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Estimation of GGBS and HVFA Strength Efficiencies in Concrete with Age

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Abstract - The utilization of supplementary cementitious materials is well accepted because of the several improvements possible in the concrete composites, and due to the overall economy. The present paper is an effort to quantify the strength of ground granulated blast furnace slag (GGBS) and high volume fly ash (HVFA) at the various replacement levels and evaluate their efficiencies in concrete. In recent years GGBS when replaced with cement has emerged as a major alternative to conventional concrete and has rapidly drawn the concrete industry attention due to its cement savings, energy savings, and cost savings, environmental and socio-economic benefits. The present study reports the results of an experimental study, conducted to evaluate the strengths and strength efficiency factors of hardened concrete, by partially replacing the cement by various percentages of ground granulated blast furnace slag and high volume fly ash for M20, M40 and M60 grades of concrete at different ages. The overall strength efficiency was found to be a combination of general efficiency factor, depending on the age and a percentage efficiency factor, depending upon the percentage of replacement. Here an effort is made towards a specific understanding of the efficiency of GGBS and HVFA in concrete, considering the strength to water cement ratio relations, age and percentage of replacement. The optimum GGBS and HVFA replacement as cementitious material is characterized by high compressive strength, low heat of hydration, resistance to chemical attack, better workability, and good durability and cost-effective. From this study it can be concluded that, since the grain size of GGBS is less than ordinary Portland cement, its strength at early ages is less but continues to gain strength over a long period.

Index Terms: Bolomey's strength relation, Cementing efficiency, Ground granulated blast furnace slag (GGBS), High volume fly ash (HVFA), strength efficiency factor,

I. INTRODUCTION

Blast furnace slag cements are in use for a reasonably long period due to the overall economy in their production as well as their improved performance characteristics in aggressive environments. GGBS is obtained by quenching molted iron slag (a product of Iron and steel making) from a Blast furnace in water or steam to produce a glassy granular product. Then it is dried and grounded in to a fine powder. In the last decade a great deal of research work has been done addressing the efficiency as GGBS and HVFA concrete are both a kind of Industry waste can act as economic and ecological resource for hardened concrete in enhancing its performance properties.

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The use of GGBS and HVFA as a cement replacement in hardened concrete results in significant enhancement of the basic characteristics of concrete, both of its fresh and hardened states. At early stage, the increase in compressive strength of ordinary (M20), standard (M40) and high (M60) grade concrete is somewhat slower but they continue to gain strength for longer period as the replacement level increases.

GGBS hardens very slowly and for use in concrete, it needs to be activated by combining with OPC. The greater the percentage of GGBS, the greater will be effect on concrete properties. The setting time of concrete is influenced by many factors, in particularly temperature and water/cement ratio.

This paper is part of wider study on the behavior of concretes with GGBS and HVFA as direct replacement for grade 53 Ordinary Portland Cement (OPC), on a one to one basis by weight in order to quantify the strength efficiency of GGBS and HVFA in concrete at 28, 90 and 180 days. Replacement levels for GGBS and HVFA vary from 10% to 70% in an increment of 10%. Typically 40% being the optimum percentage replacement of HVFA in ordinary grade concrete of 50% in standard and high grade concrete. In case of GGBS Concrete 40% is being the optimum percentage in ordinary grade concrete and in standard grade concrete and 50% in high grade concrete.

In the process of performance evaluation of GGBS and HVFA replacement, it was observed that the overall strength efficiency of GGBS and HVFA in concretes was found to be a combination of two factors: 1) general efficiency factor depending on the age of concrete and 2) a percentage efficiency factor depending upon the percentage of replacement of GGBS and HVFA. This evaluation makes it possible to design GGBS and HVFA concretes for a desired strength at any given percentage of replacement.

Supplementary Cemetitious Materials (SCM) in Concretes are in use for a reasonable long period due to the overall economy in their production as well as their improved performance characteristics in aggressive environments. Due to low hydration rate during early age GGBS and HVFA concrete mixes, curing time should be prolonged than conventional concrete. GGBS and HVFA concretes are a major breakthrough to conventional concrete due to its cement savings; cost savings, environmental and social benefits. So it's wide spread usage should be encouraged in extending then lifespan of the structures. Usage of GGBS and HVFA significantly reduces the risk of damages caused by Alkali – Silica reaction (ASR) provides higher resistance to chloride ingress by reducing the risk of reinforcement corrosion and also provides higher resistance to attacks by sulphate and other chemicals.

With the increase of specific surface and content of GGBS and HVFA the repulsion between cement particles increases improving the workability of the GGBS and HVFA in concretes. The scope of this part of research was to determine the strength efficiency of GGBS and HVFA in ordinary, standard and high grade concrete in terms of efficiency factor **'k'**. The strength efficiency factor 'k' is evaluated for two cases: HVFA replaced certain portion of cement and GGBS replaced certain portion of cement in concrete. The optimum HVFA and GGBS substitute content is found based on the experimentally evaluated compressive strengths at different percentages of replacements of HVFA and GGBS for ordinary , standard and high grades at 28, 90 and 180 days. The optimum substitute content of HVFA is 40% in ordinary grade and 50% in standard and high grades similarly optimum substitute content of GGBS is 40% in ordinary and standard grade and 50% in high grades of concrete. Due to the fact that the fineness of GGBS and HVFA is far higher than OPC as compared to the plain concrete the GGBS and HVFA in concretes has low early strength, poor durability and ease of bleeding at early stage but contains to gain strength and durability at later stages.

II. RESEARCH SIGNIFICANCE

Research work till date suggests that GGBS and HVFA improve many of the performance characteristics of the hardened concrete such as strength, workability, permeability, durability and corrosion resistance. From the present investigations it is found that the compressive strength of GGBS and HVFA depends both on the age and the percentage of replacement level. It is felt that efficiency concept can be used to understand the behavior of GGBS and HVFA in concrete. This paper presents a study on the behavior of GGBS and HVFA in hardened concrete by evaluating the efficiency of GGBS and HVFA at different percentages of replacement at 28, 90 and 180 days for ordinary (M20), Standard (M40) and High (M60) grades of concrete in terms of efficiency factor 'k'.

III. BOLOMEY'S COMPRESSIVE STRENGTH RELATION

The Bolomey's empirical expression frequently used to predict the strength of concrete is theoretically well founded when applied to hardened concrete. Efficiency factors found from this strength equation are used to describe the effect of the GGBS and HVFA replacement. Efficiency factors are generally used to describe the impact of GGBS and HVFA replacements on the compressive strength of Concrete mixes.The Bolomey's strength equation is:

$$S = A\,[(c/w)] + B \qquad (1)$$

S is the compressive strength in MPa,

c is the cement content in kg / m^3,

w is the water content in kg/m^3

Equation (1) has been shown to practically reduce to following two equations

$$S = A\,[(c/w) - 0.5] \qquad (2)$$

$$S = A\,[(c/w) + 0.5] \qquad (3)$$

These two equations represent two ranges of concrete strengths and it is due to the often observed fact that a change in slope occurs at about w/c = 0.40, when P/W (powder-water ratio) is plotted against strength. However, it is found that the equation (2) is useful for most of the present day concretes from the analysis done on test results available and also the extensive data published by Larrard who also mentions this equation in his famous book, on 'Concrete Mix Proportioning – A scientific approach'. Therefore, equation (2) can be generally used for re-proportioning. The value of constant 'A' can be found out for the given concrete ingredients, by considering a concrete mix of any w/c ratio.

For structural concrete, Equation (1) can be simplified as

$$S = A\,[(c/w) - 0.5] \qquad (4)$$

A strength efficiency factor, k, can then be computed using modified Bolomey equation

$$S = A\,[((c+ k^*g)/w)\ 0.5] \qquad (5)$$

g is the slag content replaced by weight of cement in kg/m^3 and k denotes efficiency factor.

Thus, w/(c+ kg) is the water/effective binder ratio and k*g is the equivalent cement content.

By knowing the amounts of "c", "g", "w" and the strength "S" achieved for each slag dosage from the finally arrived experimental values, efficiency factor "k" has been computed for each of the percentage replacements.

IV. CEMENTING EFFICIENCY FACTOR 'k'

This factor describes the mineral admixture's ability to act as cementing material recognizing that mineral admixture's contribution to concrete strength which comes mainly from its ability to react with free calcium hydroxide produced during cement hydration. The rate of this reaction, called as pozzolanic reaction (PR), when compared to cement hydration rate (CHR) determines the value of k. When k=1, both PR and CHR would be same and the water-binder ratios of concretes with and without mineral admixture could be almost same.

When k<1, PR would be slower than CHR and for equal strengths, the water-binder ratio of concrete with mineral admixture need to be less than that of concrete without mineral admixture and also, at same water-binder ratio, the strength of concrete with mineral admixture would be less than that of concrete without mineral admixture . In this case, the mineral admixture is less efficient than Portland cement in imparting strength to concrete. The GGBS has generally k<1 at early ages and k would reach a value of unity at later ages.

When k>1, PR would be faster than CHR and for equal strengths, the water-binder ratio of concrete with mineral admixture would to be more than that of concrete without mineral admixture .However, at similar water-binder ratios, the strength of concrete with mineral admixture would be more than that of concrete without mineral admixture. In this case, the mineral admixture is more efficient than Portland cement in imparting strength to concrete. GGBS and HVFA have generally k>1 even at early ages and therefore, the strengths of GGBS and HVFA concrete are more than that of GGBS concrete at similar water-binder ratios. Based on the average compressive strength of the control mix (100% Portland cement), 'A' value was calculated using Bolomey's equation. Then Efficiency factors for GGBS and HVFA mixes were then determined using same Bolomey equation. Bolomey's coefficients are calculated from the control mixes .Compute Bolomey Coefficient 'A' value from the equation (4) substituting values for S, c and w at 0% replacement for 28, 90 and 180 days for M20,

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M40 and M60 grades as shown in Table 7. Using computed 'A' value, calculate strength efficiency factors 'k' at all ages for all percentage replacement levels of GGBS and HVFA in concrete

V. MATERIALS USED

A. Cement **-** Ordinary Portland cement of 53 grade confirming to IS:12269-1987 used in the investigation

B. Fine aggregate **-** Locally available, natural River sand confirming to Zone-II used as fine aggregate.

C. Coarse Aggregate - Locally available crushed angular coarse aggregates of size 20mm and with specific gravity of 2.7 was used as Coarse aggregate

D. GGBS **-** Confirming to IS 12089:1981

E. HVFA - High Volume Fly Ash as per the laboratory test conducted according to ASTM method C1202

F. Water **-** Locally available potable water confirming to IS 456-2000 is used

VI. EXPERIMENTAL INVESTIGATIONS

Compressive strengths of specimens with various percentage replacement of cement with GGBS and HVFA is determined by casting concrete cubes of size 150 mm X 150mm X 150mm and testing them after 28,90 and 180 days of curing. Strength efficiency factors 'k' for GGBS and HVFA with different percentages of replacement are evaluated at 28, 90 and 180 days compressive strengths of ordinary (M20), Standard (M40) and High (M60) grades of concrete mixes.

Table I: Compressive Strength of M20 grade Concrete with various percentages of GGBS replacement of cement

Mix No	% of GGBS Replacement	Compressive Strength(MPa)		
		28 days	90 days	180 days
A-1	0%	26.45	34.12	36.22
A-2	10%	28.21	38.23	39.25
A-3	20%	32.12	42.12	46.12
A-4	30%	36.00	51.22	58.20
A-5	40%	45.30	54.12	68.50
A-6	50%	44.20	53.40	67.20
A-7	60%	39.60	52.20	62.30
A-8	70%	34.00	50.91	53.52

Table II: Compressive Strength of M40 grade Concrete with various percentages of GGBS replacement of cement

Mix No	% of GGBS Replacement	Compressive Strength(MPa)		
		28 days	90 days	180 days
B-1	0%	42.21	48.21	52.55
B-2	10%	46.32	54.12	56.12
B-3	20%	47.12	56.34	58.32
B-4	30%	48.22	58.66	63.20
B-5	40%	49.51	60.12	74.20
B-6	50%	48.41	59.40	72.60
B-7	60%	47.20	58.41	71.40
B-8	70%	44.12	53.61	63.10

Table III: Compressive Strength of M60 grade Concrete with various percentages of GGBS replacement of cement

Mix No	% of GGBS Replacement	Compressive Strength(MPa)		
		28 days	90 days	180 days
C-1	0%	65.12	70.21	74.55
C-2	10%	68.21	72.35	76.42
C-3	20%	70.50	74.21	78.12
C-4	30%	72.42	76.12	82.21
C-5	40%	77.41	79.91	86.35
C-6	50%	78.16	83.45	89.20
C-7	60%	66.41	74.23	83.20
C-8	70%	60.92	69.30	78.10

Table IV: Compressive Strength of M20 grade Concrete with various percentages of HVFA replacement of cement

Mix No	% of HVFA Replacement	Compressive Strength(MPa)		
		28 days	90 days	180 days
A-1	0%	30.11	34.31	36.23
A-2	10%	30.92	36.20	39.21
A-3	20%	31.84	38.12	41.35
A-4	30%	32.20	41.33	52.40
A-5	**40%**	**28.81**	**44.50**	**56.20**
A-6	50%	25.80	42.90	50.11
A-7	60%	22.40	36.21	45.12
A-8	70%	15.30	31.51	32.12

Table V: Compressive Strength of M40 grade Concrete with various percentages of HVFA replacement of cement

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Mix N	% of HVFA Replacemen	Compressive Strength(MPa)		
		28 days	90 days	180 day
B-1	0%	48.23	54.12	57.63
B-2	10%	47.11	56.32	61.52
B-3	20%	46.98	59.48	70.16
B-4	30%	46.30	61.51	77.60
B-5	40%	42.10	67.04	87.40
B-6	50%	40.60	74.04	88.20
B-7	60%	38.90	59.20	65.31
B-8	70%	24.60	51.20	54.51

Table VI: Compressive Strength of M60 grade Concrete with various percentages of HVFA replacement of cement

Mix No	% of HVFA Replacement	Compressive Strength(MPa)		
		28 days	90 days	180 days
C-1	0%	68.32	74.12	78.72
C-2	10%	66.25	78.32	80.12
C-3	20%	65.31	80.12	86.23
C-4	30%	64.01	82.61	92.12
C-5	40%	58.91	84.92	95.62
C-6	50%	56.42	92.73	97.21
C-7	60%	54.62	78.53	86.51
C-8	70%	48.28	69.50	75.12

Table VII: Computations of Bolomey's Coefficient (A) for Bolomey's equation for M 20, M 40 and M 60 grades Concrete Mixes

Age in Days	M 20	M 40	M 60
90	A=26.02	A=29.62	A=29.28
180	A=27.47	A=31.55	A=32.25

Table VIII: Strength Efficiency Factors when cement replaced with GGBS for all grades

Age in Days	M20	M40	M60
90	k = 2.08	k = 1.22	k = 1.21
180	k = 2.85	k =1.73	k =1.34

Table IX: Strength Efficiency Factors when cement replaced with HVFA for all grades

Age in Days	M20	M40	M60
90	k = 1.57	k = 1.58	k = 1.45
180	k = 2.14	k = 2.00	k =1.52

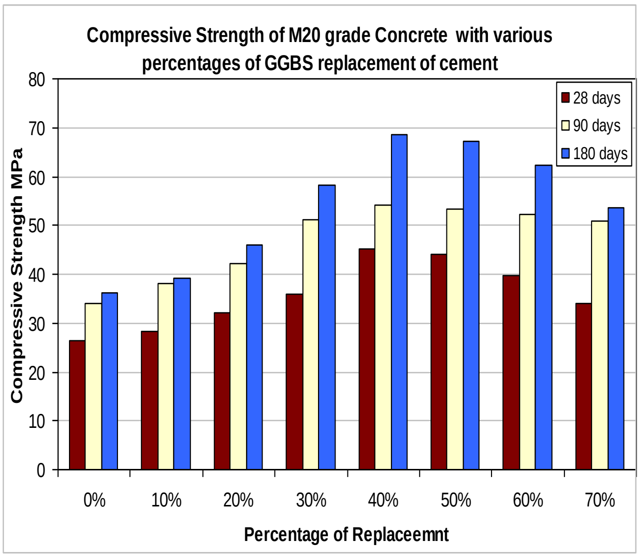

Figure 1 (a)

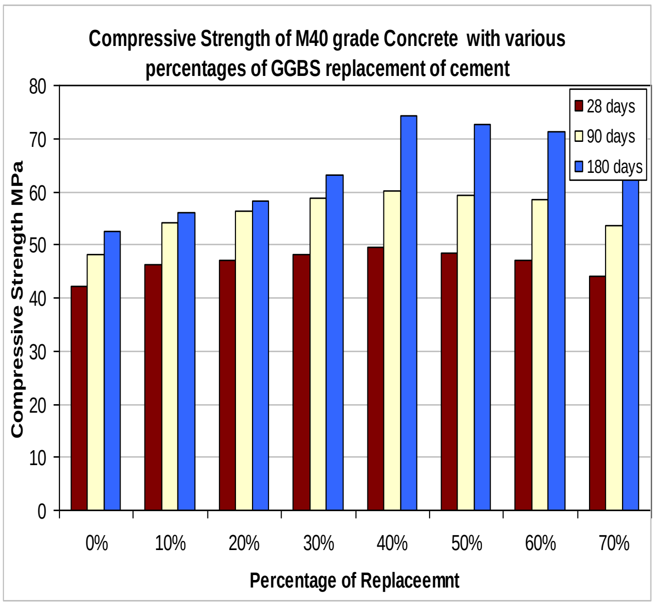

Figure 1 (b)

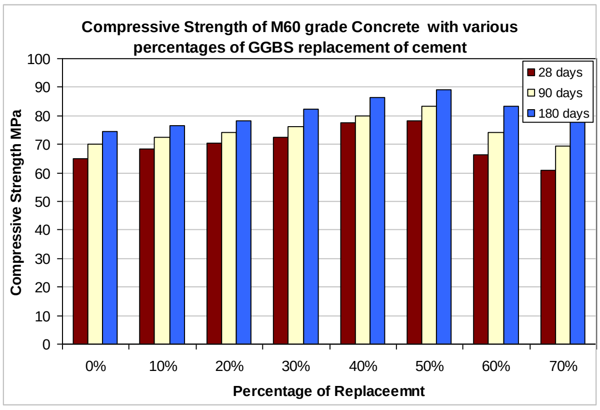

Figure 1 (c)

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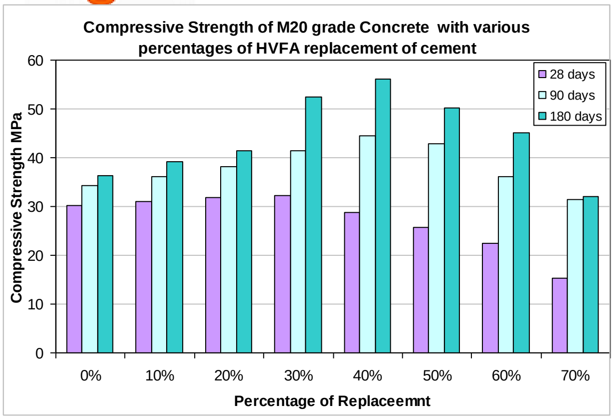

Figure 2 (a)

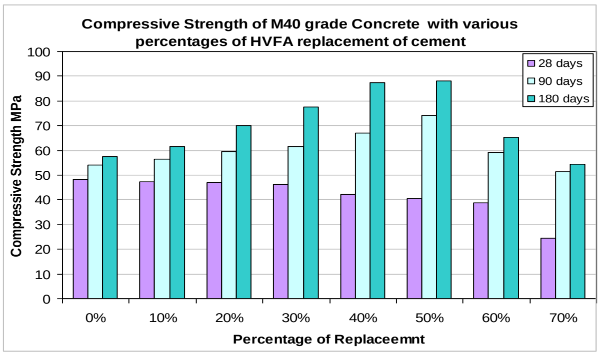

Figure 2 (b)

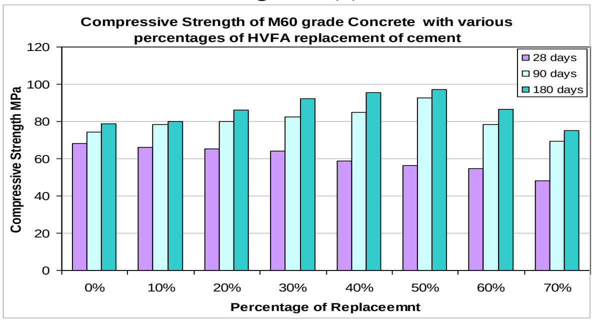

Figure 2 (c)

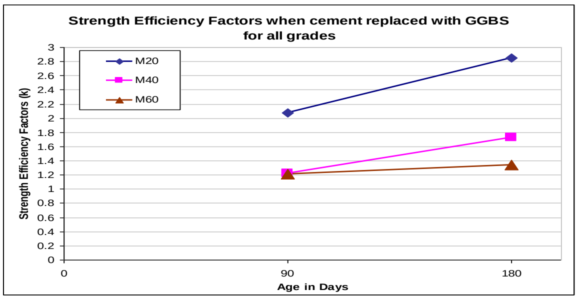

Figure 3 (a)

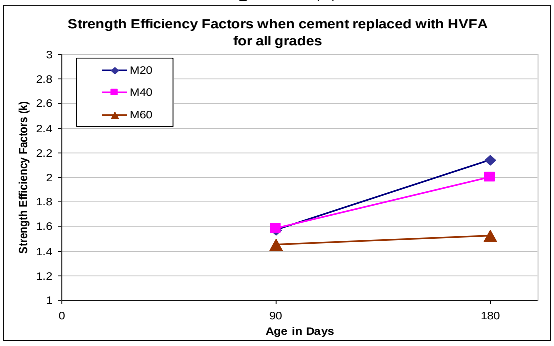

Figure 3 (b)

VII. DISCUSSION OF TEST RESULTS

The optimum dosage of percentage of replacement of cement with GGBS was found to be 40%, 40%and 50% in Ordinary (M20), Standard (M40) and High strength grade (M60) grades of concrete as shown in Tables I-III. Similarly the optimum dosage of percentage of replacement of cement with HVFA was found to be 40%, 50%and 50% in Ordinary (M20), Standard (M40) and High strength grade (M60) grades of concrete as shown in Tables IV-VI.

Efficiency factors found from Bolomey's strength equation are used to describe the effect of the GGBS and HVFA replacement in concretes on the enhancement of strength and durability characteristics. Strength Efficiency factors "k" was calculated using a modified version of the Bolomey equation, which is an empirical relationship used to predict compressive strength of concrete. This efficiency factor "k" of GGBS in Hardened concrete is the combination of two factors efficiency factor k_g depending on the age of the concrete and the efficiency factor k_p depending on the various percentages of GGBS and HVFA replacements alone in concretes.

Strength efficiency factor 'k' in case of GGBS replacement in M20 at 90 and 180 days are 2.08 and 2.85 respectively, for M40 at 90 and 180 days are 1.22 and 1.73 respectively and for M60 at 90 and 180 days are 1.21 and 1.34 respectively as shown in Table VIII.

Strength efficiency factor 'k' in case of HVFA replacement in M20 at 90 and 180 days are 1.57 and 2.14 respectively, for M40 at 90 and 180 days are 1.58 and 2.00 respectively and for M60 at 90 and 180 days are 1.45 and 1.52 respectively as shown in Table IX.

When compared to M20, M40 and M60 grade concrete mixes without any mineral admixture at 28 days, Strength efficiency of GGBS increases by 89% in M20, 41% in M40 and 20% in M60 grade concrete mixes. In case of HVFA concrete, the strength efficiency increases are 55% in M20, 53% in M40 and 23% in M60 grade concrete mixes as shown in Fig 3(a) and 3 (b).

VIII. CONCLUSIONS

The following conclusions can be drawn from the experimental investigations conducted on the behavior of concretes with GGBS and HVFA as partial replacements for cement-

1. The partial replacement of cement with GGBS and HVFA in concrete mixes has shown enhanced performance in terms of strength and durability in all grades. This is due to the presence of reactive silica in GGBS and HVFA which offers good compatibility.
2. The Bolomey's empirical expression can be used to predict the strength efficiency factors of the GGBS and HVFA in concrete mixes at different percentage of replacement levels.
3. The strength efficiency factors are mainly useful to quantify the replacement of cement by GGBS and HVFA in concrete mixes on a one-to-one basis by weight.
4. The strength efficiency factor 'k' of GGBS in concrete mixes of all grades at 90and 180 days was found to be between 1.2 to 2.85 and for HVFA 'k' is between 1.45 to 2.14 which shows the strength efficiency factors for GGBS are higher than HVFA replaced concrete.

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5. It is observed that there is an increase in the compressive strength for different concrete mixes made with GGBS and HVFA replacement mixes. The increase is due to high reactivity of GGBS and HVFA.

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