Experimental Studies on High Performance Concrete Integrating Copper Slag as Aggregates

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***Abstract*— The development of acceptable sustainable materials is one of the challenges of modern materials science, since the world is facing serious problems due to wide environmental degradation. Now a days utilization of industrial dust waste or secondary materials has encouraged in construction field for the production of cement and concrete because it contribute to reducing the consumption of natural resources. Recent scarcity in river sand (RS) across India has forced people to look for alternatives. One of the materials that have been successfully utilized at field level in real time projects is Copper Slag (CS) – a waste generated during the extraction of copper from its ore and sterlite industries. An experimental investigation was conducted to study the to produce HPC having compressive strength greater than 80 MPa by integration of copper slag.The complete replacement of standard sand by copper slag resulted in a maximum decrease in 28-day compressive strength of about 10–20% whereas, the flexural strength, fracture energy recorded was of the similar order. It can be concluded from the results) of copper slag can be used as a replacement for fine aggregates in order to obtain a concrete with good strength in HPC is technically vible.**

Keywords*— *Copper slag, sand,geopolymer, High performance

INTRODUCTION *(HEADING 1)*

Concrete is a composite material composed mainly of water, aggregate, and cement. Fine aggregate (sand) is an important material for the preparation of concrete. Now days, the demand of natural sand is high in the developing countries like India, due to the large usage of concrete to satisfy the rapid growth of infrastructure project. In India, there is a serious threat to environment andsociety due to large usage of natural sand deposits.With increasing scarcity of river sand and natural aggregates across the country, construction sector is under tremendous pressure to explore alternative to these basic construction material to meeting growing demand of infrastructure demands. The cost of the sand has increased due to its demand.

In states like Kerala, Maharashtra and Gujarat, sand mining in rivers has already been banned owing to its disastrous impact ecology. "Therefore, slag has a big potential of getting developed as a suitable alternative material to these resources. It is a new business avenue for us and we are going to make revenue out of waste. At present, across the world around 33 tonnes of slag is generated while in India three copper producers Sterlite, Birla Copper and Hindustan Copper produce around 6-6.5 tonnes of slag at different sites.Because of this condition, researches began cheaply available material as an alternative for natural sand.

Copper slag is by product of the manufacture of copper.Utilization of industrial waste or secondary material has increased in construction field for the concrete production because it contributes to reducing the consumption of natural resources.Large amount of copper slag are generated as waste worldwide during the copper smelting process. The india copper production is currently about 2-3 million tons (ICI) and it is estimated that for every ton of, copper produced, about 2.2tons of copper slag is generated as a copper waste.

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).In view of the growing environmental concern for disposal of the slag and the limited availability of iron ore resources in the region, the potential use of wastes of copper slag as raw material in place of iron ore in the production of cement was demonstrated in this study.

This slag is currently being used for many applications utilize only about 15–20 % of the copper slag generated. The remaining material used from land-filling to grit blasting, which are not very high value added applications. This is dumped as a waste, which requires large areas of and, a fast diminishing high value asset. Alternative use of it as partial or complete substitute for fine aggregates in concrete will eliminate these problems. Hence a study was undertaken to find the effect of replacement of sand by copper slag in polymer construction and in cement concrete.

a. NEED FOR THE STUDY

The sustainable development for construction involves the use of non-conventional and innovative materials, and reusing of waste materials in order to compensate for the lack of natural resources and also to find alternative ways for conserving the environment.Recent days arisen for the development of HSC using waste materials/industrial by-products.With this as main aim, the goals of the research work described in this thesis were set.

b. SCOPE OF THE STUDY

The main objective is to study the feasibility of use of copper slag as fine aggregate in cement mortar jointing material in brick masonry construction and cement concrete. The scope of the work includes the studies on the following aspects of cement mortar and cement concrete:

- Evaluation of copper slag based cement mortar in brick masonry construction.
- The percentage of copper slag used for replacement of river sand are 50,75 and 100%.
- Cement sand mortar joint thickness of 10 and 15 mm.
- Plaster ability of use of copper slag for partial replacement material for river sand.
- Use of copper slag as replacement material for river sand in cement concrete (50, 75 and 100 %)

3. MATERIAL USED

SI .No.	Materials	Symbols
1	Cement, OPC, 53-grade	C
2	Standard sand	ES
3	Copper slag	CS
4	Water	w
5	Superplasticiser	SP
6	Silica Fume	SF

a. CEMENT

Cement is a binder, a substance used in construction that sets, hardens and adheres to other materials, binding them together. Cement is seldom used solely, but is used to bind sand and gravel (aggregate) together .Cement is used with fine aggregate to produce mortar for masonry, or with sand and gravel aggregates to produce concrete.

Cements used in construction are usually inorganic, often lime or calcium silicate based, and can be characterized as being either hydraulic or non-hydraulic, depending upon the ability of the cement to set in the presence of water (see hydraulic and non-hydraulic lime plaster).

Non-hydraulic cement will not set in wet conditions or underwater; rather, it sets as it dries and reacts with carbon dioxide in the air. It is resistant to attack by chemicals after setting.

The following are the types of cement that are in practice Rapid Hardening Cement, Quick setting cement, Low Heat Cement, Sulphates resisting cement, Blast Furnace Slag Rapid Hardening Cement, High Alumina Cement, White Cement, Coloured cement, PozzolanicCement, Air Entraining Cement, Hydrographic cement.

The grade 43 and 53 in cement mainly corresponds to the average compressive strength attained after 28 days (6724 hours) in mega pascal (Mpa) of at least three mortar cubes (area of face 50 cm squared) composed of one part cement, 3 parts of standard and(conforming to IS 650:1966) by mass.

In this experimental study we are using 53 grade of cement inorder to attain high performance.

b. FINE AGGREGATE

Ennore sand(ES) i.e., Indian standard sand confirms to IS 650 –1991.The sand isavailable in three grades namely, Grade I (2.36 mm - 600µm), Grade II (1.18 mm -150 µm) and Grade III (600 µm – 90 µm). The specific gravity of the sand is 2.64. Since no coarse aggregate is introduced into the mixes of the present study, the sand contributes to the maximum particle size in the mix. The size of the sand particles is related to that size which is required based on the particle packing theory to achieve most optimal homogeneity.In the present study, the particle size is limited to 2.36 mm but not less than 150 µm.

c. COPPER SLAG

Copper slag is a by-product of copper extraction by smelting. During smelting, impurities become slag which floats on the molten metal.The world copper production is about 14.98 million tons and it is estimated that for every ton of copper produced, about 2.2 tons of copper slag is generated as a waste. Copper slag is a hard, dense abrasive with angular particles is suitable for blast cleaning of steel and stone/concrete surfaces, removal of mill scale, rust, old paint, dirt etc. Blasting the copper slag grit at the surface is reported to be a very effective for metal surface cleaning before paint spraying. The blasting media manufactured from copper slag brings less harm to people and environment than sand. Since copper slag is low in free silica, its hard particles can provide a lower-dusting job site. Copper slag was found to meet the rigid health and ecological standards. Copper slag is commonly used fast cutting, high quality, yet economical choice for use as abrasive grain in shipyards. Copper slag as abrasive is not only very good in cutting speed, but also in reducing cost of operations.

d. CHEMICAL PROPERTIES OF COPPER SLAG

Chemical component	% of Chemical component
SiO2	25.84
Fe2O3	68.29
Al2O3	0.22
CaO	0.15
Na2O	0.58
K2O	0.23
LOI	6.59
Mn2O3	0.22
TiO2	0.41
S3	0.11
CuO	1.20
Sulphidesulphur	0.25
Insoluble residue	14.88
Chloride	0.018

Table 2 Chemicial properties of copperslag

e. PHYSICAL PROPERTIES OF COPPER SLAG

Physical properties	Copper slag
Particle shape	Irregular
Appearance	Black & glassy
Type	Air cooled
Specific gravity	3.37
Percentage of voids	43.20%
Bulk density	2.08 g/cc
Fineness modulus	3.43
Water absorption	0.3 to 0.4%
Moisture content	0.1%

f. WATER

Water satisfying the drinking standards can be used for the Portland cement based concrete making. Since the reaction systems in conventional concretes (CCs) and GPCs are different, water suitable for CCs may not be appropriate. Sometimes, some ions which are tolerable in Portland cement hydration reactions, may create adverse effects in GPCs and therefore, preferably demineralised water or distilled water may be used in GPCs.

g. SUPER PLASTICIZER

Superplasticizers, also known as high range water reducers, are chemical admixtures used where well-dispersed particle suspension is required. These polymers are used as dispersants to avoid particle segregation (gravel, coarse and fine sands) and to improve the flow characteristics of suspensions such as in concrete applications. Their addition to concrete or mortar allows the reduction of the water to cement ratio, not affecting the workability of the mixture, and enables the production of self-consolidating concrete and high performance concrete. This effect drastically improves the performance of the hardening fresh paste. The strength of concrete increases when the water to cement ratio decreases. However, their working mechanisms lack a full understanding, revealing in certain cases cement-superplasticizer incompatibilities.

The most efficient superplasticisers are poly carboxylic ether-baseddispersing agents. These plasticizers also exhibit retarding characteristics, which can pose a problem for practical applications. For the low water/cement ratios used for UHPCs, the optimum superplasticiser ratio is high (approx.1.6% of cement content). The superplasticiser used in this study was Polyacrylic Ester based high-range water-reducer

h. SILICA FUME

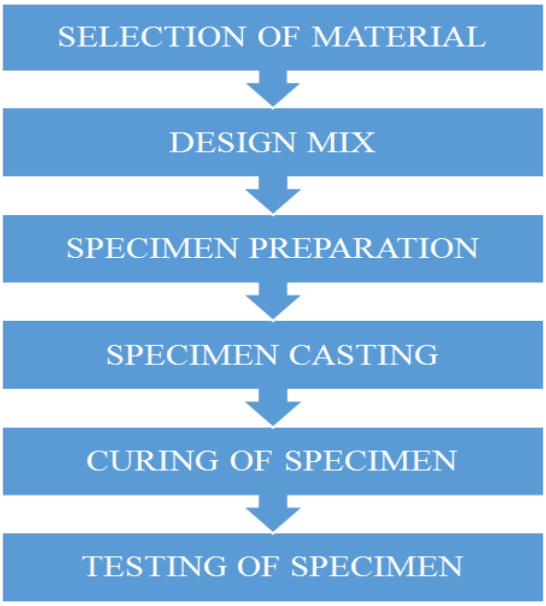
Silica fume (SF) is a byproduct from the production of silicon and ferrosilicon alloys, such as ferrochromium, ferromanganese, ferro magnesium and calcium silicon. SF or micro silica is the principal constituent of the new generation of high and ultra-high performance concretes (HPC and UHPC) in combination with superplasticiser. Due to its known superior properties such as filling ability, enhancement of rheological characteristics by purification and production of secondary hydrates by pozzolanic reaction with the lime and C-S-H phases resulting from primary cement hydration, it is now possible to produce concretes with outstanding properties. Silica fume has very fine particles, approximately 100 times smaller than the average cement particle, and has a large surface area. On certain occasions, a lower fineness of 14–18m2/g having high purity especially from zirconium industries is preferable. On the other hand, an impure silica fume with fineness of 22 m2/g has given moderate results (Richard & Cheyrezy 1994). Finally, greater the purity better the results. Silica fume in the slurry form is advantageous in case of HPC; but it is detrimental in UHPC as the water quantity in the slurry often exceeds the total water demand. Possessing very small particle size, silica fume fills the voids remaining between cement and quartz powder particles. Consequently the permeability is reduced drastically and resistance against chemical penetration is increased. The density of the composite material is increased by using particles of specific sizes well spaced throughout the granular matrix. Spherical particles are preferable to maximize the packing capabilities of the mix. Generally, spherical particles are not used in the conventional concretes. However, engineers parted with this trend when incorporating silica fume as one of the components of UHPC. With its spherical shape, particles allow for improved lubrication making the mixing process less demanding. The spherical particles of the silica fume fill voids between the larger particles thereby increasing the density of mix. Additionally, the silica fume causes increased workability of the mix. Typically the silica fume to cement ratio used for UHPC is around 0.25.

The ratio corresponds to optimum filling Performance and it is close to the dosage required for complete consumption of lime resulting from total hydration of cement. However, cement hydration is incomplete in UHPC, and the available quantity of silica fume is usually more than that required for the pozzolanic reaction. Silica fume used in the present study is densified SF conforming to ASTM C 1240-05 with a specific gravity of 2.2 and percentage passing through

45µm.sieve in wet sieve analysis of 92%. SF was used to supplement the cementations content in the mix for achieving high strength of the composite. The chemical composition of SF was found using X-Ray fluorescence (XRF). The surface area of SF determined by Brunauer-Emmett-Teller (BET) analysis was 18.36 m2/g. The LOI was 1.5%. The average particle size of silica fume was 13 µm.

Fig 2 Silica Fume

IV. METHODOLOGY



MIX PROPORTION

M25 = 1:1:2
1cubic meter = 2400Kg
Cement = 600Kg
Fine Aggregate = 600Kg
Coarse Aggregate = 1200Kg

Table 3 Mix Proportion

MATERIAL	MIX 1	MIX 2	MIX 3	MIX 4
CEMENT	500Kg	500Kg	500Kg	500Kg
FINE AGGREGATE	75% 450Kg	50% 300Kg	25% 150Kg	0%
COARSE AGGREGATE	600Kg	600Kg	600Kg	600Kg
COPPER SLAG	25% 150Kg	50% 300Kg	75% 450Kg	100% 600Kg
WATER	240Lit	240Lit	240Lit	240Lit
SUPER PLASTICIZERS	2%	2%	2%	2%
SILICA FUME	100Kg	100Kg	100Kg	100Kg

V.EXPERIMENTAL INVESTIGATION

a. Slump cone test

Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work. It is not a suitable method for very wet or very dry concrete. Additional information on workability and quality of concrete can be obtained by observing the manner in which concrete slumps. Quality of concrete can also be further assessed by giving a few tappings or blows by tamping rod to the base plate. The deformation shows the characteristics of concrete with respect to tendency for segregation.

b. Flow table apparatus

Flow table confirming to ASTM C230-08 was usedfor determination of flowability of UHPC mixes. The flow was determined as per ASTM C1437-07. To determine the flow, carefully wipe the flow table clean and dry, and place the flow mold at the center. Place a layer of mortar about 25 mm in thicknesses in the mold and tamp 20 times with the tamper. The tamping pressure shall be just sufficient to ensure uniform filling of the mold. Then fill the mold with mortar and tamp as specified for the first layer. Cut off the mortar to a plane surface flush with the top of the mould bydrawing the straightedge or the edge of the trowel with a sawing motion across the top of the mould. Wipe the table top clean and dry, and avoid removal of any water from around the edge of the flow mold. Lift the moldaway from the mortar, immediately drop the table 25 times in 15 seconds. The flow is the resulting increase in average base diameter of the mortar mass, expressed as a percentage of the original base diameter.

c. Compaction Factor

It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability as are normally used when concrete is to be compacted by vibration. The compacting factor test has been developed at the Road Research Laboratory U.K. This test works on the principle of determining the degree of compaction achieved by a standard amount of work done by allowing the concrete to fall through a standard height. The degree of compaction, called the compacting factor is measured by the density ratio i.e., the ratio of the density actually achieved in the test to density of same concrete fully compacted.

d. Vee Bee consistometer

This is a good laboratory test to measure indirectly the workability of concrete. This test consists of a vibrating table, a metal pot, a sheet metal cone, a standard iron rod. The time required for the shape of concrete to change from slump cone shape to cylindrical shape in seconds is known as Vee Bee Degree. This method is very suitable for very dry concrete whose slump value cannot be measured by Slump Test, but the vibration is too vigorous for concrete with a slump greater than about 50 mm.

e. Compression testing machine

A digital Compression Testing Machine (CTM) of 3000 KN was also used for determination of compressive strength of cube Specimens.

Fig 3 Compressive machine

The compressive strength of the concrete in terms of pressure was then calculated using the Equation:

$$f_c = P/A$$

Where,

f_c = Compressive Strength of Concrete,

P = Maximum load applied (KN), and

A = The cross-sectional area of the sample (mm^2)

MIX	COMPRESSIVE STRENGTH (Mpa)	
	7 DAYS	28 DAYS
NORMAL M-25	18.29	30.36
CS 50%	23.25	39.53
CS 75%	21.21	26.88
CS 100%	18.31	25.14

Table 4 Compressive strength results

MIX	COMP. STRENGTH 7 DAYS (Mpa)	STRENGTH GAINED 7 DAYS	COMP. STRENGTH 28 DAYS (Mpa)	STREGTH GAINED 28 DAYS
M-25	18.29	100	30.36	100
CS 50%	25.425	139.005	39.45	129.94
CS 75%	21.21	115.96	26.88	88.53
CS 100%	18.31	100.10	25.14	82.80

Table 5 Strength gained by copperslag

From the test results,it can be seen that the compressive strength of Copper slag concrete mixes with 50%, 75%, 100% fine aggregate replacement with Copper slag, were higher than control mix at all ages. It is evident from the above table that compressive strength of all mixes continued to increase with the increase in age. There is an increase in the strength of almost 55% compared to the control mix of 7 days. However, mixtures with 100% replacement of copper slag gave the lowest compressive strength 18.31 Mpa which is almost 1% greater than the strength of the control mix.

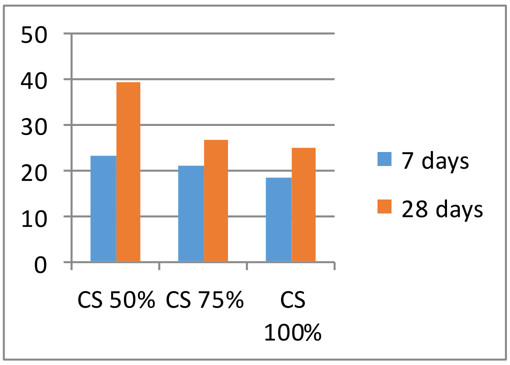


Fig 4 Compressive Strengths test result for copper Slag

f. FLEXURAL STRENGTH

Flexural strength, also known as modulus of rupture, or bend strength, or transverse rupture strength is a material property, defined as the stress in a material just before it yields in a flexure test. The transverse bending test is most frequently employed, in which a specimen having either a circular or rectangular cross-section is bent until fracture or yielding using a three point flexural test technique. The flexural strength represents the highest stress experienced within the material at its moment of yield.

The flexural strength was then calculated using Equation:

$$f_{cr} = \frac{PL}{bd^2}$$

Where

f_{cr} =Flexural Strength of Concrete, (kPa or psi)

P = Maximum load applied (KN or lb),

L = Length of the specimen between the lower supports (mm),

b = Width of the beam (mm or in), and

d = Depth of the beam (mm or in)

MIX	FLEXURAL STRENGH (Mpa)
NORMAL M-25%	3.49
CS 50%	3.75
CS 75%	3.52
CS 100%	3.83

Table 6 Flexural strength

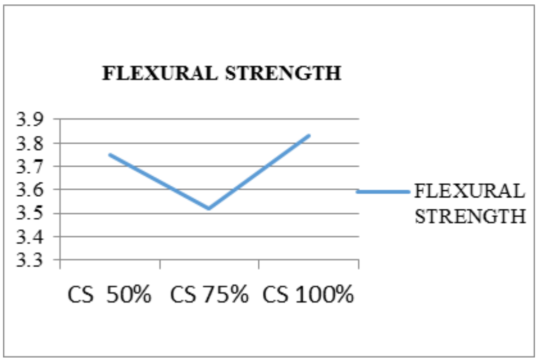


Fig 4 Flexural strength result

Here samples of size 500 x 100 x 100mm, wereprepared and tested for flexural strength at 28-days ofcuring. At least 3 samples were tested at each curingage. The average flexural strengths of the concretecomposites measured during this phase of the project are presented in Table and graphically on Fig

VII. CONCLUSION

To overcome the deficiencies and problems of the existing building materials, there has been growing interest in the utilization of some of the industrial by-products, which were earlier disposed off as wastes, either as partial or complete replacement of conventional construction materials in raw or processed form. UHPC exhibits properties such as enhanced strength, durability, ductility and long term stability. Thus, in order to ensure the efficient use of UHPC in new construction projects, a need has now arisen for the development of UHPC using waste materials/industrial by-products.

1. The design M25 grade concrete for 50% replacement of CS shows the HPC characteristics.

2. Copper Slag behaves like to River Sand both having same contain Silica (SiO_2).

3. It is observed that when increasing percentage replacement of fine aggregate by Copper slag the unit weightof concrete is gradually increases.

4. Compressive strength and flexural Strength is increased due to high toughness of Copper slag.

5. Maximum Compressive strength of concrete increased by 55% at 40% replacement of fine aggregate by copper slag, and up to 75% replacement, concrete gain more strength than control mix concrete strength.

6. It is observed that for all percentage replacement of fine aggregate by Copper slag the flexural strength of concrete is more than control mix.

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