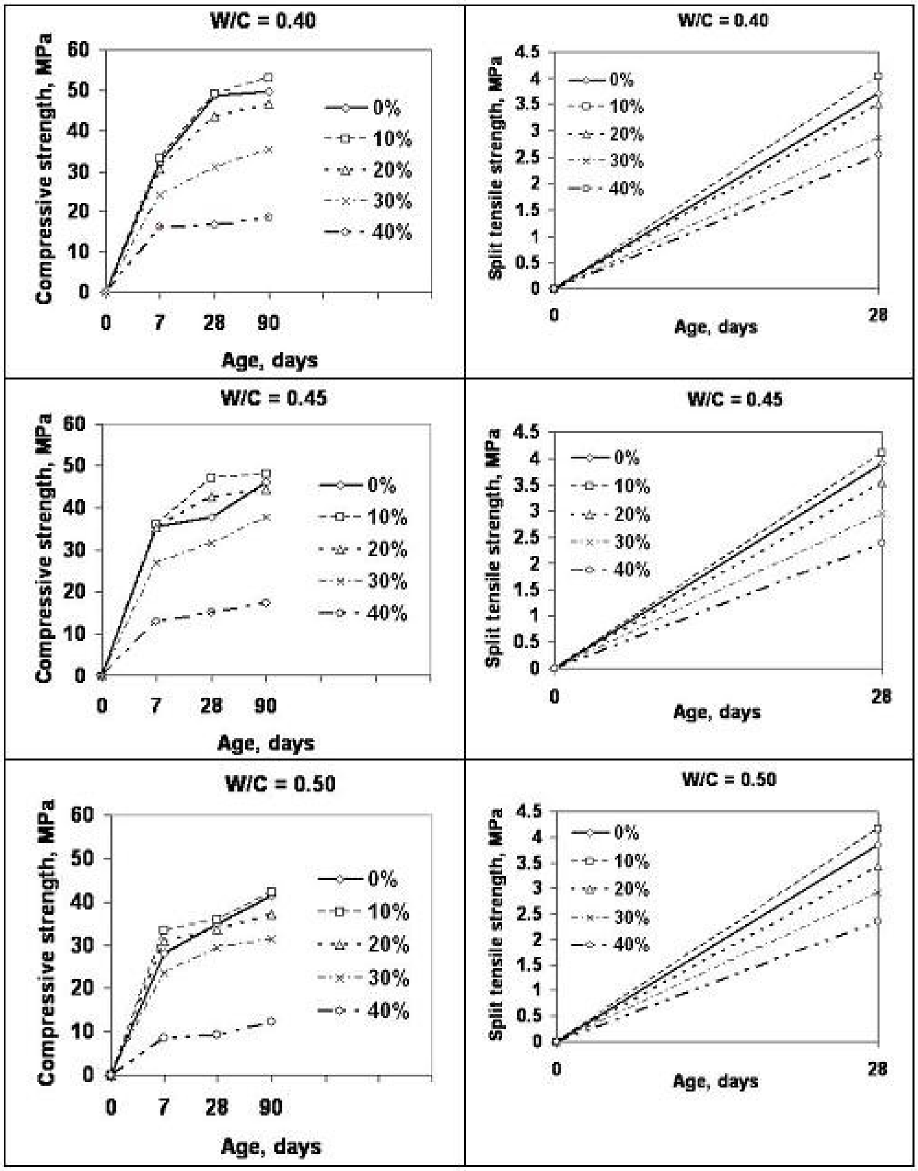


Figure 1. Variation of compressive and split-tensile strengths versus age using different percentage replacements of phosphogypsum with water-binder ratios 0.40, 0.45 and 0.50

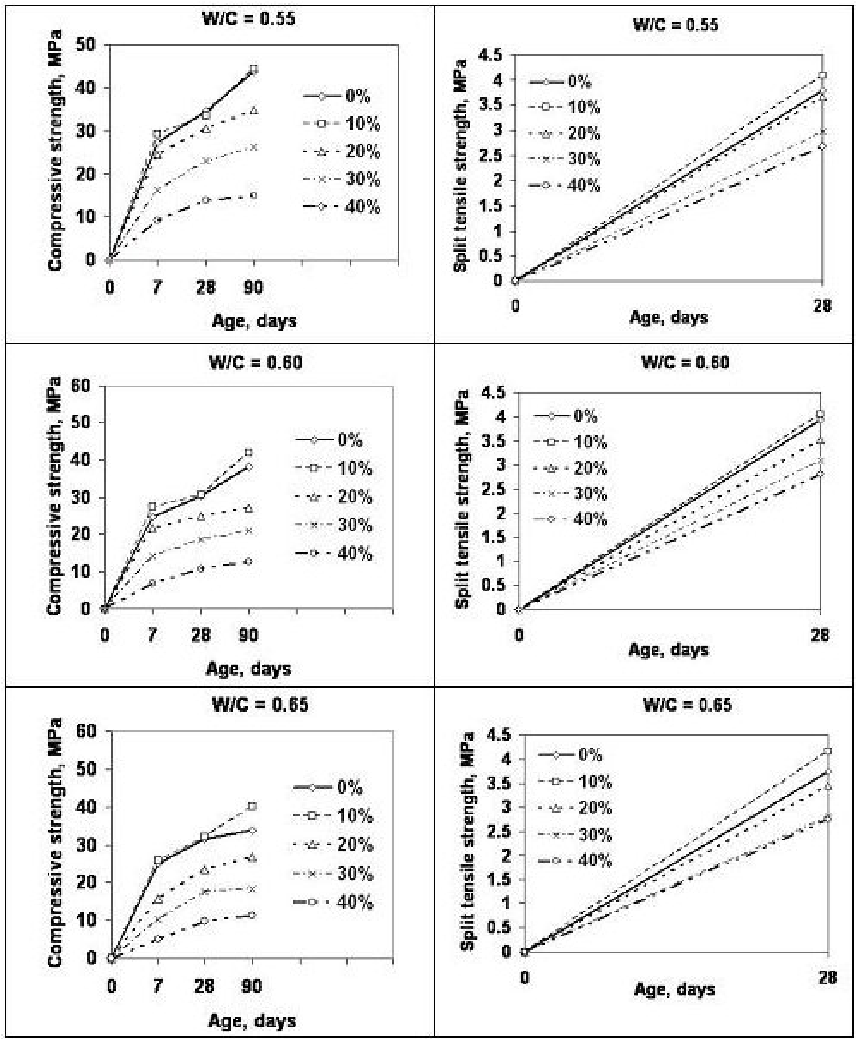


Figure 2. Variation of compressive and split-tensile strengths versus age using different percentage replacements of phosphogypsum with water-binder ratios 0.55, 0.60 and 0.65

- the compressive strength at 7 days increased significantly (around 20% increase) at water-binder ratio 0.50 and marginally (around 1-10% increase) at other water-binder ratios;
- the compressive strength at 28 days increased significantly (around 25% increase) at water-binder ratio 0.45 and marginally (around 1-3% increase) at other water-binder ratios;
- the compressive strength at 90 days increased significantly (around 19% increase) at water-binder ratio 0.65 and marginally (around 1-10% increase) at other water-binder ratios;
- the split-tensile strength at 28 days increased marginally (around 3-10% increase) at different water-binder ratios.

However, further replacement of cement with phosphogypsum lead to drastic reduction not only in the compressive strength but in the split-tensile strength also.

From Table 1 it is noted that the flexural strength not only decreased significantly with higher replacement of cement with phosphogypsum but with increase in water-binder ratio also. From the flexure test we observe that as the replacement of phosphogypsum increases, the beam fails at lower load. And as the percentage of replacement increases the deflection of the beam also increases. From the crack patterns it is observed that the width and number of cracks increased with the increase in replacement of phosphogypsum beyond 10%.

As we aimed at the target mean strength of 40 N/mm$^2$, 20% replacement can be taken as the optimum possible replacement of cement with phosphogypsum with water-binder ratios 0.40 and 0.45 respectively, because the strength in such a case of replacement is more than 40N/mm$^2$. Similarly if we aim at the target mean strength of 30 N/mm$^2$, 30% replacement can be taken as the optimum possible replacement of cement with phosphogypsum with water-binder ratios 0.40 and 0.45 respectively, or 20% replacement with water-binder ratio 0.55, or 10% replacement with water-binder ratios 0.60 and 0.65 respectively, because the strength in such a case of replacement is more than 30 N/mm$^2$. Similarly if we aim at the target mean strength of 20 N/mm$^2$, 30% replacement can be taken as the optimum possible replacement of cement with phosphogypsum with water-binder ratio 0.55, or 20% replacement with water-binder ratios 0.60 and 0.65 respectively, because the strength in such a case of replacement is more than 20 N/mm$^2$. However, it is noted from Table 1 that 40% replacement of cement with phosphogypsum lead to decrease in the compressive strengths by approximately one-third the original compressive strengths without any addition of phosphogypsum. From Table 1 it is also noted that for preparations of ‘standard concrete’ with grade designations M 25, M 30, M 35 and M 40 (as per IS 456-2000) we can use any appropriate replacement of cement with phosphogypsum in the range of 10-30% with appropriate water-binder ratio of 0.40-0.65, and for ‘ordinate concrete’ with grade designations M 10, M 15 and M 20 we can use any appropriate replacement of cement with phosphogypsum in the range of 10-30% with appropriate water-binder ratio of 0.55-0.65.

## 4. CONCLUSIONS

Based on the limited experimental investigation conducted and the analysis of test results, the following conclusions are drawn.

- An industrial waste like phosphogypsum impairs the strength development of calcined products and hence it can be used in construction industry for preparation of concrete replacing some quantity of cement, which is a valuable ingredient of concrete, to achieve economy.
- With 10% replacement of cement with phosphogypsum not only the compressive strength increased marginally/significantly with age but also the split-tensile strength at 28 days increased commendably in case of different water-binder ratios. However, further replacement of cement with phosphogypsum lead to drastic reduction not only in the compressive strength but in the split-tensile strength also.
- The flexural strength not only decreased significantly with higher replacement of cement with phosphogypsum but with increase in water-binder ratio also. The width and number

of cracks increased with the increase in replacement of phosphogypsum above 10%.

- For preparations of 'standard concrete' with grade designations M 25, M 30, M 35 and M 40 (as per IS 456-2000) we can use any appropriate replacement of cement with phosphogypsum in the range of 10-30% with appropriate water-binder ratio of 0.40-0.65, and for 'ordinate concrete' with grade designations M 10, M 15 and M 20 we can use any appropriate replacement in the range of 10-30% with appropriate water-binder ratio of 0.55-0.65.

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