EXPERIMENTAL INVESTIGATIONS ON MECHANICAL AND DURABILITY PROPERTIES OF BLENDED CONCRETE

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Abstract: Concrete is extensively used as a building material due to its low cost and versatility. We are expecting better results in the current construction scenario in a short time and to finish the work fast. So instead of using ordinary Portland cement here we use specially graded cement OPC 53-S cement which not only gives early age strength but also resists durability in addition to controlling the pollution emitted by cement manufacturing, we use GGBS as cementitious material which is a waste product from steel and iron manufacturing. Since GGBS setting time is slow, the OPC 53-S cement is used to compensate it. This project aims to know the mechanical properties such as compressive strength, size effect, flexural strength, splitting tensile strength and durability properties of concrete such as Sorpitivity, water absorption and carbonation by replacing GGBS in cement at different percentage (0%, 10%, 20%, 30%, 40%, 50%) levels by testing at different (3, 7, 14, 28, 56 and 90 days) age of concrete. And to know the micro structural and crystalline properties of (7 and 28 days) age of concrete by means of X-ray diffraction test.

Key Words: OPC 53-S, GGBS, Durability, X-Ray Diffraction, Sorpitivity, Carbonation, Water Absorption.

1. Introduction

Concrete has become a vital part of our lives; the use of concrete is increasing at a very high rate. Cement is one of the main constituents of concrete and it is the second largest material produced in world. During the cement manufacturing process nearly one ton of carbon dioxide is produced for one ton of cement. To overcome this pollution some of the cementitious materials such as GGBS, Fly Ash, Silica fume etc. are blended to reduce such emissions. by adding this type of mineral add mixtures to concrete we get more strength, workability as well as high durability more than that of OPC, which increases the performance of concrete and also used for the pumpable concrete of durability and service life. Here in
this study GGBS is used, as the fineness of cement increases the heat of hydration is also increased, which requires more curing period. so that we are using special grade cement for faster setting of concrete by adding suitable admixture to it, due to this the cost of the concrete reduces, completes the work faster and also gives good results. Performance of concrete containing GGBS enables concrete specimens to improve workability, mechanical properties and durability as environment-free content Martino’c onnel at el (2012) Mechanical and durability properties of high strength of ultrafine ground granulated blast furnace slag concrete such as compressive strength, flexural strength and Modulus of elasticity gives better results than the OPC concrete, Micro structural properties of concrete by x-ray diffraction test which gives clear view of crystalline structures of elements. Susanto Teng at el (2013).Durability properties of concrete such as acid attack, sorptivity, rapid chloride penetration test and water adsorption results in high strength with respective its age of concrete Subathradevi at el (2018) Carbonation of Concrete Containing fly ash, GGBS and silica fume observed by acceleration carbonation test and Thermogravimetric Analysis shows carbonation coefficient increased with a decrease in compressive strength and depends upon the age of concrete curing and water binder ratio for GGBS and other admixtures compared with ordinary Portland cement. Sulapha at el (2003).

2. Objectives:
- To determine the performance of concrete by partial replacement of cement by Ground granulated blast furnace slag in 10%, 20%, 30%, 40% and 50% variants.
- To observe the most optimized mix with OPC 53-S cement and GGBS for 3, 7, 14, 28, 56 and 90 days of curing.
- To know the Size effect, Flexural strength and Split tensile strength of concrete for 7 days and 28 days curing.
- To study GGBS-based concrete's durability properties through Sorpitivity, carbonation and water absorption.
- To Identify the crystalline materials and phases characterized with X-ray diffraction (XRD)

3. Material Used:

3.1 OPC-53(S) Cement:

OPC 53-S is a specially graded type of cement. OPC stands for Ordinary Portland Cement and 53 represents the compressive strength of cement and ‘S’ represents the special cements. It is generally used in manufacture of railway sleeper and marine structures. It is a specifically manufactured as originally formulated by the Indian Railways for the manufacture of concrete sleepers vide their specification No.IRS T-40. here we have used cement is bought from Railway Sleepers Plant, Pendurthi, Andhra Pradesh where precast railway sleepers are manufactured in it. The chemical compositions of cement and GGBS are shown in Table 1.

| Property | Cement (%) | GGBS (%) |
|----------|------------|----------|
| SiO₂     | 19.92      | 33.31    |
| Al₂O₃    | 6.44       | 14.60    |
| Fe₂O₃    | 1.16       | 0.40     |
| CaO      | 63.28      | 41.63    |
3.2 Ground Granulated Blast Furnace Slag (GGBS)

GGBS is produced at the Visakhapatnam Steel Plant (RINL). Ground granulated blast furnace slag (GGBS), a by-product of the manufacture of pig iron in a blast furnace that melts iron ore, calcareous and coke to 1500°C. GGBS is used as a replacement for cement up to 40 per cent for strength aspects and 20 to 85 per cent for durability. Concrete made with GGBS will gradually increase resistance over time and lead to high performance. It provides economic and environmental advantages, as light weight material performs better than ordinary concrete. The physical properties of cement and GGBS are shown in Table 2.

3.3 Fine Aggregate (Zone II sand)

The sand used for our investigation is collected form Godavari river sand which is properly graded to give minimum void ratio and conforms to Zone II as per Indian Specification IS: 383-1970 codal provisions. the natural river sand (< 5mm) with less than 5% silt and water absorption of 0.7% is used.

3.4 Coarse Aggregate

The coarse aggregate used is produced from local quarries, 10 mm and 20mm size with an angular shape which are well graded having impact value of 14%, specific gravity of 2.6 and water absorption of 0.57%.

3.5 Super plasticizer (BASF Master Glenium ACE 30)

Master Glenium ACE 30 is suitable for making precast concrete elements with highly workable, non-segregating concrete utilizing low water cement ratios and, consequently, high early and final strengths. it has economic, ecological and ergonomic precast production. The normally recommended dosage rate of Master Glenium ACE 30 is by Weight – 0.5 to 1.5 kg per 100 kg of cement.

Table 2 Physical Properties of Cement And GGBS

| Property                | OPC -53 | OPC-53 S | GGBS |
|-------------------------|---------|----------|------|
| Fineness (%),          | 10      | 8        | 6    |
| Normal Consistency (%)  | 28      | 30       | 32   |
| Initial Setting Time (min) | 45    | 65       | 90   |
| Final Setting Time (min) | 480   | 340      | 420  |

4. Concrete mix design:

Mix proportioning of concrete was done as per IS: 10262-1982. The mix proportioning of (Mix) M40 grade concrete is taken. The control mix was totally prepared with OPC 53-S grade cement, river sand (zone II) and coarse aggregates.
where the other mixtures were prepared by adding GGBS with different proportions of replacements in cement, the mix
design was taken as 1: 2.04:2.84 per one-meter cube with the w/c ratio 0.4 and superplasticizer Glenium ACE 30 is used as
admixture of 0.5% of the cement content and slump of 100mm as mentioned in table-3.

Table-3 Mix Design of M 40 Concrete

| CEMENT  | FINE AGGREGATE | COARSE AGGREGATE | WATER |
|---------|----------------|-----------------|-------|
| 390 Kg  | 795.73 kg      | 1117.70 kg      | 156.0 kg |
| 1       | 2.04           | 2.84            | 0.4   |

5. Compressive strength of cement mortar:

The compressive strength of cement mortar cubes with a standard size of 70.6 mm x 70.6 mm x 70.6mm is taken,
cement and Ennore sand is well zoned with different percentage replacements of GGBS is taken for various mixtures
obtained at 7 and 28 days of curing. It is observed that a replacement level of 40 % gives us high strength, as shown in
Table-4

Table-4 Compressive strength of cement mortar cube

| S. No | Replacement Level   | 7days(N/mm²) | 28days(N/mm²) |
|-------|---------------------|--------------|--------------|
| 1     | 100% Cement + 0% GGBS | 41.50        | 52.05        |
| 2     | 90% Cement + 10% GGBS | 42.62        | 53.80        |
| 3     | 80% Cement + 20% GGBS | 43.20        | 54.50        |
| 4     | 70% Cement + 30% GGBS | 45.25        | 55.47        |
| 5     | 60% Cement + 40% GGBS | 49.23        | 58.50        |
| 6     | 50% Cement + 50% GGBS | 38.03        | 47.00        |

6. Compressive strength of concrete:

The compressive strength of concrete cube of size 150mm X 150mm is taken with different replacements levels of
GGBS in cement and concrete mixes obtained at 3, 7, 14, 28, 56 and 90 days of curing is plotted in Fig.1 It is observed that
the strength gains in a function of time. The addition of GGBS improved the compressive strengths at all the ages
gradually. The strength is increased up to 40% replacement level but the maximum strength gain is obtained at the 56 and
90 days as shown in table-5.
### Table-5 Compressive strength of concrete (150x150x150mm) cube

| Age of concrete | Compressive Strength of Concrete for Different Replacements of GGBS in N/mm² |
|-----------------|---------------------------------------------------------------------------|
|                 | OPC 53 S | OPC53S+10% | OPC53S+20% | OPC53S+30% | OPC53S+40% | OPC 53S+50% |
| 3               | 30.96    | 30.03      | 29.60      | 27.36      | 25.20      | 22.5        |
| 7               | 40.03    | 40.50      | 41.02      | 43.08      | 44.11      | 35.42       |
| 14              | 47.06    | 45.05      | 44.62      | 46.23      | 47.20      | 40.03       |
| 28              | 49.02    | 51.50      | 50.02      | 52.30      | 54.21      | 46.36       |
| 56              | 50.23    | 52.09      | 53.00      | 53.20      | 55.60      | 47.01       |
| 90              | 51.02    | 52.90      | 53.70      | 54.23      | 56.50      | 47.92       |
7. Size effect of concrete:

The compressive strength of concrete cube of size 100mm X 100mm is taken for size effect with different replacements levels of GGBS in cement and concrete mixes obtained at 3,7 and 28 days of curing is plotted in Fig.2. It is observed that the strength gains in a function of time. The addition of GGBS improved the compressive strengths at all the ages gradually. The strength is increased up to 40% replacement level but the maximum strength gain is obtained at 28 days as shown in table-6, we can compare the strength in both sizes of concrete cubes.

Table-6 Compressive strength of concrete(100x100x100mm) cube

| Age of concrete | Compressive Strength of Concrete for Different Replacements of GGBS in N/mm² |
|-----------------|---------------------------------------------------------------------------|
|                 | OPC 53S | OPC53S+10% | OPC53S+20% | OPC53S+30% | OPC53S+40% | OPC53S+50% |
| 3               | 40.03   | 37.75      | 36.02      | 34.08      | 32.11      | 30.42      |
| 7               | 42.02   | 43.33      | 44.05      | 46.02      | 47.33      | 40.40      |
| 28              | 52.5    | 53.00      | 53.33      | 55.46      | 57.02      | 49.06      |

Figure-1 Compressive strength of concrete (150x150x150 mm) cube
8. Split Tensile Strength

The split tensile strength of concrete is done by casting standard cylinder of size 150mm X 300mm the split tensile strength of mixes was found to increase up to 40% replacement level, and thereafter, a decreasing trend was observed. However, strength was found to be more than the referral concrete up to the replacement level of 40%. The ratio of split tensile strength to compressive strength of different mixes at 7 and 28 days is almost similar. The optimum replacement level of 40% may be used for structural purposes, after studying the mineral composition of GGBS as mentioned in table-7 and figure 3.

Table -7 splitting tensile strength of concrete

| Replacement Level of GGBS (%) | Splitting Tensile Strength In N/mm² |
|-----------------------------|-----------------------------------|
|                            | 7 Days               | 28 Days               |
| 0                          | 3.50                 | 3.92                  |
| 10                         | 3.65                 | 4.03                  |
| 20                         | 4.06                 | 4.50                  |
| 30                         | 4.43                 | 4.89                  |
| 40                         | 4.76                 | 5.06                  |
9. Flexural Strength

Flexural Strength of Concrete is casting of size 100mm X 100mm X 500mm standard prismatic beam for all concrete mixes the inclusion of GGBS also brought marginal improvement in flexural strength of concrete. The results of flexural strength are obtained at the age of 7 and 28 days are listed in Table-8. The maximum improvement in flexural strength is found at 40% replacement level and the increases as compared to the referral mix. However, beyond that level the improvement is not much. The ratio of flexural strength to compressive strength at 7 and 28 days is almost similar in all the mixes. The optimum replacement level 40% is similar to other tests as mentioned in table-8 and figure-4.

Table -8 Flexural strength of concrete

| Replacement Level of GGBS (%) | Flexural Strength In N/mm² |
|------------------------------|-----------------------------|
| 0                            | 4.80                        |
| 10                           | 5.06                        |
| 20                           | 5.32                        |
| 30                           | 5.67                        |
| 40                           | 5.90                        |
| 40                           | 5.90                        |
10. Durability of concrete:

For the durability tests the concrete core is removed from the concrete specimen such as cube, cylinder to the correct specimen where the test must be carried out in compliance with the codal provisions. Here, we extracted core from the 150 mm Dia and 300 mm depth cylinders to the proper specimen and spliced into pieces needed for durability tests such as sorptivity, water absorption and carbonation. The size of the specimen extracted from the core is 100mm Dia and 50mm depth for all the above tests to be conducted. This process is done by wurth India pvt.ltd core cutting sample machine.

10.1 Sorptivity:

The Sorpitivity of concrete is a quantity that measures the unsaturated flow of fluids into the concrete. It is the property from which water was absorbed by capillary action and transmitted. The rate of water absorption is measured by the sorptivity test according to code ASTM C 1585-04, a specimen of 100 ±6 mm Dia and 50 ± mm depth is taken and dried in oven up to 110 C for more than one day and specimen weighted as $W_1$ and then sealed with water-proofing agent epoxy around sides of the specimen excluding the top surface without the concrete specimen. The top surface is covered with a sheet of aluminum or with an electric tap. It is so immersed in water that it retains a depth of 5±3 mm from bottom of the specimen as an action of capillary rise below the surface. The amount of water absorbed for every 5,10,15 and 30 minutes and weighted each specimen as $W_2$ are recorded, and the sorptivity can be found from the equation below and arranged as figure-5 and calculated as per table 9 and figure 6

\[ S = I t^{1/2} \]
\[ I = \frac{\Delta W}{A \cdot d} \]

\[ \Delta W = W_2 - W_1 \]

\[ W_1 = \text{dry weight of sample} \]

\[ W_2 = \text{wet weight of sample} \]

\[ A = \text{surface area of the specimen} \]

\[ d = \text{density of water} \]

\[ t = \text{elapsed time in minute} \]

**Figure -5 Sorpitivity test Experimental setup**

**Table 9 Sorpitivity test results**

| S. No | Percentage of GGBS Replacement | Absorption I(mm) | Sorpitivity (mm/√min) |
|-------|--------------------------------|------------------|-----------------------|
| 1     | 0%                             | 0.7639           | 0.1395                |
| 2     | 10%                            | 0.6494           | 0.1126                |
| 3     | 20%                            | 0.5602           | 0.1023                |
| 4     | 30%                            | 0.5348           | 0.0976                |
| 5     | 40%                            | 0.5093           | 0.0930                |
| 6     | 50%                            | 0.4584           | 0.0837                |
Carbonation:
Carbonation of concrete is a process by which Carbon dioxide from the air penetrates into the concrete and reacts with calcium hydro-oxide to form calcium carbonates. Conversion of Ca(OH)_2 into CaCO_3 by action of CO_2 by itself is not reactive. It is one of the main reasons to induce the steel corrosion in the reinforced concrete. The carbonation rate depends on the material factors of the concrete. In this study, the effect of the material factors, PH levels and carbonated part of concrete which leads to corrode the reinforcement cement is observed. The specimens of size 100 ±6 mm Dia and 50 ± mm depth is taken and dried in oven and sealed with epoxy coating all the sides excluding the top surface of the specimen and conditioned in laboratory for absorption of CO_2 present in the atmosphere for 1st, 2nd and 4th weeks and for each specimen 0.2% of phenolphthalein solution is sprayed gently on the surface of the specimen if the colour changes to pink its non-carbonated concrete and which remains same is carbonated concrete the depth of carbonation is observed by the carbonated part of the specimen. The average of 6 depths are taken with respective of the time period and the PH level should be above 12 as shown in the figure-7 and table 10.

Figure 6 Sorpitivity absorption rate curve
Figure 7 Carbonation depths before and after the test with respective of age of concrete

Table 10 Carbonation test results

| S no | Percentage of GGBS | Depth of carbonation (mm) |
|------|---------------------|----------------------------|
|      |                     | 1 week | 2 weeks | 4 weeks |
| 1    | 0%                  | 2.60   | 2.62    | 3.02    |
| 2    | 10%                 | 2.20   | 2.30    | 2.35    |
| 3    | 20%                 | 1.50   | 1.60    | 1.90    |
| 4    | 30%                 | 1.30   | 1.52    | 1.65    |
10.3 Water absorption:

The water absorption is used to calculate the quantity of water that a dry specimen will absorb. It thus provides the measurement of total water within the permeable pore space. The test procedure according to ASTM C 642-06 is for that specimen to be oven dried to a constant weight, then weighed immersed in heater with water of 110°C and boiled for the specified amount of time and weighed again. The specimen should not contain any damage or cracks. It is generally expressed in percentage, here the average of three specimen test samples were taken. Absorption mainly depends on the concrete specimen's permeability property. Low permeability concrete, resists ingress of water. As durability is inversely proportional to the pervious concrete this test gives us the good results in absorption rate of concrete as shown in figure 9 and table-11.

Absorption after immersion % = \[(B-A)/A\]x100
Absorption after immersion and boiling \( \% = \frac{[(C-A)/A] \times 100}{\text{A}= \text{Mass of oven dried sample in air, g}} \)

\( \text{B}= \text{Mass of surface dry sample in air after immersion, g} \)

\( \text{C}= \text{Mass of surface dry sample in air after immersion and boiling, g} \)

Figure 9 water absorption test Experimental setup

Table 11 water absorption test results

| S. No | Percentage of Replacement | Water Absorption (%) |
|-------|---------------------------|----------------------|
| 1     | 0%                        | 0.56                 |
| 2     | 10%                       | 0.42                 |
| 3     | 20%                       | 0.35                 |
| 4     | 30%                       | 0.30                 |
11. X-RAY Diffraction (XRD) Analysis:

X-ray diffraction is an effective technique for identifying crystalline phases in cement, and the phase quantity is directly proportional to the intensity of the X-ray reflections (i.e., commonly called as XRD peaks) from the major crystallographic planes in a phase. Concrete taken from the destructed cube or specimen at the point of crack occurs is crushed into fine power and thin film of cement paste is made which the X-ray can easily pass through it and the sample of thin film is kept in diffractometer the process starts with angle theta which observes the micro structural and crystalline data of elements. Here we have tested for 7- and 28-days age of concrete in vignan university Guntur and the peaks are plotted with the help of microbial origin as shown in figure 11.

| Percentage of replacement | Absorption of water |
|---------------------------|---------------------|
| 10%                       | 0.42                |
| 20%                       | 0.35                |
| 30%                       | 0.3                 |
| 40%                       | 0.28                |
| 50%                       | 0.22                |

Figure 10 water absorption test experimental results
Figure 11 Individual Peaks of X Ray Diffraction

Here the x-ray diffraction is done by the XRD diffractogram and X-ray diffractometer with 2 theta degree 40 kV, 15 mA of x-ray and wavelength of Cu Ka/1.541862 A. the peak values and the intensities of each phases matches with the components presents in the sample concrete are free lime, langbeinite, periclase and gypsum in 7 and 28 days as represented in figure 11 and 12.
Figure 11 X Ray peaks and phases Diffraction of 7 days (age of concrete)

Figure 12 X Ray peaks and phases Diffraction of 28 days (age of concrete)
12. Conclusions:

Compressive strength:
The percentage change in compressive strength for 10%, 20%, 30%, 40% and 50% GGBS replacement levels are 1.03, 1.05, 1.06, 1.10 and 0.93 respectively for 56 days when compared to conventional concrete. We can observe the initial strength gain in 7 days of curing period onwards.

Size Effect:
The percentage change in compressive strength due to size effect for 10%, 20%, 30%, 40% and 50% GGBS replacement levels are 1.01, 1.02, 1.05, 1.08 and 0.93 respectively for 28 days.

Splitting tensile strength:
The percentage change in splitting tensile strength for 10%, 20%, 30%, 40% and 50% GGBS replacement levels are 1.03, 1.06, 1.1, 1.12 and 0.96 respectively for 28 days when compared to conventional concrete.

Flexural strength:
The percentage change in flexural strength for 10%, 20%, 30%, 40% and 50% GGBS replacement levels are 1.07, 1.09, 1.1, 1.14 and 0.98 respectively for 28 days when compared to conventional concrete.

Sorpitivity:
The percentage decrease in Sorpitivity for 10%, 20%, 30%, 40% and 50% GGBS replacement levels are 19.28, 23.9, 26.7, 28.02 and 30 respectively when compared to conventional concrete, thus is impervious in nature.

Water Absorption:
The percentage decrease in water absorption for 10%, 20%, 30%, 40% and 50% GGBS replacement levels are 25, 30, 32, 41 and 50 respectively when compared to conventional concrete.

Carbonation:
The percentage decrease in carbonation depth for 10%, 20%, 30%, 40% and 50% GGBS replacement levels are 6.67, 7.02, 8.6, 11.6 and 23 respectively and pH levels ranges between 9-12 hence results in non-carbonated zone.

X-ray diffraction:
It is observed that the phase value of the elements keeps on changing by increasing percentage replacement of GGBS in cement and we can see the sudden raise in the peak value of the component present in the concrete 20% of 7 days and 40% of 28 days respectively.

13. Overview:
As the percentage of GGBS replacement levels increases the compressive strength and other mechanical properties such as tensile strength and flexural strength are gradually increasing with age of concrete. And the durability properties as Sorpitivity, water absorption and carbonation are also increasing so that we can conclude replacement levels of GGBS up to 40% has better strength and durability. The workability of concrete is increased by increasing in the percentage replacement of GGBS in concrete and depends upon the mix proportions of M40 concrete. Finally, we can conclude that the above concrete is sustainable for good strength, durability, speed in construction, economical and environmental aspects.
Cost analysis:

The concrete with GGBS mix can reduce 9% to 25% of the cost of the concrete in construction, compared to normal concrete. The concept of reducing natural resources and reusing waste materials that causes environmental pollution, was investigated from the experimental study, the concept of green technology can be made with incorporation of GGBS in concrete that will result in sustainable development.

Future scope:

The study of special grade cement and GGBS for normal OPC cement replacement in concrete for prestressing and RCC elements such as beams, slabs etc is recommended for further research

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