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Experimental Evaluation on Utilization of FlyAsh and Copper Slag as Partial Replacementto Cement in Cement Concrete

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ABSTRACT:In India, coal is the main source of fuel for power generation.About 60% power is produced in the coal based thermal stations. As a result, huge quantity of Fly Ash (FA) has been generated in the coal based thermal power stations. Also,Copper Slag (CS) is considered as one of the waste materials which can have a promising future in the construction industry as partial or full substitute of either cement or aggregates.This slag is currently used for many purposes like land filling, construction of abrasive tools, roofing granules, cutting tools and rail road ballast material, which are not very high value-added application. These applications utilize only about 15% to 20% of copper slag generated and remaining material is dumped as a waste. In order to reduce the accumulation and also to provide an alternative material for cement an approach has been done to investigate the use of copper slag and fly ash in concrete for the partial replacement of cement.This research was performed to generate specific experimental data on the potential use of copper slag and fly ash as cement replacement partially in concrete. In this study M40 grade Concrete mix is designed.

KEYWORDS: Fly Ash (FA), Copper Slag (CS), Construction Industry, M40 grade Concrete mix.

I. INTRODUCTION

The utilization of industrial waste has encouraged the production of cement and concrete in construction field. New by-products and waste materials are being generated by various industries. Dumping or disposal of waste materials causes environmental and health problems. Therefore, recycling of waste materials is a great potential in concrete industry. For many years, by-products such as fly ash, silica fume and slag were considered as waste materials. Concrete prepared with such materials showed improvement in workability and durability compared to normal concrete and has been used in the construction of power, chemical plants and under-water structures.

The fly ash or Pulverized Fuel Ash (PFA) is the residue from the combustion of pulverized coal collected by the mechanical dust collectors or electrostatic precipitators or separators from the fuel gases of thermal power plants. Its composition varies with the type of fuel burnt, load on the boiler and the type of separators. Fly ash contains oxides of calcium, aluminium and silicon, but the amount of calcium oxide is considerably less. The carbon content in the fly ash should be as low as possible, whereas the silica content should be as high as possible.

Copper industries in India take up about 3% of the entire world market for copper.Copper slag, which is produced during pyrometallurgical production of copper from copper ores, which contain materials like iron, alumina, calcium oxide, silica etc. For every tonne of metal production, about 2.2 tonnes of slag are generated.The favourable physical-mechanical characteristics of copper slag can be utilized to make the products like cement, fill, ballast, abrasive, aggregate, roofing granules, glass, tiles etc.

Figure 1.1 – Copper Slag sample

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Copper slag has a specific gravity of 3.4 which is higher than that of natural sand. It may result in the production of high-density concrete. Water absorption of CS is 0.17%, which is very less compared to fine aggregate and also the copper slag is glassy in nature.Utilization of copper slag in Portland cement as replacement in concrete has the dual benefit of eliminating the cost of disposal and lowering the cost of concrete.

II. OBJECTIVE OF STUDY

The main aim of this research work is to investigate the effective replacement of cement by copper slag and fly ash in concrete. To achieve this, an extensive study has been carried out to investigate the following using copper slag and fly ash.

➢ To find the optimum proportion of copper slag that can be used as a replacement/ substitute material for cement.

➢ To find the optimum proportion of fly ash that can be used as a replacement/ substitute material for cement.

➢ To evaluate compressive and tensile strength of copper slag and fly ash admixed concrete specimens.

➢ To investigate the durability of copper slag concrete in the normal environment.

➢ To investigate possibilities of using copper slag for various purposes.

III. METHODOLOGY

The flow diagram shows the methodology adopted for this research work.

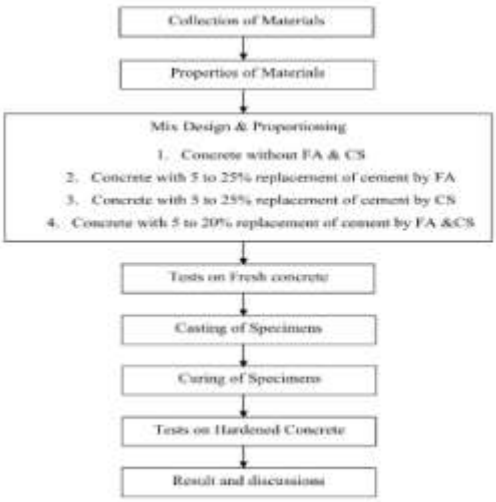

Figure 3.1 - Methodology used

In this, the properties of materials involved in this research are studied. Experimental programmes for the measurement of fresh concrete properties, hardened concrete properties and durability properties are analyzed. In fresh green state and hardened state, test specimens were cast to ascertain the workability, strength-related and durability properties such as compressive strength, splitting tensile strength etc.

3.1 Material Characteristics

3.1.1 Cement: Ordinary Portland cement (43 Grade) is used for the entire research, and it confirms the current specifications as described in IS8112 (part1):2013.The properties of the cement are given in the Table 3.1

Table 3.1 - Physical properties of cement

Physical Properties	Test result
Specific gravity	3.05
Normal consistency (%)	36%
Initial setting time (minutes)	90
Final setting time (minutes)	420

3.1.2Fine Aggregate: Locally available natural sand of zone II with 4.75mm maximum size is used as fine aggregate, which has satisfied the IS383-1970 standard. The fine aggregate is first sieved through 4.75 mm sieve to remove the particles greater than 4.75mm. The results are given in Table 3.2

Table 3.2 - Physical properties of Fine Aggregate

Specification	Results
Type	River Sand
Specific Gravity	2.51
Fineness modulus	2.79
Grading zone	II
Water Absorption	1.08%

3.1.3Coarse Aggregate: The Coarse aggregates are important constituents of any Concrete. Crushed blue granite stones of maximum size of 20mm are used as coarse aggregate, which has satisfied the IS383-1970 standard. The properties of the same are given in Table 3.3

Table 3.3-Physical properties of coarse aggregate

Specification	Results
Specific gravity	2.75

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Fineness modulus	7.6
Bulk Density kg/m3	1380
Void ratio	0.95
Grading Zone	Max size 20mm
Water absorption %	0.45

3.1.4Fly Ash: Class F fly ash obtained from Raikheda Thermal Power Station, Raipur (Chhattisgarh), Indiais used and the fly ash is classified as low calcium fly ash (class F) which has satisfied the IS3812 (part1):2003 standard. It is given in Table 3.4

Table 3.4- Physical properties of Fly Ash

Specification	Results
Type	Class F
Specific Gravity	2.2
Source	Thermal power station

3.1.5Copper Slag: Copper slag is an industrial by-product material produced from the process of manufacturing copper. The process of extracting copper from copper ore varies according to the type of ore and the desired purity of the final product. Copper slag from Industries is utilized and itsproperties are given in Table 4.5

Table 3.5 - Physical properties of Copper Slag

Specification	Results
Specific gravity	3.52
Fineness modulus	3.53
Bulk Density kg/m^3	1750
Void ratio	0.8
Grading Zone	-
Water absorption %	0.13

3.1.6Water: Potable water is generally considered for concreting purposes. Locally available potable water is used for mixing and curing.

3.2 MIX DESIGN

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required strength, durability and workability as economically as possible, is termed the concrete mix design. In this research, M40 grade concrete has been used. The Target mean strength for the mix is 49.7 N/mm2. Mix proportion is given in Table 3.6

Table 3.6 - Mix proportion of M40 grade

Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (lit/m^3)
386	758	1136	174
1	1.96	2.94	0.45

3.2.1 Mix Composition for M40 Grade

Mix proportions are prepared with, cement is partially replaced by FA and CS from 0% to 25% with 5% increment by mass Coarse aggregate, fine aggregate and water cement ratio are kept constant as 1136 kg/m3, 758 kg/m3and 0.45. Mix proportions are prepared and mixproportions of M40 grade is given in Table 3.7.

Table 3.7 - Mix Composition of M40 grade

Mix identification	Cement (kg/m^3)	Fly Ash (kg/m^3)	Copper Slag (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (lit/m^3)	S.P.
F0C0	386	0	0	758	1136	174	0.4
F5C0	366.7	19.3	0	758	1136	174	0.4
F10C0	347.4	38.6	0	758	1136	174	0.4
F15C0	328.1	57.9	0	758	1136	174	0.4
F20C0	308.8	77.2	0	758	1136	174	0.4
F25C0	289.5	96.5	0	758	1136	174	0.4
F0C5	366.7	0	19.3	758	1136	174	0.4
F0C10	347.4	0	38.6	758	1136	174	0.4
F0C15	328.1	0	57.9	758	1136	174	0.4
F0C20	308.8	0	77.2	758	1136	174	0.4
F0C25	289.5	0	96.5	758	1136	174	0.4
F5C5	347.4	19.3	19.3	758	1136	174	0.4

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F10C10	308.8	38.6	38.6	758	1136	174	0.4
F15C15	270.2	57.9	57.9	758	1136	174	0.4
F20C20	231.6	77.2	77.2	758	1136	174	0.4

3.3 CASTING OF SPECIMENS

All the specimens are casted as per mix proportions given in Table 4.7. The required materials are mixed properly and ensure uniformity and water is added with constant water cement ratio of 0.45. Then they are mixed properly. The concrete is mixed using laboratory tilting drum mixer machine. All the moulds are properly oiled before casting the specimens. Before casting the specimen, fresh concrete property is carried out and then, the concrete is placed in standard size cast ion moulds with three equal layers. Compaction has been carried out by vibrating table. After 24-hours the specimens are demoulded, transferred to curing tank and tested at required age.

Figure 3.2- Casting of cubes

3.4TESTS PERFORMED

- ➢ Slump test
- ➢ Compaction factor test
- ➢ Bulk density test
- ➢ Compressive strength test
- ➢ Split tensile strength test
- ➢ Acid and Sulphate Resistance Test

Figure 3.3 -Bulk density&Acid and Sulphate Resistance test

IV. RESULT AND DISCUSSIONS

4.1 Slump and Compaction Factor Test

The slump cone test and compaction factor test are performed to verify the workability of all the 15 mix proportions according to IS 7320-1974 & IS 5515-1983 and the results are given in the Table 4.1 and represented in the Figures from 4.1 to 4.2.

Table 4.1- Fresh concrete properties

S.N.	Mix identification	Slump (in mm)	Compaction factor
1	F0C0	78	0.85
2	F5C0	75	0.86
3	F10C0	71	0.83
4	F15C0	69	0.82
5	F20C0	63	0.79
6	F25C0	61	0.79
7	F0C5	79	0.85
8	F0C10	82	0.87
9	F0C15	82	0.88
10	F0C20	85	0.89
11	F0C25	86	0.91
12	F5C5	79	0.86
13	F10C10	81	0.88
14	F15C15	77	0.85
15	F20C20	75	0.84

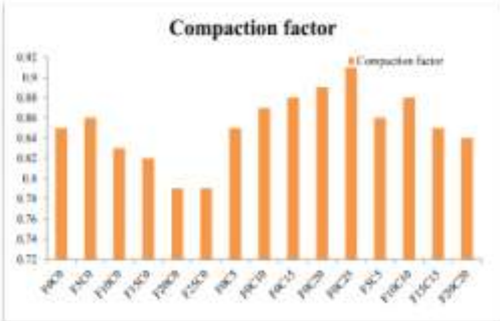

Figure 4.1 - Slump values

Figure 4.2- Compaction factor values

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It can be seen from these results, the slump and compaction factor values are gradually decreased, when increasing the percentage of fly ash replacement and increased, when increasing the percentage of copper slag replacement and also increased, when increasing the percentage of fly ash & copper slag replacement upto 5-10% (Both) and decreased, when increasing the percentage of fly ash & copper slag replacement from 15-20% (Both).

4.2 Density of Concrete Test

Density variations of concrete for all the mix proportions are measured by fresh concrete density before casting the specimen. The results are given in Table 4.2 and represented in the Figures 4.3.

Table 4.2- Density of all the mix proportion

S.N.	Mix identification	Fresh density (kg/m^3)
1	F0C0	2392.24
2	F5C0	2440.12
3	F10C0	2475.47
4	F15C0	2496.59
5	F20C0	2530.84
6	F25C0	2612.34
7	F0C5	2455.21
8	F0C10	2580.14
9	F0C15	2610.16
10	F0C20	2655.31
11	F0C25	2687.41
12	F5C5	2475.46
13	F10C10	2596.14
14	F15C15	2632.26
15	F20C20	2681.54

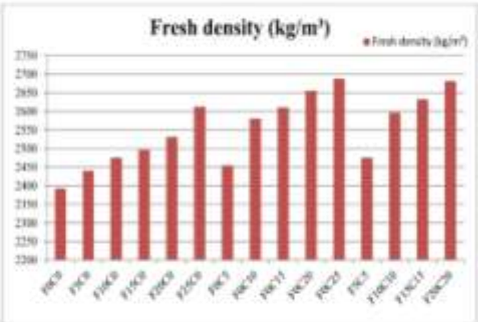

Figure 4.3- Fresh density values

4.3 Compressive Strength Test

Compressive strength test is conducted at 7-, 14- and 28-days curing periods for all mix proportions by using compression testing machine with capacity of 2000kN. The results are given in Table 4.3. From these results, generally the early strength of concrete is lower and higher strength has been developed after 28 days. At the early age, fly ash exhibits very little cementing value but at later ages, liberated surplus lime resulting from hydration of cement reacts with FA and contributes considerable strength to the concrete.

Table 4.3 - Compressive strength test

S.N.	Mix identification	Average compressive strength (MPa)		
		7days	14days	28days
1	F0C0	44.22	45.77	46.25
2	F5C0	40.14	45.80	46.87
3	F10C0	39.77	46.73	47.33
4	F15C0	39.21	45.14	45.25
5	F20C0	38.68	43.77	44.67
6	F25C0	39.16	42.41	43.14
7	F0C5	42.45	46.94	47.48
8	F0C10	42.23	47.65	48.25
9	F0C15	41.17	46.24	47.41
10	F0C20	43.41	45.25	46.22
11	F0C25	41.01	42.24	43.23
12	F5C5	42.69	47.24	48.14
13	F10C10	41.25	47.46	48.21
14	F15C15	37.74	44.54	45.01
15	F20C20	36.54	38.19	42.07

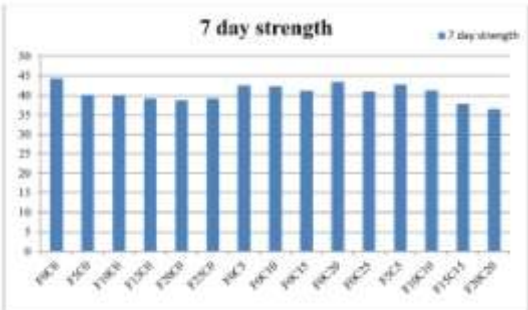

Figure 4.4– 7days strength

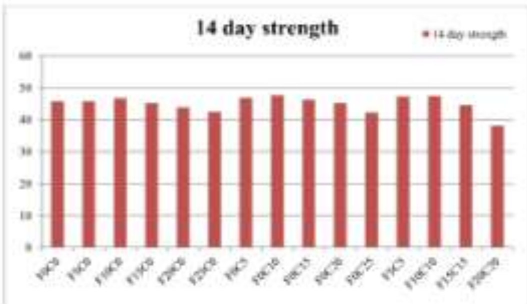

Figure 4.5– 14 days strength

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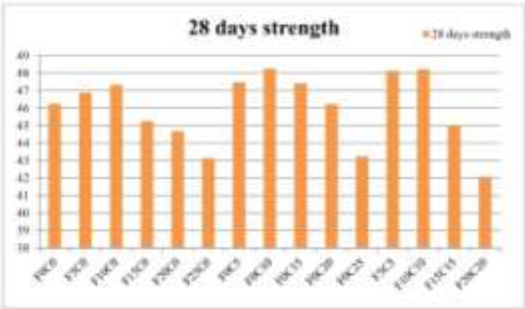

Figure 4.6– 28 days strength

4.4 Split Tensile Test

Split tensile strength is defined as a method of determining the tensile strength of concrete using a cylinder which splits across the vertical diameter. The results of the splitting tensile strength (150mm diameter x 300mm height) at 28 days are obtained in this study according to the procedures described in IS516-1959. The optimum strength is reached, when the concrete with FA and CS replacements for cement is done at 5-15%. After that, strength profiles decline. The reason for increased tensile strength may be a strong interface bond between the CS and FA paste. Irregular surfaces of CS aggregate particles are filled with hydration products. As a result, they provide better bond strength and hence, the tensile strength is increased. Usually, compressive strength is required in structural design and the tensile strength is also required in structural design for certain specific applications, such as structures in earthquake regions, airfield runways and pavement slab.

Table 4.4- Split tensile strength

S.N.	Mix identification	Tensile strength (N/mm^2)	
		7 days	28 days
1	F0C0	3.02	4.03
2	F5C0	3.17	4.18
3	F10C0	3.35	4.34
4	F15C0	3.04	4.06
5	F20C0	2.65	3.77
6	F25C0	2.45	3.55
7	F0C5	3.22	4.21
8	F0C10	3.41	4.35
9	F0C15	3.15	4.20
10	F0C20	2.84	3.98
11	F0C25	2.72	3.65
12	F5C5	3.49	4.24
13	F10C10	3.36	4.29
14	F15C15	2.76	3.84
15	F20C20	2.58	3.45

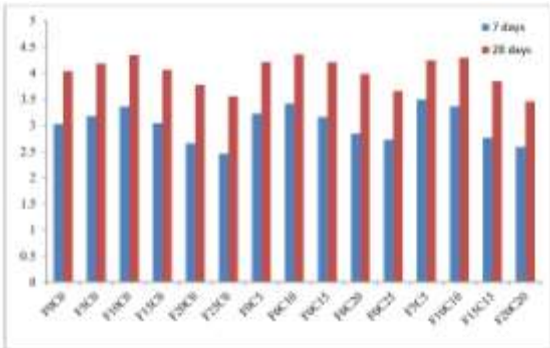

Figure 4.7– Split tensile testresults

4.5 Acid Resistance Test

Specimens were prepared and tested for acid resistance. The action of acids on hardened concrete is the conversion of ferrous compounds into the ferrous salts of the attacking acid. As a result of these reactions, the structure of concrete gets destroyed. The dimension of cube specimens was reduced 3mm at all sides. From the test results, the concrete containing copper slag was found to be lesser in resistance to the H_2So_4 solution than the control concrete.

Table 4.5- Effect of acid attack

S. N.	Mix Identif[n]	Effect of acid attack			
		Weight of cubes before and after immersion (Kg)		% Loss in wt.	Comp.Stren[th] after acid attack N/mm2
		Before	After		
1	F0C0	8.6	8.46	1.627	39.70
2	F5C0	8.36	8.04	3.827	37.14
3	F10C0	9.02	8.56	5.099	35.46
4	F15C0	9.02	8.36	7.317	33.14

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5	F20C0	9.06	8.28	8.609	32.14
6	F25C0	9.04	8.18	9.513	30.46
7	F0C5	8.36	8.04	3.827	38.14
8	F0C10	8.32	7.77	6.610	36.41
9	F0C15	9.08	8.38	7.709	35.46
10	F0C20	8.88	8.16	8.108	33.21
11	F0C25	8.96	8.22	8.258	31.12
12	F5C5	8.88	8.16	8.108	40.14
13	F10C10	8.28	7.5	9.420	39.42
14	F15C15	9.05	7.88	12.928	36.41
15	F20C20	9.04	7.86	13.052	33.12

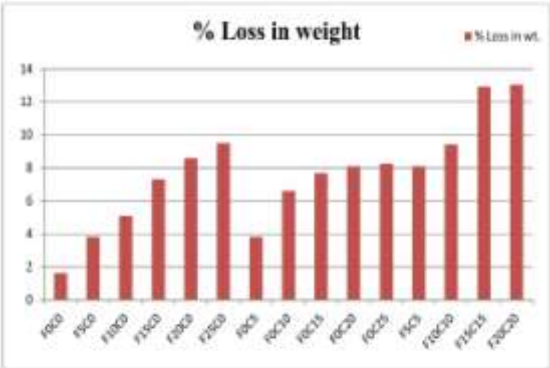

Figure 4.8– Acid resistance test results

V. CONCLUSIONS

The present study investigated the effectiveness of using copper slag and fly ash for the partial replacement of cement. Based on the investigations, the following conclusions were drawn.

1) Density of Concrete

- ➢ The density of concrete is increased, when the quantity of copper slag is increased in concrete. It happens because of high ferrous content present in copper slag.
- ➢ Based on the density of concrete, it is concluded that, higher density concrete is suitable for Reversal Loading Condition (like Bridge Counterweights), Submerged Structures, Underwater Tunnel, Radiation Shielding etc.

2) Workability

- ➢ Slump and compaction factor values are decreased, when increase the percentage of fly ash and increased, when increase the percentage of copper slag also increased, when increasing the percentage of fly ash & copper slag replacement upto 5-10% (Both) and decreased, when increasing the percentage of fly ash & copper slag replacement from 15-20% (Both).

3) Compressive and Tensile Strength

- ➢ In concrete with FA alone, the initial rate of gain of compressive strength has decreased, due to slow pozzolanic action.
- ➢ The maximum compressive strength and split tensile strength both were achieved at 10% replacement of Copper Slag (F0C10) to the weight of cement.
- ➢ Use of pozzolanic materials increases the tensile strength of concrete. Based on the tensile strength of concrete mixture are suitable for pavement, runways and airfield constructions.
- ➢ When the fly ash and copper slag both are replaced at a same time, Best result is obtained by replacing 10% of fly ash & 10% of copper slag to the weight of cement.

4) Acid Resistance

- ➢ Corrosion rate of all the mixtures varies from low to moderate. Hence, in corroded environment, it is recommended that the reinforcement should be coated with some protective coating.

Utilisation of copper slag and fly ash as Portland cement replacement in concrete has the dual benefit of eliminating the costs of disposal and lowering the cost of the concrete. The utilization of copper slag and fly ash in concrete provides additional environmental as well as technical benefits for all related industries.

VI. SCOPE FOR FUTURE WORK

- Studies are to be made for higher grades of concrete. This work may be extended to high strength concrete with constant workability.
- Study on utilization in making bricks, hollow blocks and pavement blocks can also be carried out by using fly ash and cooper slag
- Study on utilization of copper slag and fly ash in soil stabilization can be carried out.
- Copper slag can be replaced along with fly ash, silica fume and granulated blast furnace slag in concrete and RCC members which can be tested for mechanical performances.

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