ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 11, March 2017

Experimental Investigation of High Strength Concrete Using Copper slag as Fine aggregate and Metakaolin as Cement Replacement

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***Abstract*—A High Strength Concrete is something which demands much higher Strength as compared to routing concrete. Use of chemical admixtures reduces the water content, thereby reducing the porosity within the hydrated cement paste. Mineral admixtures act as pozzolanic materials as well as fine fillers, thereby the microstructure of hardened cement matrix becomes denser and stronger. Copper slag is a byproduct obtained during the matte smelting and refining of copper. Copperslag possesses mechanical and chemical characteristics that qualify the material to be used in concrete as partial replacement for aggregates.This study investigated the mechanical properties of high strength concrete incorporating copper slag as a fine aggregate and metakaolin as cement replacement. The workability and strength characteristics were assessed through series of tests on five different mixing proportions 25% incremental copper slag by weight replacement of sand from 0% to 100% and 5%,10%,15% of metakaolin replacement in cement.**

***Key Words*—High Strength Concrete;Copper slag and Metakaolin**

I. INTRODUCTION

A. GENERAL

Concrete with slag materials generally refers to concrete that achieve improvements such as strength, high workability, and high durability while having low density. Waste management is one of the most complex and challenging problem in the world which is affecting the environment. The rapid growth of industrialization gave birth to numerous kinds of waste by products which are environmentally hazard and creates problems of storage. Therefore, there is an urgent need to find and utilize alternative material for aggregates by utilizing the waste materials and by-products with little or no property modification which leads to a sustainable and greener environment along with the technical advantages .Concrete prepared with such materials showed improvement in workability and durability compared to normal concrete and has been used in the construction of power and chemical plants and under-water structures. Artificially manufactured aggregates and artificial aggregates generated from industrial wastes provide an alternative for the construction industry.

B. COPPER SLAG

Copper slag is a by-product obtained during the matte smelting and refining of copper. Major constituents of a smelting charge are sulphides and oxides of iron and copper. The charge also contains oxides such as Al_2O_3 CaO, MgO, and principally SiO_2 which are either present in the original concentrate or added as flux. As a result of this process, copper-rich matte (sulphides) and copper slag (oxides) are formed as two separate liquid phases. The molten slag is discharged from the furnace at 1000–1300 _C. When liquid slag is cooled slowly, it forms a dense, hard crystalline product where as quick solidification by pouring molten slag into water gives amorphous granulated slag. To produce every ton of copper, approximately 2.2–3 tons copper slag is generated as a by-product material. A partial replacement of cement by mineral admixtures, such as, fly ash, ground granulated blast furnace slag (GGBS), silica fume, metakaolin, rice husk ash or fillers such as limestone powders in concrete mixes would help to overcome these problems and lead to improvement in the durability of concrete. [14] analyzed microwave waveguides and components such as microwave T junctions , circulators, attenuators and Isolators.

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C. CONCEPT IN THE DESIGN OF HSC

Inordertoachievehigh strength,thevariousimportantfactorsthatgovernthestrengthofconcretearetobeunderstood.

- Thepropertiesofthecementpaste
- Thepropertiesofcopper slag andaggregate
- Thevariouschemicalandmineraladmixturesthataretobeused
- Therelativeproportionsoftheconstituentmaterialstobeused
- Mixing,CompactionandCuring

D. POPULARISING THE DESIGN OF STRUCTURES USING COPPER SLAG

Theuse of copper slag - a waste industrial by-product provide great opportunity to utilize it as an alternative to normal aggregates to determine the structural behaviour includes flexural behaviour, load-deflection characteristics and cracking behaviour. The effect of partial replacement of natural fine aggregates as copper slag on fresh and hardened concrete are also to be studied

II. EXPERIMENTAL INVESTIGATION

A. GENERAL

ThedevelopmentofHighStrengthConcreteisbasedonthefollowingwellknownrelationshipsofconcretetechnology,forhighstrength,water-cementratioshouldbelow.Loww/cratiowillrequirehighcementcontenttoensurethattheamountsofwaterandcementpasteareadequatefortheworkabilityofconcrete.However,toohighacementcontentwillcausehighheatofhydrationandincreasecrackingtendency.Hence,partofthecementistobereplacedbyothercementitiousmaterialslikesilicafume, Metakaolin, flyashorcombinationsthereof.

Table 3.1 Properties of Cement

S.No	Properties	value
	Fineness	4%
	Specific gravity	3.14
	Standard consistency	32%
	Initial setting time	35 mins
	Final setting time	280 mins

B. MATERIALS REQUIRED FOR HSC

Cement

AhighqualitybinderisnecessaryforHighStrengthConcrete.Theuseoffinecementitiousmaterial,suchasMetakaolin,isuseful asthefineparticlesgradingwouldbeextended;whichwouldresultingoodfilleractionandreducedporosity.Furthermore,thePozzolanicreactionwith Portlandcement wouldfurtherstrengthenthecementmatrixandimprovethebondstrengthbetweenaggregatesandthematrix.Sincethecementcontentofhigh strengthconcreteisunavoidablyhigh,theheatofhydrationresultingfromtheexothermicreactionofcementwithwaterishigh.

Coarse Aggregate

Coarseaggregateformsthelargestfractionofvolumeofconcretethecharacteristicsofaggregatessignificantlyinfluencethestrengthofconcrete.Thesizeof coarseaggregateplaysanimportantroleindeterminingthestrengthofconcrete.Innormalstrengthconcrete,assizeofcoarseaggregateisincreased,thewaterrequirementisreduced.Sotheneteffectisgaininstrength.ButinHighStrengthConcrete,largesizeofcoarseaggregatetendstoreducethestrength. Itmaybeattributedtosmallersurfaceareaavailableforbond.

Fine Aggregate

Theshapeandsurfacetextureoffineaggregatehasagreaterinfluenceonwaterdemandofconcretethanbecausefineaggregatescontainamuchhighersurfaceareaforagivenweight. Roundedandsmoothfineaggregateparticlesarebetterfromtheviewpointofworkabilitythansharpandroughparticles.

Copper slag

The copper slag is a black glassy particle and granular in nature and has a similar particle size range like sand. The bulk density of granulated copper slag is varying from 1.9 to 2.15 g/cc. The free moisture content present in the copper slag was found to be less than 0.5%

Table 3.2Properties of copper slag

Appearance	Black glassy
Bulk density	2.08g/cc
Specific Gravity	3.37
Percentage of voids	43.20%

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Mineral Admixtures

Theseadmixturesaregenerallynaturalorbyproductmaterials. Theseadmixturesgenerallyincludeflyash,metakaolin,and groundgranulatedblastfurnaceslag.Metakaolin is white, amorphous, highly reactive aluminium silicate pozzolan forming stabile hydrates after mixing with lime stone in water and providing mortar with hydraulic properties Heating up of clay with kaolinite $Al2O3.2SiO2.2H2O$ as the basic mineral component to the temperature of 500 °C - 600°C causes loss of structural water with the result of deformation of crystalline structure of kaolinite and formation of an unhydrated reactive form metakaolinite.

Table 3.3Chemical Composition of Metakaolin

OXIDES	VALUE
SiO_2	51.33
Al_2O_3	42-44
Fe_2O_3	<2.20
CaO	0.5
MgO	0.2
K_2O	0.05
Na_2O	0.1

Super plasticizer

In order to improve the workability of high-strength concrete, superplasticizer in the form of a polynaphthalene sulphonatebased admixture (conplast SP430) was used. This had 40% active solids in solution.

C. PRELIMINARY INVESTIGATIONS

Preliminary investigations deal with the study and testing of various materials before using them in experiment.

Fineness Test on Fine Aggregate

1kg of dry sand is taken. The sieves are arranged in the order. Now, the aggregate is transferred to the top sieves.The whole arrangement is kept in the mechanical sieve shaker and sieved for 15min.The aggregate retained in each sieve is weighted and noted down.

Fineness Modulus = Total cumulative % retained / 100

Table 3.5 Fineness Modulus of Fine Aggregate

SIZE (mm)	WEIGHT OF RESIDUE (kg)	WEIGHT RETAIN	CUMULATIVE % WEIGHT RETAINED (X)	(100-X)
4.75	0.020	2.00	2	98
2.36	0.104	10.40	12.4	87.6
1.18	0.248	24.80	37.2	62.8
0.60	0.140	14.00	51.2	48.8
0.30	0.356	35.60	86.8	13.2
0.15	0.132	13.2	100	0
Total			289.6	

Fineness modulus of fine aggregate = 3

Specific Gravity Test on Fine Aggregate

The Pycnometer bottle is cleaned, dried and weighed along with the stopper. It is fully filled with fresh water. The aggregate sample is filled up to 1/3rd aggregate filled with distilled water to fill the remaining space and weighed. The mean value of the sample is taken a specific gravity of the aggregate sample.

Specific gravity of Fine Aggregate= $\frac{w2 - w1}{(w2 - w1) - (w3 - w4)}$

Where,

W_1- Weight of empty pycnometer in gm.

W_2- Weight of pycnometer + sand in gm.

W_3- Weight of pycnometer + sand + water in gm.

W_4- Weight of pycnometer + water in gm.

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Table 3.6Specific Gravity of Fine Aggregate

TRIAL	W_1 (kg)	W_2 (kg)	W_3 (kg)	W_4 (kg)	SPECIFIC GRAVITY
1.	0.635	1.071	1.924	1.649	2.631
2.	0.638	1.069	1.922	1.658	2.648

Specific Gravity of Fine Aggregate = 2.64

Water Absorption Test on Fine Aggregate

Take 1000 g of F.A (w_1g). The sample is filled with water and kept for 24 hours. After 24 hours immersion, the sample is taken out and dried in air for getting the saturated surface dry condition (SSD).Then it is weighed (w2).

Wt of sample taken (w1) =1000g
Wt of sample in SSD state (w2) =1010g
Water absorption ={(w1-w2)/w1)} x100
Water absorption =1%

Specific Gravity Test on Copper slag

Specific gravity ofCopper slag can be calculated by using the formula

$$\text{Specific gravity} = \frac{(w_2-w_1)}{(w_2-w_1)-(w_3-w_4)}$$

Table 3.9 Specific gravity of copper slag

S. NO	DESCRIPTION	WEIGHT (in gms)
1	Empty weight of pycnometer – W1	61
2	Weight of pycnometer with copper slag– W2	141
3	Weight of pycnometer with copper slag and full of kerosene – W3	210
4	Weight of pycnometer with full of kerosene – W4	153

Specific gravity of Silica Fume = 3.37

MIX PROPORTIONS

The concrete used in this study was proportioned to attain strength of 50 MPa.It is designed as per IS 10262:2009 code specification.

Cement : 562.78 kg/m3

Water : 185 kg/m3

Fine aggregate : 350 kg/m3

Coarse aggregate : 1310 kg/m3

Chemical admixture : 4 lit/m3

Water-cement ratio : 0.33

Mix proportion is 1:0.62:2.33

Table 3.10 Mix Proportion Details

Mix	Mix Proportions
HSC without copper slag	Cement + Fine aggregate + Coarse aggregate + Water + 0.8%conplast430
HSC with copper slag	Cement+Water+FineAggregate(100,75,50,25,0%)+CoarseAggregate+ copper slag(0,25,50,75,100%) + 0.8%Conplast430
HSC with copper slag and metakaolin	Cement(95,90,85%)+Water+FineAggregate(100,75,50,25,0%)+ CoarseAggregate+copperslag(0,25,50,75,100%) +0.8%Conplast43+metakaolin(5,10,15%)

III. EXPERIMENTAL WORKS AND PROCEDURE

The experimental works consist of casting, curing and testing of cube.

Nine cubes (100 mm x100 mm x100 mm), were cast for each mix to determine the compressive strength,

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three samples were tested for compressive strengths of concretes at 7, 14, and 28 days. six cylinders (100 mm x 200 mm) were prepared for each mix to determine splitting tensile strength of concrete at 7 and 28 days. Based on the test results of compressive and tensile strength, 100mm × 150mm × 1200mm size beam specimens were cast for optimum mix proportion obtained for M50 grade of concrete. Concrete were placed in curing tank till their testing ages.

A. COMPRESSIVE STRENGTH TEST

The compressive strength test is the most common test conducted because most of the desirable characteristic properties of concrete and the structural design purpose are qualitatively related to compressive strength.The test was conducted in compression testing machine of 3000kN capacity for different ages of concrete 7 and 28 days as per the specificationsgiven in IS 516: 1959 under normal room temperature.Compressive strength = Load in N / Area in mm^2

Mix	**7 days**	**14 days**	**28 days**
Controlmix	38.24	54.66	62.12
M1C0	30.31	43.15	58.32
M1C1	32.36	44.21	59.56
M1C2	35.24	47.56	60.56
M1C3	33.25	45.36	57.45
M1C4	30.15	41.26	55.96
M2C0	31.56	42.46	60.23
M2C1	35.25	45.25	64.14
M2C2	**40.54**	**58.26**	**68.56**
M2C3	34.42	46.78	63.35
M2C4	30.25	42.56	60.15
M3C0	30.28	44.58	59.56
M3C1	32.61	47.73	61.10
M3C2	36.48	49.45	62.12
M3C3	33.19	45.32	60.25
M3C4	32.29	41.12	58.24

B. SPLIT TENSILE STRENGTH TEST

Splitting tensile strength tests were carried out at the age of 28 days for the concrete cylinder specimens of size 100 mm diameter and 200 mm length,using compression testing machine of 3000 kN capacity as per IS:516-1959.

Mix	**7 days**	**28 days**
Controlmix	3.28	4.30
M1C0	2.86	4.05
M1C1	2.95	4.16
M1C2	3.12	4.34
M1C3	2.88	4.26
M1C4	2.65	4.10
M2C0	2.98	4.32
M2C1	3.12	4.65
M2C2	**3.56**	**5.15**
M2C3	3.05	4.74
M2C4	2.85	4.34
M3C0	2.75	4.28
M3C1	2.96	4.53
M3C2	3.06	4.85
M3C3	2.84	4.37
M3C4	2.68	4.20

For the mix combination M2C2 (MK 10%and CS 50%) replacements significantly increase the split tensile strength with reference to control for M50 grade i.e., 10.8%. There is an increase in tensile strength for mix M2C2 by 20.8% than control mix for M50 grade respectively.

C. FLEXURAL STRENGTH TEST

For finding flexural behaviour, tests were carried on 100 mm x 150 mm x 1200 mm beam prototypes at the age of 28 days using 1000kN capacity flexural strength testing machine. The test setup includes two point loading using a single point loading system by which the loads are transferred equally to the two points using a spreader beam and two rollers.

Mix	Ultimate load(kN)	First crack load(kN)	Deflection(mm)
Control mix	55.8	16	10.43
Optimum mix	60.5	17.5	9.47

It can be seen that ultimate load of 60.5kN has been achieved for mix M2C2 which is 9.7% higher than M50 control beams respectively. It was observed that the beamscast with CS and MK showed higher load carrying capacities compared to controlbeam.

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D. LOAD DEFLECTION BEHAVIOUR

At every load increment, it was noted that the beam with optimum mix has higher deflection values in comparison to that of control beam. This shows that thereplacement of cement by CS and MK leads to ductile behaviour. Greater deflection was observed under loads in beams cast with admixtures than the control specimen. There is an increase in deflection for mix M2C2 (MK+CS) by 10.3% than M50 control beam respectively.

IV. CONCLUSION

From the experimental results presented in this study, the following conclusions can be drawn:

- Compared to the control mix, there was a slight increase in the Concrete density of nearly 5% with the increase of copper slag content, whereas the workability increased rapidly with increases in copper slag percentage.

- Addition of up to 50% of copper slag as sand replacement yielded comparable strength with that of the control mix. However, further additions of copper slag caused reduction in the strength due to an increase of the free water content in the mix.

- Mixtures with 75% and 100% copper slag replacement gave the lowest compressive strength value which was almost 16% lower than the strength of the control mix.

- It is recommended that less than 40% copper slag as sand substitution can achieve a high strength concrete that comparable or better than the control mix, beyond which more voids, microcracks and capillary channels appear in the microstructure of the concrete resulting in the concrete damaged at a premature strength level.

- There is a increase in the workability with the increase of copper slag quantity is attributed to the low water absorption characteristics of copper slag and its glassy surface compared with sand which caused surplus quantity of free water to remain after the absorption and hydration processes have completed.

- This increase in the workability may have beneficial effect on concrete in the sense that concrete mixes with low water-to-cement ratios, for the same amount of sand replaced, can be produced which may have good workability, greater strength and improved durability than the conventional concrete.

- There is an increase in 28 days strength for optimum mix M2C2 (MK10%+CS50%) by 12% over the control mix for M50 grade respectively.

- The Ultimate load and first crack load for the beams with optimum mix is higher than the control beam for both grades due to the immediate filler effect, the acceleration of cement hydration.

- Maximum deflection for the beam with mix M2C2(MK+CS) is increased by 7.5% over the beam with control mix for M50 grade respectively.

- The improvement in the mechanical properties of concretes incorporatingcopper slag indicates that copper slag, a waste by-product of the copper industry, can be used beneficially as fine aggregate for high-strength concrete.

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