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Experimental Investigation on Strength and Durability Aspects of Concrete using Copper Slag and Phosphogypsum

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Abstract:

Construction industry requires construction materials like cement and aggregates in large quantities. As a result of mass consumption of natural resources these are heading on a path towards depletion [1]. Hence usage of waste materials in concrete is an emerging trend. Suitable replacement waste materials used in this work are Copper Slag and Phosphogypsum. Copper slag is used to replace fine aggregate and Phosphogypsum is used to replace cement. M35 grade concrete using these waste materials were cast and tests were conducted to determine its strength and durability aspects. Phosphogypsum is used as 10% of total weight of cement and copper slag is used in varying percentage (10%, 20%, 30%, 40%, 50% and 60%). The test results show that concrete made by replacing fine aggregate at 40% by copper slag and replacing cement at 10% by phosphogypsum gives a higher strength and more durability than conventional concrete of the same grade. The proposed mix is less durable to acidic environment but shows better resistance against alkali and sulphate attack as compared to conventional concrete.

Keywords —**Copper Slag, Phosphogypsum, Strength, Durability.**

I. INTRODUCTION

Utilization of waste materials in concrete is encouraged in construction field as they are available at low prices. The growth in infrastructure sector led to scarcity of raw materials like cement and aggregates [3]. As a result, the cost of materials increased rapidly. In order to combat the scarcity of cement and the increase in cost of concrete under these circumstances the use of recycled solid wastes, agricultural wastes, and industrial by-products like fly ash, blast furnace slag, silica fume, rice husk, phosphogypsum, etc. came into use. Similar is the problem in case of fine aggregate, whose availability has been depleted gradually due to their overuse. Suitable alternatives like copper slag, steel slag, iron slag and aluminium slag could be used as a suitable alternative to fine aggregate thereby further conserving the existing resources [4]. This work is done by making concrete mixes using both these waste materials like phosphogypsum for replacing cement and copper slag for replacing fine aggregate at various levels and comparing test results with the conventional concrete mix. Here, phosphogypsum replacing cement will be maintained at a constant rate of 10% and copper slag replacement levels of fine aggregate at 0%, 10%, 20%, 30%, 40%, 50% and 60%.

II. LITERATURE REVIEW

A. Based on Copper slag

Akshay C Sankh et al. in 2014 replaced natural sand with copper slag and found an improvement in the compressive strength, splitting tensile strength and flexural strength of concrete [14]. There was increase in the flexural strength of the beam by 21% to 51%. The strength increase was observed up to 40% replacement.

Jayapal Naganur and Chethan B. A. in 2014 had done research work using M20 grade concrete. The results for concrete showed that workability increased significantly as copper slag percentage increase compared with the control mixture [8]. A substitution of up to 40 to 50% copper slag as fine aggregate yielded comparable strength to that of the control mixture. However addition of copper slag more than 50% resulted in strength reduction compared to conventional concrete.

R.R. Chavan and D. B. Kulkarni in 2013 studied the performance of copper slag on strength properties of concrete. The study shows that maximum compressive strength of concrete increased by 55% at 40% replacement of fine aggregate by copper slag, gain more strength than control mix concrete [7]. For all percentage replacement of fine aggregate by copper slag the flexural strength of concrete is more than control mix. Compressive strength and flexural strength are increased due to high toughness of copper slag.

B. Based on Phosphogypsum

Mahesh A. Bagade and S. R. Satone in 2012 reported that an industrial waste like phosphogypsum impairs the strength development of calcined products and hence it can be used in construction industry for preparation of concrete replacing some quantity of cement. The improved compressive strength of phosphogypsum cement concrete with 5-10% replacement indicates that phosphogypsum has immense potential to be utilized in concrete application, especially mass concrete work [3].

Kalvakaalava et al., in 2011 studied micro structural and phase characteristics of phosphogypsum cement mixtures. The study concluded that the addition of phosphogypsum to portland cement produced large amount of ettringite [11]. Phosphogypsum increased the degree of hydration of cement in the mixtures. The amount of carbonation in phosphogypsum based mixture was found relatively low.

D. Rupesh Kumar et al., in 2010 reported that with 10% replacement of cement with phosphogypsum, not only the compressive strength increased significantly with age but also the splitting tensile strength at 28 days increased commendably in case of different water-binder ratios. However, further replacement of cement with phosphogypsum lead to drastic reduction in the compressive strength and also the splitting tensile strength [12]. The flexural strength not only decreased significantly with higher replacement of cement with phosphogypsum. The width and the number of cracks in concrete increased with increase in replacement of phosphogypsum above 10%.

III. TESTS ON MATERIALS USED IN STUDY

A. Tests on Cement

Ordinary Portland cement of 53 grade, conforming to IS 12269-1987 was used. The results for the experimental tests on the physical properties of cement are shown in Table I.

TABLE I
Test on Cement

Sl. no.	Properties	Test Result
1	Consistency	34%
2	Specific gravity	3.1
3	Initial setting time	60 min
4	Final setting time	170 min

B. Test on Phosphogypsum

Phosphogypsum was collected from Fertilizers and Chemicals Travancore Limited, Kochi, Kerala. It was of light yellow colour and powdery form. Specific gravity of the material was found out and is shown in Table II.

TABLE II
Test on Phosphogypsum

Sl. No	Property	Test Result
1	Specific gravity	3.06

C. Tests on 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. Tests were conducted to determine their physical properties and are shown in Table III.

TABLE III
Tests on Fine Aggregate

Sl. No	Properties	Test results
1	Fineness Modulus	2.74
2	Specific Gravity	2.69
3	Water Absorption	1.06

D. Tests on Copper Slag

Copper slag was collected from Blast Line India Private Limited, Kochi, Kerala, to replace selected quantity of fine aggregate. It is having a black colour and grainy appearance. Copper slag passing through 4.75mm sieve was used. The tests results for its physical properties are shown in Table IV.

TABLE IV
Tests on Copper Slag

Sl. No	Properties	Test Results
1	Specific gravity	3.26
2	Fineness modulus	3.02

E. Tests on Coarse Aggregate

Aggregates of size greater than 4.75mm is used as coarse aggregate. Laboratory tests were conducted as per IS 383 (Part III)-1970 to determine the different physical properties. The test results are shown in Table V.

TABLE V
Tests on Coarse Aggregate

Sl. No.	Properties	Test results
1	Specific Gravity	2.71
2	Fineness Modulus	7.37
3	Water Absorption	1.03

IV. MIX NOTATION

A total of 7 mixes of concrete were prepared for testing. The entire work was done on M35 grade concrete adopting a water-cement ratio of 0.42. CC is the control mix concrete. Notations for each mix is shown in Table VI.

TABLE VI
Mix Designations Used

Sl. No.	Mix Designation	Percentage of Phosphogypsum Replacement	Percentage of Copper Slag Replacement
1	CC	-	-
2	M_1	10	10
3	M_2	10	20
4	M_3	10	30
5	M_4	10	40
6	M_5	10	50
7	M_6	10	60

V. MIX PROPORTION FOR M35 GRADE CONCRETE

From the test results found out from the testing of materials done for its physical properties, mix design for M35 grade concrete was carried out as per IS 10262:2009. The required material proportion used for the M35 grade work was in the ratio of 1:1.35:2.37. The mix proportion used for the entire work is shown below in Table VII.

TABLE VII
Proportion for Control Concrete

Sl. No.	Material	Weight (kg/m^3)
1	Cement	469
2	Fine aggregate	633.53
3	Coarse aggregate	1113
4	Water	216

VI. EXPERIMENTAL TEST RESULTS

Tests were done to study the workability, strength and durability aspects of concrete for the mixes. For workability studies slump cone test and compacting factor test were conducted. To determine the strength i.e., the hardened properties of concrete, testing was done to ascertain its compressive strength, splitting tensile strength and flexural strength. Durability study was done to find out its resistance towards acid attack, alkali attack and sulphate attack.

A. Workability studies

The workability of various mixes were found by determining the slump value and compacting factor value as per the IS 1199:1959 specification. Slump refers to the ease with which concrete can flow. Compacting factor refers to the degree of compaction achieved by a standard amount of work done by allowing the concrete to fall through a standard height. Table VIII shows the values of compacting factor and slump value for various mixes of concrete.

TABLE VIII
Workability of different mixes

Mix Designation	Slump (mm)	Compacting factor
CC	20	0.68
M_1	25	0.71
M_2	29	0.75
M_3	32	0.79
M_4	35	0.83
M_5	38	0.86
M_6	40	0.89

Fig. 1 shows variation of slump and Fig. 2 shows the variation of compacting factor for all the different concrete mixes.

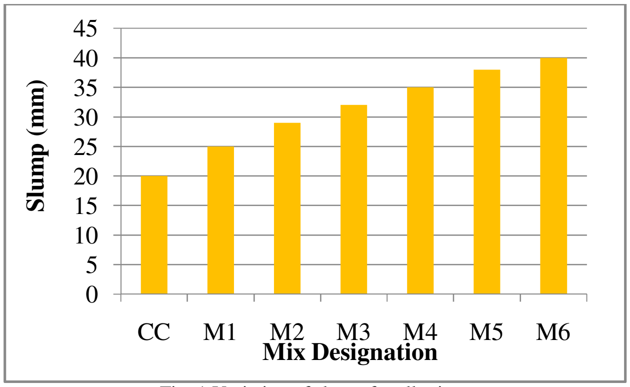

Fig. 1 Variation of slump for all mixes

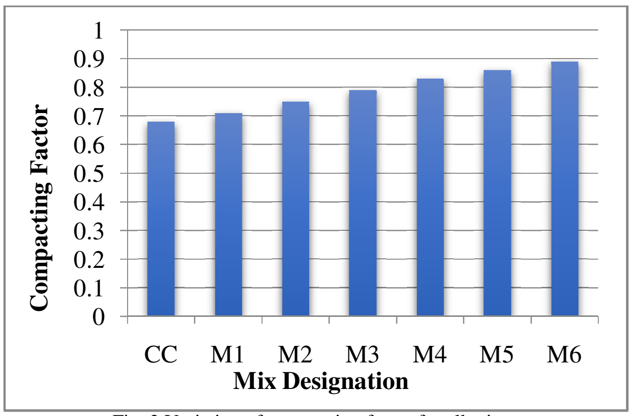

Fig. 2 Variation of compacting factor for all mixes

From the workability test, it is clear that the slump and compacting factor value increases with increase in the replacement level of copper slag. It is because copper slag is mostly angular shaped aggregates that can entrap more air leading to the formation of a more wet mix than control concrete. As the mix becomes more and more wet, the workability also increases. From Table VIII it is clear that the phosphogypsum admixed copper slag concrete gives better workability than control concrete. The maximum value of slump and compacting factor is obtained for M_6 mix.

B. Studies on Strength Aspects

The hardened properties of concrete give a realistic idea about the strength of a particular mix concrete. Compressive strength test, splitting tensile strength test and flexural strength test were conducted at 7 days and 28 days for all mixes and test results compared with control concrete to determine which mix gives higher strength.

1) Test for Compressive Strength*:* Compressive strength is the ability of the material to withstand load without causing a change in specimen size or shape. Preparation of specimens and testing is done as per IS 516:1959. Cubes of 150 x 150 x 150 mm were cast and tested. The test results are shown in Table IX and Fig. 3 shows the variation of compressive strength values for all the mixes.

TABLE IX
Compressive Strength Values

Sl. No.	**Mix Designation**	**Average Compressive Strength (N/mm^2)**	
		7th Day	**28th Day**
1	CC	27.23	41.24
2	M_1	29.41	43.98
3	M_2	32.89	47.34
4	M_3	36.10	50.88
5	M_4	40	54.63
6	M_5	37.23	49.92
7	M_6	35.31	45.21

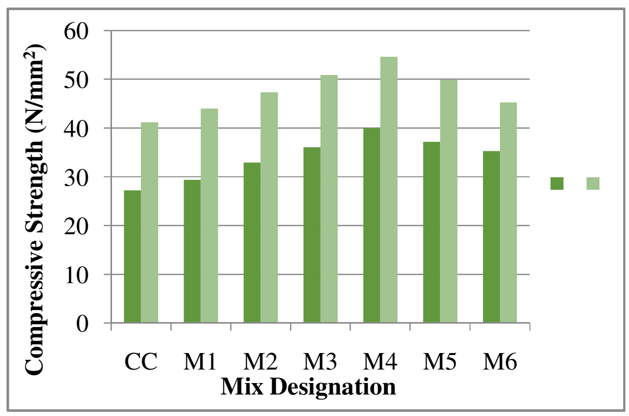

Fig. 3 Variation of Compressive Strength

It has been found that compressive strength increases up to 40% replacement of fine aggregate by copper slag and 10% replacement of cement by phosphogypsum in 7 and 28 days testing and after that it decreases gradually. This reduction in compressive strength for concrete mixes with high copper slag content is due to increase in the free water content that results from the low water absorption characteristics of copper slag in comparison with sand. This causes a considerable increase in the workability of concrete and thus reduces concrete strength. However it is to be noted that all mixes give higher values of strength than control concrete and M_4 mix gives the highest strength. So, M_4 can be considered as the optimum mix.

2) Test for Splitting Tensile Strength: Splitting tensile strength is an important parameter that is utilized for the characterization of concrete mechanical properties. Splitting Tensile Strength testing procedure is a 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 tested in accordance with IS 5816:1999. Test results are given in Table X and Fig. 4 shows its variation.

TABLE X
Splitting Tensile Strength Values

Sl. No.	Mix Designation	Splitting Tensile Strength (N/mm^2)	
		7th Day	28th Day
1	CC	2.73	4.11
2	M_1	3.13	4.51
3	M_2	3.60	4.87
4	M_3	3.89	5.19
5	M_4	4.31	5.82
6	M_5	3.89	5.36
7	M_6	3.23	5

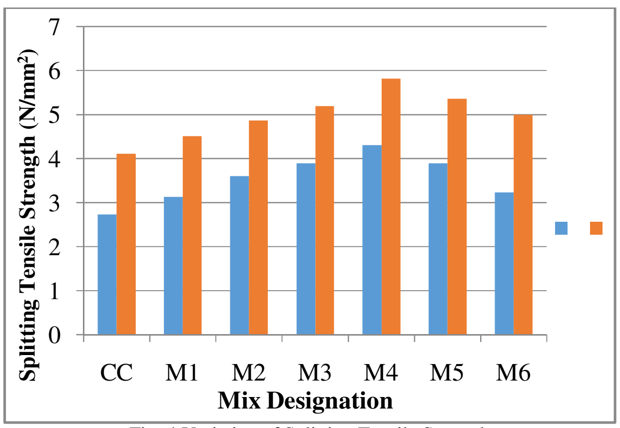

Fig. 4 Variation of Splitting Tensile Strength

It is seen that the splitting tensile strength increases up to 40% replacement of fine aggregate by copper slag and 10% replacement of cement by phosphogypsum and then the strength values gradually declines. The reason for improvement of strength may be due to the fact that copper slag has a better compressibility than sand, which can partially relieve the stress concentration, if the sand is still as the dominant fine aggregate holding the concrete matrix together. The angular sharp edges of copper slag particles have the ability to compensate to some extent the adverse effects of sand and thus, further improve the cohesion of concrete. This leads to improved mechanical performance of copper slag admixed concrete. All the mixes show higher values of strength as compared over control concrete and M_4 has higher value of splitting tensile strength than other mixes. Thus M_4 mix is considered as the optimum mix.

3) Test for Flexural Strength: Flexural strength, also known as modulus of rupture, bend strength or fracture strength, is a mechanical parameter for brittle material and is defined as a material's ability to resist deformation under load. Beams of size 500×100×100mm were tested conforming to IS 516:1959. Test results are given in Table XI and Fig. 5 shows the flexural strength variation for the mixes.

TABLE XI
Flexural Strength Values

Sl. No.	Mix Designation	Flexural Strength (N/mm^2)	
		7th Day	28th Day
1	CC	3.13	5.21
2	M_1	3.85	5.79
3	M_2	4.24	6.28
4	M_3	4.79	6.83
5	M_4	5.12	7.34
6	M_5	4.91	7.11
7	M_6	4.53	6.69

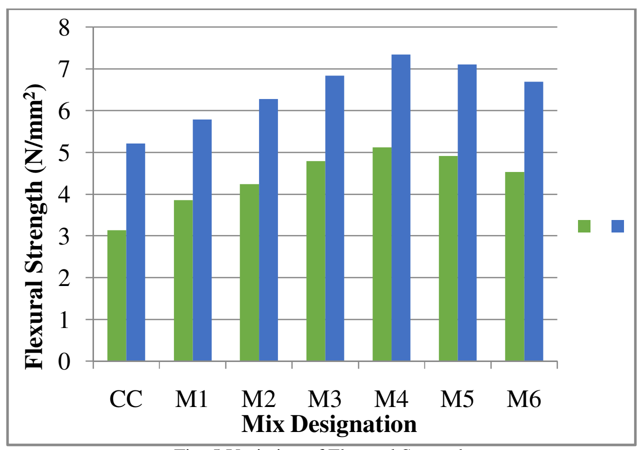

Fig. 5 Variation of Flexural Strength

From Fig. 5, we can see that the flexural strength increases up to 40% replacement of fine aggregate by copper slag and 10% replacement of cement by phosphogypsum and then reduces. The reason for reduction in strength may be the low absorption properties of copper slag which leave excess water in concrete causing excessive bleeding at higher copper slag content. Thus, the strength of concrete decreased substantially with a reduction in cohesion. But, it is observed that the strength for phosphogypsum admixed copper slag concrete of all mixes show higher strength than control mix. The maximum value of flexural strength was obtained for M_4 mix.

C. Studies on Durability Aspects

Durability testing otherwise termed as reliability 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. This testing provides recognition of compliance, analysis and resolution of damage issues and assurance of reliability. The tests conducted for durability studies are acid attack test, alkali attack test and sulphate attack test. Durability of the mixes is measured in terms of percentage strength loss and weight loss. A higher value of strength loss or weight loss means poorer resistance and hence lesser durability when exposed in chemical environment.

From the strength tests it is clearly understood that M_4 mix has the highest strength of all the phosphogypsum admixed copper slag concrete. A concrete of less strength but better durability is not an ideal situation to consider. A concrete of high strength and better durability is the suitable criteria. Since M_4 is the optimum mix in terms of strength, durability studies are conducted for M_4 mix and control concrete to ascertain which mix is better in terms of durability.

1) Deterioration due to Acid Attack: Cubes of size 150×150×150mm were cast. After 28 days, few specimens were taken for noting initial weight and compressive strength. Other specimens were immersed in 5% hydrochloric acid (HCL) solution for 60 days. After 60 days of immersing in acid solution, the specimens were taken out and were washed in running water. Subsequently the specimens were noted for their final weight and compressive strength. The percentage loss in weight and percentage loss in strength was calculated. Table XII shows the percentage loss in compressive strength and Fig. 6 shows variation in percentage loss in strength in acid solution.

. TABLE XII
Percentage Loss in Compressive Strength in Acid Solution

Mix	Compressive Strength in water (N/mm^2)	Compressive Strength in acid solution (N/mm^2)	% loss in Compressive Strength
CC	41.24	30.28	26.57
M_4	54.63	38.72	29.12

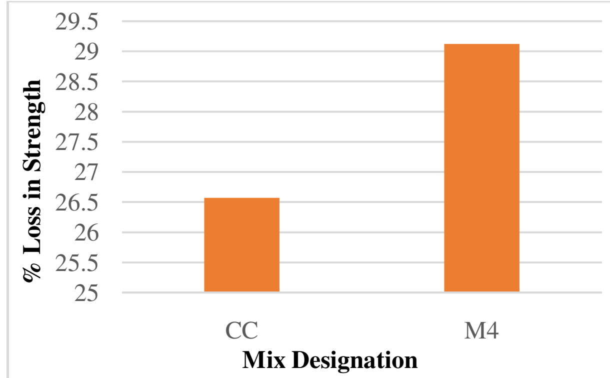

Fig.6 Variation of Percentage Loss in Strength in Acid Solution

Table XIII shows the percentage loss in weight and Fig. 7 shows the variation of weight loss in acid solution.

. TABLE XIII
Percentage Loss in Weight in Acid Solution

Mix Designation	Weight of cube in water (kg)	Weight of cube in acid solution(kg)	% loss in Weight
CC	8.71	8.33	4.36
M_4	8.88	8.45	4.84

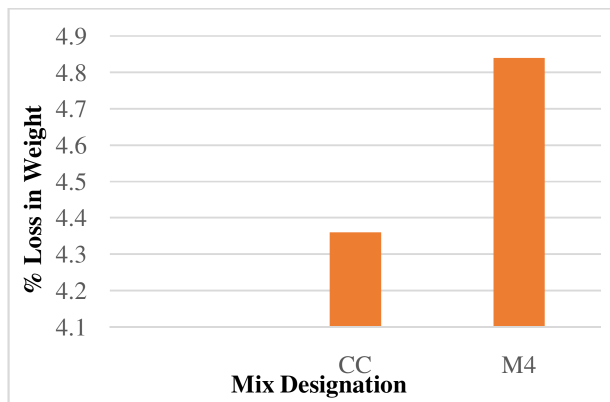

Fig. 7 Variation of Percentage Loss in Weight in Acid Solution

From the figures it is clear that phosphogypsum admixed copper slag concrete has more strength and weight loss as compared to control concrete and hence found to be less resistant to acid attack. The main reason for this may be that the higher content of iron oxide in phosphogypsum admixed copper slag concrete causes the conversion of ferrous compounds to ferric salts of the attacking acid. As a result, the structure of concrete gets destroyed. In control concrete mix when concrete is in contact with hydrochloric acid solution, the calcium hydroxide reacts with the hydrochloric acid to form water soluble calcium compounds like gypsum, which can be readily leached away.

2) Deterioration due to Alkali Attack: Cubes of size 150×150×150mm were cast. After 28 days few specimens were taken out and noted for initial weight and compressive strength. Other specimens were immersed in 5% sodium hydroxide (NaOH) solution for 60 days. After 60 days of immersing in alkaline solution, the specimens were taken out and were washed in running water. Subsequently, the specimens were noted for final weight and compressive strength. The loss percentage in weight and percentage loss in strength was calculated. Table XIV shows the percentage loss in compressive strength and Fig. 8 shows variation in percentage loss in strength in alkali solution.

. TABLE XIV
Percentage Loss in Compressive Strength in Alkali Solution

Mix	Compressive Strength in water (N/mm^2)	Compressive Strength in alkali solution (N/mm^2)	% loss in Compressive Strength
CC	41.24	31.89	22.67
M_4	54.63	43.78	19.85

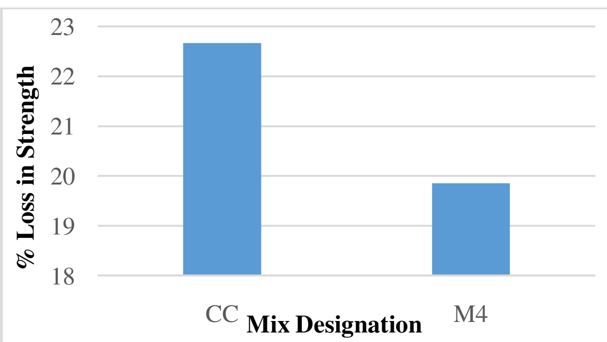

Fig.8 Variation of Percentage Loss in Strength in Alkali Solution

Table XV shows the percentage loss in weight and Fig. 9 shows the variation of weight loss in alkali solution.

. TABLE XV
Percentage Loss in Weight in Alkali Solution

Mix Designation	Weight of cube in water (kg)	Weight of cube in alkali solution (kg)	% loss in Weight
CC	8.71	8.4	3.55
M_4	8.88	8.59	3.26

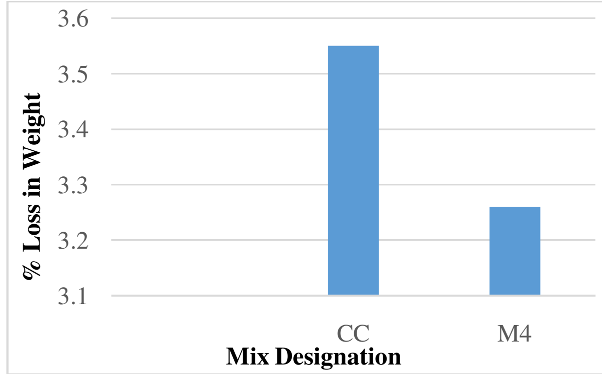

Fig. 9 Variation of Percentage Loss in Weight in Alkali Solution

Alkali attack occurs due to the reaction between silica present in the mix with the alkali solution. From the figures, it is seen that strength and weight loss for phosphogypsum admixed copper slag concrete is lesser than control concrete and hence more durable to alkali attack than control concrete mix. It is because the percentage of silica content is less in phosphogypsum admixed copper slag concrete than the control mix. The reaction of silica with alkali hydroxide causes formation of a gel that swells as it adsorbs water from the surrounding cement paste. These gels can induce enough expansive pressure to damage structure of control concrete.

3) Deterioration due to Sulphate Attack: Cubes of size 150×150×150mm were cast. After 28 days few specimens were taken out and noted for their initial weight and compressive strength. Other specimens were immersed in 5% aluminium sulphate ($Al_2(SO_4)_3$) solution for 60 days. After 60 days of immersing in sulphate solution, the specimens were taken out and were washed in running water. Subsequently, the specimens were noted for their final weight and compressive strength. The loss percentage in weight and percentage loss in strength was calculated. Table XVI shows the percentage loss in compressive strength and Fig. 10 shows variation in percentage loss in strength in sulphate solution.

TABLE XVI
Percentage Loss in Compressive Strength in Sulphate Solution

Mix	Compressive Strength in water (N/mm^2)	Compressive Strength in sulphate solution (N/mm^2)	% loss in Compressive Strength
CC	41.24	32.36	21.53
M_4	54.63	44.32	18.88

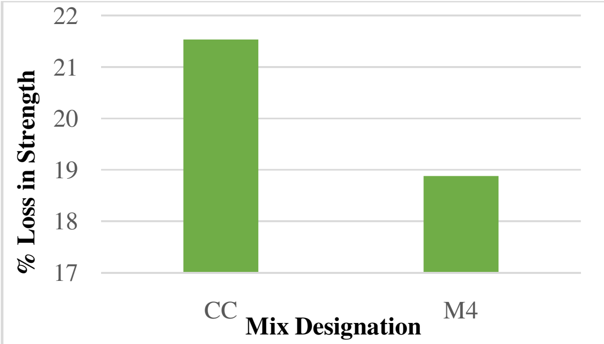

Fig.10 Variation of Percentage Loss in Strength in Sulphate Solution

Table XVII shows the percentage loss in weight and Fig. 11 shows the variation of weight loss in sulphate solution.

. TABLE XVII
Percentage Loss in Weight in Sulphate Solution

Mix Designation	Weight of cube in water(kg)	Weight of cube in sulphate solution (kg)	% loss in Weight
CC	8.71	8.38	3.78
M_4	8.88	8.64	2.70

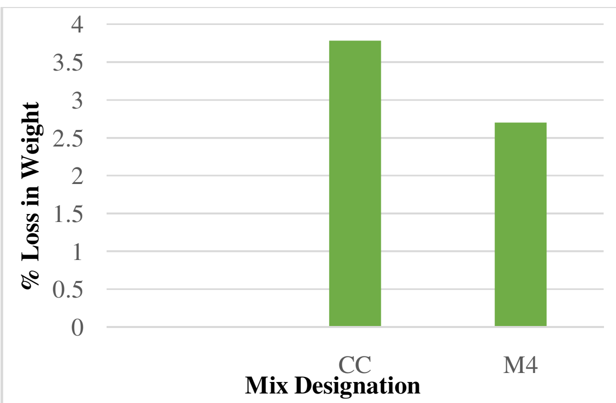

Fig. 11 Variation of Percentage Loss in Weight in Sulphate Solution

From the sulphate attack test it was observed that sulphate resistance improved in concrete containing phosphogypsum admixed copper slag than control mix. Hence, it is more resistive and durable against sulphate attack. It may be due to the reduction of soluble calcium hydroxide, the environment for formation of calcium sulfo-aluminate, the primary cause of deterioration due to sulphate attack may get reduced. In control concrete mix, the sulphates react with calcium hydroxide and calcium aluminate hydrates. These expansive reactions can produce a sufficient pressure that disrupts the cement paste. This disruption of cement paste results in concrete cracking and disintegration in control concrete.

VII. PROPORTIONING FOR PROPOSED MIX

From the tests conducted on the strength and durability properties of concrete, it is clearly seen that the phosphogypsum admixed copper slag concrete of M_4 mix shows better strength and durability properties than the control or conventional concrete. Also, of all the different mixes prepared and tested the M_4 mix showed highest value for strength as compared to other mixes. Table XVII shows mix proportion for control concrete of M35 grade used for work.

The waste materials phosphogypsum is used to replace cement at 10% by volume of concrete and copper slag is used to replace the fine aggregate at 40% by volume of concrete. This mix is M_4 mix and has better strength than all mixes cast and tested and durability for M_4 mix is better than control concrete and hence M_4 mix is proposed as the optimum mix for the work conducted and studied. Table XVIII shows mix proportion for phosphogypsum admixed copper slag M_4 mix of M35 grade concrete.

TABLE XVIII
Proportion for Proposed M_4 mix Concrete

Sl. No.	Material	Weight (kg/m^3)
1	Cement	422.14
2	Phosphogypsum	46.90
3	Fine aggregate	380.12
4	Copper slag	253.41
5	Coarse aggregate	1113
6	Water	216

From Table XVIII, it can be seen that by using phosphogypsum as replacement material for cement at 10% by volume of cement in concrete we can save 46.90 kg of cement per m^3 of concrete work. Also, by using copper slag as replacement material for fine aggregate at 40% by volume of fine aggregate in concrete we can save 253.41 kg of fine aggregate per m^3 of concrete work.

VIII. CONCLUSION

In the present work, fine aggregate was partially replaced with copper slag at a level of 0%, 10%, 20%, 30%, 40%, 50% and 60% whereas phosphogypsum replaced cement at a constant rate of 10% throughout the work. The various hardened properties like compressive strength, splitting tensile strength, flexural strength were found out. Durability characteristics of the mixes were obtained by exposing them to different environmental conditions. The main findings of the work conducted is given below

1) The workability and compacting factor of the mix increased with increase in copper slag content.

2) The compressive strength of all other mixes was higher than that of control concrete mix. The maximum value was for M_4. Increase in 28 days compressive strength between control mix and optimum mix is 32.46 %.

3) Splitting tensile strength of all replacement mixes were higher than control concrete. M_4 mix has the maximum strength. Increase in strength at 28 days between control mix and optimum mix is 41.6%

4) Flexural strength of all replacement mixes were higher than control concrete. M_4 mix has the maximum strength. Increase in strength at 28 days between control mix and optimum mix is 40.88%

5) Percentage strength and weight loss for M_4 mix concrete in acid solution was higher than control concrete. So we can say that M_4 mix has poorer resistivity to acid attack than control concrete and thus found to be less durable.

6) Percentage strength and weight loss for M_4 mix concrete in alkaline solution was lower than control concrete. So we can say that M_4 mix has better resistivity to alkali attack than control concrete and thus found to be more durable.

7) Percentage strength and weight loss for M_4 mix concrete in sulphate solution was lower than control concrete. So we can say that M_4 mix has better resistivity to sulphate attack than control concrete and thus found to be more durable.

8) From the test results for strength and durability tests conducted, we can say that phosphogypsum admixed copper slag concrete gives a high strength, durable and good quality concrete.

9) 1m^3 concrete of phosphogypsum admixed copper slag concrete gives a saving of 46.90 kg of cement and 253.41 kg of fine aggregate.

10) From the work conducted it can be concluded that replacing cement with 10% phosphogypsum and replacing fine aggregate with 40% copper slag gives a low cost, workable, high strength and durable concrete.

11) Since phosphogypsum and copper slag are waste materials these are available in very low prices and hence its use in replacement of cement and fine aggregate respectively will lead to a more economical concrete.

12) Using these waste materials in concrete also presents a solution to the disposal of waste materials in the aspect of environment friendliness.

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