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Utilisation of glass powder in high strength copper slag concrete

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Abstract. This study was focused on the use of partial replacement of cement with glass powder in high strength concrete and also copper slag as a partial replacement of coarse sand in concrete. The high strength concrete was prepared with different mineral admixtures like silica fume, fly ash and rice ash husk in different proportions. An experimental investigation has been carried to study about the effect of glass powder on high strength copper slag concrete .The range of glass powder was 10%, 15% and 20% as a replacement of cement. The range of copper slag was 0%, 20%, 40% and 60% as a replacement of natural sand. In addition to the different percentage of fly ash, silica fume, and rice husk ash 5% and 10% was also studied in copper slag concrete. Thus, a total of 51 cubes were casted and compressive strength test was performed on them.

The result of the study shows that the value of average compressive strength of concrete after addition of 10%, 15% and 20% of glass powder are 70.47, 72.01 and 73.31 respectively. The value of average compressive strength after addition of 20%, 40% and 60% copper slag as a replacement of sand are 72.18, 74.38 and 73.08 respectively. The value of average compressive strength after addition of 5% and 10% fly ash as a replacement of cement are 71.56 and 73.22. The value of average compressive strength after addition of 5% and 10% silica fume as a replacement of cement are 72.33 and 73.53. The value of average compressive strength after addition of 5% and 10% rice husk ash as a replacement of cement are 72.86 and 69.49. At the level of 20% replacement of cement by glass powder meets maximum strength as compared to that of controlled concrete and copper slag high strength concrete.

Keywords: glass powder; copper slag; fly ash; silica fume; rice ash husk

1. Introduction

The amount of waste glass is gradually increased over the recent years due to an ever-growing use of glass products. Glass is an amorphous material with high silica content, the powdered waste glass is considered a pozzolanic material in concrete if the particle size is less than 75 μm (Schwarz *et al.* 2008, Khatib *et al.* 2012, Kumar *et al.* 2013, Patil *et al.* 2013, Shekhawat *et al.*

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2014). Naturally available sand is a common form of fine aggregate used in the manufacturing of concrete and a number of fine aggregate in the form of (Lime stone waste, stone dust, quarry dust, foundry sand, marble powder, furnace slag, welding slag, steel slag and copper slag, etc.) are available with similar physical and chemical properties of sand. Copper slag is an industrial by-product abundantly available near copper producing industries and nowadays researchers and scholars are more concerned about to utilise the different types of fine aggregate as a partial replacement of sand. Concrete is a most versatile construction material because it is designed to withstand the harsh environments. The usage of industrial by-products especially industrial slag in making of concrete is an important study of worldwide interest. Many researchers have investigated the possible use of copper slag as a concrete aggregate (Khalifa *et al.* 2009, Wei *et al.* 2010, Madheswaran *et al.* 2014) they concluded that concrete made with copper slag can be used as a replacement of sand in order to obtain good mechanical properties in addition to environmental as well as technical benefits. Moreover, many researches are also ongoing into the use of supplementary cementing materials such as ground blast furnace slag, fly ash, silica fume, rice husk ash and metakaolin as calcined natural pozzolans, to improve the properties of concrete especially in combination with raw pozzolanic material such as glass powder (Bhikshma *et al.* 2009, Qamruddin *et al.* 2013, Ghavidel *et al.* 2013, Vasudevan *et al.* 2013, Obilade 2014, Wankhede1 *et al.* 2014). This study is an attempt to use a glass powder as cement replacement in combination with silica fume, fly ash and rice husk ash with and without copper slag in high strength concrete, in order to reduce the costs of materials and provide ecological and environmental benefits. For this purpose, the optimal dosages of glass powder and copper slag were firstly obtained based on concrete compressive strength and then further study were made with others optimal proportions. The mixes were evaluated for workability, density and compressive strength.

Objective of study: The objective of the study is to investigate the mechanical properties of high strength concrete with different replacement levels of ordinary Portland cement by glass powder, fly ash, rice husk ash and silica fume individually and in combination together, further the feasibility use as a partial replacement of coarse sand by copper slag in high strength concrete.

Experimental details: A total of 51 concrete specimens were casted and tested under this investigation. The specimens were cast and tested in triplicate in order to get the average of three results. All the specimens were cast in six different series. All the specimens were of cubical shape with a size of 150 mm. The concrete mixes were designed using the specification of IS: 10262-2009 [15].

2. Materials

Coarse Aggregate: Aggregates of size 12 mm down angular crushed granite with specific gravity 2.74 and fineness modulus 7.20 were used. The bulk density in loose state and compacted state were found to be 1476 kg/m^3 and 1570 kg/m^3 respectively. The water absorption was 0.95%.

Fine Aggregate: Coarse sand having the specific gravity of 2.6 and fineness modulus 2.4 was used. The bulk density in loose state and compacted state were found to be 1605 kg/m^3 and 1770 kg/m^3 respectively. The water absorption was 1.14%.

Cement: In this study 43 grade ordinary Portland cement having specific gravity of 3.15, fineness modulus of 4.62% and normal consistency of 31% was used. As per IS 4031-1988, various tests were conducted to check the quality of cement and confirmed to specifications of IS:

Table 1 Mix design for the experiment work

Mix	C	G P	Silica Fume	Rice ash	Fly ash	FA	CS	SP	CA	W
M1	493	0	0	0	0	618	0	6	1045	165
M2	443.7	49.3	0	0	0	618	0	6	1045	165
M3	419	74	0	0	0	618	0	6	1045	165
M4	394.4	98.6	0	0	0	618	0	6	1045	165
M 5	443.7	49.3	0	0	0	494.4	123.6	6	1045	165
M 6	419	74	0	0	0	370.8	247.8	6	1045	165
M 7	394.6	98.6	0	0	0	247.8	370.8	6	1045	165
M8	394.6	98.6	24.65	0	0	618	0	6	1045	165
M9	394.6	98.6	49.3	0	0	618	0	6	1045	165
M10 M 10.	394.6	98.6	0	24.65	0	618	0	6	1045	165
M 11	394.6	98.6	0	49.3	0	618	0	6	1045	165
M 12	394.6	98.6	0	0	24.65	618	0	6	1045	165
M 13	394.6	98.6	0	0	49.3	618	0	6	1045	165
M 14	394.4	98.6	0	0	0	370.8	247.8	6	1045	165
M 15	394.4	98.6	49.3	0	0	370.8	247.8	6	1045	165
M 16	394.4	98.6	0	49.3	0	370.8	247.8	6	1045	165
M 17	394.4	98.6	0	0	49.3	370.8	247.8	6	1045	165

8112-1989.

Copper slag: Copper slag with specific gravity 3.46 and fineness modulus 3.3 was used. Bulk density in both the state was found to be 1902 kg/m^3 and 1989 kg/m^3 respectively. As per the supplier results of chemical analysis the Ferrous and Silica content in copper slag was found to be 58.29 and 25.84% respectively. The water absorption of copper slag was 0.4%.

Glass Powder: The glass powder used in the present study is brought from supplier having silica content (SiO2) 67.33%, fineness modulus 3.9, specific gravity 2.5, water absorption 0.95% and moisture content was 0.3.

Rice Husk Ash: Rice husk ash used in the present experimental study was obtained from KBRL limited Gautam Budh Nagar. This RHA contains around 85 % to 90 % amorphous silica. Rice husk ash contains silica in amorphous and highly cellular form, with 50-1000 m^2 /g surface area.

Silica Fume: Silica fume is an extremely reactive pozzolanic material. It is a by-product obtained from the manufacture of silicon or Ferro-silicon.

Fly Ash: A siliceous fly ash conforming to IS: 3812 (2003) Part-1 from national thermal power corporation (NTPC), Dadri, was used.

Superplasticizer: Glenium 51 is a high performance concrete superplasticizer based on modified polycarboxylic ether was used. The Glenium 51 is compatible with all Portland cements that meet recognised international standards.

Mix Proportion: Mix design was carried out for M60 grade of concrete as per guide lines of IS 10262:2009 and the quantities of materials were calculated as shown in Table 1.0 of all the mixes. The basic mixture was prepared with the cement content of 493 kg/m^3 and water to cement ratio of 0.28. The mix proportion of materials is 1:1.25:2.12. Glass powder was replaced with cement as

Table 2 Cube compressive peak strength

Mixes/ specimens	Strength at 28 days (MPa)	Mean compressive strength (MPa)	Standard deviation (MPa)	Variance (Standard deviation) %	Population Standard deviation (MPa)	Variance (Population Standard deviation %)
M 1	70.12 71.25 71.13	70.82	0.61	0.38	0.50	0.25
M 2	70.25 71.89 69.74	70.61	1.12	1.26	0.91	0.84
M 3	71.42 72.74 71.87	72.01	0.67	0.45	0.55	0.30
M 4	73.14 73.85 72.95	73.31	0.47	0.23	0.39	0.15
M 5	72.74 71.94 71.86	72.18	0.49	0.24	0.40	0.16
M 6	73.47 75.67 74.89	74.67	1.12	1.24	0.92	0.83
M 7	73.14 72.24 73.87	73.08	0.82	0.67	0.67	0.44
M 8	74.56 73.98 74.47	74.34	0.31	0.097	0.25	0.065
M 9	77.86 75.49 76.26	76.54	1.21	1.45	0.99	0.97
M 10	74.94 73.68 75.78	74.8	1.06	1.11	0.86	0.74
M 11	69.75 70.47 72.95	71.06	1.67	2.81	1.37	1.8
M 12	70.29 72.48 71.87	71.54	1.13	1.27	0.92	0.85

Table 2 Continued

M 13	73.65 72.43 73.59	73.22	0.68	0.47	0.56	0.31
M 14	74.62 73.25 74.86	74.24	0.86	0.75	0.70	0.50
M 15	75.26 76.89 76.94	76.36	0.95	0.91	0.78	0.60
M 16	73.91 74.52 73.86	74.09	0.36	0.13	0.30	0.09
M 17	74.58 73.15 75.46	74.39	1.16	1.35	0.95	0.90

Table 3 Density of concrete mixes

Mix id	Density (kg/m^3)
M1	2267
M2	2285
M3	2291
M4	2293
M5	2362
M6	2378
M7	2495
M8	2411
M9	2425
M10	2389
M11	2397
M12	2378
M13	2392
M14	2476
M15	2421
M16	2456
M17	2448

10%, 15% and 20%, similarly copper slag was also replaced with sand in different batches with percentage replacements as 0%, 20%, 40% and 60%. In the third steps 5% and 10% silica fume, rice husk ash and fly ash each of were added in combination of glass powder in natural sand

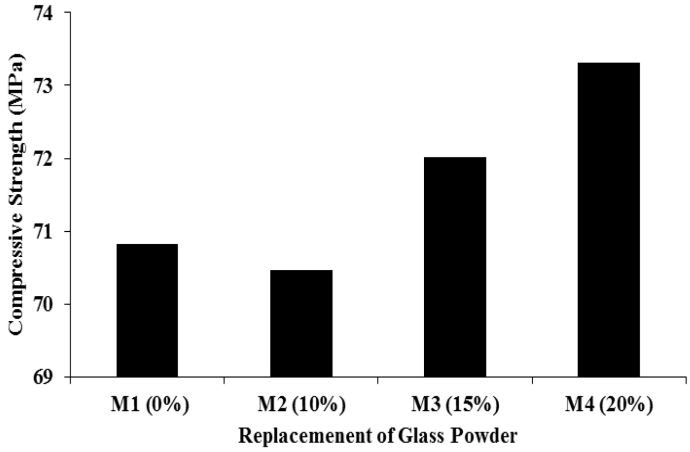

Fig. 1 Variations in compressive strength at different % age of glass powder

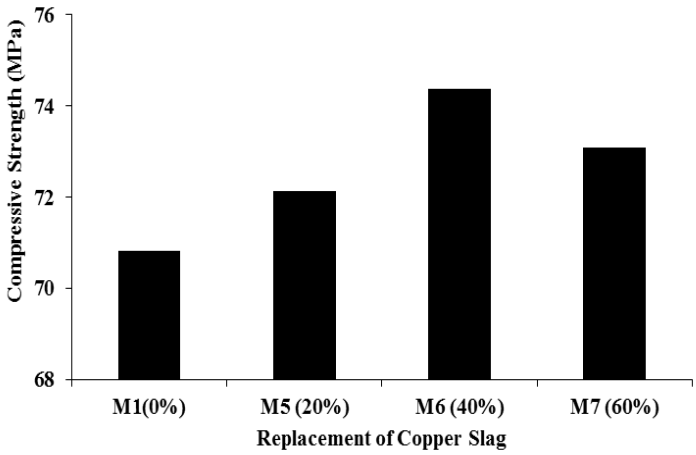

Fig. 2 Variations in compressive strength at different % age of copper slag

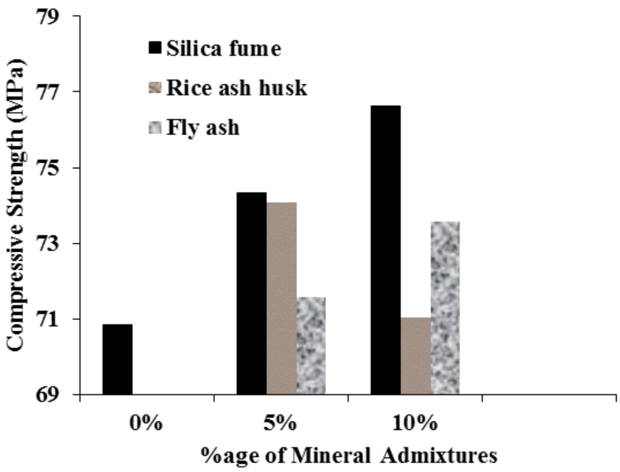

Fig. 3 Variations in compressive strength at different % age of mineral admixtures

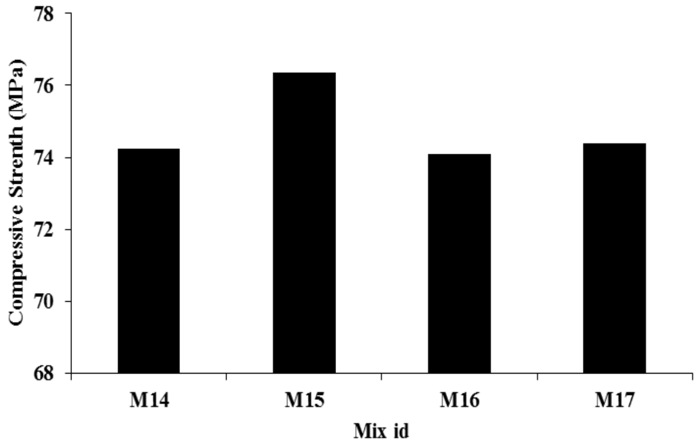

Fig. 4 Effect of mineral admixtures on copper slag glass powder concrete

concrete. In the last step of this study 20% replacement of cement will glass powder and 10% of silica fume, rice husk ash and fly ash of each were added in combination with 60% of natural sand and 40% of of copper slag according to the following table.

Casting of Cubes: Seventeen different mixes (Mix 1, to Mix 17) were prepared using cement replaced by glass powder at varying percentage of 0, 10, 15 and 20. The specimens were casted by replacing fine aggregate from 0%, 20%, 40% & 60% with copper slag. Fifty one number standard specimens of dimensions 150 mm×150 mm×150 mm were casted according to the mix proportion.

Mixing, de moulding and curing: For achieving a control concrete the proper mixing and adequate curing are required. Therefore, achieving these parameters, mixture was used for the mixing the ingredients and the process was continue till the homogeneous paste was achieved. De-moulding was done after 24 hrs of casting. Concrete cubes were thoroughly cured by using clean water and the curing temperature of the water in the curing tank should be maintained at 27±2℃ with a relative humidity should not be less than 95%.

Testing of Cubes: The compressive strength test as per IS516-1959 were carried out on all the specimens on standard compression testing machine and the results are tabulated below.

3. Result and discussion

3.1 Physical properties

The specific gravity and density of copper slag and natural coarse sand were determined in according to IS 2386 part III. The specific gravity of copper slag was 3.46 and bulk density in loose and compact form were 1902 kg/m^3 and 1989 kg/m^3 respectively. However, these values for coarse sand were 2.6,1605 kg/m^3 and 1770 kg/m^3 which may result in production of concrete with higher density. Also, the measured water absorption was 0.40 for copper slag compared to 1.14% for sand. This suggests that copper slag has less surface porosity and would demand less water than that required by sand in the concrete mix. Therefore due to the free water content in concrete matrix and also due to the higher coarseness of copper slag will increase the workability of the concrete as the copper slag content increases.

Effects of copper slag on the workability concrete: Before the fresh concrete was casted into moulds, the workability of concrete was determined on the measured slump of the fresh concrete. There is a systematic increment in slump as the glass powder in the mix increases therefore, workability increases. As there is an increment in fineness modulus of cementations material the quantity of cement paste available is more for providing lubricating effect per unit surface area of aggregate. The effects of copper slag as fine aggregate on the workability for different proportions of copper slag suggest that the workability of concrete increases with the addition of copper slag in the concrete mixes. This increment in the workability with the copper slag is attributed to the low water absorption characteristic of copper slag. The slump value of fresh concrete was recorded in the range of 70 mm to 115 mm.

Effects of copper slag on the density of concrete: The densities of all mixes are presented in Table 3. It is clear from the table that the densities of glass powder concrete seem to be the similar to the control concrete 'however' the density of glass powder concrete increases with the increment in quantity of copper slag. The density of concrete was increased by 0.6 % to 9.22%. This increment in the density of concrete is attributed to the higher specific gravity of copper slag presented in concrete mix.

Compressive strength: The results of the compressive tests of concrete are given in Table 2. From Fig. 1, the result show that the compressive strength of glass powder concrete is slightly increased when compared to control concrete. As it can be observed that by partially replacing cement with glass powder up to 20%, gives higher compressive strength compared to the conventional concrete by 3.51%. The increase in strength indicate that the glass powder contain a rich source of silica and this silica compound will react with the calcium hydroxide in the cement paste results in increase in the strength of concrete. Further high silica content effectively filled the voids gives a dense concrete microstructure. However, from the Fig. 2, the replacement of fine aggregate by copper slag at 40% gives higher compressive strength compared to the conventional concrete by 5.43% and beyond 40% compressive strength gets decreased. The above observation are supported by the other researcher who studied the influence of copper slag as a replacement of fine aggregate on high strength concrete and it is reported that the upper limit for natural sand replacement was indicated as 40%.

In Fig. 3, the compressive strength of concrete contain different percentage of mineral admixture such as silica fume, rice ash hush and fly ash are present. The compressive strength of glass powder concrete was affected much due to an increase in the percentage of mineral admixture such as fly ash, silica fume and rice husk ash with the constant water cement ratio. From the Fig. 3, it is also evident that the replacement of cement with glass powder with the combination of 10% silica fume gives the higher compressive strength compared to rice ash husk and fly-ash concrete. The results attributed due to pozzolanic reaction of fly ash and rice ash husk is a slow process as compared to silica fume concrete.

Referring the Fig. 4, in which 40% copper slag is replaced with course sand , and the cement is replaced with 20% glass powder and 10% of mineral admixtures i.e., silica fume, rice ash husk and fly ash are used. Comparing the results it shows that the overall compressive strength is achieved higher when glass powder copper slag concrete was made with silica fume. It also noted that the average compressive strength of concrete of M15, M16 and M17 in compression with M9. M11, and M13 is giving positive values which are slightly on higher side in copper slag concrete. From these results it is evident that the utilization of copper slag is used in concrete has caused some reactions which gives higher concrete strength. The use of glass powder in concrete also gives good results and has a high potential to increase the compressive strength with reducing the use of percentage of Portland cement and in co-operation into concrete as a pozzolonic material. Further it may give less cost of using this kind of admixture rather than using expensive admixtures to get the similar properties. Further the utilization of glass powder in copper slag concrete is to create a better environment and also to provide a better solution for concrete mixture to achieve the high strength concrete. Therefore, the utilization of waste glass powder in concrete as a cement replacement is possible for producing high strength concrete. Very finely ground glass whose particle size is less than 75 μm has been found to be excellent filler and may have sufficient pozzolonic properties to serve as a partial replacement of cement. The above observations are supported by the work of researchers who studied the effects of glass powder as a partial replacement of cement.

Compressive strength of concrete cubes (17 mixes×3 samples each=51 total samples) with mean compressive strength, standard deviation, variance(standard deviation), Population standard deviation and variance (population standard deviation)are presented in Table 2. The mean compressive strength of control specimen is found to be 70.83MPa and the strength varying from 70.61 MPa to 76.54 MPa with a standard deviation (SD) of 0.61 MPa and 1.21 MPa. Similarly, the minimum standard deviation and variance for other concrete specimens for different mixes are 0.31, 0.097, 0.25, 0.065 and maximum values are 1.67, 2.81, 1.37, 1.8 respectively as shown in this table. The mean compressive strength of concrete increases in mix 4 and it reaches maximum value 73.31 MPa at 20% glass powder replacement. The mean compressive strength of concrete increases in mix 6 and it reaches maximum value 74.67 MPa at 40% replacement of sand. The table also shows that the SD of compressive strength increases with the increase in copper slag content up to 40%.

4. Conclusions

The following conclusions may be drawn from the present study.

• As the percentage of glass powder increases the workability of concrete decreases however there is increase in workability in copper slag concrete irrespective of percentage of glass powder.

• Compared to the normal concrete, the copper slag based concrete achieved higher density of concrete about 9.22 percent.

• The Compressive strength of concrete increases with increase in percentage of glass powder as a replacement of cement and the higher compressive strength of concrete is achieved at 20% replacement of glass powder.

• The experimental results indicate that copper slag can be the substitute of course sand in concrete. It is observed from the results that the maximum compressive strength of concrete is achieved at 40 % of copper slag when added as replacement of fine aggregate.

• The replacement of glass powder in cement by 20%, the compressive strength of copper slag concrete mixes in M14 to M17 are 4.82%, 7.44% ,4.61% and 5.08% respectively when compared to control concrete M1 mix.

• Based on the 28-day compressive strength, concrete containing a relative dosage of 20% glass powder as cement replacements and in addition of 10% silica fume can be adopted as an optimal combination for 40% sand replacement for copper slag.

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