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Industrial waste phosphogypsum's impact on CO_2 reduction and global warming

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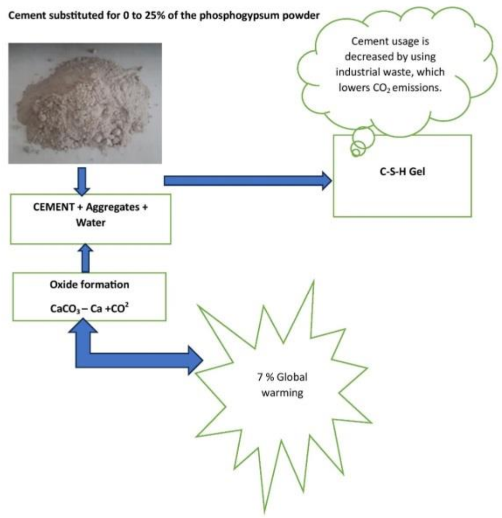
Graphical abstract



Abstract

The construction industry looks over the material alternatives whereby the conventionally materials can be replaced. The conventionally materials like fine aggregate, cement, as well as coarse aggregate. The replacements for the conventional materials are wider but the waste products and its by-products could be the better alternative. It contributes in recycling the waste and converting into useful products. Other factor to be considered while producing the cement it leaves out lot of polluting factors (CO_2) causes environmental degradation which is in the alarm rate. So, these factors are taken into account while finding the alternative materials to replace the construction materials. One among the industrial waste materials is phosphogypsum, which is till date discarding in the water bodies leads to environmental pollution. In this work phosphogypsum is considered as supplementary cementitious substituent in the concrete. In this study, different amounts of phosphogypsum were mixed with cement to study various qualities of concrete. The outcomes improved by 5 – 10 % with the addition of phosphogypsum, while CO_2 emissions decreased by the same amount. Washing and drying the phosphogypsum increased performance in all mediums. More thorough investigation into the properties of phosphogypsum and the reaction mechanism may lead to a better understanding.

Keywords: Phosphogypsum, waste management, tensile strength, compressive strength

1. Introduction

The largest part of construction materials including brick, steel, concrete, wood and so on. Nevertheless, only some of these aerials have been evolved into the contemporary technologies because of their competence in the construction environment. Concrete is one such construction material which achieved its reputation in the early 1960's. In the construction of the building and other structures concrete plays a significant role and a large amount of concrete is being utilized. Worldwide concrete has overtaken steel in tonnage of material used. As the construction industry develops, Additionally, its effect on the environment has grown. Cement industry is key source of emissions like CO_2, Nitrous oxide, sulphuric dioxide, as well as other particulate matter in total, 5-6% of all human-caused carbon dioxide is emitted due to cement production (Syamala Devi K *et al. 2018*: Saravanakumar and Revathi 2017; Saravanakumar and Revathi 2014). The common consensus is that each tonne of cement utilises as much carbon dioxide as it emits during production. The chlorophyll content of the plant and photosynthesis are both impacted by industrial pollutants from the cement making industry (Sadhana Chaurasia *et al.2013:* Saravanakumar and Revathi 2016). India is one of the world's largest and fastest growing economies, and an enormous number of industrial wastes is polluting the environment. It follows, therefore, that in the long term, increased concern for construction materials use is making the requirement for conventionally used materials constantly harder to meet.

This research has been undertaken to identify and develop the usage of phosphogypsum, which is produced in enormous quantities each year, in order to play the function of providing technology to encourage the efficient use of minerals and ores and their processing wastes. Phosphogypsum is a type of gypsum that is created as a by-product of phosphate ores during the wet process of creating phosphoric acid. Only 15% of the world's phosphogypsum production is recycled into Portland cement (Alaa M. Rashad 2017) construction products, agricultural composts, soil stabilisation modifications, or set controllers. The other 85% is disposed of in enormous, outdoor warehouses that take up a lot of room and are actually bad for the environment. Normally, these leftovers are discarded without being treated. Additionally, gases emitted from this waste that contain dangerous substances have the potential to harm the atmosphere. In order to solve environmental and disposal challenges, it is crucial to use phosphogypsum correctly following treatment. There have been initiatives in numerous countries to find applications for phosphogypsum.

When making Portland cement, phosphogypsum is utilised as an extra natural gypsum source to control the cement's rate of hydration reaction. Phosphorgypsum can be used in place of Portland cement to improve both good and hardened concrete in addition to being an inexpensive building material, in addition to the low-cost building material. In this investigation, mechanical characteristics such as split tensile strength, compressive strength, and flexural strength are measured. The test findings demonstrated that adding phosphogypsum significantly improves the microstructure and strength of the concrete. Finally, it is discovered that phosphate concrete, also known as phosphogypsum, results in increased strength and financial advantages (Jiangchuan li *et al.* 2022). The green concrete was made using the phosphogypsum aggregate type (Enlai Dong *et al.*2023)

For the M20, M25, and M30 grades of concrete, testing has shown that replacing phosphogypsum with cement at percentages of 2.5%, 7.5%, 5%, and 10% is feasible because phosphogypsum can be used to supply the necessary materials for producing the concrete with results that are both structurally and financially viable. Compressive strength is very nearly half of the tensile strength, and impact strength is nearly a quarter of the tensile strength, as a result of the replacement of phosphate in concrete with phosphogypsum (Koduru.Srinivasulu and Raghava 2017). Workability of concrete increases to a point at which it enhances by 5% substitute of phosphogypsum, with workability decreasing thereafter. This provides a simple solution to the issue of finding the optimal percentage of phosphogypsum to use in concrete (Koduru.Srinivasulu 2017). 5 to 10 percentage phosphogypsum addition to cement clinker, which was used in Portland cement manufacturing, yielded satisfactory results, which could be applied to Portland cement production (Sadiqul Islam *et al. 2016*). When phosphogypsum is added to concrete, its split tensile, compressive, and flexural strengths improve up to 8% replacement before gradually declining to M20 level concrete with something like a water binder ratio of 0.50.(Dhinakaran and Mercy Shanthi 2015). Increases in setting time and standard uniformity were brought on by using more cement than was necessary, as was the case when cement was partially replaced with phosphogypsum, but soundness was unaffected. Because of the 10% phosphogypsum substitution in cement, the compressive strength of the cement increased dramatically as it aged. However, this increase in compressive strength was supplemented by an even more impressive rise in the split-tensile strength when different water-binding ratios were employed (ShrikantNigade and MaheshBagade 2015). The compressive strength of phosphogypsum-based cement concrete with 5% and 10% phosphogypsum was excellent, indicating that phosphogypsum concrete can be used in mass concrete work as well (Mahesh and Satone 2012). Standard concrete of grade identities M10, M15, and M20 with water binder ratios of 0.40-0.65 and M25, M30, M35, and M40 grade designations with water binder ratios of 0.55-0.65 may be substituted (Siva Sankar Reddy *et al. 2010*).

This analysis as the following requirements,

- Phosphogypsum is used as supplementary cementitious material to produce concrete with a minimal price.
- To deal with the disposal as well as pollution problems of phosphogypsum, as well as to seek a substitute besides cement so that it can reduce the production of cement.
- To scrutinize the efficiency of phosphogypsum as well as the effects it has on the flexural characteristics of concrete.
- To establish a more comfortable environment without polluted space.
- One possible solution to finding a better solution for concrete mixture that gives higher strength to concrete is to look for concrete that is produced using waste products.

The objectives of this analysis are as follows,

- In addition to examining the mechanical properties of phosphogypsum concrete, such as compressive strength, split tensile strength, and flexural strength, researchers may look into the interaction of particular components to produce mechanical stability.
- It is critical to discover the optimal mix of phosphogypsum concrete.
- The findings of this experiment and study will be compared to the flexural strength of phosphogypsum concrete and control concrete.

2. Resources used

2.1. Cement

Regular Portland Cement 53 grade confirmed to IS standard 12269:2013 is used in this study. The consistency of the cement was clear throughout, with a grayish color that has a greenish hue, and without any noticeable lumps. As a result of various tests in the laboratory performed so according to IS 4031-1988, distinctly different properties are eventually revealed. Table 1 reports these characteristics.

Table 1. Cement's Physical Characteristics

S. No	Property	Result
1	Specific gravity	3.04
2	Initial setting time	34 minutes
3	Final setting time	295 minutes
4	Consistency	31.50%

2.2. Fine aggregate

After investigating the fine aggregate particle size distribution, it was discovered that a sieve was used to obtain the desired particle size distribution. For the purposes of this analysis, tests are carried out to validate the physical characteristics of fine aggregate as defined by IS 2386-1963, with the outcomes shown in Table 2.

Table 2. Fine Aggregate Physical Properties

S. No	Property	Result
1	Specific gravity	2.65
2	Fineness modulus	2.76
3	Grading zone	II

2.3. Coarse aggregate

Coarse material utilised was 20 mm in size. The qualities of the concrete are measured to check if they comply with IS 2386-1963, and a variety of tests are conducted to evaluate these parameters. Testing determined that the coarse aggregate's crushing strength was 15.02% and that its specific gravity should be 2.74.

2.4. Phosphogypsum

Gypsum ($CaSO_4.2H_2O$), which makes up 90% of the chemical formed when phosphate rock is treated with water, is what is referred to as phosphogypsum and is produced as a by-product of the fertiliser manufacturing operations. Phosphoric acid, a primary component of many fertilisers, is obtained from phosphogypsum, a by-product of the process used to make phosphate fertilisers. In the study that reported phosphoric acid production creates around 4 to 6 tonnes of phosphogypsum per tonne of phosphoric acid, a conclusion was drawn that phosphate production would likely generate phosphate compounds in the equivalent weight. Since the structure of the calcined product was not optimal, it led to slow production of the intensity of the product. Often, due to this, it is occasionally used as a replacement for cement, but there are exceptions. Powdered phosphogypsum can be used to substitute natural gypsum in the production of Portland cement, which reduces the rate of hydration reaction of the cement. Owing to its low radioactivity, gypsum is seldom used in building, and because of this, it is beneficial to use phosphogypsum. Nevertheless, it is kept for an indeterminate period of time due to its exceedingly low radioactive potency. The phosphate fertilizer factory in the region of Cochin in Kerala, which also has a specific gravity of 2.34, produces phosphogypsum, which would also be extracted and processed in facilities called phosphate treatment plants.

2.4.1. Physical properties of phosphogypsum

Depending on the temperature at which the reaction producing phosphoric acid occurs, calcium sulphate can either be dihydrate ($CaSO_4.2H_2O$) or hemihydrate ($CaSO_4.0.5H_2O$). The gypsum cake typically has a free moisture content of 25–30% after filtration. In the presence of free water, the generated hemihydrate form of phosphogypsum can quickly change into the dehydrate form. Additionally, if the process is not stopped, it will harden into a cement mass that is relatively tough. Di-hydrate is predominantly made up of soft crystal aggregates that have a silt-like appearance and measure 0.075 mm in size. The characteristics of the reactor and the source of the phosphate rock determine it.

2.4.2. Phosphogypsum chemical properties

With a small amount of silica, phosphogypsum is primarily composed of calcium sulphate dehydrate. Fluorapatite, goethite, and quartz make up the majority of the phosphate ore's mineralogical makeup, with smaller amounts of Al-phosphates, anatase, magnetite, monazite, and barite (Figure 1).

Figure 1. Phosphogypsum powder

2.5. Mix proportion

According to IS 10262:2009, a mix design for Control Concrete and Phosphogypsum Concrete of Grade M30 was created. The replacement percentages of phosphogypsum, which ranged from 0% to 5%, 10% to 15%, 20% to 25%, were given the letters CC, P1, P2, P3, P4, and P5, respectively. The final mix proportion ratio was 1:1.36:2.31, and the cement to water ratio used was 0.45.

3. Experimental procedure

To begin, experimental mixes were utilised to ensure that the proper mix ratio was obtained. 37 cube specimens with dimensions of 150 mm x 150 mm x 150 mm, 37 cylindrical specimens with dimensions of 150 mm in diameter and 300 mm in length, and 37 prism specimens with dimensions of 500 mm x 100 mm x 100 mm were cast for compressive strength. Figure 2 depicts the cast specimens.

Figure 2. Casted specimens

The specimens are demoulded in next day and cured by immersion curing technique. After a proper curing interval, the specimens are tested for compressive strength, split tensile strength, and flexural strength. After the test results were analysed and contrasted with the control mixture, additional actions were taken. Based on the result as well as comparison findings, it was decided that work was necessary and recommendations for the potential scope of work were made (Figure 3 and Table 3).

Figure 3. Specimen under loading conditions

4. Test results

4.1. Compressive strength test

Table 3. Compressive strength test results

S. No	Mix id	Strength in N/mm² after 7 days	Strength in N/mm² after 28 days
1	CC	25.98	33.72
2	P1	28.68	35.75
3	P2	26.32	33.04
4	P3	23.65	28.17
5	P4	21.15	25.42
6	P5	18.22	21.90

The concrete strength was calculated to be 30 MPa, and the cement was replaced by phosphogypsum at 0%, 5%, 10%, 15%, 20%, and 25% by weight. Figure 4 shows the results of 7-day and 28-day compression strength tests. The results reveal that adding 5% and 10% phosphogypsum to produced concrete yields equivalent outcomes to concrete without phosphogypsum after 7 days. For filed condition, a declining tendency in strength with phosphogypsum addition was observed at this age. At 28 days, the processed materials had higher concrete strength than the control sample. The 10% addition had lower strength but was judged to be optimal when all replacement levels were considered. More than 10% phosphogypsum affects concrete strength significantly in both field and processed conditions. Due to the combined effects of cement and phosphogypsum, the phosphogypsum makes concrete more workable.

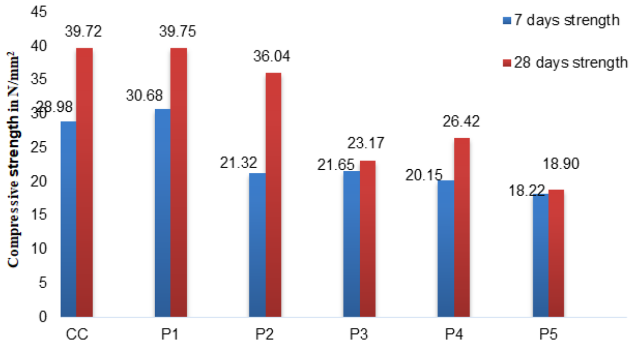


Figure 4. Compressive strength test

4.2. Split tensile strength

The split tensile strength and flexural strength of phosphogypsum and control concrete compared in Figures 5 and 6 respectively (Table 4).

Table 4. Split tensile strength.

S.No	Mix id	Strength in N/mm² after 7 days	Strength in N/mm after 28 days
1	CC	2.05	2.88
2	P1	2.08	2.87
3	P2	1.52	2.75
4	P3	1.32	1.69
5	P4	1.54	1.95
6	P5	1.45	1.92

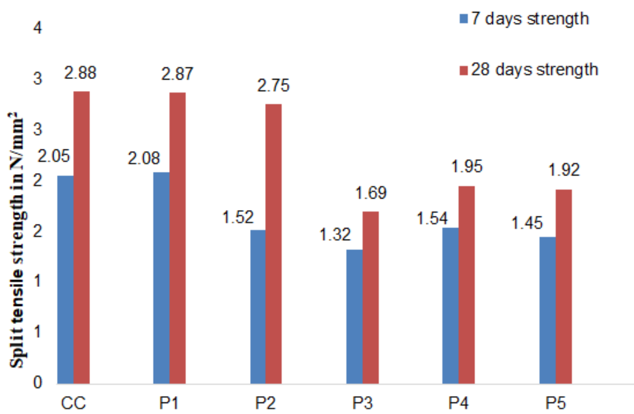


Figure 5. Split tensile strength

4.3. Flexural strength

According to Figure 5, the mix P1 with a 5% addition of phospogypsum performed better than normal concrete. However, as phospogypsum was increased further, split tensile strength decreased. The mix P1's compressive and split tensile strength from Figure 6 showed a slight improvement in flexural strength. Additionally, a rise in phospogypsum indicated a reduction in flexural strength for the mixtures P2, P3, P4, and P5. For the mix P2, P3, P4, and P5, the split tensile strength showed a similar trend. It is obvious that phospogypsum, when added in small amounts, increases the concrete's responsiveness to hydration and lowers heat production at the concrete. The substitution would lessen the impact of global warming and cement costs. It was found that Phopogypsum Concrete has a slightly higher Permeability than Conventional Concrete (Table 5).

Table 5. Flexural strength

S.No	Mix id	7 days strength in N/mm²	28 days strength in N/mm²
1	CC	3.4	5.62
2	P1	3.2	5.06
3	P2	2.82	4.67
4	P3	3.1	4.93
5	P4	2.358	3.93
6	P5	1.686	2.81

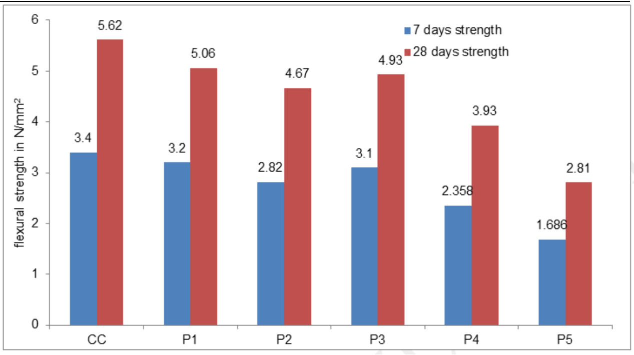


Figure 6. Flexural strength

5. Conclusion

The results of a series of experiments based on the compressive strength, split tensile strength, and flexural strength of concrete establish the following points:

- The values for compressive strength, split tensile strength, and flexural strength are almost identical to those found in control mix test results when 5% of cement is substituted with phosphogypsum. Using phosphogypsum in place of cement while maintaining the same water to cement ratio results in a thick paste that is unsuitable for testing.
- In order to produce concrete with partial cement replacement, which is a valuable component for cost-effective concrete, the construction sector can employ industrial wastes like phosphogypsum, which contribute to the development of concrete strength.
- In typical Portland cement combinations, phosphogypsum frequently slows the setting process but does not contribute to the creation of unstable cement paste.
- Phosphogypsum increases the permeability of the concrete, which enhances leachability. Therefore, concrete containing phosphogypsum is suitable for immobilising radioactive waste.
- This suggests that substitute cementitious materials, such as phosphogypsum, are being utilised for both the preparation of concrete and the production of cement.
- From the outcomes of the experiment phopogypsum plays a big part in lowering CO_2 emissions worldwide.

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