# STUDY ON UTLIZATION OF PHOSPHOGYPSUM IN FLYASH INCORPORATED CONCRETE

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**ABSTRACT:** Concrete has a tremendous influence on the environment since the majority of its composition is cement, which is a material that emits high levels of carbon dioxide. It is possible for concrete construction to have a lower impact on the environment if the usage of cement is reduced as much as possible by the addition of mineral admixtures such as fly ash Phosphogypsum, without sacrificing the durability standards at the same time. The disposal of fly ash, which is produced by power stations that burn coal for fuel, is recognised as one of the most pressing environmental issues. Phosphogypsum is the primary byproduct of the wet-acid process for producing phosphoric acid from phosphate rock. The research on fly ash admixed concrete is analysed and discussed in this publication. There have been many studies conducted on the topic of fly ash concrete and its beneficial effects. The aim of the project is to develop a sustainable concrete with improved strength, durability and having less maintenance by utilizing Phosphogypsum and fly ash. Mechanical strength for compressive strength, split tensile strength and flexural strength were conducted to find the optimum usage of alternative materials with proportions of 5%, 10% and 15% of total weight of concrete and durability tests of sulphate, chloride resistance and corrosion test were performed. From the studies, it is concluded that long term strength and durability has increased when fly ash concrete is modified by partially replacing cement with 10% of phosphogypsum. The phosphogypsum increases the workability ofthe concrete due to the combined lubricating effect of fly ash and phosphogypsum. The strength properties are similar to the addition of fly ash in concrete. From durability studies of rapid chloride permeability, with the inclusion of fly ash, chloride ingress capacity of concrete is decreased. Pore refinement and grain refinement due to reaction between fly ash and liberated lime improves impermeability. The reduction in permeability of concrete is mainly due to filling of the pores and voids with calcium carbonate precipitation.

KEYWORDS: Phosphogypsum and fly ash, Mechanical strength tests, Durability tests.

**Introduction:**

Industrialization and urbanization has led to depletion of high quality construction materials. The cost of construction materials is increasing significantly, so are their availability. So alternate construction materials are to be found and exploited. The material Phosphogypsum has been found to have certain properties which can be useful in the construction. Phosphogypsum is the primary byproduct of the wet-acid process for producing phosphoric acid from phosphate rock. It is largely calcium sulphate and has been given the name Phosphogypsum (PG). Phosphate production generates very large volumes of Phosphogypsum, which is stored in huge piles called "stacks" that cover hundreds of acres.From the production of one ton of phosphoric acid 4.5 tons of Phosphogypsum is obtained.PG contains impurities, whichare considered to be potentially harmful, such as residual acid ($P_2O_5$), fluorine compounds, and trace elements including radioactive elements. PG is a relatively harmless material and it is used for various purposes, like amendment in agriculture, building materials, asphalt mixtures, etc. However, PG is slightly more radioactive than natural gypsum. The main element is radioactive Radium (226Ra), which is naturally found in phosphate rock. Radium remains in PG after reaction with sulphuric acid in phosphoric acid preparation process. Radioactive decay transforms radium into Radon (222Rn), the last element of the inert gases group, which is also radioactive. Phosphogypsum was recycled for manufacture of fibrous gypsum boards, blocks, gypsum plaster, and composite mortars using Portland cement, masonry cement, and super-sulphate cement. hosphogypsum as also used as a soil conditioner.

Fig.1.1 Phosphogypsum Stack

## PHOSPHOGYPSUM IN CONCRETE

In India, about 6 million tons of waste gypsum such as Phosphogypsum, flourogypsum etc. are being generated annually. 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. More stringent environmental concerns over the last decade have resulted in legislation requiring Environmental Management Project Reports (EMPR) for any borrow pit or quarry established for the provision of road construction materials. This, together with the rapidly escalating value of property and hence expropriation costs for borrow pits, has resulted in an increase in the cost of providing natural materials for road construction. As materials probably make up about 70 percent of the cost of a typical rural road, significant benefits can be achieved by using materials that are already processed and stockpiled. By- product Phosphogypsum, despite having properties significantly different from conventional natural materials, has been shown in overseas studies to be a potentially useful road construction material, particularly when stabilized with cement.

Fig.1.2. Phosphate Rock silo and Conveyance System

## AIM & OBJECTIVES

Aim of the project is to develop a sustainable concrete with improved strength, durability and having less maintenance by utilizing PG. The specific objectives to achieve the aim are as follows,

To study the effect of fly ash and Phosphogypsum on cement concrete of M20 grade.

To evaluate mechanical strength characteristics of concrete by adding fly ash and Phosphogypsum.

To compare the performance with that of conventional concrete of M20 grade. To study the durability performance of Phosphogypsum added fly ash concrete. Industrialization and urbanization has led to depletion of high quality construction materials. The cost of construction materials is increasing significantly, so are their availability. So alternate construction materials are to be found and exploited. The material Phosphogypsum has been found to have certain properties which can be useful in the construction of roads.

Phosphogypsum is a by-product which is generally dumped or kept unused, if these materials are not properly dumped they could cause environmental problems. Usage of these materials for road construction is proved safe and could be utilized in an efficient manner. Phosphogypsum is a cheap material, having a cost of around Rs.1.5/kg, therefore using this material would be cost effective. Phosphogypsum being a cost effective material can be utilized in various ways. If this material proves to be effective through the tests, then it could help in reducing the construction cost along with increase in quality.

## METHODOLOGY

The methodology adopted for the study to achieve the specified objectives is as follows:

1. Literature review
2. Collection of materials
3. Testing of raw materials: The following preliminary tests are usedto find out the properties of the materials.
   i. Cement, fly ash and Phosphogypsum - Consistency, fineness,specific gravity and initial setting
   ii. Coarse aggregates- Specific gravity, water absorption and sieveanalysis.
   iii. Fine aggregates- Specific gravity and sieve analysis.
4. Mix design of control specimen concrete of M20 grade.
5. Determination of optimum percentage of phosphogypsum and fly ash as binder with proportions 5%, 10% and 15% of total weight of concrete.
6. Durability studies (sulphate and chloride resistance, corrosion test) of concrete specimens with phosphogypsum and fly ash as binder

7. Results and Discussion

8. Conclusion

**LITERATURE REVIEW**

Literature survey is the essential part of project work. Literature based on phosphogypsum concrete and fly ash concrete was reviewed. Critical review was done after reviewing the various journals. The literatures that are reviewed during the execution of project work are listed here.

**PHOSPHOGYPSUM CONCRETE**

D. RupeshKumarb,H. SudarsanaRaoand T.SivaSankar Reddy aware (2019) made investigations on the use of Phosphogypsum in concerte mix. As Phosphogypsum 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.Some attempts have also 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. In other attempts,

Phosphogypsum was recycled for manufacture of fibrous gypsum boards, blocks, gypsum plaster, composite mortars using Portland cement and masonry.

Rajesh B. Thakare and S.S.Bhaduaria ( 2018) made investigations on the effect of partial replacement of cement with raw Phosphogypsum in cement, cement mortar and concrete mixes. The results shows that mixture in which cement replaced with five percent Phosphogypsum having almost same standard or normal consistency than that of plain cement and thus water requirement of the cement – Phosphogypsum mix minutely affected. But, further replacements of ordinary Portland cement with raw Phosphogypsum seriously affect the consistency. Phosphogypsum in ordinary Portland cement mixes considerably retards setting time but does not contribute to produce unsound cement paste. Phosphogypsum can be economically used up to five percent as an ingredient or admixture of cement-mortar mix, both for stone and brick masonry work. The degree of workability of concrete mix with five percent Phosphogypsum decreases as compared to conventional concrete, but it improves cohesiveness of the concrete mix and thus reduction in segregation and bleeding. The compressive strength of Phosphogypsum cement concrete (with five percent PG) is improved indicates that Phosphogypsum has immense potential to be utilized in concrete applications, especially mass concrete work.

**FLY ASH CONCRETE**

Ahmaran et al. (2018) studied the effects of self-healing on self-consolidating concretes containing high volumes of fly ash (HVFA–SCC) when subjected to continuous water exposure. For this purpose, self-consolidating concretes were prepared with fly ash replacement ratios of 0%, 35%, and 55% having a constant w/c ratio of 0.35. Micro cracks are generated in cylindrical specimens by pre-loading up to 70% and 90% of the ultimate compressive load determined at 28 days. Later, the extent of damage was determined as percentage of loss in mechanical properties (as determined by compressive strength and ultrasonic pulse velocity) and percentage of increase in permeation properties (rapid chloride permeability and sorptivity index). After pre-loading, concrete specimens were kept in water for a month and the mechanical and permeation properties are measured at every two weeks. It was observed that HVFA-SCC mixtures initially lost 27% of their strength when preloaded up to 90% of their ultimate strength, and after 30 days of water curing that reduction was reduced to 7%, indicating a remarkable healing. On the other hand, for SCC specimens without fly ash that were pre-loaded to the same level, the strength loss was initially 19%, and after a period of 1 month moist curing it was only 13%. Similar results were also made on the permeation properties with greater effects. As the HVFA-SCCs studied have a good quantity of unhydrated fly ash available in their microstructure, these results are due to the 20 self-healing of the pre-existing cracks, mainly by hydration of anhydrous fly ash particles on the crack surfaces. Termkhajornkit et al. (2009) commented that autogenous and drying shrinkage causes cracks in concrete. Nevertheless, most of these types of cracks occur before 28 days. The slow hydration of fly ash after 28 days results in the crack sealing by these hydrated products and prolong the service life. This research investigates the self-healing ability of fly ash–cement paste. The study focused on the compressive strength, porosity, chloride diffusion coefficients, hydration reactions and hydrated products. The research focuses on behavi or after 28 days. From the experimental study, the fly ash–cement system has the self-healing ability for cracks that occur from shrinkage. The self-healing ability increased with fly ash content.

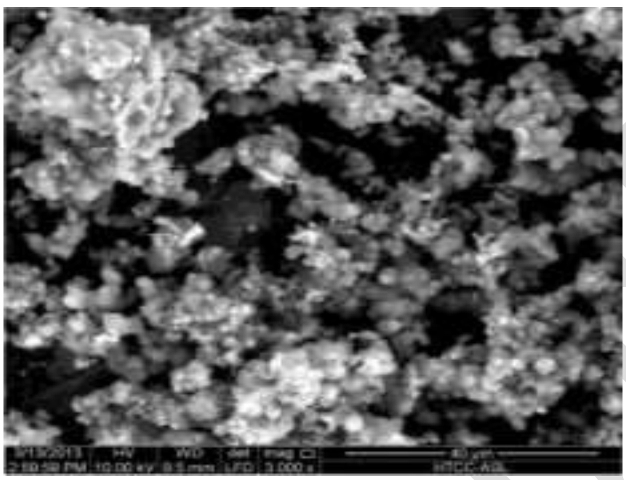

Fig. 2.2 FESEM image of fly ash concrete (Source:Shaswata Mukherjee et al.)

Mukherjee et al. (2017) carried out an experimental study to compare the self- healing of partially cracked conventional mortar (prepared with ordinary Portland cement) and cement - fly ash mortar. For cement - fly ash mortar, 20 % OPC has been replaced by class F fly ash. 21 All mortar specimens were casted with 1:3 binder to sand ratio (by weight) and with fixed 0.5 water/binder ratio. To generate micro cracks in mortar cubes, 28 day water cured specimens were subjected to direct compression (50% of corresponding 28 days compressive strength) in it. Healing environment consists of (a) curing in normal tap water for 120 days and (b) curing in normal air for 120 days separately. The compressive strength, ultrasonic pulse velocity, water absorption and rapid chloride ion permeability test on mortar specimens (with/without fly ash) confirm self-healing of cementations composites in terms of recovery of its properties and the self- healing property is more prominent for fly ash mortar as compared to cement mortar.. FESEM with EDAX and XRD of the white deposition in the crack opening was found to be calcite precipitates. Kamalakkannan and Prakash (2014) developed a self-healing concrete with the high volume fly ash being replaced for the cement and putting it into practical application in the field of Construction Civil Engineering.

Compressive strength of bacterial concrete is increased by 10 to 14 % than the conventional HVFA concrete. The split -tensile test and flexural test of conventional HVFA to Bacteria HVFA concrete is increased by 10.6%. Total ultimate load carrying capacity of the healed specimen is devastatingly higher. Since the load carried is about 85kN whereas the ordinary is about only 72kN. Hung and Su (2016) conducted extensive studies have shown that young Engineering Cementitious Composites (ECCs) have the potential to achieve effective self-healing. The present study focused on the medium-term self-healing performance of cracks in ECCs that are relevant in the medium and long-term stages of the material service life. For this purpose, the prepared ECC specimens were pre-cracked at an age of 180 days. The main experimental variables were the weight fraction of fly ash in ECCs (a fly ash to cement ratio of 1.2, 1.6, or 2.0) and the healing duration (7, 28, or 90 days). The medium-term self-healing performance is evaluated using a resonant frequency test followed by a uniaxial tensile test. In addition, 22 scanning electron microscopy and energy dispersive X-ray analyses were employed to study the micro-structure of the healed crack and identify the medium-term healing product, respectively. The results reveal that as long as water is present in the environment, ECCs has moderate medium-term self-healing ability, and can partially recover their tensile mechanical properties. As a conclusion, effective medium-term self-healing performance can be achieved within 90 days of conditioning for ECCs with a pre-strain of less than 1%.

Termkhajornkit et al. (2015) commented that autogenous and drying shrinkage causes cracks in concrete. Nevertheless, most of these types of cracks occur before 28 days. The slow hydration of fly ash after 28 days results in the crack sealing by these hydrated products and prolong the service life. This research investigates the self-healing ability of fly ash– cement paste. The study focused on the compressive strength, porosity, chloride diffusion coefficients, hydration reactions and hydrated products. The research focuses on behavior or after 28 days. From the experimental study, the fly ash–cement system has the self- healing ability for cracks that occur from shrinkage. The self-healing ability increased withfly ash content.

**CRITICAL REVIEW**

Concrete is very brittle material with low tolerance for strain, so it is expected to crack with time. These cracks expose the steel reinforcement to the elements, leading to corrosion which increases maintenance costs and compromises structural integrity over long periods of time. Fly ash continues the hydration after 28 days and also produces secondary C-S-H gel very slowly. Fly ash acts as a partial replacement material for both Portland cement and fine aggregate. Since fly ash has a medium term self-healing effect, the combined effect of fly ash and phosphogypsum on the concrete properties of strength and durability needs to be investigated in this present study.

**EXPERIMENTAL PROGRAMME**

**GENERAL**

Ordinary Portland Cement (OPC) is conventionally used as the binder to produce conventional concrete and it causes depletion of natural resources as well as various environmental issues like emission of $CO_2$. The phosphogypsum can be used as an alternative material for OPC as a binder since it has binding properties and thereby reduces the problems associated with production of OPC. The effective usage of such waste materials results in environmental benefit and sustainability. In this chapter, the description of materials, the preliminary tests done on various materials, the tests on fresh and hardened concrete are included.

**MATERIALS**

The materials collected are:

1. Cement
2. M – sand
3. Coarse aggregate
4. Fly ash
5. Phosphogypsum

**Fly ash**

Fly ash, coal combustion residue, is a pozzolanic material that reacts with Ca(OH)2 from cement hydration and produces C–S–H gel. But this reaction requires less free water than the hydration reaction of cement. IS 3812:2003 gives specification for fly ash for use as pozzolana. Table 3.1 shows the chemical composition of fly ash. Fly ash is effective for improving various properties of concrete such as long term compressive strength, permeability and resistance to chloride diffusion. The C–S–H gel produced by the pozzolanic reaction of fly ash may seal micro cracks, and accordingly it is expected that the concrete made with cement and fly ash may show self-healing ability. In this study, fly ash was collected from Hindustan Newsprint Limited, Velloor, Kottayam.

Table 3.1 Chemical composition of fly ash (Source: Civil-Aid technoclinic pvt.ltd)

| Compound | Content (% wt) |
|---|---|
| SiO2 | 54.63 |
| Al2O3 | 27.49 |
| Fe2O3 | 5.58 |

**Phosphogypsum**

Phosphogypsum was collected from FACT, Ambalamukal. Phosphogypsum is generated from filtration process in phosphoric acid plants where insoluble gypsum (and other material) are separated from the product. Phosphogypsum is a grey coloured, damp, fine grained powder, silt or silty-sand material with a maximum size ranges between 0.5mm and 1mm and the majority of the particles are finer than 0.075mm. 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/$m^3$.

Phosphogypsum consists primarily of calcium sulphate dehydrate with small amounts of silica, usually as quartz and unreacted phosphate rock, radioactive material (like Radium, Uranium), heavy metals namely arsenic, cadmium, chromium, mercury and fluoride. The concentration of the metals depends on the composition of the phosphate rock.

The following are the main concerns with respect to management of Phosphogypsum:

- High fluoride concentration (in the range of 0.5 -1.5 %) may leach fluoride and contaminate the groundwater, if not stored and handled properly.
- Presence of radio-nuclide Radium - 226 which upon decay may emit harmful alphaparticles.
- May contain heavy metals (Cd, Cr, Pb etc) that may enter into the food chain through potable water and agriculture products.

**Management And Handling Of Phosphogypsum**

Phosphogypsum retains 18-35 % moisture depending upon type of filtration and handling facilities installed for necessary disposal. In most cases, washed filter cake is received into hopper and mixed with water to make slurry so that it can be pumped to the Phosphogypsum disposal stack. In some cases, Phosphogypsum is removed from filter as dry cake and transported to the disposal area by conveyor belt or any other means of solids handling system. However, this method is not widely practiced as slurry handling is simpler and less expensive. A stabilized Phosphogypsum stack may not cause any dust problem however, dust emission can be seen during the excavation, shaping, movement of vehicles as well as maintenance of the access roads, this can be readily kept in damp condition to control particulate emissions.

**Environmental Impacts Associated With Phosphogypsum Dumping Yards**

The environmental concerns associated with Phosphogypsum stacks include fluoride uptake, ground and surface water pollution if located nearby. Main vectors for their transport into the environment are wind and water erosion, infiltration, leaching into surface and ground water and airborne emissions of gaseous and radioactive elements. Fine particles of Phosphogypsum can be picked up and transported by wind and vehicular traffic on stacks into adjacent areas. Disposal of Phosphogypsum on land may pose seepage problems beneath the repositories or the process water holding ponds if not lined or controlled properly.

**Utilization Of Phosphogypsum – Existing Practice**

Presently, most of the phosphoric acid plants are disposing the Phosphogypsum within the plant premises in stacks. Depending on the demand, the phosphoric acid units sell the Phosphogypsum for different applications which include

- For use as soil conditioning (for alkaline soil) or as fertilizer in agriculture
- In cement manufacturing to control the settling time of cement (as a retardant)
- Small quantity is used in the production of plaster, plaster boards, gypsum fiberboards, 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.

Table 3.3 Chemical Constituents Percentage

| Compound | Content (% wt) |
|---|---|
| CaO | 31.25 |
| $SiO_2$ | 3.89 |
| $SO_3$ | 42.34 |
| $R_2O_3$ | 3.66 |
| MgO | 0.47 |
| Phosphate, Fluoride | 18.48 |

**Tests on materials**

**Tests on Binders**

The Consistency, initial setting time, specific gravity and fineness tests were done on fly ash, phosphogypsum and cement.

**(i) Initial setting time and Standard Consistency of binders**

Vicat's apparatus is used to find out the initial setting time and standard consistency water requirement according to IS 4031 and IS 269.

**(ii) Specific gravity Test**

Specific gravity is defined as the ratio of weight in air of a given volume of material to the weight in air of equal volume of water. Le Chaterlier’s flask is used for specific gravity test according to IS 4031:1988 part II.

**(iii) Fineness of binders**

Fineness of binder has a great effect on the rate of hydration and rate of gain of strength. Fineness of binder increases the rate of evolution of heat. Finer binder offers a great surface area for hydration and hence faster the development of strength.
The fineness of binder is determined by dry sieving as per IS: 4031 (Part 1) – 1996. 90µm IS Sieve is used for conducting the test.

**Tests on Fine Aggregate**

The tests done on M-sand are sieve analysis and specific gravity test.

**Sieve analysis**
Sieve analysis is used to assess the particle size distribution (also called gradation) of a granular material. The gradation test is performed with a set of sieves on a sample of fine aggregate in the laboratory according to IS: 2386 part 1 and the gradation curve obtained is illustrated in next chapter.

**Specific gravity test**
Specific gravity is the ratio of the weight in air of a given volume of dry sample to the weight of an equal volume of distilled water at 4 ˚C. Using pycnometer the specific gravity of fine aggregate was determined according to IS 2386:1963 part 3 (reaffirmed 2011).

**Tests on Coarse Aggregate**

The sieve analysis, specific gravity and water absorption tests are done on coarse aggregate.

**(i) Sieve Analysis**
According to IS 2386:1963 part 1(reaffirmed 2011) sieve analysis was performed and the gradation curve is given in next chapter.

**(ii) Water Absorption and Specific gravity Test**
The specific gravity and water absorption of crushed angular aggregate was determined as per IS2386:1963 part 3 (reaffirmed 2011).

**Tests on fresh concrete**

Workability of concrete is defined as the ease with which the concrete can be mixed, transported, placed and compacted. To determine the workability of concrete, a slump test was carried out. It was conducted as per IS 1199:1959 (reaffirmed 1999). The apparatus used for doing slump test are slump cone and tamping rod. Figure 3.2 shows the slump test to determine the workability of fresh concrete.

Fig.3.2 Slump test

**Tests on hardened concrete**

The mechanical strength tests (compression and tension) were conducted on hardened concrete. Also durability tests (sulphate and chloride resistance, corrosion test) were done.

**Compressive Strength Test**

The compressive strength is defined as the resistance to failure under the action of compressive forces. It is an important parameter to determine the performance of concrete during service conditions. The cubes were cast on the basis of different mix combinations. The compressive strength test was conducted after water curing of 7 days and 28days. Load should be applied gradually till the specimen fails. Load at the failure divided by area of the specimen gives the compressive strength. The compressive strength test was conducted as per IS 516-1959 (reaffirmed 1999). Compressive strength testing of concrete cube using 2000KN capacity compression testing machine is depicted in figure 3.3.

Fig.3.3 Compressive strength test on cubes

**Split Tensile Strength Test**

The concrete is brittle and hence it is very weak in tension and is not expected to resist direct tension. The split tensile strength test is indirect tension strength in which testis carried out by placing a cylindrical specimen horizontally between the loading surface of the compression testing machine and the load is applied until the cylinder failure along the vertical diameter. The cylindrical specimen having dimensions 300mm diameter and 150mm length is used. The split tensile strength test was conducted as per IS 5816-1999 (reaffirmed 2004). Split tensile strength test was conducted for specimens with varying proportion of fly ash as binder in concrete. Figure 3.4 illustrates the cracked cylindrical specimen subjected to split tensile strength test.

Fig. 3.4 Split Tensile strength test on cylinders

**Flexural Strength Test**

Concrete is relatively strong in compression and weak in tension. The flexural strength was determined by means of a beam test. Beam specimens having size 100 x 100 x 500 mm were used. A concrete beam on bending will break on tension face. Expensive Universal Testing Machine was used for flexural strength test. The flexural strength test was conducted as per IS 516:1959 (reaffirmed in 2013). The loading was done without shock and increased continuously at a rate of loading of 180 kg/min as two point load.

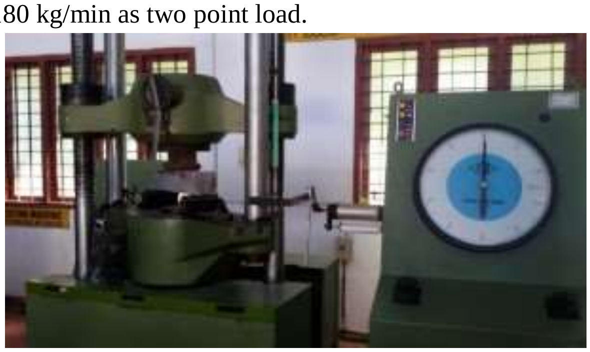

Fig. 3.5 Flexural Strength Test on Concrete Beam

**Sulphate Resistance Test**

The effect of sulphate attack on concrete is assessed by immersing 28 days water cured cubes in 5% Sodium sulphate solution. The cubes were weighed prior to immersion in sodium sulphate solution for assessment of weight loss. The cubes were tested for compression after 28, 56 and 90 days of exposure to sodium sulphate solution. The effect of sulphate attack on strength loss was assessed by testing the compressive strength of concrete cubes at respective test ages and comparing them with water cured concrete specimen of same age. The percentage of strength loss was then calculated. Similarly percentage of weight loss was also assessed comparing the weight of specimen prior to exposure and after exposure at different test ages.

**Chloride Resistance Test**

The effect of chloride attack on concrete is assessed by immersing 28 days water cured cubes in 1% hydrochloric acid solution and tests were conducted in the same manner as described in case of sulphate resistance test.

**Rapid Chloride Permeability Test**

Corrosion is mainly caused by the ingress of chloride ions into concrete which reduces the original resistance of concrete. Rapid chloride permeability test (RCPT) is a quick test able to measure the rate of transport of chloride ions in concrete. This test was conducted as per ASTM 1202-2005 method. Details of experimental set up are shown in Figure 3.6 and figure 3.7. Concrete cylinder specimen of size 95 mm diameter and 50mm thickness were cast using elastomeric rubber moulds and allowed to cure for 28 days. The saturated specimens are mounted in the plexiglass chambers and the sealant applied. One side of the chamber is filled with 3% sodium chloride solution (that side of the cell will be connected to the cathode terminal of the power supply) and other side sodium hydroxide solution of 0.3 N was poured and connected to anode terminal. The terminals are then connected to the 60V DC power supply and the current read in mA on the digital readouts every ½ hour for 6hours. The interpretation of the result is that the larger the current magnitude transferred during the test, the greater the permeability of the sample. The concrete which is more permeable will show higher charge transfer vice versa. The method has shown good correlation with chloride tests. The following formula can be used to calculate the average current flowing through one cell.

$$Q = 900(I_0 + 2I_{30} + 2I_{60} + 2I_{90} + 2I_{120} + \ldots + 2I_{300} + 2I_{330} + I_{360}) \quad (3.6)$$

Where Q is the current flowing through one cell (coulombs), $I_0$ is the current reading in amperes immediately after voltage is applied, and $I_t$ is the current reading in amperes at t minutes after voltage is applied. The value is adjusted for specimen diameters other than 95mm. ASTM 1202- 2005 contains a table which shows the rating of chloride permeability based on coulomb values.

Fig. 3.6 Moisture trap

Fig. 3.7 Rapid chloride permeability apparatus

The moisture trap is a water trap used to ensure that the air being sucked by the vacuum pump from the desiccator is completely dry and doesn't count in the pump oil . This will ensure a trouble-free operation of the vacuum pump for longer years of use.

## RESULTS AND DISCUSSION

### GENERAL

In this chapter, the results obtained for the various tests conducted on the materials,fresh and hardened conventional concrete, fly ash concrete, and modified concrete with fly ash and phosphogypsum are reported. The tests on hardened concrete include strength compressive, tensile and flexural, durability- sulphate resistance, chloride resistance and RCPT. These results are compared and analyzed in this session.

### FLY ASH CONCRETE

#### Workability

Workability is the measure of easiness with which concrete can flow. Slump test was performed to measure workability of concrete and the effects of fly ash and phosphogypsum on workability properties of concrete were studied. From the results,the addition of fly ash improves the workability of concrete mix. As per IS 1199:1957, a medium workable concrete should have slump value between 50-90mm. The fly ash inclusion increases the workability of the concrete due to the lubricating effect of fly ash. Table 4.1 tabulated the workability of concrete with fly ash with demonstration in figure 4.1.

Table 4.1 Slump value of fly ash mixes

| **Sl. No** | **Specimen** | **Notation** | **Slump Values(mm)** |
|---|---|---|---|
| 1 | Conventional mix | CM | 75 |
| 2 | Fly ash-5% | F5PG0 | 79 |
| 3 | Fly ash-10% | F10PG0 | 80 |
| 4 | Fly ash-15% | F15PG0 | 80 |

#### Strength Characteristics

The strength characteristics studied in the work are compressive strength, split tensile strength and flexural strength of concrete mixes. The fly ash concrete are made at fly ash concentrations of 5%, 10% and 15%. The strength tests are conducted to optimize the concentration of fly ash.

#### Compressive strength

Compressive strength test was conducted according to IS 516:1959 (Reaffirmed in2013). The improvement of compressive strength from a period of 7 and 28 days for mixeswith varying percentages of fly ash is presented in table 4.2.

Table 4.2 Compressive strength results fly ash mixes

| **Specimen** | **Compressive strength(N/mm$^2$)** | |
|---|---|---|
| | **7$^{th}$ day** | **28$^{th}$ day** |
| CM | 14.28 | 21.78 |
| F5PG0 | 14.24 | 22.25 |
| F10PG0 | **17.87** | **22.53** |
| F15PG0 | 17.86 | 21.91 |

From the results it is observed that on addition of fly ash, 28 day strength decreases with addition of fly ash after 10%. The decrease in strength may be due to the slow hydration process since fly ash is a slow reactive pozzolans which delays the hydration process. Therefore the fly ash percentage is optimized to 10%, for making concrete. Graph between compressive strength and curing period for varying percentage of fly ash is shown in figure 4.2.

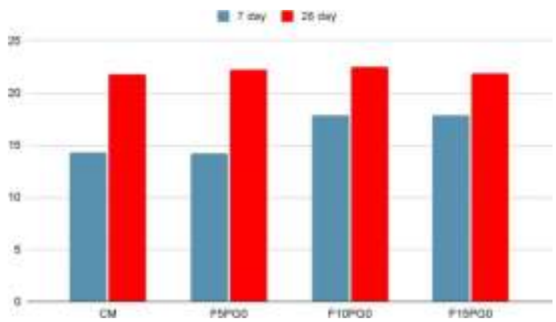


Fig. 4.2 Compressive strength results of fly ash mixes

**Split tensile strength**

Split tensile strength test was conducted on cylinders of size 150 mm diameter and 300 mm height. Test was conducted as per IS 5816:1999(Reaffirmed in 2008). The 7th and 28th split tensile strength test on concrete was performed on compression testing in accordance with the relevant Indian standard. The variation of split tensile strength for mixes with varying percentages of fly ash is presented in table 4.3. As compressive strength, split tensile strength also follows the same variation. 5% fly ash concrete shows maximum tensile strength. Graph between split tensile strength and curing period for varying percentage of fly ash is shown in figure 4.3. Beyond the 5% replacement of fly ash the split tensile strength was decreased.

Table 4.3 Split tensile strength results of various mixes

| **Specimen** | **Split tensile strength(N/mm$^2$)** | |
|---|---|---|
| | **7th day** | **28th day** |
| CM | 2.41 | 2.44 |
| F5PG0 | 3.65 | 3.97 |
| F10PG0 | 3.6 | 3.89 |
| F15PG0 | 3.62 | 3.87 |

**Flexural strength**

Flexural test was conducted as per IS 516:1959(reaffirmed in 2013).

The test was conducted on beams of size 100 mm x 100 mm x 500 mm after 28 days of water curing. The change in flexural strength with respect to different percentages of fly ash is represented in table 4.4 and figure 4.4 which shows that maximum Flexural Tensile Strength was for conventional concrete. Flexural strength decreases with increase in percentage of fly ash since slow hydration process of fly ash.

**Strength Characteristics**

The strength characteristics studied in the work are compressive strength, split tensile strength and flexural strength of concrete mixes. The phosphogypsum modified fly ash concrete are made at 10% fly ash concentrations with phosphogypsum 5%, 10% and 15%.
Fig. 4.5 Workability results of phosphogypsum modified fly ash mixes

**Compressive strength**

Compressive strength test was conducted according to IS 516:1959 (Reaffirmed in 2013). The improvement of compressive strength from a period of 7 and 28 days for mixes with varying percentages of phosphogypsum modified fly ash mixes is presented in table 4.6. From theresults it is observed that in addition to phosphogypsum in fly ash concrete, 28 day strength decreases after 10%. The decrease in strength may be due to the slow hydration process since fly ash is a slow reactive pozzolans which delays the hydration process. Graph between compressive strength and curing period for varying percentage of fly ashis shown in figure 4.6.

**Split tensile strength**

Split tensile strength test was conducted on cylinders of size 150 mm diameter and 300 mm height. Test was conducted as per IS 5816:1999(Reaffirmed in 2008). The 7th and 28th split tensile strength test on concrete was performed on compression testing in accordance with the relevant Indian standard and tabulated in table 4.7.

As compressive strength, split tensile strength also follows the same variation. 10% phosphogypsum added fly ash concrete shows maximum tensile strength.Graph between split tensile strength and curing period for varying percentage of fly ash is shown in figure 4.7. Beyond the 10% replacement of phosphogypsum the split tensile strength was decreased.

## CONCLUSIONS

### GENERAL

This research work has presented the results of an experimental investigation of phosphogypsum modified fly ash concrete. Based on strength parameters, the optimum percentage of fly ash obtained is 10% for making concrete with phosphogypsum.

### CONCLUSION

Strength properties like compressive strength, split tensile strength and flexural strength properties were evaluated. The fly ash inclusion increases the workability of the concrete due to the lubricating effect of fly ash. From the results it is observed that on addition of fly ash, 28 day strength decreases with addition of fly ash after 10%. The decrease in strength may be due to the slow hydration process since fly ash is a slow reactive pozzolans which delays the hydration process. So the optimum percentage of fly ash was fixed as 10% for the present study.

The phosphogypsum increases the workability of the concrete due to the combined lubricating effect of fly ash and phosphogypsum. The strength properties are similar to the addition of fly ash in concrete. 10% replacement of phosphogypsum is fixed as the optimum percentage.

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