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EFFECT OF COMPONENTS FINENESS OF GROUND GRANULATED BLAST FURNACE SLAG (GGBFS) ON ITS STRENGTH EFFICIENCY IN ROLLER COMPACT CONCRETE MIXES

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ABSTRACT

Application of cementitious material is a well accepted supplement to enhance the strength of concrete composites. This is due to its improvement characteristics and overall economic feasibility. The present paper aims to evaluate the strength efficiency of GGBFS in Roller Compact Concrete (RCC) mixes with finenesses of 1500cm^2/gr and 2850cm^2/gr at 28 and 90 days respectively. The investigation involved assessing the effect of replacement levels of 0, 25, 50 and 75 percent of GGBFS on strength efficiency of GGBFS (k). Results show that increase in the GGBFS fineness correspondingly enhances the strength efficiency in RCC mixes.

Keywords: Ground granulated blast furnace slag; Strength efficiency; Fineness, Roller compact concrete

INTRODUCTION

The RCC is a relatively new concept in the feasibility studies of hydraulic structures in which low workability concrete mixtures compact vibrating rollers is employed. The RCC mixes generally incorporate supplementary cementitious materials for decreasing heat generation, facilitating ideal construction process, improving performance and economizing costs (ICOLD 2003).

Application of roller compacted concrete (RCC) emerged as a viable substitute for conventional concrete in design and construction of various hydraulic structures such as diversion weirs and dams in the early 1980's (ASCE 1994).

There are considerable literature materials on the influence of various parameter changes such as the chemical composition, hydraulic reactivity, variation of slag levels in mixes, concrete age and fineness on effectiveness of GGBFS in RCC mixes. Study by Hanifi Binichi (2007) shows that increase in the value of fineness is followed by corresponding increase in the pozzolanic activity for GGBFS. It was further observed that finer ground blended cement specimens, enhances the compressive strength and by increasing the amount of GGBFS, the compressive strength of concrete mixtures containing GGBFS will also increase. However, this linear relation holds up to the optimum point at around 55% of the total binder content, where any addition of GGBFS does not make any difference on the compressive strength of the concrete(Oner and Akyuz 2007). Swamy (1998) reported that an increase in fineness of two to three times that of normal PC can preserve the benefits of material fineness on a variety of engineering properties such as bleeding, time of setting, heat evolution, high strength and excellent durability. Thus, for better performance, the fineness of GGBFS must be greater than that of cement.

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Overall investigations on the ordinary concrete made with fine slag between 400-600 m^2/kg has shown that the 28 and 90 days compressive strength of some samples have been more than control specimen (with out slag).

The aim of this paper is to evaluate the strength efficiency of GGBFS in RCC mixes with finenesses of 1500cm^2/gr and 2850cm^2/gr at 28 and 90 days respectively and computation of percentage of creasing cementitious materials for equivalent compressive strength with control concrete.

SLAG ACTIVITY INDEX AND HYDRAULIC REACTIVITY OF SLAG

ASTM C989 defines SAI (slag activity index) as the percentage ratio of the average compressive strength of slag cement (50-50%) mortar cubes to the average compressive strength of reference cement mortar cubes at a designated age. Based on this, slag was classified into three grades-Grade80, Grade100, and Grade 120, depending on the relative compressive strength. Hooton and Emery (1983) observed that the properties of GGBFS influencing its reactivity to be the glass content, chemical composition, mineralogical composition, fineness of grinding and type of activation provided. Pal, Mukherjee, Pathak (2003) in their study observed that there is a novel equation that determines relation between hydraulic index (HI) and effective parameter.

$$HI\ 28 = -36.908 + 3.11(CaO) - 3.909\ (SiO_2) + 2.98\ (AL_2O_3) + 2.425\ (MgO) + 0.966\ (glass) + 12.5(Blaine)$$

As can be seen from the above equation, the blaine (fineness) is an important factor in HI. As Oner (2000) and Oner et al (2003) show, finer slag markedly improves the compressive

FINENESS

As with all cementing materials, the reactivity of slag is determined by its surface area. In the united kingdom,GGBFS is marketed at a surface area of 3750-4250 cm^2/g blaine's,whereas some slag's in the United States have a surface area in the rang of 4500-5500 cm^2/g;Canadian slags are about 4500 cm^2/g, while in India it is found to vary from 3500 to 4500 cm^2/g Blaine's.

In general, increased in fineness has a corresponding influence in the strength development. The fineness of GGBFS is a very crucial parameter, which is dependent on energy-saving and economic consideration, influences the reactivity of GGBFS in concrete, early strength development of concrete and water requirement. For this reason, slag with two fineness of 1500cm^2/g and 2850cm^2/g are used in this study.

EXPERIMENTAL PROGRAMME

Materials for the RCC mixture

Local materials available in the neighboring areas were used for the RCC mix design.

Aggregates

The maximum size of the aggregate was 38 mm and the gradation of the coarse aggregate was found to be within the ASCE (1994) limits. The percentage of fines passing through the No.200 sieve (0.075 mm) was 2 percent on the high side, and the average fineness modulus of the fine aggregates was 2.85. Table 1 shows the percentage of passing aggregates and fines of sieves.

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Table 1. Sieve analysis of aggregates

No. sieve	*38 mm*	*25 mm*	*19 mm*	*12.5 mm*	*9.5 mm*	*4.75 mm*	*8#*	*16#*	*30#*	*50#*	*100#*	*200#*
Aggregate	100	74	58	37	26	2	-	-	-	-	-	-
Fines	-	-	-	-	100	97	69	47	32	21	6	2

Cement

Portland cement (Type II, according to ASTM C150) was used in the mix. The cement is manufactured by the Tehran cement Factory.

Granulated Blast Furnace Slag (GGBFS)

Granulated Blast Furnace Slag (GGBFS) was prepared from the Esfahan Steel-Iron plant in Iran. In this work, slag with two fineness 150m^2/kg and 285m^2/kg is used. Table 2 shows chemical properties of GGBFS.

Table 2. Chemical analysis of GGBFS used

Test Results	*SiO_2 %*	*AL_2O_3 %*	*CaO %*	*MgO %*	*Tio_2 %*	*K_2O+Na_2 %*	*MnO %*	*P_2O_5 %*	*FeO %*	*S %*
	35.2	11.1	35.1	10.7	3.82	1.03	1.47	0.25	0.65	0.66

RCC mix design

Two major philosophies have emerged with respect to RCC mix design technology and methods, which are here, termed the soils philosophy, and concrete philosophy. The high-paste RCC design, and the Japaness RCD approach, may be termed as concrete approach, and the lean-concrete approach as soils approach. The main focus of present study is on concrete philosophy.

Construction of the RCC mixture

Vibrating table was used for preparation and compressing of RCC mixture according to ASTM C1176, C1170 standard. The detail compositions of fourteen concrete mixes used in the test program are shown in Table3.

Table 3. Mixture proportions for RCC mixes

Mix No	*C+S (kg/m^3)*	*Percentage Replacement*	*Blaine (cm^2/gr)*	*W/(C+S)*	*Gravel (kg/m^3)*	*Sand (kg/m^3)*	*fc(28 days) (mpa)*	*fc(90 days) (mpa)*
1	150	0	-	0.73	1258	880	10.73	13.35
2	150	25	1500	0.73	1258	880	5.88	9.28
3	150	50	1500	0.73	1258	880	3.96	5.6
4	150	75	1500	0.73	1258	880	3.4	4.18
5	150	25	2850	0.73	1258	880	6.1	9.4
6	150	50	2850	0.73	1258	880	5.6	7.92
7	150	75	2850	0.73	1258	880	4.8	5.52
8	210	0	-	0.57	1215	850	22.75	29.99
9	210	25	1500	0.57	1215	850	16.12	22.77
10	210	50	1500	0.57	1215	850	8.50	13.04
11	210	75	1500	0.57	1215	850	5.43	7.64
12	210	25	2850	0.57	1215	850	16.5	24.27
13	210	50	2850	0.57	1215	850	11	16.41
14	210	75	2850	0.57	1215	850	9.11	9.96

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EXPERIMENTAL RESULTS AND DISCUSSION

Results of the tests on compressive strength of mixture ages of 28 and 90 days against cementitious material-to-water ratio was given in figure1 and figure2 for different amount of slag replacement (0, 25, 50 and 75 percent) with finenesses of 1500cm^2/gr and 2850cm^2/gr.

Results show that replacement of the slag by these mixtures increases the mixture strength at all ages. Results further show that by increasing the amount of slag in the mixture, there would be a corresponding increase in the strength efficiency. But, as it was observed, a significant improvement in compressive strength of samples at all ages can be achieved by increasing slag fineness from 1500cm^2/gr to 2850cm^2/gr.

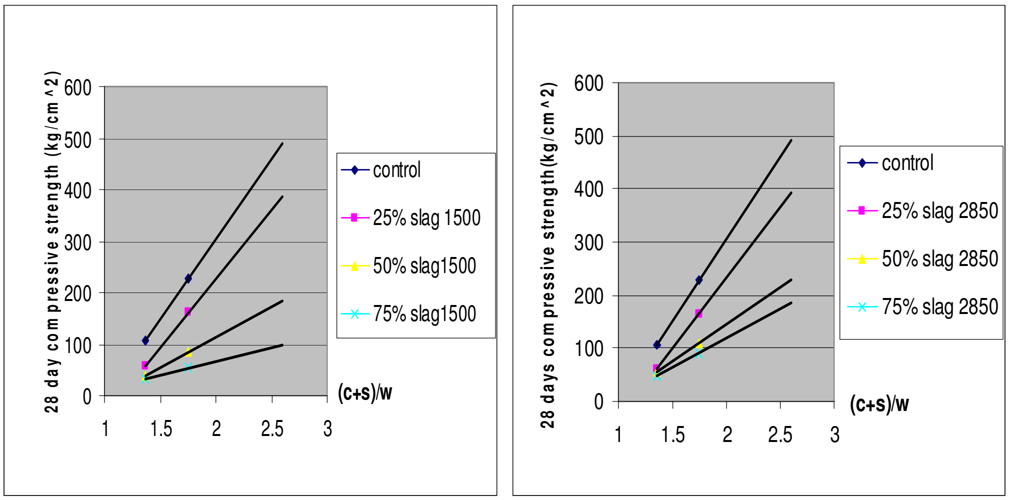

Figure 1. The effect of cementitious material-to-water ratio on RCC Compressive strength in age of 28

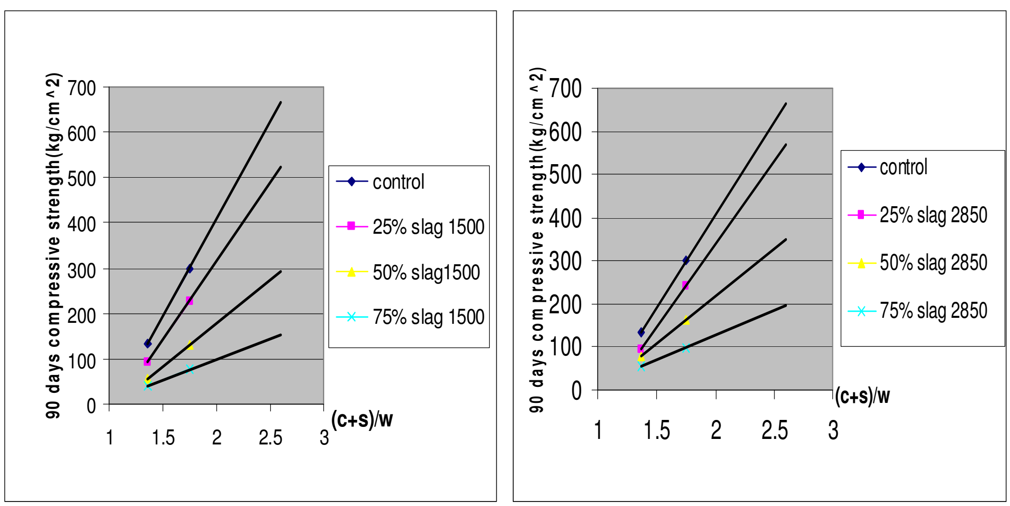

Figure 2. The effect of cementitious material-to-water ratio on RCC Compressive strength in age of 90

EFFICIENCY CONCEPTS

The efficiency of GGBFS is generally the amount of Portland Cement (pc) portions that can be replaced with one portion of slag without changing strength properties of concrete. The results of experimental researches show that strength efficiency of slag depends among other factors on amount of slag consumed in concrete mixture, Blaine of consumed slag in concrete

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mixture and the age of concrete. Some researchers present relations for determining strength efficiency. In the present study, calculating coefficient k was performed based on relations of calculation of strength efficiency conducted by Gunesh Babu (1993, 2000) the result of which has been the presentation new relations presented based on water to cement ratio.

EVALUATION OF EFFICIENCY

This paper attempts to assess the cementitious efficiency of GGBFS in RCC mixture at various replacement percentages through the efficiency concept by establishing the variation of the strength to cementitious material-to-water ratio relations of the GGBFS concretes from the normal concretes at 28&90 days. In principle, this was done by using Δw concept (according to figure3), which attempts to bring the cementitious material to water ratio $[\frac{c+s}{w}]$ closer to the cement to water ratio of the control concrete $(\frac{c_0}{w})$ by applying the cementitious efficiency factor k of GGBFS at any particular strength. The Δw concept explained earlier was used in evaluating the efficiency of GGBFS. One important contribution of this work was that it defined the consequent reduction in cementitious water materials ratio $[\frac{c+s}{w}]$ of GGBFS concrete as compared to the cement-to-water ratio $[\frac{c_0}{w}]$ of the reference concrete

(Δw Concept) as

$$\Delta w = \frac{c+s}{w} - \frac{c_0}{w}$$

$$c_0 = c + ks$$

$$\Delta w = \frac{c+s}{w} - \frac{c+ks}{w} = \frac{s}{w}(1-k)$$

The above formulation clearly shows that this reduction depends not only on the size of the efficiency factor (k), but depends additionally on the slag water ratio $(\frac{s}{w})$

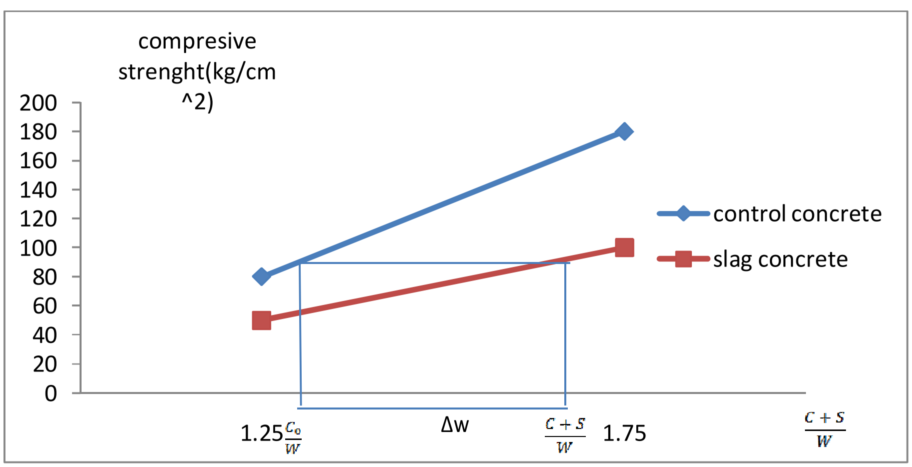

Figure 3. Compressive strengths of concrete against the cementitious materials -to -water ratio for normal and GGBFS replaced concretes

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The Computation of K For 25% Replacement GGBFS with Fineness 2850cm²/Gr at 90days

$$\Delta w = \frac{s}{w}(1-k)$$

$$\Delta w_1 = 1.46 - 1.36$$

$$\frac{c+s}{w} = 1.46 \ , \ \frac{s}{c} = \frac{1}{3} \ \Rightarrow \ \frac{s}{w} = 0.36 \ \Rightarrow \ k_1 = 0.73$$

$$\Delta w_2 = 1.89 - 1.75 \ \Rightarrow \ k = \frac{k_1 + k_2}{2} = 0.72$$

$$\frac{c+s}{w} = 1.89 \ , \ \frac{s}{c} = \frac{1}{3} \ \Rightarrow \ \frac{s}{w} = 0.47 \ \Rightarrow \ k_2 = 0.71$$

The Computation of Percentage Of Creasing Cementitious Materials For Equivalent Compressive Strength With Control Concrete At K=0.72

$$c_0 = c + ks = c + 0.72s$$

$$\Rightarrow \ c_0 = 1.24c \ \Rightarrow \ c = 0.81c_0 \Rightarrow \ c + s = 1.08c_0$$

$$\frac{s}{c} = \frac{1}{3}$$

The following table shows that the results of strength efficiency of slag at different ages include 28 and 90 days and fineness of 1500cm²/gr and 2850cm²/gr. It further shows the comparison of the amount of increase of cement materials in concrete containing slag with control mixes.

Table 4. Results of strength efficiency of slag and Percentage of increasing cementitious Materials

Slag Fineness	*Percentage of slag replacement*	*28 days efficiency (k 28)*	*Percentage of increasing cementitious materials*	*90 days efficiency (k 90)*	*Percentage of increasing cementitious materials*
2850(cm²/gr)	25	0.55	C+S=13% C=9.75% S=3.25%	0.72	C+S=8% C=6% S=2%
	50	0.46	C+S=37% C=18.5% S=18.5%	0.59	C+S=26% C=13% S=13%
	75	0.37	C+S=88% C=22% S=66%	0.5	C+S=60% C=15% S=45%
1500(cm²/gr)	25	0.52	C+S=14% C=10.5% S=3.5%	0.63	C+S=10% C=7.5% S=2.5%
	50	0.32	C+S=50% C=25% S=25%	0.45	C+S=38% C=19% S=19%
	75	0.26	C+S=124% C=31% S=93%	0.32	C+S=100% C=25% S=75%

S=amount of slag
C=amount of cement

CONCLUSION

1. Generally, with increase of percent amount of this type of slag in RCC concrete, strength efficiency decreases and the amount of replacement of cement materials (slag and cement) increases, that was due to low strength efficiency of this type of slag ($k<1$)
2. In a constant amount of slag replacement, the strength efficiency of slag with fineness of 2850cm^2/gr is more than strength efficiency of slag with fineness of 1500cm^2/gr that indicate better performance of slag with fineness of 2850cm^2/gr than slag with fineness of 1500cm^2/gr.
3. Strength efficiency at 28 days in a constant volume and in other to obtain similar strength compared to control mixes, we need to decrease the volume of replaced cement material, that show better strength performance of slag used in huge concrete of dam constructing such as RCC in old ages.

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