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FLEXURAL BEHAVIOUR OF REINFORCED GEOPOLYMER CONCRETE BEAMS WITH GGBS AND METAKAOLIN

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ABSTRACT

Present investigation embodies the flexural behavior of Geopolymer Concrete (GPC) beams cured under ambient temperature. Twelve reinforced concrete beams of size 700 mm x 150 mm x 150 mm were tested. The beams were tested under four point bending over an effective span of 660 mm. The behavior was studied with reference to first crack load, service load and ultimate load. The results were found to be similar to that of conventional cement concrete reinforced beams. The studies showed that the conventional RC theory could be used for reinforced GPC flexural beams for the computation of moment capacity, deflection within reasonable limits.

Keywords: Flexural Behaviour, Reinforced Concrete, Geopolymer Concrete, Molarity, Beams

I. INTRODUCTION

The construction industry forms a vital sector of the nation's economy. Utilization of the industrial byproducts in this sector could become an important route for large scale safe disposal of the industrial wastes and reduction of construction cost [1].

In this regard, direct alkaline activation of industrial wastes, such as fly ash and GGBS, can be employed to produce Geopolymer cements which can be gainfully utilized to manufacture novel concretes for constructions [2, 3]. This can be considered as a sustainable approach to construction since the internal energy content of these new concretes are much less than that of Ordinary Portland cement based concretes (OPCs) and by this process Portland cement, one of the largest contributors to greenhouse gas is completely eliminated [3]. OPCs are found to be less durable in some of the very severe environmental conditions; Therefore, there is a need for development of alternative concretes.

The fact that the production of cement adds to the pollution of the environment is well known to civil engineers and environmentalists. The large scale production of cement is posing environmental problems on one hand and unrestricted depletion of natural resources on the other hand. Each ton of Portland cement production results in loading about one ton of CO_2 into the environment and in 3 decades, it is expected that the demand for cement in the world will be doubled. This is because of the need for infrastructure in developing countries with large population and rapid population growth. The majority of Fly ash produced from thermal power stations in India is disposed in landfills, ponds or rejected in river systems, which may cause serious environmental problems for future generations. Some of the other waste materials that are being utilized are bottom ash, blast furnace slag etc. [4]

Concrete usage around the world is second only to water. Ordinary Portland cement (OPC) is conventionally used as the primary binder to produce concrete. The environmental issues associated with the production of OPC are well known. The amount of the carbon dioxide released during the manufacture of OPC due to the calcinations of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced. In addition, the extent of energy required to produce OPC is only next to steel and aluminium. [4,5] When used as a partial replacement of OPC, in the presence of water and in ambient temperature, fly ash reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel. The development and application of high volume fly ash concrete, which enabled the replacement of OPC up to 60% by mass, is a significant development. [4]

The extensive research works carried out by several investigators corroborate the potential of GPC as a prospective construction material [2, 3, 6 – 10]. The development of alternative concretes is of great relevance to India, where the construction industry is in a boom and large quantities of industrial wastes are being generated by the allied industries [1].

The use of GPC is slowly gaining acceptance, especially for chemical resistant structures and research in this area has gained some momentum to extend the range of application. In fact, a considerable amount of experimental work has been already carried out in Australia, US and Spain. The previous investigators were mainly engaged in identifying suitable source materials for GPC, their processing, mix design, mechanical properties, and durability aspects [11 – 13]. The GPC was found to have a high degree of durability when it had an inorganic binder based on alumina and silica containing materials like fly ash and GGBS. But, as in conventional reinforced concretes, the GPC also needs to be reinforced with steel bars for its large scale utility in civil engineering structural applications. Hence, the investigations on the behaviour of Reinforced GPC were undertaken.

This paper considers reinforced GPC beams with different binder compositions produced by ambient temperature curing. The GPC beams based on OPC were also prepared and tested for comparison of performance. A total of eleven beams consisting of GPC mixes and one OPC mixes were tested as part of this study. Performance aspects such as load carrying capacity and moments at different stages were studied. The failure modes were also recorded for the beams. The paper compares the performance of GPC beams Vs Portland cement Concrete (OPC) beams.

II. OBJECTIVE OF THE STUDY

The objective of the paper was to study the flexural behaviour of reinforced geopolymer concrete. Laboratory scale beams were cast and tested under four-point bending system (two loading point plus two simple supports) to study the yield load, ultimate load, first cracking load, failure modes.

III. MATERIALS AND METHOD

Materials
Ordinary Portland cement conforming to IS 12269 (with specific gravity of 3.15), fine aggregates, coarse aggregates and potable water were used for the control OPC test specimens. The GPC was obtained by mixing different combinations of GGBS, Metakaolin, fine aggregates, coarse aggregates and alkaline activator solution (AAS) of 8 Molar NaOH.

GGBS (Ground Granulated Blast Furnace Slag) from JSW Cements conforming to IS 12089 were used. River sand available in Vijayawada was used as fine aggregates. They were tested as per IS 2386. In this investigation, locally available granite crushed stone aggregates of maximum size 10 mm and down was used and characterization tests were carried out as per IS 2386.

The properties of the materials used are shown in Tables 1 to 6. Potable water was used for the OPC and distilled water was used for the GPCs. High strength deformed steel bars with 0.2% proof stress of 500 MPa and nominal diameters of 8 mm, 10 mm and 12mm were used as reinforcements in beams are shown in table 7.

The alkaline activator solution (AAS) used in GPC mixes was a combination of sodium silicate solution (SiO_2/Na_2O=2.5), sodium hydroxide pellets and distilled water. The role of AAS is to dissolve the reactive portion of source materials Si and Al present in GGBS and Metakaolin and provide a high alkaline liquid medium for condensation polymerization reaction. The sodium hydroxide was taken in the form of flakes of approximately 2.5

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mm in size. The sodium hydroxide (NaOH) solution of 8 Molar concentration was prepared by dissolving the computed amount of sodium hydroxide flakes in distilled water.

The NaOH solution and sodium silicate solution were prepared separately and mixed together at the time of casting. Since a lot of heat is generated when sodium hydroxide flakes react with water, the sodium hydroxide solution was prepared 24 hours before casting. It should be noted here that it is essential to achieve the desired degree of workability of the GPC concrete mix amount of Superplasticiser is added in GPC and the properties are shown in Table 8. However, excess water can result in the formation of pore network, which could be the source of low strength and low durability.

Table 1. Physical Properties of Metakaolin

Colour	Pink
Pozzolan Reactivity mg Ca $(OH)_2$ / gm	900
Average Particle size	1.4 micron
Brightness (ISO)	75 ± 2
Bulk Density (Gms / Ltr)	320 to 370
Specific Gravity	2.5

Table 2. Chemical Properties of Metakaolin

Al_2O_3	>39.0 %
Fe_2O_3	<0.8%

Table 3. Physical Properties of GGBS

Parameter	**GGBS**
CaO	37.34%
Al_2O_3	14.42%
Fe_2O_3	1.11%
SiO_2	37.73%
MgO	8.71%
MnO	0.02%
Sulphide Sulphur	0.39%
Loss of Ignition	1.41%
Insoluble Residue	1.59%
Glass Content (%)	92%

Mix Proportions

Unlike Ordinary Portland cement concretes GPCs are a new class of construction materials and therefore no standard mix design approaches are available for GPCs. While Rangan and Hardjito have presented certain guidelines for fly ash based GPCs, some of the trials carried out using these procedures indicated that the workability and strength characteristics of such mixes were not satisfactory. Such a thing is possible because GPC concrete involves more constituents in its binder (viz., Metakaolin, GGBS, sodium silicate, sodium hydroxide and water), whose interactions and final structure and chemical composition are strongly dependent on the source of the materials and their production process [1].

Therefore, the chemistry and microstructure of GPC is more complex and is still a matter of research, whereas the chemistry of cement and its structure and chemical composition are well established due to extensive research carried out over more than a century. While the strength of cement concrete is known to be well related to its water cement ratio, such a simplistic formulation may not hold good for GPCs. Therefore, the formulation of the GPC mixtures was done by trial and error basis. Numerous trial mixes were cast and tested for compressive strength at the end of 28 days. The primary objective for performing the trial and error procedure was to obtain a range of compressive strength at the end of 28 days. The proportions and composition of GPS and AAS were so decided that the test specimens cast were demoulded after 24 hours of in mould curing and the required strength could be realized. In order to compare the results of tests conducted using GPC, additional conventional concrete mixes prepared with OPC and designed as per IS 10262 – 2009 The details of the mix proportions are given in Table 4 & 5. The combinations of the GPC mixes are shown in Table 6.

Table 4. Mix Proportions of GPC

Materials	**Quantity kg/m^3**
Cementitious Materials	414
Fine Aggregate	660
Coarse Aggregate	1136
Sodium Hydroxide	53
Sodium Silicate	133
Super Plastizer	8.28

Table 5. Mix Proportions of Cement Concrete

Material	**Quantity kg/m^3**
Cement	454
Water	186
Fine Aggregate	667
Coarse Aggregate	1153
Mix Proportion	1: 1.46 : 2.53
W/C	0.41
SP	4.07

Table 6. Combinations of GGBS and Metakaolin

Mix ID	**Metkaolin (%)**	**GGBS (%)**
M1	100	0
M2	90	10
M3	80	20
M4	70	30
M5	60	40
M6	50	50
M7	40	60
M8	30	70
M9	20	80
M10	10	90
M11	0	100

Strength Characteristics of the Mixes

Specimen Details

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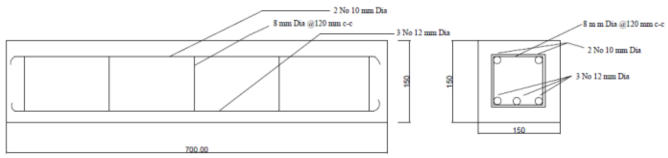

Figure 1: Geometry of the Beam Specimen

The beam specimens were 150 mm wide and 150 mm deep in cross section. They were 700 mm in length and simply supported over an effective span of 660 mm. The clear cover of the beam was 20 mm. The geometry of the beam specimen is shown in Figure 1.

High yield strength deformed steel bars of diameter 8 mm, 10 mm and 12 mm were used as the longitudinal reinforcement in the specimens. Two legged vertical stirrups of 8 mm diameter at a spacing of 132 mm centre to centre were provided as shear reinforcement. a day before casting [1].

IV. PREPARATION OF SPECIMENS

Prior to casting, the inner walls of moulds were coated with lubricating oil to prevent adhesion with the hardening concrete. The concrete was placed in the moulds in three layers of equal thickness and each layer was vibrated until the concrete was thoroughly compacted. Along with beam casting, three numbers of 150 mm cubes were cast to determine the 28 day compressive strength. Specimens were demoulded after 24 hrs [1]. The OPC beams were water cured for a period of 28 days while the GPC beams were cured in ambient condition, in the laboratory for a period up to 28 days after casting. After curing, the test specimens were tested for compressive strength and structural behaviour.

Test Setup

The test setup for the flexural test is shown in Figure 2 and Figure 3. The test specimen was mounted in a UTM of 1000 kN capacity. The effective span of the beam was 660 mm. The load was applied on two points each 226.6mm away from centre of the beam towards the support.

Dial gauges of 0.001 mm least count were used for measuring the deflections under the load points and at mid span for measuring the deflection. The dial gauge readings were recorded at different loads. The load was applied at intervals of 100 kgs until the first crack was observed. Subsequently, the load was applied in increments of 250 kgs. The behaviour of the beam was observed carefully and the first crack was identified. The failure mode of the beams was also recorded.

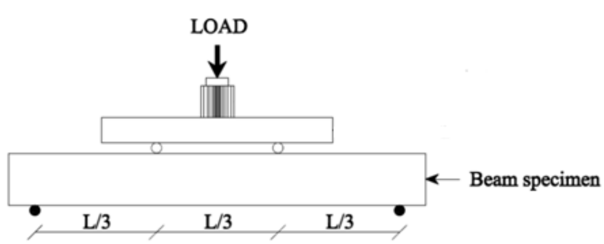

Figure 2: Schematic Diagram for Flexure Test on Beam

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Figure 3: Flexure Test on Beam

V. TEST RESULTS AND DISCUSSIONS

Table 7 gives the mechanical properties of the mixes while the load and moment capacities of GPC beams at different stages and OPC Beams are listed in Table 6**.** The Figures 4 and 5 show the load deflection behavior at midspan for the OPC and GPC beam specimens Figures 6 shows the crack pattern of the beams.

Table 7: Load carried at various stages by the beams

Mix ID	First Crack kN	Yield load kN	Service load kN	Ultimate Load kN
M1	17.17	22.07	14.72	22.07
M2	22.07	29.43	19.62	29.43
M3	39.24	68.67	45.78	68.67
M4	49.05	76.03	50.69	76.03
M5	56.41	83.39	55.59	83.39
M6	63.77	107.91	71.94	107.91
M7	68.67	118.70	79.13	118.70
M8	78.48	140.28	93.52	140.28
M9	85.84	159.41	106.28	159.41
M10	90.74	175.11	116.74	175.11
M11	98.10	188.84	125.90	188.84
M12 OPC	78.48	142.25	78.48	142.25

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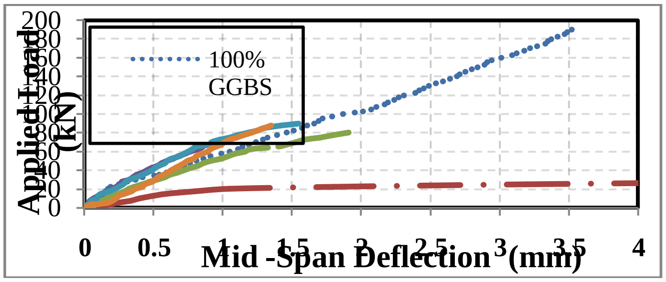

Figure 4: Applied load Versus Mid Span Deflection

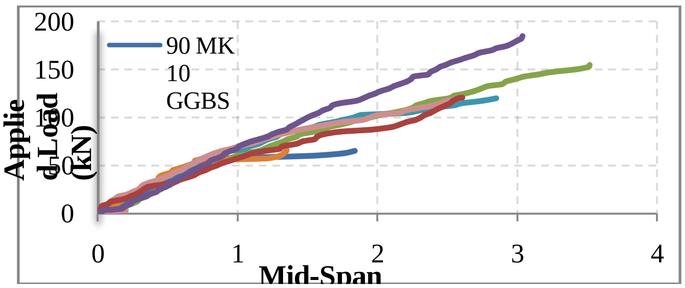

Figure 5: Applied load Versus Mid Span Deflection

Load Deflection Behaviour

The Figures 4 and 5 show the load deflection behavior at midspan for the OPC and GPC beam specimens respectively. The changes in the load deflection curves clearly indicate the different events occurring during the test. The first visible crack formation and ultimate load for GPC and OPC were found. [1]

The load deflection pattern was similar in case of OPC beams as well as GPC beams except with more specimens which contain more than 70% Mekakaolin, which had a very low compressive strength. A slight drop in the load followed the peak load, in almost all the beams is also observed. [1]

Table 8: First Crack Load

Mix ID	First Crack kN
M1	17.17
M2	22.07
M3	39.24
M4	49.05
M5	56.41
M6	63.77
M7	68.67
M8	78.48
M9	85.84
M10	90.74
M11	98.10
M12	78.48

Failure Mode and crack pattern

Beyond the peak load, the no. of flexural cracks stabilized and the cracks at the midspan. At failure load, all the beams deflected significantly. The failure pattern of the beam specimens was found to be similar for both OPC and GPC beams. The failure in all the cases was initiated by yielding of the tensile steel followed by the crushing of concrete in the compression face.[1]

In general, there was no major difference in the failure modes of GPC and OPC beams and the crack pattern at different stages were also nearly identical. There was no evidence of inadequacy of bond leading to splitting of concrete along the tensile reinforcement.

Figure 6: Crack patterns of specimens

VI. COMPARISON OF TEST RESULTS AND THEORETICALLY COMPUTED RESULTS

Flexural Moment Capacity

Table 7 compares the values of flexural moment capacity at cracking, service load and ultimate load for OPC beams and GPC beams. The predicted values were obtained by theoretical analysis using the transformed section method and strain compatibility method specified in the codes of practice for reinforced cement concrete. The flexural strength required for the computation of cracking moment was obtained from the corresponding cube strength using the formulae recommended in the codes of practice. [1]

The strength compared to that predicted by the codal formulae. Considering the typical variability in flexural strength data [14], the predicted moments are reasonably close to THE actual moment. The service load moment was obtained using the transformed section based on the allowable working stress permitted in IS: 456-2000. [15]

Table 9: Ratio of test results in flexure

Mix ID	Mu Exp	Mu The	Mu Exp/Mu The
M1	2.41	8.85	0.27
M2	3.14	10.32	0.30
M3	7.32	9.44	0.78
M4	8.11	16.81	0.48
M5	8.89	18.28	0.49
M6	11.51	17.10	0.67
M7	20.81	24.77	0.84
M8	19.29	22.41	0.86
M9	20.26	22.26	0.91
M10	19.43	20.89	0.93
M11	20.14	21.40	0.94
M12	19.23	21.00	0.91

VII. CONCLUSIONS

Based on the experimental and analytical investigations carried out on the reinforced Geopolymer cement concrete beams and conventional Portland cement concrete beams, it can be concluded that

1. The load deflection characteristics of the OPC beam and GPC beams (up to 60% GGBS – 40% Metakaolin) are almost similar. The cracking moment and service load moment were marginally lower for GPC beams (Above to 60% Metakaolin – 40% GGBS) compared to OPC beams.
2. The ultimate moment capacity of the GPC beams ARE investigated in the study was found to be more than that of the OPC beams because of their higher compressive strength.
3. The cracking, service and ultimate moment carrying capacity of the test beams are calculated using the conventional reinforced concrete principles and strain compatibility approach showed good correlation between the test and predicted values.
4. All the beams were failed in shear and flexural mode, the cracks are initiated in the tension face of the beam and cracks are propagated towards compression face as the load increases, followed by the crushing of concrete in compression face.
5. From the experimental result, it can be observed that as the first crack load, service load and ultimate load increases with increase in percentage of GGBs in geopolymer concrete.
6. The Magnitudes of experimental ultimate moments are found to be more than that of theoretical ultimate moments in GPC than that of OPC

It can be concluded that the clauses and the design provisions of IS 456 - 2000 for the design of flexure suffices and holds good for the design of Reinforced Geopolymer Concrete beams also up to 60% GGBS – 40% Metakaolin.

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