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PARTIAL REPLACEMENT OF FINE AGGREGATE IN CONCRETE BY USE OF COOPER SLAG

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***Abstract*—Copper slag is an industrial by-product generated during extraction and refining of copper metal from copper ore. Presently there are limited uses of copper slag and unused quantity is dumped unattended in the landfills, which create pollution in the environment. Particle size analysis of copper slag shows that it can be a substitute for fine aggregate in the concrete during construction of rigid pavements. The principal objective of this research is to assess the possibility of using copper slag in the construction of rigid pavements.**

The cement concrete so investigated can be utilized as the wearing course of rigid pavements on the low volume roads. Also concrete containing copper slag can be utilized for flooring of causeway, construction of median strip etc. Bulk utilization of copper slag in the rigid pavements can reduce the cost of construction. It might be a step towards sustainable construction of green highways.

***Keywords*— Rice husk ash, Admixture, Concrete properties**

1. INTRODUCTION

Rapid industrialization has result the production of huge quantity of industrial by- products. In India over the last three decades, metal industries had been developed with a great pace. There are various copper smelting industries which generate copper slag (CS) during extraction and refining of copper metal from its ore or concentrates. The slag thus produced is being dumped in the landfills. Presently there are very limited uses of CS and unused part is being dumped unattended in the landfills. Due to large production rate of different wastes and limited utilization, the stockpiling is increasing day by day. If stockpiling is continued indefinitely, it may cause serious threat to the environment and future generation. Hence there is immediate need to make bulk utilization of these wastes to ensure sustainable industrialization.

The earlier studies conducted on the utilization of various waste materials are as given in this section. A study conducted by Khatib and Hibbert[1] had shown the effect of Ground Granulated Blast furnace Slag (GGBS) and Meta-Kaolin (MK) on the strength of concrete by the partial replacement of Portland cement.The Portland cement was partially replaced with 0-80% by GGBS and 0-20% by MK. The compressive strength and dynamic modulus of elasticity (E_d) was observed to increase by the addition of Meta-Kaolin up to 20 % in early ages of hydration; however the compressive strength and dynamic modulus of elasticity (E_d) gets increased by the replacement of Portland cement by GGBS up to 60% in long term hydration. The flexural strength values was optimized with 60% GGBS and 20% MK.
Investigation carried out by Zelic, J.[2] had shown the ferro-chromium slag can be used as aggregate in concrete pavements. The 28 days compressive strength of M-35 concrete was increased to 57 MPa as control mix gives only 36.7 MPa. Due to various properties like volume stability, high volume mass, good abrasion resistance to wear make this slag suitable for wearing course of concrete pavements.

Taha et al.[3]conducted a study by the addition of fly ash and copper slag as a Controlled Low Strength Material (CLSM). Cubical and cylindrical specimens were prepared and cured at room temperature. Results indicated that with a good mix design, it was possible to produce a CLSM with good mechanical properties to meet desired requirements. The author studied the potential use of Cement By Pass Dust (CPBD), incinerator ash and copper slag as a CLSM. Mixtures were designed to produce a CLSM with low compressive strength (less than 1034 KPa) that can be excavated without using any mechanical equipment.

Hence there is an urgent need to carry out detailed study for the mass utilization of copper slag in the concrete so that natural resources can be preserved. The huge quantity of copper slag available prompted author to conduct the present study.

Copper slag is generated during extraction and refining of copper metal from its ore or concentrate. Presently in India only 10 to 20% of its production is being utilized in various purposes such as in the manufacture of cement, in the manufacture of ready mix concrete, as abrasive material in shot blasting and as embankment material in the construction of roads The remaining part is dumped unattended in the landfills. If stockpiling is continued then it might be a threat to the future generation. Therefore in the present study, fine aggregates are replaced by copper slag in different proportions in the concrete.

The prime objective of the research is to study the possible application of copper slag in cement concrete for utilization in various components of low volume road construction. In more detail; the objectives of this dissertation are as follows:

- To study the characterization of copper slag in order to contribute to a better knowledge of its properties.
- To investigate the potential use of copper slag as fine aggregate in cement concrete by partial replacement of sand.

2. METHODOLOGY

In the present study, grade of concrete mix M-25 was selected which are most commonly used in the rigid pavements. The materials such as copper slag, coarse aggregates, fine aggregates and cement were tested as per relevant Indian standards. Copper slag which was procured from Birla Copper plant was investigated for various physical properties such as gradation, specific gravity and water absorption. The physical properties of coarse and fine aggregates such as gradation, specific gravity and water absorption were determined in the laboratory. The normal consistency, initial setting time and final setting time tests for cement were carried out as per relevant Indian standard. The mix design as per IS : 10262- 2009 for concrete of grade M-25 was done by using conventional materials for a design slump of 100 - 125 mm. After that fine aggregates were replaced by copper slag with 10, 20, 30 and 40%, by weight of aggregates in the both mixes. The compressive strength at 7 days and 28 days were determined in the laboratory. The beam specimens were prepared and flexural strength at 28 days was determined for all the mixes as per relevant Indian standards (IS). Hence, total ten concrete mixes as shown in Table 2.1 were prepared and tested.

Table 2.1 Details of Concrete Mixes Prepared

Grade of Concrete	Variation in Copper Slag (% weight of fine aggregates)	Number of Mixes
M-25	0, 10, 20, 30 and 40	5

2.1 Material for Experimental Investigation

(a) Copper Slag: It was procured from Birla Copper (Hindalco Industries Ltd.), Dahej (Gujrat).
(b) Coarse Aggregates: Well graded coarse aggregates (20 mm and 10 mm) were procured from local crusher situated at Gunawata,Jaipur.
(c) Fine Aggregate (river sand): It was procured from Banas River, Tonk.
(d) Cement : Ordinary Portland Cement of 43 Grade (Shree Cement) was procured.
(e) Chemical Admixture: Naphthalene Formaldehyde and PCE Mix base (SHALIPLAST HPRA CS-2)

2.1.1 Copper Slag

The copper slag used in this research was procured from Birla copper, a unit of Hindalco industries situated at Dahej in Gujarat state. The particles of copper slag are angular with sharpe edges as shown in Figure 3.1.The specific gravity and water absorption of copper slag particles are 3.52 and 0.33% respectively as shown in Table 2.2. The gradation of copper slag and fine aggregates are shown in Table 2.3.

Figure 2.1 Copper Slag Particles

Table 2.2 Properties of Copper Slag

Property Test	Copper Slag
Sp. Gravity	3.52
Water Absorption	0.33 %

Table 2.3 The Gradation of Copper Slag and Fine Particles

S.No.	Sieve Size (mm)	% Passing	
		Fine Aggregates (River Sand)	Copper Slag
1	10.0	100.00	100.00
2	4.75	98.60	100.00
3	2.36	96.00	97.80
4	1.18	88.40	74.00
5	0.600	38.70	15.60
6	0.300	9.35	3.50
7	0.150	1.00	0.00

Sieve analysis results showed that the fine aggregates are well graded material, where as major fraction of copper slag lies between 600 micron and 2.36 mm size. In this study fine aggregates were replaced by copper slag in different proportion by weight of aggregates.

Chemical Composition of Copper Slag

The percentage range of various elements/ compounds by weight in copper slag as per chemical analysis report obtained from Birla Copper is given in Table 3.4. The copper slag generated by pyrometallurgical process dose not feature under this category of hazardous waste as per shedule I of Hazardous Wastes (Management, Handling and Transboundry Movement) Rules, 2008 issued by the Ministry of Environment and Forests (MOEF), India.

Table 2.4 Chemical Analysis of Copper Slag (Source: Birla Copper)

S. No	Element/ Compound	Percentage Range
1	Cu	0.60-0.70
2	Fe	42-48
3	SiO_2	26-30
4	Al_2O_3	1.0-3.0
5	S	0.2-0.3
6	CaO	1.0-2.0
7	MgO	0.8-1.5
8	Fe_3O_4	1.0-2.0
9	As	0.02-0.05
10	Pb	0.06-0.08

11	CO	0.01-0.03
12	Cr	0.02-0.04
13	Zn	0.2-0.4
14	Ni	0.005-0.008
15	Chloride	0.001-0.002
16	pH Value	7.0-7.5

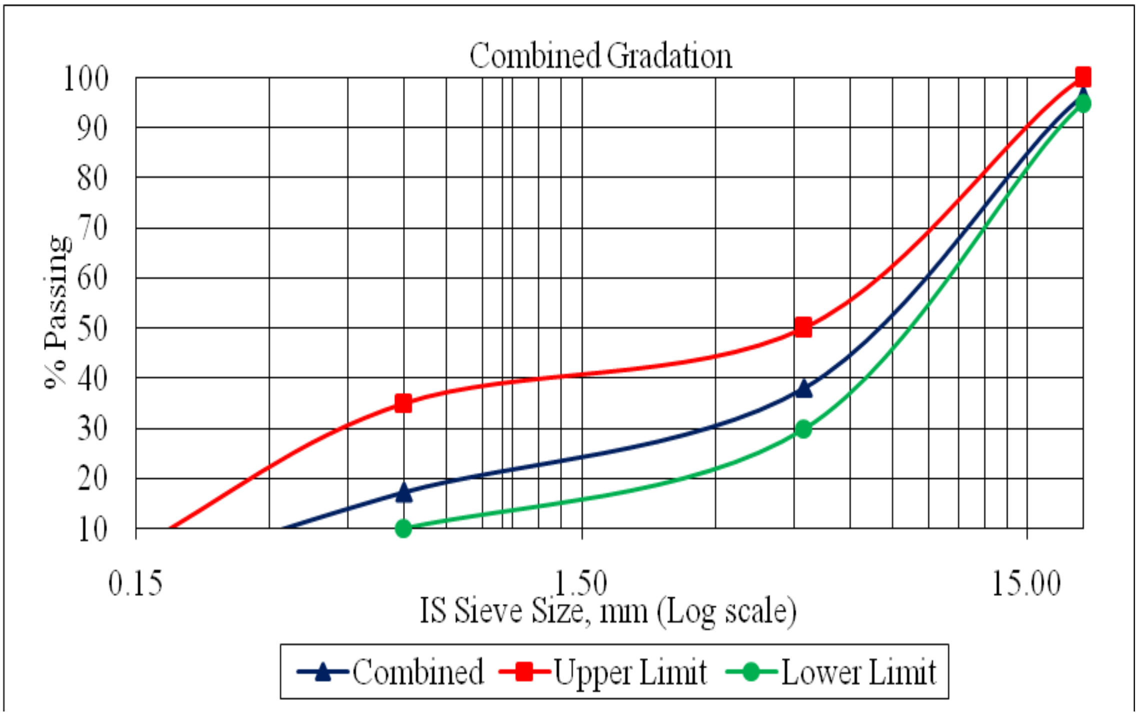
2.2 Mix Design of Concrete

The objective of concrete mix design is to arrive at the most economical and practical combinations of different ingradients that will satisfy the performance requirements under specified condition of use. The various steps involved in the design of concrete mix as per IS: 10262-2009 are as follows:

- To determine the target mean strength (f_m=f_{ck}+1.65*S) where 'f_m' is target mean strength, 'f_{ck}' is charesterstic strength and 'S' is standard deviation.
- To determine the water cement ratio as per Table 5 of IS:456-2000
- To determine the maximum water content for design slump and corresponding to nominal maximum size of aggregate
- To reduce the quantity of water by using superplasticizer (Chemical Admixture)
- To determine the maximum cement content and check as per Table 5 of IS: 456-2000.
- To fix the proportion of coarse aggregates and fine aggregates
- Proportioning of CA and FA to get the desired gradation
- To find the volume of different ingredients
- To convert the volume of aggregates in weight
- To apply moisture correction and water absorption correction to CA and FA
- To calculate final quantity of mix proportion of Cement, CA, FA and Admixture and Water

Table 2.5 Combined Aggregate Gradation

Sieve Size (mm)	% Passing						Combined Gradation	Specification Limits as per IS:383-1970	
	Coarse Aggregates (20 mm size)		Coarse Aggregates (10 mm size)		Fine Aggregates			Lower Limit	Upper Limit
	100%	36.00%	100%	24.00%	100%	40%	100%		
40	100	36.00	100	24.00	100	40.00	100.00	100.00	100.00
20	89.23	32.12	100	24.00	100	40.00	96.12	95.00	100.00
4.75	0.62	0.22	12.80	3.07	98.60	39.44	42.73	30.00	50.00
0.60	0.00	0.00	0.00	0.00	38.70	15.48	15.48	10.00	35.00
0.15	0.00	0.00	0.00	0.00	1.00	0.40	0.40	0.00	6.00



Combined Aggregates Gradation

Table 2.6 Fine Aggregates blended Mix Proportion (M-25 Grade of Concrete)

Mix Name	Cement (kg)	Coarse Aggregates		FA (Fine Aggregates) (kg)	CS (C0pper Slag) (kg)	Water (kg)
		20 mm (kg)	10 mm (kg)			
FA+CS (100+0)	350	683.15	448.59	745.38	0.00	185.42
FA+CS (90+10)	350	683.15	448.59	670.84	74.54	185.42
FA+CS (80+20)	350	683.15	448.59	596.3	149.08	185.42
FA+CS (70+30)	350	683.15	448.59	521.76	223.62	185.42
FA+CS (60+40)	350	683.15	448.59	447.22	298.16	185.42

2.3 Test on Concrete

2.3.1 Compressive Strength Test

This test method is used to determine the compressive strength of concrete as per IS code. The compressive strength depends on the size and shape of the specimen, batching, mixing procedures, the methods of sampling, molding, fabrication, age of cubes, temperature, and moisture conditions during curing. Concrete cube specimens of size 150 mm as per mix proportions were casted. After testing for slump, the fresh concrete mix was placed in three layers in the mould. The compaction of concrete was done by using laboratory table vibrator for not more than for 30 seconds. The casted concrerte cubes were numbered for identification. Six specimen were prepared for every mixes.The specimens were demoulded after 24 hrs., cured in water and then tested for 7 days and 28 days at room temperature. The cube is taken out from curing tank and clean & wipe the surface of specimen with dry cotton cloth. Then the specimen is put on compressive strength testing machine in that way rough surface of side cube should be placed. Then the load is applied to the cube. The rate of loading on cube is 140kg/cm^2/min. Digital compressive testing machine of 100 ton capacity was used for compressive strength test.Three specimen were tested after curing in chamber for 7 days and remaining three specimen were tested after 28 days as per IS:516-1959 standard code for methods of tests for strength of concrete

2.3.2 Flexural Strength

This test method is used to determine the flexural strength of concrete as per IS Code. The flexural strength depends on the size and shape of the specimen, batching, mixing procedures, the methods of sampling, molding, fabrication, age of cubes, temperature, and moisture conditions during curing. The Flexural strength of every mix wasdeterminedfor beam of size 700 mm x 150 mm x 150 mm.Three specimenswere castedfor each mix and they were cured in chamber for 28 days. The beam is taken out from curing tank and clean & wipe the surface of specimen with dry cotton cloth. They were tested as per IS:516-1959 standard code for methods of tests for strength of concrete. Then the specimen is put on the supporting rollers horizontally. Than the load is applied to the beam by loading rollers. The load is applied @ 400kg/min. Digital universal testing machine of 100 ton capacity was used for flexure strength test. The central point loading method was used in testing.

3. RESULTS AND DISCUSSIONS

The design of concrete mix of grade M-25 was carried out as per IS: 10262-2009 by using conventional aggregatess. The fine aggregates was replaced by copper slag from 10% to 40%, by weight in grade of concrete.

3.1 Test Result on Fresh Concrete

The test results conducted on fresh concrete are presented as below:

3.1.1 Workability (Slump Test Results)

the grade of concrete mixes were desinged for slump of (100 mm ± 10mm). In the present study chemical admixture SHALIPLAST HPRA CS-2 of SHALIMAR make was used by weight of cement.The design slump of M-25 control mix was 110 mm.

The increase trend in slump by increasing the quantity of copper slag might be due to less absorption by copper slag particles (0.33%) as compared to natural fine aggregates (1.10%). Due to which more free water is available and hence the slump value increases of the blended mixes.

Table 3.1 Slump Results on M-25 Grade of Concrete

S.No	Mix (F.A.+CS) (%)	Slump (mm)
1.	100+0	110
2.	90+10	120
3.	80+20	130
4.	70+30	142
5.	60+40	160

3.2 Test Results on Hardened Concrete

3.2.1 Compressive Strength

The compressive strength test results for M-25 at the age of 7 days and 28 days are presented in Table 4.2.The 7 days and 28 days compressive strength results for M-25 grade of concrete is also presented graphically by Figure 4.1 The compressive strength at 7 days of M-25 increases up to 20 % addition of copper slag and then started decreasing as shown by Figure 4.1. The compressive strength at 28 days of M-25 also increases up to 20% replacement of fine aggregates by copper slag and beyond that decreases as presented by Figure 4.1.

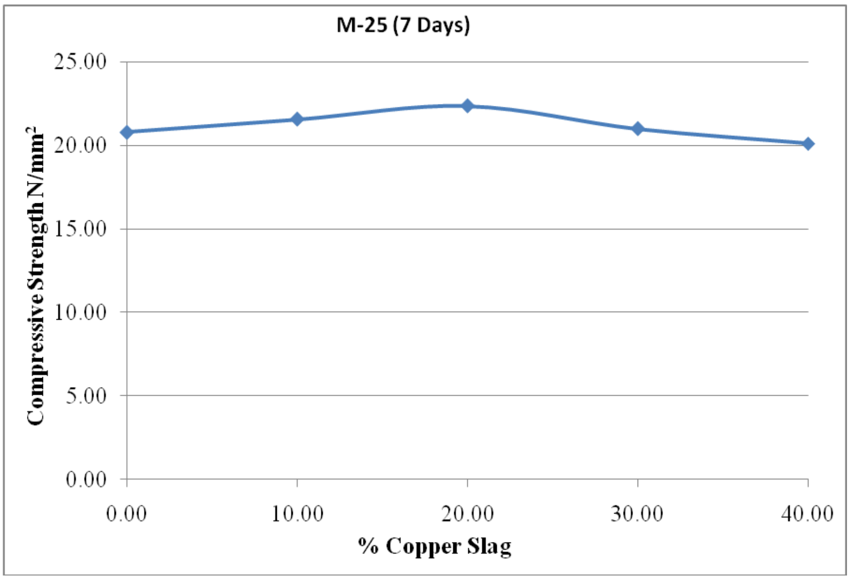


Figure 3.1 Compressive Strength (7 Days) v/s. % of Copper Slag of M-25 Grade Concrete

Table 3.2 Compressive Strength at 7 Days of M-25 Grade Concrete

F.A.+C.S. (%)	Compressive Strength	
	(N/mm^2)	% Change
100+0	20.79	-
90+10	21.56	+3.70
80+20	22.37	+7.59
70+30	21.01	+1.05
60+40	20.11	-3.27

Table 3.3 Compressive Strength at 28 Days of M-25 Grade Concrete

F.A.+C.S (%)	Compressive Strength	
	(N/mm^2)	% Change
100+0	31.92	-
90+10	32.51	+1.84
80+20	33.56	+5.13
70+30	28.71	-10.05
60+40	25.52	-20.05

3.2.2 Flexural Strength

The Flexural Strength of hardened concrete at the age of 28 days for M-25 is shown in Table 3.4 along with graph in Figure 3.2

Table 3.4 Flexural Strength at 28 Days of M-25 Grade Concrete

F.A. + C.S (%)	Flexural Strength	
	(N/mm^2)	% Change
100+0	3.68	-
90+10	4.11	+11.68
80+20	4.24	+15.21
70+30	3.84	+4.34
60+40	3.42	-7.06

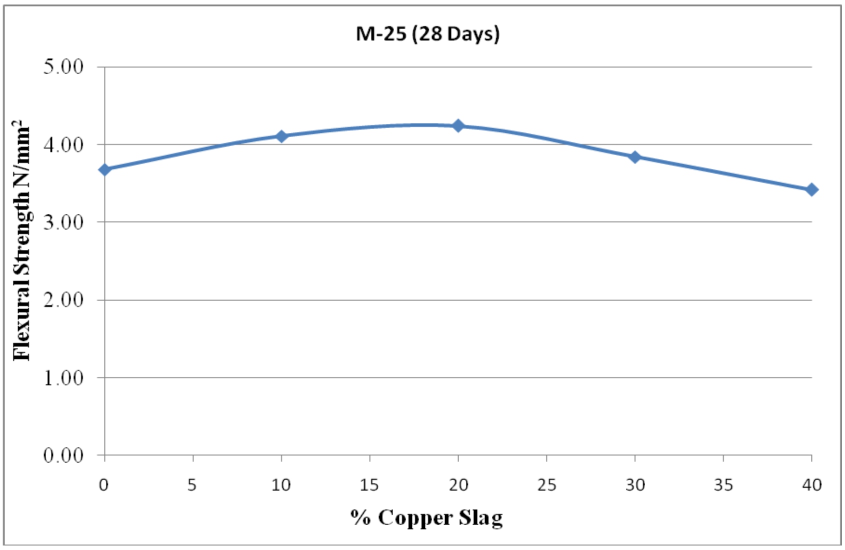


Figure 3.2 Flexural Strength (28 Days) v/s. % of Copper Slag of M-25 Grade Concrete

3.2.3 Density

The density of hardened concrete specimens with different percentage of replacement of fine aggregates by copper slag in M-25 and M-30 with respect to controlled mix is shown in Table 4.5 The density has increasing trend as the quantity of copper slag increases in M-25 shown by Figure 4.3.The density might be increased due to higher specific graviety of copper slag (3.52) as compared to natural fine aggregates (2.62).

Table 3.5 Effect of % Copper Slag on Density of Hardened Concrete of M-25 Grade

F.A. + C.S (%)	Average Density (Kg/ m^3) (7Days)	Average Density (Kg/ m^3) (28Days)
100+0	2531.95	2539.06
90+10	2540.25	2548.05
80+20	2543.01	2551.11
70+30	2553.98	2565.04
60+40	2563.06	2575.11

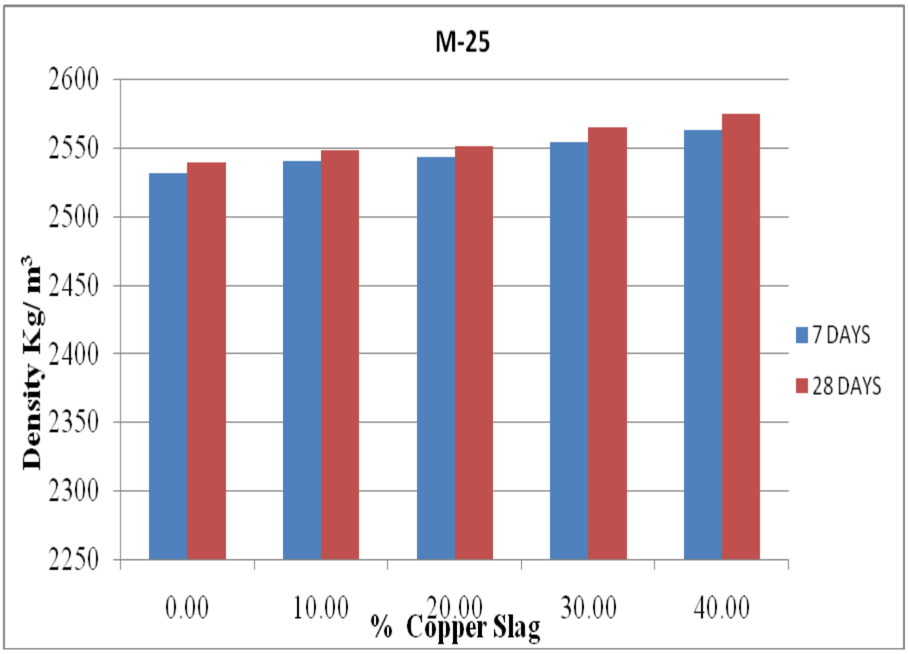


Figure 3.3 Density (7 Days and 28 Days) v/s. % of Copper Slag in M-25 Grade Concrete

4 .CONCLUSIONS

The present study documents the findings of an experimental research on the characterization and its utilization of copper slag by the partial replacement of fine aggregates in the concrete which can be utilized in the rigid pavement for low traffic roads near copper production industries. The bulk utilization of copper slag may lead to less utilization of natural resources of river sand. On the basis of experimental study, it has been observed that copper slag is one of the most suitable waste materials which can be utilized as partial replacement of fine aggregates in the concrete. The research work can be concluded in following points as follows:

1. The technical feasibility for utilization of copper slag in M-25 grade of concrete has been carried out. The experimental results revealed that copper slag has potential for being utilized in the concrete as partial substitution of fine aggregates.
2. Copper slag particles used in this study was in the size range of passing 2.36 mm sieve and retained on 600 micron sieve. The natural fine aggregates also having particle size distribution almost in the same range. Hence copper slag particles can be directly used in the production of concrete for its practical utilization.
3. The slump values of copper slag blended concrete increased for all replacement level i.e. from 10% to 40% in M-25 mix
4. The compressive strength of M-25 grade of concrete increased up to 20% replacement of fine aggregates by copper slag and beyond that started decreasing.
5. The flexural strength test results also showed increment with 10% and 20% copper slag in M-25 concrete as compared to control mix. The flexural strength got decreased with 30% and 40% replacement of fine aggregates by copper slag.
6. Bulk utilization of copper slag in the rigid pavements can reduce the cost of construction. Also it will solve the disposal problem of industries.

On the basis of above results, it was concluded that copper slag in M-25 grade of concrete can be utilized in the tune of 20% by replacing the fine aggregates within a radius of 50 kilometers of copper smelters. It might be a step towards sustainable construction of green highways.

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