Experimental Study on Concrete by Partial Replacement of Cement with Phosphogypsum and Fine Aggregate with Thermosetting Plastics

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***Abstract* - Concrete is a composite material composed mainly of water, aggregate, and cement. Usually there are additives and reinforcements included to achieve the desired physical properties of the finished material. For solving the disposal of large amount of recycled plastic material, reuse of plastic in concrete industry is considered as the most feasible application. The reuse of material can reduce the normal usage of ingredients in concrete and thereby reduce the cost of construction.**

This study is focused on the use of thermo setting plastics as a partial replacement of aggregates in concrete. The aim was to investigate the characteristics of concrete with the addition of plastic and comparing it with the control mix, thereby determining the advantages and disadvantages of doing so. In this phosphogypsum is added to a 10% by partial replacement of cement. It is proposed to replace the aggregates partially with thermosetting plastics on the basis of percentage by weight such as 0%, 0.5%, 1%, 1.5%, 2% and 2.5%. The fresh concrete is tested for slump test and the compaction factor test, while the hardened concrete for compressive, tensile, flexural strength and durability.

Keywords— Phosphogypsum, Thermosetting plastics, Durability

I. INTRODUCTION

Concrete is the most preferred and the single largest building material used by the construction industry. Concrete is a composite material composed mainly of water, aggregate, and cement. Usually there are additives and reinforcements included to achieve the desired physical properties of the finished material. When these ingredients are mixed together, they form a fluid mass that is easily molded into shape. Over time, the cement forms a hard matrix which binds the rest of the ingredients together into a durable stone-like material with many uses.

Research concerning the use of byproducts to augment the properties of concrete has been going on for many years. In the recent decades, the efforts have been made to use industry byproducts such as fly ash, silica fume, ground granulated blast furnace slag (GGBS), glass cullet, etc., in civil constructions. The potential applications of industry byproducts in concrete are as partial aggregate replacement or as partial cement replacement, depending on their chemical composition and grain size. The use of these materials in concrete comes from the environmental constraints in the safe disposal of these products. Big attention is being focused on the environment and safeguarding of natural resources and recycling of wastes materials. Actually many industries are producing a significant number of products which incorporate scrap (residues). In the last 20 years, a lot of works concerning the use of several kinds of urban wastes in building materials industrials process have been published. Many research have been extended to study new kinds of wastes to investigate deeply particular aspects. The addition of wastes, a part from the environmental benefits, also produces good effects on the properties of final products.

One of the new waste materials used in the concrete industry is recycled plastic. For solving the disposal of large amount of recycled plastic material, reuse of plastic in concrete industry is considered as the most feasible application.

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. 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.

The word “plastic” means substances which have plasticity, and accordingly, anything that is formed in a soft state and used in a solid state can be called a plastic. Therefore, the origin of plastic forming can be traced back to the processing methods of natural high polymers such as lacquer, shellac, amber, horns, tusks, tortoiseshell, as well as inorganic substances such as clay, glass, and metals. Because the natural high polymer materials are not uniform in quality and lack mass productivity in many cases, from early times it has been demanded in particular to process them easily and into better quality and to substitute artificial materials for natural high polymers. Celluloid, synthetic rubber, ebonite, and rayon are these artificial materials. Presently, it is defined that the plastics are synthesized high polymers which have plasticity, and consequently substances made of these natural materials are precluded.

In India, about 6 million tons of waste gypsum such as phosphogypsum, flourogypsum etc., are being generated annually. 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,hemi hydrate 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

The objectives of the present study are:

- To study the workability of fresh concrete.
- To study the mechanical properties of concrete in hardened state.
- To study the durability of concrete

II. EXPERIMENTAL INVESTIGATION

The aim of the experimental investigation is to ascertain and compare the improvement in the performance of concrete by the partial replacement of fine aggregate with thermosetting plastics and cement with a constant percentage of phosphogypsum thereby to arrive at the optimum replacement percentage of thermosetting plastic and to study durability of concrete mix. This study provides a comprehensive overview of engineering and construction properties of thermosetting plastics and phosphogypsum for use in concrete as partial replacement materials.

A. Test on constituent materials

Cement: Ordinary Portland cement of 53 grade conforming to IS 12269:1987 was used for the study. For the cement the standard consistency test, initial setting time test, final setting time test, specific gravity test and mortar cube compressive strength were conducted. Laboratory tests are conducted on cement to determine its standard consistency, initial setting time, final setting time and compressive strength. The standard consistency of the cement used is 36.25%

Phosphogypsum: 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. 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.

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 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. However, these impurities impair the strength development of calcined products. 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.

Phosphogypsum used in the work is shown in Fig.1. Specific gravity of phosphogypsum is 3.2

Fig. 1 Phosphogypsum

Fine aggregate: Commercially available M sand with 4.75 mm maximum size was used as fine aggregate. All physical properties were tested as per IS 383:1970. Specific gravity and fineness modulus of M-Sand used were 2.36 and 2.67 respectively.

Thermosetting plastic cannot be melted by heating because the molecular chains are bonded firmly with meshed crosslink. These plastic types are known as phenolic, melamine, unsaturated polyester, epoxy resin, silicone, and polyurethane. At present, these plastic wastes are disposed by either burning or burying. However, these processes are costly. If the thermosetting plastic waste can be reused, the pollution that is caused by the burning process as well as the cost of these waste management processes can be reduced. To achieve this purpose, a study of these thermosetting plastics for application into construction materials has been conducted, particularly for the concrete wall in buildings.

Thermosetting plastics are collected in the form of recycled plastics (RP). The plastic is green in color and it poses a size of 2.36 mm. Thermosetting plastics used in this work is shown in Fig.2. Physical properties such as specific gravity and fineness modulus of steel slag used were 2and 2.7 respectively.

Fig. 2 Thermosetting plastics

Coarse aggregate: Coarse aggregate used in this study were 20mm nominal size. The properties of coarse aggregate conforming to the IS 383:1970. The coarse aggregate used was found to belong to standard zone. Specific gravity and fineness modulus of coarse aggregate used were 2.65 and 6.49 respectively.

Water: Potable water is generally considered as being acceptable. Hence water available in the college water supply system was used for casting as well as curing of the test specimens.

B. Mix design

M25 mix was designed as per IS10262:2009 and the mix proportion was obtained as 1: 1.262 : 2.313. Water-cement ratio was 0.4. Six mixes were made namely RP0, RP0.5,RP1, RP1.5, RP2 and RP2.5 to determine mechanical properties. RP0 with 0% thermosetting plastic is considered as control mix. Other mixes are obtained by partial replacement of fine aggregate by 0.5%,1%,1.5%,2% and 2 .5% . In these mixes cement is partially replaced with 10% phophogypsum..Mix designation and Quantities of ingredients used for mix proportions are given in Table 1 and Table 2.

TABLE 1 MIX DESIGNATION FOR DIFFERENT MIXES

Sl.No	Mixes	Fine aggregate		Binding material	
		Thermosetting plastics weight (%)	M sand (%)	Phospho-gypsum (%)	Cement (%)
1	RP0	0	100	0	100
2	RP1	0.5	99.5	10	90
3	RP2	1	99	10	90
4	RP3	1.5	98.5	10	90
5	RP4	2	98	10	90
6	RP5	2.5	97.5	10	90

TABLE 2 QUANTITIES OF INGREDIENTS USED FOR MIX PROPORTIONS

Particulars	Quantity (kg/m^3)
Cement	314.53
Fine aggregate	396.937
Coarse aggregate	727.414
Water	125.812

C. Specimen details

The specimens are standard cubes of 150mm side and 100mm side, cylinders of diameter 150mm and 300mm height, beams of size 500x100x100mm. Details of number of specimens are given in Table 3.

TABLE 3 SPECIMEN DETAILS

Sl. No	Specimen	Property	Size	Numbers
1	Cube	Compressive strength	150x150x150mm	54
2	Cylinder	Split tensile strength	300mm height and 150mm diameter	18
3	Beam	Flexural strength	500x100x100mm	18
4	Small cube	Durability	100x100x100mm	72
Total number of specimens				162

D. Preparation and casting of specimens

For each mix nine concrete cubes of size 150x150x150mm for compressive strength test, three cylinders of 150mm diameter and 300mm height for compressive and splitting tensile strength test and twelve cubes of size 100x100x100 mm for durability test were casted.

E. Tests on specimens

Testing of concrete specimens plays an important role in controlling and confirming the quality of concrete. All the specimens cast were subjected to testing in order to study the effect of partial replacement of cement with constant amount of phosphogypsum and fine aggregate with thermosetting plastics on workability, strength and durability. Thus the experimental investigation carried out was divided in to three main headings. They are as follows:

1. Study on workability
   - Slump test
   - Compacting factor test
2. Study on strength
   - Compressive strength test
   - Splitting tensile strength test
   - Flexural strength test
3. Study on durability

III. RESULTS AND DISCUSSION

A. *Properties of fresh concrete*

Studies conducted on fresh properties are given in Table 4. From the results obtained it can be concluded that the slump and compacting factor increases with the percentage increase in replacement of fine aggregate with thermosetting plastics. Except RP0 cement is partially replaced with a constant amount of phosphogypsum.

TABLE 4 PROPERTIES OF FRESH CONCRETE

Sl.No.	Mix designation	Workability	
		Slump (mm)	Compacting factor
1	RP0	27	0.80
2	RP1	29	0.83
3	RP2	31	0.86
4	RP3	34	0.89
5	RP4	36	0.90
6	RP5	38	0.94

B. *Properties of hardened concrete*

Cube Compressive Strength: Compressive strength of all concrete mix was determined at 3, 7 and 28 days of curing. Comparing with the control mix the compressive strength gradually increased up to 2% and then decreased. From this study 2% of replacement of fine aggregate with thermosetting plastics and a constant amount of 10% replacement of cement with phosphogypsum was taken as the optimum mix. The increase in strength of RP4 is 6.86N/mm^2.Compared to the normal mix RP4 shows a better strength value.

Splitting Tensile Strength: Splitting tensile strength of cylinder was maximum for 2% replacement of fine aggregate with thermosetting plastics and a constant amount of 10% replacement of cement with phosphogypsum. The increase in strength of RP4 is 6.86N/mm^2.Compared to the normal mix RP4 shows a better strength value.

Flexural Strength of Beams: Flexural strength of beam was maximum for 2% of replacement of fine aggregate with thermosetting plastics and a constant amount of 10% replacement of cement with phosphogypsum. The increase in strength of RP4 is 13.4N/mm^2. The strength of RP0 is 6.6 N/mm^2 which is smaller as compared to RP4 value.

C. *Durability of concrete*

The durability of concrete is the ability to resist weathering action, chemical attack, abrasion, or any process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to its environment. For the study of durability of concrete the test conducted were Acid resistance test (Sulphuric Acid attack), Alkalinity test (Sodium hydroxide attack), Sulphate attack test, Seawater attack test.

1) Sulphuric Acid Attack Test - The weight and compressive strength of specimens immersed in H_2SO_4 solution at 56 and 90 days were determined and compared with normal cured specimen at 28 days. Fig 3 and Fig 4 shows the percentage strength loss and percentage weight loss respectivelly

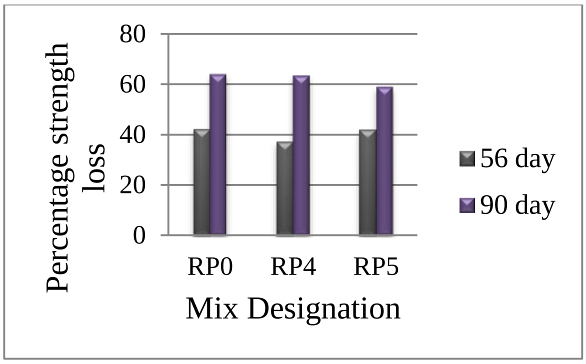

Fig 3 Percentage strength loss in acid solution

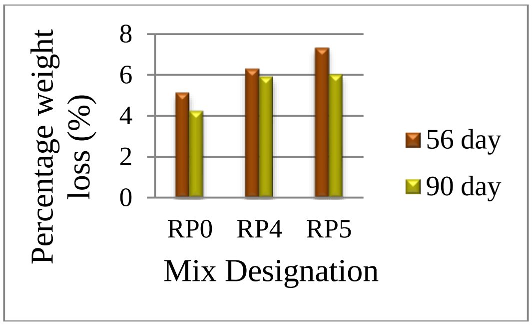

Fig 4 Percentage weight loss in acid solution

Thermosetting plastic concrete with phosphogypsum has less durability property in acid. The reduction in compressive strength increased with the increase in thermosetting plastic content after the exposure to sulphuric acid solution. Likewise the percentage weight loss was also higher for thermosetting plastic concrete than for control mix. This indicates that plastic concrete shows poor resistance to acid attack than control mix.

2) Sodium Hydroxide Attack - The specimens were tested and weighed after 56 and 90 days of NaOH exposure. Percentage strength loss and weight loss in alkaline solution is given in Fig 5 and Fig 6.

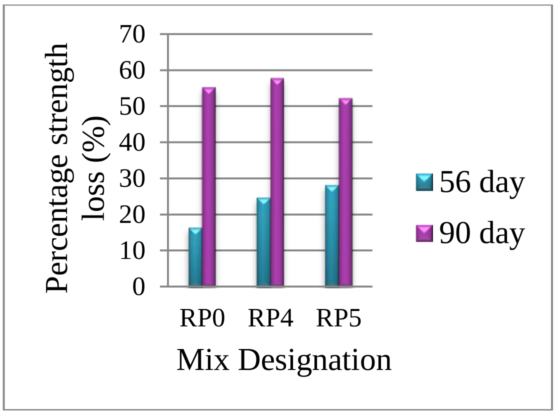

Fig 5 Percentage strength loss in alkaline solution

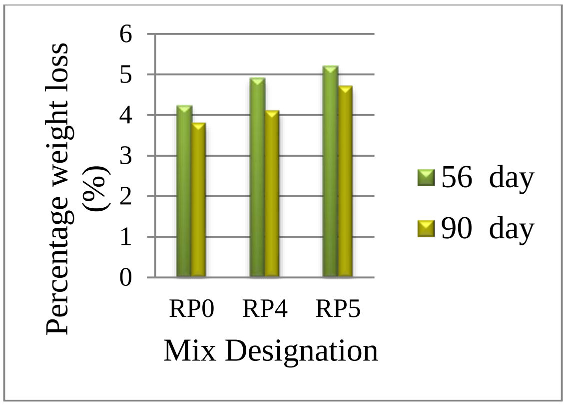

Fig 6 percentage weight loss in alkaline solution

3) Sulphate attack - To study the sulphate attack on concrete, the cubes were tested after 56 and 90 days of exposure to sulphate solution. The effect of sulphate attack on concrete specimen was assessed by measuring the compressive strength and weight loss at the respective test ages and compared them with water cured specimen at 28 day. Percentage strength loss and weight loss in sulphate solution is given in Fig 7 and Fig 8.

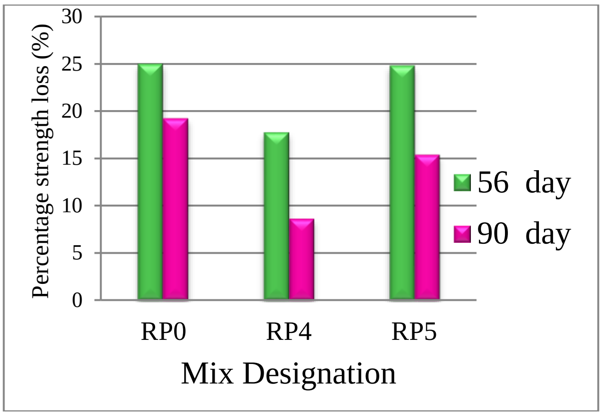

Fig 7 Percentage strength loss in sulphate solution

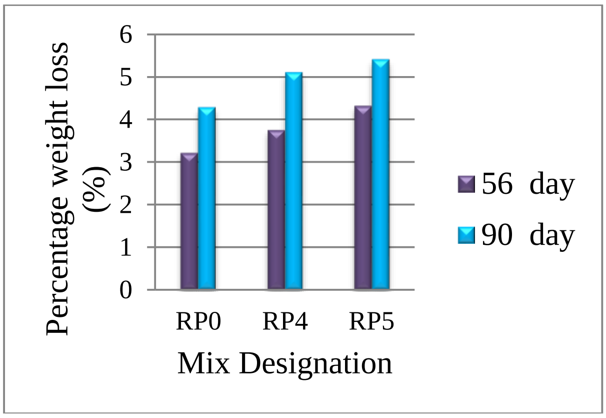

Fig 8 Percentage weight loss in sulphate solution

Thermosetting plastic concrete which contains phosphogypsum reduces the sulphate attack as compared with control mix. On 90th day the percentage strength loss for RP4 is about 8.63%. When compared to acid and alkali attack, thermosetting plastic concrete shows better durability properties. This may be due to the presence of plastic and phosphogypsum in concrete mix. Replacing a portion of Portland cement with phosphogypsum reduces the amount of reactive aluminates (tricalcium aluminate) available for sulphate reaction

4) Sea water attack - To determine the effect of sea water on concrete, the cubes were tested after 56 and 90 days of exposure to sea water. The compressive strength and weight loss at the respective test ages were determined and compared them with water cured specimen at 28 day. Percentage strength loss and weight loss in sea water is given in Fig 9 and Fig 10.

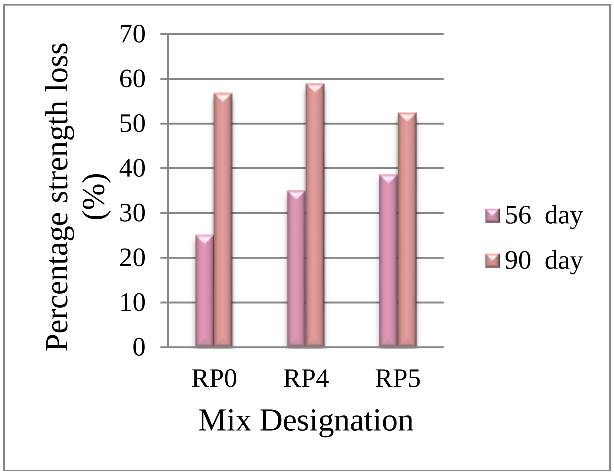

Fig 9 Percentage strength loss in sea water

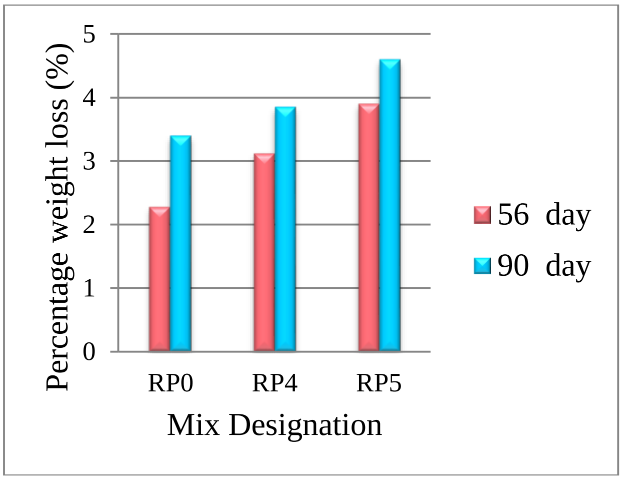

Fig 10 Percentage weight loss in sea water

Phosphogypsum present in the concrete decreases the durability in sea water. The compressive strength of concrete decreases with increase in days. The percentage loss in strength at 90 days for the mix RP0 was 56.7 % and for RP4 was 58.88 %. This indicates that RP0 showed better durability property than RP4. The weight loss obtained for RP0 was 3.4% and for RP4 was 3.85%. From this result it is clear that thermosetting concrete with phosphogypsum shows low resistant in sea water.

IV. CONCLUSION

The major conclusions of my thesis work are presented below:

- Workability increased with increase in thermosetting plastic content and provision of phosphogypsum by replacing with 10% of cement. Maximum workability was obtained at 2.5% of replacement of fine aggregate with thermosetting plastic and a partial replacement of 10% constant amount of cement with phosphogypsum.
- Compressive strength increased upto 2% replacement of fine aggregate with thermosetting plastics and a replacement of 10% constant amount of cement with phosphogypsum. The strength value decreased at RP5. The increase in compressive strength at 28th day of RP4 was about 26.27% than control mix (RP0).
- The splitting tensile strength of cylinder was maximum for 2% of replacement (RP4). The percentage of increase in splitting tensile strength of RP4 was about 34.77% than RP0.
- The flexural strength of beam was maximum for RP4. The increase in strength of RP4 shows a considerable increment than RP0.
- Thermosetting plastic concrete with phosphogypsum had less durability property in acid test. After 90 days exposure in sulphuric acid solution the compressive strength of RP4 was reduced by 63.45%. Percentage weight loss was much higher for RP4 as compared to RP0.
- On curing in NaOH solution, the percentage strength loss for RP4 was about 57.74% at 90 days. The weight loss was also much higher for RP4 compared to RP0. So thermosetting plastic concrete with phosphogypsum was less durable compared to control mix.
- The thermosetting plastic concrete with phosphogypsum reduced the sulphate attack as compared with control mix. On curing in sulphate solution , the percentage strength loss for RP4 was about 8.63% at 90 days. The weight loss was also much higher for RP4 compared to RP0.
- Plastic concrete with phosphogypsum decreases the durability in sea water. The percentage loss in strength at 90 days for the mix RP0 was 56.7 % and for RP4 was 58.88 %. The weight loss obtained for RP0 was 3.4% and for RP4 was 3.85%.

The results presented in this thesis report indicate that the partial replacement of 10% portland cement with phosphogypsum and partial replacement of fine aggregate up to 2% with thermosetting plastics can obtain the maximum strength of concrete.

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