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Studies on Impact of Copper Slag as Fine Aggregate Replacement in Concrete Pavement

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Abstract

Indian roads are at present constructed with not the right choice of material. The two major types of materials, bitumen and concrete are used in road construction in the country. A very small segment of roads in the country is made of concrete, though, it is superior on many counts as a medium for road constructed. The use of large amount of by-product materials as powder or fines not only avoids the requirement of landfills but also reduce the environmental problems. It is most essential to develop profitable building materials from used copper slag. The innovative use of used copper slag in concrete formulations as a fine aggregate replacement material was tested as an alternative to traditional concrete. This paper reports on an experimental investigations carried out to evaluate the effects of concrete mix properties prepared with partial replacement of fine aggregates by copper slag at levels of 10%, 20%, 30%, 40%, and 50%. In this study, M30 grade concrete was considered to study the strength parameters, compressive and flexural strength development for concrete curing periods of 3, 14 and 28 days. Strength properties such as Compressive Strength, Split Tensile Strength, Flexural Strength, and workability were evaluated for various mixes of concrete.

1. Introduction

India has done a major leap on developing the infrastructures such as express highways, power projects and industrial structures, dams etc. to meet the requirements of globalization. For the construction of civil engineering works, concrete play main role and a large quantum of concrete is being utilized. Both coarse aggregate and fine aggregate is a major constituent used for making conventional concrete, has become highly expensive and also scarce. In the backdrop, there is large demand for alternative materials from wastes. Concrete roads by themselves offer tremendous advantages over conventional bitumen roads in both operational and financial terms. These advantages are well known. The most salient of these advantages are durability and relative freedom from maintenance which go to offer substantial long term economies in our cash strapped cities. Use of copper slag in various construction engineering applications can solve the environmental problems.

The Tuticorin plant of Sterlite has a capacity of 400,000 tonnes per annum and the company plans to double it with an investment of Rs 2,500 crore. The key raw material for copper smelter is copper concentrate which mainly consists of copper, iron and sulphur. During the smelting operation, iron is removed as iron silicate, which is known commonly known as copper slag (Ferro sand). Copper slag can be used in concrete to improve its strength and other durability factors. Copper slag can be used as a partial replacement of fine aggregates as supplementary replacement to achieve different properties of concrete. This copper slag consumes a large area of local landfill space. Some of the wastes are land spread on cropland, or running off into area lakes and streams. Some industries burn their sludge in incinerators, contributing to our serious air pollution problems. To reduce disposal and pollution problems emanating from these industrial wastes, it is most essential to develop profitable building materials from them. Keeping this in view, investigations were undertaken to produce low cost concrete by blending various ratios of fine aggregate with used copper slag. The study will lead to possible innovative utilization of copper slag in construction of concrete roads apart from its present use in land fill application. The use of waste copper slag, if could be feasible, will not only provide for its better utilization but also will help in conserving the precious natural resource of natural sand.

2. Material Used

A. Cement

Ordinary Portland cement (OPC) is the basic Portland cement and is best suited for use in general concrete construction. It is classified into three grades, namely 33 grade,43 grade and 53 grade depending upon the strength of the cement at 28 days when tested as per IS: 4031-1996-Part II. Ramco Cements 53 grade cement conforming to IS: 12269-1987 was used in the present investigation. The tests performed on this cement are summarized in Table 1

Table 1: Properties of cement

Sl. No.	Properties	
		Results
1.	Normal Consistency (%)	34
2.	**Setting Time (minutes)**	
	i. Initial setting time	55
	ii. Final setting time	235
3.	Specific gravity	3.10

B. Coarse Aggregates

Coarse aggregates are inert particle materials that pass-through the sieve size of 80 mm and retained on sieve size 4.75 mm. In the present study, locally available granite of size 20 mm and 10mm in the proportion 60% and 40% by volume respectively was used. The physical properties of coarse aggregates are given in Table 2.

Table 2: Properties of Coarse Aggregates

Sl. No.	Properties	Results
1.	Abrasion Value, %	24.97
2.	Combined Elongation	28.0
3.	Crushing Value, %	25.36
4.	Specific gravity	2.63
5.	Water Absorption, %	0.45
6.	Impact Value, %	21.10

C. Fine Aggregates

River sand available locally was used as fine aggregate sand they conform to IS: 383-1970 (reaffirmed 1997). Sieve analysis was done using standard sieve analysis procedure and the sand conforms to Zone II. The physical properties and sieve analysis details are given in Table 3 and 4 respectively.

Table 3: Properties of Fine Aggregates

Properties	FA
Specific gravity	2.53
Water absorption,%	0.80
Moisture content, %	0.50
Fineness modulus	2.55
Bulk density, g/cc	16.7
Grading zone	Zone II

Table 4: Sieve Analysis of River Sand

IS Sieve (mm)	Percentage Passing of Sand Sand	Grading for Zone II as
4.75	100.00	90 - 100
2.36	97.10	75 -100
1.18	79.30	55 – 90
0.60	56.70	35 – 59
0.30	9.90	8 – 30
0.15	2.00	0 – 10
0.075	0.20	-
Pan	0.00	-

D. Copper Slag

Copper slag used in the present studies was procured from Sterlite Industries India Limited (SIIL), Tuticorin, TamilNadu, and India. The physical properties of Copper Slag are given in Table 5 respectively.

Table 5: Properties of Copper Slag

Properties	CS
Specific gravity	3.57
Water absorption,%	0.14
Moisture content, %	0.10
Fineness modulus	2.68
Bulk density, g/cc	0.14

E. Water

Water is the most important constituent of a concrete mass which enables bonding between cementations materials and the aggregates and also helps in the hydration of cement which is the most important phenomenon in gaining strength. Potable water which is free from salts and impurities was used for mixing and also curing purposes.

3. Mix Proportions

Control Concrete grade have been chosen as M30. For proportioning of mixes, IRC method of mix design has been followed as per IRC: 44-2008. Concrete mixtures were prepared with different percentage replacement of Copper slag by weight of fine aggregates in proportions of 0% (for control concrete), 10%, 20%, 30%, 40%, and 50%. All the mixes were proportioned by the method of absolute volumes considering the specific gravity of the constituent materials. Mix proportions of all the type of mixes considered in the present studies are given in Table 6.

Table 6: Mix Proportions Details (In kg/m^3) Considered in the present studies

Mix Materials	CC	Mix-1 (10% CS)	Mix-2 (20% CS)	Mix-3 (30% CS)	Mix-4 (40% CS)	Mix-5 (50% CS)
Cement	432	432	432	432	432	432
CA	1168	1168	1168	1168	1168	1168
FA	685	617	548	479	411	343
CS	0	98	197	296	394	493
Water	194	194	194	194	194	194

4. Experimental work

The results of fresh properties of concrete such as slump and compaction factor are determined and hardened properties such as compressive strength, Split Tensile Strength and flexural strength are presented.

A. Rheology of Concrete

Fresh concrete or plastic concrete is a freshly mixed material which can be moulded into any shape. The relative quantities of cement, aggregate and water mixed together to control the properties of concrete in the wet state as well as in the hardened state. Tests adopted for measurement of workability in the present investigation are:

1. Slump test
2. Compaction factor test

Table 7: Measurement of Workability

Mix Designation	Slump (mm)	Compactionfactor
CC	31	0.88
Mix – 1	37	0.88
Mix – 2	48	0.90
Mix – 3	57	0.90
Mix – 4	63	0.92
Mix – 5	73	0.93

B. Compressive Strength

A total number of 60 concrete cube specimens of standard dimension 150x150x150 mm were cast as per mix design and compressive strength test were conducted to evaluate the strength development of concrete mix containing copper slag of different proportions at curing periods of 3, 14 and 28 days in a compressive testing machine, as per IS: 516-1976. The cube compressive test results of various mixes considered in comparisons is given in Table 8.

Table 8: Compressive Strength Test Results

Mix Designation	Avg. Compressive Strength in N/mm^2 at curing period of			Percentage
	3 days	14 days	28 days	Strength Gain at 28 days
CC	16.33	27.45	35.42	-
Mix-1	19.27	30.24	45.71	29.05%
Mix-2	24.21	31.29	47.54	34.22%
Mix-3	25.87	33.18	49.17	38.82%
Mix-4	27.31	36.54	56.21	58.70%
Mix-5	24.12	31.1	50.24	41.84%

C. Split Tensile Strength

Tensile strength is one of the basic and important properties of the concrete. The concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. However, the determination of tensile strength of concrete is necessary to determine the load at which the concrete members crack. The cracking is a form of tension failure. The usefulness of the splitting cube test for assessing the tensile strength of concrete in the laboratory is widely accepted and the usefulness of the above test for control purposes in the field is under investigation. The standard has been prepared with a view to unifying the testing procedure for this type of test for tensile strength of concrete. The load at which splitting of specimen takes place shall then be recorded. The universal testing machine (UTM) having capacity of 100 tonne was used for the splitting tensile strength of the concrete cylinders.

Calculations:

The split tensile strength of the specimen calculated from the following formula

$$\mathbf{Tsp = (2P/\ (\pi dL))}$$

Where,

- P= maximum load in tonne
- L= length of the specimen
- d= diameter of width of the specimen

Table9: Split Tensile Strength Test Results

Mix Designation	Avg. Split tensile strength			Percentage
	3days	14days	28day	Strength Gain at 28days
CC	2.41	2.64	3.82	-
Mix-1	2.46	2.78	4.16	8.90%
Mix-2	2.87	2.89	4.84	26.70%
Mix-3	3.01	3.05	5.24	37.17%
Mix-4	3.28	3.82	6.14	60.73%
Mix-5	2.97	3.02	4.11	7.59%

D. Flexural Strength

To find the flexural strength of concrete, beam specimens of standard dimension 500x100x100 mm were cast with 10%,20%, 30%, 40%, and 50% replacement of fine aggregate by copper slag and for control concrete. The flexural strength of concrete beam specimens were determined using third point loading method. The specimens was loaded and tested in accordance with the ASTM Test Method C78. The flexural strength results of various mixes considered in comparisons is given in Table 9.

Table 10: Flexural Strength Test Results

Mix Designation	Avg. Flexural Strength in N/mm2 at Curing Period of			Percentage
	3days	14days	28day	Strength Gain at 28days
CC	4.21	6.12	8.04	-
Mix-1	4.24	6.74	8.89	10.57%
Mix-2	5.46	6.92	9.76	21.39%
Mix-3	5.81	7.04	10.57	31.47%
Mix-4	6.22	7.23	11.14	38.56%
Mix-5	5.02	6.94	9.21	14.55%

5. Results and Discussion

A. Workability

Slump values ranges from 31 mm to 73 mm and compaction factor ranges from 0.88 to 0.92. Mix-5 of 50% copper slag replacement yielded maximum slump values of 73 mm which shows good workability than the other mixes as shown in fig1 and 2.

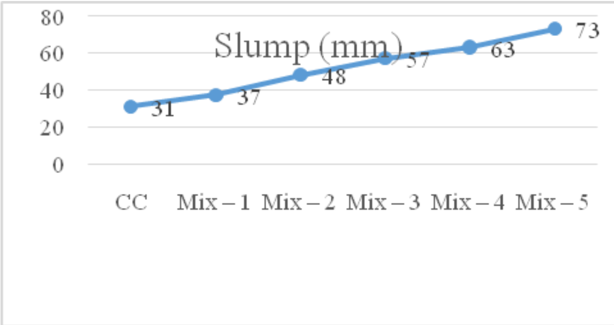

Fig. 1 Slump at values for different mixes

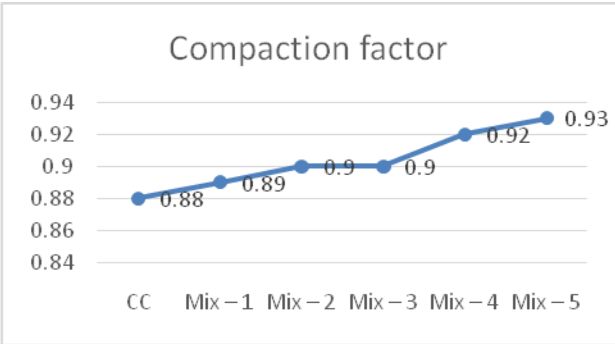

Fig. 2Compaction factor values for different mixes

B. **Strength**

The test results indicated that all mixtures yielded comparable or higher compressive, split Tensile Strength and flexural strengths than the control mixture for all curing periods. Furthermore, as copper slag content increases the compressive, split Tensile Strength and flexural strength increases up to 40% replacement. Beyond that, the strength decreased with an increase in copper slag content. The reduction in compressive strength for concrete mixtures with higher copper slag content may be 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 with a reduction in cohesion. Mix-4 specimens yielded the highest average 28days compressive strength of 56.21 N/mm2, almost 58.70%higher compared with 35.42 N/mm2 for the control mix. An increase of 54% of compressive strength was obtained at28 days for Mix-4 specimens, compared to 14 days strength. But for control specimens, the increase in strength was only

33% compared to 14 days strength. Split tensile strength also Mix-4 specimens yielded the highest average 28 days split tensile strength of6.14 N/mm2, almost 60.73% higher compared with 3.82N/mm2 for the control mix. An increase of 60.73% of split tensile strength was obtained at 28 days for Mix-4 specimens, compared to 14 days strength. But for control specimens, the increase in strength was only 44.69% compared to 14 days strength. Also Mix-4 specimens yielded the highest average 28 days flexural strength of11.14 N/mm2, almost 38.56% higher compared with 8.04N/mm2 for the control mix. An increase of 54% of flexural strength was obtained at 28 days for Mix-4 specimens, compared to 14 days strength. But for control specimens, the increase in strength was only 18.12% compared to 14 days strength.

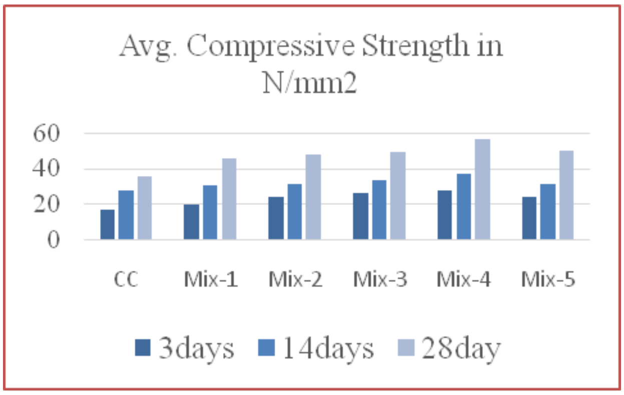

Fig. 3 Comparison of compressive strength of various mixes

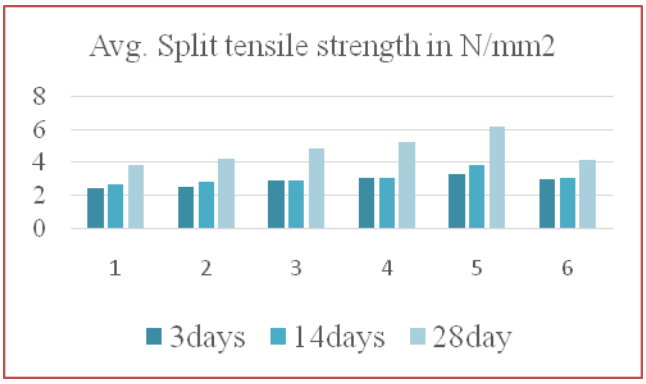

Fig.4 Comparison of Split tensile strength of various mixes

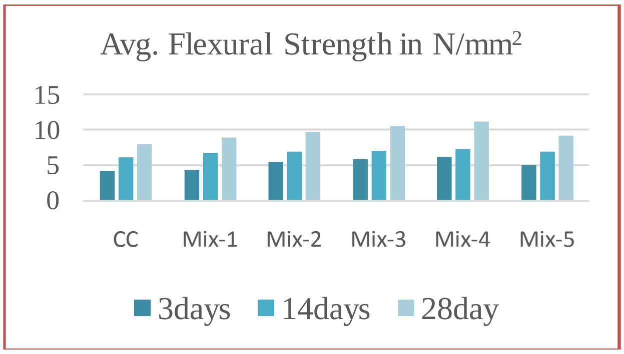

Fig.5 Comparison of Flexural strength of various mixes

6. Conclusion

Based on the experimental investigation

- ✓ Copper slag is best suited for replacement of fine aggregate in concrete pavement.
- ✓ The workability of concrete with copper slag is better than the concrete pavement.
- ✓ The Compressive strength , Split tensile strength and Flexural strength of concrete with copper slag shows increasing bind up to 40% of replacement of fine aggregate, beyond that the strength gets decreased.
- ✓ Using of copper slag in concrete pavement is one of the best method of disposal of copper slag.

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