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Study on durability of high performance concrete with industrial wastes

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Long-term performance of structures has become vital to the economies of all nations. Concrete has been the major instrument for providing stable and reliable Infrastructure. Deterioration, long term poor performance, and inadequate resistance to hostile environment, coupled with greater demands for more sophisticated architectural form, led to the accelerated research into the microstructure of cements and concretes and more elaborate codes and standards. As a result, innovations of supplementary materials and composites have been developed.

In other side, India has an enormous growth in the steel and copper industries. The following are major by products from these industries: copper slag - a by-product of copper refinery, and ground granulated blast furnace slag (GGBS) - a by-product in the manufacture of iron in steel industry. If they are not disposed off properly, they may cause environmental hazards to the surrounding area. Considering the long term performance and stability of structures, this study suggests replacing some percentage of fine aggregate with copper slag and some percentage of cement with GGBS to develop high performance concrete. This paper presents an experimental investigation to assess the durability parameters of high performance concrete with the industrial wastes. Durability parameters such as water absorption and chloride penetration are to be studied.

Keywords: Concrete, durability, copper slag, ground granulated blast furnace slag, industrial wastes

Introduction

In India, most of the construction activities are made with concrete, as it is easily available and the moulding can be done even by unskilled labour. Thus, concrete is becoming a very important material for every human. Concrete is being used for all major constructions, like dams, towers, water tanks, houses, roadways, and railway sleepers etc.

Long-term performance of structures has become vital to the economies of all nations. Concrete has been the major instrument for providing stable and reliable Infrastructure. Deterioration, long term poor performance, and inadequate resistance to hostile environment, coupled with greater demands for more sophisticated architectural form, led to the accelerated research into the microstructure of cements and concretes and more elaborate codes and standards. As a result, new materials and composites have been developed and improved cements evolved. One major remarkable quality in the making of high performance concrete (HPC) is the virtual elimination of voids in the concrete matrix, which are mainly the cause of most of the ills that generate deterioration.

Recently, composites are fastly replacing the conventional concrete. With many major developments in concrete industry, the waste material utilisation in the manufacturing of concrete, being used as a replacement material for the ingredients, is also growing.

India has an enormous growth in the steel industries and copper industries. The Following are major by products in these industries:

- copper slag - a by-product of copper refinery;

- ground granulated blast furnace slag (GGBS) - a by-product in the manufacture of iron in steel industry.

One such company producing slag is M/S. Sterlite Industries (India) Ltd. In the process of manufacture of copper granulated slag is generated as a by-product for which the company is looking for prospective buyers. Current generation of copper is around 120 000 mt/year which will go up in near future as the capacity is being expended.

Ground granulated blast furnace slag has been dried and ground to a fine powder. Iron ore, limestone, and coke are fed into the blast furnace where they reach a temperature of 1500 ^{0}C and the raw material reduced to molten iron and blast furnace slag. These are tapped off from the blast furnace and separated for processing. Molten iron is sent to the steel producing facility and slag (GGBS) is used to make concrete in combination with Portland cement. It is the glassy granular material formed when molten blast furnace slag is rapidly chilled as by immersion in water.

Need for the study

Normal concrete lacks required strength, workability and durability which are more often required for large concrete structures such as high rise buildings, bridges, and structures under severe exposure conditions. By increasing concrete strength, the required thickness of concrete members and the cost of concrete structures can both be reduced. Therefore, it is felt necessary to improve the strength and performance of concrete with suitable admixtures to cater present need. In this study, it is planned to replace some percentage of fine aggregate with copper slag and some percentage of cement with GGBS to develop the high performance concrete.

Objectives

The objectives of this research work are to study:

- the properties of Industrial wastes and their suitability in high performance concrete.
- the behaviour as well as properties of concrete in fresh and hardened state.
- the effect of GGBS and copper slag on workability of concrete.
- the structural behaviour of high performance concrete with industrial wastes.

Methodology

The methodology for this study is given in the form of flow chart. Flow chart is given in Figure 1. For any successful investigation, numerous tests have to be performed and the trend of results should be carefully before arriving at the final conclusion. To realize the results from the tests experimental set up and testing procedures are required.

Material characteristics are the following:

a. Ordinary Portland cement 53 grade with specific gravity of 3.16

b. Locally available sand with fineness modulus of 2.86 and Specific gravity of 2.61

c. Locally available coarse aggregate with fineness modulus of 5.27 and specific gravity of 2.78

d. Ground granulated blast furnace slag with specific gravity of 2.94

e. Copper slag in granular form with fineness modulus of 3.22 and specific gravity of 3.63

f. Water confirming to the requirements of water of concreting and curing.

Mix proportions for normal conventional concrete is shown in Table 1.

FIGURE 1. METHODOLOGY FLOW CHART

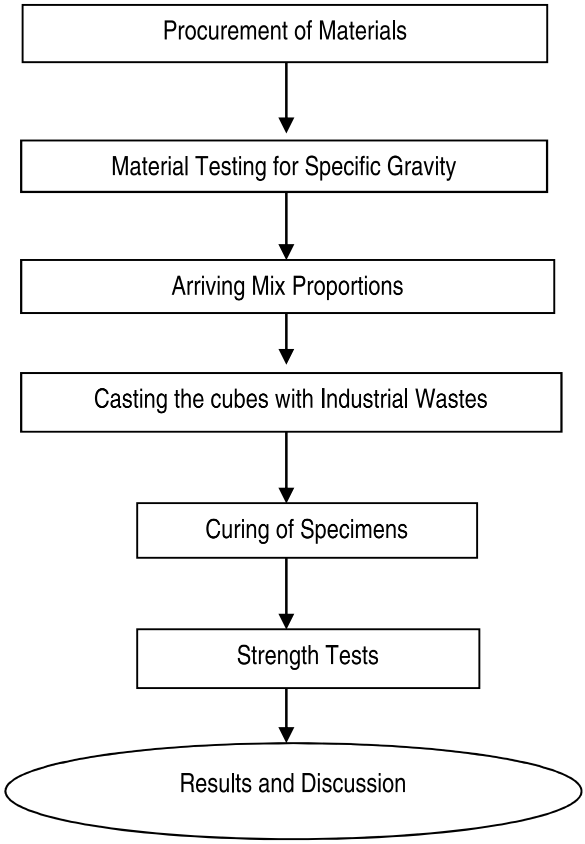


TABLE 1 MIX PROPORTIONS FOR M30 GRADE CONCRETE

S. No	Grade	Water	Cement	FA	CA
1	M30	0.370	1	1.18	2.88
		166.5 lit/m^3	450.0 Kg/m^3	531.82 kg/m^3	1296.89 kg/m^3

Correction in mix design for the replacement of cement with GGBS

Based on the above changes reviewed from the literature, the conventional IS method of concrete mix design was modified by making corrections in the compressive strength and water content

Correction on target mean strength

The target mean strength for the concrete incorporating slag is to be calculated using the formula

$$F_{ck} = (f_{ck} + tS)C$$

Where, f_{ck} - characteristic compressive strength at 28 days, MPa; S - standard deviation, Mpa (5 MPa for M30); C - multiplication constant which is obtained from the strength percentage reduction values.

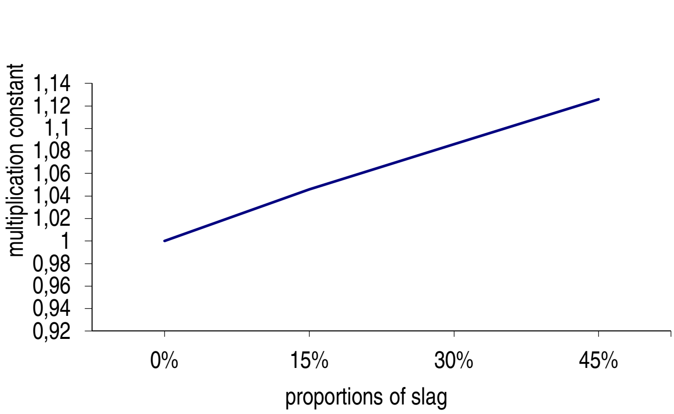
Calculation of multiplication constant

As the proportion of slag increases, the compressive strength decreases. So the target mean strength of concrete incorporating slag was multiplied by the constant C to achieve the strength of the conventional concrete. The constant C is the value of the percentage reduction in strength between the conventional concrete and the concrete incorporating slag. The generalized curve relating the proportion of slag and the multiplication constant is obtained using the software SPSS (Statistical package for the social sciences).The constant C was obtained from the equation relating the percentage reduction and proportion of slag. The multiplication constant which is to be used as a strength correction factor has been obtained and it is tabulated in Table 2.

TABLE 2 MULTIPLICATION CONSTANT FOR VARIOUS GRADES AND VARIOUS % OF GGBS REPLACEMENT

Sl.No	Concrete grade and GGBS replacement	Multiplication constant (C)
1	M30 – 15S	1.05
2	M30 – 30S	1.10
3	M30 – 45S	1.13

FIGURE. 2 GENERALIZED CURVE FOR MULTIPLICATION CONSTANT

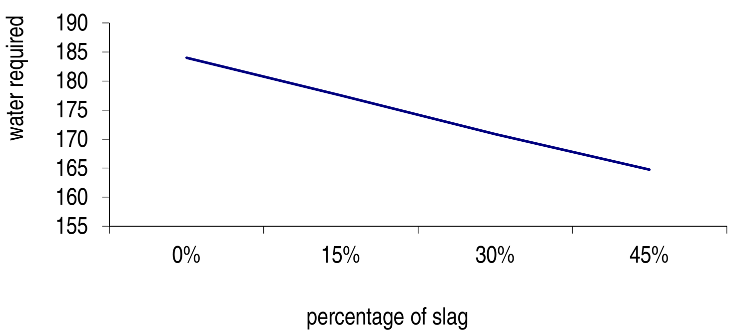


Correction on selection of water content

The lower relative density of GGBS causes an increase in paste volume. Compared to Portland cement, GGBS occupies about 9% more solid volume for the same mass. Thus, the increase in paste volume improves the workability. When slag is added to the concrete mix initially, slag particles don't react since the heat of hydration is very low. So only remaining cement particles react with water and there is always more free water. As the proportion of slag increases, the water needed for the concrete incorporating slag to maintain the same slump value as that of conventional concrete is less. Hence, water content of the mix incorporating slag is reduced so that the constant slump value is maintained. The water content of the concrete incorporating slag is reduced in order to achieve the slump value 64 mm for M30. This water correction was applied in the mix design.

The water content of the concrete incorporating slag is reduced at a percentage of 3.49%, 7.79% and 11.02% for M30 for the GGBS replacement level of 15%, 30% and 45% respectively. Thus, the overall water reduction percentage varies from 3% to 12%.

FIGURE 3 GENERALIZED CURVE FOR WATER CONTENT



Mix design for M30 grade concrete with 30% GGBS replacement levels was followed as per IS method and the ingredients are obtained as follows.

TABLE 3 MIX PROPORTIONS FOR M30 GRADE CONCRETE WITH 30% OF GGBS REPLACEMENT

S.No	Grade	GGBS Replacement with Cement	Water	Cement	FA	CA
1	M30	30%	0.35	1	1.23	3.05
			153.53 lit/m3	438.66 Kg/m3	538.08 kg/m3	1337.32 kg/m3

Correction in mix design for the replacement of sand with copper slag

The difference in Specific gravity of fine aggregate and copper slag is considered in the mix design since the copper slag have a higher density than the fine aggregate. Based on difference between the specific gravity of fine aggregate and copper slag mix proportions has been arrived for various replacement levels.

TABLE 4 MIX PROPORTIONS FOR M30 GRADE CONCRETE WITH GGBS AND COPPER SLAG REPLACEMENT

S.No	Cement-GGBS replace Ment	FA-Copper slag replace ment	Water lit/m3	Cement Kg/m3	GGBS Kg/m3	FA Kg/m3	Copper Slag Kg/m3	CA Kg/m3
1	70 – 30%	80 – 20%	153.53	307.06	131.60	455.52	113.88	1337.32
2	70 – 30%	60 – 40%	153.53	307.06	131.60	363.74	242.48	1337.32
3	70 – 30%	40 – 60%	153.53	307.06	131.60	258.89	388.89	1337.32
4	70 – 30%	20 – 80%	153.53	307.06	131.60	138.83	555.31	1337.32
5	70 – 30%	0 – 100%	153.53	307.06	131.60	0	748.39	1337.32

Schedule of test specimens

From the earlier experimental investigations, it has been observed that the optimum replacement of GGBS to cement without compromising the compressive strength is 30%. With this, it is planned to replace the fine aggregate by Copper Slag at various replacement levels. The details of test specimens to be cast are given in Table 5.

TABLE 5 SCHEDULE OF TEST SPECIMENS

S. No	Cement – GGBS Proportion	Fine aggregate - Copper Slag proportion	No of Cubes/Cylinders		
			Compressive Strength	Water absorption	RCPT
1	100 – 0%	100 – 0%	3	3	3
2	70 – 30%	100 – 0%	3	3	3
3	70 – 30%	80 – 20%	3	3	3
4	70 – 30%	60 – 40%	3	3	3
5	70 – 30%	40 – 60%	3	3	3
6	70 – 30%	20 – 80%	3	3	3
7	70 – 30%	0 – 100%	3	3	3

Tests on concrete specimens

Water absorption Test

This method is used to find the water absorption of hardened concrete based on ASTM C642-81.

Procedure as per ASTM C642-81

After 28 days curing the specimens are to be taken out from curing tank. Specimens are dried in an oven at 105 ^{0}C for 24 hrs. The dry specimens are cooled to room temperature (25 ^{0}C) weighed accurately and noted as dry weight. Dry specimens are to be immersed in a water container. Weight of the specimen at predetermined intervals to be taken after wiping the surface with dry cloth. This process is to be continued not less then 48 hours or up to constant weight are to be obtained in two successive observations.

$$\% \text{ Absorption} = \frac{\text{Saturated weight} - \text{Dry weight}}{\text{Dry weight}} \times 100$$

Rapid chloride penetration test

AASHTO T277: Electrical indication of concrete's ability to resist chloride ion penetration (Rapid Chloride Permeability Test)

In the AASHTO T277 (ASTM C1202) test, a water-saturated, 50-mm thick, 100-mm diameter concrete specimen is subjected to a 60 V applied DC voltage for 6 hours using the apparatus shown in Figure 4. In one reservoir is a 3.0% NaCl solution and in the other reservoir is a 0.3 M NaOH solution. The total charge passed is determined and this is used to rate the concrete according to the criteria included as Table 6.

FIGURE 4. ASHTO T277 (ASTM C1202) TEST SETUP

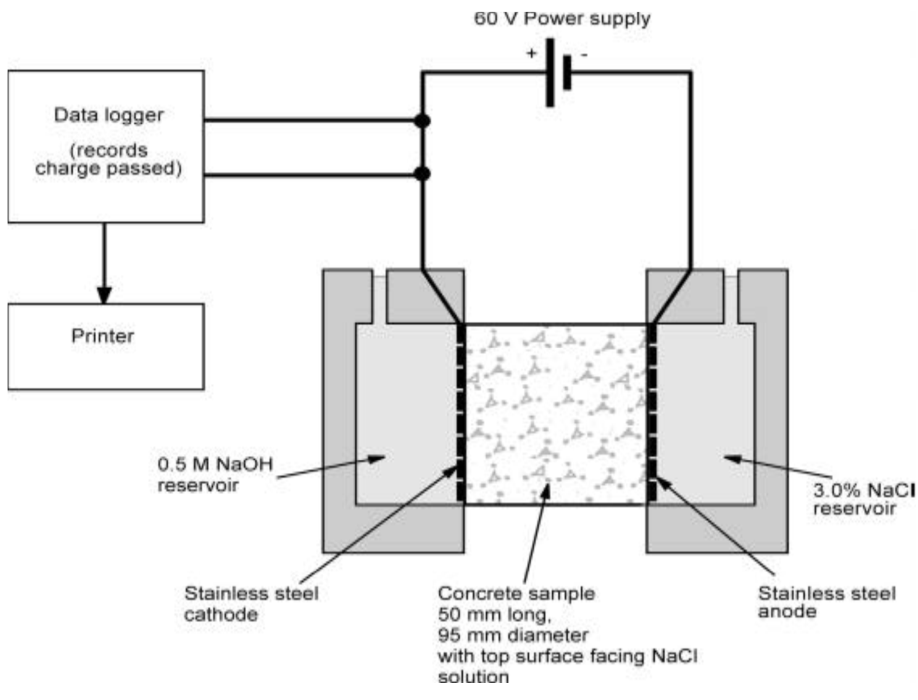


TABLE 6 RAPID CHLORIDE PENETRATION TEST (RCPT) RATINGS (PER ASTM C1202)

S.No	Charge passed (colombs)	Chloride ion penetrability
1	> 4,000	High
2	2,000-4,000	Moderate
3	1,000-2,000	Low
4	100-1,000	Very Low
5	< 100	Negligible

Alkalinity Test

After 28 days curing the specimens are taken out from curing tank. Specimens are dried in an oven at 105 ^{0}C for 24 hrs. The dry specimens are cooled to room temperature. Dry specimens are broken and separate the mortar from the concrete. Then the mortar is grinded into powder form. The powdered mortar is sieved in 150μ. 10gm of mortar is taken and it is diluted in 50ml distilled water and completely stirred it. Then the pH meter immerse into the solution and pH value of solution is noted. The general pH values of the solution and the level of inducing corrosion in the concrete were mentioned in Table 10.

Results and discussions

Slump test

The Slump test was conducted on fresh concrete for various percentage of replacement of fine aggregate with Copper slag and their results are tabulated below.

TABLE 7 SLUMP VALUES

S.No	Cement-GGBS replacement	FA-Copper slag Replacement	Slump Value in mm
1	100 – 0%	100 – 0%	60
2	70 – 30%	100 – 0%	60
3	70 – 30%	80 – 20%	65
4	70 – 30%	60 – 40%	70
5	70 – 30%	40 – 60%	75
6	70 – 30%	20 – 80%	80
7	70 – 30%	0 – 100%	85

Water absorption test

TABLE 8. WATER ABSORPTION TEST RESULTS

S.No	% Re placement of copper slag	% Decrease in Water absorption (compared with 1.548%)
1	20	20.755
2	40	46.144
3	60	66.552
4	80	74.700
5	100	76.188

Rapid Chloride Penetration Test

TABLE 9 RAPID CHLORIDE PENETRATION TEST RESULTS

Sl No.	Cement-GGBS replacement	FA-Copper slag Replacement	Total charge passed		Chloride ion Penetrability
			ICum (mA)	ICum (Coulombs)	
1	100 – 0%	100 – 0%	1261	2269.80	Moderate
2	70 – 30%	100 – 0%	884	1591.20	Low
3	70 – 30%	80 – 20%	715	1287.00	Low
4	70 – 30%	60 – 40%	624	1123.20	Low
5	70 – 30%	40 – 60%	416	748.80	Very Low
6	70 – 30%	20 – 80%	364	655.20	Very Low
7	70 – 30%	0 – 100%	286	514.80	Very Low

Alkalinity Test

TABLE 10. ALKALINITY TEST RESULTS

Sl No.	Cement-GGBS replacement	FA-Copper slag replacement	pH value of solution	Potential for corrosion
1	100 – 0%	100 – 0%	12.85	Low
2	70 – 30%	100 – 0%	12.80	Low
3	70 – 30%	80 – 20%	12.75	Low
4	70 – 30%	60 – 40%	12.75	Low
5	70 – 30%	40 – 60%	12.70	Low
6	70 – 30%	20 – 80%	12.65	Low
7	70 – 30%	0 – 100%	12.46	Low

Conclusion

Based on the above tests the following conclusions can be drawn:

1. The slump value for 100% replacement of fine aggregate with copper slag increases by 60mm to 85mm. It shows that the water consumed by the copper slag during mixing is very less as compared with river sand.
2. The water absorption for 30% replacement of cement with GGBS decreases by 4.58%. Also, the water absorption for 100% replacement of fine aggregate with copper slag decreases by 33.59%.
3. The chloride ion penetrability for 30% replacement of cement with GGBS decreases by 29.90%. Also, the 100% replacement of fine aggregate with copper slag decreases by 77.32%.
4. The pH value for 30% replacement of cement with GGBS decreases by 0.39%. Also, for 100% replacement of fine aggregate with copper slag decreases by 3.04%.

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