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FLEXURAL BEHAVIOUR OF GEOPOLYMER CONCRETE BEAMS CURED UNDER AMBIENT TEMPERATURE

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ABSTRACT

Portland cement is widely used all over the world and the consumption is next to the consumption of water. The manufacturing of Portland cement emits large quantity of CO_2 which causes pollution to the environment and makes serious impact on global warming. To reduce the emission of CO_2 by way of replacing the cement concrete, an alternative concrete called Geopolymer Concrete (GPC) was introduced in the year 1980. GPC is a new class of concrete based on an inorganic alumino – silicate binder system compared to the hydrated calcium silicate binder system of Portland cement concrete. To produce the Geopolymer Concrete (GPC) an alkali – activator solution called alkaline liquid consists of sodium hydroxide (NaOH) and sodium silicate (Na_2Sio_3) is used as a catalyst to extract the silicon (Si) and Aluminium (Al) from the source material of Ground Granulated Blast Furnace Slag (GGBS) and Fly Ash (FA) which produce a binder like gel by polymerization which is similar to the gel of Portland cement concrete by hydration. NaOH in pellet form was dissolved in potable water and mixed with Na_2 Sio_3 in liquid form to prepare the alkaline solution. Four beams of M 60 grade of size 125 x 250 x 3200 mm were cast and tested for flexure. Out of these four beams, two beams are control beams with Portland cement concrete and the remaining two are GPC beams. The GPC beams were ambient cured and the control beams by water curing. Under reinforced sections were designed for both GPC and control beams. Cubes were cast to find out the compressive strength. The flexural behavior for all the four beams was compared. Flexural strength and compressive strength were found out.

Keywords: Geopolymer concrete (GPC) alkaline liquid; polymerization; ambient cured; catalyst.

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1. INTRODUCTION

Concrete is the most widely used construction material worldwide in terms of volume and has a large impact on the environment with consequences for sustainable development. Manufacturing of Portland cement is one of the most energy- intensive materials of construction and is responsible for significant amount of emissions of carbon dioxide which is the prime greenhouse gas, causing global warming. Efforts are being made in the construction industry to address these by utilizing supplementary materials and developing alternative binders in concrete. The application of geo polymer technology is one such alternative. In fact, geo polymers have emerged as novel engineering materials with considerable promises as a binder in the manufacture of concrete.

The reaction of solid aluminosilicate with concentrated aqueous alkali hydroxide or alkali solution which produces a synthetic alkali aluminosilicate material generically termed as “geopolymer” but more broadly termed as an ‘inorganic polymer’. These materials can provide comparable performance to traditional cementitious binders in a range of applications, with significant reduction of greenhouse emissions. Though the terms geopolymer is generically used to describe the amorphous to crystalline reaction products from synthesis of alkali aluminosilicates from the raw source materials by the reaction of alkali hydroxide (or) alkali silicate solution, the geo polymeric gels and composites are generally referred as alkali activated cement, inorganic polymer concrete, geo cement, alkali bonded cement and low temperature aluminosilicate glass.

Alkali activation of Ground Granulated Blast furnace Slag (GGBS) has been used as an alternative means of Portland cement production for over 60 years and slags are frequently used as a component of geopolymeric systems. Fly ash based geopolymers are generally more durable and stronger. Similarly, cementitious binder systems other than alkali aluminosilicates have also been broadly categorized as ‘Geopolymers’ primarily due to similarities in processing. Depending on the selection of raw materials and the processing conditions, geopolymers can exhibit a wide variety of properties and characteristics, including high compressive strength, adequate flexural strength, acid resistance, fire resistance and low thermal conductivity. By taking the advantages of properties of fly ash and GGBS, this paper presents the flexural behavior of geopolymer concrete (GPC) incorporating fly Ash and GGBS at equal ratio for M60 grade, cured at ambient temperature to suit the practical conditions.

2. LITERATURE REVIEW

Increasing emphasis on energy conservation and environmental protection has led to investigation of alternatives to customary building materials. Among the goals of these investigations are to reduce greenhouse gas emissions and minimize the energy required for material production. Currently, Portland cement is the leading material for industrial concrete demand worldwide, fulfilling a demand of over 2.5 billion tons annually. The production of Portland cement is energy intensive and releases a significant volume of carbon dioxide (CO_2) to the atmosphere [1].

The term "geopolymer" is generically used to describe the amorphous to crystalline reaction products from the synthesis of alkali aluminosilicates with alkali hydroxide and alkali silicate solution [2]. Geopolymeric gels and composites are also commonly referred to as low-temperature aluminosilicate glass, alkali-activated cement, geocement, alkali-bonded ceramic, inorganic polymer concrete, and hydroceramic [3]. A geopolymer paste can be used to bind loose aggregates and other non-reacted materials together to form geopolymer concrete [4]. Geopolymer binders can provide comparable performance to traditional Cementitious binders in a range of applications with the added advantage of significantly reduced greenhouse gas emissions[5].

A combination of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH)is most commonly used an alkaline activator [6]. The ratio of these components is important in designing activators, because of the slow reactivity of fly ash at ambient temperature, considerable heat must be applied to increase the kinetics energy and degree of the reaction that produces the geopolymer, thus increasing the density of the pore system and improving the mechanical properties of the resultant composite. Xu and Deventer reported that the proportion of alkaline solution to alumino-silicate powder by mass should be approximately 0.32 to allow the geopolymeric reactions to occur [7]. Alkaline solutions formed a thick gel instantaneously upon mixing with the alumino-silicate powder.

3. EXPERIMENTAL PROCEDURE

3.1 Materials

M 60 grade of concrete was used for casting RCC and GPC beams with following details. Slag (GGBS), low calcium fly Ash of class F according to ASTM C 618(14) produced from Mettur ,T.N, India, fine Aggregates, coarse Aggregates12.5 mm and down size and Catalytic Liquid System (CLS), Ordinary Portland Cement (OPC) and high yield strength rebar of Fe 500 grade were used. The GGBS has fineness of $400m^2/kg$ and specific gravity of 2.9. Class F fly ash collected for Mettur thermal power station has been used. The chemical composition of fly ash as determined by XRF (mass percentage) is presented in Table 1 [9]. The chemical composition of GGBS is presented in Table 2.

Table 1: Chemical composition of fly ash

Compound	% mass
SiO_2	52.50
Al_2O_3	26.70
Fe_2O_3	11.10
CaO	1.28
Na_2O	0.45
K_2O	0.81
TiO_2	1.56
Mgo	0.87
P_2O_5	1.54
SO_3	1.70
Loi	1.36

Table 2: Chemical composition of GGBS

Compound	% mass
SiO_2	43.20
Al_2O_3	12.60
Fe_2O_3	1.30
CaO	40.20
Na_2O	0.90
K_2O	0.60
TiO_2	-
Mgo	1.45
TiO_2	-
GNO_3	-

Coarse aggregate collected from local quarry of size 7 to 12.5mm and river sand both at SSD condition have been used.

3.2 Catalytic Liquid System (CLS)

The term CLS is used to indicate the alkaline activator solution (AAS) in geopolymer concrete. The CLS is a combination of sodium hydroxide (NaOH), water and sodium silicate (Na_2SiO_3).The role of AAS is to activate the source materials such as silicon (Si) and Aluminium (Al) available in GGBS and flyash.

3.3 Preparation of CLS

The sodium hydroxide was taken in the form of pellets available in commercial grade with 97 to 98% of purity and the NaOH solution was prepared by dissolving the pellets in potable water one day before concreting since lot of heat is generated when NaOH reacts with water. On the day of casting, the Na_2SiO_3 in liquid form is mixed with the prepared NaOH solutions at a ratio of 2:4 and the mixed solution is called CLS (or) Alkali Activated Solution (AAS). AAS with a Molarity of 7(7 M) was prepared (7 x 40 = 280 gms) of NaOH pellets per liter of water since the molarity of NaOH is 40grams. It should be noted here that the water is the medium for dissolution and polymerization of aluminum and silicon precursors in order to take place appropriately and also necessary to achieve the degree of workability of the concrete mix. At the same time, adding excess water leads to pore network which will be the source for low strength and less durability. The properties of NaOH and Na_2SiO_3 are presented in Tables 3 and 4.

Table 3: Properties of NaOH

Molecular formula	NaOH
Molar mass	39.99 g/mol
Appearance	White solid
Density	2.12 g/cm^3
Melting point	318^{o}C, 591K
Boiling point	1388^{o}C, 1661K

Solubility in water	111 g/100ml
Sol Solubility in ethanol	13.8 g/100ml
Solubility in methanol	23.86 g/100ml
Solubility in glycerol	Soluble
Acidity (pKa)	13
Refractive Index	1.412

Table 4: Properties of Na_2SiO_3

Ph value	Neutral
Assay of Na_2O	7.5 %- 8.5 %
Assay of SiO_2 Free alkali	25%-28% Passes test

3.4 Mix design

The primary difference between the geopolymer concrete and Portland cement concrete is the binder. The silica and Aluminum oxides in the GGBS and Class F fly ash reacts with the alkaline liquid to form the geopolymer paste which binds the coarse aggregates and fine aggregates and other non-reacted materials together to form the geopolymer concrete. As in the case of Portland cement concrete, the coarse and fine aggregate occupy about 75 to 80% of the mass of geopolymer concrete. The design of GPC is carried out using the tools currently available for Portland cement concrete.

The compressive strength and the workability of GPC are influenced by the proportions and properties of the constituent materials which make the geopolymer concrete. The influence and role of aggregates are considered to be the same as in the case of cement concrete. The workability of fresh concrete and the compressive strength of hardened concrete are selected as the performance criteria. Ambient curing method was adopted and the performance of GPC was observed.

3.5 Mix proportions

A mix ratio of 1:1.2:1.80, 1 [one part (70% GGBS + 30% Flyash): 1.20 part fine aggregate: 1.80 part (80% 12mm +20% 20mm coarse aggregate] with CLS to binder (GGBS + FA) ratio as 0.62 with super plasticizer has been obtained for GPC M 60 grade. A mix ratio of 1:1.30:1.5 with water cement ratio of 0.30 + p.c.e based hyper plasticizer was adopted for Portland cement concrete M 60 grade.

Table 5: Constituents of GPC per m^3

Item	Quantity
Mix Ratio	1:1.2:1.80
AAS/Binder ratio	0.62
NaSiO3 / NaOH	2.4
C.A: F.A	60: 40
Molarity	7M
Fly Ash	111.1 kg
GGBS	259.3kg

F.A	720kg
C.A (7 to20mm)	1080 Kg
Na (OH)	67.53kg
Na_2SiO_3	162.10 kg
Super plasticizer SNF	3.10kg

3.6 Mixing, casting and curing

The GGBS, fly ash and the aggregates were dry mixed together in a pan mixer for about 3 minutes. All the aggregates were taken at SSD condition. The CLS was then added to the dry materials and the mixing was further continued for about 4 minutes to manufacture the fresh concrete as shown in Fig. 1.

Figure 1. Fresh GPC Concrete

The fresh concrete was cast as cube of size 150 x 150 x 150 mm, immediately after mixing as well as into the beam of size 125 x 250 x 3200 mm. The GPC specimens are kept in ambient curing and the cement concrete specimens are kept in water for 28 days. The compressive strength of GPC &RCC cement concrete at 7 and 28 days were 84&89.0 N/mm^2 and 93.0&96.5 N/mm^2 respectively. Two beam specimens were cast with GPC and another two beam specimens were cast with Portland cement concrete for the same grade M60. Totally four beams of size 125 x 250 x 3200 mm were cast, out of which two are RCC control beams and the remaining two are GPC beams of same grade M60. The beams were designed as under reinforced section, reinforced with 2-16# at bottom and 2-10# at top with 6mm dia. stirrups @ 150 mm c/c and the yield strength of steel used was f_y= 500 N/mm^2.

3.7 Testing of beams

Beams were tested in four point bending and the maximum stress was present over the center one third portion under static monotonic loading and test setup is shown Fig. 2. A view of the test set up is shown in Fig. 3. The test specimen is mounted in a loading frame which has a load capacity of 300 kN. Dial gauges of 0.001 mm least count is used for measuring the deflections under the load points and at mid span for measuring the deflection. The dial gauge readings are recorded at different stages of loads. The first crack loads obtained by visual examination. Fifty ton capacity hydraulic jack is used for loading and fifty ton capacity proving ring is used for measuring load. The loading is increased in stages with recording of the deflection and strain reading. Observations like the ultimate load carried by the beam, the load at first crack, maximum crack width, and maximum deflection were made. It is observed that the control beams failed in flexure. As the load increased, the crack started to widen and propagated towards the location of loading.

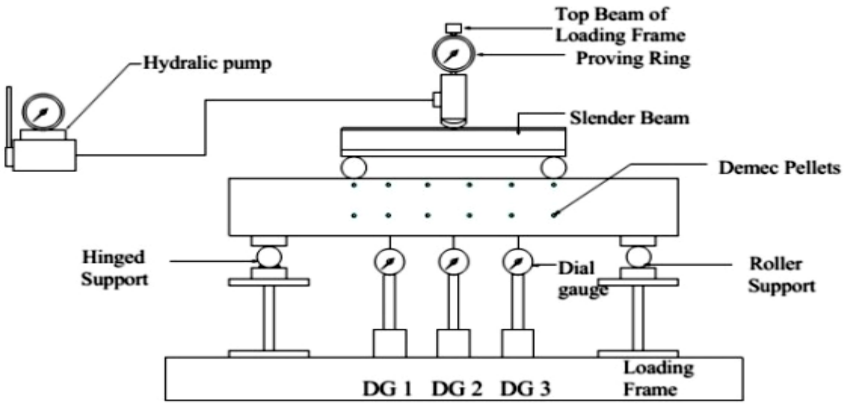

Figure 2. Test setup


Figure 3. Testing of beam

The specimen is kept in the loading frame and two dial gauges are kept below the loading point and one dial gauge at the center of the beam. The specimens are tested under monotonically increasing load until failure. As the load increased, beam started to deflect and flexural cracks developed along the middle span of the beams. Eventually, all beams failed in a typical flexure mode.

While testing the load deflection behaviour of control beams at initial stage of loading, the concrete behaves in a linear elastic manner. When the load increases, the extreme fibre stresses in bending increase up to the tensile strength of concrete and the first crack appears in the middle of constant bending moment region. Then several flexural cracks develop with the increasing of load on the beam. The tension steel reinforcement carries the maximum amount of bending moment and at the same time rotation of beams increases further causing increase in steel stress. Due to the stress in steel reaches yield value, the overall stiffness of beam gets reduced. Further, flexural cracks extend vertically upwards with increasing crack width. Then, cracks appear in the support region in inclined direction. The final failure of the beam takes place with increasing in deflection with constant ultimate load.

The crack pattern of control and GPC beams are shown Fig. 4.

i. RCC Beams

ii. GPC Beams

Figure 4. Crack pattern of RCC and GPC beams

There is a reduction in deflection of beams when compared to control beam. This response may be attributed to increase in lever arm due to bonding.

4. RESULTS AND DISCUSSION

The summary of test results is given Table 6. The load deflection curves of RCC and GPC beams are shown in Fig. 5.

Table 6: Summary of Test Results

Beam Code	**Ist Crack Load (kN)**	**Yield Load (kN)**	**Ultimate Load (kN)**	**Max. Deflection (mm)**
CB1	29.5	79.0	84.0	63.0
CB2	32.0	81.5	89.0	67.0
GPC1	28.0	88.0	93.0	56.0
GPC2	31.0	91.5	96.5	61.0

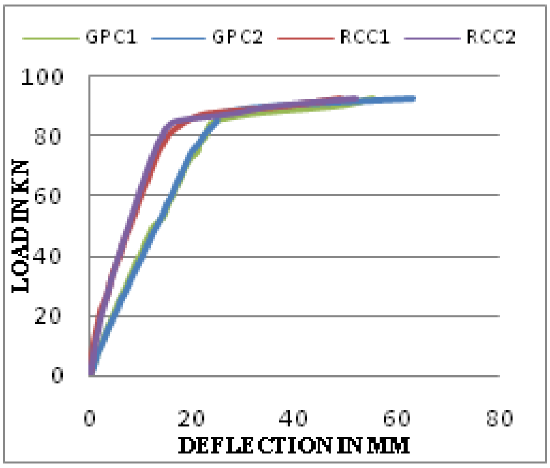

Figure 5. load deflection Curves of Beams

From the test results, it is seen that the GPC beams show marginal increase in load carrying capacity. The comparison of RCC and GPC beams at first crack load, yield load and ultimate load is shown in Figs. 6, 7, & 8.

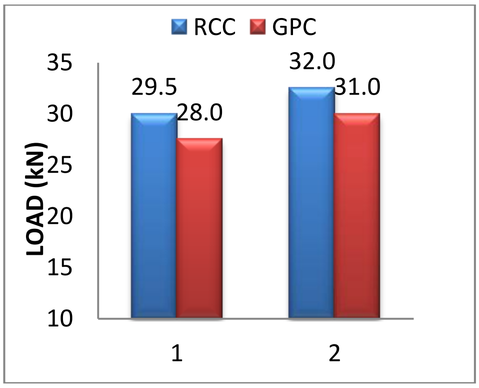

Figure 6. Comparison of RCC and GPC beams at first crack load

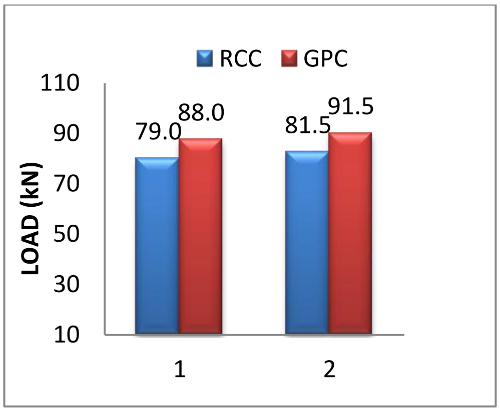

Figure 7. Comparison of RCC and GPC beams at yield load

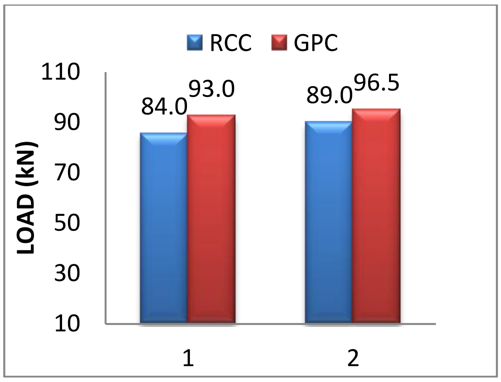

Figure 8. Comparison of RCC and GPC beams at ultimate load

5. CONCLUSION

1. It is observed that the compressive strength of geopolymer concrete is higher than the Portland cement concrete for the sameM60 grade of design mix.
2. The compressive strength increases with the increase of GGBS.
3. After 7 days of ambient temperature curing, the increase in the compressive strength is not significant.
4. The flexural strength of GPC beams is higher than the flexural strength of conventional RC concrete beams.
5. Ambient cured Geopolymer concrete is convenient for practical in situ concrete.

The deflection of GPC beams at working load was calculated and found to be comparable with reinforced cement concrete.

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