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UTILIZING FLY ASH AND GGBS AS CEMENT SUBTITUTES TO ENHANCE STRENGTH IN SUSTAINABLE CONCRETE FLEXURAL MEMBER

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Abstract— Geo polymer concrete (GPC) is emerging as a sustainable alternative to conventional concrete, offering reduced environmental impact and enhanced strength. It is made up of industrial by-products like Fly ash Class F and ground granulated blast furnace slag (GGBS), activated with alkaline solution such as sodium hydroxide (NaOH) and Sodium Silicate ($NaSi_2O_3$).

Fly ash and GGBS are partially used in GPC increases the mechanical properties of concrete compared to conventional concrete. In literatures, it was noted that when increase the molarity of NaOH ; the slump value is decreased in GPC. When the fly ash in GPC exceeds more than 50% were increase the compressive strength but reduce the workability during the geo polymerization. Here, increasing the NaOH and $NaSi_2O_3$ concentration ratio, 1:2 Ratio in GPC can accelerate the alumino- silicate breakdown promoting the rapid formation of geo polymer gels gives more binding in GPC. GGBS was added in percentage for achieving the higher compressive strength and workability. The research focused on preparation and performance of M50 grade of GPC mix designed for 10 molarity alkaline solution using Class F Fly ash and GGBS. The mechanical properties like compressive, tensile & flexural strengths and durability property like water absorption were studied and compared with conventional concrete. The experimental results were analysed using Ansys software and validated.

Keywords: Geo polymer concrete, Fly Ash, GGBS, Alkaline solution, NaOH and $NaSi_2O_3$.

I. INTRODUCTION

Ordinary Portland cement (OPC) is the most widespread and indispensable building material in the field of civil engineering, whereas the excessive energy consumption and environmental issues induced by OPC production are increasingly highlighted [[1], [2]. The production processes of conventional concrete ingredients, such as cement, coarse and fine aggregates, along with the reactions during the process of cement hydration, have a substantial influence on the depletion of natural resources, sustainability and the greenhouse gases emissions [3]. It is estimated that the emitted CO_2 from cement production accounts for 5–8% of anthropogenic CO_2 emissions [[4], [5], [6], [7]]. Concrete is widely used in construction because of its durability, strength, and low cost. However, Ordinary Portland Cement (OPC), the main ingredient in concrete, emits about 2.4 billion tons of CO_2 each year, contributing significantly to global warming [8]. To reduce these emissions, the construction industry is looking at alternative materials to replace or enhance conventional Portland cement [9]. Geopolymer is a polymer family consisting of alumino-silicates which is chemically synthesized by activating alkaline materials of different alumino-silicates materials or aluminum, silicon-rich agricultural and industrial waste products, for instance,(SF), (GBFS) , (FA)

The production of geopolymer composites involves the geopolymerization of alumino-silicate materials, such as agricultural and industrial residual ashes, with metallic alkaline activator, such as NaOH and Na_2SiO_3, which significantly lowers CO_2 emissions than Portland cement [10]. Because of its enormous potential in terms of environmental and financial benefits, this alternative cement-free material has attracted the interest of researchers all around the globe. Geopolymer concrete has been used with success in a variety of structural engineering application, including precast columns and beams, tunnel lining, slabs and rigid pavement. Fundamental justification was that it exhibits structural characteristics that was comparable to that of regular Portland cement concrete [10, 11].

Mohammed Ali. M Rihan et al (2024) Influence of sodium hydroxide (NaOH) molarities on the performance of fly ash/sugarcane bagasse ash-based geopolymer concrete (GPC). Previous studies have shown that GPC offers environmental benefits by eliminating cement, thus reducing carbon emissions. However, the use of alkaline activators like sodium/potassium hydroxide and silicate contributes to carbon emissions, limiting GPC's sustainability. Research indicates that increasing NaOH molarity (10 M to 16 M) results in a 3.75–10.2% improvement in compressive strength, with 10 M still achieving high strength.

Sabbir Ahamed et al (2023) Uses of geopolymer concrete (GPC) as a sustainable alternative to traditional concrete. It examines the effects of varying fly ash and GGBS percentages, sodium hydroxide molarities, and sodium silicate to sodium hydroxide ratios on GPC's strength and durability. The study also compare the ambient and membrane curing methods. The findings show that higher GGBS content improved compressive strength and reduced water absorption, with the 100% of GGBS and 50–50% fly ash and GGBS mix outperforming conventional concrete.

II. MATERIAL USED

3.1 FLY ASH:

Fly ash is a fine, powdery material produced as a byproduct of burning pulverized coal in power plants. Fly ash is commonly used in construction, particularly in cement and concrete production, due to its pozzolanic properties, which enhance the strength and durability of concrete. Fly ash was collected from Muthu kumar traders, Metturdam, Salem, Tamil Nadu.

3.2 GBBS:

Ground Granulated Blast Furnace Slag (GGBS) is a byproduct of the steel industry, created by rapidly cooling molten iron slag from a blast furnace with water or steam, forming a granular material. GGBS was collected from Astrra Chemicals, Moores road, Thousand lights, Chennai.

3.3 ALKALINE SOLUTION:

The alkaline activators are used to activate the silica and alumina present in the binder materials to form the geo polymer gel. The activators are typically a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3).

A liquid alkaline solution NaOH having molarlities ranging between 8M to 16M was used.The Na_2SiO_3/NaOHratio is a critical factor in the Geo polymerization process , typically varying b/w 1.0 to 2.5 Alkaline solution was collected from Thirumalai chemicals, Tirunelveli, Tamil Nadu.

III. MIX DESIGN

Geo polymer concrete is a new construction material which is under research by manty researchers. There is no standard mix design are available. so, the design of geo polymer concrete mix assume the unit weight of concrete is 2400 kg/m^3.In preparation of geo polymer concrete of 50:50 ratio we use fly ash and GGBS instead of cement. Take water content ratio may selected in standard grade, water cement ratio is 0.42 , cement content is 456.14 kg/m^3 then the fly ash content 228.07 kg/m^3 and GGBS content 228.07 kg/m^3.The combined aggregate may be selected to match the standard grading curves used in the design of Portland cement concrete mixtures. For coarse aggregate is 62% is contain 1116 kg/m^3. There we use (2/3) of 20 mm aggregate is 744 kg/m^3 and (1/3) of 12.5 mm aggregate is 372kg/m3 and fine aggregate in GPC 38% which contain 684 kg/m^3. In geo polymer concrete, alkaline solution occupies 6% by mass of concrete. So, alkaline solution is 144 kg/m^3. The ratio of alkaline liquid for GPC is 0.315. The typical molar ratio between NaOH and Na_2SiO_3 in Geo polymer concrete is around 1:2 (1 mole of NaOH for every 2 mole of Na_2SiO_3). So, NaOH required (1/3) is 48 kg/m3 solution and Na_2SiO_3 required (2/3) is 96 kg/m3. Let's assume we need water for workability, which is typically b/w 0.05 to 0.10 of binder mass (5% to 10%) and water is 42.57 kg/m^3.

CONVENTIONAL MIX DESIGN

The M50 grade mix proportion per m^3 of concrete is as per IS 10262:2019

MIX RATIO

0.35: 1: 1.495: 2.91

IV. MATERIALS PROPERTIES

This chapter covered all of the components needed to make Sustainable concrete including cement, coarse aggregate, Fly Ash, GGBS and water. It also included the computation of the concrete mix design for the cube and test findings.

1. Fly Ash Class F fly ash (a by-product of coal combustion in power plants) is used as the primary binder in the geo polymer concrete mix. Fly ash is rich in silica (SiO_2) and alumina (Al_2O_3), which are essential for the alkali activation process that forms the geo polymer matrix. In this study, Fly ash was collected from Muthu kumar traders, Metturdam, Salem, TN. The specific gravity of fly ash was 2.30

2. Ground Granulated Blast Furnace Slag (GGBS)

In some mix designs, GGBS is used as a supplementary binder to improve the workability, strength, and durability of GPC. Slag is an industrial by-product obtained from the iron-making process and is known for its cementitious properties. The slag used in this study conforms to the standard BS EN 15167-1:2006. In this study GGBS was collected from Astrra Chemicals, Moores road, Thousand lights, Chennai. The specific gravity of GGBS is 2.20

3. WATER

Potable tap water was used our campus government college of engineering, Tirunelveli as per IS 456-2000 for the plain and Reinforces cement concrete.

4. SODIUM HYDROXIDE

The sodium hydroxides are available in solid state by means of pellets and flakes. The cost of the sodium hydroxide is mainly varied according to the purity of the substance. Since our geopolymer concrete is homogeneous material and its main process to activate the sodium silicate so it is recommended to use the lowest cost i.e. up to 94% to 96% purity. It was collected from Thirumalai chemicals, Tirunelveli, Tamil Nadu. The colour of NaOH was colourless. The specific gravity of NaOH was 2.13 and its pH was 14

5. SODIUM SILICATE

Sodium silicate is also known as water glass or liquid glass, available in liquid (gel) form. In present investigation sodium silicate 2.0 (ratio between Na_2o to Sio_2) is used. As per the manufacturer, silicates were supplied to the detergent company and textile industry as bonding agent. Same sodium silicate is used for the manufacturing geo polymer concrete. It was collected from Thirumalai chemicals, Tirunelveli, Tamil Nadu.

The chemical properties and the physical properties of the silicates are given the manufacturer as follows.

Physical and chemical properties of sodium silicate

The chemical formula of sodium silicate is $Na_2O \cdot xSiO_2$, and it appears as a colourless compound. It contains 15.9% Na_2O, 31.4% SiO_2, and 52.7% H_2O. In terms of appearance, sodium silicate is in a liquid (gel) form. Its colour is described as a light yellow liquid (gel).

The boiling point of sodium silicate is 102°C for a 40% aqueous solution. The molecular weight of the compound is 184.04, and its specific gravity is 1.6.

6. Fine Aggregate (M-Sand)

M-sand-Filler, or manufactured sand, is increasingly used in concrete production as a substitute for natural sand. It is produced by crushing rocks to create particles with a cubical or angular shape, which enhances the strength and interlocking of concrete. Fine aggregate, was used for fill the concrete mix. It was collected from local region of tirunelveli, tamilnadu.

Properties of Fine Aggregate

The fine aggregate used in the study was tested and found to have a specific gravity of 2.67, which indicates the relative density of the material compared to water. The fineness modulus was recorded as 2.89, which suggests a medium range of particle size distribution. The water absorption capacity of the fine aggregate was 0.60%, meaning it can absorb 0.60% of its weight in water, which is important for mix design adjustments. The density of the fine aggregate was found to be 1670 kg/m³.

7. Coarse Aggregate

Coarse aggregate is an ingredient that gives concrete more strength and stability. Particulates larger than 4.75 mm in size are referred to be coarse aggregates. Uniform coarse aggregate with a length of 20 mm and 12.5 mm compliance with IS 383-1970 were employed in this analysis. The characteristics of coarse aggregate are shown in Table.

Properties of Coarse Aggregate

The coarse aggregate used in the study exhibited a specific gravity of 2.79, indicating a slightly higher density than the fine aggregate. The fineness modulus was noted as 7.34, which corresponds to a coarser gradation of particles. The water absorption of the coarse aggregate was 0.20%, which is relatively low, indicating good quality material. The density of the coarse aggregate was found to be 1730 kg/m³.

8. Curing

Curing in geopolymer concrete is quite different from conventional concrete. It plays a critical role in achieving strength and durability because geopolymerization is a chemical reaction that depends heavily on temperature, moisture, and time. Geopolymer concrete hardens through polymerization of aluminosilicate precursors (e.g., fly ash, slag, metakaolin) when activated by alkaline solutions. This reaction is not hydration, like in OPC, but a condensation reaction that forms three-dimensional polymeric chains. In ambient Temperature Curing, Suitable when calcium-rich materials (like GGBS) are used. It can cure like conventional concrete at room temperature (~25°C).

$$Al_2O_3 \cdot 2SiO_2 + NaOH/Na_2SiO_3 \rightarrow (–Si–O–Al–O–)_n + H_2O$$

V. DESIGN OF BEAM

The design of beam 1m span of beam, M50 grade of concrete, Fe 415 grade of steel, the breadth of beam is 0.150 m, the depth of beam is 0.100 m, the effective length provide 800 mm, clear cover of beam is 25 mm, the beam lays simply supported and one point load acting on the middle of the span.(IS 456, SP 16 Indian code are used) Area of Tension reinforcement (Ast) Ast = 251.3mm^2 Provide 4 numbers of 10 mm dia bar, Mu lim = 163.39 KN.m and Shear resistance capacity of the beam, Ʈc =1.01 N / mm ^{2}, Ʈc Max =4 N / mm^2 ,Ʈv = 2.17 N/ mm, (Check condition is Ʈv >Ʈc < Ʈc max) Hence shear reinforcement is to be provided. Provide 4 nos of 10 mm bar have longitudinal reinforcement & 8 mm dia of 2 – legged vertical stirrups at 135 mm c/c distance.

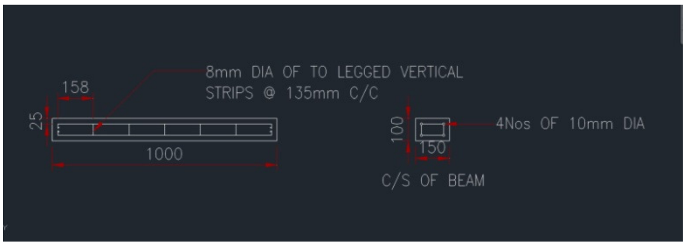


Fig 1: Beam with Reinforcement details.

Fig 2: Casting of beam

Mix Type	Compressive strength in (N/mm^2)			Average strength(N/mm^2)
	Cube 1	Cube2	Cube3	
Conventional mix	58.36	63.56	63.45	63.79
Geo polymer mix	68.21	65.89	66.25	66.78

VI. EXPERIMENTAL TESTING

Casting of test sample

A total number of 6 cubes & 8 beams were casted for compressive strength, split tensile and flexural strength test. When the Fly ash level is increased beyond 50% the mechanical properties gets affected. The GPC posses good durability properties, also the GGBS are very good alkali-resistant. They are added in GPC. Usually the w/c ratio used in GPC is 0.30-0.40 to get good mechanical properties of concrete.

Mix Type	**Split tensile strength**			**Average strength (N/mm^2)**
	Cylinder 1	Cylinder 2	Cylinder 3	
Conventional mix	4.25	5.43	4.89	4.85
Geo polymer mix	5.65	4.98	5.21	5.28

Table1: Mix designation

Mix designation	Fly Ash (%)	GGBS (%)
Conventional mix	0%	0%
Geo polymer mix	50%	50%

TEST RESULTS AND DISCUSSION

1. Workability test:

Tests were carried out an each mix to evaluate the workability characteristics. It's referred from IS 456:2000

Table 2: Slump values

Mix type	Fly Ash (%)	GGBS (%)	W/C ratio	Slump value (mm)
Conventional mix	0%	0%	0.35	97
Geo polymer mix	50%	50%	0.315	105

Slump cone tests were carried out on each mix to evaluate the workability characteristics of the concrete. In addition of (1:2 $Na_2SiO_3/NaOH$ratio) and GGBS the slump value decreased because of the properties of stiffness and low water absorption capacity.

2. Compressive strength test

The compressive strength tests are carried out on each mix at 28 days. The tests are carried out at 28 days in compression testing machine and the load carrying capacities are noted. The following tables were shows the compressive strength values at 28 days. Compression test was conducted on hydraulic compression machine (Lawrance & Mayo), Ram dia was 165 mm and its load capacity 1000 kg.

Table 3: Compressive strength at 28 days curing

3. Split tensile strength

This test gives more uniform result. The tests are carried out at 28 days n compression testing machine. It gives 5 to 12% higher value than the direct tension test. Split tensile strength is calculated using the following formula,

$$F_{sp} = 2P / \pi dl$$

Where,

F_{sp} = Split tensile strength

P = Maximum load in 'N' applies to the specimen

d = Measured diameter in 'mm' of the specimen

l = Measured length in 'mm' of the specimen

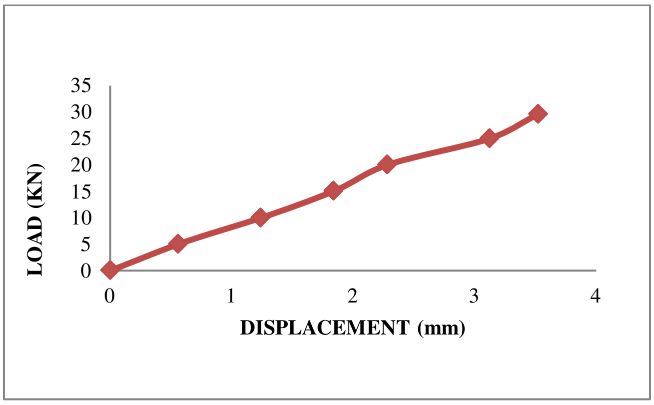
Table 4: Split tensile strength at 28 days curing

Split tensile test was conducted on compression testing machine and its load capacity was 1000 KN. Tests were carried out on each mix to evaluate the characteristics of split tensile strength of concrete. From the result, the split tensile strength attain by the concrete at 28 days was found to be increasing. At partially replaced with cement fly ash and GGBS the split tensile strength was 5.28 N/mm^2which is 8% increased. Hence it is observed the addition of GGBS and10 molarity alkaline solution increase the split tensile strength

4. Flexural strength test

The four conventional & geo polymer beams measuring 1000 x 150 x 100 mm were tested under static & cyclic loading condition with the center point loading. The instrument used for testing was Leaf Spring Testing Machine. The machine has the loading accuracy of well within+- 1% in confirmation with IS 1828/ BS1610. It is designed as per IS 1135 1984 having the maximum capacity of 200KN. The beam specimens were simply-supported on two line supports and loaded in flexure under a line load at mid-span on a span of 740 mm. The beams were loaded up to failure and their failure pattern has been obtained. This chapter helps us to understand the load deflection behaviour of conventional & geo polymer beams using flexural strength test under static & cyclic loading condition and the results are help us to compare the behaviour of conventional & geo polymer beams

Table 5: Conventional Beam Flexural strength at 28 days



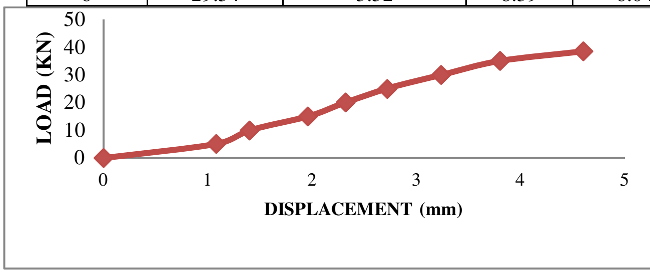
Graphical representation of Conventional Beam in Static load Act on mid-span

Cycle Number	Peak Load	Displacement	Stiffness	Stiffness Degradation
	kN	mm	kN/mm	kN/mm
1	5	0.48	10.42	
2	10	1.12	8.93	14.29%
3	15	1.59	9.43	9.50%
4	20	2.17	9.22	11.52%
5	25	3.48	7.18	31.09%
6	30	3.8	7.895	24.23%
7	35	5.16	6.78	34.93%
8	40	6.1	6.56	37.04%
9	45	7.89	5.7	45.29%
10	50	9.65	5.18	50.28%
11	52.89	11	4.81	53.84%

Table 6: Geo polymer Beam Flexural strength at 28 days Ambient curing

Load Number	Static Peak Load	Displacement	Stiffness	Stiffness Degradation
1	5	1.08	4.63	
2	10	1.4	7.14	35.15%
3	15	1.96	7.65	39.48%
4	20	2.32	8.62	46.25%
5	25	2.72	9.19	49.62%
6	30	3.24	9.26	50.00%
7	35	3.8	9.21	49.73%
8	38.51	4.6	8.37	44.68%

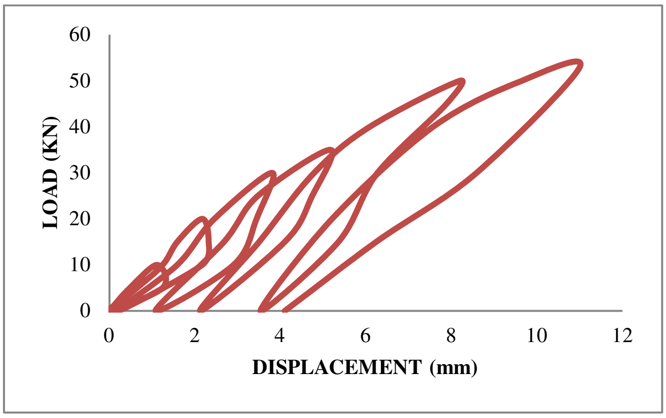
Load Number	Static Peak Load	Displacement	Stiffness	Stiffness Degradation
1	5	0.56	8.93	
2	10	1.24	8.06	9.74%
3	15	1.84	8.15	8.73%
4	20	2.28	8.77	5.63%
5	25	3.12	8.01	10.30%
6	29.54	3.52	8.39	6.04%



Graphical representation of Geo polymer Beam in Static load Act on mid-span

The Table 9 & 10 shows that behaviour of conventional & geo polymer beams under the Static loading point at mid span. From the above testing, we observed that the ultimate load carrying capacity of conventional beams was formed at the load of 29.54kN with a deflection of 3.52mm & the ultimate load carrying capacity of geo polymer beams has been observed to be 38.51kN with a corresponding deflection of 4.6mm while subjected to static loading. From the above discussion, it is seen that the geo polymer beams did not break but they did buckle.

Table 7: Conventional Beam Flexural strength at 28 days curing

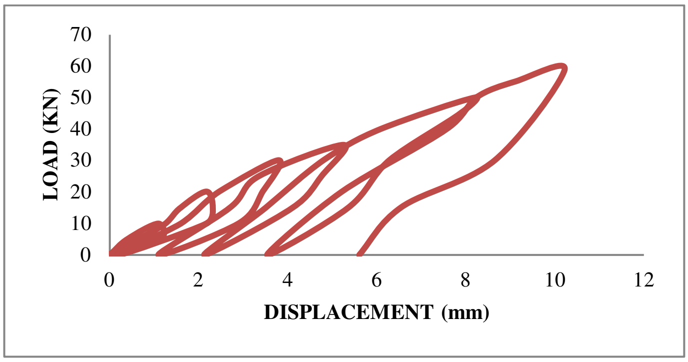


Graphical representation of Conventional Beam in Cyclic load Act on mid-span

Table 8: Geo polymer Beam Flexural strength at 28 days Ambient curing

Beam	Dry Weight	Wet Weight	Water Absorption Percentage
Conventional Beam	41.742	42.85	2.65
Geo polymer Beam	38.50	39.960	3.79

Cycle Number	Peak Load	Displacement	Stiffness	Stiffness Degradation
	kN	mm	kN/mm	kN/mm
1	5	0.4	12.5	
2	10	1.09	9.17	26.64%
3	15	1.59	9.43	24.56%
4	20	2.17	9.22	26.24%
5	25	3.35	7.46	40.32%
6	30	3.80	7.89	36.88%
7	35	5.25	6.67	46.64%
8	40	6.1	6.56	47.52%
9	45	7.89	5.7	54.40%
10	50	8.2	6.09	51.28%
11	55	9.11	6.04	51.68%
12	58.65	10.21	5.74	54.08%



Graphical representation of Geo polymer Beam in Cyclic load Act on mid-span

The Table 11 & 12 shows that behaviour of conventional & geo polymer beams under the Cyclic loading point at mid span. From the above testing, we observed that the ultimate load carrying capacity of conventional beams was formed at the load of 52.89 kN with a deflection of 11 mm & the ultimate load carrying capacity of geo polymer beams has been observed to be 58.65kN with a corresponding deflection of 10.21mm while subjected to Cyclic loading. From the above discussion, it is seen that the compare the conventional and geo polymer beams were increase 10.89 % geo polymer beam increased.

5: Water Absorption Test

The two conventional & geo polymer beams measuring 1000 x 150 x 100 mm were tested for durability. The wet weight of beam and dry weight of beam measured were in specimen weight measuring machine.

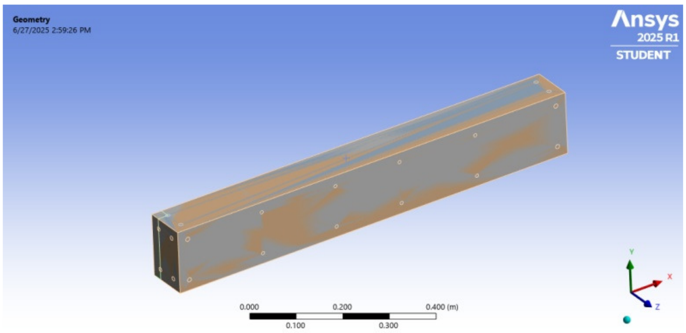
Table 9: Water Absorption Test

Water absorption tests were conducted on both conventional and geopolymer concrete beams to assess their porosity and potential durability. The conventional concrete beam wet weight was 41.742 kg and dry weight was 42.850 kg, resulting in a water absorption of 2.65%. In comparison, the geopolymer concrete beam had an dry weight was 38.500 kg and a wet weight was 39.960 kg, a water absorption of 3.79%. The higher absorption observed in the geopolymer beam indicates a slightly more porous structure compared to the conventional beam. However, both beams showed water absorption values below 5%, which is typically considered acceptable for good-quality concrete.

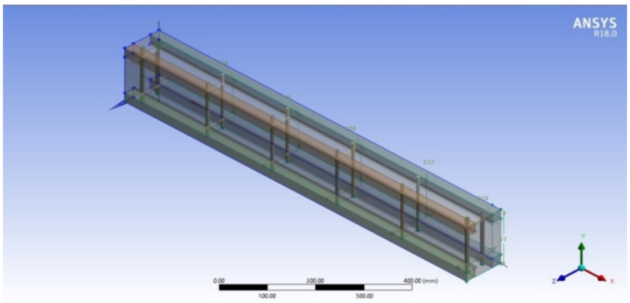
VII. ANALYTICAL TEST RESULTS

Analytical test results on designed reinforced concrete beam subjected to static loading

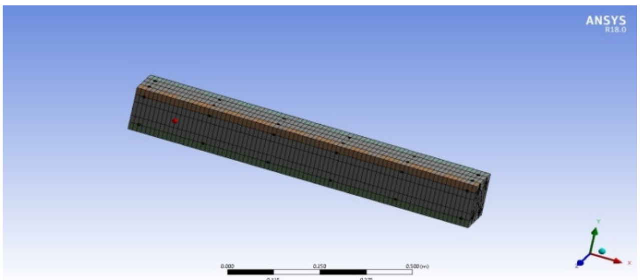
The analytical test results on the designed reinforced concrete beam subjected to static loading are given below. Figure 7.1 shows the 3D modelling of the reinforced concrete beam with dimensions 100 cm length, 15 cm breadth, and 10 cm depth. Figure 7.2 shows the meshing applied to the beam geometry, ensuring an adequate mesh density for capturing stress variations. Figure 7.3 shows the reinforcement details of the beam, including 4 longitudinal 10 mm diameter bars and 8 mm diameter two-legged stirrups placed at 135 mm center-to-center spacing.



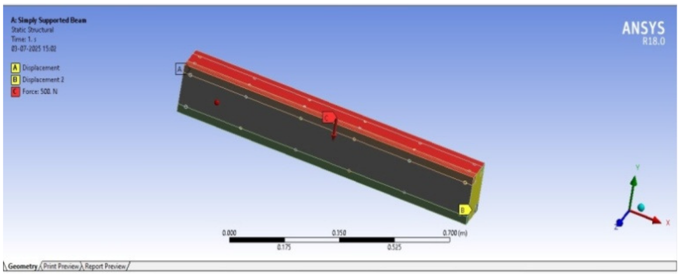
7.1 Geometry



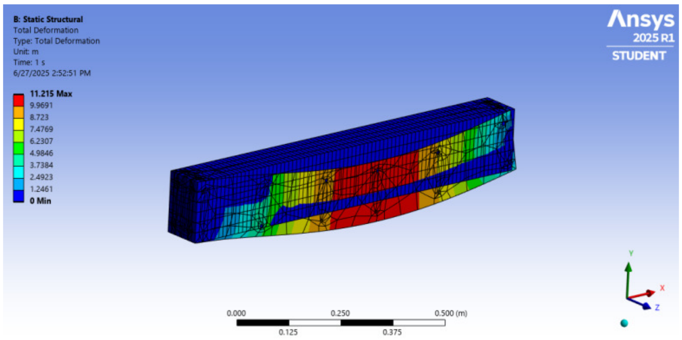
7.2 Reinforcement details of the beam



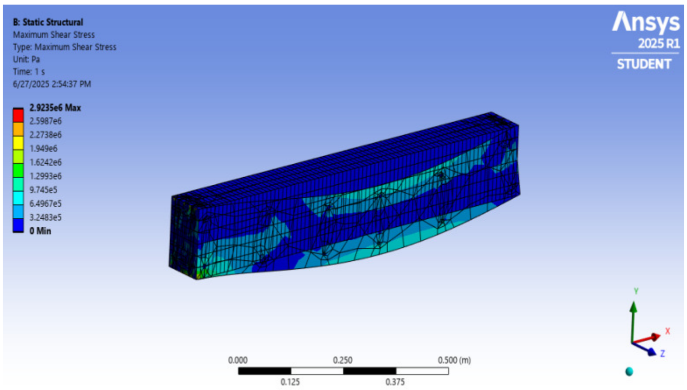
7.3 Meshing



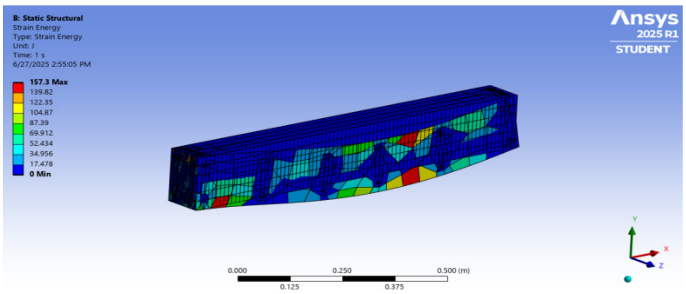
7.4 Loading condition at Mid-Span



7.5 Total Deformation



7.6 Maximum Shear Stress



7.7 Strain Energy

COMPARISON OF ANALYTICAL RESULTS WITH EXPERIMENTAL RESULTS

The analytical results of beam were compared with the experimental results under static loading. The experimentally observed ultimate loads have been given as input in the

ANSYS.

Table 10 Comparison of Analytical results with Experimental results

Contents	Load (kN)	Deflection (mm)	Stress (N/m m^2)	Strain
Analytical Results	50	12.5	21.68	0.00062
Experimental Results of Conventional Beam	29.54	3.52	19.68	0.00056
Experimental Results of Geo polymer Beam	38.51	4.6	25.67	0.00073

VIII. CONCLUSION

In this chapter, the following conclusions were obtained from comparing the test results of the experiments conducted on conventional beam and Geopolymer beam.

- 28 days "Compressive strength" partially replaced cement with fly ash and GGBS in 10 molarity of alkaline solution (Na_2SiO_3/NaOHratio is a critical factor in the Geo polymerization process, typically varying b/w 1.0 & 2.0). We take our study 1:2 ratio of alkaline solution. When compare GPC to conventional mix around 14.7% increased.
- GPC gives more workability due to addition of (1:2 Na_2SiO_3/NaOHratio) and GGBS. Alkaline solution react to get geo polymerization so, there no curing needed geo polymer concrete. Ambient curing gives more mechanical strength.
- 28 days "Split tensile strength" was increased partially replaced cement with fly ash and GGBS. When GPC compare to conventional concrete around 30% increased.
- 28 days "Flexural strength in static load" was increased partially replaced cement with fly ash and GGBS. When GPC compare to conventional concrete around 13.6% increased.
- 28 days "Flexural strength in cyclic load" was increased partially replaced with cement fly ash and GGBS. When GPC compare to conventional concrete around 8.56% increased.
- From the durability test "Water absorption at 28 days" both beams showed water absorption values below 5%, which is typically considered acceptable.
- The analytical results were also analysed by using ANSYS.
- The Analytical results were observed from ANSYS was approximately similar to the experimental results observed from static loading.
- Hence, ANSYS can be used for analytical investigation

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