

**EXPREIMENTAL INVESTIGATION AND FINITE
ELEMENT ANALYSIS OF ONE PART GEOPOLYMER
FOR SUSTAINABLE STRUCTURAL APPLICATION**

A PROJECT REPORT

Submitted by

RITHIKA A (VTP4473)

in partial fulfillment for the award of the degree of

**MASTER OF TECHNOLOGY IN
STRUCTURAL ENGINEERING**

Guided by

**Dr. A. CHITHAMBAR GANESH
ASSOCIATE PROFESSOR**

Professor in Civil Engineering

**DEPARTMENT OF CIVIL ENGINEERING SCHOOL
OF MECHANICAL & CONSTRUCTION**



Vel Tech
Rangarajan Dr. Sagunthala
R&D Institute of Science and Technology
DEEMED TO BE
University
(Estd. u/s 3 of UGC Act, 1956)
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BONAFIDE CERTIFICATE

Certified that this Report titled “**EXPREIMENTAL INVESTIGATION AND FINITE ELEMENT ANALYSIS OF ONE PART GEOPOLYMER FOR SUSTAINABLE STRUCTURAL APPLICATION**” is the bonafide work of **RITHIKA A (24PEST0011)** who carried out the work under my supervision. Certified further that to the best of my knowledge the work reported herein does not form part of any other report or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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CERTIFICATE OF EVALUATION

PROGRAM : Master of Technology
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The report of the project work submitted by the above student in partial fulfillment for the award of Master of Technology in Structural Engineering of Vel Tech Rangaraja Dr. Sagunthala R&D Institute of Science and Technology for the Viva – Voce examination held on 26-05-2026 has been evaluated and confirmed.

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ABSTRACT

This project investigates one-part geopolymer concrete prepared using fly ash, Ground Granulated Blast Furnace Slag (GGBS), sodium metasilicate as solid alkaline activator, fine aggregate, coarse aggregate and water for sustainable structural applications. The study mainly focuses on reducing the use of ordinary Portland cement and lowering CO₂ emissions while maintaining the workability, strength and structural performance required for reinforced concrete members. The one-part geopolymer system was selected because dry precursor materials and solid activator can be mixed directly with water, making the process safer, simpler and more practical than conventional liquid alkaline systems. Four trial mixes were prepared by varying fly ash–GGBS proportions and activator dosage. Fresh concrete properties were evaluated using slump test, compaction factor test and Vee-Bee test. Hardened concrete properties were determined using compressive strength, split tensile strength and flexural strength tests. Among the trial mixes, Mix3 containing 10% fly ash, 90% GGBS and 150 kg/m³ sodium metasilicate activator showed optimum performance with compressive strength of 45.8 MPa, split tensile strength of 4.1 MPa and flexural strength of 6.3 MPa. The optimum mix properties were transferred into ABAQUS for finite element analysis of a reinforced beam of size 230 mm × 300 mm × 1000 mm. Concrete Damage Plasticity (CDP) model was adopted to simulate nonlinear compression and tensile cracking behaviour of geopolymer concrete. The ABAQUS analysis evaluated stress distribution, deflection behaviour, bending response and reinforcement interaction of the reinforced OPGC beam under loading condition. The study demonstrates the integration of sustainable concrete development, experimental investigation and finite element analysis for reinforced structural applications.

Keywords: ABAQUS, Alkaline Activator, Finite Element Analysis, Fly Ash, Geopolymer Concrete, GGBS, Reinforced Beam, Sodium Metasilicate, Sustainable Concrete

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LIST OF ABBREVIATION

SYMBOL	DESCRIPTION
A	- Area
c/c	- Center to Center
CDP	- Concrete Damage Plasticity
CST	- Compressive Strength Test
D	- Depth
FA	- Fly Ash
FEM	- Finite Element Method
f_c	- Compressive Strength
f_r	- Flexural Strength
f_t	- Tensile Strength
GGBS	- Ground Granulated Blast Furnace Slag
Kg/m ³	- Kilogram per Meter Cube
L	- Length
M	- Mix
mm	- Millimeter
MPa	- Mega Pascal
mm	- Millimeter
MPa	- Mega Pascal
OPC	- Ordinary Portland Cement
P	- Load
%	- Percentage
w/b	- Water-to-Binder Ratio
π	- Pi

CHAPTER 1

1. INTRODUCTION

1.1 GENERAL

This chapter discusses geopolymer concrete, one-part geopolymer concrete, environmental benefits, aim and objectives, and the scope of the present study related to sustainable concrete and finite element analysis of reinforced geopolymer concrete beams using ABAQUS software

1.2 GEOPOLYMER CONCRETE

Geopolymer concrete is a concrete in which the binder is produced by chemical activation of alumino-silicate source materials. [1] Fly ash contributes silica and alumina, while GGBS contributes calcium-rich compounds that improve early hardening. [7] When these materials react with the alkaline activator, geopolymer and calcium alumino-silicate gel products are formed. [6] These products bind the aggregates and produce a hardened concrete matrix.

The performance of geopolymer concrete depends on binder composition, activator dosage, water content, aggregate grading and curing condition. [2] A good mix must show both workability and strength. For reinforced applications, tensile strength and flexural behaviour are also important because cracking and load transfer control the response of beam members. [8], [9]

1.3 ONE PART GEOPOLYMER CONCRETE

One-part geopolymer concrete is also known as just-add-water geopolymer concrete. [4] In this system, fly ash, GGBS and solid alkaline activator are mixed in dry form, and water is added during batching. This is different from two-part geopolymer concrete, where alkaline liquid solutions are prepared separately before casting. [5]

The one-part system is more convenient for laboratory and field use because it reduces handling difficulty and improves batching safety. [4] In the present project, four trial mixes are prepared to study the influence of binder proportion and activator dosage. The final selection of the best mix is made only after completing the fresh and hardened concrete tests. [6]

1.4 ENVIRONMENTAL BENEFITS

The main environmental benefit of one-part geopolymer concrete is the significant reduction in the use of ordinary Portland cement, which is one of the major sources of carbon dioxide (CO₂) emissions in the construction industry. [3] Fly ash and GGBS are industrial by-products, and their use in concrete supports circular material utilization by converting waste materials into useful construction products. [1] This reduces waste disposal pressure and lowers the embodied carbon of the binder system. Since cement production involves high energy consumption and large CO₂ emissions, replacing cement with geopolymer binders helps in reducing greenhouse gas emissions and promotes sustainable construction practices. [10]. Another benefit is the practical handling of the one-part system. Since the activator is added in solid form, the mixing process becomes similar to conventional dry batching used in normal concrete production. [2] This improves ease of handling, safety, storage and transportation when compared with liquid alkaline activators used in two-part geopolymer systems. The simplified mixing procedure increases the possibility of future large-scale construction applications, provided that the required strength, workability and reinforcement compatibility are achieved. [4], [5]

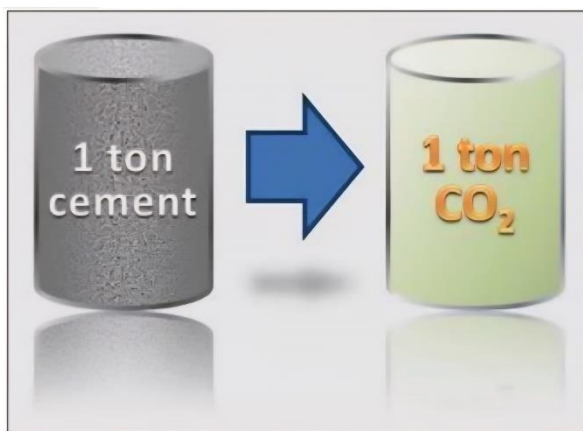


Figure 1.1 Cement and CO₂ emissions

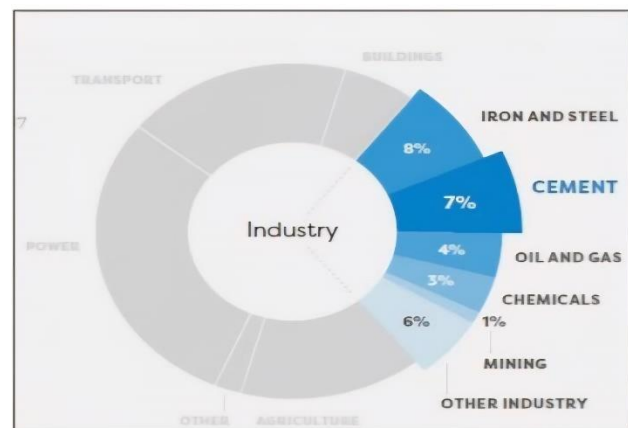


Figure 1.2 Share of global CO₂ emissions that
Comes from cement production

1.5 AIM AND OBJECTIVES

- To develop and study one-part geopolymer concrete using fly ash, GGBS, solid alkaline activator, aggregates and water.
- To prepare four trial mixes and evaluate their fresh concrete behaviour using slump, compaction factor and Vee-Bee tests.
- 3. To determine hardened concrete properties using compressive strength, split tensile strength and flexural strength tests.
- To identify the best-performing mix after experimental comparison and use its properties for reinforced beam modelling.
- To analyse a 230 mm x 300 mm x 1000 mm reinforced beam in ABAQUS and explain the structural response clearly.

1.6 SCOPE OF STUDY

- The study is limited to one-part geopolymer concrete made with fly ash, GGBS, solid activator, fine aggregate, coarse aggregate and water.
- The experimental work includes fresh tests and hardened strength tests only; long-term durability tests are discussed but not experimentally performed.
- The finite element study is limited to a reinforced beam model with concrete damage plasticity and embedded steel reinforcement.
- The cube, cylinder and prism results are used as material properties for ABAQUS, not as direct geometric conversions into the beam.
- The work provides a project-level foundation for sustainable concrete application and can be extended with durability, bond and full-scale beam testing.

CHAPTER 2

2. LITERATURE REVIEW

2.1 GENERAL

This chapter presents the literature review related to geopolymer concrete, one-part geopolymer concrete and ABAQUS analysis. It helps in understanding previous research and the background of the present study.

2.2 OVERVIEW OF GEOPOLYMER CONCRETE

J. Davidovits investigated geopolymer cement as an alternative binder system with the objective of explaining the chemistry and development of geopolymer cement. The study used alumino-silicate source materials and alkaline activators and reviewed geopolymer reaction mechanisms and binder formation. The findings showed that geopolymer cement can harden at room temperature and has lower carbon potential compared with Portland cement. The study concluded that alumino-silicate materials can be effectively used as sustainable binders in geopolymer concrete. [1]

T. Srividya et al. investigated the development and field applications of geopolymer concrete with the objective of reviewing its performance and practical applications. The study used fly ash, GGBS, alkaline activators and aggregates and reviewed fresh properties, strength, durability and field applications. The findings indicated that geopolymer concrete can achieve structural-grade strength with proper activation and curing conditions. The study concluded that geopolymer concrete is a sustainable material suitable for structural applications. [2]

M.Verma et al. investigated geopolymer concrete for sustainable development in Indian construction industries with the objective of studying geopolymer concrete as an eco-friendly construction material. The materials considered included fly ash, slag and industrial by-products. The methodology focused on reviewing material properties and environmental advantages of geopolymer systems. The findings showed that geopolymer concrete reduces cement dependency and environmental impact. The study concluded that geopolymer technology supports sustainable construction practices. [3]

2.3 PREVIOUS RESEARCH ON ONE PART GEOPOLYMER CONCRETE

S.Haruna et al. investigated long-term strength development of fly ash-based one-part alkali-activated binders with the objective of studying strength development under ambient curing conditions. The materials used included fly ash and anhydrous sodium metasilicate. Experimental evaluation was carried out for different activator dosages to study strength and durability-related behaviour. The findings showed that activator dosage influenced strength, water absorption and long-term performance. The study concluded that solid activator systems are suitable for one-part geopolymer concrete applications. [4]

I. Faridmehr et al. investigated optimization of fly ash-slag one-part geopolymers with the objective of optimizing one-part geopolymer mixtures. The materials used included fly ash, slag and alkaline source materials. The study adopted both experimental and machine learning approaches for mix optimization. The findings revealed that slag content and alkaline source content strongly influence compressive strength. The study concluded that optimization of binder and activator proportions is important in one-part geopolymer systems. [5]

B.S. Mohammed et al. investigated high-calcium fly ash one-part geopolymer cement using granular activator with the objective of studying its mechanical and microstructural properties. The materials used were high-calcium fly ash and granular activator. Mechanical testing and microstructural investigations were performed to evaluate performance. The findings showed that solid activator systems can develop useful mechanical properties without the need for liquid alkaline solutions. The study concluded that one-part geopolymer systems offer practical advantages for construction applications. [6]

2.4 MECHANICAL PROPERTIES OF OPGC

P. Janardhan et al. investigated the mechanical behaviour of fly ash and GGBS based geopolymer concrete with the objective of studying the role of fly ash and GGBS in strength development. The materials used included fly ash, GGBS, alkaline activator and aggregates. Experimental evaluation of mechanical properties was carried out. The findings showed that GGBS improved strength, while fly ash contributed to workability and long-term reaction. The study concluded that blended fly ash-GGBS binders improve geopolymer concrete performance. [7]

K. K. Poloju et al. investigated the impact of GGBS and strength ratio on geopolymer concrete with the objective of studying the influence of GGBS content on mechanical properties. The materials used included fly ash, GGBS, alkaline activator and aggregates. Different mix proportions were experimentally tested for compressive and tensile strength. The findings indicated that suitable GGBS replacement improved mechanical performance. The study concluded that proper binder proportioning is important for geopolymer concrete performance. [8]

G. S. Ryu et al. investigated the mechanical properties of fly ash-based geopolymer concrete with alkaline activators with the objective of studying the effect of activator chemistry on strength behaviour. The materials used were fly ash and alkaline activators. Experimental evaluation was carried out under different activator conditions. The findings showed that activator selection and mixture design influence strength development. The study concluded that activator chemistry plays a major role in geopolymer concrete performance. [9]

2.5 DURABILITY STUDIES

C. Zhao et al. investigated carbonation behaviour of geopolymer concrete with the objective of reviewing durability mechanisms in geopolymer systems. The study considered different geopolymer binder systems and reviewed pore structure, binder chemistry and exposure conditions. The findings showed that carbonation behaviour depends on binder chemistry and environmental exposure. The study concluded that durability evaluation is important for long-term geopolymer concrete applications. [10]

Srividya et al. investigated the development and field applications of geopolymer concrete with the objective of studying reinforcement interaction and structural applications of geopolymer concrete. The materials used included geopolymer concrete and steel reinforcement. The methodology involved reviewing bond behaviour, structural performance and reinforcement compatibility in geopolymer systems. The findings showed that bond between steel reinforcement and geopolymer concrete is an important factor for structural applications. The study concluded that structural-grade geopolymer concrete should be evaluated beyond compressive strength alone and supports the reinforcement modelling adopted in the present ABAQUS study. [2]

Zinkaah et al. investigated numerical and theoretical analysis of FRP reinforced geopolymer concrete beams with the objective of studying flexural behaviour of reinforced geopolymer beams using finite element analysis. The materials used included geopolymer concrete and FRP reinforcement bars. Nonlinear 3D finite element models were developed in ABAQUS to analyse beam behaviour. The findings showed that numerical models can accurately predict geopolymer beam response when validated with available beam data. The study concluded that finite element modelling is reliable for understanding reinforced geopolymer beam behaviour and supports the use of FEM in the present project. [13]

2.6 REINFORCEMENT IN GEOPOLYMER CONCRETE

T. Srividya et al. investigated the development and field applications of geopolymer concrete with the objective of studying the bond behaviour between steel reinforcement and geopolymer concrete for structural applications. The materials used included geopolymer concrete and steel reinforcement. The methodology involved reviewing reinforcement interaction, structural behaviour and field applications of geopolymer concrete. The findings showed that bond behaviour between steel and geopolymer concrete is important for structural performance. The study concluded that structural-grade geopolymer concrete must be evaluated beyond compressive strength alone and supports the reinforcement modelling adopted in the present ABAQUS study. [2]

N. A. M. Mortar et al. investigated the structural behaviour of geopolymer reinforced concrete beams using ABAQUS with the objective of analysing reinforced geopolymer concrete beams numerically. The materials used included geopolymer concrete and steel reinforcement. ABAQUS finite element modelling with Johnson-Cook damage modelling was adopted to study beam behaviour under loading conditions. The findings showed stress distribution, displacement and damage response in reinforced geopolymer beams. The study concluded that numerical modelling can effectively predict reinforced geopolymer beam behaviour and supports the reinforced beam analysis carried out in the present project. [11]

O. H. Zinkaah et al. investigated numerical and theoretical analysis of FRP reinforced geopolymer concrete beams with the objective of studying flexural behaviour using finite element analysis. The materials used included geopolymer concrete and FRP reinforcement bars. Nonlinear 3D finite element models were developed in ABAQUS to analyse beam behaviour. The findings showed that numerical models can accurately predict geopolymer beam response when validated with available beam data. The study concluded that finite element modelling is reliable for understanding reinforced geopolymer beam behaviour and supports the use of FEM in the present project. [13]

2.7 FINITE ELEMENT ANALYSIS STUDIES

A. Chithambar Ganesh and Muthukannan investigated finite element analysis of geopolymer concrete using ABAQUS with the objective of comparing the flexural behaviour of ordinary concrete and geopolymer concrete. The materials used included conventional concrete and geopolymer concrete. ABAQUS finite element modelling was adopted to study deformation, cracking pattern and load-deflection behaviour. The findings showed that finite element analysis effectively predicts structural response, deformation and cracking behaviour of geopolymer concrete beams. The study concluded that ABAQUS is suitable for analysing the flexural behaviour of geopolymer concrete members and supports the numerical analysis carried out in the present project. [12]

N. A. M. Mortar et al. investigated finite element analysis on structural behaviour of geopolymer reinforced concrete beams using ABAQUS with the objective of studying stress and damage response under loading conditions. The materials used included geopolymer concrete and steel reinforcement. ABAQUS numerical modelling with Johnson-Cook damage modelling was adopted to analyse stress distribution, displacement and damage response. The findings showed that finite element analysis can effectively evaluate reinforced geopolymer concrete beam behaviour under loading. The study concluded that numerical modelling is useful for understanding stress and damage characteristics in reinforced geopolymer concrete beams and supports the present reinforced OPGC beam analysis. [11]

O. H. Zinkaah et al. investigated numerical and theoretical analysis of FRP reinforced geopolymer concrete beams with the objective of studying flexural performance using nonlinear finite element analysis. The materials used included geopolymer concrete and FRP reinforcement bars. Nonlinear 3D finite element modelling was performed in ABAQUS to analyse beam behaviour. The findings showed that geometry, material properties and proper validation are essential for reliable finite element analysis. The study concluded that ABAQUS modelling can accurately evaluate flexural behaviour of reinforced geopolymer concrete beams and supports the modelling procedure used in the present project. [13]

2.8 RESEARCH SUMMARY

The reviewed studies show that geopolymer concrete is a promising sustainable binder system when source materials, activator dosage and curing conditions are properly selected. One part geopolymer concrete is especially useful because it follows a simpler dry mixing and water addition method. The literature also confirms that structural application requires more than compressive strength; tensile behaviour, flexural behaviour and reinforcement interaction must also be considered.

The present project addresses this requirement by preparing four trial mixes, testing fresh and hardened properties and then using the selected experimental material properties in ABAQUS. The literature review therefore supports the complete project path from material development to reinforced beam analysis.

CHAPTER 3

3. MATERIALS AND METHODOLOGY

3.1 GENERAL

This chapter discusses the materials used for preparing one-part geopolymer concrete and the methodology adopted for experimental testing and ABAQUS finite element analysis.

The chapter also explains the fresh concrete tests, hardened concrete tests and reinforced beam modelling procedure followed in the present study.

3.2 MATERIALS USED

The materials used in this study are fly ash, GGBS, fine aggregate, coarse aggregate, solid alkaline activator, water and steel reinforcement. Fly ash and GGBS act as the source materials. The solid activator starts the chemical reaction, aggregates form the skeleton of concrete and water provides the mixing medium.\

Table 3.1 IS Codes and Purpose of Using Materials in OPGC

Material	Reference / Guidance	Purpose
Fly ash	IS 3812 (Part 1)	Alumino-silicate precursor
GGBS	IS 16714	Calcium-rich supplementary binder
Fine aggregate	IS 383 and IS 2386	Workability and packing
Coarse aggregate	IS 383 and IS 2386	Skeleton and strength
Water	IS 456 guidance	Mixing and reaction medium
Steel reinforcement	IS 1786	Tension resistance in beam
Fresh concrete tests	IS 1199	Workability evaluation
Hardened tests	IS 516 and IS 5816	Strength evaluation

3.2.1 FLY ASH

The fly ash used in the present study was obtained from a local thermal power plant ash supplier. The material conforms to IS 3812 (Part 1) requirements. The fly ash possessed a specific gravity of 2.20 and was classified as Class F fly ash. It is rich in silica and alumina, which are essential for geopolymer gel formation and long-term strength development.

3.2.2 GGBS

The Ground Granulated Blast Furnace Slag (GGBS) used in this project was procured from a local slag material supplier and satisfied IS 16714 specifications. The material had a specific gravity of 2.85 and belonged to Grade 120 classification. GGBS contributed calcium content, which improved early strength and supported ambient curing conditions.

3.2.3 ALKALINE ACTIVATOR

The alkaline activator used in the present study was sodium metasilicate in solid powder form obtained from a local chemical supplier. The activator had a specific gravity of approximately 2.40. Sodium metasilicate was selected because it effectively dissolves silica and alumina from fly ash and GGBS and initiates the geopolymerisation reaction in the one-part geopolymer system.

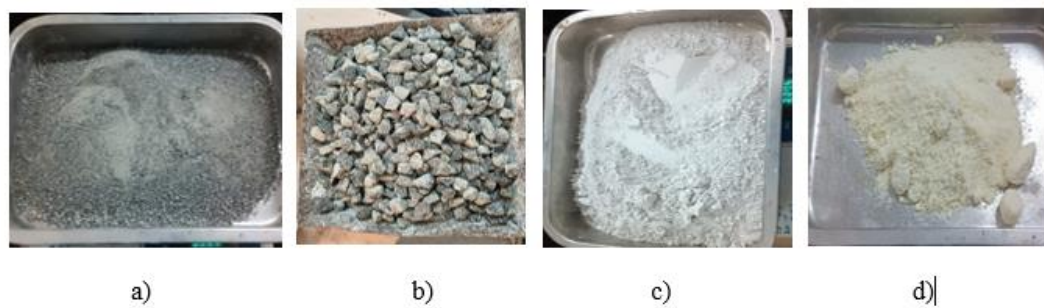


Figure 3.1 Raw materials a) GGBS b) CA c) FA d) Na_2SiO_3

3.2.4 FINE AGGREGATE

The fine aggregate used in this study was manufactured sand (M-sand) collected from a local sand supplier. The material conformed to IS 383 requirements. The fine aggregate had a specific gravity of 2.65, fineness modulus of 2.75 and belonged to Zone II grading. The material was clean and properly graded to improve concrete cohesion and workability.

3.2.5 COARSE AGGREGATE

The coarse aggregate used in the present work was crushed stone aggregate of 20 mm maximum size obtained from a local quarry. The aggregate properties were evaluated according to IS 2386. The coarse aggregate possessed a specific gravity of 2.70 and fineness modulus of 6.90. Well-graded and clean aggregates were selected to provide strength and stiffness to the concrete matrix.

3.2.6 STEEL REINFORCEMENT

The reinforcement considered in the beam analysis was Fe500 grade steel obtained from a local steel supplier and conforming to IS 1786. The steel reinforcement had a specific gravity of 7.85 and was selected because of its high strength and common use in reinforced concrete structures. The reinforcement arrangement included longitudinal bars and stirrups to represent flexural and shear resistance in the ABAQUS beam model.

3.2.7 MIX DESIGN OF OPGC

Four trial mixes are prepared to compare the effect of fly ash-GGBS ratio, activator dosage and water-to-binder ratio. At this stage, no mix is declared optimum. The purpose of the mix design table is only to show the planned proportions used for experimental comparison.

3.2.8 CASTING PROCEDURE

The dry materials are weighed accurately before mixing. Fly ash, GGBS and solid activator sodium metasilicate are first blended to obtain a uniform binder. Fine aggregate and coarse aggregate are then added. Water is introduced gradually and mixing is continued until a uniform fresh concrete is obtained. Fresh tests are conducted immediately because workability may change with time.

Concrete is placed in cube, cylinder and prism moulds in layers and compacted using tamping or vibration. Each specimen is marked with the mix number and casting date. Cubes are used for compression, cylinders for split tensile testing and prisms for flexural testing. These specimen shapes are different because each test measures a different property.

3.2.9 CURING METHOD

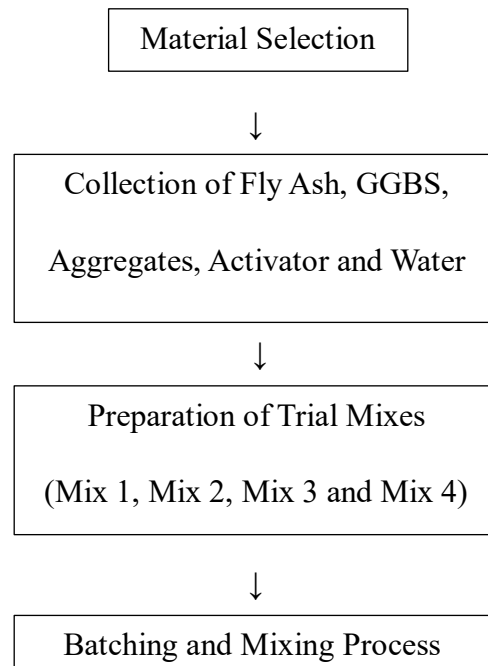
Ambient curing is used because one-part geopolymer concrete is intended for practical field application. After casting, specimens are left undisturbed until initial hardening and then demoulded. All mixes are cured under the same condition so that the test results can be compared fairly.

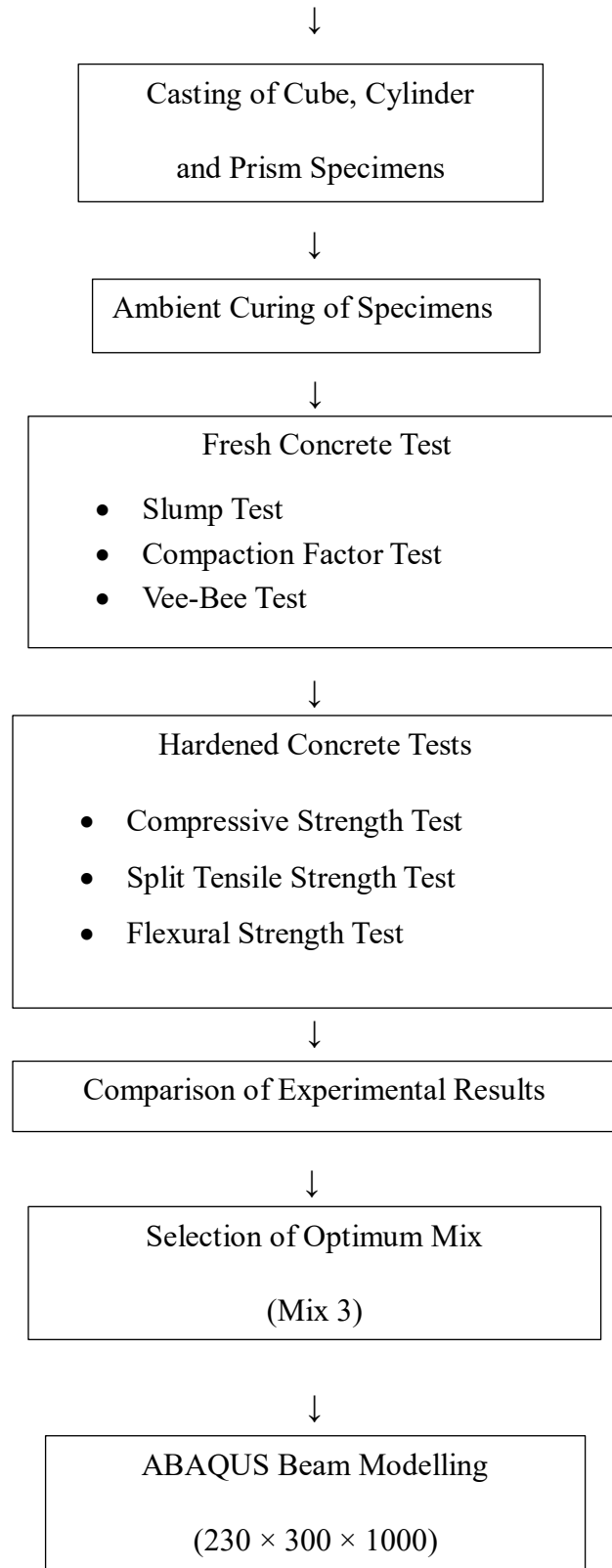
Table 3.2: Mix Design Details for OPGC Trial Mixes

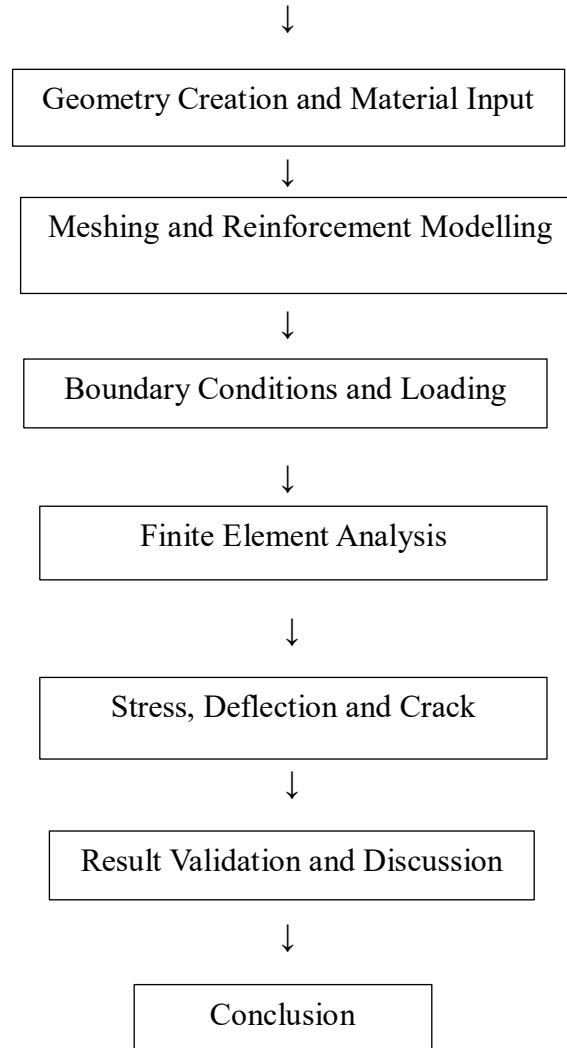
Mix	Fly Ash %	GGBS %	Binder kg/m ³	Fly Ash kg/m ³	GGBS kg/m ³	Fine agg. kg/m ³	Coarse agg. kg/m ³	Sodium Metasilicate kg/m ³	Water kg/m ³	w/b
Mix 1	30	70	500	150	350	589	1041	100	175	0.35
Mix 2	20	80	500	100	400	579	1027	125	175	0.35
Mix 3	10	90	500	50	450	569	1006	150	175	0.35
Mix 4	15	85	500	75	425	559	989	175	175	0.35

3.3 METHODOLOGY

The methodology of the present study was planned to evaluate the behaviour of one-part geopolymer concrete for sustainable structural applications. The complete sequence of experimental investigation and finite element analysis adopted in this project is illustrated in the following flowchart.







3.4 EXPERIMENTAL INVESTIGATION

3.4.1 SLUPM TEST

- The slump test was conducted to determine the workability and consistency of fresh one-part geopolymer concrete mixes prepared in the present study.
- The test was carried out according to IS 1199 [19] guidelines.
- Before starting the test, the slump cone apparatus, tamping rod and base plate were cleaned properly.
- The slump cone was placed on a smooth and level non-absorbent surface.
- Fresh geopolymer concrete was filled into the cone in three equal layers.
- Each layer was compacted uniformly with 25 blows using the tamping rod.

- After compacting the top layer, the surface was levelled carefully using a trowel.
- The slump cone was lifted vertically in a slow and steady manner without disturbing the concrete.
- The concrete subsided under its own weight after removal of the cone.
- The vertical difference between the original height of the cone and the slumped concrete was measured and recorded as the slump value.
- The slump values obtained from all trial mixes were compared to evaluate the workability behaviour of the geopolymer concrete mixes

3.4.2 Compaction Factor Test

- The compaction factor test was conducted to evaluate the compactability and workability of fresh one-part geopolymer concrete mixes having low and medium workability.
- The test procedure was carried out according to IS 1199 [19] recommendations.
- Before testing, the compaction factor apparatus was cleaned properly and the trap doors were checked.
- Fresh geopolymer concrete was gently placed into the upper hopper without applying manual compaction.
- The top surface of concrete in the upper hopper was levelled carefully.
- The trap door of the upper hopper was opened so that the concrete fell into the lower hopper.
- Immediately, the trap door of the lower hopper was opened and the concrete was allowed to fall into the cylindrical mould.
- Excess concrete at the top of the cylinder was removed carefully using a trowel.
- The weight of partially compacted concrete was measured and recorded.
- The cylinder was emptied and refilled with fresh concrete in layers.

- Each layer was fully compacted using a tamping rod to obtain completely compacted concrete.
- The weight of fully compacted concrete was measured and recorded.
- The compaction factor was calculated as the ratio of partially compacted concrete weight to fully compacted concrete weight.
- The obtained compaction factor values were compared for all geopolymer concrete trial mixes.

3.4.3 Vee-Bee Test

- The Vee-Bee consistometer test was conducted to determine the consistency and remoulding characteristics of fresh one-part geopolymer concrete mixes.
- The test was carried out according to IS 1199 [19] provisions.
- The Vee-Bee consistometer apparatus was cleaned properly before conducting the test.
- The slump cone was placed centrally inside the cylindrical container of the apparatus.
- Fresh geopolymer concrete was filled into the slump cone in layers.
- Each layer was compacted uniformly using the tamping rod.
- After filling and compaction, the top surface was levelled properly.
- The slump cone was lifted vertically to allow the concrete to subside freely.
- The transparent disc attached to the rotating arm was gently placed over the concrete surface.
- The vibrating table was switched on immediately after placing the disc.
- The concrete gradually remoulded from the slump shape into a cylindrical shape under vibration.
- The time required for complete remoulding was measured using a stopwatch and recorded as the Vee-Bee time.

- The same procedure was repeated for all geopolymer concrete mixes and the obtained Vee-Bee times were compared.

3.4.4 Compressive Strength Test

- The compressive strength test was conducted to determine the load carrying capacity and compressive strength of hardened one-part geopolymer concrete specimens.
- The test was carried out according to IS 516 [20] guidelines.
- Cube specimens of size 150 mm × 150 mm × 150 mm were cast for all trial mixes.
- After casting, the specimens were kept undisturbed for 24 hours and then demoulded carefully.
- The demoulded specimens were cured under ambient laboratory conditions until the testing age.
- Before testing, the cube specimens were cleaned properly and surface moisture was removed.
- The dimensions of the cube specimens were checked before placing them in the compression testing machine.
- The specimen was placed centrally on the compression testing machine platform.
- Load was applied gradually and continuously without shock until failure occurred.
- The maximum load at failure was recorded for each specimen.
- The compressive strength was calculated using the relation:
- $$f_c = \frac{P}{A}$$
- The compressive strength values obtained for different trial mixes were compared to identify the optimum mix.

3.4.5 Split Tensile Strength Test

- The split tensile strength test was conducted to evaluate the tensile behaviour of hardened one-part geopolymer concrete.
- The test was performed according to IS 5816 [21] provisions.
- Cylindrical specimens of standard dimensions were cast for all geopolymer concrete mixes.
- The specimens were demoulded after 24 hours and cured under ambient laboratory conditions until the testing age.
- Before testing, the cylinder surfaces were cleaned and dried properly.
- The dimensions of the specimens were measured carefully before testing.
- The cylindrical specimen was placed horizontally between the loading plates of the compression testing machine.
- Packing strips were placed along the top and bottom generator lines of the specimen to ensure uniform load distribution.
- Load was applied gradually and continuously until the cylinder failed by splitting along the vertical diameter.
- The maximum applied load at failure was recorded.
- The split tensile strength was calculated using the formula:
- $$f_t = \frac{2P}{\pi DL}$$
- The obtained tensile strength values were compared for all trial mixes to evaluate tensile performance.

3.4.6 Flexural Strength Test

- The flexural strength test was conducted to determine the bending strength and crack resistance of hardened one-part geopolymer concrete.
- The test was carried out according to IS 516 [20] recommendations.

- Prism specimens were cast for all geopolymer concrete trial mixes.
- After casting, the specimens were demoulded after 24 hours and cured under ambient laboratory conditions until the testing date.
- Before testing, the prism specimens were cleaned and their dimensions were measured properly.
- The specimen was placed on the flexural testing machine with proper support spacing.
- Two-point loading arrangement was adopted during the test.
- Load was applied gradually without shock until failure occurred in the specimen.
- The maximum load carried by the specimen before cracking and failure was recorded.
- The flexural strength or modulus of rupture was calculated using the standard flexural strength equation.
- $f_r = \frac{PL}{bd^2}$
- Crack pattern and failure behaviour of the prism specimens were observed during testing.
- The flexural strength values obtained from all mixes were compared to identify the optimum geopolymer concrete mix.

CHAPTER 4

4. EXPERIMENTAL RESULTS AND INVESTIGATION

4.1 GENERAL

This chapter presents the experimental results and investigation carried out on one-part geopolymer concrete mixes. The fresh concrete properties, hardened concrete strength results and comparison of trial mixes are discussed to identify the optimum mix.

4.2 FRESH CONCRETE TESTS

Fresh concrete tests are conducted to understand the behaviour of concrete before hardening. Workability is important because concrete must be placed and compacted without segregation. In OPGC, workability depends on fly ash content, GGBS content, activator dosage, aggregate grading and water content.

4.2.1 SLUMP TEST

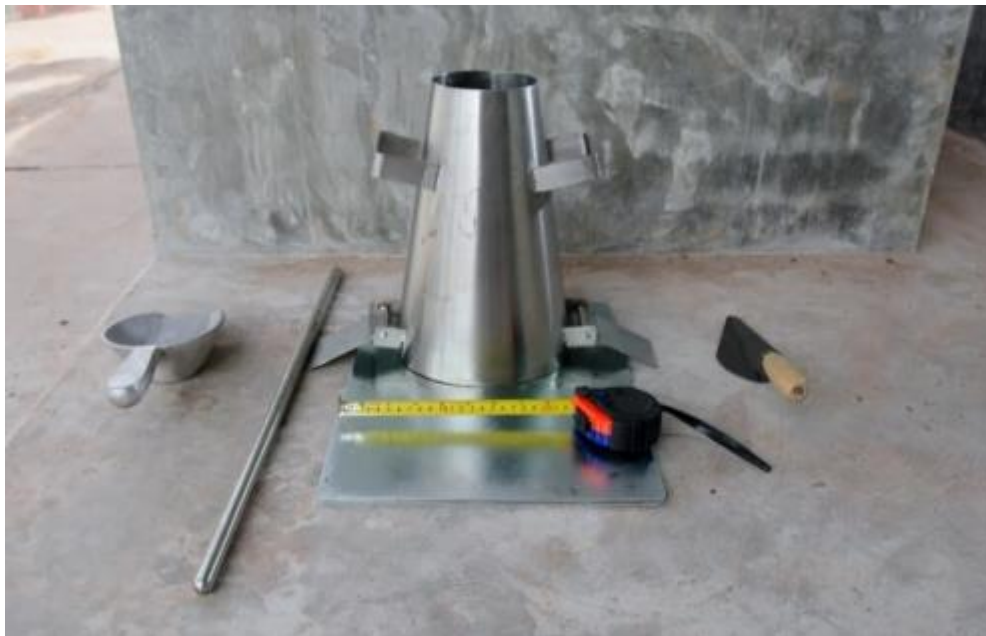


Figure 4.1 Slump Cone Apparatus used for the Slump Test of Concrete

The slump test measures the consistency and flowability of fresh concrete. The test is performed using a slump cone and tamping rod. A very low slump indicates a stiff mix, while an excessively high slump may indicate loss of cohesion. For structural concrete, the mix should be workable but stable.

Table 4.1 Slump values of various OPGC mixes

Mix	Slump value (mm)	Interpretation
Mix 1	62	Stiffer trial mix
Mix 2	78	Improved workability
Mix 3	92	Workable and cohesive
Mix 4	105	High flow but not necessarily best strength balance

The slump values increase from Mix 1 to Mix 4. Mix 4 gives the highest slump, but highest flow alone is not enough for selection. Mix 3 provides good workability without excessive flow, so it is suitable for casting and compaction.

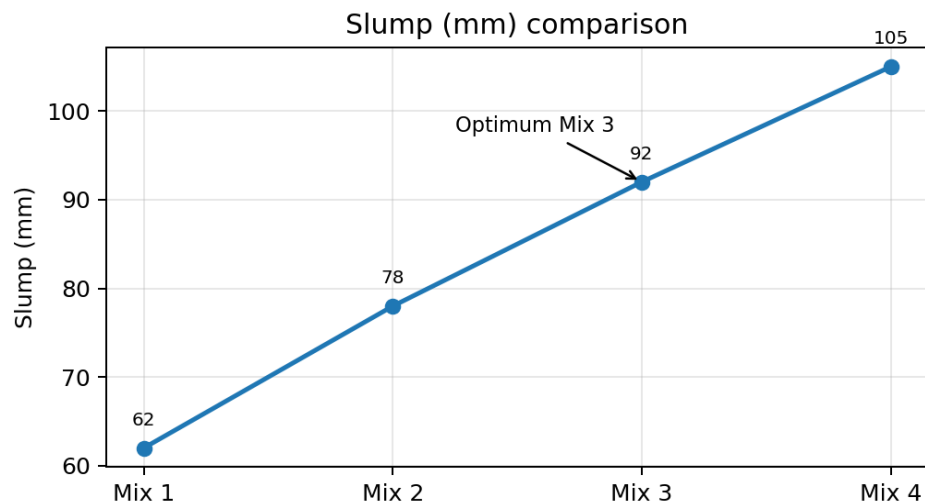


Figure 4.2 Slump Test Result

4.2.2 COMPACTION FACTOR TEST

The compaction factor test evaluates how efficiently concrete can be compacted under standard dropping conditions. This test is useful because a concrete mix may have acceptable slump but still may not compact well. Good compactability reduces air voids and improves hardened strength.



Figure 4.3 Compaction Factor Test Apparatus

Table 4.2 Compaction factor of various OPGC mixes

Mix	Compaction factor	Interpretation
Mix 1	0.86	Lower compactability
Mix 2	0.89	Moderate compactability
Mix 3	0.94	Best compactability
Mix 4	0.91	Good, but lower than Mix 3

Mix 3 gives the highest compaction factor value. This indicates that it can be placed and compacted more efficiently than the other trial mixes. The result is important because proper compaction improves strength and reduces defects.

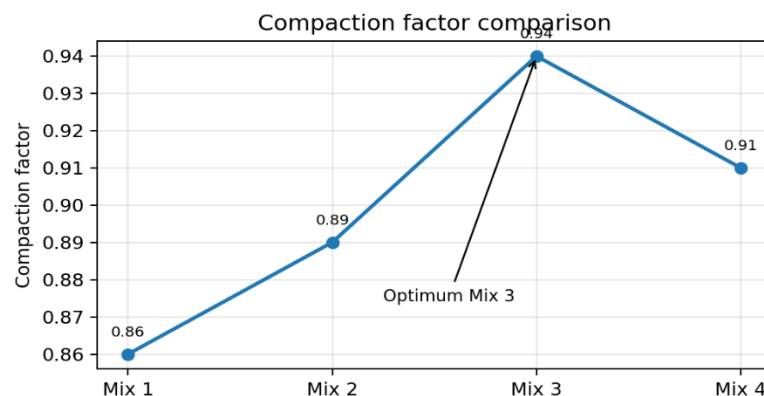


Figure 4.4 Compaction factor Test Result

4.2.3 VEE-BEE TEST

The Vee-Bee test measures the time required for concrete to remould under vibration. A lower time indicates higher workability. The test is useful for mixes where cohesiveness and vibration response must be observed.



Figure 4.5 Vee-Bee Consistometer Apparatus

Table 4.3 Vee-Bee values for various OPGC mixes

Mix	Vee-Bee time (s)	Interpretation
Mix 1	12	Stiff mix
Mix 2	9	Moderate workability
Mix 3	6	Good workability with cohesion

Mix 4	5	Very workable but not best in strength comparison
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Mix 3 gives a Vee-Bee time of 6 seconds, which indicates that the mix responds well to vibration. Mix 4 gives a slightly lower time, but later strength results show that Mix 3 provides better overall performance. Therefore, the fresh test results support Mix 3 as a balanced mix.

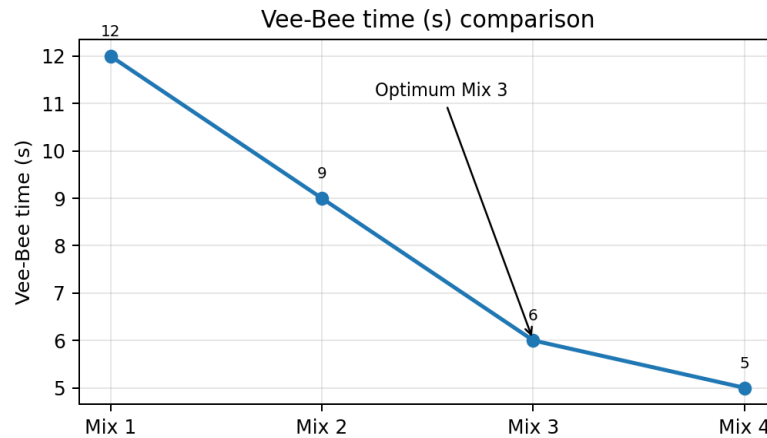


Figure 4.6 Vee-Bee Test Result

4.3 HARDENED CONCRETE TESTS

Hardened concrete tests are performed after curing to determine the mechanical properties of each mix. Cube specimens are used for compressive strength, cylinders for split tensile strength and prisms for flexural strength. These tests provide the values required for selecting the optimum mix and defining the ABAQUS material model.

4.3.1 COMPRESSIVE STRENGTH TEST

The compressive strength test is conducted on 150 mm cube specimens. Load is applied in a compression testing machine until failure. The compressive strength is calculated by dividing the ultimate load by the loaded area. This test shows the crushing resistance of the concrete matrix.



Figure 4.7 Compressive Strength Testing

Table 4.4 Compressive Strength for various OPGC mixes

Material	Quantity per m ³	Quantity per 150 mm cube
Binder	500 kg	1.688 kg
Fly ash	50 kg	0.169 kg
GGBS	450 kg	1.519 kg
Fine aggregate	569 kg	1.920 kg
Coarse aggregate	1006 kg	3.395 kg
Sodium metasilicate	150 kg	0.506 kg
Water	175 kg	0.591 kg
Mix	28-day Compressive Strength (MPa)	Remarks
Mix 1	31.2	Trial mix
Mix 2	38.6	Improved strength
Mix 3	45.8	Highest compressive strength
Mix 4	42.1	Lower than Mix 3

The compressive strength results show that Mix 3 achieved the highest 28-day compressive strength of 45.8 MPa. This indicates that its binder ratio and activator dosage produced the most effective hardened matrix among the four mixes.

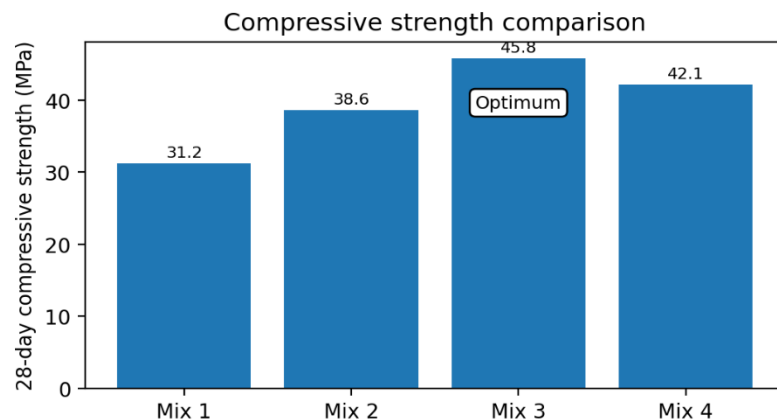


Figure 4.8 Compressive Strength Test Graph

4.3.2 SPLIT TENSILE STRENGTH TEST

The split tensile strength test is conducted on 150 mm diameter and 300 mm height cylinders. The cylinder is placed horizontally and loaded along its length. The test indirectly measures tensile resistance, which is the tensile stress exceeds its capacity.



Figure 4.9 Split Tensile Strength Testing

Table 4.5 Split Tensile Strength for various OPGC mixes

Material	Quantity per m3	Quantity per cylinder
Binder	500 kg	2.650 kg
Fly ash	50 kg	0.265 kg
GGBS	450 kg	2.385 kg
Fine aggregate	569 kg	3.016 kg
Coarse aggregate	1006 kg	5.332 kg
Sodium metasilicate	150 kg	0.795 kg
Water	175 kg	0.928 kg
Mix	28-day split tensile strength (MPa)	Remarks
Mix 1	2.7	Trial mix
Mix 2	3.3	Improved tensile response

Mix 3	4.1	Highest tensile strength
Mix 4	3.8	Lower than Mix 3

Mix 3 achieved the highest split tensile strength of 4.1 MPa. This value is later used in ABAQUS as the tensile cracking stress. It is important for predicting crack initiation in the reinforced beam model.

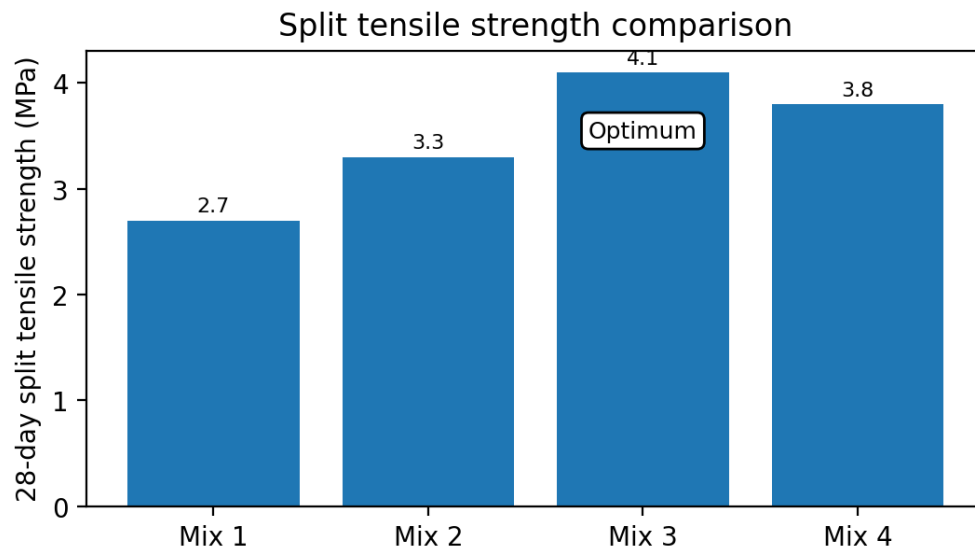


Figure 4.10 Split Tensile Strength Test Result

4.3.3 FLEXURAL STRENGTH TEST

The flexural strength test is conducted on 150 mm x 150 mm x 700 mm prism specimens. The prism is loaded in bending to determine the modulus of rupture. This test is directly relevant to beam behaviour because beams fail mainly due to bending and cracking.



Figure 4.11 Flexural Strength Testing

Table 4.6 Flexural Strength for various OPGC mixes

Material	Quantity per m3	Quantity per prism
Binder	500 kg	7.875 kg
Fly ash	50 kg	0.788 kg
GGBS	450 kg	7.088 kg
Fine aggregate	569 kg	8.962 kg
Coarse aggregate	1006 kg	15.845 kg
Sodium metasilicate	150 kg	2.363 kg
Water	175 kg	2.756 kg
Mix	28-day flexural strength (MPa)	Remarks
Mix 1	4.2	Trial mix
Mix 2	5.1	Improved flexural response
Mix 3	6.3	Highest flexural strength
Mix 4	5.8	Lower than Mix 3

Mix 3 achieved the highest flexural strength of 6.3 MPa. Considering the fresh and hardened results together, Mix 3 is selected as the optimum mix for this project. From this point onward, Mix 3 properties are used for ABAQUS analysis of the reinforced beam.

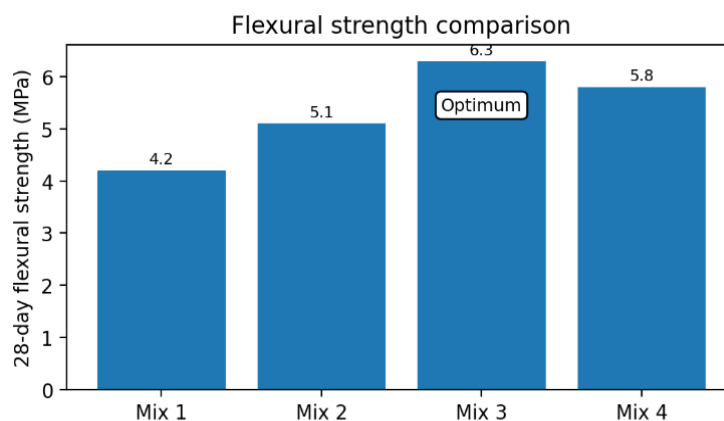


Figure 4.12 Flexural Strength Test Result

CHAPTER 5

5. FINITE ELEMENT ANALYSIS USING ABAQUS

5.1 GENERAL

This section presents the ABAQUS analysis results obtained for the reinforced one-part geopolymer concrete beam. The stress distribution, deflection response, bending behaviour and shear force behaviour are discussed to understand the structural performance of the 230 mm $\times$ 300 mm $\times$ 1000 mm OPGC beam under loading condition.

5.2 INTRODUCTION TO ABAQUS

ABAQUS was used to simulate the structural behaviour of the reinforced one-part geopolymers concrete (OPGC) beam. The analysis extended the experimental investigation from material level to structural member level by transferring Mix 3 material properties into the finite element model. The concrete beam was modelled using three-dimensional solid elements, while steel reinforcement was modelled using embedded truss elements. The analysis mainly focused on stress distribution, deformation response, cracking tendency and load-carrying behaviour of the beam under static loading condition [11], [12].

5.3 TRANSFER OF EXPERIMENTAL RESULTS TO ABAQUS

The experimental compressive strength, split tensile strength and flexural strength values obtained from Mix 3 were assigned as material properties in ABAQUS. The cube, cylinder and prism specimens were not directly converted into beam geometry. Instead, their strength values were used to define the behaviour of the reinforced beam model with dimensions of 230 mm × 300 mm × 1000 mm. The compressive strength of 45.8 MPa, split tensile strength of 4.1 MPa and flexural strength of 6.3 MPa were used for Concrete Damage Plasticity (CDP) modelling in ABAQUS [11], [12].

5.4 GEOMETRY PROPERTIES INPUT

The beam geometry is created with 230 mm width, 300 mm depth and 1000 mm length. The concrete part is defined as a deformable solid. Reinforcement bars are positioned inside the concrete with suitable cover. The bottom bars resist tensile stress under bending, while top bars and stirrups support the reinforcement cage and shear resistance.

Correct geometry is essential because beam stiffness depends on depth, width and reinforcement position. Any error in geometry changes the moment of inertia and load response. Therefore, dimensions must be checked before meshing and analysis.

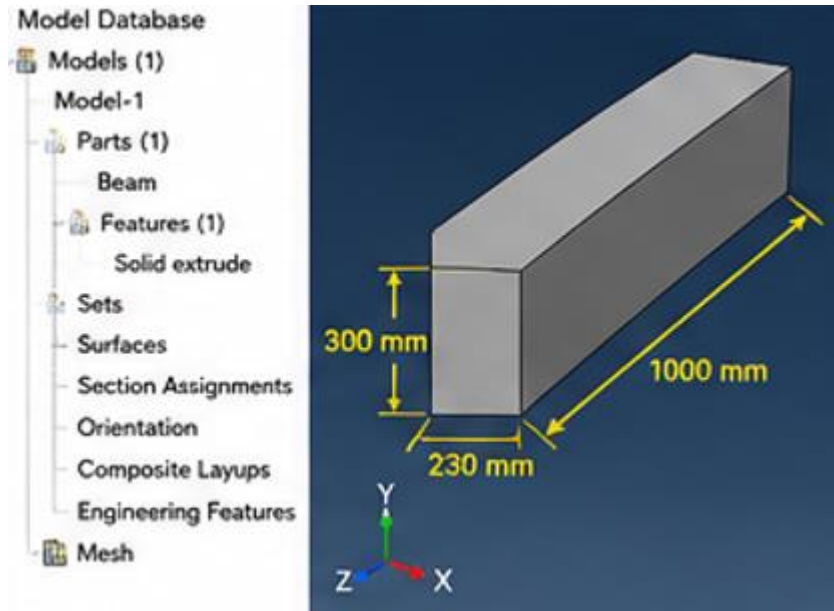


Figure 5.1 Geometry of Reinforced OPGC Beam Model in ABAQUS

The concrete material is defined using Mix 3 experimental values. Density is taken as 2100 kg/m³. Modulus of elasticity is taken as 28 GPa and Poisson ratio as 0.20. The compressive strength is taken as 45.8 MPa, split tensile strength as 4.1 MPa and flexural strength as 6.3 MPa. These values represent the experimentally selected OPGC material.

Density represents the mass of concrete per unit volume. Elastic modulus controls the initial stiffness and deflection response. Poisson ratio represents lateral strain behaviour. Compressive and tensile strengths define the nonlinear damage model. Steel reinforcement is assigned a modulus of elasticity of 200 GPa, Poisson ratio of 0.30 and yield strength of 500 MPa.

Table 5.1 ABAQUS Material Properties Used for Selected OPGC Mix

Property	Value used	Purpose
Concrete density	2100 kg/m ³	Mass density of OPGC
Concrete elastic modulus	28 GPa	Initial stiffness and deflection
Concrete Poisson ratio	0.20	Lateral strain behaviour
Compressive strength	45.8 MPa	Mix 3 cube test input

Split tensile strength	4.1 MPa	Crack initiation input
Flexural strength	6.3 MPa	Bending validation
Steel elastic modulus	200 GPa	Reinforcement stiffness
Steel yield strength	500 MPa	Fe500 steel behaviour

5.5 CONCRETE DAMAGE PLASTICITY MODEL

Concrete Damage Plasticity (CDP) model was used to represent nonlinear compression crushing and tensile cracking behaviour of geopolymer concrete in ABAQUS [11], [13]. The material properties such as density, elastic modulus, Poisson ratio, compressive stress-strain values and tensile cracking strain values obtained from experimental Mix 3 were assigned in the Property Module. The commands used included Create Material, Elastic Properties, Compression Hardening and Tension Stiffening options. The CDP parameters such as dilation angle, eccentricity, viscosity parameter and yield surface constants were also assigned to simulate realistic concrete damage behaviour. The output obtained from this stage included nonlinear stress response, tensile crack initiation, compression damage progression and stiffness degradation behaviour of the OPGC beam under loading condition.

Table 5.2 Concrete Damage Plasticity (CDP) Parameters Used in ABAQUS

Parameter	Value	Explanation
Dilation angle	30 degrees	Controls plastic volumetric expansion
Eccentricity	0.10	Controls plastic potential shape
f_{b0}/f_{c0}	1.16	Biaxial to uniaxial compressive strength ratio
K_c	0.667	Yield surface shape parameter
Viscosity parameter	0.0005	Improves convergence in nonlinear analysis

Compressive stress (MPa)	Inelastic strain	Comment
0	0.00000	Initial point
15	0.00020	Early nonlinear range
30	0.00075	Pre-peak response
40	0.00135	Approaching peak
45.8	0.00200	Peak compressive strength
38	0.00300	Post-peak softening
28	0.00450	Damage progression
Tensile stress (MPa)	Cracking strain	Comment
4.1	0.00000	Crack initiation
3.0	0.00008	Tension softening
2.0	0.00020	Post-cracking stress transfer
1.0	0.00050	Reduced tensile capacity
0.2	0.00100	Residual tension stiffening

Edit Material

Name: One Part Geopolymer Concrete (OPGC)

General Mechanical Thermal Other

Concrete Damage Plasticity

Density $\rho = 2100 \text{ kg/m}^3$

Elastic

E = 28 GPa

$\nu = 0.20$

Inelastic (CDP Parameters)

Dilation Angle (ψ) 30°

Eccentricity (ϵ) 0.10

f_{b0} / f_{c0} 1.16

Kc 0.667

Viscosity Parameter 0.0005

Figure 5.2 Material Property Input and Concrete Damage Plasticity Parameters in ABAQUS

5.6 REINFORCEMENT MODELLING

The reinforcement was modelled using embedded truss elements inside the concrete beam. Four bottom bars of 16 mm diameter, two top bars of 12 mm diameter and 8 mm diameter stirrups at 150 mm c/c spacing were assigned in the model to represent flexural and shear reinforcement [11], [13]. Wire geometry option was used to create reinforcement bars and truss element type was assigned for steel modelling. The Embedded Region constraint was used to create perfect bond assumption between concrete and reinforcement. The output obtained from this modelling stage showed proper interaction between steel and concrete, tensile stress resistance by reinforcement and improved flexural response of the beam.

Table 5.3 Reinforcement Details of OPGC Beam Model Used in ABAQUS

Reinforcement	Details	Purpose
Bottom bars	4 numbers of 16 mm dia	Main tension reinforcement
Top bars	2 numbers of 12 mm dia	Holding and compression side reinforcement
Stirrups	8 mm dia at 150 mm c/c	Shear reinforcement
Steel grade	Fe500	Yield strength 500 MPa
Bond assumption	Embedded region	Perfect bond between concrete and steel

5.7 ASSEMBLY AND INTERACTION

In the assembly module, the concrete beam and reinforcement are positioned correctly. The concrete is selected as the host region and the steel reinforcement is selected as the embedded region. This creates a perfect bond assumption between steel and concrete.

The embedded method is suitable for this project-level analysis because it represents composite action without complex bond-slip modelling. However, actual experimental beams may show some bond slip, so this assumption is mentioned as a limitation.

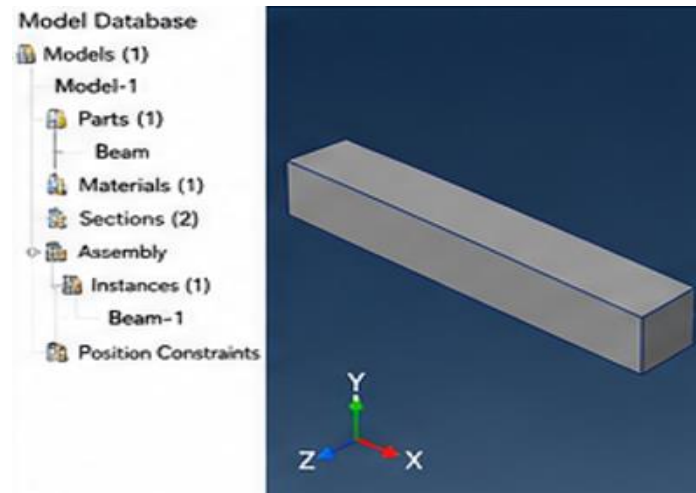


Figure 5.3 Assembly of OPGC Beam Model in ABAQUS

5.8 MESHING

Meshing was carried out to divide the concrete beam into smaller finite elements for numerical analysis. The concrete beam was meshed using C3D8R solid elements, while reinforcement bars and stirrups were meshed using T3D2 truss elements [11], [12]. In the Mesh Module, Seed Part, Assign Element Type and Generate Mesh commands were used. A global mesh size of 25 mm was selected to balance computational accuracy and convergence behaviour. The output obtained from meshing included accurate finite element discretization, better stress distribution observation, proper deformation tracking and improved convergence during nonlinear analysis.

Table 5.4 Mesh and Element Details Used in ABAQUS Analysis

Part	Element type	Mesh size	Reason
Concrete beam	C3D8R	25 mm	Solid concrete modelling
Longitudinal steel	T3D2	25 mm	Embedded reinforcement
Stirrups	T3D2	25 mm	Shear reinforcement modelling

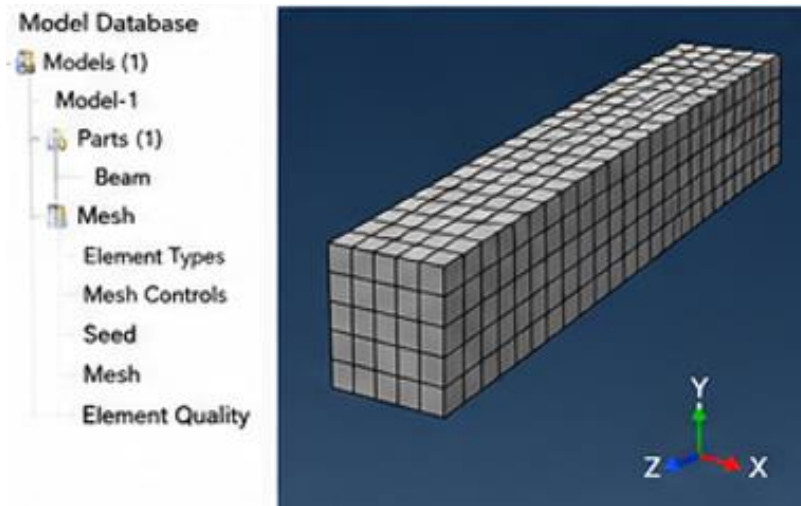


Figure 5.4 Meshing of Reinforced Beam Model in ABAQUS

5.9 BOUNDARY CONDITIONS

The beam was modelled as simply supported by assigning one end as pinned support and the other end as roller support [11]. In the Load Module, displacement and rotation boundary condition commands were used. The pinned support restrained horizontal and vertical movement, while the roller support restrained only vertical displacement and allowed horizontal movement. This support arrangement prevented artificial axial restraint during analysis. The output obtained from boundary condition assignment was realistic support behaviour, stable load transfer mechanism and proper bending response of the reinforced OPGC beam.

Table 5.5 Boundary Conditions Applied for ABAQUS Beam Analysis

Support	Restraint	Purpose
Left support	$U1 = 0, U2 = 0, U3 = 0$	Pinned support
Right support	$U2 = 0, U3 = 0$	Roller support
Rotation	Free as per solid model behaviour	Allows bending response

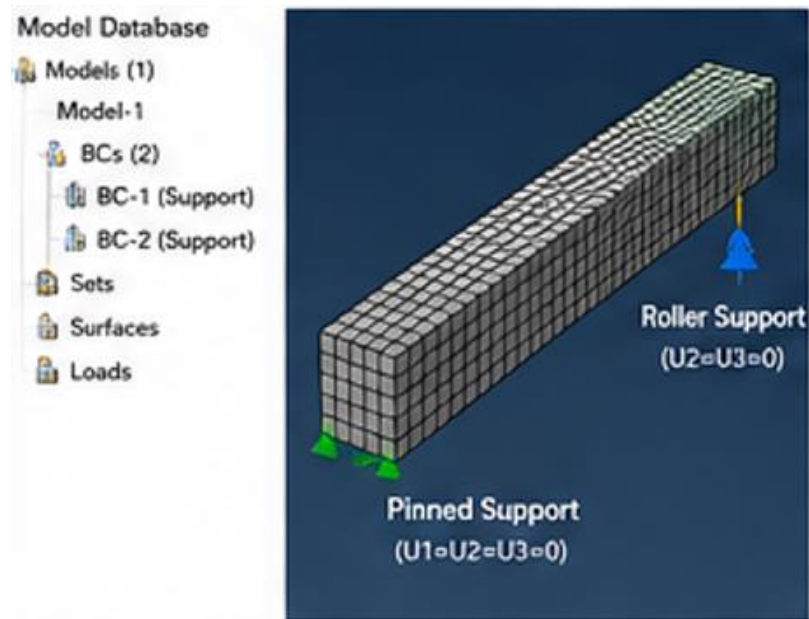


Figure 5.5 Boundary Condition Setup for Finite Element Analysis

5.10 LOADING CONDITIONS

A concentrated load was applied at the midspan of the beam in the downward direction to study flexural behaviour [11], [12]. In the Step Module, Static General analysis step was created and concentrated force command was used for load application.

The load was applied gradually with nonlinear increment control to improve convergence behaviour during analysis. The output obtained from this stage included midspan bending response, stress concentration at loading region, beam deformation behaviour and tensile cracking tendency near the bottom zone of the beam.

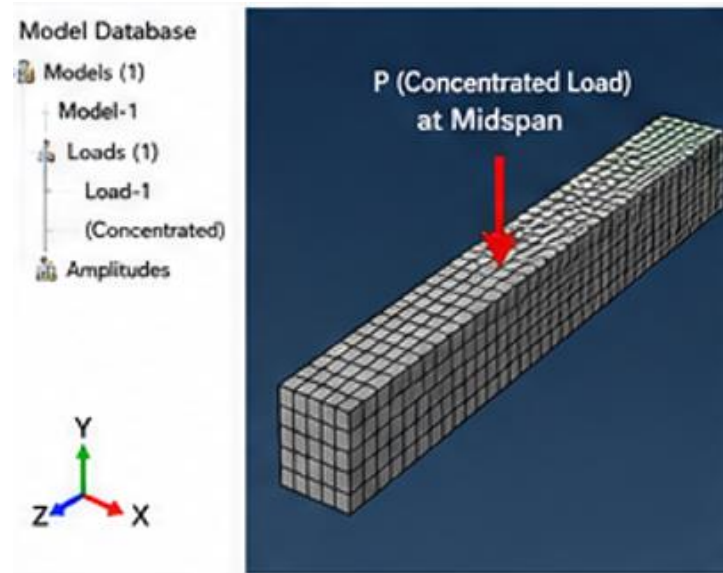


Figure 5.6 Application of Midspan Concentrated Load on OPGC Beam in ABAQUS

5.11 ANALYSIS PROCEDURE

The analysis was performed using Static General analysis with geometric nonlinearity activated in ABAQUS [11], [12]. Automatic increment control and viscosity regularization were used to improve convergence during nonlinear solution process. After assigning geometry, material properties, reinforcement interaction, meshing, supports and loading conditions, the analysis job was created and submitted in the Job Module. The results were viewed in the Visualization Module. The output obtained from the analysis included stress distribution contours, deformation response, tensile damage zones, crack initiation tendency, reinforcement stress behaviour and overall structural response of the reinforced one-part geopolymer concrete beam.

5.12 STRESS DISTRIBUTION

The stress distribution result obtained from ABAQUS showed that the maximum von Mises stress developed near the midspan region of the reinforced OPGC beam where the concentrated load was applied [11], [12]. Higher compressive stress was observed at the top portion of the beam, while tensile stress developed at the bottom region due to flexural action. The stress contour indicated proper load transfer between concrete and steel reinforcement through the embedded interaction model. The Visualization Module in ABAQUS was used to

observe the stress variation and deformation contour after completion of the nonlinear static analysis. The output confirmed that the beam behaviour was mainly governed by bending action and reinforcement resisted tensile cracking effectively. High stress concentration was also observed near the support and loading regions, which matched the expected theoretical behaviour of a simply supported reinforced beam [13].

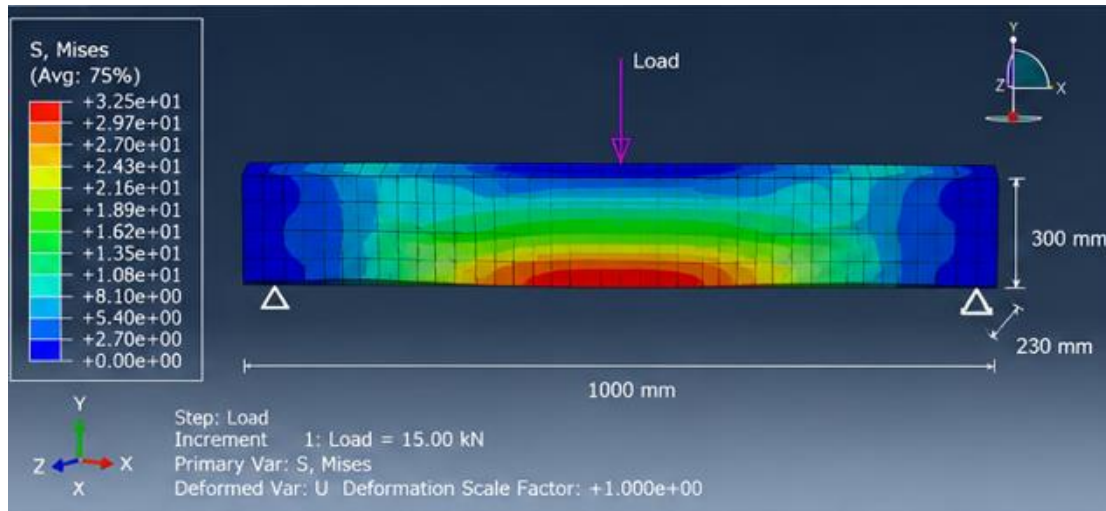


Figure 5.7 ABAQUS Analysis Results Showing Von Mises Stress Distribution and Deformed Shape of OPGC Beam

5.13 DEFLECTION

The deflection result obtained from ABAQUS showed that the maximum vertical displacement occurred at the centre of the beam where the midspan load was applied [11], [12]. The displacement gradually reduced towards the support regions because of the pinned and roller support conditions assigned in the model. The deformation shape observed in the Visualization Module confirmed the flexural response of the reinforced one-part geopolymers concrete beam. The deflected profile showed smooth curvature without sudden instability, indicating proper stiffness and load transfer behaviour. The reinforcement bars helped in controlling excessive deformation and improving the overall flexural response of the beam. The deformation contour obtained from ABAQUS also confirmed that the beam maintained structural continuity under applied loading condition [13].

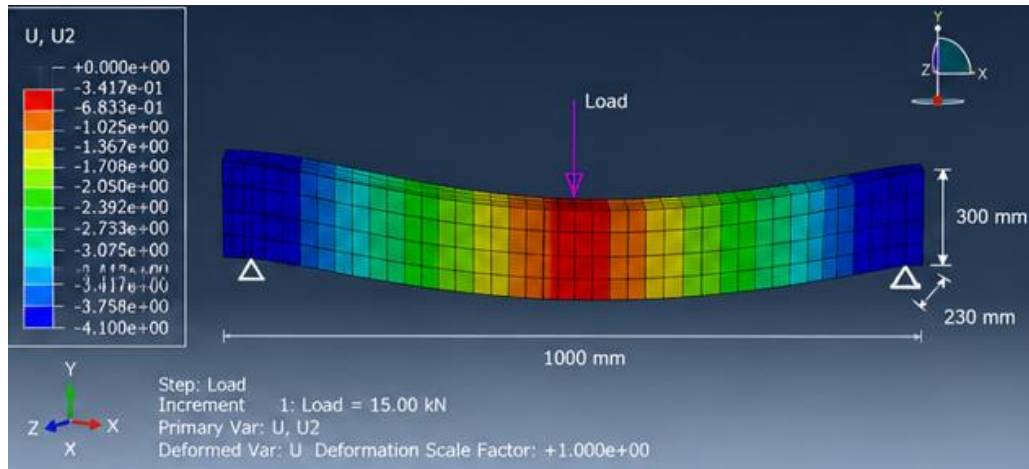


Figure 5.8 ABAQUS Deflection Contour Showing Midspan Deformation of Reinforced OPGC Beam

CHAPTER 6

6. CONCLUSION

6.1 GENERAL

This chapter presents specific conclusions .

6.2 SPECIFIC CONCLUSION

The present study concludes that one-part geopolymer concrete is a practical and sustainable binder system when proper mix proportioning is adopted [1], [3]. The replacement of ordinary Portland cement with fly ash and GGBS reduced dependence on cement and supported industrial by-product utilization, thereby contributing to reduction in CO₂ emissions and embodied carbon of construction materials [2], [10]. The one-part geopolymer system also simplified the mixing procedure because dry activator and source materials were mixed directly with water during batching [4], [6]. Among the four trial mixes, Mix 3 was identified as the optimum mix after completing fresh and hardened concrete tests. The mix showed balanced workability, compactability and strength characteristics. The higher GGBS content improved strength development, while the sodium metasilicate activator provided effective geopolymerisation reaction [7], [8]. The compressive strength, split tensile strength and flexural strength results confirmed that Mix 3 was suitable for structural application and numerical analysis [20], [21]. The ABAQUS finite element analysis successfully demonstrated the transfer of experimental material properties into a reinforced beam model [11], [12]. The beam geometry remained separate from the material specimen geometry because cube, cylinder and prism tests were used only for obtaining material properties. The reinforced beam with dimensions of 230 mm × 300 mm × 1000 mm was analysed to study stress distribution, deformation behaviour and reinforcement interaction under loading condition [13]. The analysis confirmed that the reinforcement effectively resisted tensile stress and improved flexural behaviour of the OPGC beam.

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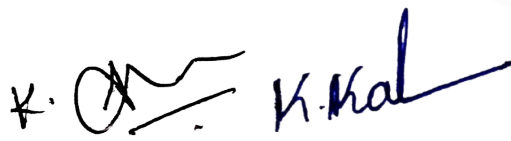
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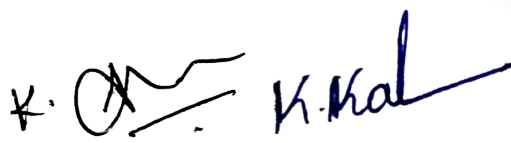
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