Experimental Study on High Strength Concrete Developed Using Industrial Waste

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Abstract

Rapid urbanization of all metro cities results in intensive construction activities. Now-a-days it has become inevitable to go for tall structures to cater to the infrastructure requirements. High strength concrete are required for construction of tall structures. So there is a need for developing high strength concrete. Also, the construction industry is in need of searching an alternative material for natural resource like sand and aggregate to reduce environmental pollution. The objective is to develop a green concrete by utilizing the available copper slag (industrial waste) to replace the river sand in concrete and to achieve high strength and high durability which will minimize the cost of construction material and produce high strength concrete. Different materials such as silica fume, fumed silica and quartz powder have been tried to develop ahigh strength concrete. An alternate slag was identified to replace the river sand. Also that, coarse aggregate is completely avoided resulting in high dense concrete. Various tests have been carried out to enhance the mechanical properties of the developed concrete mixtures. The maximum compressive strength, split tensile strength and flexural strength obtaind are 76.88,11.24 and 10.13MPa, respectively.

Keywords: *High strength Concrete, Copper Slag, Green Concrete, Accelerated Curing, Fumed Silica*

1. Introduction

At present, across the world around 33 tonnes of copper slag is generated while in India by three copper producers namely Sterlite, Birla Copper and Hindustan Copper produce around 6-6.5 tonnes of slag at different sites. Used copper slag is the largest source of waste from shipyards and refineries. A single copper industry produces 4 lakh ton/year of copper and during the process, around 8 lakh ton of copper slag is generated in a year, for every ton of a metal, 2.2 tons of slag is obtained. The copper is being produced from a copper concentrate containing around 30 - 35% of copper, iron and sulphur each along with around 12% of silica and 5% of calcium. While producing copper, a slag with rich iron and moderate silica content is also generated. In copper industry about 30% production goes as waste, which is not being recycled at present making it a viable alternative to be used as a aggregate. Use of industrial wastes in concrete-making will lead to a greener environment. Current options of management of this slag are Sand Blastering, recycling, Recovering of metal, Replacement of sand as a fine aggregate, production of value added products and disposal in slag dumps or stockpiles.

Fly Ash, Silica Fume and Fumed Silica are pozzolanic material which have similar constituents like Cement and can be used to improve the density and Strength of Concrete and reduces porosity.A High Strength concrete (HSC) mix has high compressive strength and has better flexural properties.Using Copper slag to replace the Coarse Material and by adding fumed silica, silica fume and quartz powder in HSC will produce a Concrete that will be more Eco-Friendly.

Smarzewki et.al (1) presents the mechanical properties of High strength concrete (HSC) at 28 and 56 days of maturation. The mathematical model has been developed for the characteristics of the material obtained from the compound composition. Dawod (2) investigated the effect of fiber on the high strength flowing concrete. Two different fibers namely steel fibers and palm were added in the concrete by volumetric fraction. Steel fiber addition in the concrete increases the compression strength, while the hybrid fiber decreases the compression strength. Kharzadi (3) studied the mechanical properties of the high strength concrete incorporating copper slag as coarse aggregate. In this research lime stone aggregate was replaced by copper slag aggregate. Compressive strength and split tensile strength of the concrete increased by 15% and 18%, respectively for using copper slag aggregates. Najimi et.al (4) reported the findings of durability of copper slag contained concrete exposed to sulfate attack. Cement was replaced with copper slag by 0, 5, 10, 15 percentages. Replacement of cement for slag improves the sulfate resistance attack against the concrete. Ambiley et.al (5) studied the properties of ultra-high performance concrete using copper slag as fine aggregates. Copper slag of three different grades (coarse, medium and fine) was used in the research with different proportions. The compressive strength obtained for hundred percentage replacement of fine aggregate by copper slag was 152 MPa.

2.Materials and Testing

In this study, specimens of various mix proportionsare prepared by trial and error method to study the compressive strength properties of the concrete at the ages of 7, 14 and 28 days. The concrete having better performance in compression strength was further studied for other mechanical properties.

2.1 Materials

Portland cement of OPC 53grade satisfies the requirement of BIS 12269-2013(6) was used in this research. Locally available silica fume and quartz powder delivered in a 50kg bag having specific gravity of 2.2 was used. The polycarboxylate ether type water reducing superplasticizer was used with specific gravity of 1.2 at room temperature. Brass coated micro steel fibre and basalt fibre were used to improve the flexural property of the mortar.

2.2. Mix Proportions

To develop a high strength concrete, the ingredients are selected based on the chemical composition and particle size. To optimize the correct mix proportions, trials mixtures with different combinations of ingredients aredeveloped and tested. It is proposed to cast 40x40x40mm and 70.6x70.6x70.6 mm cube specimens for compression test and 40x40x160mm prisms for flexural and split tension test as per the Japanese Industrial standard JIS A 1181:2005(7) and IS:4031– 1996(8). All the ingredients were weighed accurately and mixed in the variable speed pan mixer for homogeneity of the materials in the mortar.

2.3Choice of Materials

2.3.1 Particle Size Distribution

Thematerials for the mix proportions were selected based on the materials having minimum void ratio and maximum density. Copper slag was collected separately in different sieve sizes, passing 2.36mm, 1.18mm, 600µ, 300µ, 150µ, 90µand 75µ. Fig.1 shows that particle size distribution of various sizes of copper slag and river sand. As per IS code 383-2016(9) the copper slag passing through 1.18mm sieve belongs to Grading Zone II, hence it can be used as a fine aggregate for RCC works.As discussed in literature (10), the different grading of copper slag and comparing it with river sand were studied.

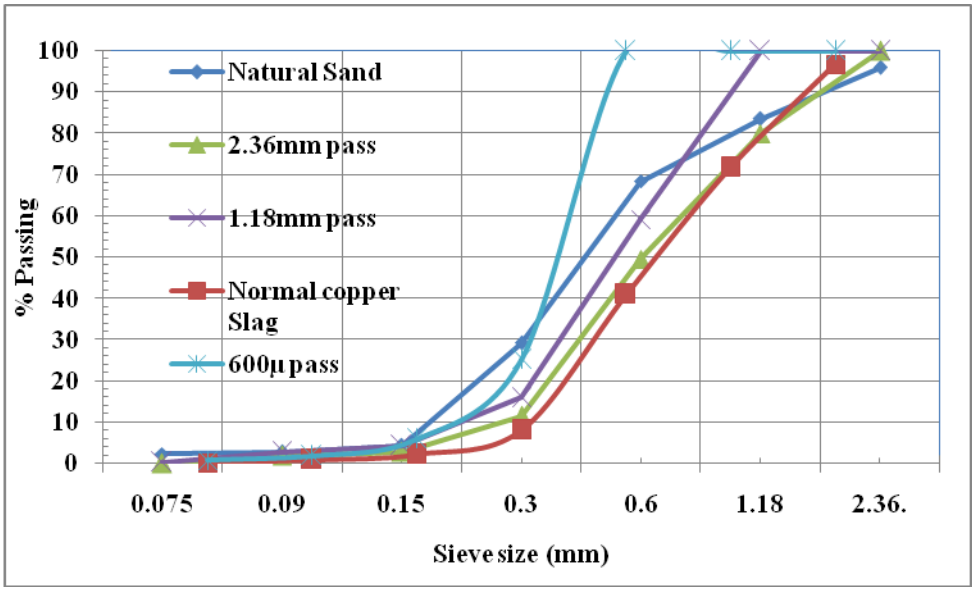

Fig.1Particle Size Distribution of Copper Slag and Natural sand

2.3.3 Selection of Mix

Based on the grading of aggregate and study of literatures, sixteen trial mixtures were tried and cured in normal water curing to evaluate the mechanical properties. Tests were conducted in universal testing machine of capacity 1000kN with ranges of 100kN, 250kN, 500kN and 1000kN. 40x40x40mm and 70.6x70.6x70.6 mm cubes were tested for compressive strength. As discussed in literatures (11), that increasing cement content will increase the compression strength, tensile strength and flexural strength. Also that, from literatures (12), the silica fume content is restricted to 5 to 10%. Figs. 2 and 3 shows the homogeneity and flow of mix and prepared test specimens from the selected mix proportions.

Fig. 2 ConcretehomogeneityFig. 3 Concrete Specimen

Based on the above trial mixtures, six mixtureswere selected and studied for compressive strength at the ages of 3, 7, 14 and 28 days, flexural strength and split tensile strength at the age of 28 days. As discussed in literatures (13), the compression strength decreases when cementitious materials like silica fume and fumed silica are replaced with cement. Hence, the cementitious materials are added to the concrete mixture rather than replacing it with cement. Table 1 shows the mix proportions of the optimized mix. The mix duration is fixed at the range of 20-30 minutes as discussed in literatures (14).

Table 1: Mix proportion of Optimized mix

Specimen Id	Cement (Kg/m^3)	Copper slag (Kg/m^3)	Silica fume (Kg/m^3)	Fumed silica (Kg/m^3)	Water / Cement ratio	SP (%)
CC1-SF	1045.45	1254.54	104.55	52.27	0.25	2
CC2-SF	1263.73	1036.26	126.37	50.55	0.23	2
CC1A-SF	920.00	1380.00	110.40	55.20	0.25	3
CC3-SF	920.00	1380.00	110.40	55.20	0.25	3
CC1B-SF	1069.77	1230.24	149.77	42.79	0.25	3

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3. Result and discussion

3.1Mechanical Properties of the Concrete

The following tests are conducted to record the mechanical properties of the concrete. The results of the compressive test at 3,7,14 and 28 day, split tensile strength and flexural strength tested at the age of 28 days are presented in Table 2.

Table 2: Mechanical properties of the Optimized Mix

Specimen Id	Compressive strength (MPa)				Split Tensile (MPa)	Flexure (MPa)
	3 days	7 days	14 days	28 days		
CC1-SF	30.68	55.00	63.02	74.06	9.84	8.91
CC2-SF	56.12	75.63	75.93	76.88	11.24	10.13
CC1A-SF	42.12	62.50	77.85	70.00	9.32	8.07
CC3-SF	39.62	48.13	62.74	75.00	10.86	9.62
CC1B-SF	43.82	48.13	56.49	65.94	8.62	7.58

From the obtained test results, the maximum compressive strength attained from the optimized mix is 76.88 MPa for the specimen CC2-SF. From the Mix ratios of the optimized mix it is studied that the quantity of copper slag should be less that the cement quantity in the concrete mix. For all other mix the quantity of copper slag is more than the cement quantity. This variations in the cement – copper slag quantity may have an impact in attaining high strength.Increasing the silicafume content in the mixture increases the compression test upto 10 % and on further addition the compression strength of the mixture started to decreases. Fumed silica was added in the concrete to improve the dispersion of the material. But addition of more amount of fumed silica increases the workability but decreases the strength. So fumed silica was limited to 2 % in the mixture and this used to maintain the workability at the constant level. As discussed in literatures (15), the compression strength can be increased from 1.5 to 2.1% by the addition of the fumed silica. Figure 4 shows the idealized stress- strain curve for the developed mixtures using copper slag as fine aggregates

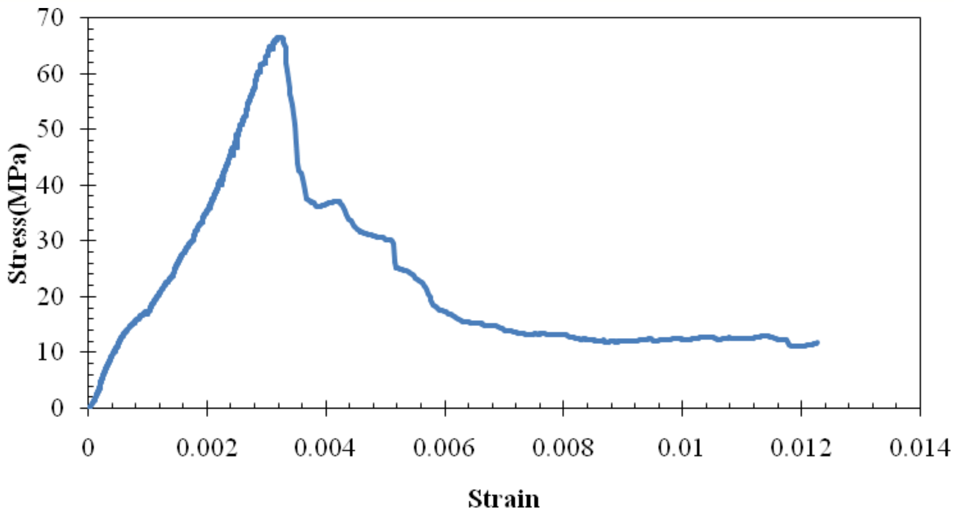

Fig.4 Idealized stress vs strain curve for concrete using copper slag as fine aggregate

From the experimental test results, the mathematical relationship was developed between tensile strength and corresponding corresponding compression strength based on CEB-FIP MC-90(16).

$$f_r = 2.3(f_c'/10)^{(2/3)} \text{-------------------------}(1)$$

$$f_{sp} = 1.04\ (f_c')^{(2/3)} \text{--------------------------}(2)$$

And also the mathematical relationship was developed between the tensile strength and the corresponding compressive strength based on the regression analysis as per ACI 318-11(17).

$$f_r = 0.57\sqrt{(f_c')} \text{----------------------------}(3)$$

$$f_{sp} = 1.17\sqrt{(f_c')} \text{----------------------------}(4)$$

From the above developed equations, flexural strength of the concrete has lower value, when compared to the ACI 318-11(17). This is because of that the developed equation was hundred percentage replacement of sand with copper slag. But the equation proposed by ACI 318-11(17) was for the concrete using sand as fine aggregate. The reduction in the value of the strength was because of the bond strength between the slag and cement in the concrete. Sand and cement has better bond strength when compared to slag and cemenet. The equation proposed for concrete specimen by Jung J.Kim based on CEB-FIB MC-90(16)correlates the experimental and mathematical results with only change in difference of 2 -3 MPa. Replacement of copper slag for sand results in lower compressive strength than control concrete but the slag usage in the concrete gives solution for disposal of waste and also depletion of natural resources.

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The mathematical relation was developed between flexure strength and tensile strength of the concrete using the experimental data. The developed equation holds good for the concrete using copper slag.

$$f_r = 0.9695 \text{ x } f_{sp} – 0.8094 \text{ ………………………… } (5)$$

(Where R^2 = 0.9844)

Where f_c' - Compressive strength of concrete f_r – Flexural strength of concrete f_{sp}-Split tensile strength of concrete

3.3 Rapid Chloride Permeability Test (RCPT)

The penetrability of concrete is obviously related to the pore structure of the cement paste matrix. This will be influenced by the water-cement ratio of the concrete, the inclusion of supplementary cementitious materials which serve to sub-divide the pore structure. The lower the quality of concrete, the greater the current at a given voltage and thus the greater heat energy produced. This heating leads to a further increase in the charge passed, over what would be experienced if the temperature remained constant. Thus, poor quality concrete looks even worse than it would otherwise. The objective of this test is to study the chloride ion penetrability into the concrete. The most important factor affecting the permeability of concrete is the internal pore structure of the developed concrete specimen. This is also dependent on the extent of hydration of the cementitious materials.The developed concrete mix has only nano particles and has less number of voids present in it. Here, normal curing is carried out for all the optimized mix and this does not have any reaction on the concrete sample when subjected to RCPT test. The rapid chloride permeability test has been done for all the optimized mixtures and the results of the mix having highest compressive strength is given below

The RCPT test has been carried out for six hours. Readings are noted down for every 30 minutes and the values are givenin Table 3. The RCPT ratings as per ASTM C1202 (18) is presented in table 4. Thus the result is compared with the tabulated value.

Table 3: RCPT Values

Time (minutes)	0	30	60	90	120	150	180
Channel Value(Ampere)	0.103	0.099	0.099	0.099	0.099	0.099	0.099

Time (minutes)	210	240	270	300	330	360	390
Channel Value(Ampere)	0.099	0.098	0.096	0.092	0.091	0.088	0.087

Table 4: RCPT Ratings (as per ASTM C1202)

Charge Passed (coulombs)	Chloride Ion Penetrability
> 4,000	High
2,000-4,000	Moderate
1,000-2,000	Low
100-1,000	Very Low
< 100	Negligible

The calculated RCPT Value (Q) from the above mentioned formula is 1926.6 Coulombs. This falls under low Chloride Ion Permeability as per ASTM C1202.

4. Conclusion

The main objective of this paper is to develop a high strength concrete by avoiding natural resources like sand. From the results obtained from the experiemnetal data, the following conclusions are arrived

- This paper studied the feasibility of completely replacing the sand by industrial waste by developing high strength concrete. The maximum compression strength achieved under normal water curing with 100% replacement with industrial waste is 76.88 MPa. For the same mix the split tensile strength is 11.24 MPa and the flexure strength is 10.13 MPa.
- It is observed that the developed had low chloride ion permeability which in general results in high durable concrete.
- The developed mix may be applied in sandwich panel's resulting in slimmer size which will intern increase the carpet area.
- The strength of the concrete can be further improved by adopting different curing regime and also by adding nano fibresviz. carbon fibres.

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