Study on Strength and Durability of Concrete Using Phosphogypsum and Copper Slag as the Replacement Materials

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Abstract- **The gradual increasing population accompanied by development seeks the necessity for new engineering structures. The sudden development has also shunted the availability of various resources. This unavailability or shortage of resources results in increasing demand of the material which also adds up to the cost. Since sustainability is the future of development, we need to explore more ways by which the remaining resources are not depleted at the same time the by-products from earlier developments must be properly disposed or utilized. One such problem faced by us is the unavailability of materials for construction. This problem can be overcome by using suitable alternatives in place of the aggregates and materials that we have been using for years. This paper aims to develop concrete mixes using waste materials like phosphogypsum and copper slag replacing cement and fine aggregate at various levels to ensure sustainability and environment friendly approaches. Here, phosphogypsum replacing cement will be maintained at a constant rate of 10% and copper slag replacement levels of fine aggregate will be maintained at 0%, 10%, 20%, 30%, 40%, 50% and 60%.**

Keywords-Copper slag, Phosphogypsum

I. INTRODUCTION

Concrete is the world's second most consumed material after water, and its widespread use is the basis for urban development. It is estimated that 25 billion tonnes of concrete is manufactured each year. With the advancement of technology and increased field application of concrete and mortar, the strength, workability, durability and other characteristics of the ordinary concrete is continually undergoing modifications to make it more suitable for any situation. Concrete is a composite material composed mainly of water, aggregate, and cement. Often, additives and reinforcements are included in the mixture 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. India, being a developing country that is nearing the path of a developed nation is the second largest consumer of aggregates in Asia after China and fifth largest consumer in the world. Most of the aggregate demand in India comes from the construction industries and rest from the transportation field which includes road construction. The large scale consumption has depleted our natural aggregate resources and since sustainability is the future of all development, it is necessary that we conserve our remaining resources from depletion. But nowadays, it is very difficult to obtain required amount of fine as well as coarse aggregates due to its overuse causing scarcity. This paves the way for finding suitable alternatives replacing the naturally depleted aggregates. One of the suitable replacements for natural aggregates is the use of various industrial waste products like copper slag, fly ash, etc. So researchers developed waste management strategies to apply for replacement of both the aggregates for specific need. Copper slag (CS) is one of the materials that are considered as a waste material which have a promising future in construction industry as partial or full substitute of either cement or aggregates. It is a by-product obtained during the matte smelting and refining of copper. To produce every ton of copper, approximately 2.2–3.0 tons copper slag is generated as a by-product material. Copper slag have been widely used for abrasive tools, roofing granules, cutting tools, abrasive, tiles, glass, road base construction, rail road ballast and cement and concrete industries. Phosphogypsum (PG) is a by-product of phosphate fertilizer plants and chemical industries. Phosphogypsum is a by-product in the wet process for manufacture of phosphoric acid by the action of sulphuric acid on the rock phosphate. The use of phosphogypsum waste products with concrete in partial amounts replacing cement paved a role for: modifying the properties of the concrete; controlling the concrete production cost; to overcome the scarcity of cement; and finally the advantageous disposal of industrial waste. The use of particular waste product will be economically advantageous usually at the place of abundant availability and production. The objectives of present study are:

- To study the workability.
- To study the compressive strength of cubes at 3, 7 and 28 days
- To study the splitting tensile strength of cylinders at 28 days.

- To study the flexural strength of beams at 28 days.
- To study the durability properties of control mix, optimum mix and final mix at 56 and 90 days.
- To study the impact resistance of discs at 28 days.

II. INVESTIGATION

The aim of the project work is to determine the mechanical properties and durability properties of normal concrete and copper slag concrete. The various durability tests conducted are acid attack, alkali attack, sulphate attack and seawater attack.

A. *Test on constituent materials*

1) *Cement*

Ordinary Portland cement of 53 grades conforming to IS: 12269-1987 was used. Different laboratory tests were conducted on cement to determine specific gravity, standard consistency, initial and final setting time as per IS: 4031-1988.

2) *Fine aggregate*

Commercially available M-sand passing through 4.75 mm IS sieve and conforming to grading zone 2 of IS: 383-1970 was used for experiment. Sieve analysis was done to determine the fineness modulus and grain size distribution of M-sand. The specific gravity and fineness modulus were found to be 2.394 and 2.743 respectively.

3) *Coarse aggregate*

Aggregates of size greater than 4.75mm is said to be coarse aggregates. Laboratory tests were conducted on coarse aggregates to determine the different physical properties as per IS 383 (Part III)-1970. The physical properties and sieve analysis determinations were done for coarse aggregate. The specific gravity and fineness modulus were found to be 2.886 and 6.723 respectively.

4) *Phosphogypsum*

In the present experimental work, waste material phosphogypsum is collected from Arasan Phosphates Private Limited, Tuticorin, Tamil Nadu for the study. The colour was light yellow. The material was in a powdered sandy form just as that of cement. The specific gravity was found to be 3.12.

5) *Copper slag*

In the present work Copper slag material was collected from Sterlite Industries Private Limited, Tuticorin, Tamil Nadu to replace selected amount of fine aggregate. It is having a black colour and grassy appearance. The specific gravity and fineness modulus were found to be 3.53 and 3 respectively and conforms to zone II.

6) *Water*

Drinking water directly drawn from the college water supply line was used for the work

B. *Mix Design*

The entire work was performed on M25 concrete mix adopting a water-cement ratio of 0.43 as per IS 10262:2009 for the development of 7 mixes: CS0, CS10, CS20, CS30, CS40, CS50 and CS60. Here, CS0 is considered as the control concrete mix with 10% phosphogypsum replacing cement and 0% copper slag replacing fine aggregate. In rest of the mixes, a constant 10% phosphogypsum is replacing cement and copper slag replacing fine aggregate is maintained at 10%, 20%, 30%, 40%, 50% and 60%. Here, CS60 is considered as the final mix.

TABLE 1 QUANTITY OF INGREDIENTS USED FOR NORMAL MIX PROPORTION

Particulars	Quantity (kg/m^3)
Cement	389.25
Fine aggregate	613.15
Coarse aggregate	1206.00
Water	186
Phosphogypsum	43.25

C. *Specimen Details*

TABLE 2 NUMBER OF SPECIMENS CAST

Specimen	Test	Size	Numbers
Cube	Compressive strength	150mmx150mmx150mm	63
Cylinder	Splitting tensile strength	300mm height and 150mm dia	21
Beam	Flexural strength	500mmx100mmx100mm	21
Small cube	Acid attack, alkali attack, sulphate attack and seawater attack	100mmx100mmx100mm	78
Disc	Impact Resistance	64mm height and 150mm dia	21

D. Preparation and casting of specimens

Various concrete specimens were prepared for different mixes and for the purpose of testing. For compressive strength test, cubes of size 150mm×150mm×150mm were cast. For splitting tensile strength test, cylinders of size 150mm diameter and 300mm height were cast and for flexural strength test, beams of size 500mm×100mm×100mm were cast. For durability tests, small cubes of size 100mm×100mm×100mm were cast for sulphuric acid attack, sulphate attack, seawater attack and sodium hydroxide attack. Cast specimens were de moulded after 24 hours of casting and were kept in a curing tank for water curing. The cubes were taken from the curing tank on 3rd, 7th and 28th days for compressive strength test. Beams and cylinders were taken from the tank after 28 days of curing for flexural strength and splitting tensile strength test. Durability tests were done after 28 days of water curing.

E. Experimental Investigation

Testing of concrete specimens plays an important role in controlling and confirming the quality of concrete. Thus the experimental investigation carried out was divided into three main categories. 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
- Impact resistance test

3) *Study on durability*

- Acid attack test
- Alkali attack test
- Sulphate attack test
- Seawater attack test

III. RESULTS AND DISCUSSION

A. Properties of fresh concrete

The workability of various mixes were found by determining the compacting factor and slump value as per the IS 1199:1959 specification. Table 3 shows the workability of concrete mixes. The slump and compacting factor values increase with increase in percentage replacement of copper slag.

TABLE 3 WORKABILITY OF CONCRETE MIXES

Mix Designation	Slump (mm)	Compacting factor
CS0	28	0.82
CS10	31	0.83
CS20	33	0.85
CS30	34	0.86
CS40	36	0.88
CS50	39	0.91
CS60	40	0.92

B. Properties of hardened concrete

1) *Compressive Strength:*

Compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. Cube specimens of size 150mm × 150mm × 150mm were casted and tested for this purpose in accordance with IS: 516-1959. These cubes were tested on 3, 7 and 28 days from the day of curing in the compression testing machine. Loads were applied uniformly on the specimens till the failure load was obtained. From test results it can be concluded that compressive strength increases up to 40% replacement of copper slag after that the value decreases. So the optimum mix was obtained as CS40.

2) *Splitting Tensile Strength*

Splitting tensile strength is an important parameter that is utilized for characterization of concrete mechanical properties. It is method of determining the tensile strength of concrete using a cylinder which splits across the vertical diameter. Cylinders of size 150mm diameter and 300mm height were prepared for performing this test at the end of 28 days from the day of curing. Cylinders were prepared for all the 7 mixes: CS0, CS10, CS20, CS30, CS40, CS50 and CS60. From test values it is clear that the splitting tensile strength increases up to 40% replacement of fine aggregate by copper slag and after that it decreases gradually. So, CS40 has higher value of splitting tensile strength than other mixes.

3) *Flexural Strength*

Flexural strength, also known as modulus of rupture, bend strength, or fracture strength, a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. Beams of size 500mm×100mm×100mm were cast for all the mixes and were tested after 28 days from day of curing. From test values it is clear that the flexural strength increases up to 40% replacement of copper slag and after that it decreases gradually. The maximum value of flexural strength was obtained for CS40 mix.

4) *Impact resistance*

The impact resistance of the specimen was determined by using drop weight method. The size of the specimen is 150mm diameter and 64mm thickness and weight of hammer is 4.54 kg with a drop of 457mm. The number of blows required for the first visible crack to form at the top surface of the specimen was to be recorded and also for ultimate failure to be recorded. The first crack was based on visual observation (N1). Ultimate failure was determined was determined in terms of the number of blows required to open the cracks in the specimens (N2). The disc specimens were cast for all the mixes. CS40 mix was found to be more resistant to impact loading than other mixes and was found to vary in accordance with the compressive strength.

TABLE 4 IMPACT RESISTANCES OF CONCRETE MIXES

Mix Designation	No: of drops at first crack (N_1)	No: of drops at failure (N_2)
CS0	24	32
CS10	36	46
CS20	40	51
CS30	45	58
CS40	51	66
CS50	47	60
CS60	42	54

5) *Durability of concrete*

Durability testing allows the assessment of a product's response to the physical and climatic hazards that may occur throughout the operational life of the product. The main durability tests performed were acid attack test, alkali attack test, sulphate attack test and seawater attack.

a) *Acid attack*

For this test, small cubes of size 100mm×100mm×100mm were prepared and after 28 days of water curing, they were immersed in 5% sulphuric acid (H_2SO_4) solution in water for 56 and 90 days. This test was performed only for CS0, CS40 and CS60 mixes as they form the control mix, optimum mix and final mix respectively. After 28 days of water curing, the initial weight of specimen was calculated. After 56 and 90 days, the cubes were removed from acid solution and final weight of the specimen along with the compressive strength was calculated after thoroughly washing it with fresh water. The percentage loss in compressive strength and percentage loss in weight were also calculated. Table 4 shows the test result for acid attack. From the values it is clear that optimum mix and final mix were less durable than the normal mix in sulphuric acid.

TABLE 5 TEST RESULT FOR ACID ATTACK

Mix Designation	% strength loss		% weight loss	
	56 days	*90 days*	*56 days*	*90 days*
CS0	39.26	53.9	5.31	5.77
CS40	40.18	54.03	5.63	6.71
CS60	42.00	55.09	6.36	7.28

b) *Alkali attack*

For this test, small cubes of size 100mm×100mm×100mm were prepared and after 28 days of water curing, they were immersed in 5% sodium hydroxide (NaOH) solution in water for 56 and 90 days. This test was performed only for CS0, CS40 and CS60 mixes as they form the control mix, optimum mix and final mix respectively. After 28 days of water curing, the initial weight of specimen was calculated. After 56 and 90 days, the cubes were removed from alkali solution and final weight of the specimen along with the compressive strength was calculated after thoroughly washing it with fresh water. The percentage loss in compressive strength and percentage loss in weight were also calculated. Table 5 shows the test result for alkali attack. From the values it is clear that control mix and final mix show better resistance to alkali attack than control mix.

TABLE 6 TEST RESULT FOR ALKALI ATTACK

Mix Designation	% strength loss		% weight loss	
	56 days	*90 days*	*56 days*	*90 days*
CS0	36.52	40.32	5.86	6.02
CS40	30.54	34.78	5.52	5.7
CS60	27.41	31.22	5.37	5.49

c) *Sulphate attack*

For this test, small cubes of size 100mm×100mm×100mm were prepared and after 28 days of water curing, they were immersed in 5% magnesium sulphate ($MgSO_4$) solution in water for 56 and 90 days. This test was performed only for CS0, CS40 and CS60 mixes. After 28 days of water curing, the initial weight of specimen was calculated. After 56 and 90 days, the cubes were removed from sulphate solution and final weight of the specimen along with the compressive strength was calculated after thoroughly washing it with fresh water. The percentage loss in compressive strength and percentage loss in weight were also calculated. Table 6 shows the test result for sulphate attack. From the test values it is clear that optimum mix and final mix shows better resistance to sulphate attack than control mix. The percentage strength loss and weight loss were found to be higher in control mix.

TABLE 7 TEST RESULT FOR SULPHATE ATTACK

Mix Designation	% strength loss		% weight loss	
	56 days	*90 days*	*56 days*	*90 days*
CS0	29.67	35.38	5.56	5.94
CS40	28.83	31.06	5.46	5.72
CS60	24.72	27.36	4.65	5.12

d) Seawater attack

For seawater attack test, concrete cubes of size 100mm×100mm×100mm were prepared for various mixes. The specimen were casted and cured in mould for 24 hours, after 24 hours, all the specimen were de moulded and kept in curing tank for 28 days. After 28 days all the specimens were weighed and immersed in fresh seawater containing 3.5% dissolved salts solution for 56 and 90 days. After 56 and 90 days of immersing in seawater solution, the specimens were taken out and were washed in running water. Subsequently, the specimens were weighed and compressive strength was noted. The loss percentage in weight and percentage loss in strength was calculated. Table 7 shows the test result for seawater attack. From the test values it is clear that all the mixes are highly resistant to seawater attack. But optimum and final mix are more durable than the control mix.

TABLE 8 TEST RESULT FOR SEAWATER ATTACK

Mix Designation	% strength loss		% weight loss	
	56 days	*90 days*	*56 days*	*90 days*
CS0	18.71	23.45	3.45	4.64
CS40	17.14	21.12	3.33	4.14
CS60	14.35	18.94	2.94	3.74

IV. CONCLUSIONS

- Workability increases with increase in the replacement level of copper slag replacing fine aggregate.
- Compressive strength, splitting tensile strength and flexural strength were found to be higher for the optimum mix CS40 than other mixes. Control mix attained the lowest values of strength properties.
- On comparing control mix and optimum mix, the compressive strength, splitting tensile strength and flexural strength of optimum mix increases by 40%, 31% and 63.63 % respectively at 28 days.
- Acid attack test shows that copper slag concrete mixes CS40 and CS60 were low resistant to acid solution.
- Alkali attack test shows that copper slag concrete was more durable than control concrete in alkali solution.
- Copper slag concrete was found more durable to sulphate as well as seawater attack than control concrete mix.
- CS40 mix was found to be more resistant to impact loads when compared to other mixes. Impact resistance of mixes were found to vary with their compressive strength.

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