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# STRENGTH AND FLEXURAL BEHAVIOUR OF REINFORCED CONCRETE WITH GROUND GRANULATED BLAST FURNACE SLAG

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## ABSTRACT

The Ordinary Portland Cement (OPC) is one of the main ingredient used for the production of concrete. But manufacturing of cement involves emission of large amounts of carbon-dioxide gas in to the atmosphere which is a major contributor for greenhouse effect and global warming. Many researchers have studied the properties of ordinary portland cement concrete using cementitous materials like fly ash, silica fume, and Ground Granulated Blast furnace Slag(GGBS) as replacement materials. This paper mainly aims at studying the flexural behaviour of concrete without GGBS (control beams) and concrete with GGBS beams experimentally. Twenty four reinforced concrete beam specimens comprising of 8 control beams, 8 beams with 40% GGBS and 8 beams with 50% GGBS were cast and tested. The specimens were tested at 28th, 56th, 90th and 120th day from the date of casting. Data presented include cracking behaviour, load-deflection, moment-curvature relationship and displacement ductility. Results of this investigation suggests that replacement of OPC with 50% GGBS can be used in reinforced concrete specimens as it shows good strength, moment carrying capacity and ductility.

***Keywords**: Cracking, load-deflection, moment-curvature, load-strain , displacement ductility*

## 1 INTRODUCTION

Concrete is typically the most massive individual material element in the built environment. It was analysed that approximately 93% of the total embodied energy of concrete and around 7% of the world wide $CO_2$ emissions are during the manufacturing of cement. Efforts are being carried out to conserve energy by means of promoting the use of industrial wastes or by-products, as mineral admixture for partial replacement of cement. Due to its long term durability, the utilization of pozzolanic materials in concrete as partial replacement of cement is increasing rapidly.

Ground Granulated Blast furnace Slag is a by-product of iron manufacturing industry. This paper mainly aims at studying the flexural behaviour of concrete without

GGBS (control beams) and concrete with GGBS beams experimentally. Research work has been carried out to study the mechanical properties of concrete by replacing ordinary portland cement by 30% to 70% GGBS by conducting various test on workability, water absorption, compressive strength, split tensile and flexural strength. The structural behavior of concrete with GGBS is also to be studied in order to utilize it in the building construction. Hence it was proposed to study the flexural behaviour of Reinforced Concrete (RC) beams after optimizing the replacement percentage of GGBS with the results obtained from mechanical properties.

## 2.0 PRELIMINARY INVESTIGATIONS

To study the mechanical behavior of concrete with GGBS, tests on workability, setting time, water absorption, compressive strength, split tensile strength and flexural strength were conducted on cube, cylinder and prism specimens. The specimens were cast and tested on 28 & 56 days of curing.

### 2. 1 Observations

The use of ordinary Portland cement partially replaced with GGBS resulted in an increase in setting time, as the initial rate of reaction of slag is slower than that of cement. The delay in setting time was closely linked to the slag replacement level, as higher the amount of slag higher is the setting time. There was increase in slump flow as the GGBS content is increased up to 40% and beyond that the mix was quite stiff. The slump had shear type of failure as the GGBS content was increased. No segregation and bleeding in any of the mixes were observed**.** The water absorption test revealed that the control concrete specimens absorbed more water than the GGBS samples. The amount of water absorbed by the GGBS samples is lower than that absorbed by the control concrete samples and higher the GGBS content, the lower the amount of water absorbed. The mechanical properties of all test specimens are tabulated in Table 1.

**Table 1 Mechanical Properties of Control Concrete and Concrete with GGBS**

| % of GGBS in | Fresh Properties | | Hardened Properties | | | |
|---|---|---|---|---|---|---|
| | Slump Values | Setting Time | Water | Compressive | Split | Flexural |

| Concrete | (mm) | | (min) | | Absorption (%) | | Strength (N/mm$^2$) | | Tensile Strength (N/mm$^2$) | | Strength (N/mm$^2$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial slump | After one hour | Initial | Final | 28 days | 56 days | 28 days | 56 days | 28 days | 56 days | 28 days | 56 days |
| 0 | 255 | 115 | 40 | 390 | 7 | 5.5 | 40.9 | 43.13 | 3.38 | 3.42 | 5.01 | 5.24 |
| 30 | 210 | 129 | 50 | 420 | 6.6 | 5.3 | 41 | 45.4 | 3.45 | 3.68 | 4.95 | 5.45 |
| 40 | 215 | 130 | 60 | 445 | 5.6 | 5.2 | 39.9 | 44.45 | 3.3 | 3.66 | 4.61 | 5.41 |
| 50 | 200 | 105 | 70 | 460 | 5.5 | 5.1 | 38.0 | 43.00 | 3.2 | 3.4 | 4.49 | 5.35 |
| 60 | 185 | 95 | 90 | 510 | 5.0 | 5.0 | 27.3 | 30.36 | 2.85 | 3.00 | 3.85 | 4.1 |
| 70 | 150 | 70 | 95 | 560 | 5.2 | 4.8 | 22.2 | 27 | 2.65 | 2.9 | 3.5 | 3.8 |

The addition of slag to concrete had a significant effect on compressive strength, tensile and flexural strength. The concrete specimens with GGBS had low early strengths compared to control concrete. Since slag cement is a latent hydraulic material, low early strengths were expected. The concrete with GGBS had low strength at early ages, but had increased rates of strength gain beyond 28 days compared to OPC concrete. From the test results higher compressive strength for concrete is observed for mixes up to 40% GGBS at all ages. Even for concrete with 50% GGBS, the strength was equal to that of control concrete at 56 days. As the strength of concrete beyond 50% GGBS is found to be very less when compared to control concrete, flexural studies were carried out in RC beams with 0%, 40% and 50% GGBS.

## 3.0 TEST ON FLEXURAL BEAHVIOUR OF RC BEAMS WITH GGBS

Twenty four numbers of reinforced concrete beams with and without GGBS were cast and tested in the loading frame. Experiments were carried out on control beams and beams with 40% and 50% GGBS. The span of the beam was 2500 mm and of size 150mm x 250mm. Geometry of the beam specimen and reinforcement details are shown in Figure 1.

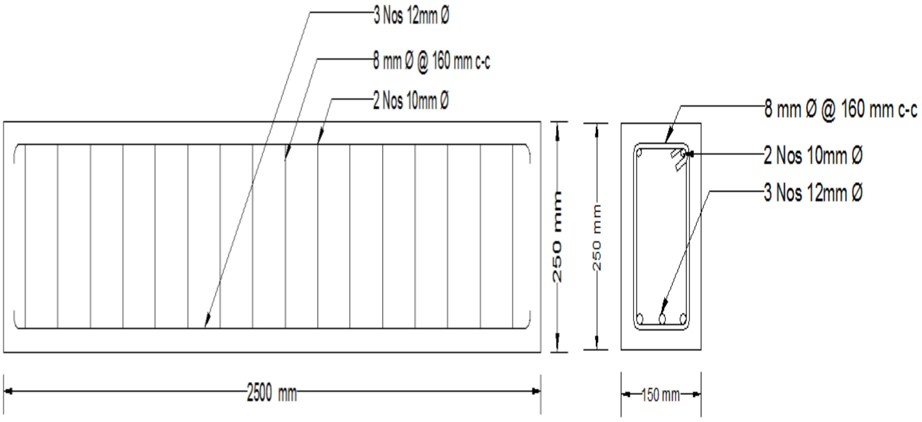
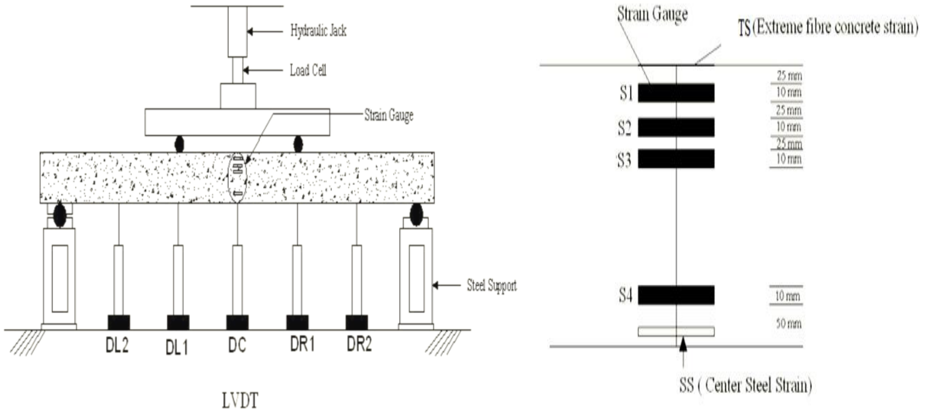


**Figure 1 Geometry and Reinforcement Details of Beam Specimen**

Out of the 24 specimens tested, eight specimens were cast without GGBS, eight specimens with 40% GGBS and eight specimens with 50% GGBS. Two specimens were cast and tested in each series. The specimens were tested at 28th day, 56th day, 90th day and 120th day from the date of casting. A four lettered designation is given to the specimens. First letter represents the beam, 2nd letter represent percentage of GGBS added and 3rd one identity of specimen in a particular series as two specimens were tested in each series and the last one indicates on which day the specimen was tested.

Strain gauges of 10 mm were fixed to the reinforcement at the bottom to measure the strain. The testing was carried out in a loading frame of 400kN capacity. Strain gauge was fixed at the mid span of the tension bar .The top surface of the beam was instrumented with strain gauge to measure the concrete compressive strains in the pure bending region. Strain gauges were also attached to the concrete surface in the central region of the beam to measure the strain at different depths. Linear Variable Displacement Transducers (LVDT) was used for measuring deflections at several locations. Strain gauges and LVDTs were connected to a data logger from which the readings were captured by a computer at every load intervals until failure of the beam occurred. Figure 2 shows the test set-up.



**(a) Position of LVDT** **(b) Position of Strain Gauges**

**Figure 2 Test set up**

The beams were subjected to two-point loads under a load control mode. All the measurements including deflections, strain values and crack widths were recorded at regular intervals of load until the beam failed. The failure mode of the beam was also recorded.

### 3.1 Results and Discussion

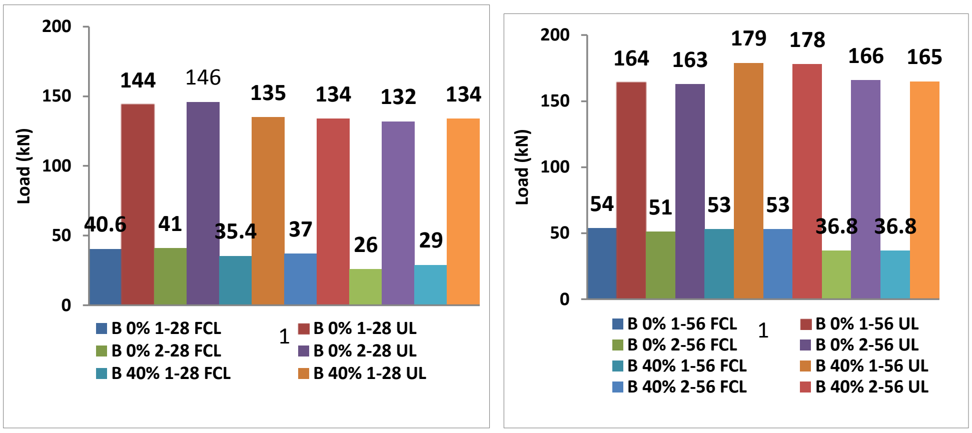
Vertical flexural cracks were observed in the constant-moment region and final failure occurred due to crushing of the compression concrete with significant amount of ultimate deflection. When maximum load was reached, the concrete cover on the compression zone started to fall for both beams with and without GGBS. Figures 3 show the failure pattern of the test specimens. Crack formations were marked on the beam at every load interval at the tension steel level. It is noticed that the first crack always appears close to the mid span of the beam. The cracks formed on the surface of the beams were mostly vertical, suggesting flexural failure in beams. The crack widths at service loads for GGBS concrete beams ranged between 0.18mm to 0.2mm and this is within the maximum allowable value as stipulated by Indian codal provisions for durability requirements.

**(a) Control beam** **(b) 40% GGBS** **(c) 50 % GGBS**

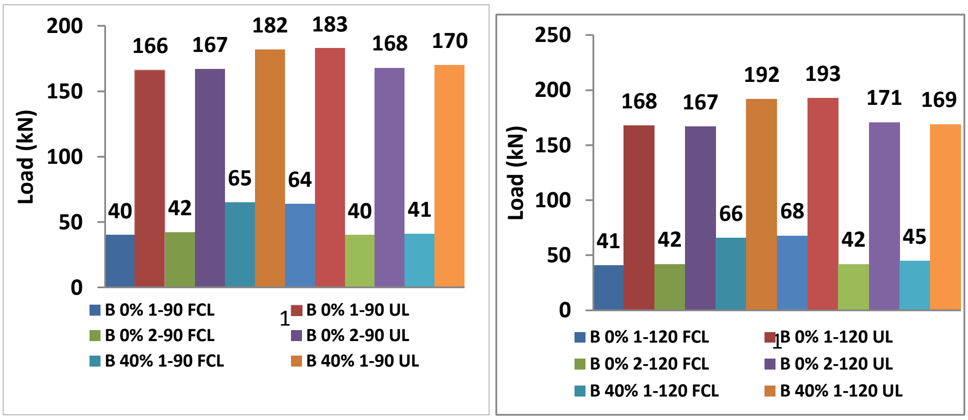
**Figure 3 Crack Pattern in the Beam Specimens**

### 3.1.1 Ultimate Load Carrying Capacity

It was observed that all the beam specimens at 28th day developed crack at an early stage. But slowly with increase in age of concrete there is delay in formation of initial crack. Addition of 40% GGBS has also prolonged the initial crack formation.



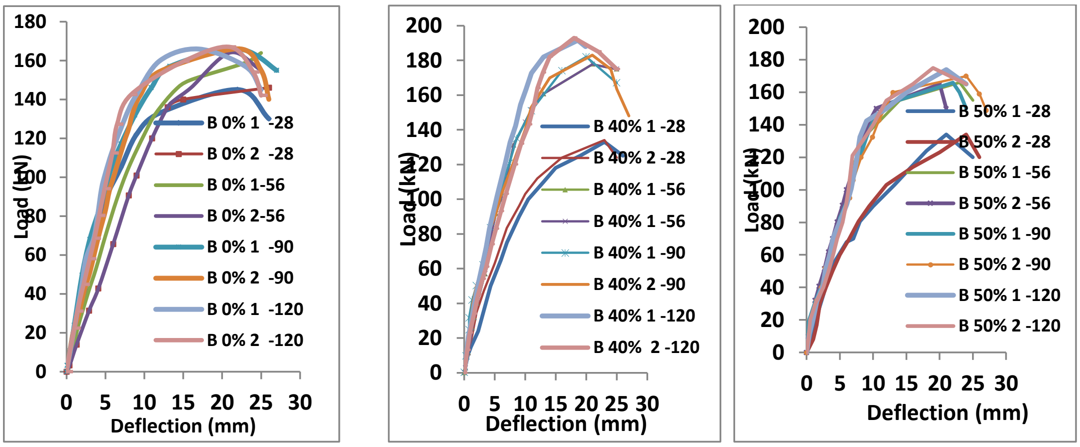
**(a) 28th day** **(b) 56th day**



**(c) 90th day** **(d) 120th day**

**Figure 4 Comparison of First Crack Load and Ultimate Load**

From the load- mid span deflection plot Figure 5 (a) - (d) it is found that the ultimate load carrying capacity for beams with 40% and 50% GGBS was less than the control beam at 28th day, but after 28 days it is higher than the control beams. The increase in the strength of mortar and concretes due to the addition of GGBS can be attributed to the improved aggregate - matrix bond associated with the formation of a less porous transition zone and a better interlock between the paste and the aggregate. It is also found that addition of GGBS in concrete has reduced the deflection and increased the load carrying capacity.

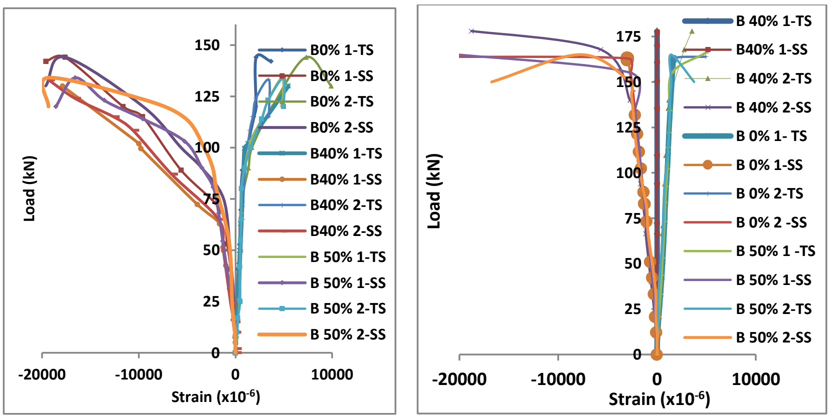


**(a) Control Concrete** **(b) 40% GGBS** **(c) 50% GGBS**

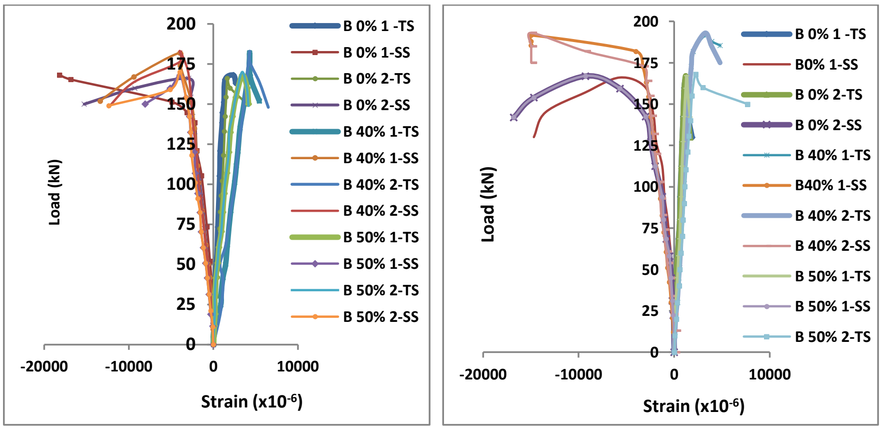
**Figure 5 Mid Span Deflection of Beam specimens**

### 3.1.2 Load Strain

The concrete and steel strains measured at every load increments show the strain distribution for the concrete and steel at 28th, 56th, 90th and 120th days respectively. The positive strain value represents the compressive strain and the negative strain value indicates the tensile strain. The comparison of strain in concrete and steel for control beams and beams with GGBS is shown in Figures 6 (a) to (d). The measured concrete strains at the top surface and steel strains at ultimate load revealed that GGBS concrete is able to achieve its full strain capacity under flexural loading.



**(a) 28th day** **(b) 56th day**



**(c) 90th day** **(d) 120th day**

**Figure 6 Comparison of Steel and Concrete Strain**

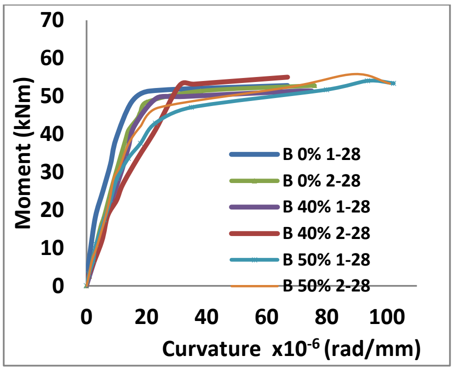
### 3.1.3 Displacement Ductility

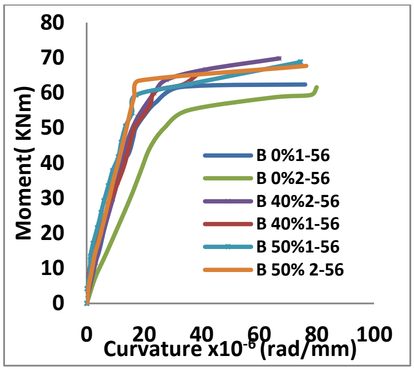
Ductility is the property which allows the structure to undergo large deformation without losing its strength. Ductility is explained by the ductility factor. Yield displacement is taken as the yield displacement of the equivalent elasto-plastic system with reduced stiffness found as the secant stiffness at 75% of the ultimate load of the real system. Ultimate displacement is taken as the displacement corresponding to peak load displacement relation.

From the Table 2, it was found that the average displacement ductility values for all the beams ranged between 2.6 to 3.5. From the table it was found that the GGBS concrete beams showed adequate displacement ductility and can be considered for structural members subjected to large displacement such as sudden forces caused by earthquake.

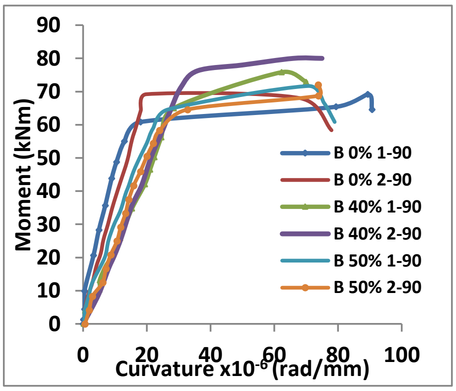
### 3.1.4 Moment- Curvature relationship

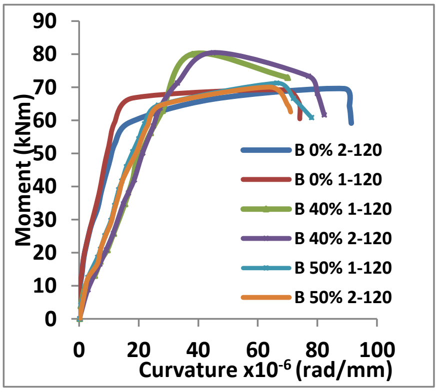
The comparison of the moment-curvature curve for specimens having the same reinforcement spacing and longitudinal reinforcement but different percentage of GGBS is shown in Figures 7 (a) to (d). The figure shows that a member with lower strength exhibits less curvature at ultimate load than a member with higher strength. It was found that the curvature at yield decreases and the curvature at ultimate increases with high characteristic strength of concrete. The curvature corresponding to moment appears to increase slightly for the higher members. The higher strength concrete members are stiffer than lower strength concrete members, because the flexural rigidity (EI) of concrete increases with strength. **Mandal**(7) also reported that increase in the characteristic strength of concrete increases the neutral axis depth, hence moment capacity of the section increases. It can be assumed that there will be increase in the concrete strength.





**(a) 28th day** **(b) 56th day**





**(c) 90th day** **(d) 120th day**

**Figure 7 Moment-Curvature for Beam Specimens**

The performance details obtained from all the beam specimens subjected to bending are summarized in Table 2.

**Table 2 Performance Details of the Specimens**

| Beam ID | First Crack Load (kN) | Ultimate Load(kN) | Maximum Displacement (mm) | Displacement Ductility | Maximum Moment (kNm) | Deflection at Service Loads (mm) |
|---|---|---|---|---|---|---|
| B0% 1-28 | 40.6 | 144 | 26 | 2.9 | 60 | 9 |
| B0% 2-28 | 41 | 146 | 25 | 2.94 | 61 | 8.5 |
| B40% 1-28 | 35.4 | 135 | 23 | 2.43 | 56 | 9 |
| B40% 2-28 | 37 | 134 | 24 | 2.81 | 56 | 8.1 |
| B50% 1-28 | 26.1 | 132 | 25 | 3.04 | 55 | 8 |
| B50% 2-28 | 29 | 134 | 23 | 3.25 | 56 | 7.9 |
| B0% 1-56 | 53.7 | 164 | 24 | 3.47 | 68 | 7.5 |
| B0% 2-56 | 51 | 163 | 23 | 3.43 | 68 | 8 |
| B40% 1-56 | 53.1 | 179 | 22 | 3.2 | 75 | 7.5 |
| B40% 2-56 | 56 | 178 | 20 | 3.0 | 74 | 8.1 |
| B50% 1-56 | 36.8 | 166 | 21 | 3.43 | 69.5 | 8 |
| B50% 2-56 | 38 | 165 | 24 | 3.33 | 69 | 8 |
| B0% 1- 90 | 40 | 166 | 22 | 3.69 | 69. | 7.6 |
| B0% 2- 90 | 42 | 167 | 23 | 3.33 | 70 | 8 |
| B40% 1-90 | 65 | 182 | 21 | 3.25 | 76 | 7.9 |
| B40% 2-90 | 64 | 183 | 20 | 3.18 | 77 | 8 |
| B50% 1-90 | 40 | 168 | 23 | 3.13 | 70 | 8.3 |
| B50%2- 90 | 41 | 170 | 20 | 3.35 | 71 | 8.1 |
| B0% 1-120 | 41 | 168 | 21 | 3.45 | 70 | 7.6 |
| B0% 2-120 | 42 | 167 | 22 | 3.66 | 70 | 7.9 |
| B 40%1-120 | 66 | 191.6 | 17 | 3.3 | 80 | 8.1 |
| B50% 1-120 | 42 | 171 | 21 | 3.14 | 71 | 8.3 |
| B 50% 2-120 | 45 | 169 | 20 | 3.26 | 70 | 7.9 |

## CONCLUSIONS

- The use of slag in concrete resulted in an increase in setting time, as the initial rate of reaction of slag is slower than that of cement. The delay in setting time is closely linked to the slag replacement level, as higher amount of slag increases the setting time.
- There is a significant improvement in the compressive, tensile and flexural strength of ordinary portland cement replaced with GGBS concrete beyond 28 days because of the high pozzolanic nature of the GGBS and its void filling ability.
- The crack patterns observed for GGBS beams are found to be similar to the OPC concrete beams.
- The ultimate moment capacity of GGBS concrete beams beyond 28 days was better than control concrete beams.
- The displacement ductility for concrete beams with GGBS ranged between 3 to 4 which shows adequate displacement ductility**.** Hence it can be considered for structural members subjected to large displacement such as sudden forces caused by earthquake.

Results of this investigation suggest that concrete with 50% GGBS as replacement for cement can be used in RC specimens as it showed good strength, moment carrying capacity and ductility. The study contributes to the development of new eco-friendly binder in concrete. Use of industrial waste products saves the environment and conserves natural resources. Reuse of the slag helps to protect the environment from pollution.

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