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An Experimental Study on High Performance Concrete Using Mineral Fly Ash and GGBS with M-60 grade Concrete

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Abstract: This work presents the determination of the mechanical properties (compression, split tensile and flexural tests) of the specimens (cubes, cylinders, and beams). The specimens are of M60 grade high strength concrete which includes ground granulated blast furnace slag (10 %, 20 %, 30 % and 40%) and Fly ash (10 %, 20 %, 30 % and 40%) to obtain the desired strengths and properties. Finally, we used in combination of fly ash and ground granulated blast furnace slag in different percentages as replacement of cement and concrete was prepared. We used SP430-Sulphonated Naphthalene Polymers as a super plasticizer for better workability for high performance concrete. Dosage for super plasticizers is same for all mix proportions. We casted concrete cubes, beams, and cylinders and are kept for curing for a period of 28days. The tests are conducted after 7, 14 and 28 days of curing period. To obtain such desired strength that cannot be obtained from conventional concrete and by the current method, a large number of trial mixes with different percentages of fly ash and different percentages of ground granulated blast furnace slag are required to select the desired combination of materials that meet the required strength.

Keywords: Ground Granulated Blast Furnace Slag, Cement Concrete, Workability, Compressive Strength, Flexural Strength.

1. INTRODUCTION

Concrete has basic naturally, cheaply and easily available ingredients as cement, sand, aggregate, and water. After the water, cement is second most used material in the world. But this rapid production of cement creates two big environmental problems for which we have to find out civil engineering solutions. First environmental problem is the emission of CO2 in the production process of the cement. We know that CO2 emission is very harmful which creates lots of environmental changes whatsoever. Ground Granulated Blast furnace slag (GGBS) is a by-product of the manufacture of pig iron and obtained through rapid cooling by water or quenching molten slag. Here the molten slag is produced which is instantaneously tapped and quenched by water. This rapid quenching of molten slag facilitates the formation of “Granulated slag”. Ground Granulated Blast furnace Slag (GGBS) is processed from Granulated slag. Fly ash is one of the residues created during the combustion of coal in coal-fired power plants. Fine particles rise with flue gasses and are collected with finely-divided mineral admixture, available in both uncompact and compacted forms. This ultra-fine material will better fill voids between cement particles and result in a very dense concrete with higher compressive strengths and extremely low permeability.

2. LITERATURE REVIEW

Anjali Prajapati et. al. (2017) studied the effect of the performance of HPC using mineral admixture i.e. fly ash and GGBS with M-60 grade of IS cube specimen.We partially replaced Portland cement by weight of the binder. Fly ash and GGBS replacement vary from 10% to 30%. We used Conplast SP430-Sulphonated Naphthalene Polymers as a superplasticizer for better workability for high performance concrete. Dosage for superplasticizers is same for all mix proportions. Also, we have replaced fine aggregate in different proportions with foundry sand. We have investigated compressive strength, split tensile strength and flexural strength for all different cases. The HPC mix, grade M60concrete is designed as per Indian standards.

Praveen Kumar S R et. al. (2016) prepared a high strength SCC of grade M60 by partially replacing the cement content with the untreated industrial by-products like fly ash & ground granulated blast furnace slag (GGBS) and also by replacing 100% of natural sand with manufactured sand (M. Sand). With the use of these industrial by-products, it results in an eco-friendly environment and also solves the problem at its disposal.

Their work deals with the comparative study on mechanical properties like compressive strength, split tensile strength and flexural strength of SCC for various percentages of powder contents with the use of glass fibers at 0%, 0.1% & 0.2% to the total volume of the concrete mix. In this study two types, SCC mixes were prepared namely, Conventional SCC in which cement content was replaced by 30% with fly ash and Triple blended SCC in which cement content was reduced to 50% & the rest of the cement content was replaced with fly ash & GGBS by 25% each. The specimens are casted, cured & tested for the required number of days.

Rajith M & Amritha E K (2015) investigated the behaviour of M30 concrete by partial replacement of cement and fine aggregate by Ground granulated blast furnace slag (GGBS) and Granulated blast furnace slag (GBS). Cubes, cylinders, and beams are tested for compressive, split tensile and flexural strength after 28 days curing. Cubes are used to find the ultra-sonic pulse velocity. Replacement percentage of cement and fine aggregate by GGBS and GBS are 20, 25, 30 and 25, 50, 75 respectively. Water cement ratio used in this work is 0.45. It is found that by partial replacement of cement with GGBS and sand with GBS helped in improving the strength of concrete compared to normal mix concrete.
Rafat Siddique (2014) covers the properties of GGBS, reaction mechanism and its effect on strength and durability properties of concrete.

Reshma Rughooputh and Jaylina Rana (2013) studied the effects of partial replacement of OPC by GGBS on various properties of concrete including compressive strength, tensile strength, splitting strength, flexure strength, modulus of elasticity, drying shrinkage and initial surface absorption. Cement was partially replaced by 30 % and 50 % of GGBS by weight and test was performed at 7 and 28 days. It was found that GGBS in concrete leads to lower early compressive strength gain but higher later compressive strength gain. Flexural strength of test specimens increased by 22% and 24%, tensile strength increased by 12% and 17% to 30% and 50% replacement respectively. Drying shrinkage increased by 3% and 4%.
S. Arivalagan (2012) investigated the strength and strength efficiency factors of hardened concrete, by partially replacing cement with 20 %, 30% and 40% GGBS at different ages. The specimens when tested at 7 and 28 days, showed an increase in compressive strength for 20% replacement of cement. Split tensile strength and flexural strength of concrete also increased at 20% cement replacement. The increasing strength is due to filler effect of GGBS. It was also found that the degree of workability of concrete was normal and it increased with the addition of GGBS.

Yogendra O. Patil et. al. (2012) researched on the effects on compressive strength and flexural strength of concrete with partial replacement of cement with various percentages of GGBS. The tests were conducted at 7, 28 and 90 days with replacement ranging from 10 % to 40 %. It was observed that the strength of concrete is inversely proportional to the percentage of replacement of cement with GGBS. The replacement of OPC by GGBS up to 20% shows the marginal reduction of 4 – 6 % in compressive and flexural strength for 90 days curing and beyond that of more than 15%. He concluded that, GGBS as replacement of OPC by 20% results in a reduction in the cost of concrete at the current market rate.

T. Vijaya Gowri et. al. (2011) investigated the effects of partial replacement of cement with GGBS on compressive strength, split tensile strength and flexural strength of concrete at 28, 90, 180 and 360 days. He used 50% GGBS as replacement material of cement for various water/binder ratios i.e. 0.55, 0.50, 0.45, 0.40, 0.36, 0.32, 0.30 and 0.27. He observed that the High Volumes of slag concrete gains an appreciable amount of strength at later ages (90 days onwards) and it increases with a decrease in water/binder ratios. He found out that the strength of high volume of slag concrete is more at later ages because of slower hydration of slag with $Ca(OH)_2$ and water. He concluded that on replacement of cement by 50% GGBS helps to reduce the cement content of concrete, thereby reducing the cost of concrete and also protecting the environment from pollution.

Venu Malagavelli et. al. (2010) focused on investigating characteristics of M30 concrete with partial replacement of cement with Ground Granulated Blast furnace Slag (GGBS) and sand with the ROBO sand (crusher dust). The cubes and cylinders are tested for both compressive and tensile strengths. It is found that by the partial replacement of cement with GGBS and sand with ROBO sand helped in improving the strength of the concrete substantially compared to normal mix concrete.

3. MATERIALS AND METHODS

The concrete mix was designed as per of IS 10262-1984 and it was prepared by using the following materials:

- Cement- The 53 grade Ordinary Portland cement conforming to IS: 12269-1987 was used in the work with a specific gravity of 3.15.
- Fly ash- Fly ash is available in dry powder form and is procured from Rajrajeshwari, Mandideep, and Bhopal. The fly ash produced by the company satisfies all the requirements of the IS: 3812-1981.
- GGBS conforming to IS 12089-1981 was used in the investigation and is procured from Sri Satguru Associates, Bhopal.
- Fine Aggregate- Locally available river sand passing through 4.75 mm IS sieve conforming to grading zone-II of IS: 383-1970 was used with a specific gravity of 2.74.
- Coarse Aggregate- Crushed stone aggregate with combinations of 12 mm and 10 mm in 60% and 40% respectively from a local source having the specific gravity of 2.74 conforming to IS: 383-1970 was used.
- Water- Potable water is used for mixing and curing concrete.
- Super Plasticizers- Super plasticizer in the form of sulphonated Naphthalene Polymers complies with IS 516 – 1959 and ASTM C 642 type F as a high range water reducing admixture (VARAPLAST PC 100) was used.

3.1 CONCRETE MIX DESIGN
Mix design is made for M60 grade concrete accordance with the Indian Standard Recommended Method IS 10262-2009.

Table 1 Mix Design

Mix	Fly Ash %	GGBS %	Quantity (Kg/m^3)						
			Cement	Fly Ash	GGBS	Coarse Aggregate	Fine Aggregate	Super Plasticizer	Water
M1	0	0	466.66	0	0	1205	585	9.33	140
M2	10	10	419.99	46.66	46.66	1205	585	9.33	140
M3	20		335.99	83.99	46.66	1205	585	9.33	140
M4	30		326.66	139.99	46.66	1205	585	9.33	140
M5	40		279.99	186.66	46.66	1205	585	9.33	140
M6	10	20	419.99	46.66	93.33	1205	585	9.33	140
M7	20		335.99	83.99	93.33	1205	585	9.33	140
M8	30		326.66	139.99	93.33	1205	585	9.33	140
M9	40		279.99	186.66	93.33	1205	585	9.33	140
M10	10	30	419.99	46.66	139.99	1205	585	9.33	140
M11	20		335.99	83.99	139.99	1205	585	9.33	140
M12	30		326.66	139.99	139.99	1205	585	9.33	140
M13	40		279.99	186.66	139.99	1205	585	9.33	140
M14	10	40	419.99	46.66	186.66	1205	585	9.33	140
M15	20		335.99	83.99	186.66	1205	585	9.33	140
M16	30		326.66	139.99	186.66	1205	585	9.33	140
M17	40		279.99	186.66	186.66	1205	585	9.33	140

3.2 CASTING AND CURING OF TEST SPECIMENS
After proper mixing, the mix poured in to the cube moulds of size 150 x 150x 150 mm, a beam of size 500mm x 500mm x 700mm and standard cylinder of 150 mm diameter and 300 mm height and then compacted manually using tamping rods. In this work, we mainly Prepared 17 different mixes of M60 Grade namely conventional aggregate concrete (CAC), concrete made by replacing GGBS and fly ash.

Fig. 1: Casting of Cubes, Beams, and Cylinders

The cubes are demolded after 1 day of casting and then kept in water for curing at room temperature with a relative humidity of 85% the cubes are taken out from curing after 7days, 21 days and 28 days for testing.

3.3 TESTING OF SPECIMEN

3.3.1 WORKABILITY TEST

The workability of fresh concrete was measured by means of the conventional slump test as per IS: 1199(1989). Before the fresh concrete was cast into moulds, the slump value of the fresh concrete was measured using slump cone.

Fig. 2: Workability Test Conducted in Lab

3.3.2 WATER ABSORPTION TEST- One of the most important properties of a good quality concrete is low permeability, especially one resistant to freezing and thawing. A concrete with low permeability resists ingress of water and is not as susceptible to freezing and thawing. Water enters pores in the cement paste and even in the aggregate.

Fig. 3: Water Absorption Test Conducted in Lab

3.3.4 COMPRESSIVE STRENGTH TEST

The compressive strength test was carried out conforming to IS 516-1959 to obtain compressive strength for an M60 grade of concretes.

Fig. 4: Compressive Strength Test

3.3.5 FLEXURAL STRENGTH TEST

Flexural strength test was conducted on beam specimens prepared as per I.S.516-1959 for an M60 grade of concrete under two point loading over an effective span of 600 mm divide into three equal parts.

Fig. 5: Flexural Strength Test

3.3.6 SPLIT TENSILE STRENGTH TEST

Split tensile strength test was conducted on concrete prepared as per IS: 5816-1976 for M60 grade of concrete.

4. RESULTS AND DISCUSSIONS

4.1 WORKABILITY TEST

It is observed that the slump value of concrete increases as the percentage of GGBS increases up to 20% replacement and then decreases. The increase in slump value is due to the higher smoothness and fineness of slag increases the entrainment of air in the matrix, subsequently increasing the volume of paste. It is clear from the figure below, constant 20% GGBS has shown more cohesiveness. But the stickiness in concrete was observed with increase percentage of GGBS and fly ash i.e. 30% to 40% and increase the percentage of GGBS and fly ash i.e. 0% to 10%, the stickiness in concrete was observed.

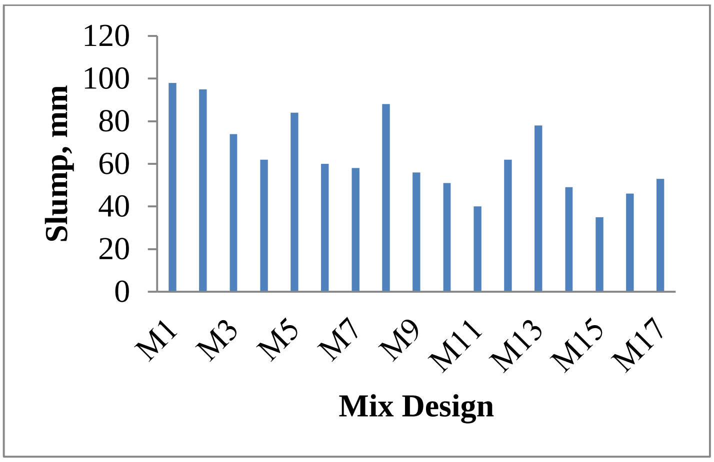

Fig. 6: Variation of Slump of Concrete with Cement Replacement by GGBS and Fly Ash for M60

4.2 WATER ABSORPTION TEST

From the below fig., it is observed that the water absorption of concrete decreases as the percentage of GGBS increases. From this result, it is concluded that the GGBS can be used to improve the water impermeability characteristics of the structure. Hence the corrosion of reinforcement may be retarded & durability of R.C.C. structure may be increased.

Fig. 7: Water absorption of M60 concrete

4.3 COMPRESSIVE STRENGTH TEST

4.3.1 FOR 7 DAYS OF CURING

For 7 days of curing, fly ash of 10 %, 20 %, 30 % and 40 % with GGBS of 10 % shows 4.66 %, 6.03 %, 7.01 % and 11 %, GGBS of 20 % shows 11.8 %, 7.46 %, 11.9 % and 13.4 %, GGBS of 30 % shows 17.13 %, 12.34 %, 13.84 % and 16.4 % and GGBS of 40 % shows 8.68 %, 5.42 %, 5.57 % and 7.91 %.

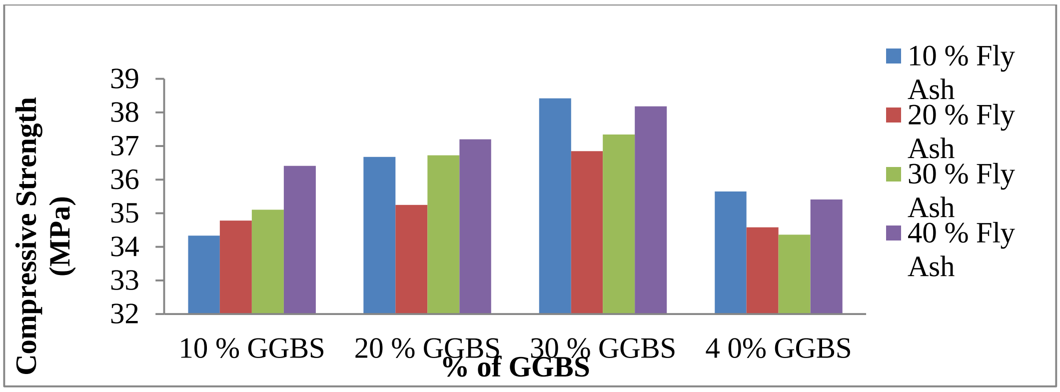

Fig. 8: Compressive Strength of M60 Grade Concrete at 7 Days Curing

4.3.2 FOR 21 DAYS OF CURING

For 21 days of curing, fly ash of 10 %, 20 %, 30 % and 40 % with GGBS of 10 % shows 2.94 %, 4.2 %, 5.91 % and 11.2 %, GGBS of 20 % shows 5 %, 7.9 %, 11.2 % and 11.9 %, GGBS of 30 % shows 7.13 %, 12.5 %, 11.3 % and 14.83 % and GGBS of 40 % shows 5.38 %, 6.4 3.77 % and 3.36 %.

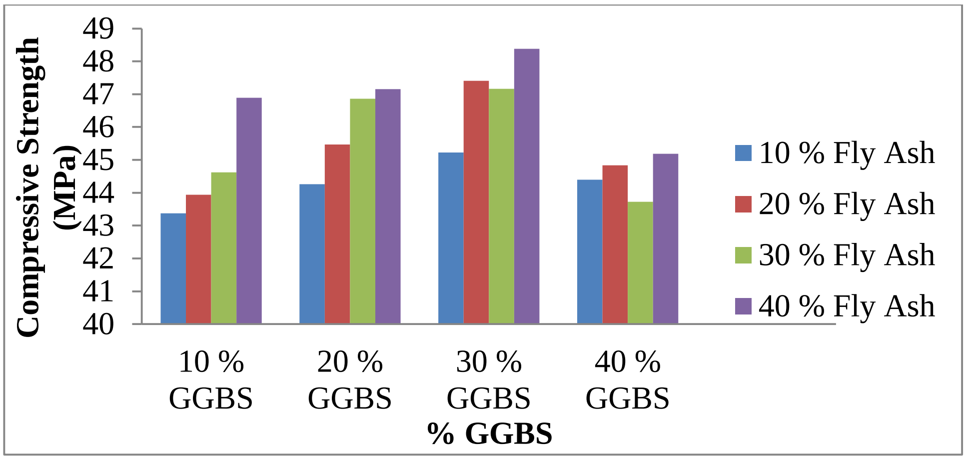

Fig. 9: Compressive Strength of M60 Grade Concrete at 21 Days Curing

4.3.1.3 FOR 28 DAYS OF CURING

For 28 days of curing, fly ash of 10 %, 20 %, 30 % and 40 % with GGBS of 10 % shows 4.76 %, 5.51 %, 8.63 % and 11.24 %, GGBS of 20 % shows 7.33 %, 8.51 %, 12.5 % and 11.24 %, GGBS of 30 % shows 10.14 %, 13.21 %, 14.23 % and 17.89 % and GGBS of 40 % shows 5.48 %, 8.61 %, 10.14 % and 12.39 %.

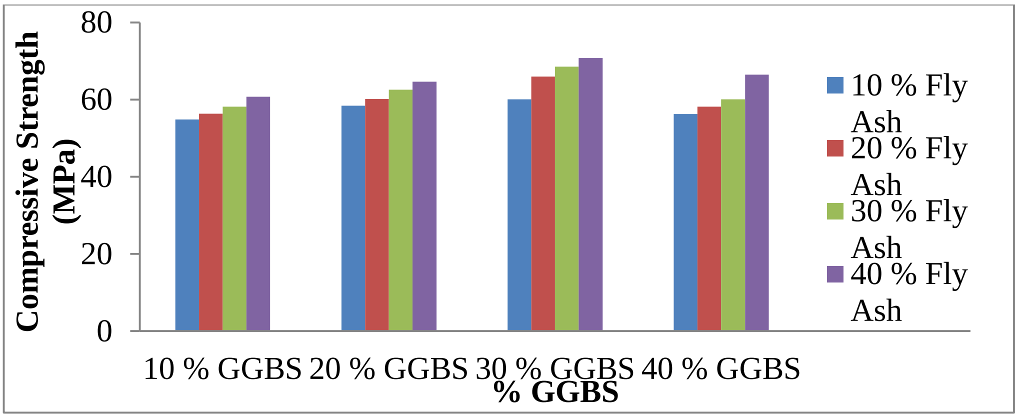

Fig. 10: Compressive Strength of M60 Grade Concrete at 28 Days Curing

4.3.2 FLEXURAL STRENGTH TEST

For 28 days of curing, fly ash of 10 %, 20 %, 30 % and 40 % with GGBS of 10 % shows 24.4 %, 49.5 %, 58.92 % and 74.2 %, GGBS of 20 % shows 48.8 %, 61.9 %, 92.85 % and 78.7 %, GGBS of 30 % shows 72.02 %, 78.5 %, 83.3 % and 94 % and GGBS of 40 % shows 44.8 %, 73.2 %, 89.2 % and 68 %.

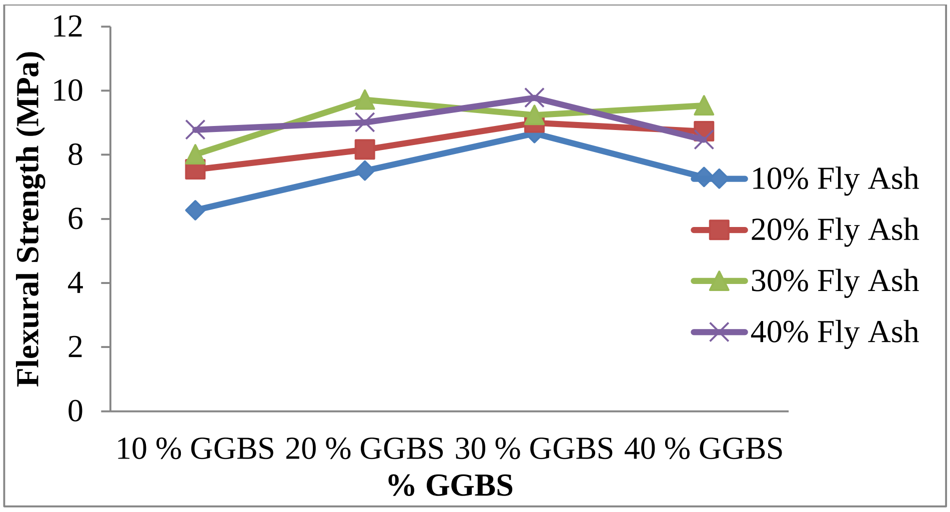

Fig. 11: Flexural Strength of M60 Grade Concrete at 28 Days Curing

4.3.3 SPLIT TENSILE STRENGTH TEST

For 28 days of curing, fly ash of 10 %, 20 %, 30 % and 40 % with GGBS of 10 % shows 6.22 %, 11.4 %, 14.44 % and 18.8 %, GGBS of 20 % shows 22.48 %, 26.3 %, 28.71 % and 31.5 %, GGBS of 30 % shows 44.3 %, 44.9 %, 50.2 % and 58.8 % and GGBS of 40 % shows 11.4 %, 14.4 %, 8.63 % and 13.8 %.

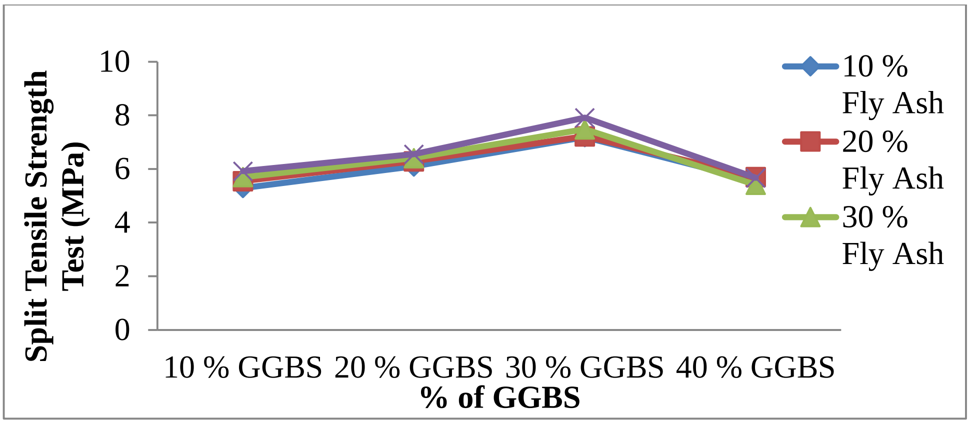

Fig. 12: Split Tensile Strength of M60 Grade Concrete at 28 Days Curing

5. ECONOMIC FEASIBILITY OF HPC M60 GRADE WITH CONVENTIONAL CONCRETE

Material cost estimation includes the cost of water, cement, fine aggregate and coarse aggregate for a particular design mix. As per the mix design calculation, we obtained that the weight of water, cement, fine aggregate and coarse aggregate respectively for concrete. As the water is largely available material in India hence its cost can be neglected. The present study shows that the replacement of cement by GGBS can be done as much as 30% (by weight). Analysis of the cost of concrete with and without GGBS is given below in table 2.

Table 2 Cost of Material per Cubic Meter of Concrete

Material	Rate	Conventional Concrete		M 60 (Optimum Fly Ash and GGBS Concrete)		% Saving
		Quantity	Cost	Quantity	Cost	
Cement	Rs 400 per bag	8.5 bags	Rs 3400	3.4 bags	Rs 1360	19.07 %
Fly Ash	Rs 2.75/ kg	0	0	225 Kg	Rs 618.75	
GGBS	Rs 0.5/Kg	0	0	255 Kg	Rs 127.5	
Fine Aggregate	Rs 860/m^3	0.249 m3	Rs 214	0.249 m^3	Rs 214	
Coarse Aggregate	Rs 2500/m^3	0.428 m3	Rs 1070	0.428 m^3	Rs 1070	
Super Plasticizer	Rs 40/Kg	0	0	10 Kg	Rs 400	
			Rs 4684		Rs 3790.75	

From the above table, we observe that the use of GGBS and fly Ash in concrete saves money up to 19.07 % over the conventional cement concrete. This is a significant saving of money. Hence GGBS and fly ash concrete are more economical.
Fig. 13 shows the cost comparison between conventional concrete and M60 mix.

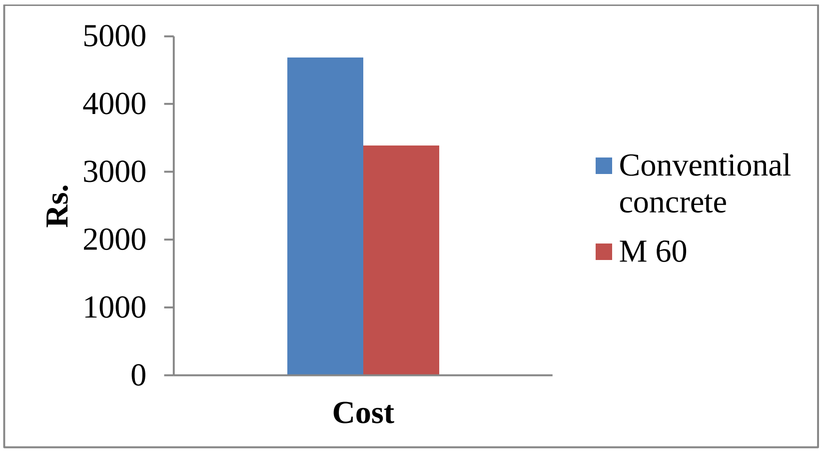

Fig. 13: Cost Comparison

6. CONCLUSION

- It is observed that the slump value of concrete increases as the percentage of GGBS increases up to 20% replacement and then decreases. The increase in slump value is due to the higher smoothness and fineness of slag increases the entrainment of air in the matrix, subsequently increasing the volume of paste.
- It is observed that the water absorption of concrete decreases as the percentage of GGBS increases. From this result, it is concluded that the GGBS can be used to improve the water im-permeability characteristics of the structure. Hence the corrosion of reinforcement may be retarded & durability of R.C.C. structure may be increased.
- Cement replacement by in combination of fly ash and adding Ground granulated blast furnace slag leads to increase in compressive strength upto 30 % GGBS and 40 % Fly Ash for M60 grade of concrete. Beyond 40% replacement of fly ash and 30 % of ground granulated blast furnace slag compressive strength decreased.
- For 7 days of curing, fly ash of 10 %, 20 %, 30 % and 40 % with GGBS of 10 % shows 4.66 %, 6.03 %, 7.01 % and 11 %, GGBS of 20 % shows 11.8 %, 7.46 %, 11.9 % and 13.4 %, GGBS of 30 % shows 17.13 %, 12.34 %, 13.84 % and 16.4 % and GGBS of 40 % shows 8.68 %, 5.42 %, 5.57 % and 7.91 %. The maximum values of compressive strength at 30% GGBS and 40% fly ash are 38.18 MPa.
- For 21 days of curing, fly ash of 10 %, 20 %, 30 % and 40 % with GGBS of 10 % shows 2.94 %, 4.2 %, 5.91 % and 11.2 %, GGBS of 20 % shows 5 %, 7.9 %, 11.2 % and 11.9 %, GGBS of 30 % shows 7.13 %, 12.5 %, 11.3 % and 14.83 % and GGBS of 40 % shows 5.38 %, 6.4 3.77 % and 3.36 %. The maximum values of compressive strength at 30% GGBS and 40% fly ash are 48.38 MPa
- For 28 days of curing, fly ash of 10 %, 20 %, 30 % and 40 % with GGBS of 10 % shows 4.76 %, 5.51 %, 8.63 % and 11.24 %, GGBS of 20 % shows 7.33 %, 8.51 %, 12.5 % and 11.24 %, GGBS of 30 % shows 10.14 %, 13.21 %, 14.23 % and 17.89 % and GGBS of 40 % shows 5.48 %, 8.61 %, 10.14 % and 12.39 %. The maximum values for compressive strength at 30% GGBS and 40% fly ash are 70.75 MPa.
- The maximum percentage of the GGBS and fly ash on the replacement of cement should be 30 % and 40 % when OPC used. From the above observations, we have concluded that the compressive strength is increasing normally for 28 days when compared with controlled concrete.
- After testing flexural strength test of beam it can be concluded that maximum flexural strength of 9.78 MPa is achieved in the mix (fly ash-40% and GGBS-30%).
- Beyond 40% replacement of fly ash and 30 % of ground granulated blast furnace slag flexural strength decreased.
- A similar increase in the split tensile strength was observed when the GGBS is increased 30 % (7.91 MPa at the end of 28 days).
- Beyond 40% replacement of fly ash and 30 % of ground granulated blast furnace slag flexural strength decreased.
- The split tensile strength at the end of 28 days decreases when the GGBS percentage is increased beyond 30%. However, the split tensile strength of M60 concrete at the end of 28 days for 40% replacement of fly ash and 30 % of GGBS is 7.91 MPa.
- From all above, it can be concluded that replacement of 30% GGBS works best for all tests than any other.
- Use of GGBS in concrete saves money up to 19.07 % over the conventional cement concrete. This is a significant saving of money. Hence GGBS and fly ash concrete are more economical.

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