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Analysis of Effect of Ground Granulated Blast Furnace Slag (GGBFS) on the Mechanical Properties of Concrete using Destructive and Non-destructive Tests

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Abstract

Ground granulated furnace slag is a waste material which is rich in Calcium. Aim of this study is to observe the effect of mixing of ground granulated blast furnace slag as a replacement of cement in concrete. The study is conducted on M-30 grade concrete. The cement is replaced partially by the ground granulated blast furnace slag to obtain a cost-effective mix. The concrete mixes are prepared by replacing the cement by 15%, 30%, 45%, 60% and 75 % ground granulated blast furnace slag. The tests are performed to know the compressive strength, flexural strength and workability of concrete. Non-destructive tests like rebound hammer test and ultrasonic pulse velocity tests are also performed to understand the post hardening characteristics of the concrete. It is found that the replacement of cement GGBFS reduces the initial strength of concrete but increases the ultimate strength if mixed in optimum amount. The optimum percentage of ground granulated furnace slag in M-30 concrete is found to be 45%. The workability increases as the amount of GGBFS is increased in the mix. The post hardening tests show the better performance of concrete at 30% and 45% mixing of GGBFS in concrete.

Keywords : GGBFS, waste management, concrete, flexural strength, compression strength

I. Introduction

Cement is one of the most widely used construction material in the world. The researchers have always attempted to reduce the cost of construction by replacing the cement with some local material [I, II]. The properties of the concrete mix can be improved by using the industrial waste like fly ash and glass powder [IV]. The properties like workability, flexural strength, compression strength of concrete etc. can be improved using different materials. The cement can't be replaced completely with any kind of material. So, partial replacement of cement with fine materials is done for the improvement of characteristics of concrete and cost effectiveness [VII, IX]. The manufacturing process of cement is responsible for the environmental pollution also. The amount of carbon di oxide (CO2) is ejected in the environment at time of cement manufacturing [III, XII]. So, it is desirable to replace the cement partially with some other material.

Ground granulated blast furnace slag (GGBFS) is a white powder with bulk density 1200 Kg/m3 and specific gravity 3.4 [X]. GGBFS is a waste residue of production of iron in a blast furnace where coke and iron are heated up to 1500°C.The materials melt in blast kiln and molten iron and molten slag are produced. The molten slag is lighter and floats on the top of the molten iron. The process involves cooling the molten slag through high-pressure water jet. The granulated slag is grinded in rotating hall mill to produce ground granulated blast furnace slag (GGBFS). Ground granulated furnace slag (GGBFS) consists of Calcium Oxide (Cao), Silica Oxide (SiO2), Aluminum Oxide (Al2O3) and Magnesium Oxide (MgO). Calcium Oxide and Silica Oxide makes about 75% proportion of GGBFS [XI, XII]. The amount of calcium present in GGBFS is useful in providing the cementious effect to the mix. So, large cement proportions can be replaced by ground granulated blast furnace slag (GGBFS).

Ground granulated blast furnace slag (GGBFS) is used as a construction material from 17th century. Firstly it was used to make mortar with lime. The quality of GGBFS is improved with further development. In France, the GGBFS is used in construction of metro in 1889. According to a study conducted by Hogan and Meusel in 1981 shows that GGBFS is used in nearly 20% of the hydraulic cement produced in Europe. Since the late 1950s, use of GGBF slag as a separate cementious material added at the concrete mixer with Portland cement has gained acceptance in South Africa, Australia the United Kingdom (U.K.), Japan, Canada, and the United States America (U.S.A.).

Aim of this study is to analyze the effectiveness of ground granulated blast furnace slag (GGBFS) as a replacement of cement in concrete mix. The studyobserves the effect of different percentages of GGBFS in M-30 concrete mix and observes the changes in characteristics of the pre-hardened and post hardened concrete.

II. Materials and Methods

The GGBFS can be used from 25% to 75% in concrete. The materials used for this study are cement, fine aggregates, coarse aggregates, water and ground granulated blast furnace slag (GGBFS). The materials are tested for their different properties.

Birla Uttam Ordinary Portland Cement (OPC) of grade 43 is used. Normal consistency, initial setting time, specific gravity, soundness and final setting time are determined. Vicat apparatus is used to determine the consistency of cement, initial setting time and final setting time. The values obtained experimentally are compared with the standard values given in IS:8112-1989 as shown in Table 1.

Table 1. Physical Properties of Cement

S.NO	Properties	Experimental Value	As per IS:8112-1989
1	Cement used	OPC43 Grade	-
2	Consistency	32%	28-33%
3	Initial setting time	100 min	>30 min
4	Final setting time	220 min	<600 min
5	Specific gravity	3.15	3.15
6	Soundness	0.75mm	<10 mm

The coarse aggregates used in this study are obtained from quarries of Rajasthan, India. The coarse aggregates are sieved on various sieve sizes and their physical properties are determined. Maximum size of the coarse aggregate is kept 20mm. Specific gravity is found to be 2.82 which lies between permissible limit according to codal provision. Water absorption is found to be 0.4 per unit weight. Yamuna river sand is used as fine aggregates. Specific gravity, water absorption and soundness tests are conducted to evaluate the suitability of fine aggregates. The specific gravity is found to be 2.6 and water absorption is 2.3 %. The fineness modulus is 2.66.

Table 2. Physical Properties of Ground Granulated Blast Furnace Slag (GGBFS)

Physical properties	GGBFS
Colour	Off white powder
Bulk density (loose)	1200 kg/m3
Relative density	2.85-2.95
Specific gravity	3.4

GGBFS used in this study has taken from Dehradun, India. GGBFS is used as a replacement of cement because somewhere the chemical properties of OPC and GGBFS are same. It is very cheap as compare to cement and its production has not affected the environment. Table 2. Shows the physical properties of GGBFS such as colour, the Bulk density, specific gravity and relative density. Concrete admixtures are utilized to enhance the behaviour of fresh concrete.

Table 3. Final Design Mix

Materials	Quantity
Cement	414.8 Kg/m^3
Water	165.9 Kg/m^3
Fine aggregate	666.66 Kg/m^3
Coarse aggregate	1214.8 Kg/m^3
Water cement ratio	0.40
Chemical admixture	0.622Kg/m^3

In This investigation, a poly-carboxylic ether super-plasticizer conforming to ASTM C494 Type G was used and its quantity was 0.15% of cementious material. Water is also an important ingredient of the concrete. The pH value of the water used in this study is 6.8 which is within permissible limits. Potable water is used for preparation of concrete mix. The concrete mix designing is performed according to IS 10262: 2009. The final gradation of the mix is given in Table 3.Six set of samples are prepared. Each set consists of 3 cubes and 3 beams. Table 4. Shows the replacement of GGBFS with cement. The mixing is done in the mixer with proper quality control. The samples are prepared in the concrete moulds. It is attempted to minimize the segregation and bleeding defects of concrete. Workability, flexural strength and compression strength tests are done.

Table 4. Sampling with GGBFS Proportion

Nomenclature (concrete mix)	Cement %	GGBFS %
M1	100	0
M2	85	15
M3	70	30
M4	55	45
M5	40	60
M6	25	75

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The tests performed on the hardened concrete are rebound hammer test and ultrasonic pulse velocity test.

III. Results and Discussions

The study concentrates on the properties of M30 concrete with replacement ofcement byground granulated blast furnace slag (GGBFS)in 15%, 30%, 45%,60% and 75% proportion. The optimum percentage of the GGBFS is found out from these results.

The workability test is performed to determine the effect of GGBFS on the workability of concrete. It is found that the workability of the concrete increases as the content of the GGBFS increases in the mix. Figure 1 shows the progressive increase of workability with the increase in proportion of the GGBFS in the mix.

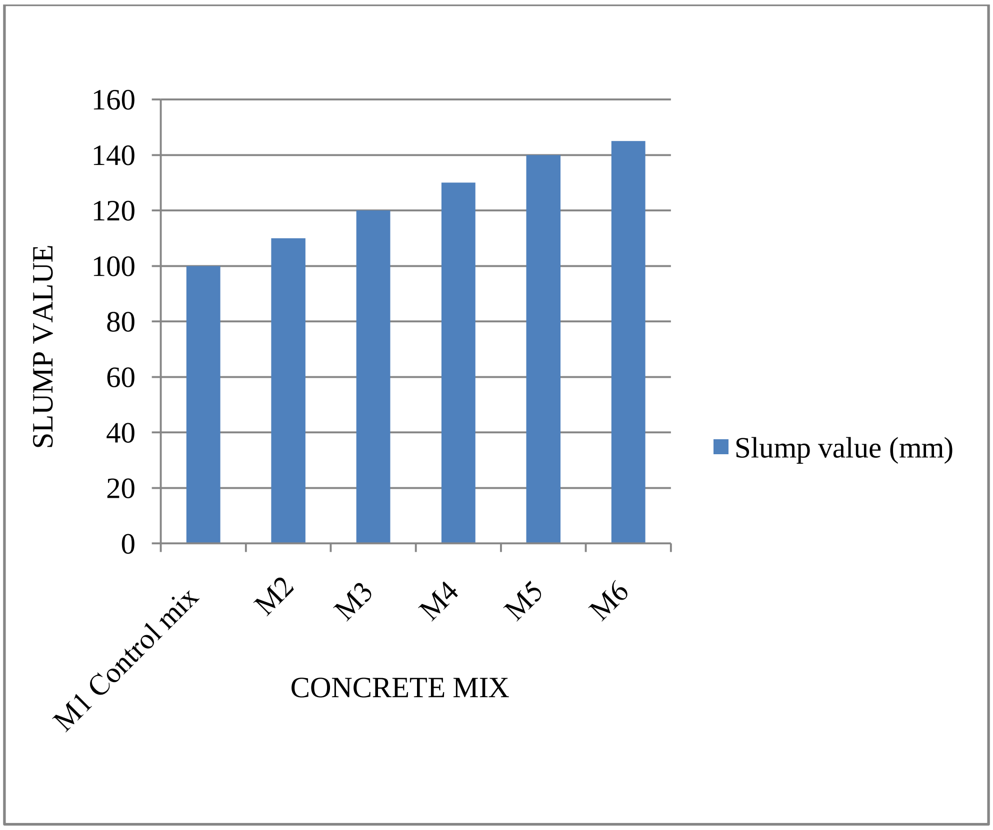

Figure 1. Variation of Workability with GGBFS

Figure 2 shows the variation of the compression strength with respect to the amount of ground granulated blast furnace slag (GGBFS). The compression test is performed according to IS 516: 1959. The cubes were tested immediately after removing out of curing tank. The cubes were placed in between the jaws of the compression testing machine in such a way, so that load applied on the specimen's surface to check the proper strengths. The load applied and increases gradually till the specimen break down or cracks. And then it has been noted the applied load value on broken condition of the specimen. Average of three strengths was recorded for 7 days, 14days and 28 days.

The compressive strength of mixes M1, M2, M3, M4, M5 and M6 are 40.1 N/mm^2,36 N/mm^2,40.5 N/mm^2,42 N/mm^2,38 $N/mm^2$and 34 N/mm^2 respectively at 28 days .The maximum compressive strength is of mix M4 in which the 45% of the cement proportion is replaced. So according to these results 45% is the optimum dose of GGBS. Result also shows that the compressive strength of GGBS mixes at 7days and 14days is less as compare to control concrete. The initial strength of the concrete reduces but the final strength reaches near to the control mix concrete.

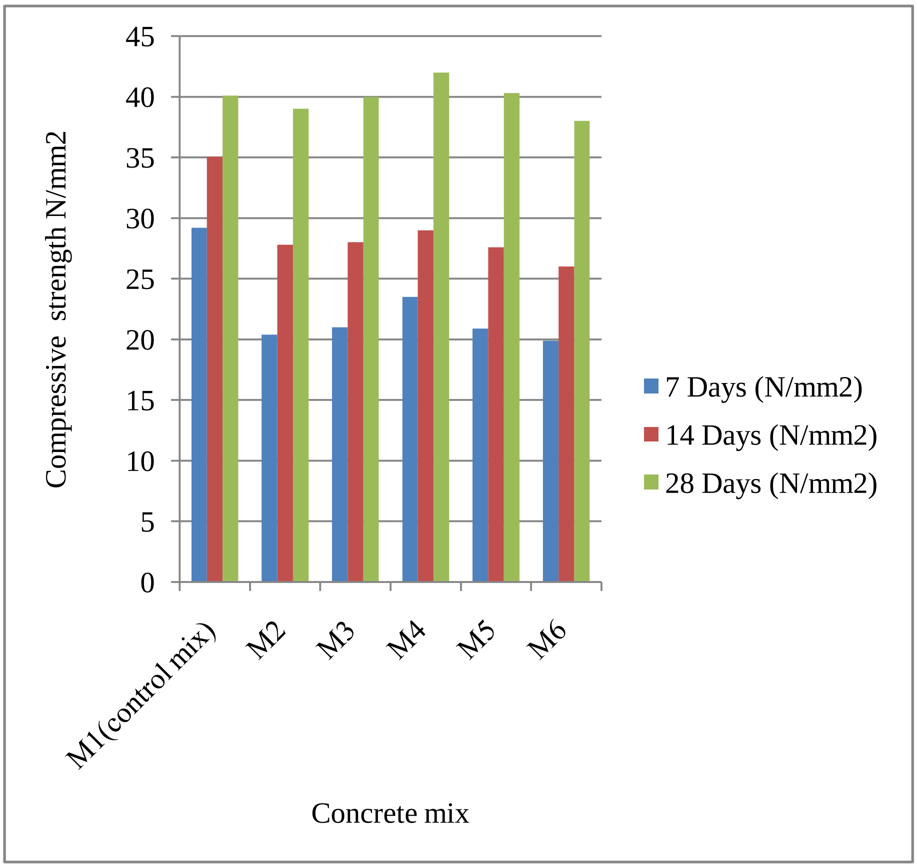

Figure 2. Variation of Workability with GGBFS

Beams of size (10×10×50 cm) were cast and beams were cured for 28 days in curing tank and test was performed on a flexural test machine as per IS 516-1959. Figure 3.

Shows the variation of the flexural strength of the beams with the increasing amount of ground granulated blast furnace slag (GGBFS).

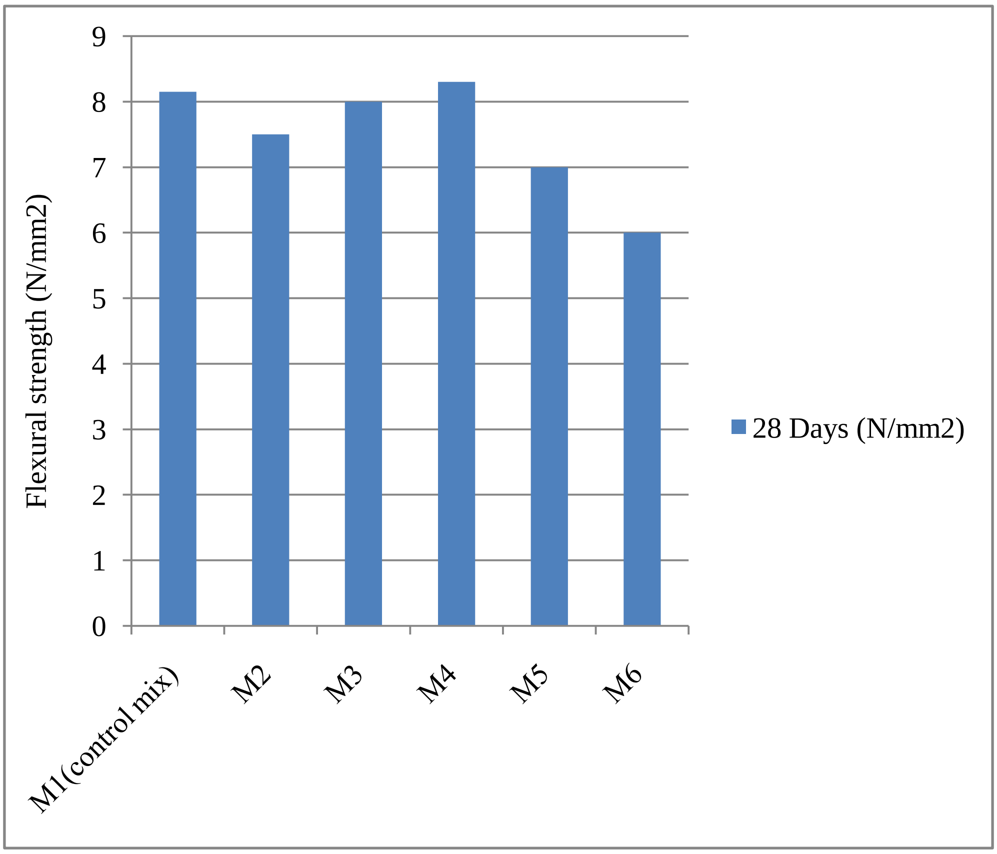

Figure 3. Variation of Flexural Strength with GGBFS

The flexural strength of mixes M1, M2, M3, M4, M5 and M6 are found out to be 8.15 N/mm^2, 7.5 N/mm^2, 8 N/mm^2, 8.3 N/mm^2, 7 $N/mm^2$and 6 N/mm^2 at 28 days. The mix M4 in which 45% of the cement proportion is replaces gave the maximum flexural strength 8.3 N/mm^2.So the optimum % of GGBS is 45% as per as flexural strength test. The initial flexural strength is less as compared to the control mix but the concrete acheives sufficient strength after completion of 28 days. It is also expected that the strength may increases further with the duration of time.

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Table 5. Variation of Rebound Number for Concrete Mixes

Concrete mix design	Days	Avg. Rebound no	Quality of concrete
M1(control mix)	7	33	Good layer
	14	38	Good layer
	28	45	Very good layer
M2	7	25	Fair layer
	14	31	Good layer
	28	40	Very good layer
M3	7	27	Fair layer
	14	32	Good layer
	28	42	Very good layer
M4	7	30	Good layer
	14	34	Good layer
	28	46	Very good layer
M5	7	26	Fair layer
	14	31	Good layer
	28	41	Very good layer
M6	7	23	Fair layer
	14	29	Fair layer
	28	38	Good layer

Non-destructive tests are also performed to analyse the optimum amount of ground granulated blast furnace slag (GGBFS) in the concrete mix. Schmidt Hammer test and Ultrasonic pulse velocity test are performed. As per IS 13311(part2): 1992, Rebound hammer test on concrete structure starts with the calibration of rebound hammer.For doing this, the rebound hammer is checked against the test anvil made of steel Brinell hardness number of about 5000 N/mm2.After the rebound hammer is checked for the precision on the test anvil, the rebound hammer is placed at right angle to the facade of concrete structure for the record the readings. For testing, the surface of specimen or concrete structure should be smooth, clean and dry. The point of contact of rebound hammer on the concrete surface should be least 20mm away from edge or shape discontinuity. Six readings of rebound number were taken and then the average value of the readings is taken.This test was performed at the age of 7days, 14 days and 28 days. The quality of concrete according to rebound number is tabulated below in the Table 5.

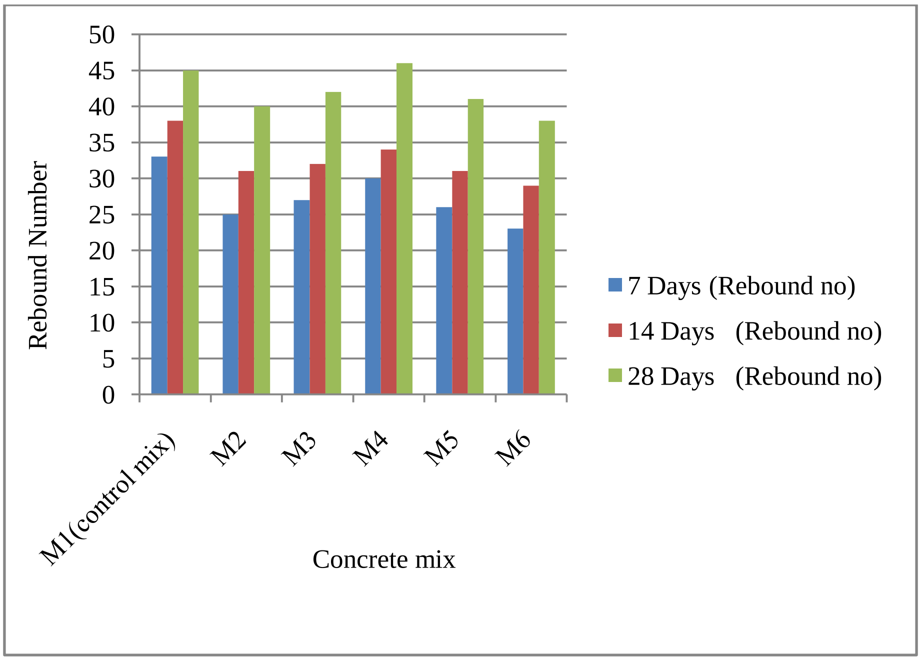

Figure 4. Variation of Rebound Number for Different Mixes

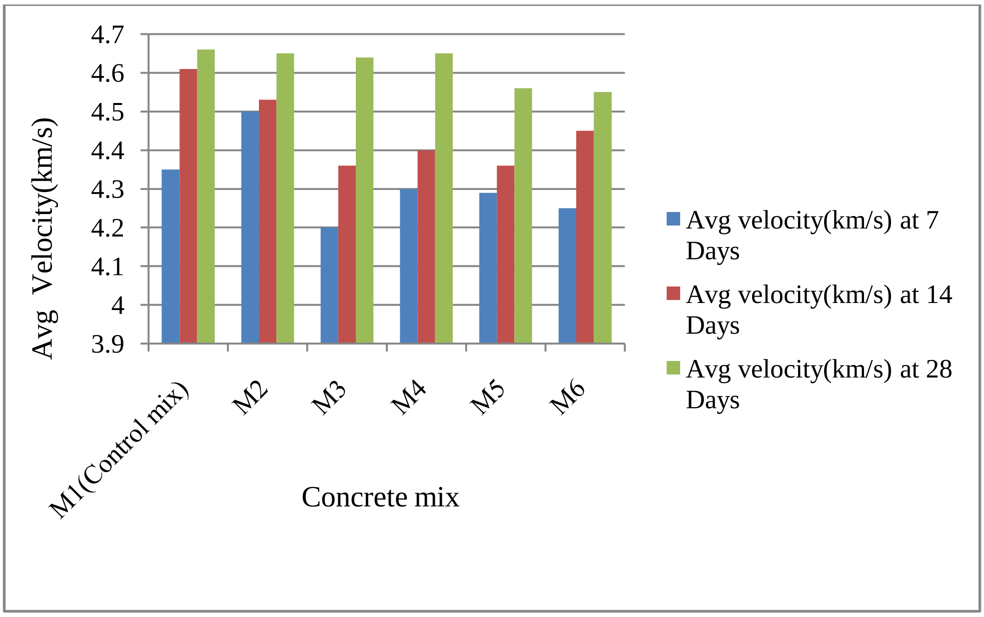

Figure 5. Variation of Average Velocity with Increasing GGBFS

It is found that the rebound number remained less as compared to the control mix while the characteristics improved with time. M4 mix showed the best results at initial and final stages both. The rebound number was maximum for 45% of the cement replaced by ground granulated blast furnace slag (GGBFS). Figure 4. shows the variation of rebound number with increasing amount of GGBFS in the mix.

Table 6. Variation of Average Velocity with Increasing GGBFS

Concrete mix design	Days	Avg. Velocity (km/s)	Quality of concrete
M1(control mix)	7 14 28	4.35 4.61 4.66	Good Excellent Excellent
M2	7 14 28	4.2 4.36 4.64	Good Good Excellent
M3	7 14 28	4.5 4.63 4.75	Excellent Excellent Excellent
M4	7 14 28	4.3 4.4 4.65	Good Good Excellent
M5	7 14 28	4.29 4.36 4.56	Good Good Excellent
M6	7 14 28	4.25 4.45 4.55	Good Good Excellent

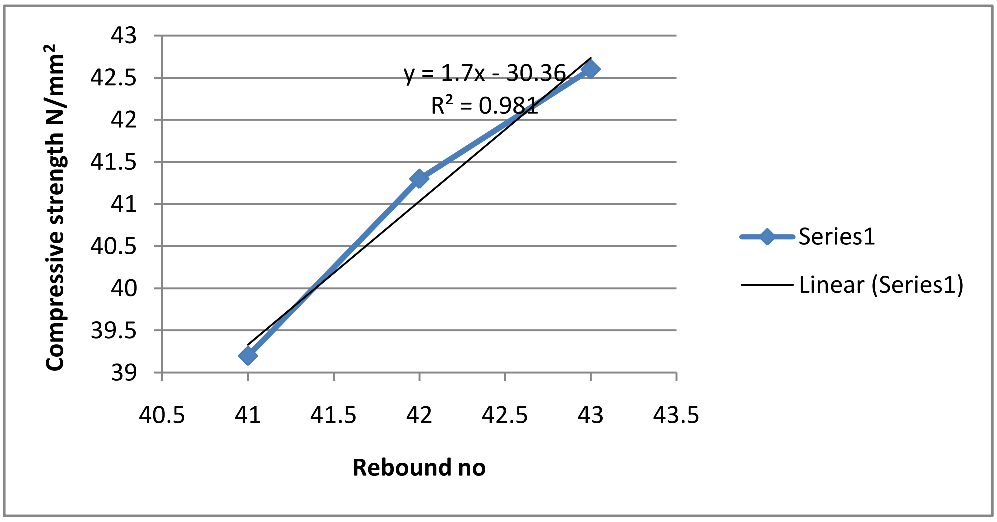

Figure 6. Relationship between Rebound Number and Compression Strength

Theutra-sonic pulse velocity test is done to assess the quality of concrete by ultrasonic pulse velocity method as per IS: 13311 (Part 1) 1992.The underlying principle of this test is the method consists of measuring the time of travelof an ultrasonic pulse passing through the concrete being tested. Comparatively higher velocity is obtained when concrete quality is good in terms of density, uniformity, homogeneity etc. Ultrasonic pulse velocity test results are shown in figure 5.

According to Codal provision, the quality of mixes can be considered as given in Table 6. It is found that the best results are shown by the concrete at mixing of 30% ground granulated blast furnace slag.

A relationship between the rebound number and the compression strength can be established. The rebound number gives approximate value of compression strength. Figure 6 shows the relationship between compression strength and rebound number.

Similarly, a relationship between ultra-sonic pulse velocity value and compression strength. Figure 7 shows the relationship between ultra-sonic pulse velocity values and compression strength.

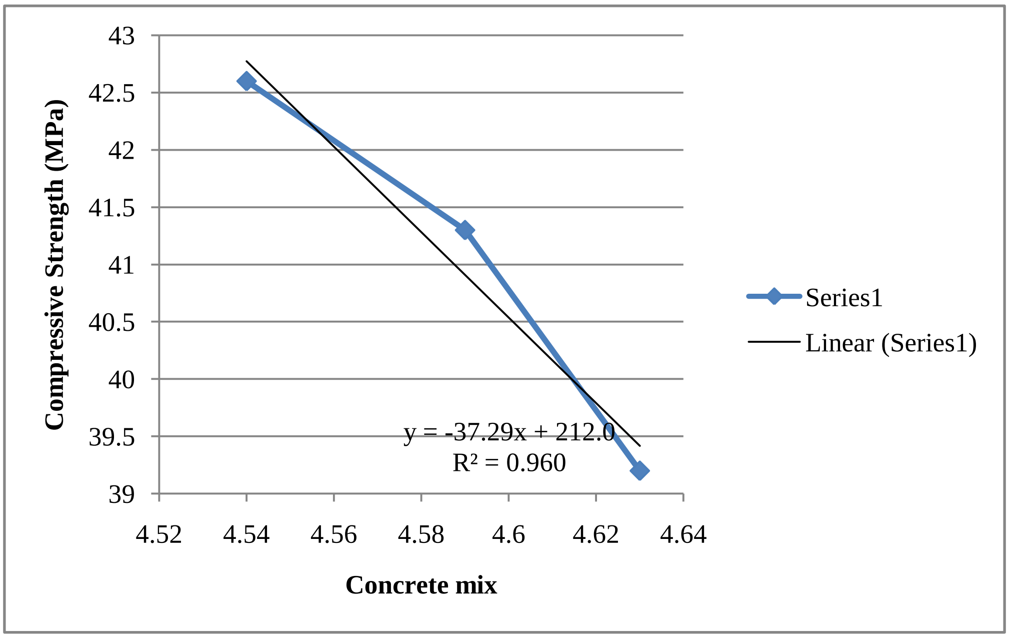

Figure 7. Relationship between UPV Values and Compression Strength

The optimum amount of the ground granulated blast furnace slag (GGBFS) in concrete mix is found to be 45% in most of the cases. The initial strength of the concrete mix always reduces with the mixing of the ground granulated blast furnace slag (GGBFS) but the strength increases as the time passes. The 28 days strength is improved in some cases.

IV. Conclusion

Ground granulated blast furnace slag (GGBFS) can replace a significant amount of cement in concrete. The initial strength of the concrete mixed with ground granulated blast furnace slag (GGBFS) is found to be less as compared to control mix. The strength of the GGBFS mixed concrete increases with the time. The 28 days strength is found to be near to the strength of control mix. In some cases, the 28 days strength is better than the control mix. It can be concluded that GGBFS can replace cement in concrete mix and provides a cost effective and strong mix. The works where initial strength of concrete is required, the use of GGBFS should be avoided. The non-destructive tests also suggests that GGBFS mixed concrete can give good layer characteristics.

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