IJIRSET

International Journal of Innovative Research in Science, Engineering and Technology
Vol. 1, Issue 1, November 2012

EVALUATION OF CONCRETE PROPERTIES USING GROUND GRANULATED BLAST FURNACE SLAG

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Abstract: Traditionally, Ordinary Portland Cement concrete is used for making the civil structures. Portland cement can be replaced by Ground Granulated Blast Furnace Slag (GGBFS) which is a non-metallic and non-hazardous waste of the Iron industry. It is suitable for concrete mix and improves properties of concrete like compressive strength, workability etc. It has been seen that when cement is replaced with GGBFS compressive strength increases. However, this increase in compressive strength continues up to a certain percentage of replacement, but higher ratios gives lower compressive strength. The main objective of this research work is to determine the optimum replacement percentage which can be suitably used under the Indian conditions. To fulfil the objective various properties of concrete using GGBFS have been evaluated.

Keywords: compressive strength, workability, optimum ratio, slag activity index

I. INTRODUCTION

Ground Granulated Blast Furnace Slag (GGBFS) is a byproduct of the steel industry. GGBFS is produced when molten slag is quenched rapidly using water jets, which produces a granular glassy aggregate. Thus Ground Granulated Blast Furnace Slag is advantageous over various other cementing materials because of the following reasons:-

- Non-hazardous and non-metallic waste of the Iron industry.
- Eco-friendly and useful for construction work.
- Helps to improve the properties of concrete like compressive strength, workability etc.
- Low cost and easily available.

In India, about 7.8 million tons of GGBFS is produced per year. All the Blast Furnace Slags are by quenching the molten slag by using high power water jet, making 100% glassy slag granules of 0.4 mm size. Ground Granulated Blast Furnace Slag is used as an admixture in making concrete. Now in India, since GGBFS is available separately, its use as an admixture should become more common.

The replacement of cement with GGBFS will reduce the unit water content necessary to obtain the same slump. This reduction of unit water content will be more pronounced with increase in slag content and also on the fineness of slag. This is because of the surface configuration and particle shape of slag being different than cement particle. In addition, water used for mixing is not immediately lost, as the surface hydration of slag is slightly slower than that of cement.

Ground Granulated Blast Furnace Slag blended with OPC gives lower strength in early stages of concreting and gains strength slower than normal OPC concrete. Thus, concrete with GGBFS have greater place-ability and workability.

II. FINENESS TEST

The Fineness of cement or any other alternative has an important bearing on the rate of hydration and hence on the rate of strength gain and also on the rate of evolution of heat.

Table I Fineness Test

FINENESS OF SAMPLE IN THEIR RAW STATE (mm)		
BHILAI SAMPLE	ROURKELA SAMPLE	CEMENT SAMPLE
3.36	2.36	0.00009

In the research work the slag sample was checked for its fineness in the raw state.

From the Table I it can be seen that the fineness of the slag sample is very high. Thus the slag sample had to be grounded further to match the fineness of the cement sample. Reduction of bleeding is not significant with slag of 4000 cm^2/g fineness. But significant beneficial effect is observed with slag fineness of 6000 cm^2/g.

III. STANDARD CONSISTENCY TEST

Table II Standard Consistency Test

STANDARD CONSISTENCY(mm)					
BHILAI SAMPLE		**ROURKELA SAMPLE**		**CEMENT**	
W/C RATIO	DEPTH	W/C RATIO	DEPTH	W/C RATIO	DEPTH
24%	29.5	24%	31.5	24%	29
26%	**33**	**26%**	**35**	26%	31
28%	37.4	28%	40	**28%**	**33**
30%	39.5	30%	42	30%	36

From the Table II it is evident that the consistency of the slag samples is 26% of the weight of sample taken. On the other hand the cement consistency is higher at 28% of the weight of sample taken. Fig. 1 shows the variation of consistency at different water cement ratios for Bhilai and Rourkela samples and standard cement.

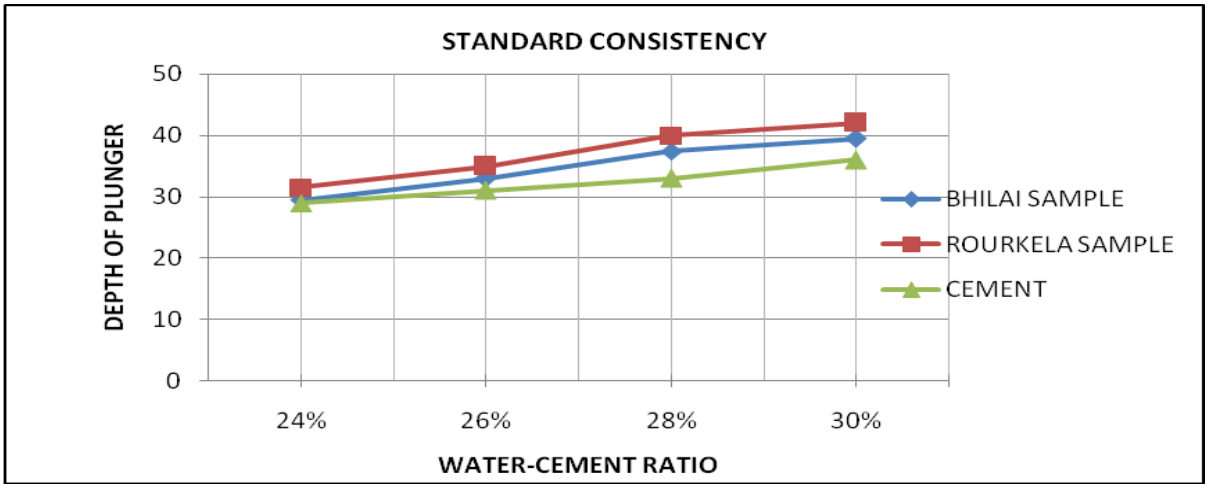

Fig 1 Variation of Depth of Plunger with varying Water Cement ratios

IV. SETTING TIME TEST

Initial setting time is defined as the time elapsed between the moments that the water is added to the cementing material, to the time that the paste starts losing its plasticity.

Table III Initial and Final Setting Time Test

INITIAL SETTING TIME		
BHILAI SAMPLE	**ROURKELA SAMPLE**	**CEMENT SAMPLE**
25'26"	26'49"	45'
FINAL SETTING TIME		
BHILAI SAMPLE	**ROURKELA SAMPLE**	**CEMENT SAMPLE**
1080'	1240'	640'

From the above table III it is seen that although the initial setting time of the slag samples is very low, the final setting time is much higher than the cement sample.

V. Specific Gravity Test

In concrete, specific gravity is made use in the design calculations of the concrete mixes. With the specific gravity of each constituent known, its weight can be converted into solid volume and hence a theoretical yield of concrete per unit volume can be calculated. Specific Gravity is also required to calculate the compacting factor in connection of the workability measurements.

Table IV Specific Gravity Test

SPECIFIC GRAVITY		
BHILAI SAMPLE	**ROURKELA SAMPLE**	**CEMENT SAMPLE**
2.27	2.32	2.74

The above Table IV shows that the slag sample has lower specific gravity than the cement sample.

VI. Workability

The lubrication required for handling concrete without segregation, for placing without loss of homogeneity, for compacting with the amount of efforts forth-coming and to finish it sufficiently easily, the presence of a certain quantity of water is of vital importance [12]. The quality of concrete satisfying the above requirements is termed as *Workable Concrete.* Every job requires a particular workability. A concrete which is considered to be workable for mass concrete is not workable for concrete used in roof construction, or even in roof construction, concrete considered workable when vibrator is used is, is not considered workable when used concrete is to be compacted by hand.

The amount of cement used in these tests is replaced by 30%, 40%, 45% and 50% by slag sample.

Table V Workability Test using the Rourkela Slag Sample

WORKABILITY TEST		
ROURKELA SAMPLE		
PERCENTAGE REPLACED	**HEIGHT OF SUBSIDENCE**	
	M20	**M25**
30%	45	55
40%	60	70
45%	73	82
50%	85	103
BHILAI SAMPLE		
PERCENTAGE REPLACED	**HEIGHT OF SUBSIDENCE**	
	M20	**M25**
30%	48	50
40%	65	65
45%	75	80
50%	90	105

From Table V and Fig. 2 it is seen that M25 mix, is mostly of the high workable nature and is suitable for sections with congested reinforcement.

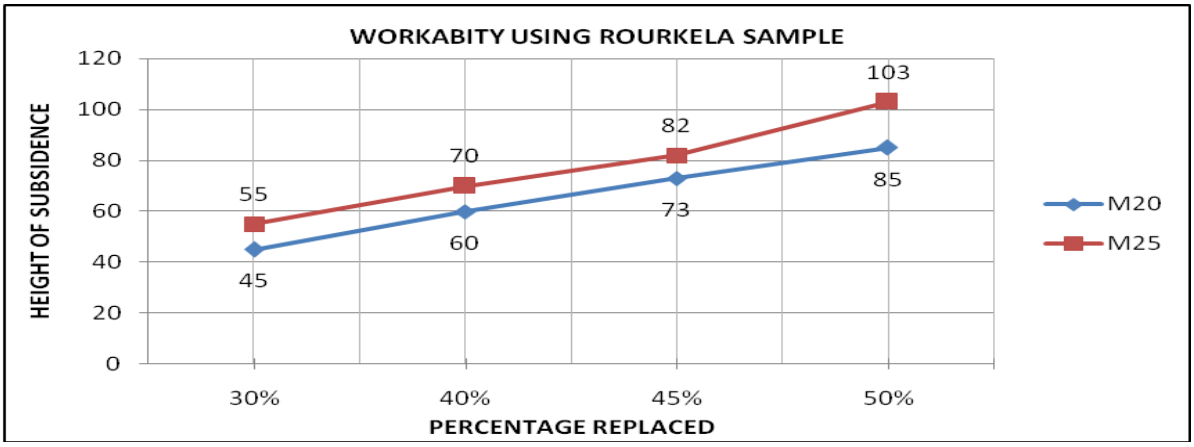

Fig 2 Variation of the Height of subsidence with varying mix ratios

But they are not normally suitable for vibration. They can also be used for pumping and tremie placing.

VII. COMPRESSION TEST

The compression test of concrete is the ultimate test for any concrete mix. The compression test refers to the strength the concrete mix attains at the end of 28 days of curing. Although compressive strength is checked at the end of 28 days, the compressive strength at 3, 7 and 14 days are also recorded. In this the compressive strength of slag replaced concrete and that of normal concrete (0% replacements) is determined and compared. In this test the concrete mix is prepared in water-cement ratio of 0.5 and results are tabulated in Table VI and Table VII.

Table VI Compressive strength of M20 Concrete using Rourkela slag sample

COMPRESSIVE STRENGTH OF M20 MIX USING BHILAI SAMPLE			
PERCENTAGE REPLACED	**COMPRESSIVE STRENGTH(N/mm^2)**		
	DAYS OF CURING		
	3 DAYS	**7 DAYS**	**28 DAYS**
0%	8.14	13.33	20.21
30%	5.33	8.44	19.66
40%	7.11	9.33	20.92
45%	7.91	10.22	17.44
50%	7.55	11.11	15.56
COMPRESSIVE STRENGTH OF M20 MIX USING ROURKELA SAMPLE			
PERCENTAGE REPLACED	**COMPRESSIVE STRENGTH(N/mm^2)**		
	DAYS OF CURING		
	3 DAYS	**7 DAYS**	**28 DAYS**
0%	8.14	13.33	20.21
30%	5.12	8.42	19.67
40%	7	9.35	21.20
45%	7.72	10.01	17.88
50%	7.32	11.21	15.56

Fig. 3 and Fig. 4 show the compressive strength for M20 grade for Rourkela and Bhilai Sample respectively at different partial substitute percentages of GGBFS.

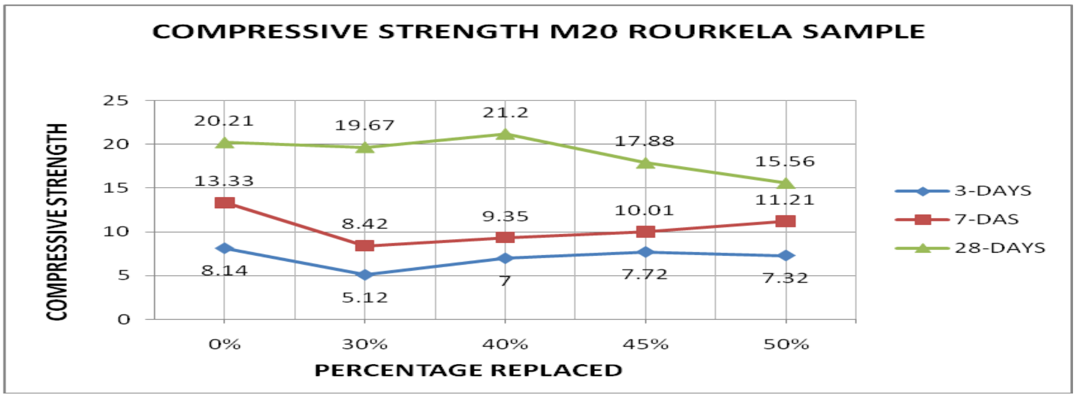

Fig 3. Variation of compressive strength with varying replacement percentage

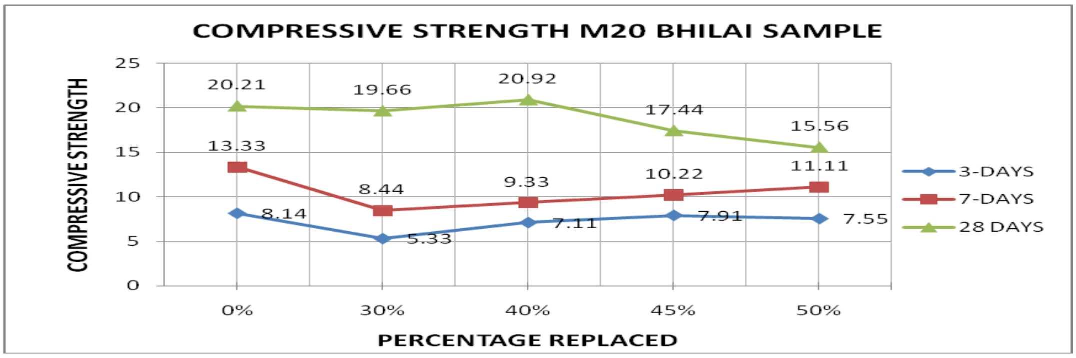

Fig 4. Variation of compressive strength with varying replacement percentage

Table VII Compressive strength of M25 Concrete using Bhilai and Rourkela Sample

COMPRESSIVE STRENGTH OF M25 MIX USING BHILAI SAMPLE			
PERCENTAGE REPLACED	COMPRESSIVE STRENGTH(N/mm^2)		
	DAYS OF CURING		
	3 DAYS	7 DAYS	28 DAYS
0%	9.87	16.25	25
30%	8.33	11.52	22.21
40%	10.72	12.67	25.02
45%	11.11	13.01	26.77
50%	10.98	12.98	24.01
COMPRESSIVE STRENGTH OF M25 MIX USING ROURKELA SAMPLE			
PERCENTAGE REPLACED	COMPRESSIVE STRENGTH(N/mm^2)		
	DAYS OF CURING		
	3 DAYS	7 DAYS	28 DAYS
0%	9.87	16.25	25
30%	8.89	11.55	22.33
40%	11.55	19.11	23.22
45%	13.33	16.89	28.44
50%	12	15.11	26.67

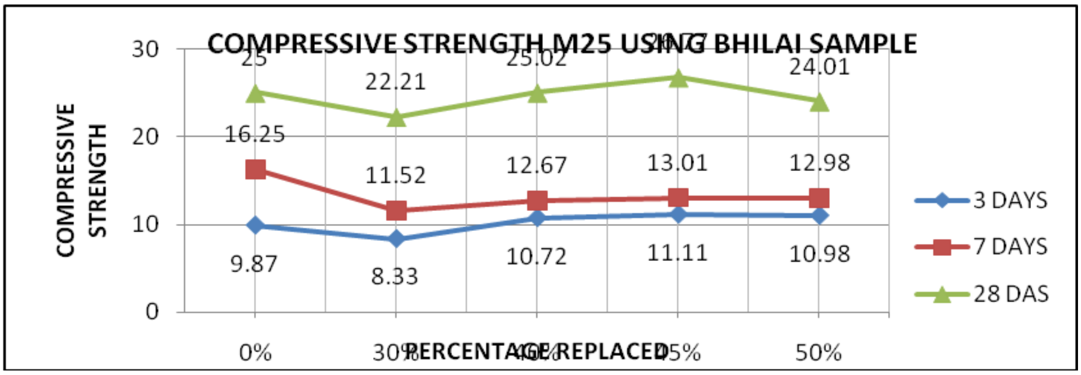

Fig 5. Variation of compressive strength with varying replacement percentage

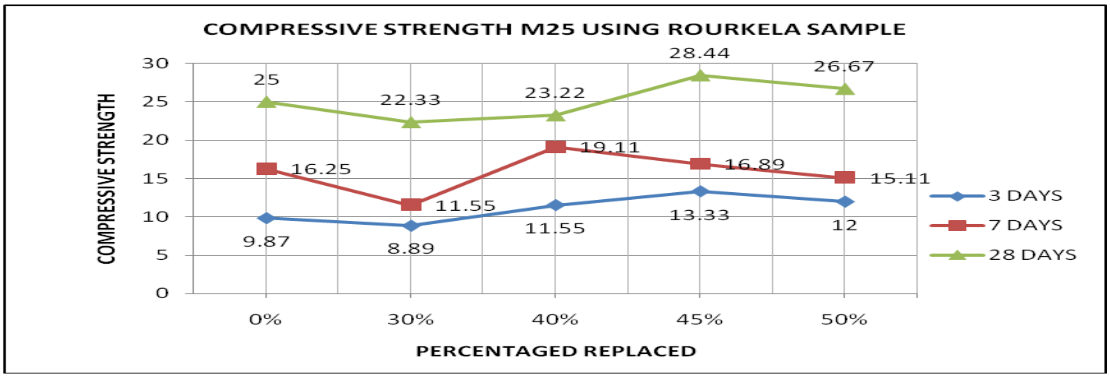

Fig. 6. Variation of compressive strength with varying replacement percentage

The compressive strength development of slag concrete depends primarily upon the type, fineness, activity index, and the proportions of slag used in concrete mixtures. Fig. 4 and Fig. 5 show the compressive strength for M25 grade for Bhilai and Rourkela Sample respectively at different partial substitute percentages of GGBFS. For M20 grade 40% substitution of GGBFS to cement shows maximum compressive strength while for M25 grade 45% substitution of GGBFS to cement shows maximum compressive strength.

VIII. SLAG ACTIVITY INDEX

In accordance with ASTM C989, GGBFS has three strength grades which are determined by their respective mortar strength when they are mixed with equal mass of Portland cement. The three grades, 80, 100, and 120, are classified according to their slag activity index which is average compressive strength of the slag-reference cement cubes (SP), divided by the average compressive strength of the reference cement cubes (P), multiplied by 100 [9],

Mathematically, Slag Activity Index, % = (SP/P) x 100

Minimum Slag Activity Index Chart

MINIMUM SLAG ACTIVITY INDEX		
DAY INDEX	GRADE TYPE	AVG. INDIVIDUAL SAMPLE
	GRADE 80	
7 DAYS	GRADE 100	70
	GRADE 120	90
	GRADE 80	70
28 DAYS	GRADE 100	90
	GRADE 120	110

International Journal of Innovative Research in Science, Engineering and Technology
Vol. 1, Issue 1, November 2012

Table VIII Slag Activity Index Test

COMPRESSIVE STRENGTH (kN)		
SLAG ACTIVITY INDEX (S.A.I)		
	CEMENT	CEMENT + SLAG
CURING DAYS		
7 DAYS	60	40
28 DAYS	80	70

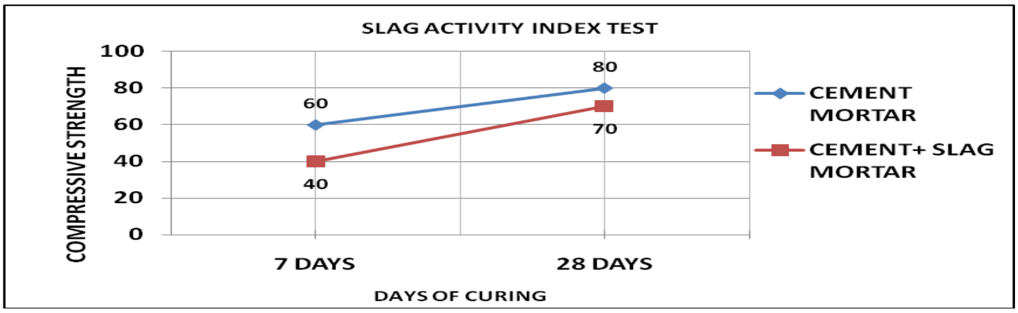

Fig 7. Variation of Compressive strength of mortars

From Table VIII and Fig. 7, it can be concluded that the slag that has been used is of Grade100.

IX. Electrical Conductivity Test

Checking the electrical conductivity of concrete is done to maximize its application. Nowadays roadways are being laid which have sensors embedded in them. This helps in the traffic system of the area.

The test is done on fresh concrete. The conductivity is determined by using the conductivity meter. The conductivity meter is dipped into the fresh concrete mix. The reading on the digital scale fluctuates continuously. The reading is left to steady and then the reading is recorded.

Table IX Electrical Conductivity Test

ELECTRICAL CONDUCTIVITY	
PERCENTAGE REPLACED	CONDUCTIVITY(mho)
0%	0
30%	1.6
40%	1.42
45%	1.4
50%	1.3

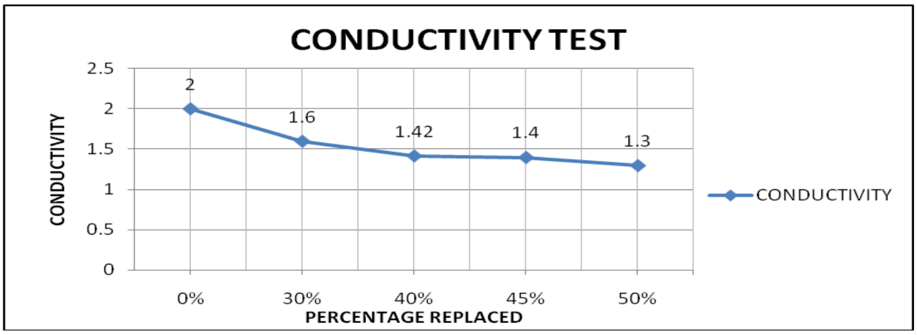

Fig 8.Variation of Electrical Resistance with varying percentages

The Table IX and Fig. 8 show that slag replaced concrete is not a very good conductor of electricity.

X. MODULUS OF ELASTICITY

Concrete deforms when load is applied but its deformation does not follow any simple set of rule. The deformation depends upon the magnitude of load, the rate at which the load is applied and the elapsed time after which the observation is made [12]. Modulus of elasticity of concrete is a key factor for estimating the deformation of buildings and members, as well as a fundamental factor for determining modular ratio, n, which is used for the design of section of members subjected to flexure. Based on the property of modulus of elasticity of concrete, that it is proportional to the square root of compressive strength in the range of normal concrete strength.

The modulus of elasticity was determined by the following equation and results are tabulated in Table X

$E=k.1486.\sigma_B^{1/3}\gamma^2$

Where $k=k_1.k_2$

k_1=correction factor with regard to coarse aggregates

k_2=correction factor with regard to mineral additions

σ_B=compressive strength of concrete at the age of 28 days

γ=unit weight of concrete

Table X Modulus of Elasticity for M20 mix

MODULUS OF ELASTICITY(M20 GRADE) (MPa)		
ROURKELA SAMPLE	**BHILAI SAMPLE**	**CONCRETE SAMPLE**
21558.125	21533.97	22360.68
MODULUS OF ELASTICITY(M25 GRADE) (MPa)		
ROURKELA SAMPLE	**BHILAI SAMPLE**	**CONCRETE SAMPLE**
24299.83	23945.16	25000

Modulus of elasticity of concrete is frequently expressed in terms of compressive strength. Many empirical equations for predicting modulus of elasticity have been proposed by many investigators. The reason is considered to be that the mechanical properties of concrete are highly dependent on the properties and proportions of binders and aggregates.

XI. CONCLUSION

The Ground granulated blast furnace slag is better replacement of cement than various other alternatives. The rate of strength gain in slag replaced concrete is slow in early stages but with proper curing the strength goes on increasing tremendously. For a given mix, the substitution of grade 120 ground granulated blast furnace slag for up to 50 percent of the cement will generally yield a compressive strength at 7 days and beyond equivalent to or greater than that of the same concrete made without ground granulated blast furnace slag. Substitution of grade 100 ground granulated blast furnace slag will generally yield an equivalent or greater strength at 28 days. However, concrete made with grade 80 ground granulated blast furnace slag will have a lower compressive strength at all ages. To provide a product with equivalent or greater compressive strengths, only grades 100 and 120 ground granulated blast furnace slag should be used. However, in mass concrete, the heat of hydration may be an overriding factor, and the use of grade 80 slags may be appropriate. At 30% replacement the Strength gained is lower than normal Concrete. Concrete mix with 40% replacement of cement with GGBFS gives higher compressive strength. The compressive strength decreases when the cement replacement is more than 50%. There is a need for proper curing because of the increased heat of hydration and reduced rate of strength gain at early ages. Setting time of concrete containing slag increases as the slag content increases. An increase of slag content from 35 to 65% by mass can extend the setting time by as much as 60 minutes. The higher fineness of slag also increases the air-entraining agent required, compared to conventional concrete. However, slag unlike fly ash does not contain carbon, which may cause instability and air loss in concrete. Use of slag or slag cements usually improves workability and decreases the water demand due to the increase in paste volume caused by the lower relative density of slag. Grade 100 GGBFS cement concrete has high compressive strength at later ages. GGBFS cement concrete shows low electrical conductivity. Thus it cannot be used to lay roads with sensors in city areas. From the above conclusions it is evident that 45% replacement of cement by GGBFS gives the highest amount of compressive strength. But keeping in view the high heat of hydration produced by GGBFS and the high temperature fluctuations in India, it is suggested that the replacement of cement with slag should be limited to 40%.

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Biography

Mrs. Veena G. Pathan was born in 1982 in Nagpur City. She received her Bachelor of Engineering degree in Structural Engineering from the Visvesvaraya National Institute of Technology in 2003. In 2007 she received her Master’s Degree in Structural Engineering from RTM, Nagpur University and was awarded Gold Medal for her outstanding performance by University. She joined Priyadarshini College of Engineering in 2007 as a faculty where she is now Assistant Professor in Civil Engineering Department with a total experience of 9 years in field of Research, Designing and education. She has many papers published in International and National Conferences and International Journals. She also received the Best Paper Award for her paper on Micro Hydro Power in an International Conference at Sangamner in 2010.

Mr. Vishal S. Ghutke was born in 1976 in Nagpur City. He received his Bachelor of Engineering degree in Civil Engineering from the RTM, Nagpur University in 1999. In 2001 he received his Master’s Degree in Rock Mechanics from IIT Delhi. He joined Priyadarshini College of Engineering as a faculty in 2007 where he is now Assistant Professor in Civil Engineering Department with a total experience of 11 years in field of Research and education.

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