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Characterization and Development of Eco-Friendly Concrete Using Ground Granulated Blast Furnace Slag and Alccofine

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Abstract: This study presents a research on the compressive strength and flexural strength comparison of Ground Granulated Blast Furnace Slag (GGBS) on alccofine based concrete mix of grade M30. The compressive strength of concrete was conducted on cubes of dimension (150×150×150 mm), after the cubes were cured in a curing tank for 3, 7,14 and 28 days, respectively. GGBS was varied from 0, 15 and 30% whereas alccofine was varied from 0-20% at 5% increments. The results indicate that replacement of cement by alccofine material increases the mechanical strength (both in compression and in flexure) to a large extent and extensively at 10% replacement of cement.

Key words: Compressive strength, particle size distribution, ground granulated blast furnace slag, alccofine, grade

INTRODUCTION

Cement is an important construction material used widely in construction works. In construction industry, concrete and mortar are the most commonly used construction materials which are made using cement. "Concrete is one of the most widely used construction materials in the world. However, the production of portland cement, an essential constituent of concrete, leads to the release of significant amount of CO_2, a greenhouse gas; one ton of portland cement clinker production is said to creates approximately one ton of CO_2 and other greenhouse gases. Environmental issues are playing an important role in the sustainable development of the cement and concrete industry" (Naik and Moriconi, 2005). Environmental issues are playing an important role in the sustainable development of the cement and concrete industry (Chen, 2006). With the increase in the requirements of cement, the cost of cement has also increased resulting in the increase in pollution in terms of carbon dioxide emission. Now day's comprehensive attempts are being made in term of reduction of such demand, cost and pollution by way of using industrial waste materials without comprising the strength and durability properties of concrete. Ground Granulated Blast furnace Slag (GGBS) and alccofine are some of the alternative cementitious materials which are mostly industrial wastes. Using GGBS and alccofine in concrete helps in reducing the cost of concrete and saves the environment from pollution (Wang, 2008).

The specimens were cast and tested for M30 grade concrete with 0, 30 and 60% GGBS replacing cement and with varying dosages of alccofine from 0, 5, 10, 15 and 20% replacing cement. Compression test were carried out after 3, 7, 14 and 28 days of moist curing and flexural strength test was carried out after 28 days of moist curing (Kulkarni *et al.*, 2011).

Objectives:

- To determine the optimum dosage of GGBS and alccofine that can be used as replacement of cement in concrete
- To determine the mechanical properties of concrete in terms of compressive strength on addition of GGBS and alccofine (IS 10262, 2009)
- A comparative analysis to be made on these test results among conventional concrete, i.e., control concrete (without GGBS and alccofine) and concrete made with GGBS and alccofine (IS 383, 1970)
- To summarize the findings obtained from the analysis and discussion of test results

MATERIALS AND METHODS

Cement: The 43 grade Ordinary Portland Cement, conforming to IS: 12269-1987 was used. The cement was procured from local markets and in one lot to maintain uniformity throughout the investigation (IS 516, 1959).

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Fig. 1: GGBS (sample)

Fig. 2: Alccofine (sample)

GGBS: GGBS is a by product of the production of iron in blast furnace where iron ore, limestone and coke are heated to about 1500°C. When these materials melt in the blast furnace, two products are produced-molten iron and molten slag. The molten slag was lighter and floats on the top of the molten iron (Shetty, 2009). The process of granulating the slag involves cooling the molten slag through high-pressure water jets. The granulated slag was further processed by drying and then ground to a very fine powder, named as GGBS (Siddique, 2008) (Fig. 1 and 2).

Alccofine: Alccofine-1203 was specially processed product based on high glass content with high reactivity obtained through the process of controlled granulation. Alccofine provides reduced water demand for a given workability, up to 70% replacement level as per requirement of concrete performance. Alccofine can also be utilized as a high range water reducer to improve compressive strength or as a super workability aid to improve flowability (Upadhyay and Jamnu, 2014).

Table 1: Specific gravity for various materials

Materials	Specific gravity
Cement	3.14
GGBS	2.72
Alccofine	2.87
Fine aggregate	2.63
Coarse aggregate	2.77

Fine aggregate: The locally available river sand confirming to (IS 383, 1970) was used as fine aggregate in the present investigation. The fine aggregate was free from clay matter, silt and organic impurities (Sunil and Shah, 2013). The fine aggregate has a specific gravity 2.63 in accordance with IS 2386-1963 and the fine aggregate used conformed to grading Zone 3 as per Table 1 of (IS 383, 1970).

Coarse aggregate: Coarse aggregate from local source confirming to Anon (IS 383, 1970) was used. It was free from impurities such as dust, clay particles and organic matter. The coarse aggregate had specific gravity 2.77.

Water: Ordinary potable tap water was used for mixing and curing operations.

Concrete: Ordinary Portland cement of 43 grade was used throughout the investigation. The maximum size of aggregate was 20 mm and the size of fine aggregate ranged between 150 microns and 4.75 mm (Patel *et al*., 2013; Siddique, 2008). After casting the specimens were cured in a curing tank for about 28 days so as to help the concrete to stabilize its own properties like compressive strength and flexural strength. The strength of concrete under axial compression was determined by loading a standard cube (150×150×150), cylinder (150 mm diameter and 300 mm length).

Experimental investigation: This deals with the laboratory tests done to assess various properties of materials to achieve the objectives. Different mix proportions are designed and standardized. The aim of the study is to determine the compressive strength and flexural strength of concrete cubes and cylinder cast with various mix proportions.

Primary laboratory test

Specific gravity: The specific gravity of the materials used for making concrete was determined as per IS 2386-1963. Table 1 shows the specific gravity values for various materials.

Sieve analysis: Locally available river sand was used as a fine aggregate (150 μ to 4.75 mm) on which sieve analysis was conducted to determine the fineness as per IS 383-1970. Fine aggregate used conformed to grading Zone 3 as per Table 2 of IS 383:1970 with fine modulus 2.63 (Bagade and Satone, 2012).

Physical and chemical properties: GGBS comprises mainly of CaO, SiO_2, Al_2O_3 and MgO and it contains <1% crystalline silica, along with <1 ppm water soluble chromium IV. It has the same main chemical constituents as ordinary Portland cement but in different proportions. Table 2 shows the chemical constituents present in GGBS, cement and alccofine (Brightson *et al*., 2014). Because of these chemical similarities, GGBS can be used as a replacement material for Portland cement in concrete mixes by as much as up to 95% according to European standard (BS EN 197-1:2000, 2000). Table 2 shows the physical properties of GGBS (Ramalekshmi *et al*., 2014).

Workability test: The workability test was carried out using a mould known as a slump cone. The cone was placed on a hard non-absorbent surface (Brightson *et al*., 2014; Ramalekshmi *et al*., 2014). This cone was filled with fresh concrete in three layers, each layer was tamped 25 times using a tamping rod of standard dimensions. At the end of the third layer, concrete was struck off flush to the top of the mould. The mould was carefully lifted vertically upwards, so as not to disturb the concrete and the slump value was measured in a standard manner. It was found to be 35 mm.

Strength properties

Compressive strength: The compressive strength is the capacity of a material or structure to with-stand loads tending to reduce size. It can be measured by plotting applied force against deformation in a testing machine (Naik and Moriconi, 2005). Some materials fracture at their compressive strength limit while others deform irreversibly, compressive strength is a key value for design of structures. For this study concrete cubes of size 150×150×150 mm were prepared.

Table 2: Physical properties of GGBS

Colors	Off-white powder
Bulk density (loose)	1.0-1.1 tonnes/m^3
Bulk density (vibrated)	1.2-1.3 tonnes/m^3
Relative density	2.85-2.95
Surface area	400-600 m^2/kg Blaine

Table 3: Chemical properties of cement, GGBS and alccofine

Chemical properties	OPC (%)	GGBS (%)	Alccofine (%)
SiO_2	61.55	11.00	34.00
Al_2O_3	19.65	10.18	33.20
Fe_2O_3	5.65	2.02	22.50
CaO	5.40	51.00	1.40
SO_3	2.40	-	0.11
MgO	3.90	11.20	6.20

RESULTS AND DISCUSSION

Table 4 shows the calculated compression test of concrete cubes after 3, 7, 14 and 28 days of moist curing.

Compressive strength: Table 5 shows the percentage variation in compressive strength when compared with the control mix. Observations based on results are as shown (Upadhyay and Jamnu, 2014) (Fig. 3).

The 3 days compressive strength of concrete with 10% alccofine replacing cement (C90G0A10) mix gave 75% higher compressive strength than the control mix (C100G0A0) and 11.687 % higher on the 28 days. It was also found that concrete mix with 10% alccofine (C90G0A10) strength was 62% higher than concrete with 30% GGBS (C70G30A0) mix. The 7 days compressive strength of concrete without GGBS and with 10% alccofine (C90G0A10) mix was 39% higher than the control

Table 4: Compressive strength of various concrete mixes

	Compressive strength (N/mm^2)			
Mix designation	3 days	7 days	14 days	28 days
C100G0A0	13.33	21.27	27.38	32.300
C70G30A0	16.06	24.46	27.95	32.280
C40G60A0	20.13	20.59	22.52	29.020
C95G0A5	17.46	23.24	26.75	32.430
C65G30A5	17.77	25.67	26.39	30.350
C35G60A5	15.82	20.28	29.28	31.970
C90G0A10	23.28	29.46	31.37	36.075
C60G30A10	15.82	26.55	27.51	36.480
C30G60A10	14.97	23.88	25.46	27.460
C85G0A15	14.21	26.66	27.39	30.310
C55G30A15	18.88	23.68	27.37	28.640
C25G60A15	13.84	22.37	23.72	25.770
C80G0A20	13.49	24.68	25.95	28.670
C50G30A20	16.97	22.24	26.14	26.850
C20G60A20	12.54	21.53	22.41	24.470

Table 5: Percentage variation in compressive strength when compared with control mix

	Control mix days (%)			
Mix designation	3	7	14	28
C100G0A0				
C70G30A0	20.480	14.9970	2.0810	-6.190
C40G60A0	51.012	-5.3590	-17.7500	-10.150
C95G0A5	30.980	9.2610	-2.3000	0.400
C65G30A5	33.080	20.6860	-6.2450	-6.037
C35G60A5	18.679	-4.6540	7.3040	-1.021
C90G0A10	74.640	38.5040	14.5720	11.687
C60G30A10	18.679	24.8230	0.4740	12.940
C30G60A10	12.303	12.2700	-7.0120	-14.980
C85G0A15	10.277	25.3400	0.0360	-6.160
C55G30A15	41.635	11.3300	-0.0365	-11.330
C25G60A15	3.825	5.1710	-13.3670	-20.216
C80G0A20	1.200	16.0310	-5.2220	-11.238
C50G30A20	27.306	4.5604	-4.5280	-16.873
C20G60A20	5.926	-1.2220	-18.1500	-24.240

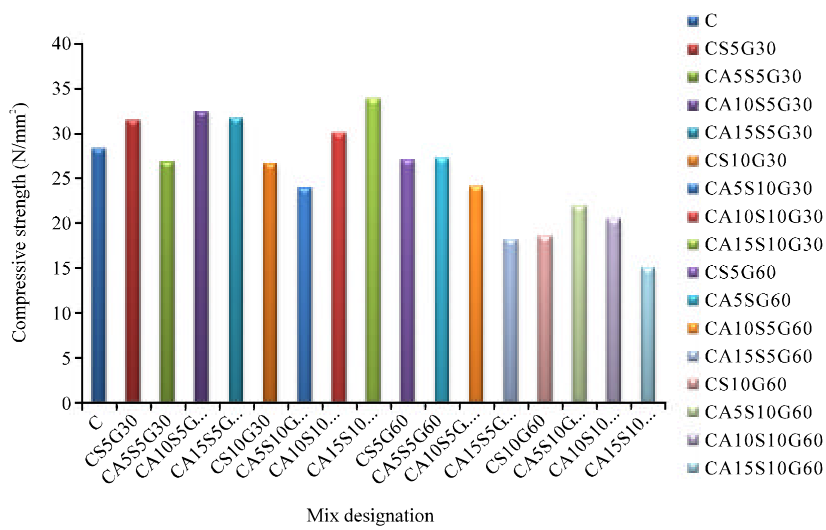

Fig. 3: Compressive strength of various mix of 28 days strength

mix (C70G30A0) mix while the 7 days compressive strength of concrete with 30% GGBS and 10% alccofine (C60G30A10) mix shows highest strength when compared with 30% GGBS without alccofine (C70G30A0), 5% alccofine (C65G30A5) and 15% alccofine (C60G30A15) mixes.

The 14 days compressive strength of concrete with 60% GGBS and 5% alccofine (C35G60A5) mix was 17% higher than the control mix (C100G0A0) but the 14th day compressive strength of (C35G60A5) mix was higher than (C70G30A0) and (C40G60A0) mix.

The 28 days compressive strength of concrete C60G30A10 mix was 12.94% higher than the control mix C100G0A0 mix. The 28 days compressive strength of concrete (C90G0A10) mix was 11.68% higher than the control mix (C100G0A0). The 28 days compressive strength of concrete in all the mixes has achieved the characteristic strength other than (C25G60A15) mix. The 28 days compressive strength of concrete (C25G60A15) showed very low strength than all other mixes.

CONCLUSION

The salient conclusions are drawn from the analysis and discussions of result are presented here. From the experimental results, based on compressive strength of concrete it was found that the optimum dosage level of alccofine was 10% by the volume of cement. The optimum dosage level of GGBS was 30% by the volume of cement. The combination of cement replacement by 10% alccofine and with 30% of GGBS gives the highest improvement in compressive strength compared to all other mixes.

Replacement of 60% GGBS reduces the strength but however, it yields good result with the 5% alccofine combination. By addition of alccofine the early age strength was excellent but after 14 days of curing in water there was a gradual increase in compressive strength. Alccofine has the better performance when compare to the other slag material. The compressive strength achieved by alccofine (10%) and GGBS 30% was 36.48 N/mm^2 whereas GGBS improves the strength only by 30% replacement of cement when added with alccofine. If the percentage level of alccofine was increased beyond that level it acts as a filler material and yields good workability to the concrete.

Since, these materials gives good strength at the early stage, the form work removal can be done earlier. By that way the cost can be reduced to certain limit. The highest flexural strength was seen in 20% alccofine without GGBS replacing cement when compared to all other mixes. Addition of alccofine and GGBS in concrete resulted in increase of flexural strength for all mixes when compared to control mix.

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