An Experimental study on properties of fly ash based geopolymer concrete by using recycled concrete aggregate

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Abstract — To scrutinize the performance of fly ash based Geopolymer concrete. Geopolymer concrete includes coarse aggregate, fine aggregate, alkaline liquid, fly ash and water. The alkaline liquid is a fusion of sodium silicate and sodium hydroxide. To make alkaline liquid solution, sodium hydroxide solids were added with the water about 5 minutes. Then, the sodium hydroxide solution was blended with the sodium silicate. This liquid was prepared one day before of mixing day. The fly ash used Geopolymer concrete is more environmentally friendly and the potential to take over from OPC concrete in many applications such as precast units. Geopolymer technology does not only grant to the rebate of greenhouse gas emission but also reduced disposal cost of industrial waste. The significance of recycled aggregate addition on the fresh and hardened properties of geopolymer concrete is completely reviewed in this paper. The optimal mix combination was taken for casting of reinforced concrete beam and to search the strength and durability properties were captured with concrete with hardened and fresh concrete.

Keywords Compressive strength, Fly ash, Geopolymer, Split tensile strength, alkaline solution, ground granulated blast furnace slag, Alkaline Activator Solution and recycled coarse aggregate.

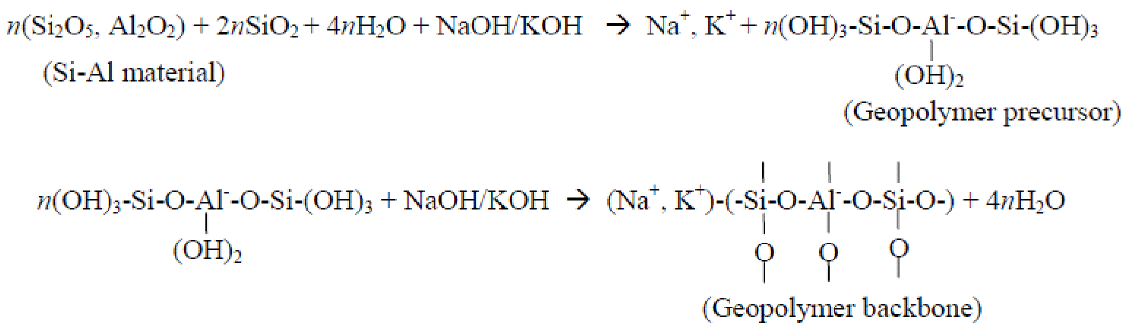
I. INTRODUCTION

Considering the high consumption of concrete and the increasing necessity for cement production, high attention to the environmental degradation effects of this substance is needed. These effects include 7% of CO^2 emission and the considerable consumption of energy such as electricity and fossil fuels. Hence the provision of alternative products in order to move towards sustainable development is essential. Therefore, the use of an eco-friendly concrete enables the reduction of consumption of ordinary Portland cement (OPC) with activated pozzolanic binders as a replacement, leading to lower emission of CO^2 in the atmosphere.

Geopolymers are in the family of mineral polymers, in which their chemical combinations are similar to zeolite materials, whereas their microscopic structure is amorphous rather than crystalline. The use of polymers such as concrete adhesives result in the production of geopolymer concrete (GPC) that can be a suitable substitute for OPC.

In addition to Portland cement, fine aggregate and coarse aggregate is also a principal component of concrete. The typical coarse aggregate used in concrete construction is Natural coarse aggregate. With the rising demands for concrete for new construction, natural resources like limestone and river sand are being rapidly exhausted and also construction waste also increased day by day. Therefore, to preserve the environment, it is necessary to search for and explore new possibilities to develop a concrete material that is eco-friendly, and yet remains an efficient construction material, to partially or completely replace the recycled coarse aggregate as coarse aggregate.

This study aims at arriving at a mix design for GPC with Recycled coarse as Coarse aggregate and comparing its mechanical properties with natural coarse aggregate. Compression, split tension, flexural tests were carried out after 28 days of casting.



II. Literature Review

H.V.Moulya [1], Geopolymer Recycled Coarse Aggregate Concrete emerges at a critical juncture in history to address two issues. Firstly, utilizing Geopolymers derived from the waste of industry to replace cement which reduces the use of cement and thus emissions of CO2, and secondly, Recycled Coarse Aggregate In the current study, Geopolymer Concrete was made with a constant ratio of fly ash and GGBS (50:50), a sodium silicate to Sodium Hydroxide ratio of 2.5, a Sodium Hydroxide concentration of 8 Molarity, an alkaline to binder ratio of 0.4, and different proportions of Recycled Coarse Aggregate that was partially and completely replaced with Natural Coarse aggregate with the percentage of (0% to 100%). The test results showed that Recycled Coarse Aggregate can be used as a Natural Coarse Aggregate in Geopolymer Concretes by replacing 70%, with a 28-day compressive strength of 60.02 MPa, which is almost same as 100% Natural Aggregate in Geopolymer Concrete. The reduction in strength after 90 days of exposure to the HCL solution was up to 1.28 percent for Geopolymer Concrete using Recycled Coarse Aggregate. The Compressive Strength of Geopolymer Concrete using Recycled Coarse Aggregate decreased by up to 1.89 percent after the same period of exposure to the Sulphate solution. In this study combination of fly ash, GGBS, 70% Recycled Coarse Aggregate, and an 8 Molarity NaOH concentration-based Geopolymer Concrete was recommended for precast construction with ambient curing. **Rohan Sanjay Salunkhe[2],** This report generally consists of fly ash and GGBS based geopolymer mortar with replacement of sand with brick waste. Fly ash and GGBS percentage was varied as 0:100, 30:70, 50:50, 70:30, 100:0 %. Study was carried on different molarities of sodium hydroxide (NaOH) i.e. 4M, 6M, and 8M. Percentage of replacement of sand with brick waste was kept as 10%, 20% and 30%. Sodium silicate and sodium hydroxide were used as alkaline activators. Ratio of Sodium silicate to sodium hydroxide was kept 2.5. Initial tests like normal consistency, final setting time, etc. were carried on each mix. Flow test was taken to fix a unique solution to binder ratio. Ambient curing of 70.6 x 70.6 x 70.6 mm cube for 28days was performed and later tested for compressive strength. 100% of GGBS in geopolymer mortar shown optimum results. **Atul S. Kurzekar [3]** in this research work take sustainable efforts to develop alternative materials such as construction and dismantling waste and industrial waste to be used as replacements of natural aggregates also we replace ordinary Portland cement 100% by fly ash with binders to make Geopolymer concrete. In this research we have studied the production of different class-F fly ash based aggregates and, the influence of binder on the physical and mechanical properties of pelletized aggregates and the effects of alkali addition and curing methods on the strength gain. Mostly focus on harden properties & durability of Geopolymer concrete incorporating with complete replacement of natural aggregates by class F fly ash and construction and dismantling waste aggregate. **Sarah Sameer Hussein [4],** his paper showed strength of geopolymer mixtures made of fly ash and then replaced fly ash with slag in different percentages. The geopolymer mixes were prepared using a ground granulated blast-furnace slag (GGBFS) blend and low calcium fly ash class F activated by an alkaline solution. The mixture compositions of fly ash to slag were (0.75:0.25, 0.65:0.35, 0.55:0.45) by weight of cementitious materials respectively and compared with reference mix of conventional concrete with mix proportion 1:1.5:3 (cement: sand: coarse agg.), respectively. The copper fiber was used as recycled material from electricity devices wastes such as (machines, motors, wires, and electronic devices) to enhance the mechanical properties of geopolymer concrete. The heat curing system at 40 oC temperature was used. The results revealed that the mix proportion of 0.45 blast furnace slag and 0.55 fly ash produced the best strength results. **JianheXie [5],** The aim of this study is to investigate the combined effects of GGBS and fly ash considering water-binder (W/B) ratio on the fresh and hardened properties of alkali activated GRAC. The slump, setting time, compressive strength, stress-strain relation, elastic modulus, Poisson's ratio, toughness and failure mode of alkali activated GGBS and fly ash based GRAC containing 100% recycled coarse aggregates were experimentally examined. In addition, the hydration mechanisms were studied by XRD and SEM. Finally, the failure mechanism of this kind of novel green concrete subjected to compression was revealed. The results show that GGBS and fly ash exhibits a superior synergetic effect on the performance of GRAC, i.e. fly ash and GGBS are mainly responsible for the workability and mechanical properties, respectively. GGBS/fly ash ratio has a significant influence on the fresh and hardened properties of GRAC. Moreover, the effect of W/B ratio on GRAC strongly depends on the GGBS/fly ash ratio. GGBS content at less than 25% was found to slightly influence the consistency and compressive strength of GRAC. The combination of 50% GGBS and 50% fly ash with a 0.5 W/B ratio could provide excellent mechanical performance and workability for GRAC. **ZhuoTang[6],** In this study, the compressive behavior of GRAC based on fly ash and slag was experimentally investigated under both quasi-static and dynamic loadings. Quasi-static compressive tests were performed by using a high-force servo-hydraulic test system, while dynamic compressive tests were carried out by using a Ø80-mm split Hopkinson pressure bar (SHPB) apparatus. The compressive properties of GRAC under dynamic loading, including stress-strain curves, energy absorption capability, and failure modes were obtained and compared with those under quasi-static loading. The results show that the compressive properties of GRAC exhibit a strong strain rate dependency. Although the recycled aggregate replacement decreases the quasi-static compressive strength, it exhibits a slight effect on the compressive strength at high strain rates. The dynamic increase factor (DIF) for compressive strength exhibits an significant increasing trend with the recycled aggregate replacement. On the other hand, the incorporation of slag increases the quasi-static compressive strength, dynamic compressive strength, and DIF. As for the energy absorption capacity, a minor enhancement is achieved with the recycled aggregate replacement, while a significant improvement is identified after the inclusion of slag. **Amer Hassan[7],** This paper presents the results of an experimental study carried out to examine the performance of fly ash based Geopolymer concrete. Geopolymer concrete includes coarse aggregate, fine aggregate, alkaline liquid, fly ash and water. The alkaline liquid is a combination of sodium silicate and sodium hydroxide. To make alkaline liquid solution, sodium hydroxide solids were mixed with the water about 5 minutes. Then, the sodium hydroxide solution was mixed with the sodium silicate. This liquid was prepared one day before of mixing day. The fly ash Based Geopolymer concrete is more environmentally friendly and the potential to replace OPC concrete in many applications such as precast units. **S. V. Srinidhi [8],** literature on the flexural behavior of geopolymer concrete (GPC) beams have been studied and compared with the reference concrete beams of the respective grade. From the literature, It has been observed that the development of flexural cracks are relatively less in geopolymer RCC beams compared to conventional beams, the failure occurred in the beams was in flexural mode and the cracks are generated from the tension zone to the compression zone and also the compressive strength greater than before due to decrease in porosity, as the fineness of fly ash enhanced. **Avinash Ojha [9],** This study aims to ascertain the impact of recycled aggregates on mechanical properties of fly ash-based geopolymer concrete and to see whether it can be utilized in place of conventional concrete. The result of the experimental investigation depicts the acceptable performance of the geopolymer concrete over conventional concrete. Although the compressive strength and splitting strength of geopolymer concrete remains less than the conventional concrete, they are well within the permissible range. Based on test results in this study geopolymer concrete can be a suitable alternative of conventional concrete.

4. Scope

- An alternative construction material to OPC by geo-polymerization of industrial wastes.
- The proper usage of industrial wastes and construction and demolition wastes can reduce the problem of disposing the waste products into the atmosphere.
- In terms of reducing the global warming, the geopolymer technology could reduce the CO2 emission to the atmosphere caused by cement and aggregates industries by about 80% (Davidovits, 1994c).

5. Objective

- To reduce the usage of Ordinary Portland Cement and to improve usage of eco-friendly material.
- To study the effectiveness of Recycled coarse aggregate in replacing Natural coarse aggregate.
- Comparative study of the compressive strength, split tensile strength and flexural strength of geopolymer concrete with Natural coarse aggregate partially and fully replaced by Recycled coarse aggregate.
- To attain high strength of fly ash based geo polymer concrete addition alkaline activator solution.
- To develop and evaluate the geo polymer concrete products suitable for precast manufacture viz. products such as beams.

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6. Research Methodology

The following procedure as follows to carry out the research.

- Design of concrete mix as per IS: 10262-2009
- Adding geopolymer concrete with fly ash, alkaline activator solution, fine aggregate, recycled coarse aggregate
- Casting of concrete cubes.
- Testing on cube materials.

7. Materials used and their properties

1. Fly Ash and Ground Granulated Blast Furnace Slag (GGBS)

Fly ash is a by-product from coal based thermal power plants. Fly ash contains amorphous silica, which is responsible for its pozzolanic activity. The predominant constituents of fly ash are 16 inert mineral oxides. It is predominantly made up of oxides of calcium, aluminium and silica. In this study, GGBS produced by JSW was used.

Table – 1 Chemical composition

Chemical composition	Fly Ash	GGBS
SiO2	60.1	34.81
Al2O3	26.5	17.92
Fe2O3	4.2	0.66
CaO	4	37.63
MgO	1.21	7.8
SO3	0.33	0.2
Na2O	0.2	-
LOI	0.85	-

Figure - 1 **Class F Fly Ash**

Figure - 2 **GGBS**

2. Alkaline Activator Solution (AAS)

The AAS consists of hydroxides and silicates of alkali. The preferred alkali is sodium since it is more economical than potassium and is a very strong alkali. In this study, a mixture of sodium hydroxide flakes, sodium silicate solution and water were used. Sodium hydroxide flakes are white crystalline substance that readily absorbs CO_2 and moisture from air. It is added to sodium hydroxide for diluting the mixture. Sodium hydroxide flakes were dissolved in water and allowed to cool for 24 hours, after which sodium silicate solution was added into it. Sodium hydroxide Solution of 12M and silicate to hydroxide ratio of 2.5 was used for preparation of AAS. Since the molecular mass of NaOH is 40, for 12M solution, 480 grams (40×12) of NaOH pellets was mixed with one litre of water.

Figure - 3 **Sodium hydroxide flakes**

Figure - 4 **silicate solution**

3. Recycled coarse aggregate

Collecting waste concrete cubes from ready mix plant and transporting to quarry for crushing purpose, in that quarry having large size of crusher, first process collected cubes put it in that crusher that should be crushed total cubes. In that process dried mortar and aggregates should separate. After this separation process recycled coarse aggregate should taking into another process of screening after will get the recycled concrete product is free of dirt, clay, wood, plastic and organic materials. This is done by water floatation, hand picking, air separators, and electromagnetic separators.

Figure - 5 **Collected Demolished Concrete from site**

Figure - 6 **Recycled coarse aggregate**

III. EXPERIMENTAL WORK AND RESULTS

1. Test for fly ash and GGBS

a. Specific gravity of Fly Ash and GGBS

The specific gravity of fly ash was determined using kerosene and Le Chatelier's flask. The flask is completely dried and ensured that no water or moisture content is present. Some kerosene was filled in the flask such that the kerosene level was anywhere between 0 and 1 ml. The volume of kerosene and corresponding weight of the flask with kerosene was noted down. Then fly ash was filled inside the flask such that the kerosene level rises above the bulb after 18 ml to a notable value. The new volume and corresponding weight is also noted down. The specific gravity is determined by dividing the difference in weight by difference in volume

Fig – 7

Determination of specific gravity using Le Chatelier's flask

Table – 3

Specific gravity of Fly Ash

S.no	Description	Values
1.	Weight of empty bottle(w_1) (g)	26.8
2.	Weight of bottle + water (w_2) (g)	75
3.	Weight of bottle + kerosene (w_3) (g)	65.5
4.	Weight of bottle + fly ash + kerosene (w_4) (g)	74.8
5.	Weight of fly ash (w_5) (g)	12.5

The Specific gravity of Fly ash is **2.21**

b. Specific gravity of GGBS

Table – 4

Specific gravity of GGBS

S.NO	DESCRIPTION	VALUES
1.	Weight of empty bottle(w_1) (g)	26.8
2.	Weight of bottle + water (w_2) (g)	75
3.	Weight of bottle + kerosene (w_3) (g)	68.2
4.	Weight of bottle + fly ash + kerosene (w_4) (g)	78.6
5.	Weight of fly ash (w_5) (g)	13.2

The Specific gravity of Fly ash is **2.82**

2. Test for Fine aggregate

a. Specific gravity of Fine aggregate

Table – 5

Specific gravity of GGBS

S.NO	DESCRIPTION	VALUES
1.	Weight of empty bottle(w_1) (g)	460
2.	Weight of bottle + water (w_2) (g)	960
3.	Weight of bottle + kerosene (w_3) (g)	1470
4.	Weight of bottle + fly ash + kerosene (w_4) (g)	1200

The Specific gravity of Fly ash is **2.64**

b. Fineness modulus of Fine Aggregate

Sieve analysis is carried out as per IS 2386-1(1963) **[11].** For fine aggregates, 500g of sample was taken and made to pass through sieves of size 4.75 mm, 2.36mm, 1.18 mm, 600 µm, 300 µm and 150 µm using a sieve shaker

Fig – 8

Sieve shaker

Fig – 9

Weigh balance fine aggregate

Table – 6

Fineness modulus of Fine Aggregate

Fine Aggregate					
Sieve size (mm)	**Weight retained (g)**	**Cumulative weight retained(g)**	**Cumulative % weight retained**	**Cumulative % weight passing**	**IS 383 standard zone-II**
4.75mm	1	1	0.33	99.67	90-100
2.36mm	7	8	2.67	97.33	75-100
1.18mm	40	48	16	84	75-90
600µ	120	168	56	44	35-59
300 µ	50	218	72.67	27.33	8-30
150 µ	72	290	96.67	7.33	1-10
Pan	10	300	-	-	-

The Fineness modulus of Fine Ash is **2.44 (Fine aggregate confirming to Zone II)**

3. Test for Coarse aggregate

a. Specific gravity test of Coarse Aggregate

Table – 7

Specific gravity of Coarse Aggregate

S.no	Description	Values
1.	Weight of empty bottle(w_1) (g)	450
2.	Weight of bottle + water (w_2) (g)	800
3.	Weight of bottle + kerosene (w_3) (g)	1405
4.	Weight of bottle + fly ash + kerosene (w_4) (g)	1180

The Specific gravity of Fly ash is **2.8**

b. Fineness modulus of Coarse Aggregate

Sieve analysis is carried out as per **IS 2386-1(1963)[12]**. For coarse aggregate 2.5 kg sample was taken and sieved through 20 mm, 12.5 mm, 10 mm, 6.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm and 150 µm. The weights of sample retained were noted to calculate the fineness modulus.

Table – 8

Fineness modulus of Coarse Aggregate

IS Sieve Size (mm)	Weight Retained (g)	Cumulative weight retained (g)	Cumulative % weight retained	Cumulative % weight passing
80mm	0	0	0	100
40mm	0	0	0	100
20mm	360	360	12	88
10mm	1850	2210	73.67	26.33
4.75mm	625	2835	94.5	5.5
2.36mm	165	3000	100	0
1.18mm	0	0	100	0
600µ	-	-	100	0
300µ	-	-	100	0
150µ	-	-	100	0

The Fineness modulus of Coarse Aggregate is **6.8**

4. Water absorption test

Weight of saturated surface dry sample (w_1) = 2010 g

Weight of oven dry sample (w_2) = 1990 g

Water absorption
$$= \frac{(w_1 - w_2)}{100} \quad (1)$$

$$= \frac{2010 - 1990}{100}$$

= 0.2 %

5. Fresh concrete properties

a. Slump Test

To assess the workability of selected concrete mix by conducting slump test. Vertical settlement of a standard cone of fresh concrete (actually frustum of a cone) under its own weight is called slump. For such concretes, Vee bee time test is suitable. For highly workable mixes, slump is of the order of a few inches, which can be measured accurately. Hence slump test is to be preferred in such cases.

Table – 8

Slump value for Different Mix Proportions

Mix	Slump Value
CC	60mm
GPC-1 (40%RCA)	52mm
GPC-2 (50%RCA)	49mm
GPC-3 (60%RCA)	45mm

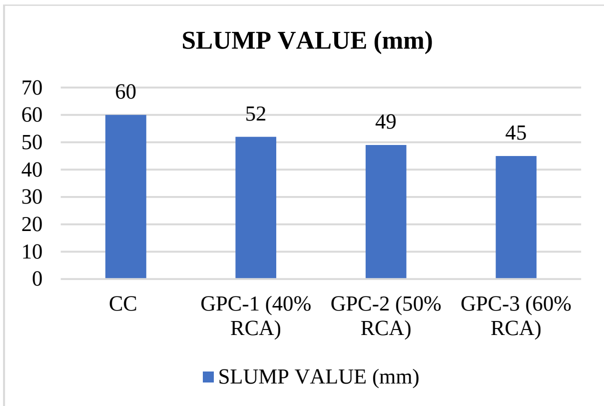

Fig - 10 **Graphical Representation for Slump value using Different Mix Proportions**

6. Destructive tests on hardened concrete

a. Compressive strength test

Compressive strength is the capacity of a material or structure to withstand axially directed pushing forces. When the limit of compressive strength is reached, materials are crushed. Out of many tests applied to concrete, this is utmost important which gives an idea about all characteristics of concrete. By this single test one can judge whether concreting has been done properly or not. For most of the works cubical moulds of size 15 cm x 15 cm x 15 cm are commonly used. The mould is applied with oil for lubrication. Concrete is laid in the mould in 3 equal layers and then after each layer the moulds are kept on the vibration machine to get better compaction. Same procedure as explained above is followed for all mixes with different percentages of granite powder to fine aggregate replacement. These specimens are tested in Compression Testing Machine after 3days, 7 days, 14 days and 28 days. Load is applied gradually at a rate of 140 kg/cm2 per minute till the specimen fails. Load at failure divided by area of specimen gives compressive strength of concrete.

Compressive strength test, fck= $\frac{\textbf{Failure Load}}{\textbf{Cross sectional area}}$ **(2)**

Fig - 11 **Compressive strength tests**

Mix	7 Days (N/mm²)	14 Days (N/mm²)	28 Days (N/mm²)
CC	23.33	32.43	41.69
GPC-1 (40% RCA)	22.12	30.34	38.76
GPC-2 (50% RCA)	22.58	30.79	40.60
GPC-3 (60% RCA)	19.52	28.76	36.78

Table – 9

Compressive Strength value for Different Mix Proportions

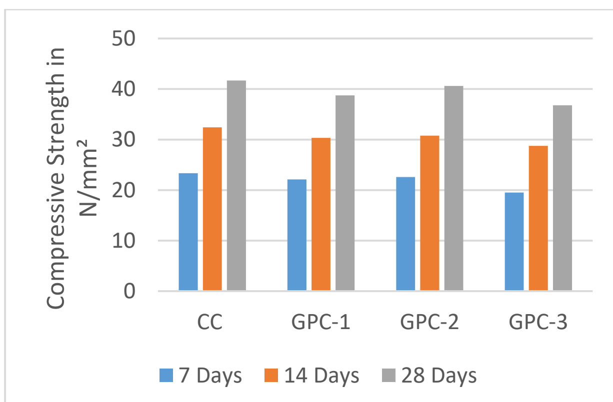

Fig - 12 **Graphical Representation for Compressive Strength value using Different Mix Proportions**

7. Splitting tensile strength test

Direct tensile strength tests are not applicable on concrete, so the tensile strength is measurement is done by means of the splitting method. Splitting tests are well known indirect tests used for determining the tensile strength of concrete. Cylinder of size 10 cm diameter and 15 cm height are used in present work. Concrete is laid in the mould in 3 equal layers; each layer is compacted with tamping rod. The above procedure is same for all mixes with different percentages of Recycled Coarse aggregate replacement.

$$\mathbf{fct} = \frac{2P}{\pi l d} \qquad \textbf{(3)}$$

where,

P = Compressive load on the cylinder
l = Length of the cylinder
D = Diameter of the cylinder

Fig - 13 **Split tensile strength test**

Mix	7 Days (N/mm^2)	14 Days (N/mm^2)	28 Days (N/mm^2)
CC (40% RCA)	2.46	2.76	2.96
GPC-1 (40% RCA)	2.29	2.56	2.62
GPC-2 (50% RCA)	2.33	2.61	2.76
GPC-3 (60% RCA)	2.09	2.18	2.33

Table – 10

Split tensile Strength value for Different Mix Proportions

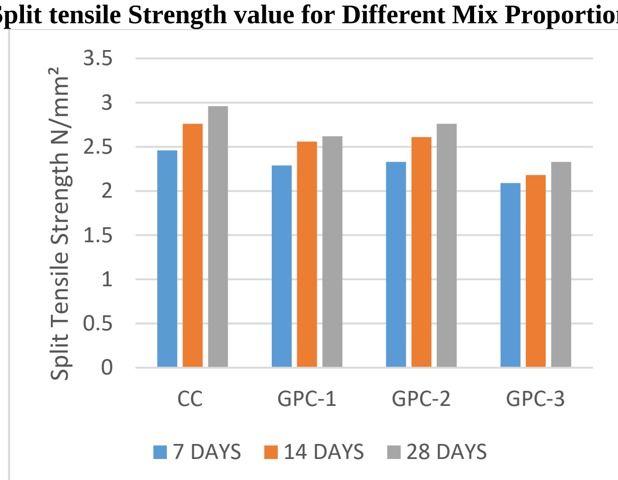

Fig - 14 **Graphical Representation for tensile Strength value using Different Mix Proportions**

8. **Flexural strength test**

Flexural strength properties were determined as per IS 516-1959 standard. The strength properties of the beam specimens were determined at 7, 14 and 28 days age of concrete. For this purpose, Flexural Testing Machine having a maximum capacity of 100 kN was employed. During the testing, the concrete beams were placed such that the load acts at middle-third portions (Fig. 16) and the load at which the concrete fails and the distance of the failure initiation point from the supports was recorded for each specimen. The flexural strength of the specimens was then calculated and was reported by taking the average of the total specimens tested. The flexural strength (Fb) of the specimen is given by:

$$Fb = \frac{PL}{bd^2} \quad (4)$$

Fig - 15 **Flexural strength test**

Mix	7 Days (N/mm²)	14 Days (N/mm²)	28 Days (N/mm²)
CC (40% RCA)	7.5	8.5	10.5
GPC-1 (40% RCA)	7.125	8.10	9.25
GPC-2 (50% RCA)	7.375	8.25	10.25
GPC-3 (60% RCA)	7	7.825	9.15

Table – 11

Flexural Strength test value for Different Mix Proportions

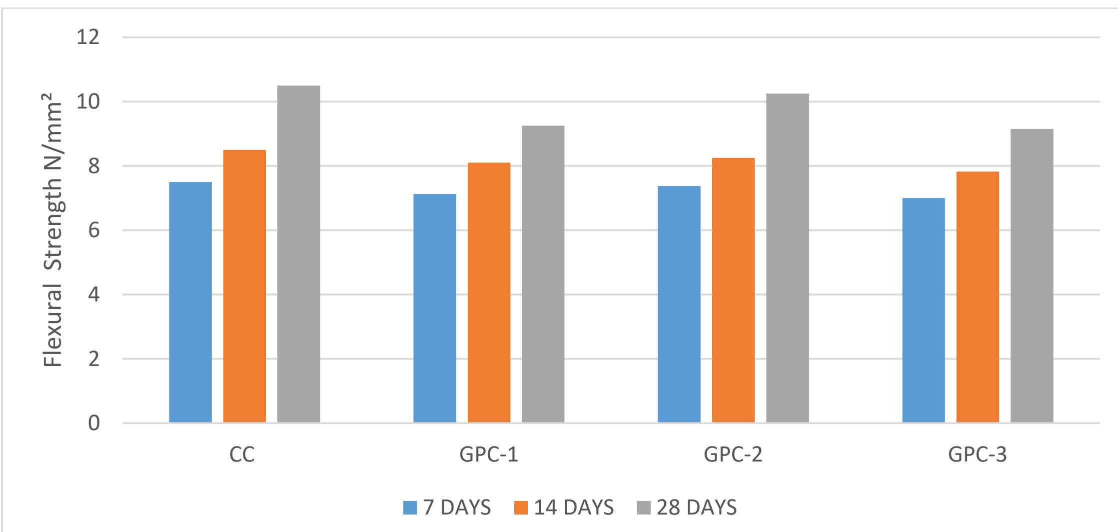

Fig - 16 **Flexural strength test**

Fig. 19 Graphical Representation for Flexural Strength value using Different Mix Proportions

IV. Conclusion

This experiment was conducted with fly ash and GGBS based geopolymer concrete with different proportions of recycled coarse aggregate after performing compressive, splitting and flexural tests following conclusions can be accounted. Using recycled coarse aggregates in the geopolymer concrete up to a certain limit is feasible in terms of utilizing wastes and by-product materials, thus, creating a sustainable binding material is achievable. Using non-cementitious binders such as GGBS and fly ash instead of ordinary Portland cement (OPC) in the matrix could result in improved strength of the recycled coarse aggregate geopolymer concrete. Based on the results, to achieve mechanical properties and workability the incorporation of Fly ash and GGBS binder having ratio of 1:1. When mixes were made by replacing 40%, 50% and 60% coarse aggregate with recycled coarse aggregate 50% RCA mix shows good results in terms of compressive strength, and splitting tensile strength. When mixes were prepared by replacing 100% cement with Fly ash and GGBS together with 40%, 50% and 60%RCA, replacement of cement with Fly ash (50%) and GGBS (50%) shows a better result in terms of compressive strength.

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