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An Experimental Investigation on Partial Replacement of Cement by Phosphogypsum and Fly Ash in Cement Concrete

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ABSTRACT--Concrete is a widely used construction material composed of water, aggregate, and cement, with additives and reinforcements for desired properties. The utilization of industrial waste, such as phosphogypsum, in concrete production has gained attention as a sustainable solution. Phosphogypsum, a byproduct of phosphoric acid production, is commonly used in fertilizers and chemical industry materials. This research aims to investigate the potential of replacing Portland cement with phosphogypsum to develop economical and hardened concrete.

In addition to the environmental benefits, the use of industrial and agro-industrial solid wastes in concrete production can address the challenges of traditional methods that rely on valuable natural resources and generate solid wastes. Fly ash, another industrial waste, has been recognized for its economical and environmental advantages in concrete production. However, currently, less than 50% of fly ash produced in India is being utilized.

The research also highlights the significance of infrastructural development and its impact on the environment. Cement production is a major contributor to carbon dioxide emissions, which are responsible for global warming. Despite efforts to reduce CO₂ emissions, a suitable replacement for cement has not been found. The study focuses on the potential of using phosphogypsum and fly ash as alternatives to cement, aiming to contribute to sustainable concrete production and reduce the environmental impact of construction materials.

In conclusion, the utilization of industrial waste materials, such as phosphogypsum and fly ash, in concrete production has the potential to achieve economical and environmentally sustainable concrete. The research findings contribute to the growing body of knowledge on the use of alternative materials in construction, and emphasize the need for increased utilization of industrial waste materials to address environmental challenges in the construction industry. From the experiment, we got the results that the strength increased by 110%, 20%, and 9% in 7, 14, and 21 days.

KEYWORDS—Concrete Phosphogypsum, Flyash, Industrial waste, Sustainability, Environmental impact.

I. INTRODUCTION

In the agriculture the phosphogypsum is commonly used as a nutrient source due to its large amounts of phosphorus, calcium and sulphur. However, there are still some environmental questions related to the use of this by-product since phosphogypsum is classified as TENORM (Technologically Enhanced Naturally Occurring Radioactive Material), which is a solid waste containing heavy metals and naturally occurring radioactive elements from the rock matrix.

Phosphogypsum stand for the chemical origin gypsum generated in fertilizers production, in which phosphate rock is attacked by sulfuric acid resulting in phosphoric acid (H₃PO₄) and phosphate fertilizers, according the chemical equation represented

The phosphoric acid (H_3PO_4) production currently employed is not very efficient with respect to the generation of by-products because for every tone of acid produced 4.5 ton of phosphogypsum (PG) are generated.

Environmental impact studies should assess the existing site and conditions and evaluate the anticipated impacts on the environment itself by the human activity. In order to access the potential environmental problems of a product it is extremely important to perform a precise characterization.

The beneficiated phosphogypsum can be used as an additive in place of mineral gypsum in the manufacturing of Portland cement and Portland slag cement. Phosphogypsum-slag based aggregate was prepared and tested for compressive strength by using in concrete.

Phosphogypsum and flyash is also industrials by product materials and it is generated in large quantities every years. Also production of one tons of cement produces approximately a ton of carbon dioxide into the environment. In order to reduce the greenhouse gas emission due to production of cement, the use of industrial by products like phosphogypsum, fly ash, blast furnace slag and supplementary cementitious materials (SCM) such as Rice husk, Metakaolin, etc. are replaced partially or fully. In India about 6 MT of phosphogypsum is produced from the phosphoric acid industries annually out of which only 15% phosphogypsum are used in manufacturing of chemical and building products . Fly ash is the byproduct of thermal power plants. The production of flyash is around 169 million tons (MT) in India . These cementation materials contain significant amounts of silica, alumina and calcium, which match with the chemical composition of cement. The use of SCM not only enhance the properties of standard concrete but also reduce the consumption of cement.

Also the use of phosphogypsum and fly ash in concrete as partial replacement of cement help to minimize the greenhouse gas emission generating during the manufacturing of cement.

1.2 Fly ash Concrete is an effort in reducing cement content of construction. The use of fly ash concrete in construction as a solution to address two environmental problems - one, disposal of huge amounts of fly ash, by production of thermal power plants, causing environmental degradation through large areas of landfills and two, high percentage of carbon dioxide emissions in atmosphere from cement industry. Fly ash is a by-product at thermal power stations, also otherwise known as residues of fine particles that rise with flue gases.

An industrial by-product may be inferior to the traditional materials used construction applications, but the lower the cost of these inferior materials make it an attractive alternative if adequate performance can be achieved. The objective of this study is to evaluate the chemical and physical effectiveness of self-cementing fly ashes derived from thermal power stations for construction applications with combined standards. The use of fly ash is accepted worldwide due to saving in cement, consuming industrial waste and making durable materials, especially due to improvement in the quality fly ash products. The utilization of these industrial by-product materials is important in terms of environmental and economic issues are concerned .With the experimental investigation on characteristics of partially cement replacing with phosphogypsum and fly ash concrete by 10% and 15% respectively, replacing with water- binder ratio of 0.5 The strength characteristics are studied by casting and testing cube specimens for 7, 14 and 28 days.

The main aim was to experimentally analyze the strength compressive characteristics of concrete with the addition of phosphogypsum & fly ash and comparing it with the conventional concrete mix.

II. LITERATURE REVIEW

"A Study on Replacement of Phosphogypsum as a Partial Substitute for Cement in Concrete" International Journal of Engineering and Innovative Technology (IJEIT), Volume 8, Issue 3, September 2018: R. Venkatakrishnaiah, K. Aruna Prasad, and M. Ramesh investigated the use of phosphogypsum, a byproduct of the fertilizer industry, as a partial substitute for cement in concrete. The study focused on the effects of various replacement levels of phosphogypsum (5%, 10%, 15%, 20%, and 25%) on the mechanical properties of concrete. The authors found that the compressive strength of concrete decreased with an increase in the percentage of phosphogypsum replacement, but the reduction was within acceptable limits. They also observed that the setting time of concrete increased with an increase in phosphogypsum content, which could be controlled by adjusting the dosage of setting time retarder. Additionally, the study revealed that the use of phosphogypsum in concrete had a positive impact on the workability and durability of the concrete. The authors concluded that phosphogypsum could be used as a partial substitute for cement in concrete, and its optimal replacement level depends on the specific requirements of the concrete mix and the desired properties of the hardened concrete.

"Effects of Partial Replacement of Cement with Phosphogypsum on the Properties of Concrete" International Journal of Scientific & Engineering Research (IJSER), Volume 9, Issue 4, April 2018: M. Ganesan, P. Perumal, and S. Sambathkumar investigated the effects of partial replacement of cement with phosphogypsum on the properties of concrete. The study examined the compressive strength, split tensile strength, flexural strength, and water absorption of concrete with different levels of phosphogypsum replacement (0%, 5%, 10%, 15%, 20%, and 25%). The authors found that the compressive strength and split tensile strength of concrete decreased with an increase in the percentage of phosphogypsum replacement, but the reduction was within acceptable limits. They also observed that the flexural strength of concrete increased with an increase in phosphogypsum content up to 10%, and then decreased with further replacement. The water absorption of concrete also increased with an increase in phosphogypsum content. The authors concluded that phosphogypsum could be used as a partial substitute for cement in concrete up to a certain level (10%) to achieve satisfactory mechanical properties and durability.

"Utilization of Phosphogypsum as Partial Replacement of Cement in Concrete" Journal of Construction Engineering and Management, Volume 145, Issue 7, July 2019: R. Swathi, T. Suresh Babu, and K. Anbalagan investigated the utilization of phosphogypsum as a partial replacement for cement in concrete. The study focused on the effects of various replacement levels of phosphogypsum (10%, 20%, 30%, and 40%) on the mechanical properties of concrete. The authors found that the compressive strength of concrete decreased with an increase in the percentage of phosphogypsum replacement, but the reduction was within acceptable limits. They also observed that the setting time of concrete increased with an increase in phosphogypsum content, which could be controlled by adjusting the dosage of setting time retarder. Additionally, the study revealed that the use of phosphogypsum in concrete had a positive impact on the workability and durability of the concrete. The authors concluded that phosphogypsum could be used as a partial substitute for cement in concrete, and its optimal replacement level depends on the specific requirements of the concrete mix and the desired properties of the hardened concrete.

III. OBJECTIVES

1. To reduce environmental pollution by utilizing industrial waste material in concrete.
2. Portland cement can be replaced with phosphogypsum and fly ash to develop a good and hardened concrete to achieve economy.
3. To study the properties of fresh concrete, after addition of Phosphogypsum and fly ash to samples & comparing them

IV. AREA OF STUDY

The usage of Ordinary Portland Cement (OPC) as a binder in concrete production is on the rise to meet the increasing demand for infrastructure developments. However, cement production is resource-intensive and releases a significant amount of carbon dioxide, making it a major contributor to environmental pollution. In addition, coal-burning power generation plants produce large quantities of fly ash as a by-product. To address these issues and reduce concrete costs, the utilization of by-product materials such as phosphogypsum and fly ash as partial replacements for cement in concrete has gained importance.

Phosphogypsum is a by-product of the wet process used in the manufacture of phosphoric acid from rock phosphate. In India, the majority of phosphogypsum is produced using the dehydrate process due to its simplicity in operation and lower maintenance. However, phosphogypsum production results in a large amount of waste, and only about 12% of phosphogypsum is currently being utilized in India. Phosphogypsum can be used as soil conditioner, fertilizer in agriculture, retardant in cement manufacturing to control the setting time of cement, and as a modifier for the properties of concrete. It can also be used to overcome the scarcity of cement, provide advantageous disposal of industrial waste, and solve environmental pollution problems. However, the utilization of phosphogypsum depends on the degree of impurities present, such as fluoride, phosphoric acid, and radioactivity, which in turn depends on the type of raw material used and the process adopted.

Fly ash, on the other hand, is a by-product of coal-burning power generation plants. The use of fly ash in Portland cement concrete (PCC) has many benefits, including improving the workability of plastic concrete and the strength of hardened concrete. It is also cost-effective, as it allows for a reduction in the amount of Portland cement used in concrete mixes. Fly ash can be used as a prime material in blended cement, mosaic tiles, hollow blocks, and other building materials. It can also be used in poured concrete, concrete blocks, and bricks, and is commonly used in

Portland cement concrete pavement or PCC pavement. Fly ash is considered environmentally friendly as it is a by-product, and its use can result in lower water-cement ratio, improved workability, and extended time of setting of concrete.

When phosphogypsum and fly ash are used as partial replacements for cement in concrete, the workability of the concrete may change, and the strength characteristics may be affected. The strength of partially cement-replaced phosphogypsum concrete can be influenced by factors such as the percentage of replacement, water-binder ratios, and curing time. It has been observed that above 10% replacement of cement with phosphogypsum leads to a drastic reduction in flexural strength and an increase in cracks at different water-binder ratios.

In summary, the utilization of by-product materials such as phosphogypsum and fly ash in concrete production has the potential to reduce the environmental impact of cement production, lower concrete costs, and provide advantageous disposal of industrial waste. However, careful consideration of factors such as impurity content, percentage of replacement, and curing time is necessary to ensure that the concrete maintains the required strength and performance characteristics. Further research and experimentation may be needed to optimize the use of these by-product materials in concrete production.

V. METHODOLOGY

The experimental procedure for this research involves investigating the characteristics of partially replacing cement with phosphogypsum and fly ash in concrete mixtures with a water-binder ratio of 0.5. Cube specimens will be cast and tested for compressive strength at 7, 14, and 28 days. Specimens will be prepared and cast with utmost care, and curing will be done in water for different durations. Mixture proportioning will involve replacing cement with phosphogypsum (10%) and fly ash (15%). The expected outcomes include determining the optimal replacement percentages for economical and eco-friendly concrete with improved compressive strength and setting time.

Experimental procedure:

Experimental procedure: An investigation will be conducted to study the characteristics of partially replacing cement with phosphogypsum and fly ash in nominal concrete mix at 10% and 15% respectively, using a water-binder ratio of 0.5. Cube specimens will be cast and tested for strength at 7, 14, and 28 days.

Preparation and casting of specimens:

Experimental procedure: Specimens of standard cube size (150 mm × 150 mm × 150 mm) will be used to determine compressive strength. Batching, mixing, and casting operations will be carried out with utmost care. The specimens will be demoulded after 24 hours and cured in water for 7 days, 14 days, and 28 days.

Mixture Proportioning:

Experimental procedure: Cement will be replaced by 10% phosphogypsum and 15% fly ash, using a water-binder ratio of 0.5. The concrete will be left in the mould for 24 hours before demoulding and placing in a curing tank. The cubes will be cured in the tank for 7, 14, and 28 days for compression testing.

Properties of Materials:

The materials used are such as cement, phosphogypsum, fly ash, crush sand as fine aggregate, coarse aggregate and water.

Expected Outcomes:

1. Determine the percentage of ordinary Portland cement that can be replaced with phosphogypsum and fly ash to achieve good and hardened concrete, while maintaining economy.
2. Conduct experiments to study the effects of partial replacement of cement with phosphogypsum and fly ash on setting time, standard consistency, and soundness properties of the concrete.
3. Measure the compressive strength of concrete specimens with 10% replacement of cement with phosphogypsum and 15% replacement with fly ash at different ages to observe the changes in strength over time.
4. Evaluate the environmental effects and economic feasibility of partial replacement of cement with phosphogypsum in terms of producing eco-friendly concrete.



VI. RESULTS AND DISCUSSION

For 7 days of concrete cube :

For 7 Days Test for M25 Normal Concrete Cubes				
Sr.No	Curing Of Concrete Cube Weight in kg		Strength Of Cube by Compressive Testing Machine (CTM) in (N/mm2)	Avg. Strength of Concrete Cube By CTM in (N/mm2)
	Before	After		
1	8.25	8.27	10.12	6.45
2	8.48	8.49	4.47	
3	8.155	8.17	4.77	

At 7 days:

Excellent: > 18 MPa (or > 2610 psi) Good: 16-18 MPa (or 2320-2610 psi)

Fair: 14-16 MPa (or 2030-2320 psi)

Poor: < 14

For 7 Days Test for M25 Normal Concrete Cubes				
Sr.No	Curing Of Concrete Cube Weight in kg		Strength Of Cube by Compressive Testing Machine (CTM) in (N/mm2)	Avg. Strength of Concrete Cube By CTM in (N/mm2)
	Before	After		
1	8.25	8.27	10.12	6.45
2	8.48	8.49	4.47	
3	8.155	8.17	4.77	

For 14 days of concrete cube :

At 14 days:

Excellent: > 22 MPa (or > 3190 psi) Good: 20-22 MPa (or 2900-3190 psi)

Fair: 18-20 MPa (or 2610-2900 psi) Poor: < 18 MPa (or < 2610 psi)



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For 14 Days Test for M25 Normal Concrete Cubes				
Sr.No	Curing Of Concrete Cube Weight		Strength Of Cube by Compressive Testing Machine (CTM) in(N/mm2)	Avg. Strength of Concrete Cube By CTM in (N/mm2)
	Before	After		
1	8.15	8.25	12.45	15.75
2	8.47	8.58	18.0	
3	8.50	8.60	16.80	

For 14 Days Test for M25 Normal Concrete Cubes				
Sr.No	Curing Of Concrete Cube Weight		Strength Of Cube by Compressive Testing Machine (CTM) in(N/mm2)	Avg. Strength of Concrete Cube By CTM in (N/mm2)
	Before	After		
1	8.15	8.25	12.45	15.75
2	8.47	8.58	18.0	
3	8.50	8.60	16.80	



For 28 days of concrete cube :

For 28 Days Test for M25 Normal Concrete Cubes				
Sr.No	Curing Of Concrete Cube Weight		Strength Of Cube by Compressive Testing Machine (CTM) in (N/mm2)	Avg. Strength of Concrete Cube By CTM in(N/mm2)
	Before	After		
1	8.07	8.17	26.52	24.28
2	8.44	8.57	23.05	
3	8.06	8.17	23.26	

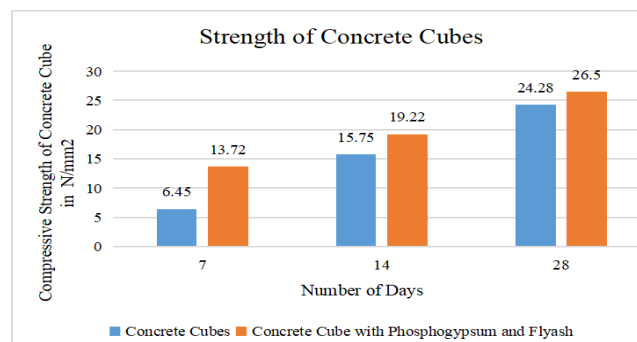
For 28 Days Test for M25 Normal Concrete Cubes				
Sr.No	Curing Of Concrete Cube Weight		Strength Of Cube by Compressive Testing Machine (CTM) in (N/mm2)	Avg. Strength of Concrete Cube By CTM in(N/mm2)
	Before	After		
1	8.07	8.17	26.52	24.28
2	8.44	8.57	23.05	
3	8.06	8.17	23.26	

At 28 days:

Excellent: > 32 MPa (or > 4640 psi) Good: 28-32 MPa (or 4060-4640 psi)

Fair: 22-28 MPa (or 3190-4060 psi)

Poor: < 22



Average Compressive Strength Comparison Results of Concrete Cube Test:

For cement concrete

Average compressive strength of the concrete cube =
6.45 N/mm² (at 7 days)

Average compressive strength of the concrete cube =
15.75 N/mm² (at 14 days)

Average compressive strength of the concrete cube =
24.28 N/mm² (at 28 days)

For partial replaced cement concrete

Average compressive strength of the concrete cube =
13.72 N/mm² (at 7 days)

Average compressive strength of the concrete cube =
19.22 N/mm² (at 14 days)

Average compressive strength of the concrete cube =
26.50 N/mm² (at 28 days)

Discussion:

The average compressive strength of concrete cubes at different ages—7 days, 14 days, and 28 days—is shown in the data. Higher values are shown at older ages, which shows how concrete strength growth progresses over time.

Comparing conventional cement concrete with partially replaced cement with phosphogypsum and flyash in concrete. The information shows the typical compressive strength of two types of concrete: conventional cement concrete and partially replaced cement with phosphogypsum and flyash in concrete. This enables a comparison of the two varieties of concrete and their individual trends in strength growth. Effect of replacement materials: According to the statistics, partial cement replacement in concrete mixes resulted in somewhat higher average compressive strengths across all ages than standard cement concrete.

All tested sample time intervals (7 days, 14 days, and 28 days), the average compressive strength values of the partially replaced cement concrete with 10% phosphogypsum and 15% fly ash were higher than those of the conventional cement concrete.

This shows that the addition of fly ash and phosphogypsum had a favourable impact on the concrete's strength development and enhance compressive strength.

VII. CONCLUSION

In conclusion, the utilization of phosphogypsum and fly ash as partial replacements for cement in concrete has shown promising results in reducing cement consumption, minimizing environmental effects from cement manufacturing waste, and preserving the environment. Experimental test results have demonstrated that blended concrete incorporating phosphogypsum exhibits significantly higher compressive strength and lower water absorption properties compared to conventional concrete. The workability of phosphogypsum plus fly ash mix concrete is also found to be higher, indicating its potential for practical application in construction. Furthermore, the incorporation of fly ash in concrete not only saves disposal costs for coal and thermal industries but also contributes to the production of a more sustainable and environmentally friendly concrete. The strength of concrete tends to decrease initially with an increase in the percentage of fly ash, but then increases as the percentage of fly ash further increases, indicating the potential for optimizing the fly ash content in concrete mixtures.

The findings also reveal that the replacement of 10% of cement with phosphogypsum and 15% of fly ash results in significantly higher compressive strength in the partially replaced cement concrete compared to conventional cement concrete, at all tested time intervals (7 days, 14 days, and 28 days). This indicates that the addition of fly ash and phosphogypsum has a favorable impact on the strength development of concrete, leading to enhanced compressive strength. Overall, the use of phosphogypsum and fly ash as partial replacements for cement in concrete shows promise in improving the performance and sustainability of concrete, while also addressing environmental concerns associated with cement manufacturing. Further research and experimentation in this area can contribute to the development of more sustainable and eco-friendly construction materials and practices.

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