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Flexural Behaviour of Potassium Based Geopolymer Concrete

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Abstract: **The global usage of cement occupies the second position next to water. As the development of country and infrastructure, their materials needed get increased. Meanwhile for the development of the infrastructure concrete plays the major role. In concrete the major material or ingredient is ordinary Portland cement (OPC). OPC creates two major problems at the time of production; the emission of CO2 due to calcination of limestone and the usage of extensive amount of energy. On the other hand, fly ash is the material which is emitted from the power plants at the time of electricity production which has similar and superior properties of cement. If fly ash is mixed with any kind of hydroxide and silicate it forms as the binder, which is termed as geopolymer. In this paper we used the Potassium Hydroxide and Potassium Silicate as the combination of the alkaline solution. The present paper presents the study of potassium based geopolymer concrete with paper sludge ash as partial replacement of fly ash for 0%, 5%, 10%, 15% and 20% in geopolymer concrete under various curing conditions such as Hot air Oven curing, Sun light curing and Ambient curing. The Flexural behavior of geopolymer concrete beams, flexural strength test, Load carrying capacity, ductility factor, crack pattern, beam deflection and moment curvature etc., for the geopolymer concrete produced from the Fly Ash and Paper Sludge Ash with Catalytic liquid system and aggregates under various curing conditions such as Hot air Oven curing, Sun light curing and Ambient curing.**

Keywords: Geopolymer, Potassium Hydroxide, Potassium Silicate, Paper sludge ash.

I. INTRODUCTION

Geopolymer is an inorganic polymer. Geopolymers are material based on pure aluminosilicate source materials such as fly ash, GGBS, calcined clays such as metakaolin activated with an alkali hydroxide and silicate solution [1]. Geopolymerisation is an exothermic process involving dissolution – reorientation - solidification reactions. Geopolymers can be produced with various microstructures in relation to Si: Al ratio. A low of Si: Al ratio leads to rigid formation of structures and of high ratio leads to polymeric characters of geopolymer materials.

Geopolymers are considered as tow- component system (reactive based material and alkaline activation solution), they are suitable in precast industries. The manufactures of the products such as larger diameter pipes and roofing tiles, precast concrete products, structural and non-structural members for building systems and bridge structures, railway sleepers, electric power poles, road bases, marine products and other products for infrastructure are possible uses of the geopolymer [2]. Besides these high-tech applications, special geopolymer concrete has been used for repairing runways or motorways because they set and harden quickly and develop the high compressive strength in four hours [3].

Low calcium fly ash based geopolymer concrete resembles in good compressive strength as well as resistance to sulphate attack [4]. Geopolymer concrete does not require any quantity of water for hydration process to held, yet requires only alkaline solution. The solution should reach the maximum of pH value so that the hydration process would be taken in proper way. It was found that geopolymer concrete strength depends upon the factors such as concentration of hydroxide, the silicate to hydroxide ratio, curing time, admixture, handling time and age of concrete.

II. EXPERIMENTAL PROGRAME

A. Materials Used

Fly ash used for geopolymer concrete belongs to Class F (Low calcium based fly ash), which obtained from Mettur Thermal Power station with specific gravity of 1.90. Paper sludge ash was collected from SPB Paper Mill, Pallipalayam with specific gravity of 2.29 Fine aggregates were clean and naturally obtained for the river, with the specific gravity of 2.70. Coarse aggregate were locally obtained with the specific gravity of 2.74

TABLE I CHEMICAL COMPOSITION OF FLY ASH

Component	Fly ash
SiO_2	56.5
Al_2O_3	22.14
Fe_2O_3	4.54
TiO_2	2.26
K_2O	1.07
CaO	0.95
Mgo	0.55
Others	10.52
LOI*	1.47

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TABLE II CHEMICAL COMPOSITION OF PAPER SLUDGE ASH

Components	Paper sludge ash (SPB) %
SiO2+Al2O3+Fe2O3	87.43
SiO2 (Alone)	71.17
MgO	3.84
LOI	-
CaO	7.04

B. Preparation of Alkaline Solution

Potassium hydroxide obtained in pellets form and made to solution and potassium silicate obtained in gel form. Ratio between K_2O/SiO_2 was 2 and the ratio between the potassium silicates to potassium hydroxide was 2.5. Solution was prepared for 16 molarity. Since the mixing of hydroxide with the water is an exothermic reaction which liberates heat out. Water used for making of solution is general tap water. Alkaline solution is prepared prior day before for casting the specimen.

C. Mix Proportion

For Geopolymer concrete it was designed as per trial and error method with the reference of "Low calcium fly ash based geopolymer concrete – B.V. Rangan".

TABLE 3 MIX PROPORTION

Component	Quantity (kg/m^3)
Fly ash	380.68
Fine aggregate	554.4
Coarse aggregate	1293.6
Potassium Hydroxide (KOH)	26.38
Potassium Silicate (K2SiO3)	122.37
Water	22.96
Super plasticizer	7.61

D. Mould Details for Beam

Beam mould of size 2000mmx125mmx250mm confirming to IS10086-1999, were cleaned and assemble to the specified size, then the inner surface were oiled to avoid the adhesion of concrete in moulds and easy removal of specimens.

Fig. 1 Beam Mould

E. Mixing of GPC

The alkaline liquid activator, a combination of potassium hydroxide solution and potassium silicate solution was used .The potassium hydroxide solution was prepared by dissolving the potassium hydroxide pellets in distilled water. All the liquids are mixed together before one day, adding in the aggregates. The aggregates in saturated dry condition and the dry fly ash were mixed together. At the end of this mixing, the alkaline solution was added to the aggregates, and the mixing is continued for specified period of time. It is glossy in nature.

Fig. 2 Mixing of GPC

Fig. 2 Casting of GPC in Beam Mould

F. Curing of GPC

After casting the specimens, they were kept in rest period for five days and then they were remoulded. The term 'Rest Period' was coined to indicate the time taken from the completion of casting of test specimens to the start of curing at an elevated temperature. At the end of the Rest Period geopolymer concrete specimen curing done by varying Curing condition.

Oven Curing: The specimens were kept at 60^{o}C in hot oven curing conditions for 24 hours.

Fig. 4 Oven Curing of GPC Specimens.

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Sunlight curing: In Sunlight curing instead of putting the specimen in oven, the specimen are placed in open sunlight

Fig. 5 Sun light Curing of GPC Specimens

Ambient curing: In ambient curing the specimens are placed in room itself for curing. After the end of curing period the specimens were tested.

Fig. 6 Ambient Curing of GPC Specimens

G. Bond Strength Test

Bond strength between paste and steel reinforcement is of considerable importance. A perfect bond, existing between concrete and steel reinforcement is one of the fundamental assumptions of reinforced concrete. Bond strength arises primarily from the friction and adhesion between concrete and steel. The roughness of the steel surface is also one of the factors affecting bond strength. The bond strength of concrete is a function of compressive strength and is approximately proportional to the compressive strength

H. Flexural strength test for reinforced concrete beam

`To determine the flexural strength of geopolymer concrete and control cement concrete beam moulds of size 2000mmx125mmx250mm were used. The beam moulds were cleaned thoroughly using a waste cloth and properly oiled along its face. The concrete material was mixed in a mixture machine and concrete as then filled in mould and then compacted in using a table vibrator. After curing, all the specimens were white washed in order to facilitate marking of cracks. The specimens were tested for flexural strength of 28 days.

The beams are tested under symmetrical two point loading on over hanging span of 300mm and 1700mm. The beam is placed on one roller and one hinged supports, resting on iron blocks, placed on the wing table of the loading frame. Before resting the beam on iron blocks, the beam was centered by using a plumb bob so that its center lies exactly under the center of the loading head. The beam was simply supported over a span of 1850 mm, which is considered as the effective span. The beam was supported on the iron blocks by a hinged plate at one end and roller plate at the other end. The load is from the fixed cross head of the machine as two point loading, on the one roller, one hinged placed one third from the support apart, by a loading beam of sufficient stiffness. The two point load applied in applicable to the specimen at slow rate till the specimen fails. Flexural cracks were marked on the beam at every load interval.

Flexural strength of beam can be calculated by following formula,

Flexural Strength = Pl / bd^2.

Where,

P = Maximum load in kN applied to the specimen

l = length of the specimen in mm

d = depth measured in cm of the specimen at the point of failure

b = measured width of the specimen in mm

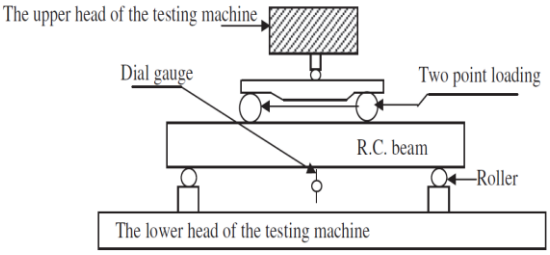

Fig. 7 Pattern of Two point loading.

Fig. 8 Two Point Loading Setup

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III. RESULTS & DISCUSSION.

A. *Load Deflection Curve*

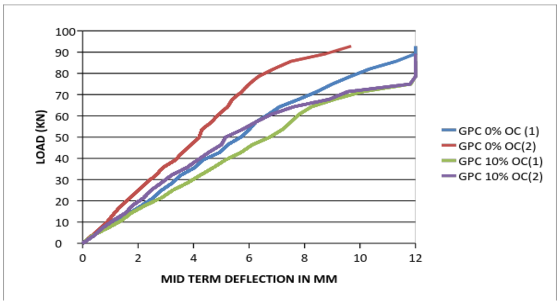

Fig. 9 Load Deflection Curve for Oven Curing Specimens

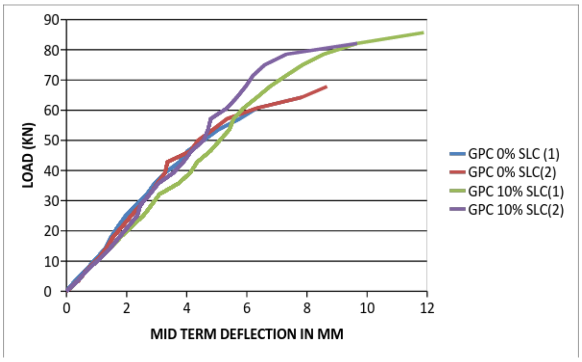

Fig. 10 Load Deflection Curve for Sun light Curing Specimens

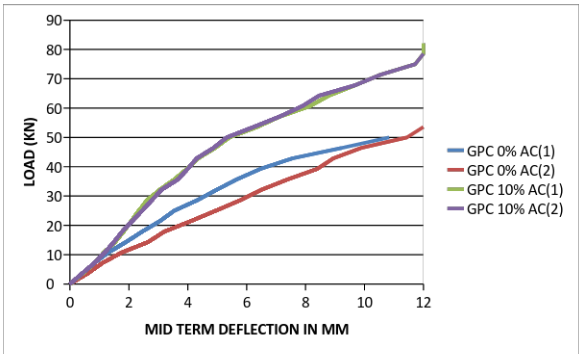

Fig. 11 Load Deflection Curve for Ambient Curing Specimens

B. *Moment Curvature Relationship*

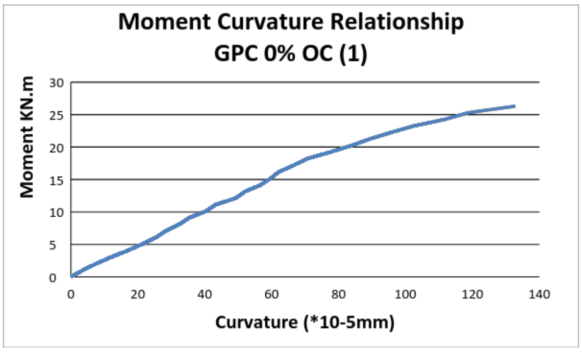

Fig. 12 Moment Curvature for GPC 0% Oven Curing.

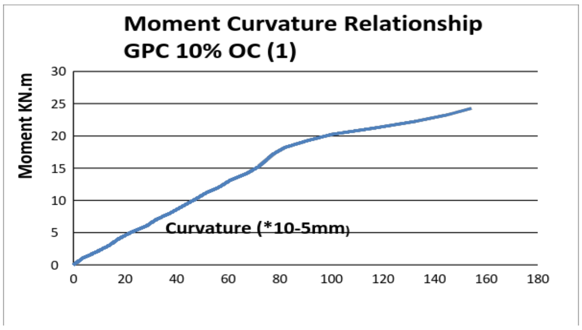

Fig. 13 Moment Curvature for GPC 10% Oven Curing

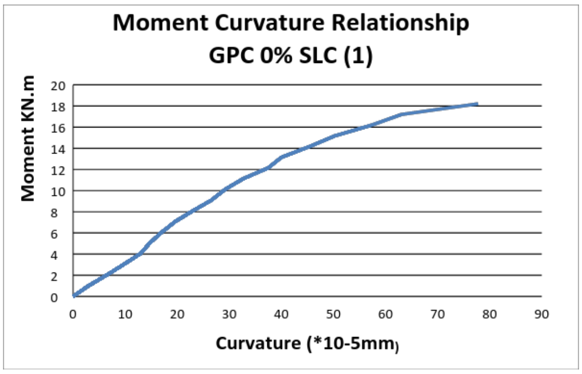

Fig. 14 Moment Curvature for GPC 0% Sun Light Curing

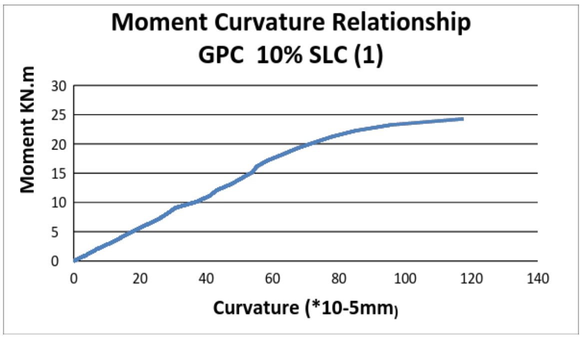

Fig. 15 Moment Curvature for GPC 10% Sun Light Curing

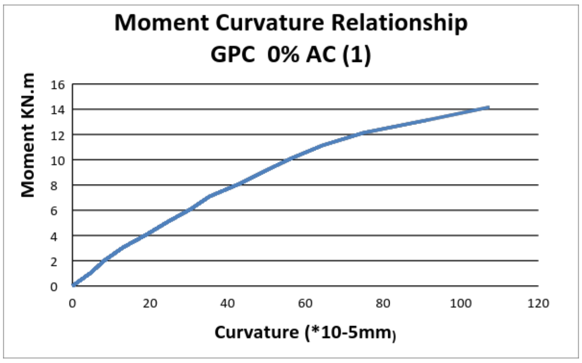

Fig. 16 Moment Curvature for GPC 0% Ambient Curing

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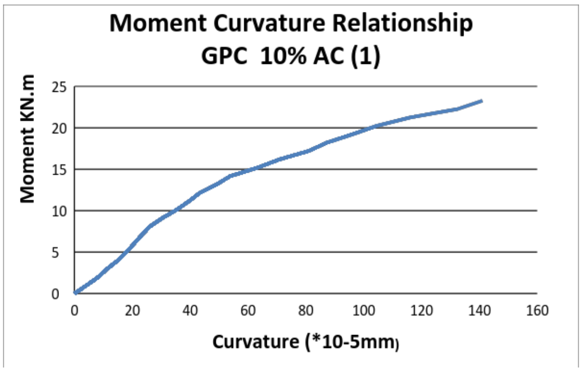

Fig. 17 Moment Curvature for GPC 10% Ambient Curing

C. *Crack Pattern*

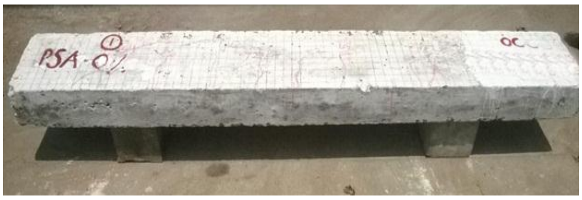

Fig. 18 Crack Pattern of GPC 0 % Oven Cured Specimen.

Fig. 19 Crack Pattern of GPC 10 % Oven Cured Specimen.

Fig. 20 Crack Pattern of GPC 0 % Sun Light Cured Specimen.

Fig. 21 Crack Pattern of GPC 10 % Sun Light Cured Specimen.

Fig. 22 Crack Pattern of GPC 0 % Ambient Cured Specimen.

Fig. 23 Crack Pattern of GPC 10 % Ambient Cured Specimen.

IV. CONCLUSION

The significant conclusions drawn from the study are given below.

1. As a new material to the Geopolymer concrete the paper sludge ash can be used as a replacement material to flyash and cement.
2. Bond strength test results were conducted on cylindrical specimens of size 100mm diameter x 200mm height. From the Results we can see that the increase in percentage of paper sludge ash 10% increases the bond strength and then it will be decreased. The maximum value of bond strength is 8.65 N/mm2 in hot air oven curing.
3. From the flexural behavior of GPC beam, among three different curing condition viz. Hot air oven curing, Sunlight curing and ambient curing, the 100% FA based GPC produce higher flexural strength of 24.97 N/mm2 under hot air oven curing compare to other
4. On adding 10% PSA into the FA based GPC beam, the flexural strength is more or less same among three different curing condition in the following order HAOC >SLC >AC
5. By using PSA into FA based GPC the concrete can be cured even under ambient temperature which produce flexural strength of 22.08 N/mm2 (than greater than ambient cured FA based GPC beam).
6. From the structural behavior of beam study of geopolymer concrete with PSA (10%), it was concluded that the FA based geopolymer concrete with PSA can be used for manufacturing structural member. Successful Commercial productions of precast geopolymer units such as Box culverts, sewer pipe lines were available.
7. The failure pattern of all the beam specimens was found to be similar. At early load stages, flexural cracks appeared in the center portion of the beam, and gradually spread towards the supports. As the load increased existing cracks propagated and new cracks developed along the span. The failure occurred by the crushing of concrete in the compression zone, notably beneath and adjacent to the loading plates. Concrete spalling at the compression zone was observed after the ultimate load.
8. From the bond strength, flexural strength behavior of FA based GPC and PSA&FA based GPC member, finally it is recommended to use the sunlight temperature and ambient temperature cured PSA&FA based GPC members on considering economic factors.
9. Even though the cost of fly ash, paper sludge ash based geopolymer concrete production in the lab is high, the large scale industrial commercial products will reduce the cost considerably.

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