

Study on the Mechanical Properties of High Strength Geopolymer Concrete

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ABSTRACT: Finding means of utilizing industrial by-products has assumed importance in the field of research, of late. Efforts are already underway all over the world, to develop environment friendly construction materials, which help in reducing greenhouse gas emissions from cement industry. In this context, Geopolymer concrete (GPC) is a new class of building material that has emerged as an alternative to Ordinary Portland Cement (OPC) concrete and has got the potential to revolutionize the building construction industry. Researchers have critically examined the various aspects of its viability as binder system. GPC is produced from fly ash mixed with alkaline activators of Sodium Hydroxide and Sodium Silicate solutions of specific molar concentration. High range water reducing admixtures are used for developing sufficient workability. The objective of the present work is, to study the effect of Supplementary Cementitious Materials (SCM) in fly ash based Geopolymer concrete, at room temperature curing. The present work deals with the development of Ground Granulated Blast Furnace Slag (GGBS) based GPC. Trial mixes were carried out and results were compared with the nominal mix. Workability properties of fresh concrete were measured and mechanical properties were assessed for 7 and 28 days. Flexural strength properties were assessed for the Reinforced GPC and OPC concrete beams. Beams were designed considering a balanced section for the expected characteristic strength.

KEYWORDS: Geopolymer concrete (GPC), Ordinary Portland Cement (OPC), GGBS, Alkaline activators, Beams.

I. INTRODUCTION

Cement is the second most consumed product in the world. Around 5-8% of the world's man made greenhouse gas emissions are from the cement industry. On the other hand, the demand for concrete is increasing day by day because of its ease of preparation and fabrication into all sorts of convenient shapes. To overcome this problem, environment friendly concrete has to be utilized by replacing the cement with industrial by-products which are dumped on open lands leads to pollution. Geopolymer Concrete is a relatively new cement free concrete material and plays an important role in the context of sustainability and viable solution for all environment issues. In 1978, Davidovits termed the word Geopolymer. The Geopolymer or alkali activated cement describes an inorganic, Polymeric Silicon-Oxygen-Aluminium frame work structure, similar to zeolites, but without crystal structure. A wide range of materials are being used for geopolymerisation, the source material rich in Si (fly ash, slag and rice husk) and Al (clays like Kaolin, Bentonite and burned clays) reacts with a highly alkaline solution, to produce binding material. The polymerization process involves a substantially fast chemical reaction under highly alkaline conditions on the Si-Al minerals that result in three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. Several previous studies have reported the performance of Geopolymer materials cured at high temperatures. These studies

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indicate that the heat cured fly ash based Geopolymer concrete developed high tensile and compressive strengths and low effective porosity, which are beneficial for the concrete used in an aggressive environment. Heat cured fly ash based Geopolymer concrete, showed better resistance to sea water environment than the OPC concrete of similar compressive strength. The development of Geopolymer without curing at increased heat will widen its application. Hence, an attempt has been made here, to use the GGBS, rather than flyash as the source material. A comparison between OPC and GGBS based GPC specimens are carried out. As an extension, flexural behaviour of Reinforced OPC concrete and GGBS based GPC beams are studied for 7 and 28 days strength.

II. LITERATURE REVIEW

Maneeshkumar C S et al.(2015) The necessity of heat curing of concrete was eliminated by incorporating GGBS and fly ash in a concrete mix. The strength of Geopolymer concrete increased with increase in percentage of GGBS in a mix and gave maximum compressive strength of 74.67Mpa. GGBS and Fly ash-based Geopolymer concrete has excellent compressive strength and is suitable for structural applications.[1]

Mr. Ahmed Mohmed Ahmed BlashDr. T.V. S. VaraLakshmi(2016)The incorporation of GGBS in the Geopolymer concrete mixes resulted in finer pore structure thus producing low permeability concrete for longer curing durations . It was also observed that high performance concrete may be used in terms of high strength and durability and is significant to special structures such as marine structures..[2]

Mathew Sudhakar and Natarajan [2010] Coal Ash and GGBS Combination is taken along with 15M Alkaline Solution and total replacement of about 30% is taken into consideration and Higher compressive strength up to 57Mpa is obtained .However, the Cost of GGBS added Geopolymer is 7% Higher than the OPC but when we consider strength aspect, it is almost 3 times that of OPC at 7 days.[3]

Mr. Gautam L et.al(2015) A successful development of fly ash based and fly ash and GGBS based Geopolymer concretes with low Molarity is achieved. Twenty different mixes using NaOH solutions of Molarities 3, 4, 5 and 6 were selected. The W/B ratio is observed to have a significant effect on the strength realized.[4]

P. Chindaprasirt et.al (2011) They studied the synthesis of high-strength Geopolymer using fine high-Calcium fly ash. The results indicate that the setting time of paste, decreases with an increase in fly-ash fineness. The flow strength, and drying-shrinkage characteristics of mortars improved using fine fly ash. Geopolymer mortars with high 28-day compressive strength of 86.0 MPa were obtained. [5]

Partha, Prabir and Pradip [2014] investigated that when the GGBS was added in the range of 0 - 20% of total binder, significant increase in strength and some decrease in workability was observed in Geopolymer concrete. The addition of GGBFS enhanced the setting of concrete at ambient temperature. The effect of mixture variables on the development of tensile strength was similar to that on the development of compressive strength. [6]

Sunil Kumar.R, Dr V.Ramesh(2015) 18 types of mixes of Geopolymer Concrete were prepared for three different water to Geopolymer solids, for two different binder proportions of 375 kg/m³ and 420 kg/m³ by keeping the Molarities constant (alkali solution 8M), optimum f_{ck} was selected to cast the plain Geo polymer concrete beam specimen and cylinders. As reported 35% GGBS (65% fly ash), in the total binder content resulted in the early strength development of geo polymer concrete under SUN DRYING which showed better strength properties.[7]

V Supraja, M. Kanta Rao (2012) in this paper an attempt was made to produce the Geopolymer concrete, fully replaced with GGBS and alkaline liquids which were used as binding materials. Different molarities of Sodium Hydroxide solution i.e. 3M, 5M, and 7M and 9M was taken to prepare different mixes. Two different curing were carried out i.e. oven curing at 50⁰c and curing directly by placing the specimens under direct sunlight. Authors observed that the compressive strength increased with an increase in the molarity of Sodium Hydroxide and sun light curing is convenient for practical conditions.[8]

V. Eswaraiah, G. NageshKumar(2014) carried out analysis and design of recorn 3s- polypropylene fibers in GPC under hot air oven curing temperature of 60⁰C for 24 hours. They observed less shrinkage and water absorption property when compared with ordinary Portland concrete.

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III. MATERIALS

GGBS

Ground Granulated Blast Furnace Slag is a by-product from blast furnaces, used to make Iron. Blast furnaces are fed with controlled mixture of iron ore, coke and lime stone and operated at a temperature of about 1500°C. When iron ore, coke and lime stone melt in the blast furnace, two products are produced i.e., molten iron and molten slag. The molten slag comprises mostly Silicates and Alumina from the original iron ore, combined with some oxides from lime stone. Using high pressure water jets, this rapidly quenches the slag and forms granular particles, generally not bigger than 5 mm in size. The rapid cooling prevents the formation of larger crystals and the resulting granular material comprises of around 95% non-crystalline Calcium Alumino Silicates. The granulated slag is further processed by drying and then grinding in a vertical roller mill or rotating ball mill into very fine powder, GGBS. The physical properties and the chemical composition of GGBS used in the present work are given in tables 1(a) and 1(b) respectively.

TABLE 1(a): PHYSICAL PROPERTIES OF GGBS USED

Property	GGBS
Specific Gravity	2.8
Fineness(m ² /kg)	350 to 450
Appearance/ Colour	Light yellow
Structure	Glassy

TABLE 2(b): CHEMICAL COMPOSITION OF GGBS USED

Compound	GGBS(obtained from JSW cements)
CaO	37.34%
Al ₂ O ₃	14.42%
Fe ₂ O ₃	1.11%
SiO ₂	37.73%
Magnesium Oxide (MgO)	8.71%
Manganese Oxide (MnO)	0.02%
Sulphide Sulphur	0.39%

Alkaline Liquids: In the present work, Sodium Hydroxide solution (NaOH) and Sodium Silicate solution (Na₂SiO₃) are used as alkaline activators. Sodium Hydroxide solution is prepared by dissolving pellets in deionised water. Excessive heat is evolved during mixing of pellets in water, and to avoid this solution is prepared one day in advance. Sodium Silicate is known as liquid glass or water glass, and is available in liquid (gel) form. The chemical composition and physical properties of Sodium Silicate and Sodium Hydroxide solutions are tabulated below in table 2.

TABLE 2: PHYSICAL PROPERTIES OF SODIUM SILICATE AND SODIUM HYDROXIDE SOLUTION

Property ↓	Material →	Sodium Silicate	Sodium Hydroxide solution
Colour		Light yellow	White
Appearance		Liquid (Gel)	Pellets
Molecular Weight		122.06 g/mole	39.99 g/mole
Specific Gravity		1.7	1.3

Aggregates:

The locally available river sand of Zone II and crushed granite of medium size 20 mm and 12.5 mm was used as fine aggregate and coarse aggregate in the present investigation. The properties of aggregates are given in following tables. The sieve analysis of fine aggregates is given in table 4 and coarse aggregates in table 5 and 6.

TABLE 3: MATERIAL PROPERTIES OF AGGREGATES

Property ↓	Material →	Fine Aggregates	Coarse Aggregates	
			20 mm	12.5 mm
Specific gravity		2.68	2.79	2.81
Bulk density(kg/m ³)		1452.91	1343.98	1230.8

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TABLE 4: SIEVE ANALYSIS OF FINE AGGREGATE

IS Sieve Size	Weight Retained (g)	% Retained	Cumulative Percentage Retained	Cumulative Percentage Passing
4.75 mm	37	3.7	3.7	96.3
2.36 mm	27	2.7	6.4	93.6
1.18 mm	208	20.8	27.2	72.8
600 micron	458	45.8	73.0	27.0
300 micron	243	24.3	97.3	2.7
150 micron	19	1.9	99.2	0.8
Lower than 150 micron	2	0.2	99.4	0.6

TABLE 5: SIEVE ANALYSIS OF COARSE AGGREGATES OF SIZE 20 mm

IS Sieve Size (mm)	Weight Retained (g)	% Retained	Cumulative Percentage Retained	Cumulative Percentage Passing
40	0	0	0	100
20	44	0.44	0.44	99.56
10	3174	31.74	32.18	67.82
4.75	6689	66.89	99.07	0.93
Pan	55	0.55	99.62	0.38

TABLE 6: SIEVE ANALYSIS OF COARSE AGGREGATES OF SIZE 12.5 mm

IS Sieve Size (mm)	Weight Retained (g)	% Retained	Cumulative Percentage Retained	Cumulative Percentage Passing
16	0	0	0	100
12.5	70	2.33	2.33	97.6
10	1705.1	56.83	59.16	40.84
4.75	1223.5	40.78	99.94	0.06
2.30	1.4	0.046	99.986	0.014
Pan	0	0	0	0

Water:

Distilled water for GPC and potable water for normal concrete which are free from chemicals and organic materials were used for this investigation

Cement:

Ordinary Portland cement 53 grade conforming to Indian Standard is used, in the present study with a Specific Gravity of 3.12.

Super plasticizer –Structro 202:

In the present investigation, a High Range Water Reducing (HWRA) admixture named Structro 202, has been used.

IV. EXPERIMENTAL PROGRAMME

A. MIX DESIGN OF GEOPOLYMER CONCRETE

In the design of Geopolymer design mix, the total aggregate is taken as 75% of the entire concrete mix, by mass. Fine aggregate was taken as 25% of total aggregates. The average density of Geopolymer concrete is similar to that of OPC concrete (2400kg/m^3). The combined mass of alkaline liquid and GGBS are known by the density of Concrete. The addition of sodium silicate is to enhance the process of geopolymerisation. For the present investigation, concentration of Sodium Hydroxide was taken as 5M and alkaline sodium ratio as 0.5. The mix proportions are given in table 7.

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TABLE 7: MIX PROPORTIONS OF GEOPOLYMER CONCRETE

Designation of Mix	Mix1
Coarse Aggregate kg/m ³	900
Fine Aggregate kg/m ³	805
GGBS kg/m ³	350
Sodium Hydroxide kg/m ³	132
Sodium Silicate Solution kg/m ³	132
Alkaline Solution Ratio	0.5
Water / Binder Ratio	0.59
Molarity	5M

B. MIX DESIGN OF CEMENT CONCRETE

The mix design was done as per the ACI code. M60 grade of Concrete was adopted for the study. The water cement ratio adopted for the concrete mix is 0.29. The mix proportions are given in table 8.

TABLE 8: MIX PROPORTIONS OF CEMENT CONCRETE

Designation of Mix	Mix2
Coarse Aggregate kg/m ³	1038
Fine Aggregate kg/m ³	711
Cement kg/m ³	542
Water Cement Ratio	0.29
Silica Fume kg/m ³	37.94
Super Plasticizer (litres) kg/m ³	4.336

C. MECHANICAL PROPERTIES OF MIX 1 AND MIX2

Three cubes of size 150mm x150mm x150 mm have been tested for compressive strength using the Compression Testing Machine (CTM). Three cylinders of size 150mm x300mm were cast and were tested for Split Tensile Strength.

Mechanical Property	Mix 1		Mix 2	
	7 days	28 days	7 days	28 days
Compressive Strength(N/mm ²)	73	83.5	60.9	72.1
Split Tensile Strength(Nmm ²)	4.1	5.213	3.71	4.23

D. SPECIMEN DETAILS OF BEAMS

Four numbers of Vibrated Reinforced Cement Concrete (VRCC) beams and Geopolymer Reinforced Concrete (GRPC) were casted and tested. The total length of the beam cast was 1150 mm and cross section dimensions were 100 mm X 150 mm. Beams were simply supported over the span of 1000 mm. The clear cover to reinforcement was kept as 25mm, and reinforcement details of the specimen tested are given in the figure1. The specimens were tested at ages of 7 and 28 days from the date of casting,

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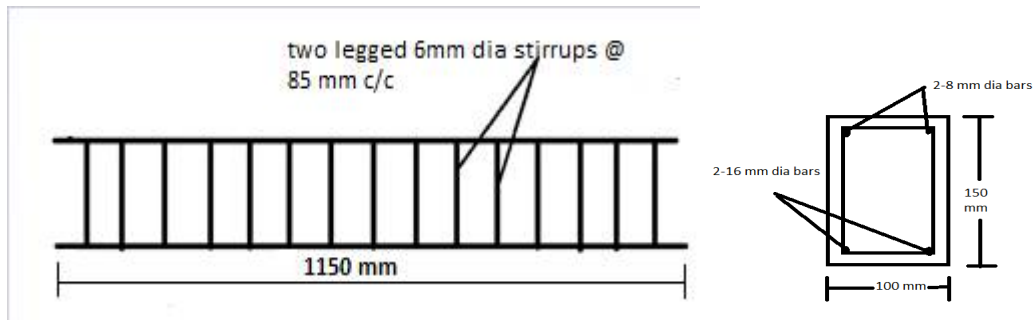


Figure1: Beam specimens reinforcement details

E. PREPARATION OF BEAM SPECIMENS

Prior to casting, the inner walls of moulds were coated with lubricated oil to prevent adhesion with the hardening concrete. Both VRCC and GRPC were mixed in a pan mixing machine for about 6-8 mins. Concrete was placed in a mould, in equal thickness of three layers and each layer was vibrated using the needle vibrating machine, until concrete was thoroughly compacted. The steel bars as per the design were placed over the 25mm core blocks. The VRCC beams were water cured for a period of 28 days while the GRPC beams were cured at room temperature in the laboratory, for a period of 28 days, after casting. The specimens were then tested after the curing period.

F. TEST PROCEDURE

The testing was carried out in a computerized UTM of 100 tones capacity. The beam was simply supported over a span of 1000mm. The load considered on the beam was 2 point static loading under load control mode. Dial gauges were fixed at mid span and at a distance of 280 mm and 720 mm from the supports, for measuring deflections. The load was applied gradually. In increments of 5kN, the deflections were measured and the behaviour of the beam was observed carefully by noting the cracks developed using a marker pen gradually. The test set up was shown in figure 2 and cracks distribution at failure load is shown in figure 3 respectively.



Figure 2: Beam Under Loading Condition



Figure 3: Crack Distribution At Failure Load.

G. RESULTS AND DISCUSSION

Cube specimens were tested for Compressive Strength and cylinders for Split Tensile Strength. The beam specimens showed a deflection when tested under two point static loading until failure. The flexural cracks were developed along the span of the beam as the load increased. In general, the beam specimens will fail due to yielding of tensile steel but in the present investigation, the design of beams is undertaken as over reinforced, hence it is observed that failure of

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concrete in compression zone (Shear compression) would fail rather than yielding of tensile steel at the failure load. As the loads increases cracks got propagated and new cracks developed, along the span. The numbers of flexural cracks developed are more for the VRCC beams than the GRPC beams.

Table 9: Test Results

Age of the Specimen in days	Mix ID	First Crack Load(kN)	Ultimate Load(kN)
7	GRPC1	25	89.95
	GRPC2	27	87.7
	VRCC1	31	115.5
	VRCC2	27	105.95
28	GRPC1	29.8	107.8
	GRPC2	27.95	103.9
	VRCC1	31.5	127.1
	VRCC2	31	124.3

H. LOAD DEFLECTION CHARACTERISTICS

The experimental load deflection curves of VRCC beams and GRPC beams are shown in figure 4, 5 and 6 for 7 days and in figures 7, 8 and 9 for 28 days are shown respectively. The ultimate load of the concrete specimens increased the deflections, also showed an increasing trend in the case of VRCC whereas, in the case of GRPC the deflections were on the lower side than those of VRCC.

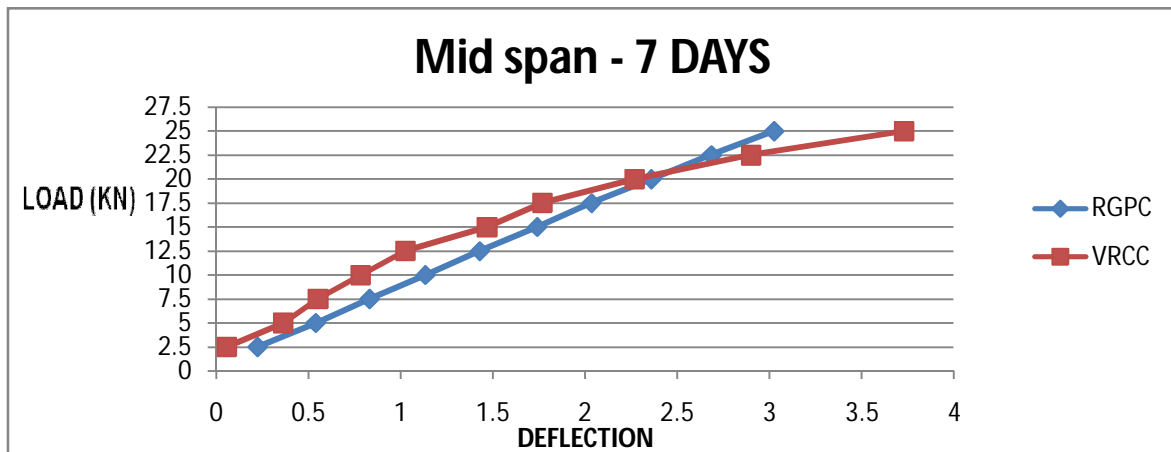


Figure 4: Load Deflection Curves At 7 Days @Mid Span

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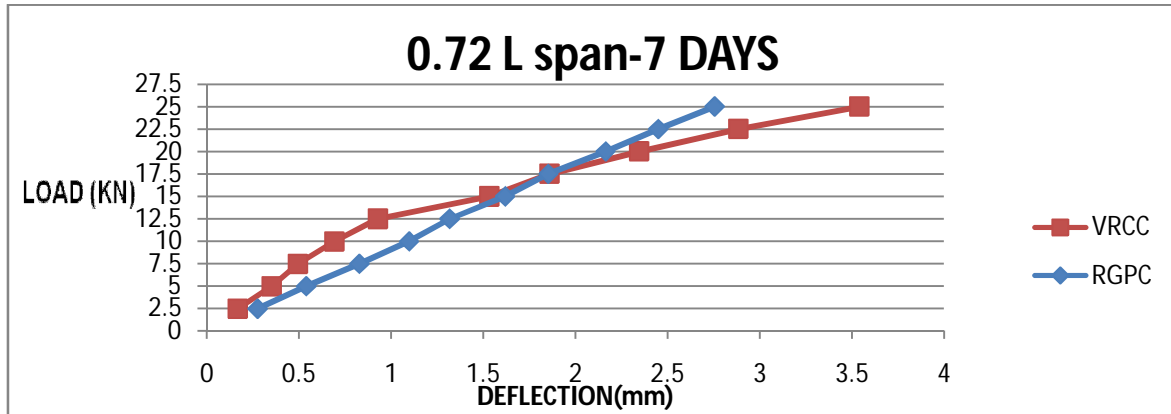


Figure 5: Load Deflection Curves At 7 Days @ 0.72 L

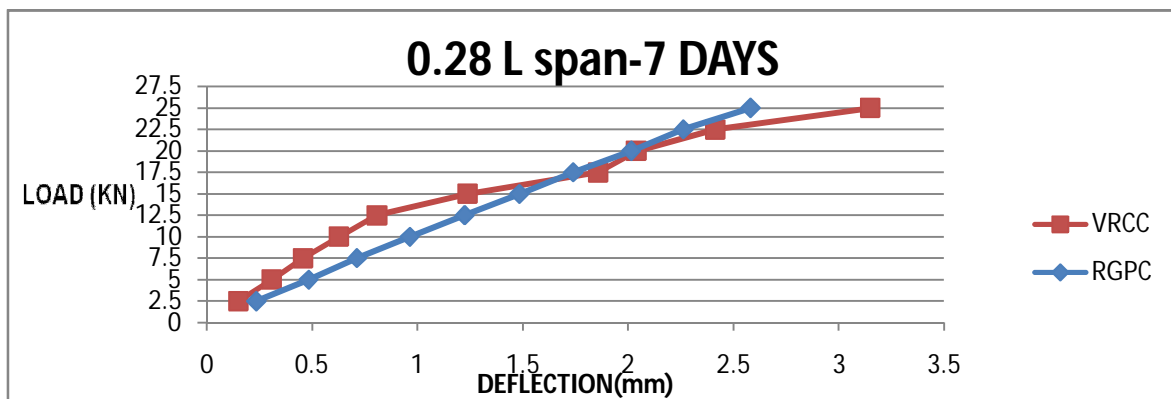


Figure 6: Load Deflection Curves At 7 Days @ 0.28 L

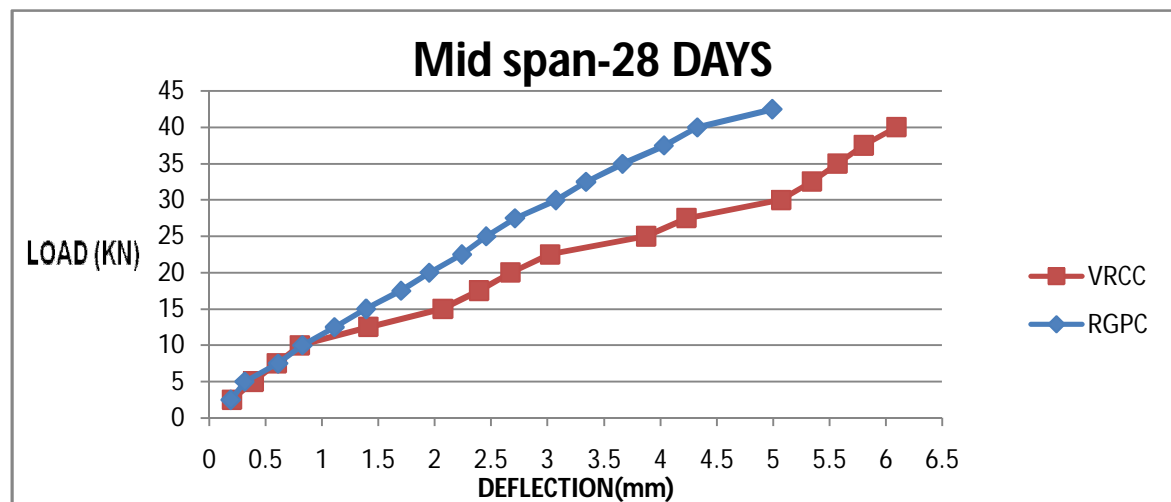


Figure 7: Load Deflection Curves At 28 Days @ Mid Span

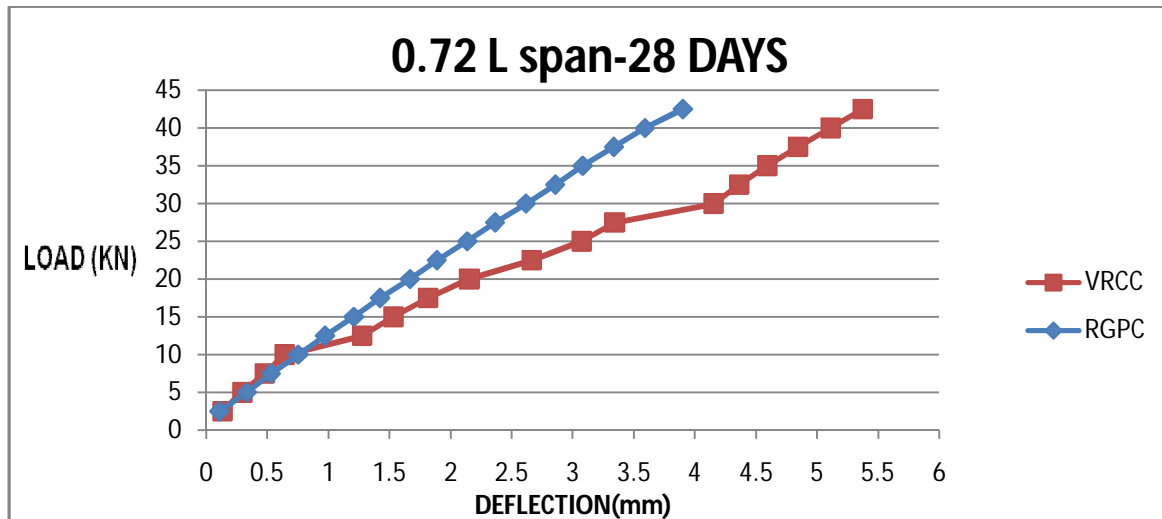


Figure 8: Load Deflection Curves At 28 Days @0.72 L

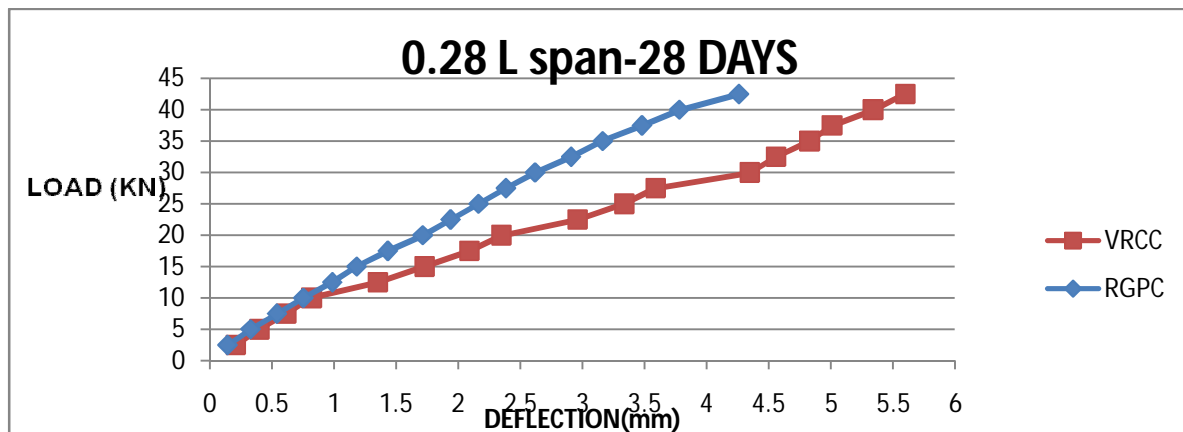


Figure 9: Load Deflection Curves At 28 Days @ 0.28l

I. FAILURE MODE:

The failure pattern of beam specimens was found to be similar for both VRCC and GRPC Beams. The crack patterns are similar for both the beam specimens. In the present investigation, due to the over reinforced section, compression failure (cracking of concrete) occurred before the yielding of steel.

V.CONCLUSIONS

- Use of Geopolymer concrete (GPC) in Civil Engineering construction helps reduce the environmental pollution. Hence GPC can be considered an eco friendly material.
- Workability characteristics of GPC depend on mixing time of GPC that is workability of GPC is directly proportional to the mixing time.
- To check the suitability of GPC in cast-in-situ conditions, specimens are cured at room temperature, which gave good results.
- When compared with plain GPC and OPC concrete, Compressive Strength and Split Tensile Strengths at 7 days and 28 days are higher in GPC.

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- From the load vs deflection graphs, it is observed that deflections are smaller in GRPC when compared with VRCC beams.
- Diagonal cracks in flexure and shear are observed to be smaller in magnitude in the GRPC beam, when compared to VRCC beam.
- Beams are observed to fail initially by crushing of concrete in the compression zone as the section is an over reinforced.

REFERENCES

1. Maneeshkumar C S et al. "An Experimental Investigation on GGBS and Flyash Based Geopolymer Concrete with Replacement of Sand by Quarry Dust". Int. Journal of Engineering Research and Applications www.ijera.com ISSN : 2248-9622, Vol. 5, Issue 5, (Part -1) May 2015, pp.91-95
2. Mr. Ahmed Mohamed Ahmed Blash "Studies on the Physical Properties of Ground Granulated Blast- Furnace Slag Incorporating in Geopolymer Concrete" International Journal of Engineering Research & Technology (IJERT)ISSN: 2278-0181 Vol. 5 Issue 02, February-2016
3. Mr. Bennet Jose Mathew, Mr. M Sudhakar, Dr. C Natarajan. "Strength, Economic and Sustainability Characteristics of Coal Ash –GGBS Based Geopolymer Concrete", International Journal Of Computational Engineering Research (ijceronline),ISSN 2250-3005 Vol. 3 Issue. 1,page 207-212.
4. Mr. Gautam L et.al " Development of High Strength Geopolymer Concrete using Low Molarity NaOH"International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 www.ijert.org IJERTV4IS070243 Vol. 4 Issue 07, July-2015
5. P. Chindaprasirt, T. Chareerat, S. Hatanaka, and T. Cao "High-Strength Geopolymer Using Fine High-Calcium Fly Ash"Journal of Materials in Civil Engineering, Vol. 23, No. 3, March 1, 2011. ©ASCE, ISSN 0899-1561/2011/3-264–270.
6. ParthaSarathiDeb,PradipNath, Prabirkumarsarker, "The Effects of GGBFS Blending with Flyash and Activator Content on the Workability and Strength Properties of Geopolymer Concrete Cured at Ambient Temperature ", Elsevier, Material and design,62(2014),page 32-39
7. Sunil Kumar.R, DrV.Ramesh "Study On Behaviour Of GeoPolymer Concrete" : International Journal Of Civil And Structural Engineering Research Issn 2348-7607 (Online) Vol. 3, Issue 1, Pp: (384-388), Month: April 2015 - September 2015,
8. V.supraja , M.kantarao , "Experimental Study on Geopolymer Concrete Incorporating GGBS", International Journal of Electronics, Communications and Self Computing Science and Engineering (IJCSCSE), 2012 , ISSN : 2277-9477, Page 11-15
9. V. Eswaraiah, G. Nagesh Kumar "Fibre Reinforced Eco Concrete"International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064.August 2014.
10. IS 456:2000 Plain and Reinforced Concrete - Code of practice
11. IS 10262-2009 –Concrete Mix Design- Code of practice

BIOGRAPHY



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