STUDY ON MECHANICAL AND STRUCTURAL PROPERTIES OF GEOPOLYMER CONCRETE MADE WITH RECYCLED AGGREGATES

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Abstract - *This paper presents the study on Mechanical and Structural properties of Geopolymer concrete prepared by using recycled materials as coarse aggregate. The strength properties include Compressive strength, Split tensile strength and Flexural strength. The structural properties deals with the study of first crack, ultimate load, load deflection behaviour and failure mode. RGPC Geopolymer concrete beam size 100x150x1800mm was cast. Totally 6 beams were cast for different properties of Fly ash and GGBS with recycled coarse aggregate. The test results revealed that compared to control Geopolymer concrete, recycled aggregate replaced Geopolymer concrete exhibiting better results in both mechanical and structural properties.*

***Key Words*: GPCS, Alkaline solution, Fly ash, GGBS, Recycled coarse aggregates.**

1. INTRODUCTION

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2. RESEARCH SIGNIFICANCE

The significance of the present investigation is to study the performance of GPC with RCA. Totally 9 beam specimens were cast to find the flexural behaviour, ductility and stiffness. The specimens were cured in ambient condition. The structural parameters such as load deflection behaviour, first crack load, ultimate load were investigated. Hence, the investigations on behavior of RGPC incorporated with recycled coarse aggregates were undertaken. Different mixes with partial replacement of recycled coarse aggregates in GPC and OPC were designed as per IS code, prepared ant tested for comparison of performances such as load carrying capacity, moments and deflection at different stages were studied. Crack widths for all the specimens were measured. This paper compares the performance of reinforced Geopolymer concrete beams with reinforced cement concrete beams when replaced with recycled coarse aggregates.

3. MATERIALS

3.1. Cement

Ordinary Portland cement, 53 Grade conforming to IS: 12269-1987.with specific gravity of 3.1.

3.2. Fly ash

Fly ash used in this study was obtained from National Thermal Power Corporation, and the specific gravity of fly ash is 2.14.

3.3. Ground granulated blast furnace slag

Ground granulated blast furnace slag (GGBS) is a by-product from the blast-furnaces used to make iron. GGBS is a glassy, granular, non-metallic material consisting essentially of silicates and aluminates of calcium and other bases. The specific gravity of GGBS is 2.9.

3.4. Fine Aggregates

Locally available river sand conforming to Grading Zone III of IS: 383- 1970 with specific gravity 2.7 and fineness modulus 2.96 as fine aggregate (FA). The properties of the aggregates and sieve analysis results are given in Table 1 and 2.

Table 1: Properties of fine aggregates

Name of test	Test Results
Specific gravity	2.6
Water Absorption (%)	1.15
Bulk Density (kg/m3)	1678

Table 2: Sieve Analysis of fine aggregates

IS Sieve Size	Weight retained (gms)	Percentage retained	Cumulative percentage retained	Cumulative percentage passing
4.75mm	15	1.5	1.5	98.5
2.36mm	45	4.5	6	94,0
1.18mm	195	19.5	25.5	74.5
600 micron	195	19.5	45	55
300 micron	385	38.5	83.5	16.5
150 micron	135	13.5	97	3
Lower than 150 micron	30	3	3	0

3.5. Coarse Aggregates

Crushed blue granite stones aggregate of maximum size of 20 mm and graded as per IS: 383-1970 with specific gravity 2.70 and fineness modulus 6.69 as coarse aggregate (CA).

Table 3: Properties of coarse aggregates

Name of test	Test Results
	Natural aggregates
	20mm
Specific gravity	2.79
Water Absorption (%)	0.5
Bulk Density (kg/m^3)	1636
Percentage Voids (%)	0.41
Crushing value (%)	----
Impact value (%)	28.7

3.6. Recycled coarse Aggregates

Recycled aggregates obtained from demolished building of having age 8 years were used. Various properties of coarse aggregates are given in table 3. The results of sieve analysis are given in Table 4 and 5.

Table 4: Properties of Recycled coarse aggregates

Name of test	Test Results Recycled Aggregates
Specific gravity	2.75
Water Absorption (%)	1.5
Bulk Density (kg/m^3)	1548.6
Percentage Voids (%)	0.43
Crushing value (%)	----
Impact value (%)	30.5

Table 5: Sieve Analysis of Coarse aggregates

IS Sieve Size	Weight retained (gms)	Percentage retained	Cumulative percentage retained	Cumulative percentage passing
40mm	0	0	0	100
20mm	90	3.0	3.0	97
10mm	2885	96.16	99.16	0.84
4.75mm	25	0.833	99.993	0.007
pan	0	0	100	0

3.7. Alkaline activator

The alkaline activator liquid used was a combination of sodium silicate solution and sodium hydroxide. An analytical grade sodium hydroxide in Flakes form (NaOH with 98% purity) was used. To avoid effects of unknown contaminants in laboratory tap water, distilled water was used for preparing activating solutions. The activator solution was prepared at least one day prior to its use in specimen casting.

3.8. Water

Portable water was used for mixing and curing of specimens.

3.9. Alkaline liquids

Alkaline activator for the present work is prepared using commercially available sodium silicate liquid and sodium hydroxide pallets. The alkaline solution is prepared with NaOH molar concentration varying from 8 to 16; the mass ratio of sodium silicate to sodium hydroxide varied from 1.75 to 3.0; and the mass ratio of alkaline liquid to fly-ash also varied from 0.25 to 0.40. Water to geo-polymer solid ratio by mass is maintained constant as 0.2559 throughout investigation. The sodium hydroxide solution was prepared 24 hours prior to use as it terminates to semi solid liquid state after 36 hours. The sodium hydroxide (NaOH) solution was prepared by dissolving the pellets in distilled water.

3.10. Super plasticizer

To achieve workability of fresh Geopolymer concrete composites, Sulphonated naphthalene polymer based super plasticizer Conplast SP430 in the form of a brown liquid instantly dispersible in water, was used in all the mixtures.

4. DETAILS OF EXPERIMENTS

4.1. Mix design of Geopolymer concrete

As there are no standard codal provisions for the mix design of geo polymer concrete, the design mix can be arrived by assuming the density of geo polymer concrete as 2400 kg/m^3. The total volume occupied by fine and coarse aggregate is around 77-80%.

1. Coarse aggregate 77%
2. The alkaline liquid to fly ash ratio is kept as 0.4.
3. 10 Molarity
4. The ratio of sodium silicate to sodium hydroxide is kept as 2.5.
5. Extra water 20% of cementitious material.

6. Super Plasticizer 3% of cementitious material.

Table 6 Mix proportions for Geopolymer concrete

Fly Ash (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	NaOH (kg/m^3)	Na_2SiO_2 (kg/m^3)	Water (kg/m^3)	SP (kg/m^3)
394.3	554.4	1293.4	45.1	112.6	59.14	11.83

4.2. Mix design of Cement concrete

The mix design was done as per IS: 10262 (2009). The grade of concrete adopted for this study is M20. Maximum size of aggregate taken is 20mm. The water - cement ratio adopted for concrete mix was 0.45.

Table 7: Mix Proportions of Geopolymer concrete

Mix ID	Coarse Aggregate (Kg/m3)	Recycled Coarse aggregates Kg/m3	Fine Aggregate (Kg/m3)	Flyash, Kg/m^3	GGBS,Kg/m3	NaoH Solution (Kg/m3)	Na2SiO3 Solution (Kg/m3)	Super plasticizer (Kg/m3)	Extra Water (Kg/m3)	Alkaline solution / Flyash (ratio)
Mix 1	1294	0	554	295.7	98.6	45.1	112.6	11.83	59.14	0.4
Mix 2	1164.6	129.4	554	295.7	98.6	45.1	112.6	11.83	59.14	0.4
Mix 3	905.8	388.2	554	295.7	98.6	45.1	112.6	11.83	59.14	0.4
Mix 4	1294	0	554	197.2	197.2	45.1	112.6	11.83	59.14	0.4
Mix 5	1164.6	129.4	554	197.2	197.2	45.1	112.6	11.83	59.14	0.4
Mix 6	905.8	388.2	554	197.2	197.2	45.1	112.6	11.83	59.14	0.4

4.3. Casting of Specimens

Nine numbers of reinforced concrete beams with and without GGBS were cast and tested. The span of the beam was 1200 mm and of size 100 mm x 200 mm. Beams were simply supported over an effective span of 1000mm.Out of the 9 specimens tested, Mixes-7,8and 9 and cast with cement and 0%, 10% and 30% partial replacement of recycled coarse aggregates. and mixes-1,2 and 3 were cast with GGBS as 25% and replacement for fly ash and 0%,10% and 30% partial replacement of recycled coarse aggregates..and mixes -4,5 and 6 were cast with GGBS as 50% and replacement for fly ash and 0%,10% and 30% partial replacement of recycled coarse aggregates, specimens were tested at the age of 28th day from the date of casting.

4.4. Preparation of Specimens

Prior to casting, the inner walls of moulds were coated with lubricating oil to prevent adhesion with the hardening concrete. Both OPCC and GPC were mixed in a tilting drum mixer machine for about 6-8 minutes. The steel bars as per the design is placed over the 25mm cover block .the Concrete was placed in the mould in three layers of equal thickness and each layer was vibrated until the concrete was thoroughly compacted. Specimens were demoulded after 24hrs.The RCC beams were water cured for a period of 28 days while the RGPC beams were cured in ambient temperature, in the laboratory for a period upto 28 days after casting, after the curing period the specimens were tested.

4.5. Test Procedure

The compressive strength determination was the primary objective. The cube specimens of 150 mm size were tested at the ages of 7 and 28 days. All the specimens were tested under saturated surface dry condition. Three identical specimens were tested in all the mixtures. The Compression Testing Machine of 2000kN capacity was used to find compressive strength of specimens. All cubes of Plain Concrete were tested in a Compression Testing Machine with the references of IS: 516 – 1959 to determine Compressive Strength of concrete at the age of 7 and 28 days. Fig.3.10 shows the cube specimen for compressive strength test.

The test setup is shown in Fig-5.The testing was carried out in a UTM of 1000KN capacity. The beam was simply supported over a span of 1000mm. The load was applied on two points each 333.33mm away from the supports. One dial gauges was used at mid span for measuring deflections. All the specimens were white washed in order to facilitate marking of cracks. The beams were subjected to two-point loads under load control mode. The load was applied in increments of 5KN.The deflections at mid span was measured using dial gauge. The behaviour of the beam was observed carefully. The development of cracks was observed and the crack widths were measured using a hand-held microscope with an optical magnification of X50 and a sensitivity of 0.02 mm.

5. RESULTS AND DISCUSSION

5.1. General observations

This chapter briefly explains the results of the various mechanical and structural properties of the specimen. In this chapter we will also discuss about the reason for the change in the mechanical and structural properties due to the addition of Recycled coarse aggregates.

5.2. Compressive strength of Geopolymer concrete

Tables 4.1 and 4.2 show the compressive strength of GPC cubes at the age of 7 and 28 days. The compressive strength of GPC of 9 mix proportions is presented in Figure 4.1 and Figure 4.2. The Figures show the compressive strength of Geopolymer concrete at the age of 7 and 28 days. There was an increase in the compressive strength of the Geopolymer concrete from 7^{th} to 28^{th} day. The compressive strength of GPC at 7 days was 31.38 MPa which is 77.8% of 28 days strength for the molarity 10M and alkaline ratio 2.5. From the Figure 4.3, it was observed that as the molarity of sodium hydroxide increases the compressive strength was also increased from 8M to 10M, but decreases for 14M for the ratio of sodium silicate to sodium hydroxide 2 and 3. But for alkaline ratio of 2.5 when the molarity increases the compressive strength also increases for different molarity. It was observed from the test results that the maximum compressive strength for the alkaline ratio of 2.5 was in the range of 34.01 MPa to 41.2 MPa for different molarities. The results compare favourably with those of (Bhosale M. A.2012) for ratio Na_2SiO_3/ NaOH = 2.51.

Table 8 Compressive strength of GPC cubes at the age of 7 days

SL.NO.	Ratio of sodium silicate to sodium hydroxide	Molarity		
		8M	10M	14M
1	2	17.8	23.78	28.32
2	2.5	22	32.01	31.52
3	3	20.28	28.56	29.88

Table 9 Compressive strength of GPC cubes at the age of 28 days

SL.NO.	Ratio of sodium silicate to sodium hydroxide	Molarity		
		8M	10M	14M
1	2	25.86	32.95	30.56
2	2.5	34.26	41	41.5
3	3	31.3	37.9	36.5

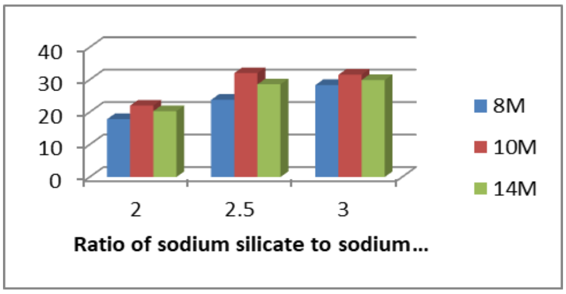

Figure 1 Compressive strength of GPC cubes at the age of 7 days

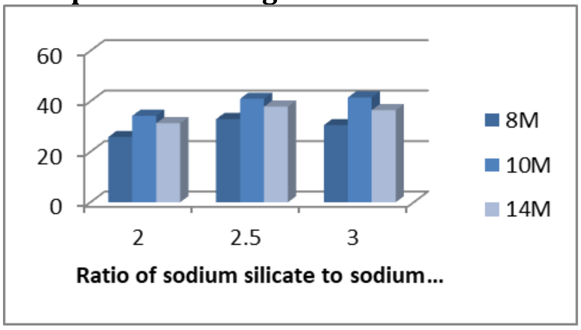

Figure 2 Compressive strength of Geopolymer concrete cubes at the age of 28 days.

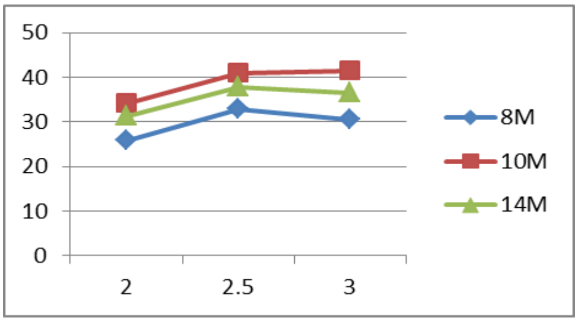

Figure 3 Compressive strength vs. Molarity of GPC at the age of 28 days

5.3. Spilt Tensile Strength

Table 4.3 shows the spilt tensile strength of GPC at the age of 28 days. The variations of results for spilt tensile strength of 28days of cylinder size 100x 200mm are presented in Figure 4.4. From the Figure, it is clear that the strength

Increases as alkaline ratio increases for different molarity. The split tensile strength increases up to ratio 2.5, and then suddenly the strength decreases for alkaline ratio of 3. Similarly the split tensile strength increases as molarity of sodium hydroxide solution is increased from 8M to 10M but decreases for 14M is marginally (1.9%) less than that for 10M for same alkaline ratio. Hence it can be concluded that the optimum alkaline ratio is 2.5 and a molarity of 10M can be adopted for Geopolymer concrete mixes using fly ash and sodium based alkaline solution. It is found to be similar to compressive strength of GPC.

Table 10 Spilt tensile strength of GPC at the age of 28 days

SL.NO.	Ratio of sodium silicate to sodium hydroxide	Molarity		
		8M	10M	14M
1	2	2.98	3.28	3.56
2	2.5	3.42	3.82	3.65
3	3	3.14	3.61	3.32

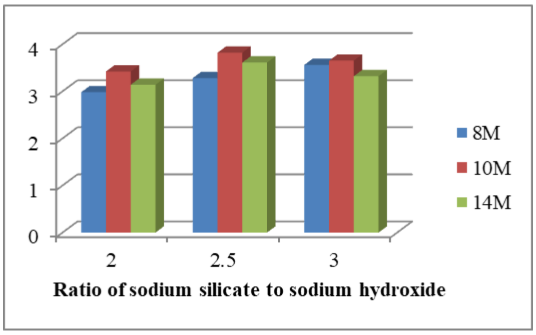

Figure 4 Split tensile strength of Geopolymer concrete at the age of 28 days

5.4 Compression test, Split tensile strength test on Geopolymer concrete partially replaced with RCA

5.4.1. Compressive strength of cubes cured in oven

For the determination of compressive strength of concrete, cubes of size 100 mm were cast and cured for 18 hours at 90 C in oven for Geopolymer concrete. Water curing was adopted for cement concrete. After oven curing, the Geopolymer concrete cubes were kept at ambient temperature and specimens were tested in compression testing machine at the age of 7, 14 and 28 days. After water curing the cement concrete cubes with replacement of recycled aggregates were tested in compression testing machine at the age of 7, 14 and 28 days. Compressive strengths of Geopolymer concrete with 0%, 10% and 30% replacement of RCA varied with the variation of GGBS content (25% and 50% replacement of fly ash) in the mixture. The mix 1 to 6 represents GPC and mixes 7 to 9 gives the compressive strength of cement concrete. Strength of concrete mixtures increased from the early age of 7 days and continued to gain strength up to 28 days. Table 4.5 shows the compressive strength of oven cured GPC and OPC cubes for various mixes using RCA at the age of 7, 14 and 28 days. The compressive strength of the different mixtures at the ages of 7, 14 and 28 days are shown in Figures. 4.6, 4.7 and 4.8. All the results are shown in Figure 4.9**.** From the figures it was observed that maximum compressive strength of 53.65 MPa was observed for GPC mix – 4 (0%RCA, 50%FA and 50%GGBS) at the age 28 days. Fig.4.10 shows Compressive strength at the age of 28 days with various percentages of RCA. From the figure, it is clear that the compressive strength decreases with increase in the RCA percentages. Also, maximum compressive strength is obtained for 50% GGBS.

Table 11 Compressive strength of oven cured GPC and OPC cubes for various mixes using RCA at of 7, 14 and 28 days.

Mix ID	Binder composition RCA/Fly ash/GGBS/Cement	Compressive Strength (MPa)		
		7 Days	14 Days	28 Days
Mix 1	0%RCA, 100%Cement	13.85	18.12	21.86
Mix 2	10%RCA, 100%Cement	10.32	12.95	18.88
Mix 3	30%RCA, 100%Cement	6.56	10.12	14.56
Mix 4	0%RCA, 75%FA, 25%GGBS	36.87	42.98	45.23
Mix 5	10%RCA, 75%FA, 25%GGBS	32.35	35.12	39.86
Mix 6	30%RCA, 75%FA, 25%GGBS	2.52	28.2	31.25
Mix 7	0%RCA, 50%FA, 50%GGBS	4.62	49.85	52.82
Mix 8	10%RCA, 50%FA, 50%GGBS	39	44	49.65
Mix 9	30%RCA, 50%FA, 50%GGBS	24	30.21	33.84

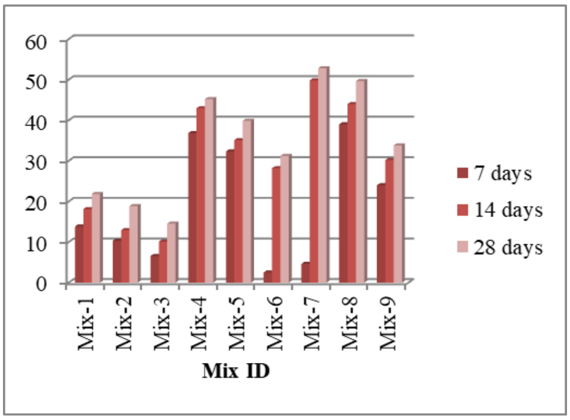

Figure 5 Compressive strength of oven cured GPC and OPC cubes for various mixes using RCA at of 7, 14 and 28 days.

Table 12 Reduction in compressive strength of cubes for various Percentages of RCA

SL.NO.	Percentage	Reduction for GPC		Reduction
		25% GGBS	50% GGBS	
1	10%	11.21%	7.27%	14.74%
2	30%	32.20%	36.81%	37.72%

5.4.2. Spilt tensile strength

For the determination of split tensile strength of concrete, cylinder specimens of size 100mm x 200mm, having diameter to length ratio 1:2 were used. To reduce the magnitude of the high compression stresses near the points of application of the load, narrow packing strips of plywood were placed between the specimen and loading platens of the testing machine. It allows distribution of load over a reasonable area. The use of GGBS as partial replacement of fly ash improved the splitting tensile strength of Geopolymer concrete and showed decrease in the strength when 10% and 30% RCA was used in the mixture.

Table 4.7 shows the split tensile strength for various mixtures using RCA at 28 days. The splitting tensile strength of various mixtures is shown in Figure4.12. A maximum spilt tensile strength of 3.55 MPa was observed for Mix -4. (0%RCA, 50% GGBS and 50% FA). Figure 4.13 shows the split tensile strength at the age of 28 days for various percentage of RCA. Figure 4.11 shows the split tensile strength testing on cylinder using RCA.

Table 13 Split tensile strength for various mixtures using RCA at 28 days

Mix ID	Binder composition RCA/Fly ash/GGBS/Cement	Split tensile strength in MPa at 28 days
Mix-1	0%RCA, 100%Cement	3.28
Mix-2	10%RCA, 100%Cement	3.1
Mix-3	30%RCA, 100%Cement	2.4
Mix-4	0%RCA, 75%FA, 25%GGBS	3.6
Mix-5	10%RCA, 75%FA, 25%GGBS	3.9
Mix-6	30%RCA, 75%FA, 25%GGBS	2.7
Mix-7	0%RCA, 50%FA, 50%GGBS	1.7
Mix-8	10%RCA, 50%FA, 50%GGBS	1.5
Mix-9	30%RCA, 50%FA, 50%GGBS	1.13

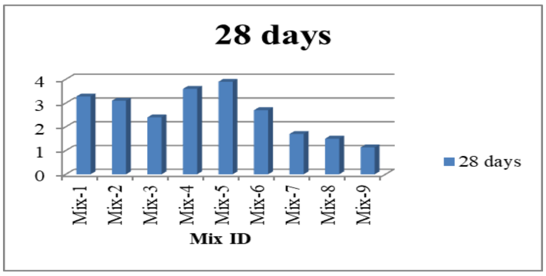

Figure 6 Split tensile strength for various mixtures using RCA at 28 days

Table 14 Reduction in Split tensile strength of cubes for various percentage of RCA

SL.NO.	Percentage	Reduction for GPC		Reduction
		25% GGBS	50% GGBS	
1	7%	12.23%	7.27%	13.02%
2	29%	26.12%	36.81%	38.03%

5.5. Load-deflection characteristics

The experimental load-deflection curves of the RC beams with 0%, 10%and30% RCA and partial replacement of GGBS when tested at 28th day for all mixes are shown in Figure -9. The average ultimate loads for beams of various mixes were ranging from 39.85 kN to 104.28 kN respectively. The Deflection of concrete beams for Geopolymer concrete ranged between 5.23 mm to 6.22mm. And for Cement concrete ranged between 4.62mm to 5.8 mm.

Table 15 Summary of beam test results

Beam ID	Crack Load (KN)	Ultimate Load WE (KN)	Ultimate Moment ME (KNm)	Deflection (mm)
Beam 1	18	56.12	9.98	4.62
Beam 2	17	50.68	8.95	5.2
Beam 3	14	39.85	6.85	5.8
Beam 4	24	83.26	14.65	5.65
Beam 5	22	76	15.36	5.89
Beam 6	19	65.6	11.32	6.12
Beam 7	27	104.28	18.11	5.23
Beam 8	26	93.12	15.12	6.22
Beam 9	25	84.12	13.99	8.25

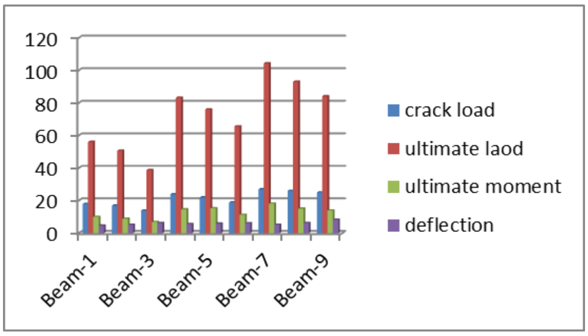

Fig 7 Summary of beam test results

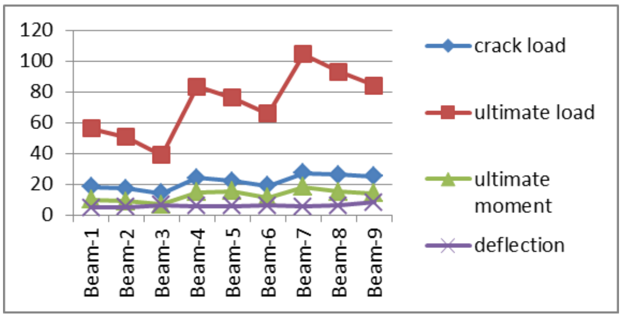

Fig 8 Summary of beam test results

5.6. Failure mode and crack pattern

The cracks at the mid-span opened widely thereafter with the yielding of steel when the beams reached above the ultimate load. The failure pattern of the beam specimens was found to be similar for both RCC and RGPC beams.

6. CONCLUSIONS

- Investigations were conducted to understand the effect of GGBS and Recycled Coarse Aggregates on material characteristics and flexural behaviour of fly ash based Geopolymer concrete. Based on the studies, the following conclusions are made.
- The compressive strength of Geopolymer concrete increases with increase in curing time from 7 days to 28 days.
- Based on the results of compressive and split tensile strength the optimum alkaline ratio is found to be 2.5.
- Hence a molarity of 10M can be adopted for sodium hydroxide solution in Geopolymer concrete mixes using fly ash and sodium based alkaline solution.
- It was observed that there is reduction in compressive strength when RCA is used in GPC and OPC. However, the reduction is less for GPC when compared to OPC. For 30% RCA, the percentage reduction in strength is 32 to 36% for GPC (oven cured). When 50%GGBS is used, the percentage reduction is more than the 25% GGBS for 30% RCA and less for 10% RCA.
- It was observed that the reduction in split tensile strength increases with increase in RCA percentage. However, the percentage reduction is less for GPC when compared to OPC. For 30% RCA, the percentage reduction in strength is 25 to 29% for GPC. When 50%GGBS is used, the percentage reduction is more than the 25% GGBS mix for 10% RCA and less for 30% RCA.
- For the same mix, the compressive strength of GPC is increased when cured at 90 C (Oven curing) compared to ambient curing.
- From the load deflection curve, the deflection for Geopolymer concrete beams was found to be less than that for OPC beams for the same load.
- The crack patterns and failure modes observed for reinforced Geopolymer concrete beams are found to be similar to reinforced cement concrete beams. The beams failed initially by yielding of the tensile steel followed by the crushing of concrete in the compression face.
- The difference between theoretical deflection and experimental deflection at service load was less than 30% for mixes 1,2,4,5 and 6 for RGPC beams and less than 40% for mix-3 (30 % RCA, 75% FA and 25% GGBS).

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