International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

# A Study on Partial Replacement of Cement by Micro Silica and Sand by Copper Slag in Self Compacting Concrete

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**Abstract:** ***The extensive use of concrete in infrastructure leads to depletion of natural resources and also effects the environment. The aim of the present study is to evaluate the effect of replacing cement with micro silica and fine aggregate with copper slag in self compacting concrete. For this study M30 grade self compacting concrete is prepared and is evaluated for fresh concrete properties and hardened concrete properties like compressive, split tensile and flexural strength. Ordinary portland cement is replaced with micro silica at 0, 4, 8 and 12%, while the fine aggregate is replaced with copper slag at 0, 20, 40 and 60% by weight. The compressive, split tensile and flexural strength properties are compared among all the mixes at periods of 7, 28 and 56 days. The results show that the use of micro silica and copper slag improves the mechanical properties of concrete. The optimum results were observed at 8% and 40% replacements of micro silica and copper slag respectively. The increase in compressive strength at 28 and 56 days was found to be 14.9% and 10.8%, which is 42.4MPa and 45.1MPa when compared to the nominal mix which is 36.9MPa and 40.7MPa respectively.***

**Keywords:** Micro silica, Copper slag, fly ash, workability, self compacting concrete and strength

## 1. Introduction

Concrete is one of the major building materials used in modern day construction. Due to its extensive usage, 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. Self-Compacting concrete (SCC), also known as self-consolidating concrete, is a highly flowable, non-segregating concrete that can spread into place, fill the formwork and encapsulate the reinforcement under its own weight, without any mechanical consolidation.

Micro silica, also known as Silica fume, is an amorphous (non crystalline) polymorph of silicon dioxide. It is a by-product of the industrial manufacture of ferrosilicon and metallic silicon in high temperature electric arc furnaces. It is composed of very fine solid glassy spheres of silicon dioxide ($SiO_2$) with an average particle diameter of 150 nm. It is an ultrafine airborne material with spherical particles less than 1µm in diameter, the average being about 0.1µm. This makes it approximately 100 times smaller than the average cement particle. The unit weight, or bulk density, of silica fume depends on the metal from which it is produced. Its unit weight usually varies from 130 to 430 kg/m3. The specific gravity of silica fume is generally in the range of 2.20 to 2.5.

Copper slag is one of the materials that are considered as a waste material which could have a promising future in construction industry as partial or full substitute of either cement or aggregates. Copper slag (CS) is an industrial by-product obtained through the manufacture of copper metal by smelting. For every ton of metal production, approximately 2.2 - 3.0 tons of copper slag is generated as a by-product material. Dumping or disposal of such huge quantities of slag cause environmental and space problems. It is glassy black in colour and granular in nature and has a similar particle size range like sand which indicates that it could be used as replacement for the sand in cementitious mixture.

## 2. Literature Review

**Muhsin Mohyiddeen, Maya T. M.**, have studied the "Effect of silica fume on concrete containing copper slag as fine aggregate" from which they have concluded that 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 increased, 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 percentage increase in compressive strength and flexural strength were found to be 29.925% and 25.84% respectively for mix containing 8% Silica fume and 40% copper slag replacement.

**A. Deepika, S. Krishnamoorthi, G. S. Rampradheep,** have done a "Study on the properties of Self-consolidating concrete with fly ash and Silica fume" and found out that at 10% replacement level the mix have good compressive strength (43.5 N/mm$^2$) compared to 20%, 30% replacement levels. The compressive strength of the mix decreases with the increase in replacement percentage of the admixtures. It was concluded that it is possible to produce self-consolidating concrete using fly ash and silica fume at 10% replacement of sly ash and silica fume by weight of cement. The workability properties of SCC such as filling ability, passing ability and segregation resistance meet EFNARC specifications.


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**Edwin Fernando, Vandana C. J., Indu G. Nair,** have done “Experimental Investigation on Self compacting concrete with Copper slag” and found out that viscosity modifying agents (VMA) may not be strictly necessary for the material used to obtain SCC. However its presence showed marginal improvement in the passing ability of the mixes. Cement content could be as low as 225kg/m$^3$. Testing of fresh concrete properties must be done within a short time period after mixing, in order to get a true measure of performance in various tests. In addition to the above, powder ratio can be relaxed to obtain self-compacting concrete.

## 3. Experimental Details

The experiments were carried out at 0, 4, 8 and 12% replacements of cement by micro silica and 0, 20, 40 and 60% replacements of fine aggregate by copper slag. The fresh concrete properties were studied and hardened properties of concrete were carried out at 7, 28 and 56 days.

### 3.1 Properties of the materials

**3.1.1 Cement:** Ordinary Portland Cement (OPC) of 53 Grade from a single lot was used throughout the experimental investigation. The specific gravity of cement obtained is 3.12.

**3.1.2 Fine aggregate:** The sand obtained for the investigation is from nearby river course. The sand obtained from quarry was sieved through all sieves. The specific gravity of fine aggregate is 2.6 and fineness modulus is 2.72.

**3.1.3 Coarse aggregate:** The coarse aggregate used in this investigation are obtained from local crushing unit. The size of aggregate used in this investigation is 10mm. The specific gravity of fine aggregate is 2.76 and fineness modulus is 7.26.

**3.1.4 Water:** The water available in the JNTU College of engineering has been used for this experimental investigation. The water used is portable drinking water.

**3.1.5 Fly ash:** The fly ash used in this experimental investigation was obtained from Vijayawada thermal power station. It is used as a filler material and specific gravity of fly ash is 1.975.

**3.1.6 Micro silica:** The micro silica used in this experimental investigation was obtained from the supplier GRR Associates, Visakhapatnam. The specific gravity is 1.9.

**3.1.7 Copper slag:** The copper slag used in this experimental investigation was obtained from Vasudevarao civil materials, Visakhapatnam. The specific gravity is 3.51.

**3.1.8 Super plasticizer:** The super plasticizer used in this experimental investigation is Conplast SP430. The specific gravity is 1.20

**3.1.9 Viscosity modifying agent**: The viscosity modifying agent used in this experimental investigation is Auromix 400. The specific gravity is 1.105.

## 4. Specimen Details

Cube specimen of size 150 mm x 150mm x 150mm, Cylinder specimen of 150 mm diameter and 300 mm height and beam of size 700 mm x 150 mm x 150 mm were casted to study the hardened properties of concrete such as compressive strength, split tensile strength and flexural strength.

### 4.1 Mix notations

A1- Nominal scc mix
A2- 4 % micro silica and 20% copper slag
A3- 8% micro silica and 40% copper slag
A4- 12% micro silica and 60% copper slag

## 5. Mix Proportions

A30 grade of concrete is casted. The design is based on IS 10262-2009. The quantities obtained from this design were correlated with EFNARC specifications. The quantities were tabulated in table 1.

**Table 1:** Details of mix proportion

| S. No | Material | Units | Material quantities | | | |
|---|---|---|---|---|---|---|
| | | | A1 | A2 | A3 | A4 |
| 1 | Cement | kg/m$^3$ | 430 | 412.8 | 395.6 | 378.4 |
| 2 | Fly ash | kg/m$^3$ | 105 | 105 | 105 | 105 |
| 3 | Micro silica | kg/m$^3$ | - | 17.2 | 34.4 | 51.6 |
| 4 | Fine aggregate | kg/m$^3$ | 827.5 | 662 | 496.5 | 331 |
| 5 | Copper slag | kg/m$^3$ | - | 165.5 | 331 | 496.5 |
| 6 | Coarse aggregate | kg/m$^3$ | 827.5 | 827.5 | 827.5 | 827.5 |
| 7 | Water | lit/m$^3$ | 204.5 | 198.3 | 192.1 | 187.4 |
| 8 | Super Plasticizer | lit/m$^3$ | 3.8 | 3.8 | 3.8 | 3.8 |
| 9 | V.M.A | lit/m$^3$ | 2.1 | 2.1 | 2.1 | 2.1 |

## 6. Test Results

### 6.1 Fresh concrete test results and graphs

**Table 2: Results of fresh concrete**

| S. No | Mix Id. | Slump flow (mm) | Slump flow at $T_{50\ cm}$(sec) | V-Funnel (sec) | V-Funnel at $T_{5\ min}$ (sec) | L-Box | J-Ring (mm) |
|---|---|---|---|---|---|---|---|
| 1. | A1 | 654 | 4.9 | 9.2 | 12.5 | 0.87 | 2 |
| 2. | A2 | 665 | 4.3 | 8.5 | 10.5 | 0.93 | 3 |
| 3. | A3 | 680 | 3.1 | 6.2 | 11.8 | 0.96 | 4 |
| 4. | A4 | 655 | 5.6 | 13 | 15 | 0.97 | 8 |

The fresh concrete properties were tabulated in table2 and the variations of properties were shown in the figures 1-6.


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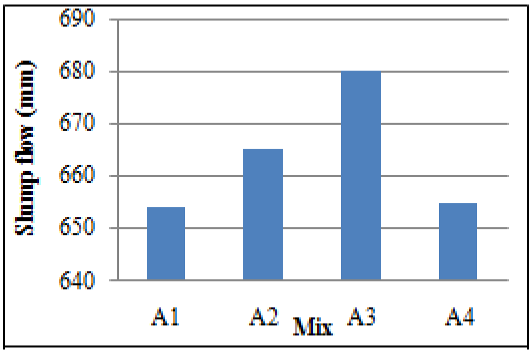


**Figure 1:** Slump flow values (mm)

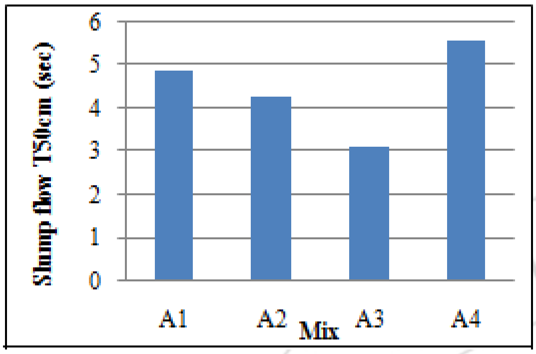


**Figure 2:** Slump flow $T_{50\ cm}$ (sec)

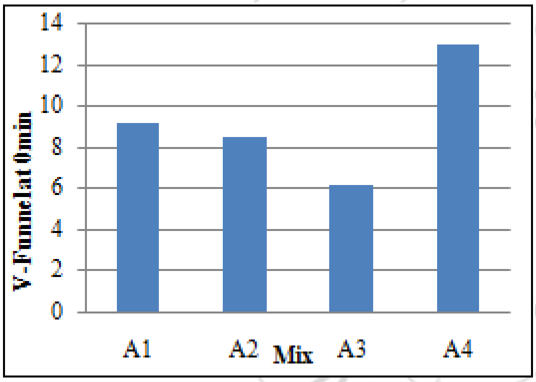


**Figure 3:** V-funnel (sec)

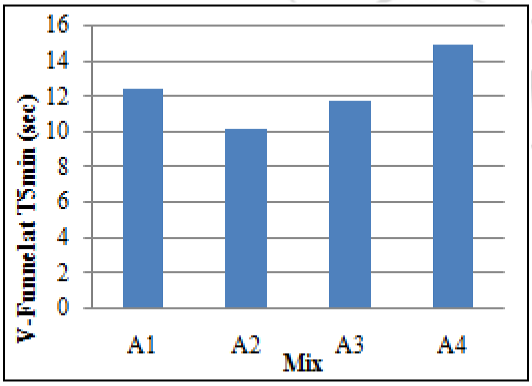


**Figure 4:** V-Funnel at $T_{5\ min}$ (sec)

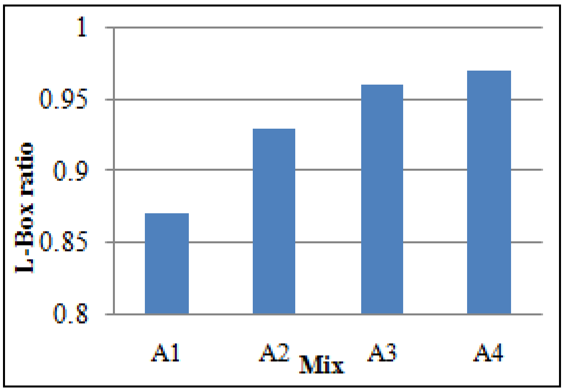


**Figure 5:** L-Box ratio

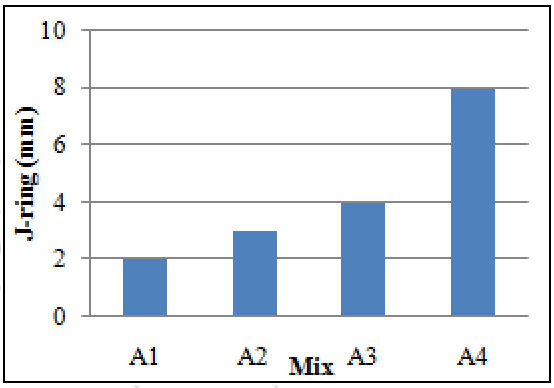


**Figure 6:** J-Ring (mm)

- The above figures shows the variation of flow properties between A1, A2, A3, and A4 mixes
- It was observed that as the micro silica content increases the flow properties are reducing
- Whereas for copper slag the flow properties increases with increase in copper slag content.

### 6.2 Hardened concrete test results and graphs

**Table 3:** Hardened properties (MPa)

| Mix Id. | Compressive strength | | | Split tensile strength | | | Flexural strength | | |
|---|---|---|---|---|---|---|---|---|---|
| | 7d | 28d | 56d | 7d | 28d | 56d | 7d | 28d | 56d |
| A1 | 22.6 | 36.9 | 40.7 | 1.1 | 2.1 | 2.3 | 3.5 | 4.2 | 5.4 |
| A2 | 23.3 | 38.4 | 41.3 | 1.1 | 1.8 | 2 | 3.3 | 4.4 | 5.6 |
| A3 | 25.6 | 42.4 | 45.1 | 1.9 | 2.7 | 3.2 | 5.8 | 6.2 | 6.4 |
| A4 | 23.8 | 37.3 | 40.2 | 1.4 | 2.2 | 2.6 | 3.5 | 4.2 | 5.4 |

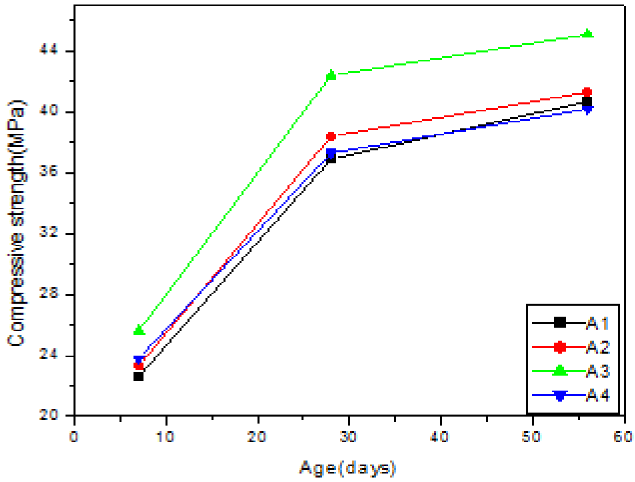


**Figure 7:** Compressive strength Vs. Age


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- It was observed that there was a 14.9% and 10.8% percentage increase in compressive strength at 28 and 56 days respectively for A3 mix.
- It was observed that compressive strength result for 12 and 60% replacement mix i.e. A4 is nearly same as A1 mix.
- There was an increment of 4.1% and 1.5% in compressive strength for mix A2 when compared to the nominal mix at 28 and 56 days respectively.
- The optimum values for compressive, split tensile and flexural strengths were found at replacements of 8% Micro silica and 12% Copper slag.

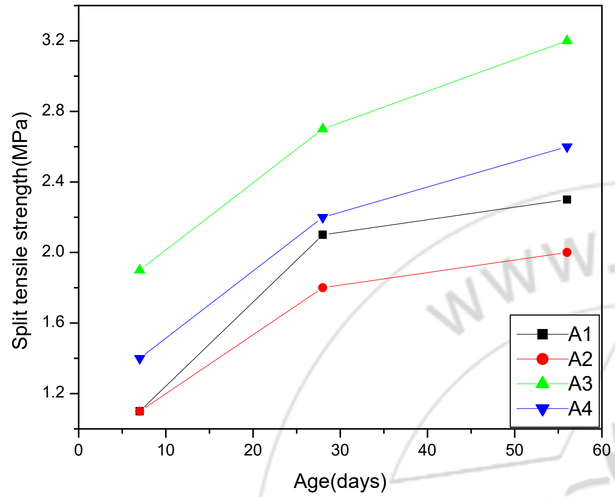


**Figure 8:** Split tensile strength Vs. Age

- It was observed that there was an increase of 28.6% and 39.1% in split tensile strength when compared to the nominal mix at 28 and 56 days respectively.
- An increment of 4.8% and 13% was observed in split tensile strength for A4 when compared to A1 at 28 and 56 days respectively.
- A significant decrement in split tensile strength at 28 days and 56 days is observed for mix A2 when compared with the nominal mix; with a percentage decrease of 14.3% and 13% at 28 and 56 days respectively.
- The optimum value for split tensile strength at 28 and 56 days is 2.69 MPa and 3.2 MPa for A3 mix respectively

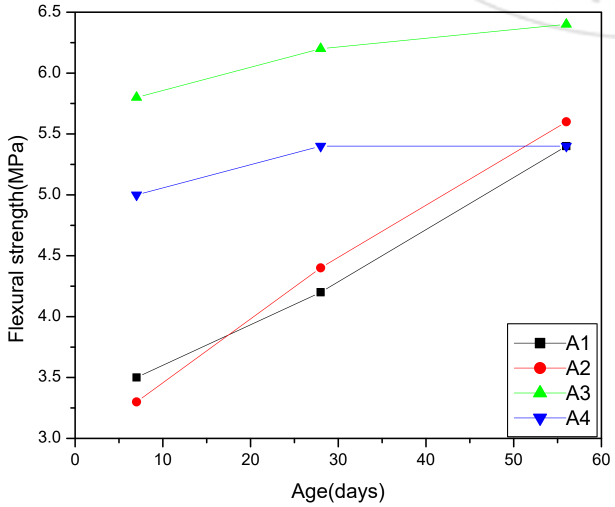


**Figure 9:** Flexural Strength Vs. Age

It was observed that there was a 47.6% and 18.5% increase in flexural strength when compared to the nominal mix at 28 and 56 days respectively.

- The mix A2 showed similar flexural strengths when compared to the nominal mix with a 4.8% and 3.7% increment at 28 and 56 days.
- The maximum flexural strength obtained at 28 and 56 days is 6.2 MPa and 6.40 MPa for mix A3 respectively.

## 7. Conclusions

- The workability of concrete increased with increase in copper slag content but decreased with increase of micro silica beyond 8%.
- The optimum values for compressive, split tensile and flexural strengths were found at replacements of 8% Micro silica and 12% Copper slag.
- The compressive strength for 8% micro silica and 12% copper slag at 28 and 56 days is 42.44 MPa and 45.11 MPa respectively.
- The percentage increase in compressive strength is 14.9% and 10.8% at 28 and 56 days for A3 mix.
- The optimum value for split tensile strength at 28 and 56 days is 2.69 MPa and 3.2 MPa for A3 mix respectively.
- The increase in split tensile strength when compared to the nominal mix is 28.6% and 39.1% at 28 and 56 days respectively.
- The maximum flexural strength obtained at 28 and 56 days is 6.2 MPa and 6.40 MPa for mix A3 respectively.
- There is a 47.6% and 18.5% increase in flexural strength when compared to the nominal mix at 28 and 56 days respectively.
- It was observed that compressive strength result for 12 and 60% replacement mix i.e. A4 is nearly same as A1 mix.
- There is an increment of 4.1% and 1.5% in compressive strength for mix A2 when compared to the nominal mix at 28 and 56 days respectively.
- An increment of 4.8% and 13% was observed in split tensile strength for A4 when compared to A1 at 28 and 56 days respectively.
- A significant decrement in split tensile strength at 28 days and 56 days is observed for mix A2 when compared with the nominal mix; with a percentage decrease of 14.3% and 13% at 28 and 56 days respectively.
- The mix A2 showed similar flexural strengths when compared to the nominal mix with a 4.8% and 3.7% increment at 28 and 56 days.
- It is also observed that at 56 days, all the mixes have continued to gain strength.
- It indicates that cement can be replaced by micro silica up to 8% and sand by copper slag up to 40% based up on the experimental investigations.
- However the density of the concrete made with copper slag is higher than the conventional concrete.

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