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Effect of Silica Fume on Concrete Containing Copper Slag as Fine Aggregate

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Abstract- Concrete is one of the major building materials used in modern day construction. For a variety of reasons the concrete construction industry is not sustainable. The sustainable development in construction involves use of waste materials and by-products to replace Portland cement and aggregates. The aim of the present study is to evaluate the effect of replacing cement with silica fume and fine aggregate with copper slag. For this research work M30 grade concrete is prepared and is evaluated for fresh concrete properties and hardened concrete properties like compressive strength and flexural strength. Portland cement is replaced with silica fume at 0, 4, 8 and 12 % and fine aggregate is replaced with copper slag at 0, 20, 40 and 60 %. The results show that the use of silica fume and copper slag as replacement material improves mechanical properties of the concrete. Concrete incorporating 40 % copper slag and 8 % silica fume as replacement material shows better performance among all the mixes.

Index Terms- Copper Slag (CS), Silica Fume (SF), Physical Properties, Compressive Strength, Flexural Strength.

1. INTRODUCTION

Concrete is the most widely used material in the world next to water. It is strong, gives flexibility in design and comes with a low cost [11]. But the concrete industry is not sustainable due to environmental concerns with the production of cement and aggregates.

Aggregates are the essential component of concrete and about 42 % of 15 billion tons of aggregates produced each year are used in concrete, of which only 8 % are recycled aggregates [11]. Thus this component of concrete has larger impact through disturbance of virgin lands and rivers for its production. The sustainable development for construction involves the use of waste materials to compensate the lack of natural resources and to find alternative ways for conserving the environment.

Copper slag is considered as a waste material which can be used as partial or full substitute of either cement or aggregates. It is a by- product obtained during the matte smelting and refining of copper. Approximately 2.2–3.0 tons copper slag is generated as a by-product material to produce every ton of copper [9]. This slag is currently being used for many applications like land filling, grit blasting, etc. and utilises only about 15–20 % of the copper slag generated [8].

Another important component of concrete is Portland cement. During its production fuel is combusted to heat raw materials to temperatures exceeding 1500°C causing the decarbonation of lime stone to occur. During the production of cement 0.81 kg of CO_2/kg of cement is released owing to fuel construction and decarbonation [10]. The cement industry is also responsible for the emission of carbon dioxide and other pollutants to the atmosphere which will increase the effect of global warming. Hence it is obvious to use a material which can be used as an alternative or supplementary material to cement which also increases the strength and durability of concrete.

Silica fume is a mineral admixture that can be used as an admixture or replacement of cement and other concrete constituents. It is an ultrafine powder collected as a by-product of silicon and ferrosilicon alloy production which can be readily used as a replacement for cement thus reducing the effect of Portland cement. The researches shows that the silica fume have a beneficial influence on strength and durability of reinforced concrete. When pozzolanic materials are incorporated to concrete, the silica present in these materials reacts with the calcium hydroxide released during the hydration of cement and forms additional calcium silicate hydrate (C-S-H), which improve the mechanical properties of concrete [3].

The scope of the present study is to evaluate the effect of replacing cement with silica fume and fine aggregate with copper slag in concrete. M30 concrete is evaluated for fresh concrete properties and mechanical properties.

2. EXPERIMENTAL INVESTIGATION

2.1. *Materials*

2.1.1. *Cement*

Portland pozzolana cement confirming to IS: 1489:1991 from Dalmia cement was used and the properties are as shown in Table 1.

Table1. Properties of cement

Properties		Results
Standard consistency		32%
Specific gravity		3.1
Fineness		0.85%
Setting time	Initial	120 minutes
	Final	310 minutes
Compressive strength	3 day	29.4 MPa
	7 day	40.1 MPa
	28 day	43 MPa

2.1.2. *Fine Aggregate*

Fine aggregate used in this study were M-sand procured from the local crushing unit and conformed to zone II as per IS: 383-1970. Table 2 shows the properties of fine aggregate.

Table 2. Properties of fine aggregate

Properties		Results
Fineness modulus		3.83
Specific gravity		2.5
Water absorption		1.5%
Void ratio		0.455
Bulk density	Loose	1636 kg/m^3
	Compact	1725 kg/m^3

2.1.3. *Coarse Aggregate*

The coarse aggregate used in the experimentation were of 20 mm and down size aggregate and conforms to IS: 2386-1963 (Part I, II and III) specifications. The properties of coarse aggregates are as shown in Table 3.

Table 3. Properties of coarse aggregate

Properties		Results
Fineness modulus		3.55
Specific gravity		2.8
Water absorption		0.8
Void ratio		0.699
Bulk density	Loose	1.503
	Compact	1.69

2.1.4 *Copper Slag*

The copper slag used in this study is obtained from Sterlite industries, Tuticorn. This material replaces fine aggregate in mix proportion. The copper slag used in this study confirms to zone II. Table 4 and Table 5 show chemical and physical properties of copper slag respectively.

Fig 1. Copper slag

Table 4. Chemical properties of coarse aggregate

Constituents	Percentage weight
Silica SiO_2	26-30%
Free silica	<0.5%
Al_2O_3	1-3%
FeO	42-48%
CaO	1-2%
MgO	0.8-1.5%
CuO	0.60-0.70%
Sulphates	0.0008-0.001%
Chlorides	0.001-0.002%

Table 5. Physical properties of copper slag

Properties	Results
Colour	Black, glassy
Grain shape	Angular, multifaceted
Hardness	6-7 Moh
Specific gravity	3.51
Bulk density	1.87 tonnes/m^3
pH	7.0
Conductivity	4.8 mS/m
Weight loss on ignition	4%
Water content	<0.1%

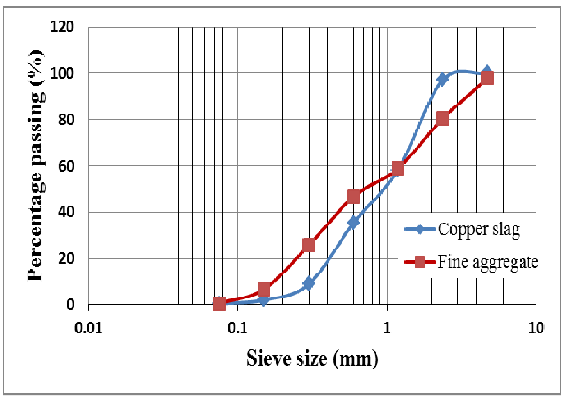

Fig 2. Sieve analysis

2.1.4. *Silica Fume*

Silica fume used in this study is procured from BSS private limited, Edapally. Silica fume is very fine powder, with particles about 100th times minor than average cement grain. It confirms to IS: 15388-2003. Table 6. shows the properties of silica fume.

Fig 2. Silica fume

Table 6. Properties of silica fume

Properties	Results
SiO_2	>97%
SO_3	0.4
Al_2O_3	0.5%
Colour	Premium white
Specific gravity	2.2
Particle size	1μ
Bulk density	576 kg/m^3
Surface area	20000 m^2/kg
Fineness	3 %

2.1.5. *Water*

Water conforming to as per IS: 456- 2000 was used for mixing as well as curing of Concrete specimens.

2.1.6 *Super Plasticizer*

Super plasticizer used in this study is CONPLAST SP430 in the form of sulphonated naphthaline polymer confirms to IS: 9103-1999 and ASTM 494 type F was used to improve the workability of concrete.

2.2 *Mix proportion*

Concrete mix design was carried out according to IS: 10262-2009. The experimental program was designed to study the mechanical properties of concrete by partially replacing fine aggregate by copper slag and cement by silica fume for M30 grade concrete. Fine aggregate was partially replaced with copper slag at 0, 20, 40 and 60 %. Cement was partially replaced with silica fume by 0, 4, 8 and 12 %. In this study, w/c ratio is fixed as 0.45. Table 7 shows mix proportion of concrete and Table 8 shows the type and notation of mix in this study.

Table 7. Mix proportion

Material	Quantity (kg/m^3)
Cement	378
Fine aggregate	655
coarse aggregate	1246
Water	170

Table 8. Type of concrete mixes

Mix	Notation
M-0-0	Concrete with 0% SF and 0% CS
M-4-0	Concrete with 4% SF and 0% CS
M-8-0	Concrete with 8% SF and 0% CS
M-12-0	Concrete with 12% SF and 0% CS
M-0-20	Concrete with 0% SF and 20% CS
M-0-40	Concrete with 0% SF and 40% CS
M-0-60	Concrete with 0% SF and 60% CS
M-4-20	Concrete with 4% SF and 20% CS
M-8-20	Concrete with 8% SF and 20% CS
M-12-20	Concrete with 12% SF and 20% CS
M-4-40	Concrete with 4% SF and 40% CS
M-8-40	Concrete with 8% SF and 40% CS
M-12-40	Concrete with 12% SF and 40% CS
M-4-60	Concrete with 4% SF and 60% CS
M-8-60	Concrete with 8% SF and 60% CS
M-12-60	Concrete with 12% SF and 60% CS

(SF- silica fume, CS- copper slag)

2.3. *Methodology*

2.3.1. *Specimen preparation*

Specimens used in this test were 150 mm size cubes, and 500x100x100 mm beams. The mould confirms to IS: 10082-1982. 150 mm size cubes were used to find compressive strength of concrete. Flexural strength is determined on beams of 500x100x100 mm.

2.3.2 *Tests*

Compressive strength test and flexural strength test were carried out according IS: 516-1959. Compressive strength is determined on automatic compression testing machine with a loading capacity of 5000 kN. Flexural strength is determined on universal testing machine of 600 kN loading capacity.

2.4. *Results and discussion*

2.4.1. *Workability*

The workability of concrete is measured by compaction factor test in accordance with IS: 1199-1959. Trials were carried out to improve the workability by incorporating super plasticizer in to the mix. The results show that as the percentage of copper slag increases workability also increases and workability decrease when the percentage of silica fume increases. The increase in workability with copper slag is due to low water absorption characteristics of copper slag and the decrease in workability with silica fume is due to high specific surface of silica fume. When silica fume is added to concrete containing copper slag as fine aggregate workability is slightly decreased. The workability of different mixes is shown in the Fig 4.

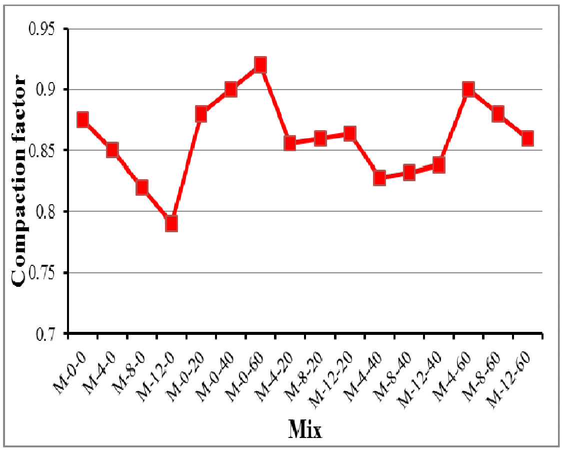

Fig 4. Compaction factor test

2.4.2. *Compressive strength*

The average 28 day compressive strength for different concrete mixes is shown in Fig 5 and Table 9. The result shows that as the percentage of copper slag and silica fume increases compressive strength also increases. For copper slag as replacement material for fine aggregate, maximum compressive strength is obtained at 40% replacement level (47.4 MPa) and the percentage increase in strength is 18.20% when compared to the control mix. This is because copper slag has better compressibility than natural aggregates and it partially relieves the stress concentration, if natural sand is still as the dominant fine aggregate holding together the mix. Also the angular sharp edges of copper slag can improve the cohesion of concrete mix [1]. For 60% replacement level the value is comparable to control mix. This is due to the excessive free water content in the concrete mix. In the case of silica fume as replacement material for cement, maximum compressive strength is for 8% replacement level (50.2 MPa) and the percentage increase in strength is 25.18% compared to control concrete mix. When silica fume is incorporated into concrete containing copper slag as fine aggregate compressive strength of the concrete also increases. The increase in compressive strength is due to the high pozzolanic nature of silica fume and its void filling ability [5]. The maximum value of compressive strength is obtained as 52.1 MPa for the mix M-8-40 and the percentage increase in strength for this mix is 29.925% when compared to control concrete.

Table 9. Compressive strength

Mix	Compressive strength (MPa)
M-0-0	40.1
M-4-0	45.0
M-8-0	50.2
M-12-0	41.9
M-0-20	46.0
M-0-40	47.4
M-0-60	41.2
M-4-20	47.8
M-8-20	50.4
M-12-20	45.2
M-4-40	49.6
M-8-40	52.1
M-12-40	48.1
M-4-60	42.4
M-8-60	44.6
M-12-60	40.5

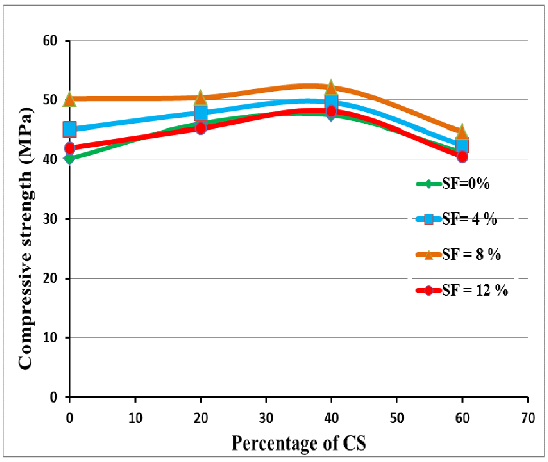

Fig 5. Compressive strength

2.4.4. *Flexural strength*

Table 10 and Fig 6. show the average flexural strength of beam specimens. For copper slag as replacement material for fine aggregate, maximum flexural strength is obtained at 40% replacement level and the percentage increase in flexural strength is 17.45%. For silica fume as replacement material for fine aggregate, maximum flexural strength is obtained at 8% replacement level and the increase in flexural strength is about 19.13%. When silica fume is added to concrete containing copper slag as fine aggregate flexural strength of concrete also increases. Maximum flexural strength is obtained for the mix M-8-40 and the increase is 25.84% when compared with control concrete. The ultrafine silica fume particles which mainly consist of amorphous silica enhance the flexural strength by both pozzolanic and physical action. [5]

Table 10. Flexural strength

Mix	Flexural strength (MPa)
M-0-0	5.96
M-4-0	6.7
M-8-0	7.1
M-12-0	6.3
M-0-20	6.4
M-0-40	7.0
M-0-60	6.2
M-4-20	6.7
M-8-20	6.9
M-12-20	6.5
M-4-40	7.2
M-8-40	7.5
M-12-40	6.6
M-4-60	6.8
M-8-60	6.5
M-12-60	6.0

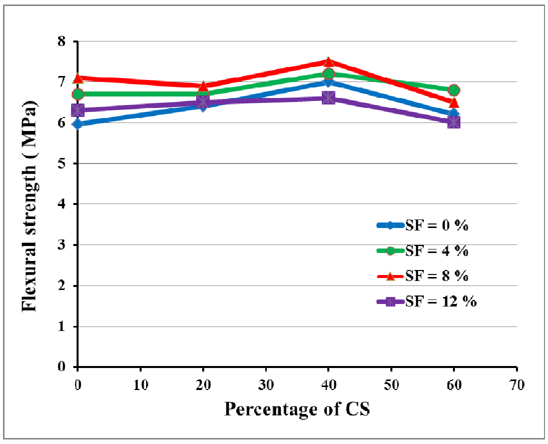

Fig 6. Flexural strength of concrete mix

3. CONCLUSIONS

- Workability of the concrete increases with increase in copper slag percentage and decreases with increase in silica fume percentage. Workability is reduced when silica fume is added to concrete containing copper slag as fine aggregate.
- When replacement level of silica fume increases all the mechanical properties are increased up to 8% and up to 40% replacement level of copper slag all the mechanical properties are increased.
- The maximum values of mechanical and durability properties are obtained for the mix M-8-40. The percentage increase in compressive strength and flexural strength are 29.925% and 25.84% respectively.

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