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Assessment of the Property of Concrete by Partial Replacement of its Contents using Ground Granulated Blast Furnace Slag and Ceramic Waste

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***Abstract*: The paper deals with the assessment of the property of concrete on partial replacement of its contents using Ground Granulated Blast Furnace Slag (GGBS) and Ceramic Waste. The paper mainly focuses on the use of GGBS and ceramic waste for the production of cost effective and economic concrete. The reuse of ceramic waste has been done which is otherwise being dumped in the land causing pollution due to its non-biodegradable nature. Also the use of GGBS considerably reduces CO2 emission which is associated with cement. The investigation work has been done for the compressive strength of M25 grade of concrete by the partial replacement of cement using GGBS and using ceramic waste as partial replacement for coarse aggregate. The percentage replacement of cement is from 10% to 30% by mass and coarse aggregate at a constant proportion of 15% by mass.**

Keywords: Ground granulated blast furnace slag, Ceramic waste, Compressive Strength, Cement, Coarse aggregate etc.

1. INTRODUCTION

Concrete is the one of most widely used construction material because of its unique properties like high compressive strength, stiffness and durability under different environmental conditions. Because of this the consumption of concrete is very high which is leading to the reduction in availability of its raw materials (cement, fine aggregate, coarse aggregate and water) and consequently day by day increase in the cost of concrete production. Due to this limitation on availability of natural material there is need of use of some economical alternative materials in its production. In the present paper experimental investigation has been done on the basis of strength analysis to describe the feasibility of using the GGBS and ceramic waste in concrete production by partial replacing cement and coarse aggregate respectively.

Ground granulated Blast furnace slag is a by-product of the iron manufacturing industry. In the blast furnace during the production of pig iron the hematite and limestone are heated then limestone break and form quick lime with the liberation of carbon dioxide. This quick lime react with impurities and form slag which is known as GGBS.

GGBS is used to make durable concrete structures in combination with ordinary Portland cement. GGBS has been broadly used in Europe, United States and in Asia (mostly in Japan and Singapore) for its properties like enhancing concrete durability, increasing the lifespan of buildings etc. GGBS also increases the setting time of Concrete as compare to ordinary Portland cement so the structure continues to gain strength over a longer period of time. Become of this property of GGBS heat of hydration reduces and this avoids the formation of cold joints and cracks.

GGBS has also been found to considerably decrease the damages which are caused due to alkali–silica reaction (ASR) and have a resistance against chloride penetration, thus reducing the risk of corrosion in steel reinforcement.

Hogan and Meusal (1981)[1]conducted experiments on development of strength and durability properties on concrete and reported that the flexural and compressive strength-gain characteristics of concrete containing GGBS can vary over a extensive range. When compared to Portland cement concrete, use of GGBS typically results in reduced strength at early age (1 to 3 days) and increased strength at later age (7 days and beyond).

Malhotra (1987)[2] has found that the compressive strength development of slag concrete depends primarily upon the fineness, type, proportions and the activity indices of slag used in concrete mixtures. In common, the development of strength of concrete including slag is slow at 1-5 days compared with that of the normal concrete. Between 7 and 28 days, the strength approaches that of the normal concrete; beyond this period, the strength of the slag concrete surpass the strength of normal concrete.

D. Suresh and K. Nagaraju(2014)[3] has reviewed about the GGBS found that with the same content of cementitious material (*i.e.* the total weight of Portland cement plus GGBS), similar 28 day strengths to Portland cement will be achieved when we use up to 50% GGBS. At higher GGBS percentages the cementitious content is needed to be increased to achieve similar 28 days strength. GGBS concrete gains strength more gradually than similar conventional concrete made with Portland cement. For the similar 28 day strength, a GGBS concrete will have lower strength at initial ages but its long term strength will be greater, the lowering in early strength being most perceptible at high GGBS levels and less temperatures. Usually a Portland cement concrete will attain about 75 percent of its 28 days strength at seven days, with a slight increase of five to ten percent between 28 and 90 days. By correlation, a 50 percent GGBS concrete will typically achieve about 45 to 55 percent of its 28 days strength at 7 days, with a gain of between 10 and 20 percent from 28 to 90 days. At 70 % GGBS, the seven day strength would be normally about 40 to 50 % of the 28 day strength, with a continued strength gain of 15 to 30 percent from 28 to 90 days. Under usual circumstances, the striking times for concretes containing up to 50 percent GGBS, do not increase adequately to appreciably affect the construction programme. However, concretes with higher levels of GGBS will not always attain sufficient strength after one day to allow removal of vertical formwork, particularly at lesser temperatures, lower cementitious contents and in thinner sections.

Gao et al. (2005)[4] investigated the Interfacial Transition Zone (ITZ), micro structure of concrete containing GGBS using, Scanning Electron Microscope, X-Ray Diffraction (XRD) and micro-hardness measurements. The experimental results confirmed that the GGBS considerably decreases both the size and the orientation of CH crystal at the ITZ. The weak ITZ between aggregate and cement paste was strengthened due to the pozzolonic reaction of GGBS. The pozzolonic reaction rate was found to be in straight relation to the specific surface area of GGBS. The weak zone at the ITZ almost vanishes when 40 percent cement is partially replaced by GGBS with a specific surface area of 425 m^2/kg; and completely vanishes when GGBS with a specific surface area of 600 m^2/kg replaces 20 percent of cement.

Newman John and Choo (2003)[5] stated that GGBS is a very reactive pozzolana. In the existence of water, it reacts with calcium hydroxide to produce a stable, insoluble cementitious hydrate. The pozzolonic reaction reduces reduces the permeability and porosity of cement paste making it stronger and considerably more durable. Also, the use of GGBS as a partial replacement for cement in properly designed concrete mixes improves acid resistance, sulphate resistance and freeze and thaw resistance. In addition, it was seen that it also increases the resistance to the penetration of chloride ions and eradicates alkali-silica reaction.

C. Medina, M.I. Sanchez de Rojas (2011)[6]*, M. Frias* studied the reuse of sanitary ceramic wastes as coarse aggregate. Due to its more irregular shape, it has greater specific surface area than natural aggregate (gravel), which is rounded and thus lacks edges. Moreover, this irregular shape provides a stronger bond between reprocessed ceramic aggregate and the paste. Furthermore, the ceramic aggregate showed little pozzolonic activity in the surface part due to its chemical composition and grain size. Thus the recycled, eco-efficient concrete offered better mechanical behaviour in terms of compressive and tensile strength than the conventional concrete and the interfacial transition zone (ITZ) between paste and recycled ceramic aggregate was more dense, narrower and less porous than that between normal paste-gravel.

Benito Mas et al. (2012)[7] studied strength of recycled aggregate, which had ceramic products as a major constituent. A 15-18% decrease of compressive strength and split tensile strength was reported with replacement of 20 to 25%.The loss of strength was less for 90 days as compared with 7 and 28 days, when aggregate replaced in mixed fraction. Results were acceptable because of more porous structure of recycled ceramic aggregate.

Mashitah et al. (2008)[8] investigated recycling of homogeneous ceramic tiles for the production of concrete block. The strength of the concrete block determined as per IS 516-1959, was found to be lower as compared with control concrete and it lied within a range of 41.1–48.8MPa. Strength of concrete decreased with higher replacement.

Sekar et al. (2011)[9] studied compressive strength characteristics of ceramic aggregate concrete with ceramic insulator waste. Results showed 16% lower compressive strength and 11% lower split tensile strength than the conventional concrete at 28 days. The reason of decreased strength was due to smooth surface texture of ceramic aggregates and poor bonding properties of the matrix with aggregates.

Senthamarai et al. (2011)[10] reported effect of ceramic waste aggregate concrete on durability property and conducted on chloride ion permeability of ceramic aggregate concrete. Average charge passed through two cells of ceramic waste aggregate concrete and conventional concrete was 4908 and 2650 coulombs respectively for water cement ratio of 0.50. Penetration character increased with increasing water cement ratio due to water absorption and pore structure of the ceramic aggregate.

In the present work, GGBS have been used for preparation of standard M25 grade concrete, content varying from 10%, 20%, 30% by weight.

2. EXPERIMENTAL PROGRAM

2.1 MATERIALS

Ground granulated blast furnace slag, Ceramic waste, Cement, sand, coarse aggregate etc were used in the experimental work.

1. ***Cement***

The cement used was Ordinary Portland Cement of 43 Grade (OPC-43) by manufacturer Jaypee Cement. The cement used has been tested for various properties as per IS: 4031 and found to be confirming to various specifications of IS-8112-1989. The properties are given in Table 1.

2. Coarse Aggregate

Angular crushed stones passing through 12.5 mm and retained on 10 mm sieve used as coarse aggregate. The properties are given in Table 2.

3. *Fine Aggregate*

Locally available sand conforming to zone III (as per) IS 383-1970 was used. The properties are given in Table 3.

4. *Ground granulated Blast furnace slag*

It is a by-product of the iron manufacturing industry. GGBS has compositions relatively similar as cement. The concrete made with GGBS cement sets more sluggishly than concrete made with ordinary Portland cement, thus continues to gain strength over a longer period in production environments. This marks in lower heat of hydration and lower temperature rises, and avoids cold joints and cracks.Ground Granulated Blast Furnace slag (GGBS) confirming to BS9966. GGBS used is procured from Stallion Energy Pvt. Ltd. Rajkot, Gujarat. The chemical and physical properties is given in Table 4.1, 4.2.

5. *Ceramic waste*

Ceramic wastes are generated as a waste during the process of dressing and polishing. It is estimated that 15 to 30% of total raw material produced are waste. The disposal of these waste materials acquire large land areas and remain scattered all around, spoiling the aesthetic of the entire region. With increasing restrictions on landfills in European Union area, the cost of deposition will increase and the industries will have to find ways for reusing their wastes. Although the reutilization of ceramic wastes and has been practiced, the amount of wastes reused in that way is still negligible. The ceramic waste used is obtained from the local sanitary shop. The properties are given in Table 5.

6. Water: Regular tap water has been used for mixing the ingredients.

3. VARIOUS TEST CONDUCTED ON MATERIALS:

3.1 Tests done on fine aggregate:

1. Particle Size Distribution
2. Bulking of Sand
3. Water Absorption
4. Specific Gravity

3.2 Tests on coarse aggregate:

1. Impact test
2. Abrasion Test
3. Crushing Test
4. Water Absorption Test
5. Fineness modulus
6. Specific gravity

3.3 Tests on cement:

1. Fineness test
2. Normal consistency
3. Initial and final setting time
4. Compressive strength test
5. Specific gravity test
6. Soundness

3.4 Tests on ceramic waste:

The ceramic waste used was taken from the local area and the tests performed are same as that for coarse aggregates.

3.5 Ground Granulated Blast Furnance Slag Tests:

Ground Granulated Blast Furnace slag (GGBS) confirming to BS9966. GGBS used in the process is procured from Stallion energy Pvt. Ltd. Gujarat. The data required has been provided.

4. VARIOUS EQUIPMENTS USED:

Figure 1: Vi Cat Apparatus for consistency test

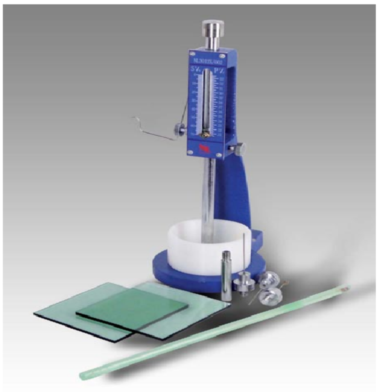


Figure 3: Soundness test apparatus

Figure 2: Vi cat apparatus for Setting time

Figure 4: Fine aggregate

Figure 5: Coarse aggregate

Figure 6: Impact testing machine

Figure 7: Compression testing machine

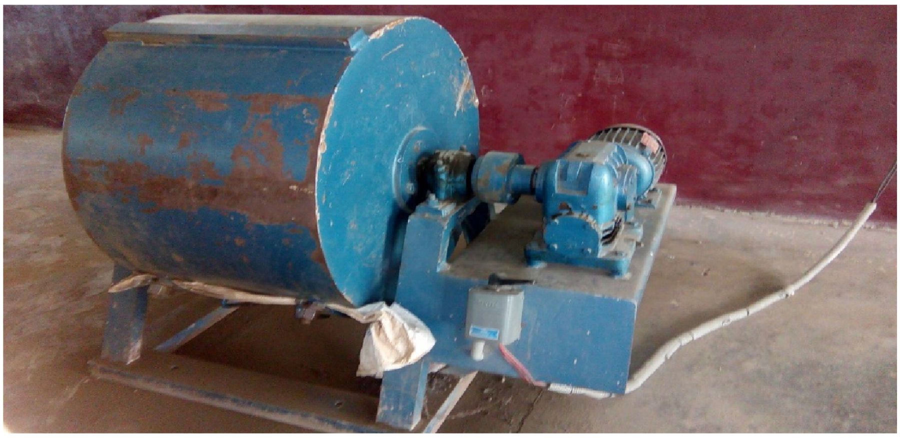


Figure 8: Los Abrasion testing machine

Figure 9: Ceramic waste

Figure 10: OPC 43 CEMENT

Figure 11: Ground Granulated Blast Furnace Slag

Table 1. Properties of Cement (confirming to various specifications of IS-8112-1989)

S.No.	Name of Experiment	Obtained Value			
		Sample 1	Sample 2	Sample 3	Average
1.	Initial Setting Time	100	103	97	100 minutes
2.	Final Setting Time	219	223	220	221 minutes
3.	Consistency of Cement	39%	37%	40%	38%
4.	Fineness	0.1%	0.09%	0.07%	0.08%
5.	Soundness	1.1	1.3	1.2	1.2
6.	Compressive Strength Test (3 days strength)	24.60 MPa	24.61 MPa	23.62 MPa	24.27 MPa
7.	Compressive Strength of Cement Cubes (at 7 days)	39.36 MPa	37.39 MPa	35.42 MPa	37.39 MPa
8.	Compressive Strength of Cement Cubes (at 28 days)	48.84 MPa	47.62 MPa	46.26 MPa	47.57 MPa

Table 2. Properties of Coarse Aggregate

S.No.	Name of Experiment	Obtained Value			
		Sample 1	Sample 2	Sample 3	Average
1.	Crushing Value Test	22.6%	23.8%	23.4%	23.27%
2.	Impact Value Test	11.32%	13.32%	11.09%	11.91%
3.	Abrasion Value Test	30.17%	33.0%	33.5%	32.2%
4.	Compacted Bulk Density	1.42 kg/litre	1.41 kg/litre	1.41 kg/litre	1.413 kg/litre
5.	Loose Bulk Density	1.42 kg/litre	1.32 kg/litre	1.39 kg/litre	1.37 kg/litre
6.	Water Absorption	0.36%	0.31%	0.28%	0.29%
7.	Specific Gravity	2.92	2.84	2.80	2.88

Table 3. Properties of Fine Aggregate

S.No.	Name of Experiment	Observed Value			
		Sample 1	Sample 2	Sample 3	Average
1.	Specific Gravity	2.54	2.62	2.64	2.60
2.	Water Absorption	2.64%	2.62%	2.66%	2.64%
3.	Bulking	6.35%	3.27%	4.84%	4.82%

Table 4.1 Physical Properties of GGBS

S.No.	Physical Property	Test Result
1.	Bulk density (loose)	1.0-1.1 tons/m^3
2.	Bulk density (compact)	1.2-1.3 tons/m^3
3.	Specific gravity	2.85-2.95

NOTE: Data as per the manufacturer Stallion energy Pvt. Ltd. Gujarat

Table 4.2 Chemical Properties of GGBS

S.No.	Chemical Property	Laboratory Test Result (%)
1.	Silica as SiO2	35.47
2.	Calcium as CaO	35.89
3.	Magnesium as MgO	8.06
4.	Iron Oxide as Fe2O3	2.41
5.	Alumina as Al2O3	14.27
6.	Mangnese oxide MnO	0.34
7.	Alkalies	0.20
8.	Fineness cm2/gm	38.20

NOTE: Data as per the manufacturer Stallion energy Pvt. Ltd. Gujarat

Table 5: Test results of ceramic waste

Property	Sample 1	Sample 2	Sample 3	Average Value	Standard value
Specific gravity	2.41	2.51	1.99	2.30	2.3
Fineness Index	7.83	7.99	6.43	7.56	7.95
Max size (mm)	12.5	12.5	12.5	12.5	12.5
Impact Value	17	21	19	19	20
Abrasion Value	25	20	21	22	24
Crushimg value	23	27	22	24	27

5. MIX PROPORTIONS

M25 concrete was designed as per IS 10262:2009. A total of four mixes at 0 %, 10%, 20% and 30% GGBS replacement at constant proportion of 15% ceramic waste replacement for was prepared. The adopted w/c content was 0.48 at cement content of 380 kg/m^3 for all mixes. On the basis of these fine aggregate content was kept at 941 kg/m^3 and coarse aggregate content was maintained at 962.65 kg/m^3. The typical mix proportion has been given in table 6.

6. TEST CONDUCTED ON FRESH CONCRETE

Figure 12: Preparation for slump test

6.1 Slump flow test

Slump flow is one of the most commonly used to determine the workability of conventional concretes as described in ASTM C143 (2002).

The main difference between the slump flow test and ASTM C 143 is that the slump flow test measures the spread or flow of the concrete sample once the cone is lifted rather than the traditional slump of the concrete sample. The T50 test is determined during the slump flow test. It is simply the amount of time the concrete takes to flow to a diameter of 50 cm

concrete at the current time. This test involves the use of slump cone used with After conduction test on two, three fresh concrete mixes the slump value of around 50 mm was obtained.

7. TEST CONDUCTED ON HARDENED CONCRETE

7.1 Preparation of test specimens for compressive strength testing

Figure 13: TAMPING PROCESS

Figure 14: CUBE CASTING

Figure 15: VIBRATION MACHINE

Cubes of 150 X 150 X 150 mm size cast in cast iron mould for compression strength testing. Fresh concrete was placed into the moulds and compacted using vibration machine. Top surface was levelled smoothly using trowel and after that the moulds were securely placed in the room temperature for 24 h. The specimens were systematically placed in curing tanks after 24 hours for 7, 28 and 56 days.

Figure 16: FINAL CUBES AFTER CASTING

7.2 COMPRESSIVE STRENGTH TEST

Compressive strength of concrete is defined as the load, which causes the failure of a standard specimen divided by the area of cross section in uniaxial compression under a given rate of loading. This is one of the most important test to determine the property of concrete. The testing of compressive strength has been done on cubes 150 mm size cubes.

This test was performed to find the compressive strength of concrete at different proportion of GGBS and Ceramic waste replacement and compared with conventional concrete to determine optimum percentage of replacement at which strength is maximum. The compressive strength of concrete with different mix proportions was determined at 7, 28 and 56 days according to IS 516-1959. The results are given in table 7.

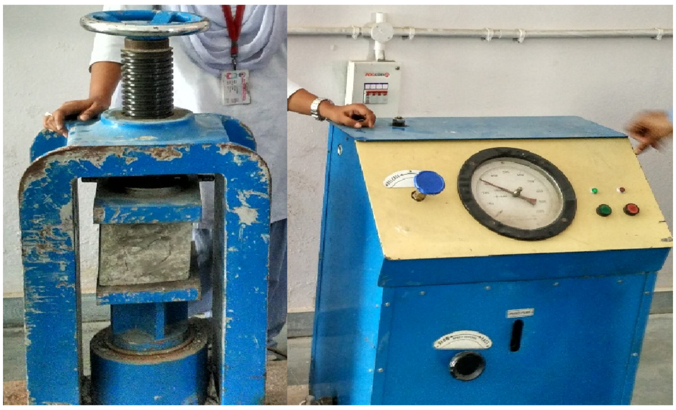


Figure 17: COMPRESSION TESTING MACHINE

Figure 18: CUBES DURING LOADING

Figure 19: FAILED SPECIMEN AFTER COMPRESSIVE STRENGTH TEST

Table 6. Mix Proportions

DESIGN MIX	MIX	CEMENT (kg)	WATER (ml)	FINE AGGREGATE (kg)	COARSE AGGREGATE (kg)	CERAMIC WASTE (kg)	GGBS (kg)
0 % GGBS and 0 % CERAMIC WASTE	0	1.28	617	3.17	3.248	0	0
10 % GGBS and 15 % CERAMIC WASTE	10	1.15	617	3.17	2.760	0.48	0.13
20 % GGBS and 15 % CERAMIC WASTE	20	1.02	617	3.17	2.760	0.48	0.25
30 % GGBS and 15 % CERAMIC WASTE	30	0.89	617	3.17	2.760	0.48	0.38

Table 7: Compressive strength values of different specimens

MIX	PROPORTIONS	7 DAYS			28 DAYS			56 DAYS		
		C1	C2	C3	C1	C2	C3	C1	C2	C3
0	GGBS-0% CERAMIC WASTE-0%	24.18	27.72	26.10	28.67	29.78	29.47	35.21	34.16	35
10	GGBS-10% CERAMIC WASTE-15%	18.07	17.17	17.93	23.22	23.16	22.54	25.98	24.86	26.06
20	GGBS-20% CERAMIC WASTE-15%	22.12	19.97	21.73	26.34	25.89	27.67	29.87	31.24	30.69
30	GGBS-30% CERAMIC WASTE-15%	19.97	19.00	19.30	22.18	22.75	22.17	28.31	27.72	27.90

Table 8: Average values of compressive strength

S.NO	MIX	Compressive Strength at 7 days (N/mm^2)	Compressive Strength at 28 days (N/mm^2)	Compressive Strength at 56 days (N/mm^2)
1	0	26	29.47	34.79
2	5	17.72	22.97	25.63
3	10	21.27	26.63	30.60
4	20	19.42	22.17	27.49

8. RESULTS AND DISCUSSION

Table 8 gives the test results of compressive strength at 7, 28 and 56 days. The test results showing the decrease in compressive strength from conventional concrete till 10% replacement of GGBS, but later shows a considerable increase till 20% by weight of GGBS and then again decreases afterwards. Thus at around 20% we could see maximum increase in strength. The ceramic waste replacement was at constant proportion of 15%. The variation is shown in following graphs:

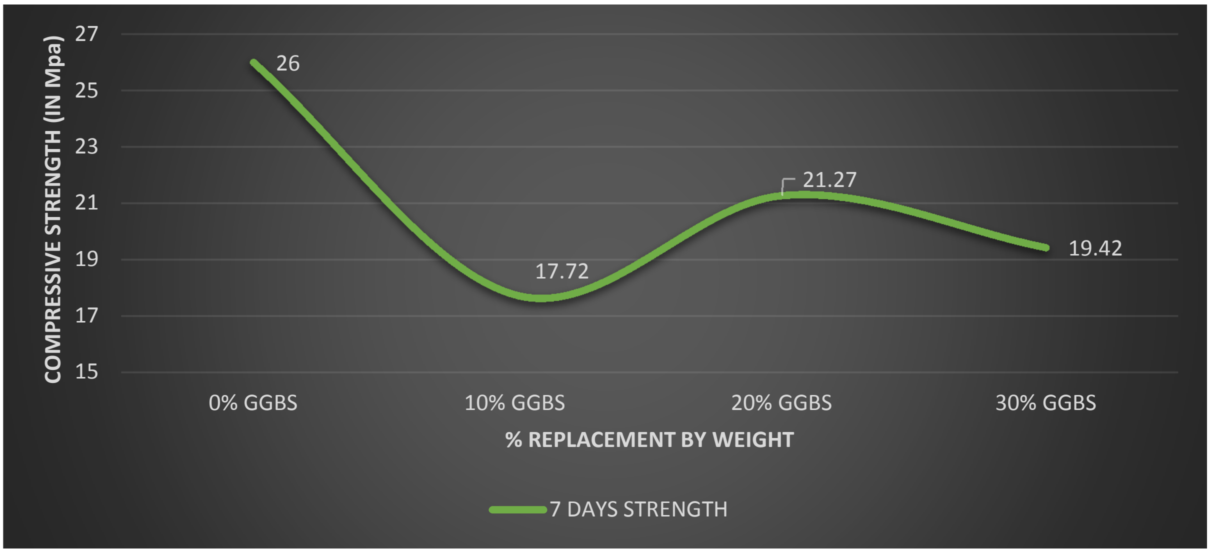


Figure 20: Variation of Compressive Strength at different value of GGBS at 7 days

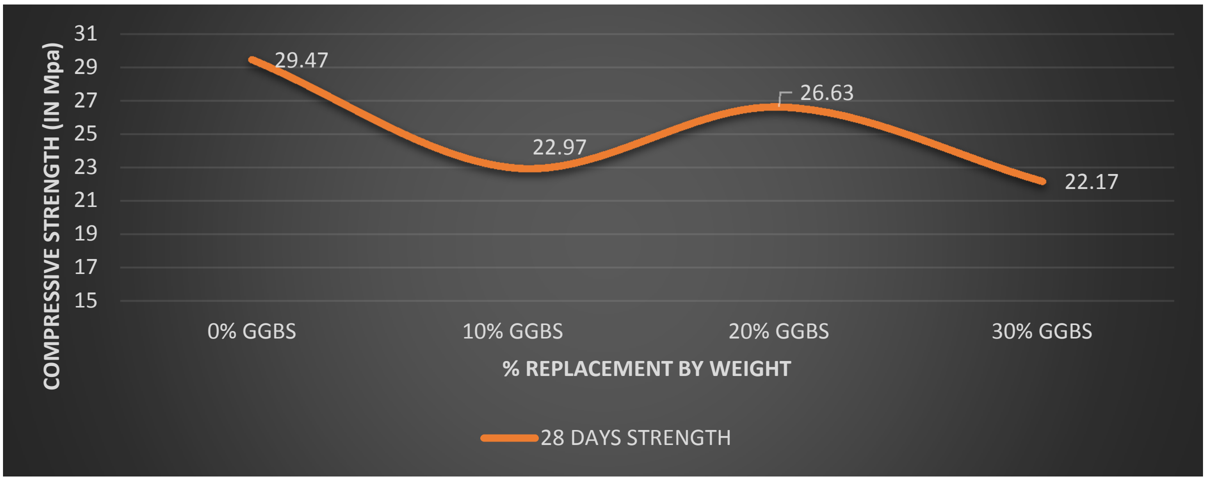


Figure 21: Variation of Compressive Strength at different value of GGBS at 28 days

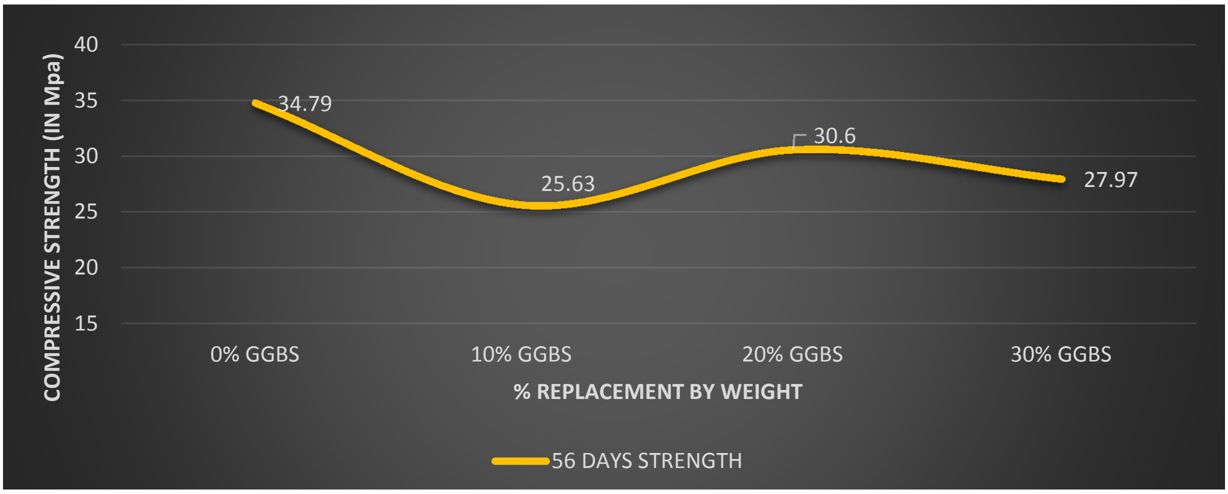
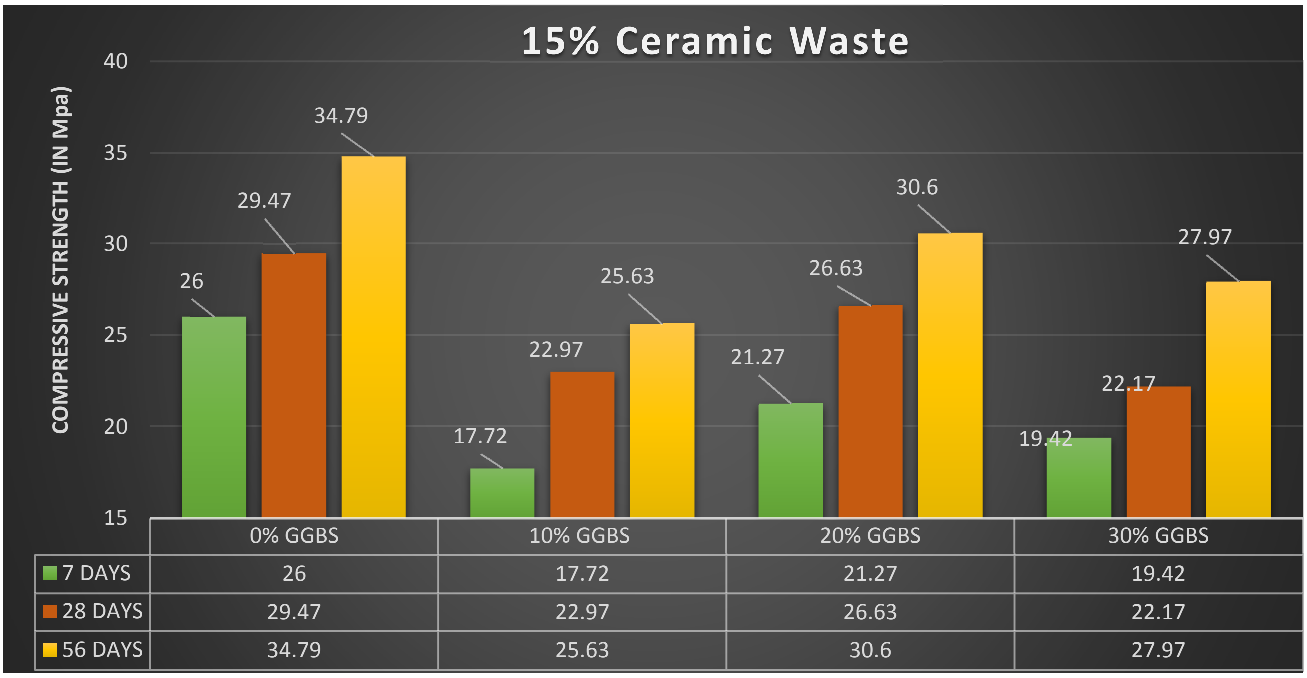


Figure 22: Variation of Compressive Strength at different value of GGBS at 56 days

Comparison of compressive strength of concrete at different proportion of GGBS at 7 day, 28 day, 56 day:



	0% GGBS	10% GGBS	20% GGBS	30% GGBS
🟩 7 DAYS	26	17.72	21.27	19.42
🟧 28 DAYS	29.47	22.97	26.63	22.17
🟨 56 DAYS	34.79	25.63	30.6	27.97

Figure 23: Variation of Compressive Strength at different value of GGBS at 7, 28 and 56 days

9 COST ANALYSIS

Following table summarises the cost of one cube before the addition of GGBS and Ceramic Waste:

Table 9.1: Cost of one cube before the addition of GGBS and Ceramic Waste

S.No.	Material	Rate (in INR)	Quantity (in one cube)	Cost (per cube)
1.	Cement	Rs. 310 per 50 kg	1.28 kg	Rs. 7.94
2.	Coarse Aggregate	Rs. 47 per cubic feet Or Rs. 1659.7909per cubic metre	$1.1278*10^{-3}$ m^3	Rs. 1.87
3.	Fine Aggregate	Rs. 33 per cubic feet Or Rs. 1165.3851 per cubic metre	$1.2219*10^{-3}$ m^3	Rs. 1.42
4.	GGBS	Nil	Nil	Nil
5.	Ceramic Waste	Nil	Nil	Nil

Total cost of conventional cube
= Rs. (7.94+1.87+1.42)
= Rs. 11.23 for one cube

Following table summarises the cost of one cube after replacement of 20% Cement by GGBS and 15% Coarse Aggregate by Ceramic Waste:

Table 9.2: cost of one cube after the addition of GGBS and Ceramic Waste

S.No.	**Material**	**Rate (in INR)**	**Quantity (in one cube)**	**Cost (per cube)**
1.	**Cement**	Rs. 310 per 50 kg	1.024 kg	Rs. 6.35
2.	**Coarse Aggregate**	Rs. 47 per cubic feet Or Rs. 1659.7909 per cubic metre	$9.5861*10^{-4}$ m^3	Rs. 1.59
3.	**Fine Aggregate**	Rs. 33 per cubic feet Or Rs. 1161.93 per cubic metre	$1.2219*10^{-3}$ m^3	Rs. 1.42
4.	**GGBS**	Rs.1600 per metric ton	0.256 kg	Rs. 0.41
5.	**Ceramic Waste**	Nil	$2.0719*10^{-4}$ m^3	Nil

Total cost of cube
= Rs. (6.35+1.59+1.42+0.41)
For one cube= Rs. 9.77 per cube
Now volume of one cube = 0.15^3 m^3
That means one cubic metre concrete costs Rs. 3327 (approximately) before addition of GGBS and Ceramic Waste.
And after addition one cubic metre concrete cost = Rs. 2894 (approximately)
Therefore reduction in cost = $\frac{(3327-2894)}{3327}$
=13%

Thus from above **we conclude that there is a saving of 13.0%**

10. CONCLUSIONS

Based on investigations conducted with varying percentage of cement and fixed level of coarse aggregate replacement, the following conclusions can be drawn:

1) Ground Granulated Blast Furnace Slag concrete mix having various cement replacement level up to 30% exhibited satisfactory results for compressive strength.
2) The optimum use of slag upto 20% replacement was found good for the M25 mix.

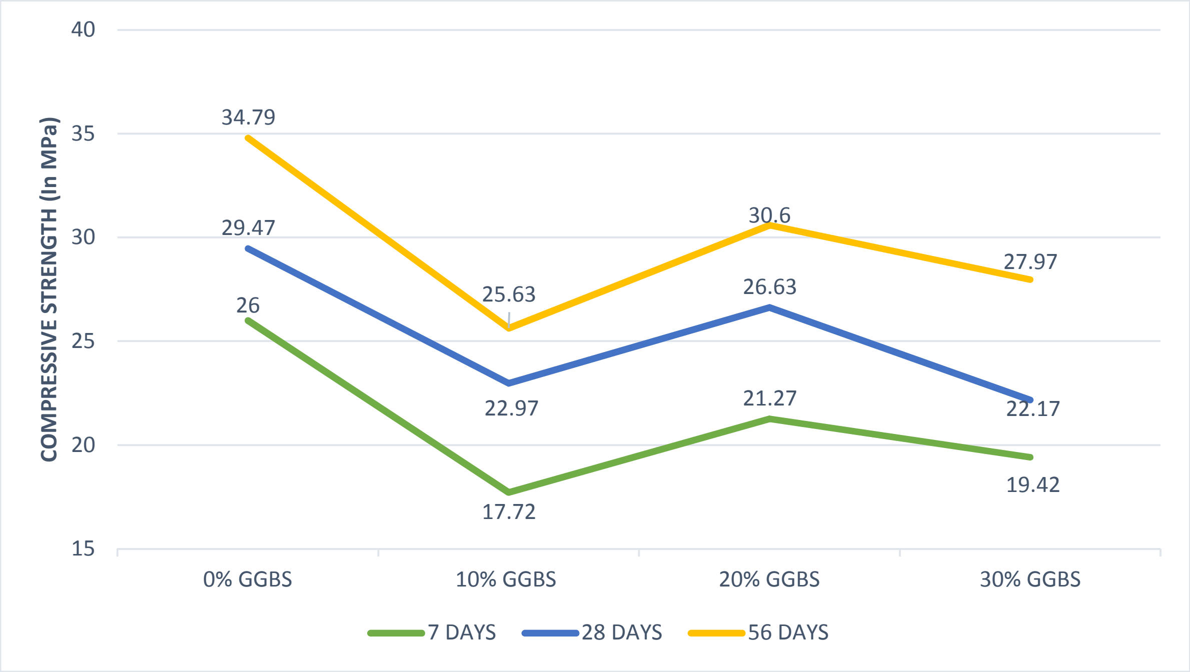


Figure 4.5: Graph showing comparison of Compressive Strength at different value of GGBS and 15% ceramic waste at 7, 28 and 56 days

3) Use of slag as a replacement of cement, in any construction work, provides lower impact on environment (reduced CO2 emission) and judicious use of resources (energy conservation, use of by-product etc.)

4) Use of slag reduces the amount of cement content as well as heat of hydration in a mix. Thus, the construction work with slag concrete becomes economical and also environmentally safe.Ceramic Waste is generated from construction and demolition waste and ceramic industries. It is difficult to dump into yards due to its unique characteristic like brittleness. It is not biodegradable, so waste is growing up day by day. Substitution of coarse aggregate by ceramic waste aggregate into concrete composition is one of the solution for helping in saving the environment.

5) Using ceramic waste (15% replacement of coarse aggregate) also makes the concrete economical and helps in saving the money.

6) Using GGBS and Ceramic waste as alternate materials for replacing cement and coarse aggregate has considerably reduce cost i.e. about 13% as compare to conventional concrete (as per cost analysis data), thus reducing burden on natural raw materials and also achieving economy in cost.

7) Mechanical properties of ceramic aggregate are similar to the natural aggregate and its behaviour is similar but not same. Water absorption, crushing value, impact value, and abrasion values are higher than natural coarse aggregate.

8) Slag concrete has a lot of advantages in comparison to normal concrete other than being economical and environment saving.

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We are extremely grateful to all the researchers who has done a great work in the field of concrete technology. We remain indebted for their contribution on the finding of the materials which can be alternatively use as a raw material for the production of concrete.

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