EFFECT OF COPPER SLAG AS PARTIAL AGGREGATE REPLACEMENT IN ENGINEERED CEMENTITIOUS COMPOSITE (ECC)

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Abstract
Engineered Cementitious Composite (ECC) is a type of high performance fiber reinforced concrete, characterized by high ductility and tight crack width. ECC composed of cement, silica fume, fly ash, fine aggregate (sand) and polypropylene fibers. This study mainly intends to focus on strength characteristics of ECC when the fine aggregate is partially replaced by copper slag at varying percentages (10% to 50% at 10% intervals). Optimum content of copper slag is obtained by conducting compressive strength test on specimens and ECC with maximum compressive strength was taken as one with the optimum copper slag content.
Index Terms: Compressive Strength, Copper Slag, ECC, Flexural Strength, Splitting Tensile Strength

I. INTRODUCTION

Concrete is one of the most widely used construction material in India. Concrete mainly consist of cement, fine aggregate, coarse aggregate and water. Mix proportioning of concrete can be done for the required grade. Grade refers to the strength in N/mm^2 the concrete can achieve by 28 days curing. Admixture may be added if required, in order to obtain required workability.

ECC is a new generation concrete which is highly ductile and has large flexural strength than that of our conventional concrete. Due to the absence of coarse aggregate in ECC, it demands for large percentage by volume of binder in it compared to conventional concrete. Cement emits more carbon dioxide into the atmosphere with the passage of time, so usage of material such as silica fume, fly ash as cementitious materials in ECC make the composite more sustainable provided mix designing is done properly. Conventional concrete is highly brittle and have sudden failure. ECC is ultra-ductile in nature and has got better flexural properties compared to conventional concrete.

ECC consist of fibers, usually polymer fibers which are short and discontinuous. Fibers are usually added to account for the flexural strength of ECC.

Copper slag is a by-product from copper industry. Its disposal is difficult and causes various environmental problems. It is estimated that about 24.6 million tons of copper slag is produced worldwide annually. The best way of disposal is its use in construction industry. Copper slag can be used as an alternative for cement or fine aggregate in concrete.

In this study the fine aggregate in ECC is partially replaced by copper slag. Five specimens were made by varying the amount of fine aggregate replacement from 0% to 50% (at 10% intervals). The optimal content of copper slag in ECC concrete was found in order to effectively utilize it in the construction industry.

II. EXPERIMENTAL INVESTIGATION

A. Materials used

Materials used for the study included cement, fine aggregate, coarse aggregate, fly ash, copper slag, silica fume, polypropylene fibers and admixture. Table i gives the Specific Gravity of the different materials used in the study. The fine aggregate used was M-sand, passing through 4.75 mm sieve and had a specific gravity of 2.608. The grading zone of fine aggregate was zone I as per IS 456: 2000. Fly ash is of Class F type, typically derived from bituminous and anthracite coals and consists primarily of alumino-silicate glass, with quartz, mullite, and magnetite. Class F, or low calcium fly ash has less than 10 percent CaO. Silica fumes, also known as microsilica are an amorphous (non-crystalline) polymorph of silicon dioxide. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. It is mainly used as a pozzolanic material for high performance concrete. The specific gravity value of copper slag is 4.12 and has a sieve size of less than 2mm. Polypropylene fiber is a synthetic hydrocarbon polymer. Its use enables reliable and effective utilization of intrinsic tensile and flexural strength of the material along with significant reduction of plastic shrinkage cracking and minimizing of thermal cracking. It is available in 3 different sizes i.e. 6mm, 12mm and 24 mm. In the present investigation 12mm fiber length is used. Admixture used is Master Glenium SKY 8233 product offering from BASF comprises new generation high-range water-reducing super plasticizers that are specially formulated for concrete applications where slump retention, high/early strengths and durability are required.

Table i. Specific gravity details of the materials used

Material used	Specific gravity
Cement	3.00
Fly ash	2.6
Silica fumes	2.3
Fine aggregate	2.608
Coarse aggregate	2.77
Polypropylene fibre	2.7
Admixture	1.01
Copper slag	4.12

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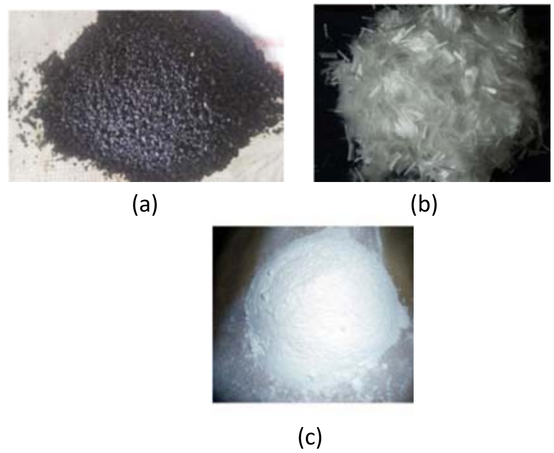

Fig.1.(a) Copper Slag (b) Polypropylene Fiber (c) Silica Fume

B. Mix proportioning

Mix proportion for conventional concrete M 45 and ECC M45 were prepared. For conventional concrete mix proportioning was done as per IS 456 : 2000. Table ii gives the mix proportion for conventional concrete M45.

Table ii. Mix proportion used for ECC M45.

Cement	Fine aggregate	Coarse aggregate	Water	Admixture
1.0	1.681	2.299	0.393	2×10^{-3}

IS code specifies mix proportion for conventional concrete only. For the mix proportion of ECC specimen with grade 45 literature survey was conducted and a proportion was selected based on the literature survey and trials were conducted.

Table iii. Mix proportion for ECC M45 [5]

Cement	Fly ash	Silica fumes	Sand	Water	Admixture
1	1.5	0.25	1	0.7	0.01

ECC specimen was prepared using a concrete mixer with rotating blades. Dry ingredients such as cement, fly ash, silica fume, sand were initially added .Water was added to the mix. Once the dry ingredients are thoroughly mixed admixture was added to the mix after diluting with water. Polypropylene fibers were added by 2% of total volume and were blended properly.

Fly ash to cementitious material was kept 1.2. The water to binder ratio was limited 0.26. The mix prepared thus was self-compacting in nature and was placed into the greased moulds. The specimen was demoulded after 24 hours. The specimens were cured for 28 days.

To the mix proportion ECC of grade 45 so obtained the fine aggregate is replaced by copper slag from 10 to 50% (at 10% intervals) and optimum copper slag replacement content was found out by compressive strength test on cubes. Cube cylinder and beam specimens were cast for ECC and ECC with copper slag replaced specimen. The results so obtained were compared with conventional concrete.

III.RESULTS AND DISCUSSIONS

A. Compressive Strength

The test specimens were cubes of side 150mm. For each mix, 3 cubes were cast and compression test was conducted after 28 days of curing as per IS 516 : 1959.

Fig.2. Compressive testing machine

ECC with copper slag

Trial Specimen were cast for ECC specimen with fine aggregate replaced with copper slag in different proportion ranging from 10 to 50 % where the values goes on increasing beyond 20 % till 40%, were it attains a maximum value of 53.2 N/mm2 after which the values again shows a decreasing trend.

Table iv. Compressive strength test results on trials

SPECIMEN	Compressive strength in N/mm^2
	28 days
ECC 10	46.1
ECC 20	49.4
ECC 30	51.7
ECC 40	53.2
ECC 50	48.2

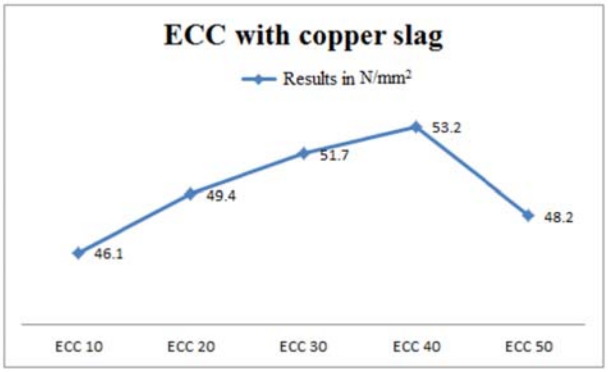

Fig.3. Graphical representation of Compressive strength of ECC with copper slag replacement

Table v. Compressive strength test results

Trial No.	Compressive strength (N/mm^2)		
	CC	ECC	ECC-40
1	47.8	49	53.2
2	46.67	48.2	53.5
3	46.6	48.6	53

Average compressive strength of conventional concrete (CC) specimen was 47.05 N/mm^2, Engineering Cementitious Composites (ECC) was 48.6 N/mm^2 and that of ECC with 40% optimum copper slag replaced as fine aggregate (ECC-40) is 53.2 N/mm^2.

B. Splitting Tensile Strength

The test specimens were cylinders of 150mm diameter and 300mm length. The splitting tensile strength is Tsp is calculated using the formula as per IS 5816-1999

T_{sp}=2P/(3.14*DL)

Where P- Applied load,

d- Diameter of specimen

L- Length of specimen

Average Splitting Tensile Strength of conventional concrete (CC) specimen is 3.25 N/mm^2, Engineering Cementitious Composites (ECC) is 6.2N/mm^2 and that of ECC with 40% optimum copper slag replaced as fine aggregate (ECC-40) is twice that of conventional concrete.

Table vi. Splitting Tensile Strength test results

Trial No.	Splitting tensile strength (N/mm^2)		
	CC	ECC	ECC-40
1	3.32	6.4	6.6
2	3.24	6.2	6.8
3	3.2	6.0	6.3

C. *Flexural Strength*

Strength was determined by testing standard beam of size 100 x 100 x 500mm. As per IS 516 : 1959 the formula for calculating modulus of rupture f_b depends on the value of 'a'.

$f_b = PL/(bd^2)$ when 'a' greater than 13.3 cm

$f_b = 3Pa/(bd^2)$ when 'a' less than 13.3 cm

where,

P- Applied load L- Length of specimen b and d- width and depth of section respectively a- Distance between the line of fracture and the nearer support measured on the centre line of the tensile side of the specimen in cm.

Fig.4. Flexural test

Table vii. Flexural Strength test results

Trial No.	Flexural strength (N/mm^2)		
	CC	ECC	ECC-40
1	5.5	8.9	9.2
2	5.8	8.7	9.5
3	5.7	9.1	9.0

Average Flexural Strength of conventional concrete (CC) specimen is 5.66 N/mm^2, Engineering Cementitious Composites (ECC) is 8.9 N/mm^2 and that of ECC with 40% optimum copper slag replaced as fine aggregate (ECC-40) is 9.2 N/mm^2. The flexural strength of Ecc specimen is on an average 55% more than that of the conventional concrete. Addition of copper slag as fine aggregate replacement increased the flexural strength by 60% than that of conventional concrete. Thus the ECC-40 will have improved flexural properties.

D. *Test results*

Table viii. Average test results

Test conducted	Result(N/mm^2)		
	CC	ECC	ECC-40
Compressive strength	47.05	48.6	53.2
Splitting tensile strength	3.25	6.2	6.54
Flexural strength	5.66	8.9	9.2

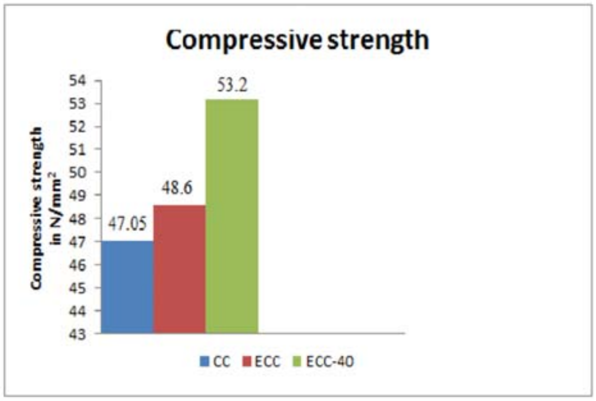

Fig. 5. Graph showing Compressive strength in N/mm^2

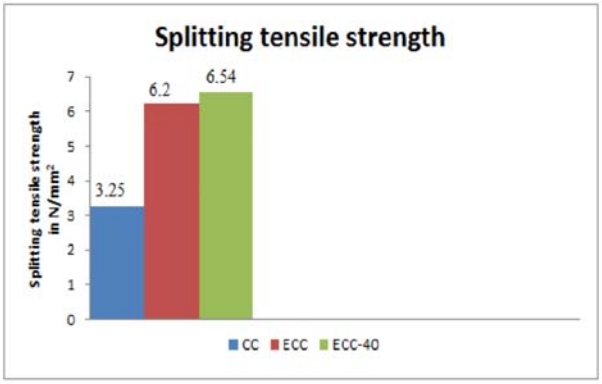

Fig. 6. Graph showing Splitting tensile strength in N/mm^2

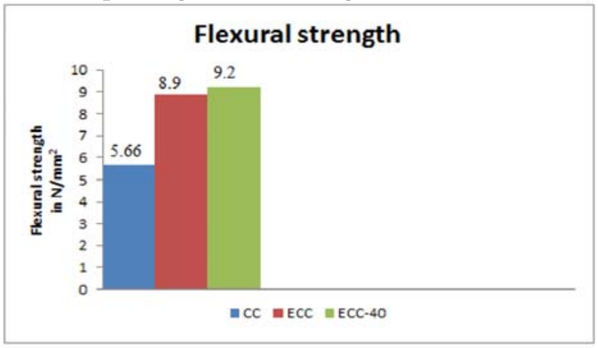

Fig. 7. Graph showing Flexural strength in N/mm^2

E. Advantages and Applications

- ECC have better compressive strength and flexural properties than that of conventional concrete.
- ECC have tighter crack width.
- Self-compacting in nature and can be used in places where it is difficult to provide compaction.
- Usage of ECC at the beam column joint zone have high load and shear capacity, damage tolerance, ductility and energy absorption compared to conventional concrete and thus they can be used in beam column joint.
- ECC is more durable in sulphate and sulphate chloride environment and thus usage of ECC in hydraulic structures can improve its performance.

IV. CONCLUSION

- Splitting tensile strength and flexural strength of ECC specimen was found to be greater that of conventional concrete.
- It was found that 10% replacement by copper slag decrease the strength of the specimen and as the percentage replacement increased, the strength increased up to 40% replacement by copper slag and the strength decreased at 50% replacement by copper slag.
- Thus it was concluded that 40% replacement of fine aggregate by copper slag yield maximum strength and thus 40% is the optimum copper slag content.
- The flexural strength and splitting tensile strength of the ECC with optimum copper slag was found to be 9.2 N/mm^2 and 6.54 N/mm^2 respectively which is comparatively greater than normal ECC.

More studies have to be done to know the durability properties of the ECC with fine aggregate replaced by copper slag by optimum percentage.

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