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PROPERTIES OF CONCRETE INCORPORATING COPPER SLAG AS FINE AGGREGATE AND DIATOMACEOUS EARTH AS CEMENTITIOUS MATERIAL

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Abstract-*Concrete is a composite material that consists of cement, fine aggregate, coarse aggregate and water. There is a need of alternatives for the conventional constituents of concrete for the safety of environment. This study aims to analyze the compatibility of a natural pozzolana diatomite and waste material copper slag in partial replacementof cement and fine aggregate respectively in concrete. At first when the diatomite was added to the concrete by different percentages, 4% diatomite content shows the maximum strength. This was obtained by conducting the standard cube compression test. In the 4% optimum mix, the copper slag was added by different percentages from 30 to 70. Copper slag content of 40% showed the maximum strength in all the standard tests like cube compression, flexural strength, split tensile test. More properties were analyzed by conducting the durability tests like bulk diffusion, carbonation and Sulphate resistant test in concrete containing different percentages of copper slag and 4% diatomite (D4C40). The strength generating property were confirmed by conducting load deflection test of optimum mix specimen and the conventional concrete specimen in loading frame of 100T capacity. From that test, the mix D4C40 specimen was found to have 43% higher strength than the conventional concrete.*

***Keywords**: copper slag; pozzolana; diatomite; conventional concrete; durability test; load deflection test*

I. INTRODUCTION

Concrete is a composite material composed of coarse aggregate fine aggregate and cement together with water which hardens over time. To reduce the extensive use of natural resources for the production of constituents of concrete we have to introduce suitable materials in concrete. Pozzolans are siliceous or siliceous and aluminous materials which possess cementitious property when react with the calcium hydroxide generated by the reaction of water with cement. Diatomite is a sedimentary rock primarily composed of skeletons of microscopic single celled aquatic plants called diatoms. These are composed of amorphous silica. They are light in weight, chemically stable and inert. The benefits of pozzolana use in cement and concrete are threefold. First is the economic gain, second is the lowering of greenhouse gases emitted during the cement production and the third is the increased durability.

Copper slag is one of the materials that is considered as a waste material and having a promising future in construction industry. It is a by-product obtained during the refining of copper. To produce every ton of copper, approximately 2.2-3.0 tons of copper slag is generated as a by-product material. Copper slag has also gained popularity in the building industry for use as a fill material. Contractors may also use copper slag in place of sand during concrete construction and also the formation of blocks. Copper slag is widely used in the sand blasting industry and it has been used in the manufacture of abrasive tools to remove rust, old coating and other impurities in dry abrasive blasting due to its high hardness (6-7 Mohs), high density (2.8- 3.8 g/cm^3) and low free silica content[3].

II. EXPERIMENTAL DETAILS

2.1 Materials

The materials used in this investigation were: Ordinary Portland cement, coarse aggregate, fine aggregate, diatomite, copper slag and potable water. The properties of each material in concrete mix were studied at this stage.Ordinary Portland cement of 53 grade conforming to IS 12269 was usedand its properties are shown in Table 1. Crushed stone sand and copper slag were used as fine aggregate. Laboratory tests were conducted on fine aggregate to determine the different physical properties and it is shown in Table 2. Crushed granite stones obtained from local quarries were used as coarse aggregate. The nominal size of coarse aggregate was 20 mm and its properties are shown in Table 3. Thediatomite was collected from ASTRRA chemicals Chennai and copper slag was collected from Blastline industries, Cochin.The Chemical composition of diatomite wereshown in Table 4 and physical properties of copper slag were shown in table 5. Potable water was used as mixing water.

Table-1 Properties of cement

PARTICULARS	VALUES
Fineness of cement	3%
Specific gravity of cement	3.13
Consistency of standard cement paste	30.25%
Initial setting time	85minutes
Final setting time	260minutes

Table-2 Properties of fine aggregate

PARTICULARS	VALUES
Specific gravity	2.6
Sand type	Medium
Grade	Zone II

Table-3 Properties of coarse aggregate

PARTICULARS	VALUES
Specific gravity	2.74
Porosity	42.25%
Bulk density (g/cm^3)	1.58
Void ratio	0.73

Table-4 Chemical composition of diatomite

Chemical component	% of Chemical Component
SiO2	69.20
Fe2O3	9.49
Al2O3	21.74
CaO	1.63
MgO	0.64
Na2O	-
K2O	-
SO3	-

Table-5 Physical properties of copper slag

Physical properties	Copper Slag
Particle shape	Irregular
Appearance	Black and glassy
Specific gravity	3.93
Percentage of voids %	34
Water absorption %	0.18
Moisture content %	0.13
Fineness Modulus	3.28
Bulk density	1900 Kg/m3

2.2 Mix proportioning

M30 grade concrete was designed as perIS 10262-2009 based on the material properties. The same mix proportion was used for all the mixes in order to compare the properties. The concrete mix proportion of 1:1.45:2.6with water cement ratio 0.44. Table 6 shows the details of the mix.

Table-6 Details of the mix

Water	Cement	Coarse aggregate	Fine aggregate	Super plasticizer	W/C Ratio
153.26	436 kg	1141.018 kg	635.88 kg	0.35%	0.44

In this mix the cement was replaced with diatomite by 0%, 4%, 6%, and 8%. The optimum percentage of diatomite was found out by cube compressive strength at 7 and 28 days. Based on this optimum percentage of diatomite another set of mix containing 30%, 40%, 50%, 60%, 70% copper slag were prepared. The specimens of these mixes were tested in the laboratory for finding the optimum percentage of copper slag in the concrete.The fresh properties are also analyzed using compacting factor test and slump cone test. The tests for determining the mechanical properties are cube compressive strength test, flexural strength test, split tensile test and modulus of elasticity. Also conducting durability parameters such as bulk diffusion test, Sulphate attack and carbonation test.The given designations for different percentages of diatomite and copper slag are shown in Table 7.

Table-7 Mix designation

Mix	Composition
D0	0 % diatomite
D2	2% diatomite
D4	4% diatomite
D6	6% diatomite
D8	8 % diatomite
DoptC40	Optimum diatomite and 30% copper slag
DoptC40	Optimum diatomite and 40% copper slag
DoptC50	Optimum diatomite and 50% copper slag
DoptC60	Optimum diatomite and 60% copper slag
DoptC70	Optimum diatomite and 70% copper slag

2.3 Specimen preparation and curing

Curing is the process of preventing the loss of moisture from concrete while maintaining a satisfactory temperature. After casting the moulded specimens are stored in the laboratory and at room temperature for 24 hours from the time of addition of water to dry ingredients. After this period the specimens are removed from the moulds, immediately submerged in clean and fresh water. And each specimen will be tested after 28 days. Preparation of concrete and the curing of specimens were shown in Fig 1 and Fig 2.

Figure-1 Mixing of concrete

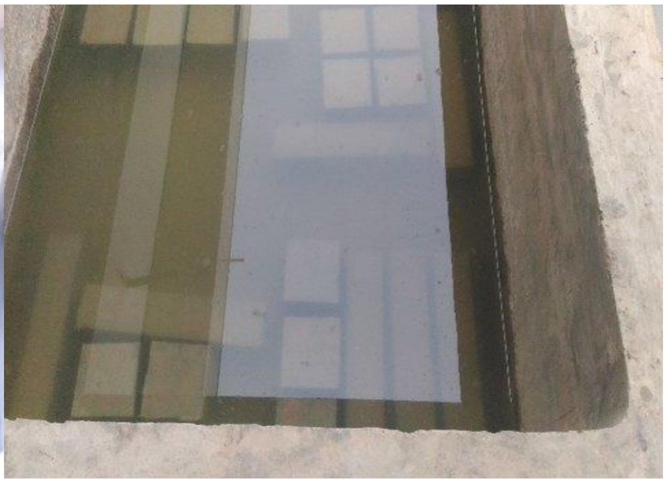

Figure-2 Curing of specimens

Cube specimen of 15x15x15cm and 10x10x10cm, 1000x150x250 mm beam specimens, 15cm diameter and 30cm height cylinder specimens, 10cm diameter and 20cm height cylinder specimens and 50 x 10 x 10 cm beams specimens were casted. A total of 196 specimens were casted for the experimental study.

2.4 Workability of fresh concrete

Freshly mixed concrete remains plastic for only a short time. Plastic concrete properties are important because they affect the quality and in-place cost of the hardened concrete. For most applications, fresh concrete should flow sluggishly without segregating. Workability is the term used to describe the relative ease or difficulty of handling, placing and consolidating concrete.Slump test is the most commonly used method for measuring workability of concrete in laboratory or site.It was observed that the workability reduced as copper slag content increased. This indicates the increase in copper slag content leads to the restriction of flow of concrete. Super plasticizer was added to increase the workability. Due to the presence of diatomite having higher surface area and water absorption capability the slump value gets decreased.

It is one of the most efficient tests for measuring the workability of concrete. 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.As the copper slag content increases the compaction factor decreases. This shows the reduction in the workability. This is due to the water absorbing nature of diatomite present in each mix.

2.5 Strength study on hardened concrete

The compressive strength of concrete will be measured by breaking concrete cube specimens in compression testing machine. 7 and 28 day compressive strength test were conducted on three specimens having size 150mm x150mm and the average strength was taken as the cube compressive strength of concrete. This test was carried out for mixes containing 0%, 2%, 4%, 6% and 8% diatomite to find the optimum percentage of diatomite. The details of the test were shown in Table 8.

Table-8 Compressive strength of specimens containing different percentages of diatomite

Mix	Strength after 7 days (MPa)	Strength after 28 days(MPa)
D0	25.33	37.55
D2	22.66	24.8
D4	24	27.7
D6	23.11	26
D8	21.7	25.4

The diatomite shows a lower compressive strength when compared with conventional concrete. But in the specimens containing 4% diatomite, the strength gets nearly as the mean compressive strength ie, 30N/mm^2. So the 4% diatomite content were taken as the optimum value. The test set up were shown in Fig 3.The mixes containing optimum percentage of diatomite, ie, 4% were taken for the optimum calculation of copper slag. In that mix the fine aggregate were replaced with copper slag by 30, 40, 50, 60 and 70%.Mechanical tests and durability tests were conducted in these mixes. The compressive strength details of mixes containing optimum diatomite content and the different percentages of copper slag were shown in Table 9.

Figure-3 Compression testing

Table-9 Compressive strength of specimens containing different percentages of copper slag

Mixes	7th day compressive strength (MPa)	28th day compressive strength (MPa)
D0C0	25.33	37.55
D4C30	24.55	39.9
D4C40	28.33	42.77
D4C50	26.77	39.74
D4C60	24.88	36.67
D4C70	21.33	34.11

Flexural strength is a measure of the tensile strength of concrete. The test confirms to IS 516- 1959. It will be measured by breaking concrete beams of size 10 x 10 x 50 cm. The test was carried out after 28 days. The experimental set up and specimen for flexural test were shown in Fig 4 and Fig5.

Figure-4 Flexural strength

Figure-5 Test Beam specimen

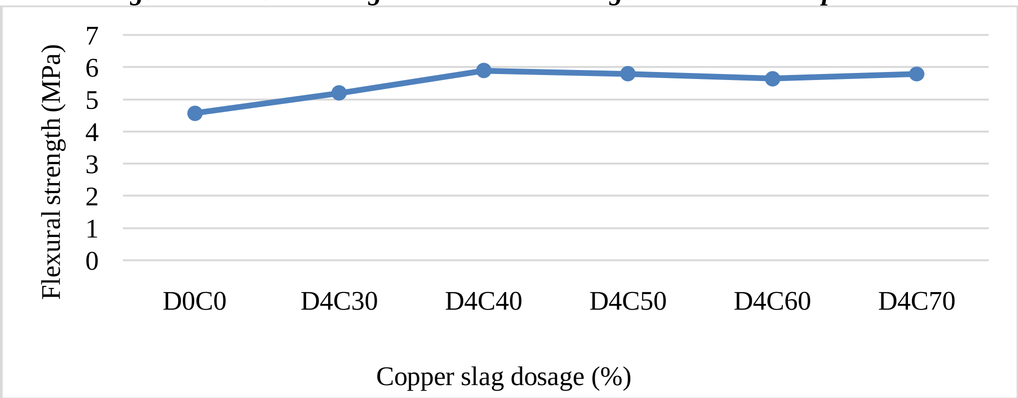

Figure-6 Flexural strength variation with copper slag dosage

Fig 6 shows the flexural strength variation with copper slag dosage. The results show that there was an increase in flexural strength as the copper slag content increased. At an optimum dosage of 40% copper slag by weight of sand indicated the maximum flexural strength. This indicates that the added copper slag in the matrix acts as a crack arresting mechanism and improves tensile strength of concrete. Beyond the optimum, dosage the flexural strength was reduced. But it remains similar that of D4C40 mix. This can be justified as the extra amount of copper slag reduces the free flow of concrete and the compaction achieved.

The split tensile strength is the tensile strength of concrete determined indirectly by splitting a concrete cylinder specimen across its vertical diameter.For split tensile strength test, cylinder specimens of size 15 cm diameterand 30 cm heightwere used.The failure of concrete in tension is governed by micro cracking, associated particularly with the interfacial region between the aggregate particles and the cement, also called interfacial transition zone. The load applied on the cylindrical concrete specimens induces tensile and shear stresses on the aggregate particles and the cement paste. Fig 7 shows the test set up.

Figure-7 Split tensile strength on cylinder

The split tensile strength of the mixes were showing an increasing trend when compared to that without copper slag content. The mix containing 40% copper slag shows high strength and the increase in copper slag content reduces the strength. D4C40 mix shows 18% higher split tensile strength than the D0C0 mix. Table 10 shows the test result.

Table-10 Split tensile strength after 28 days

Mix	Strength after 28 days, f_t (MPa)
D0C0	3.5
D4C30	3.75
D4C40	4.13
D4C50	3.9
D4C60	3.5
D4C70	3.4

The modulus of elasticity, denoted as E, is defined as the ratio between normal stress to strain below the proportional limit of a material, according to IS 516-1959, and it is used to measure instantaneous elastic deformation. The elastic modulus is then calculated by determining the slope of the straight line in the stress-strain diagram. Test specimen is a concrete cylinder of 15 cm diameter and 30 cm height. The axial deformation of the cylinder was measured using a dial gauge of accuracy 0.002 mm fitted to a longitudinal compressometer of gauge length 200 mm. A series of readings were taken with in the elastic limit. The test was conducted after 28 days of curing. The Fig8 shows the test set up for modulus of elasticity. Variation of modulus of elasticity are shown in Table 11.

Figure-8 Experimental set up for finding modulus of elasticity

Table-11Modulus of elasticity after 28 days

Mix	Strength after 28 days, ft (GPa)
D0C0	29.836
D4C30	28.5
D4C40	27.9
D4C50	27.2
D4C60	26.68
D4C70	25.89

The modulus of elasticity decreases with the increase in copper slag dosage. This is due to the high strains in higher percentages of copper slag and also due to the reduction in workability.

2.6 Durability study on hardened concrete

Durability is described as the ability of concrete to resist wear and tear without breaking up. It can be determined by carbonation, sulphate resistance and bulk diffusion tests.Carbonation occurs in concrete as the calcium bearing faces are attacked by carbon dioxide of air and are converted to calcium carbonate.The cylinder specimen of 10x20 cm will be casted and split into halves in longitudinal direction using UTM. The broken face is sprayed with a solution of phenolphthalein diluted in alcohol. The uncoloured area will indicate the carbonated region. Specimen tested for carbonation is shown in Fig 9.It was observed that the carbonation effect gets reduced as the percentage of copper slag increases. From the results the mixes containing 50% and more copper slag shows low carbonation effect than the other mixes. Fig 10 shows the variations in the carbonation depth for various mixes.

Figure-9 Carbonation test

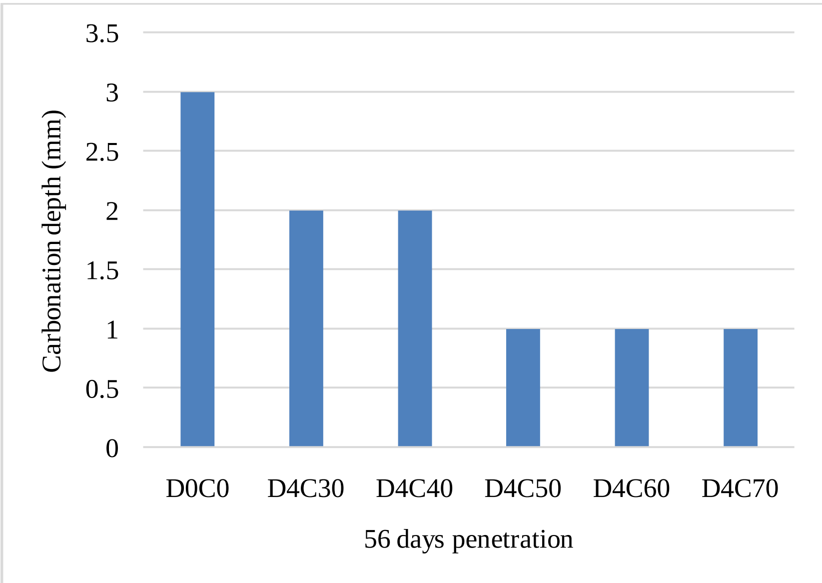

Figure-10Variation of carbonation depth

For Sulphate resistance test the cube specimens of 10cm size were kept in water for 3 days of curing and then in magnesium sulphate solution for 56 days. The compressive strength and the loss of mass of cube specimens with and without Sulphate attack were compared after 56 days of curing. Table 12shows the strength variation of different samples.

Table-12 Strength variation after 56 days

Mix	Water cured strength (MPa)	Sulphate cured strength (MPa)	Percentage strength loss (%)
D0C0	42.37	37	12.6
D4C30	42	37.5	10.71
D4C40	46.9	42	10.44
D4C50	39.8	35.7	10.3
D4C60	36.59	32.9	10.08
D4C70	35.62	32.1	9.8

The percentage loss of strength after 56 days of each specimens were compared with the control mix specimen. The strength loss were found to be less than that of the control mix for each specimen containing 4% diatomite and different copper slag percentages.The mass variation of samples of different mixes are shown in Table 13. The percentage loss of mass of each specimen containing copper slag and diatomite were found to be less than that of the control mix. From the percentage loss of strength and mass it can be analyzed that the mixes containing 4% diatomite and different percentages of copper slag shows better performance in sulphate attack.

Table-13 Mass variation of specimens after 56 days

Mix	Mass of water cured specimen (kg)	Mass of sulphate cured specimen (kg)	Percentage weight loss(%)
D0C0	2.74	2.6	5.1
D4C30	2.76	2.7	2.17
D4C40	2.8	2.73	2.5
D4C50	2.82	2.75	2.48
D4C60	2.82	2.74	2.8
D4C70	2.86	2.79	2.4

Bulk diffusion test was used to determine the attack of chloride ions in the concrete. The nature of concrete were analyzed by using the diffusion coefficient calculated from the depth of penetration of chloride ions. For evaluating the depth of penetration, the split surface of 10x20 cm cylinders exposed to 1.8 M NaCl solution for 56 days were sprayed with the 0.1 M $AgNO_3$ solution. The development of white precipitates in the split surface indicates the chloride penetration. The depth of penetration of chloride ions and the diffusion coefficient are shown in Table 14.Based on these results it was analyzed that all the concrete mixes were of low permeability in nature.In high percentages of copper slag the concrete becomes more permeable than the lower percentage concretes. Fig 11 shows the test specimen.

Table-14 Depth of penetration and diffusion coefficient for different mixes

Mix	Depth of penetration (mm)	Diffusion coefficient (10^{-12})m^2/s
D0C0	5	0.322
D4C30	3	0.116
D4C40	3	0.116
D4C50	4	0.206
D4C60	5	0.322
D4C70	5	0.322

Figure-11 Specimen for bulk diffusion test

2.7 Load deflection test

The beam specimens were tested under simply supported condition in loading frame of 100T capacity. The testing arrangements consist of loading frame, hydraulic loading jack and digital measuring system. The beam specimens of 1000x150x250 mm were used for load deflection testing. All these specimens were tested after 28 days of curing. The test set up is shown in Fig 12.

Figure-12 Load deflection test set up

The ultimate load and deflection of control beams and copper slag and diatomite admixed beams are shown in Table 15.The ultimate load obtained for the concrete containing 4% diatomite and 40% copper slag (D4C40) shows 43% higher strength than the ordinary concrete mix (D0C0). This is mainly due to the bonding with natural pozzolana diatomite and the copper slag.

Table-15 Load deflection test results

Specimen	Ultimate load (kN)	Maximum deflection(mm)
Control beam (D0C0)	191	4.64
Final mix (D4C40)	273	8.99

III CONCLUSION

Based on the results and observations of the experimental investigation presented in this study, the following conclusions could be drawn:

1. Pozzolana materials can be used with cement in concrete. This contributes strength to the concrete.
2. Adding diatomite reduces the strength when compared with conventional concrete.
3. In concrete, the cement can be replaced with diatomite by about 4%. The concrete contains 4% diatomite shows strength nearly as that of target strength.
4. The workability of concrete decreased with the increase in the copper slag content.
5. By adding copper slag to the diatomite admixed concrete in place of sand, the compressive strength, split tensile strength and flexural strength gets increased. 40% replacement of sand with copper slag was found to be the maximum.
6. Compressive strength of D4C40 get increased by 13.9% than the control mix specimens.
7. An increase of 29% was found in flexural strength in the D4C40 mix than the D0C0 mix.
8. The split tensile strength gets increased by 18% than the conventional mix.
9. By the durability tests such as bulk diffusion, carbonation and sulphate resistance test, the mixes containing higher percentages of copper slag shows more durable characteristics.
10. By the load deflection test, the ultimate load carrying capacity of D4C40 specimens were found to be 43% higher than that of the conventional mix specimens.
11. The D4C40 mix which contains 4% diatomite and 40% copper slag is economical than the conventional concrete (D0C0).

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