STRENGTH STUDIES ON ULTRA HIGH PERFORMANCE GEOPOLYMER CONCRETE

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Abstract - — *Concrete is most frequently used composite material. Concrete is homogeneous mix of fine aggregate, Coarse aggregate and binding medium of concrete paste. Due to high demand of cement Co2 emission is very high, it leads to global warming. So, in this project to eliminate the carbondioxide emission, cement is fully replaced with Flyash and GGBS. Ultra High Performance concrete is a unique class of concrete that has been flourished in recent decades for its exceptional properties of strength and ductility. Geopolymer concrete combines an alkaline liquid with geological source material containing silicon and aluminium to form a binder that does not use any Portland cement. By combining the above two concrete the strength properties can be increased. From the past studies the content of silica fume and steel fibers were calculated. Here four different mixes were produced based upon the To investigate the strength properties several tests like compressive strength, Split tensile strength, Flexural strength test were studied. The main outcome of this study to increase the strength and ductility properties. Modelling and Finite element analysis of beam is done using ANSYS software and its results were discussed.*

***Key Words*: Flyash, GGBS, Steel fibre, Glass fibre, Polypropylene fibre, Ultra High Performance Concrete, Geopolymer concrete.**

1.INTRODUCTION

All the construction materials such as cement , sand and coarse aggregate are obtained directly from natural sources. Due to infrastructure development there is a huge requirement to meet the demand. Concrete being a most preferred material for construction is used in many industries. this increases the depletion of the available natural resources. The increased production of cement causes environmental effects.

As a material on the leading edge of concrete innovation, Ultra high performance concrete provides a new products and solutions. By combining Portland cement, supplementary cementitious materials, reactive powders, limestone and quartz flour, fine sand, high range water reducers and water UHPC is produced. These materials are combined to provide minimum compressive strength of 120 MPa to 150 MPa, flexural strength of 15 MPa to 25 Mpa. For aesthetic purpose, In the matrix the usage of fine material provide a dense and smooth surface. UHPC construction is simplified by eliminating the need for reinforcing steel in some applications and the material high flow characteristics that make it self compacting. By reacting aluminate and silicate bearing materials with caustic activator geopolymer concrete is made. Commonly, waste material such as flyash or slag from iron and metal production are used, which helps leads to cleaner environment. Heat is not required to produce Geopolymer concrete.

Ultra high performance concrete typically made with high strength steel fibers etc. which is more expensive than conventional concrete. It provides excellent protection of embedded steel reinforcement and it is highly durable.

The U.S Army corps of Engineers were the first users of Ultra high performance concrete in the year 1980 and in 2000 it is easily available in USA. In 1997 For the construction of pedestrian bridge, it was first used in North America. Davidovits is the person who first introduce the term geopolymer for the mineral binders whose chemical composition is similar to zeolites but varying microstructure.

Geopolymer contains geological source materials and alkaline liquids as two main constituents. By product materials like Flyash, GGBS, Red mud etc., are the geological materials and they should be rich in both silicon and aluminium. Sodium hydroxide, Sodium silicate, Potassium hydroxide etc., are the alkaline liquids. In china an unique invention which is low cost geopolymer based UHPC, called as ultra high performance geopolymer concrete where for replacement of Portland cement geopolymer composites in conventional UHPC. Due to the higher compressive strength, higher tensile strength with ductility, Increased durability and higher initial unit cost. The above two concrete types are combined to achieve high strength properties. The main advantage of combining the above concrete types is that the whole cement contentcontent is replaced by Flyash and GGBS and the CO2 emission is reduced. The effect of replacing the steel fibers by different fibers (Glass and polypropylene fiber) is investigated in this study.

2. OBJECTIVE

a. To study the strength characteristics of ultra high performance geopolymer concrete

b. The main objective is to replace whole cement content using Flyash and GGBS to produce ultra high performance geo polymer concrete.

c. To investigate the behaviour of ultra high performance Geopolymer concrete by studying its basic properties.

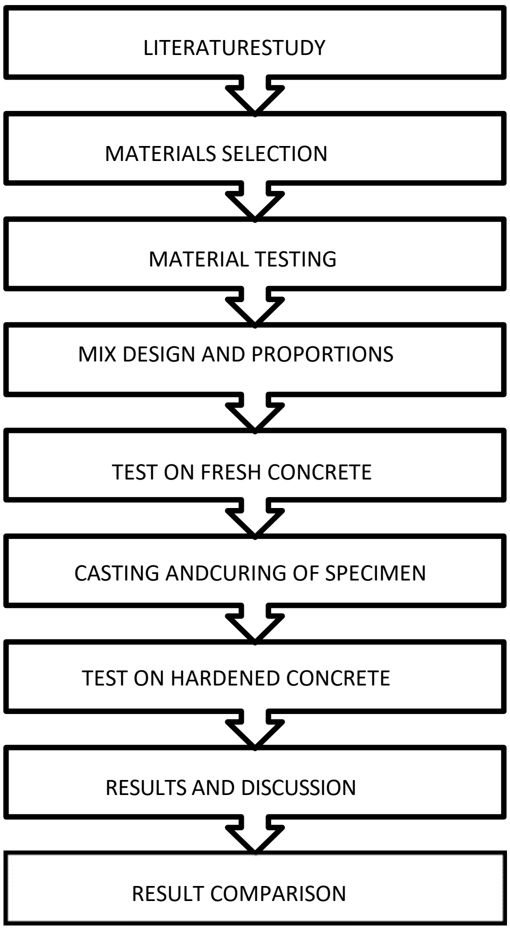
3. SCOPE

a. To increase the strength and durability properties of geopolymer UHPC

b. To examine the outcome of using steel fibre, glass fibre and polypropylene fibres on strength properties of Geo polymer UHPC.

c. To investigate the behavior of geopolymer UHPC, modelling and analysis of UHPGC is done using ANSYS.

4. METHODOLOGY



5. MATERIAL USED:

5.1 ORDINARY 5.1 PORTLAND CEMENT:

One of the most commonly used Portland cement type is Ordinary Portland cement. Cement is a bonding agent with cohesive and adhesive properties that allows it to bind together various construction materials and form a compacted assembly. Cement is a fine grey powder that can be mixed with water to make a paste. To make concrete, the cement is mixed with water and other materials including sand, gravel, and crushed stone. Ordinary cement is made up of two main ingredients: argillaceous and calcareous. Clay predominates in argillaceous materials, while calcium carbonate predominates in calcareous materials.

Table -1: Physical properties of cement

Sl.No	Physical properties	OPC (53)
1	Initial setting time	**35 min**
2	Final setting time	**560 min**
3	Specific gravity	**3.15**
4	Standard consistency	**30 %**
5	Compressive strength	**53 M Pa**

Table -2: Chemical properties of cement

Sl.No	Chemical properties	OPC (53)
1	C3S	45–75%
2	C2S	7–32%
3	C3A	0–13%
4	C4AF	0–18%
5	Gypsum	2–10%

5.2 FLYASH

Flyash that results from burning sub-bituminous coals is referred to as ASTM Class C fly ash or high-calcium fly ash, as it typically contains more than 20 percent of CaO. On the other hand, fly ash from the bituminous and anthracite coals is referred to as ASTM Class F fly ash or low- calcium fly ash. The main constituent is aluminosilicate glass and it contains less than 10 percent of CaO. The colour of fly ash can be turned to dark grey, depending upon the chemical and mineral constituents.

Table 3 Physical properties of flyash

Sl. No	properties	CLASSF FLYASH
1	Bulk density	**1.2 g/cc**
2	Specific gravity	**2.3**
3	Porosity	**50 %**

Chemical properties	CLASS F
SiO2	**58**
Al2O3	**26.32**
CaO	**3.6**
SO3	**1.8**
Na2O	**2**
MgO	**1.91**

Table 4 Chemical properties of Flyash

5.3 GROUND GRANULATED BLAST FURNACE SLAG:

GGBFS is the recyclable green material and is the by-product of iron, steel and ground iron slag blast furnaces and during the iron production the raw material used which is major composition. Its other composition are silicates, aluminates, CaO and MgO. The concrete structure which are surviving in the high temperature (450˚) must face dehydration, permeability, thermal expansion and cracking problems as a results, reduction in strength and increased porosity affects the concrete structures. The loss of strength will be 15-20 % at at elevated temperature. The slag cement added as a partial replacement of cement (up to 40%) had higher compressive and flexural strengths than normal concrete modified by Portland cement. The GGBFS modified concrete structures using iron slag is a sustainable construction materials for pavements, pipes, foundation and for marine applications.

Table 5 Physical properties of GGBFS

Sl.No	Physical properties	GGBFS
1	Specific gravity	**2.9**
2	Bulk density	**900 kg/m³**
3	Colour	**Off white**
4	Fineness modulus	**400 m²/kg**

Table 6 Chemical properties of GGBFS

Sl.No.	Chemical properties	GGBFS (%)
1	CaO	**40**
2	SiO	**35**
3	Al2O3	**12**
4	MgO	**8.2**
5	Fe2O3	**0.2**

5.4 FINE SAND :

Due to high demand of river sand in concrete construction, Manufactured sand (M-Sand) is discovered as a substitute. By crushing the hard granite stone M Sand is produced and its size is less than 4.75 mm .The resulted crushed sand is of cubical shape with grounded edges. It is washed , uniformly graded and used as a construction material.The sand whose specifications are conforming to Indian Standard Specifications IS: 383- 1970 is used as fine aggregate.

Table 7 Physical properties of M Sand

Sl. No	Physical properties	M SAND
1	Bulk density	15.1 kN/m³
2	Specific gravity	2.63
3	Water absorption	2.2

Table 8 Physical properties of M Sand

Sl.No	Chemical properties	M sand (%)
1	Sio_2	**99.7**
2	Al_2o_3	**0.14**
3	Fe_2o_3	**0.016**
4	K_2o	**0.04**

5.5 WATER :

Generally, drinking water, lakes and stream water that contain marine life are most suitable for concrete use. We does not need any sample water when water is obtained from above sources. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries, it should not be used in concrete unless tests indicate that it is satisfactory. Water from such sources should be avoided since the quality of the water could change due to low water or by intermittent tap water is used for casting. Ordinary portable water is used for mixing and curing the concrete specimen.

5.6 SILICA FUME :

Silica fume was used as dry and non compacted form in most of the concrete mixtures. The silica fume had a silicon dioxide content of 90%, and a specific surface area of 18-20 m2/g. The chemical composition of silica fume used in this experimental program are shown. For filling voids and to enhance mechanical and durability properties of concrete, silica fume is used. Generally, the size range of silica fume os from 0.1μm to 1μm.

Table 9 Physical properties of Silica fume

Sl.No	Physical properties	Silica fume
1	Specific gravity	**2.2**
2	Bulk density	**240 kg/m³**
3	Colour	**Dark grey**
4	Fineness modulus	**20000m²/kg**

Table 10 Chemical properties of Silica fume

CHEMICAL COMPOSITION	SILICA FUME CONTENT (%)
SiO2	90
Al2O3	1
Fe2O3	1
CaO	0.4
MgO	1
Cl	2

5.7 QUARTZ POWDER :

Quartz is a hard, crystalline chemical compound consisting of one part silicon and two part oxygen atoms which are linked in a continuous framework of SiO2 silicon-oxygen tetrahedral.Quartz is commonly known as silica sand for producing float glass, fibre glass, automotive glass and other types. Quartz has its important applications in the electronic industry. Quartz powder is also used in making porcelain, scouring soaps, sandpaper, wood fillers and with solar panels

Table 11 Physical properties of Quartz powder

Sl. No	Physical properties	Quartz powder
1	Colour	**White to grey powder**
2	Melting point	**1660-1710 °C**
3	Density	**2.2 g/cm^3**

Table 12 Chemical properties of Quartz powder

CHEMICAL COMPOSITION	QUARTZ (%)
SiO2	99.5%
Al2O3	0.08%
TiO2	0.04%
CaO	0.01%
MgO	0.01%
L.O.I.	0.28%
Alkalies	0.29%
Fe2O3	0.04%
MESH	100M

5.8 STEEL FIBRE

Steel fibre of diameter 0.2mm and length 13mm is used in this study. The size are taken from the past studies and literature. To increase the strength of the concrete pavement steel fibres are used.

Table 13 Physical properties of Steel fibre

Sl.No	Physical properties	Steel fibre
1	Length	13mm
2	Diameter	0.2mm
3	Density	7800 kg/m^3
4	Tensile strength	2600 Mpa

5.9 GLASS FIBRE

The material made from fine fibres of glass are light weight, extremely strong and robust material which is Glass fibre and is also called fibre glass. It is easily formed using molding process and its properties are more favorable. Addition of glass fibres of about 10% by volume increased the tensile strength by roughly two times, and the impact resistance by about 10 times. Its diameter ranges from 5 to 24 µm and its length is 6mm .

Table 14 Physical properties of Glass fibre

Sl.No	Physical properties	Glass fibre
1	Length	13mm
2	Specific gravity	2.68 g/cm^3
3	Density	2.59 g/m^3
4	Tensile strength	26001700 Mpa

5.10 POLYPROPYLENE FIBRE

Polypropylene is a 100% synthetic textile fibroid is formed by about 85% propylene. The monomer of polypropylene is propylene. Propylene is a by-product of petroleum. It is cheap in price than polyester. It is used as the alternatives of plastic. This polypropylene is harmful for the environment because it is non degradable with soil. Also it is not decomposed by water for this region it is used in concrete. Fibrillated polypropylene fiber of length 12mm and diameter 34 micron and low density of 0.9 KN/m3 was used in this project. By using this fibre there is a slight increase in strength properties of concrete.

Sl.No	Physical properties	Polypropylene fibre
1	Length	13mm
2	Diameter	34 micron
3	Density	0.9 kN/m^3
4	Tensile strength	500 Mpa

Table 15 Physical properties of Polypropylene Fibre

5.11 ALKALINE SOLUTION

A combination of commercially available 98% pure sodium hydroxide (pellet form) and sodium silicate (liquid gel form) was used as alkaline activators for geopolymerization.

A) SODIUM HYDROXIDE PELLETS:

Sodium hydroxide are available in the form of pellets and flakes. The cost of the sodium hydroxide is mainly varied according to the purity of the substances. In this investigation the sodium hydroxide pellets form were used. Whose chemical property and physical property are given by manufacturer are as follows for solid sodium hydroxide pellets. The physical and chemicall properties are given below.

Table 16 Physical properties of NaOH Pellets

Sl. No	Physical properties	NaOH
1	Colour	colourless
2	Specific gravity	2.13
3	Ph	14

Table 17 Chemical properties of NaOH Pellets

Sl.No.	Chemical properties	Na_2Sio_3
1	Na2CO3	2
2	Cl	0.01
3	SO2	0.05
4	Pb	0.001
5	Fe	0.001

B) SODIUM SILICATE SOLUTION:

Sodium silicate is available in form of liquid (gel) form and is also called as water or liquid glass.

Table 18 Physical properties of Na_2Sio_3 solution.

Sl. No	Physical properties	Na_2Sio_3
1	Specific gravity	1.6
2	Boiling point	102 ℃ for aqueous solution
3	Molecular weight	184.04

Table 19 Chemical properties of Na_2Sio_3 solution.

Sl. No	Chemical properties	Na_2Sio_3
1	Na2O	15.9
2	SiO2	31.4
3	H2O	52.7

5.12 SUPER PLASTICIZER

Super plasticizer is also known as water reducer. It increases the workability of geopolymer concrete. Superplasticizer used in this project is **conplast SP430**. It suitable for use with all types of portland cement, and cement replacement materials.

6. MIX DESIGN AND PROPORTIONS OF UHGPC :

Design stipulations

a) Characteristic compressive strength = 150MPa

b) Maximum size of aggregate (angular) = 10mm

c) Specific gravity of fly ash = 2.3

d) Specific gravity of GGBS = 2.83

e) Specific gravity of fine aggregate = 3.1

f) Sand conforming = zone III

g) Specific gravity of NaOH = 1.47

h) Specific gravity of Na2Sio3 = 1.6

Step 1: Selection of binder and aggregate

From the literature studies, the content of binder and aggregate are taken as 712 Kg/m^3 and 1020 kg/m^3

Content of Binder:

Fly Ash = 0.50 × 712 = 356 kg/m^3

GGBS = 0.50 × 712 = 356 kg/m^3

Step 2: Selection of alkaline/binder Ratio

The alkaline-binder ratio is taken as 0.5 and the optimum ratio of Na2SiO3/NaOH is taken as 2.5 and 12 M NaOH solution is considered which is taken from the past studies.

Step 3: Calculation of Alkaline Content

The total alkali liquid is calculated by multiplying the Alkaline/Binder ratio to the total binder content.

Alkaline Content = Alkaline binder ratio x Binder content

= 0.5 x 712

= 356 kg/m^3

Step 4: Calculation of NaOH and Na2sio3 Content

Considering the ratio of Na2SiO3/NaOH as 2.5, the quantity of individual alkaline liquids can be calculated,

Alkaline solution = NaOH + Na2SiO3 Na2SiO3/NaOH solution = 2.5 Na2SiO3 = 2.5 NaOH

NaOH solution = 356/3.5 = 101.7 kg/m^3 Na2SiO3 Solution = 2.5 × 101.7 = 242.85 kg/m^3

Step 5:Determination of Silica Fume Content

Silicafume =10% (Binder + aggregate + Alkaline)

= 10/100 (712 + 1020 +356)

=208 kg/m^3.

Step 6:Determination of Quartz powder Content

QuartzPowder =10% (Binder + aggregate + Alkaline)

= 10/100 (712 +1020 +356)

=200 kg/m^3

Step 7: Determination of Steel fibre Content

Steel fibre = 3% (Binder + aggregate + Alkaline)

= 3/100 (712 +1020+356)

= 62.64 kg/m^3

Step 8: Determination of Super Plasticizer Content

Super plasticizer = 1% of Binder content

= 7.12 L/m^3

Step 9:Determination of Excess Water Content

Excess Water Content = 12% of Binder Content

= 12/100 (712)

= 85.44 L/m^3

Table 20 Mix proportions for UHPGC

MATERIALS	PROPORTIONS
Binder Content	712 kg/m^3
Alkaline	356 kg/m^3
Alkaline/Binder Content	0.5
NaOH	101.7 kg/m^3
Na2Sio3/NaOH	2.5
Na2Sio3	254.2 kg/m^3
Fine Aggregate	1020 kg/m^3
Silica Fume	208 kg/m^3
Quartz powder	200 kg/m^3
Steel Fibre	62.64 kg/m^3
Super plasticizer	7.12 l/m^3
Extra Water Content	85.44 l/m^3
Water Binder ratio	0.22

Table 21 Mix proportions for UHPGC

BINDER CONTENT	FINE AGGREGATE	W/B RATIO
712 kg/m^3	1020 kg/m^3	0.22

BINDER CONTENT	FINE AGGREGATE	W/B RATIO
1	1.432	0.22

7. FRESH CONCRETE TEST :

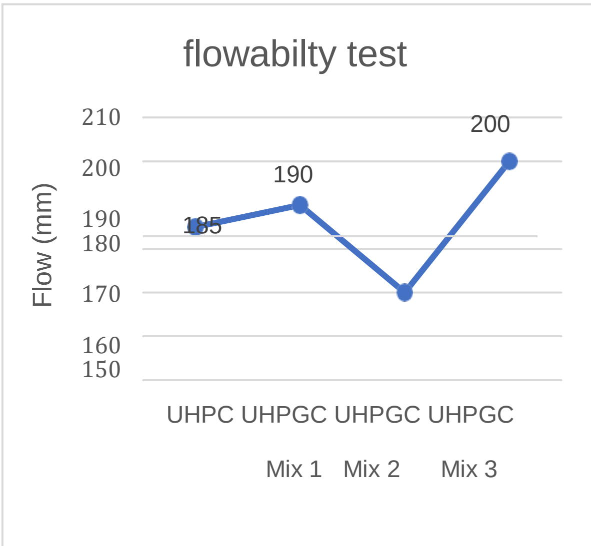
7.1 SLUMP CONE TEST:

The most commonly used test to determine the consistency and workability of concrete is Slump cone test. In this project the slump testis carried out for four different mixes of UHPGC containing different fiber. The Flowabiliy values for different mixes were shown below.

Table 22 Flowability of UHPGC

SPECIMEN TYPE	SLUMP FLOW VALUES
UHPC	185 mm
UHPGC MIX 1: UHPGC + Steel Fibre (3%)	190 mm
UHPGC MIX 2: UHPGC+ Glass Fibre (3%)	170 mm
UHPGC MIX 3: UHPGC+ Steel Fibre (2%)+ Polypropylene Fibre (1%)	200 mm

Chart 1 Graph showing the flow values of UHPGC



8. HARDENED CONCRETE TEST :

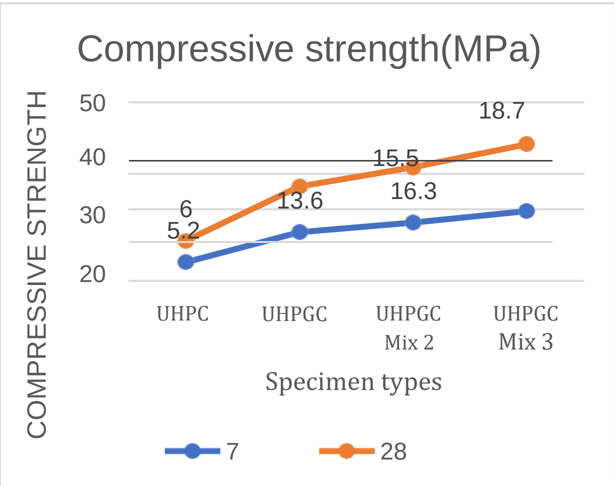
8.1 COMPRESSIVE STRENGTH TEST:

The test used to calculate the maximum load bearing capacity of concrete is compressive strength test. Here rhe cube specimen of size 150 x 150 x 150 mm is used. Usual range of strength value is 120 to 150 M Pa. In comparison with normal concrete it is 10 times stronger. The strength at 7 day and 28 day is taken. The strength results for different mixes is shown below.

Table 23 Compressive strength of UHPGC

TYPES OF SPECIMENS	COMPRESSIVE STRENGTH (N/mm²)	
	7 days	28 days
UHPC	98.8	152.4
UHPGC MIX 1: UHPGC + Steel Fibre	100.75	155.6
UHPGC MIX 2: UHPGC+ Glass Fibre	102.7	158.9
UHPGC MIX 3: UHPGC+ Steel Fibre+ Polypropylene Fibre	107.25	165.3

Chart 2 Graph showing the compressive strength values of UHPGC



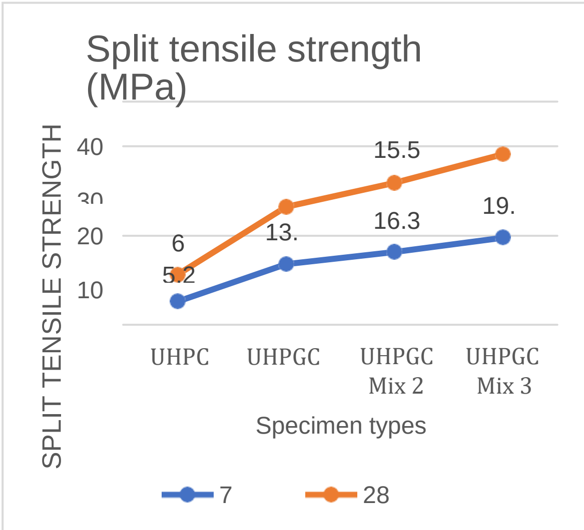
8.2 SPLIT TENSILE STRENGTH TEST:

The indirect method to determine the tensile strength of concrete, split tensile strength is carried out. For determining the tensile strength, cylinder specimen is tested. The diameter and height of cylinder specimen 150mm and 300 mm. The test is carried out at age of 7 days and 28 days. The tensile strength results for different mixes are shown below

Table 24 Split tensile strength of UHPGC

TYPES OF SPECIMENS	SPLIT TENSILE STRENGTH (N/mm²)	
	7 days	28 days
UHPC	33.5	38.4
UHPGC + Steel Fibre	20.1	24.3
UHPGC+ Glass Fibre	24.6	30.8
UHPGC+ Steel Fibre+ Polypropylene Fibre	41.5	45.6

Chart 3 Graph showing the split tensile strength values of UHPGC



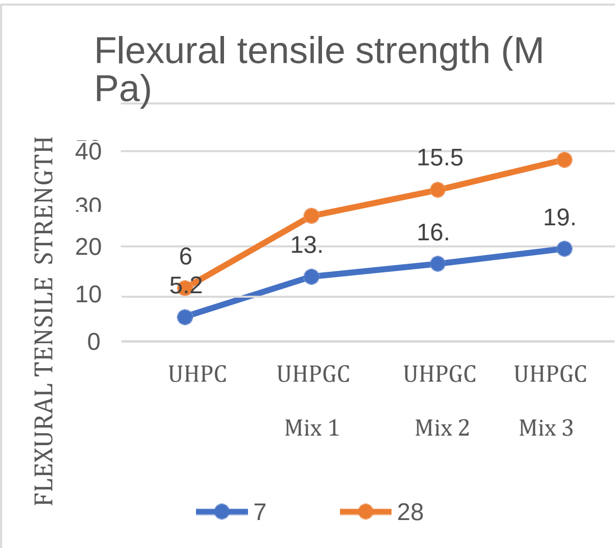
8.3 FLEXURAL STRENGTH TEST:

It is also used to determine the flexural tensile strength, But it is carried out in concrete beam or slab. It is about 10 to 20 percent of compressive strength depends on material composition. The specimen size is 100 x 100x 500 mm. The test were carried out at the age of 7 days and 28 days. The flexural results for mixes are shown.

Table 25 Flexural strength of UHPGC

TYPES OF SPECIMENS	FLEXURAL STRENGTH (N/mm²)	
	7 days	28 days
UHPC	5.2	6.0
UHPGC + Steel Fibre	13.6	12.8
UHPGC+ Glass Fibre	16.3	15.5
UHPGC+ Steel Fibre+ Polypropylene Fibre	19.5	18.7

Chart 4 Graph showing the split tensile strength values of UHPGC



9. MODELLING AND ANALYSIS IN ANYSYS :

The most commonly used methos for solving engineering and mathematical models is finite element method (FEM). The FEM divides a large system into smaller and simpler parts called finite elements while solving problem. ANSYSWorkbench is acommon platform for solving engineering problems. Basically, we use the DesignModel to create the geometry and the Simulation to set up the materials. This modelling technology consists of three stages namely,pre processing,analysis and post processing. The charateristic study of load deflection and creation of analytical beam model isdone using ANSYS workbench.

Fig 1 Modelling of UHPGC Beam

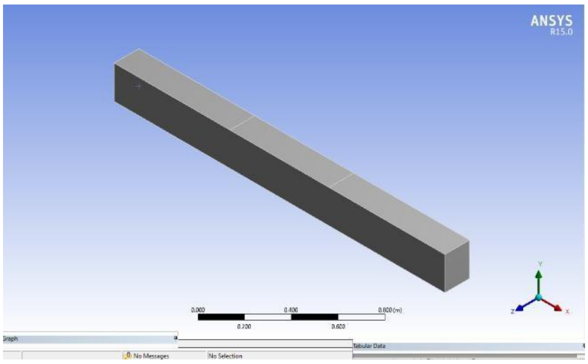


Fig 2 Maximum and Minimum deformation of UHPGC Beam

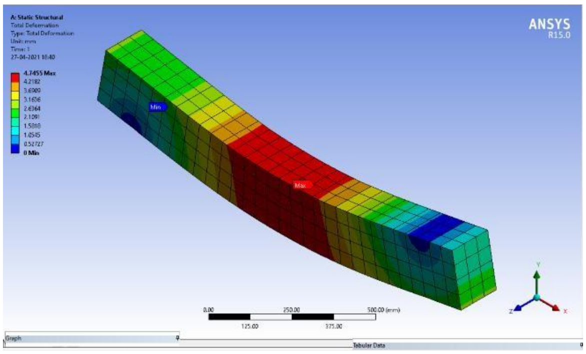
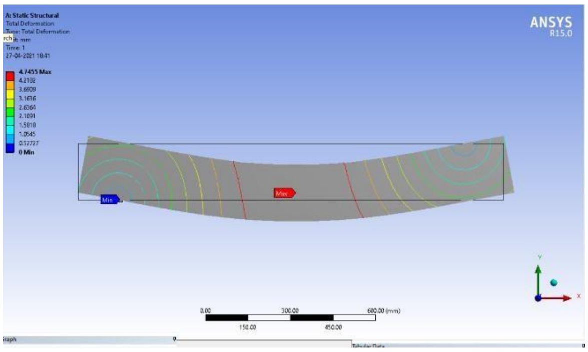


Fig 3 Total deformation of UHPGC Beam



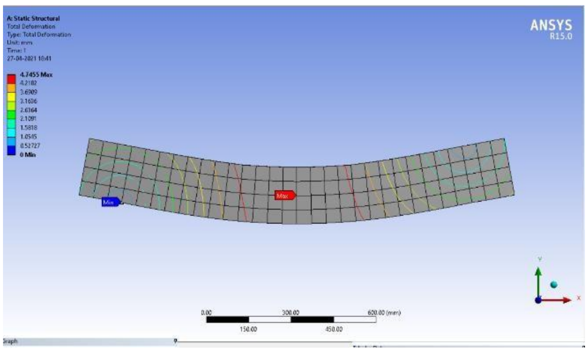


Fig 4 Total deformation of UHGPC Beam

Fig 5 Stress pattern of UHPGC Beam

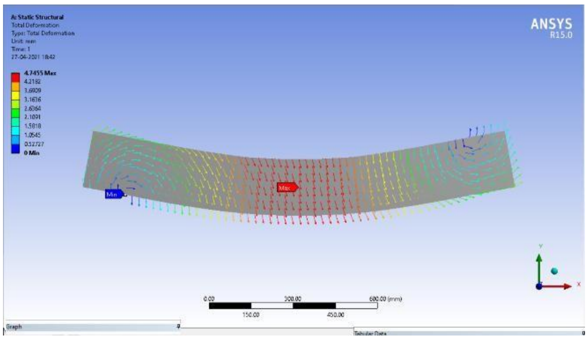


Fig 6 Maximum principal stress

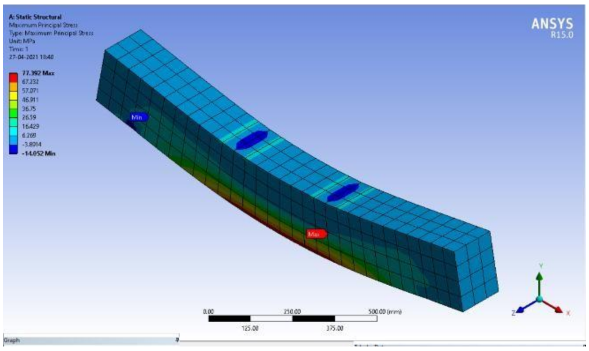


Fig 7 Minimum principal stress

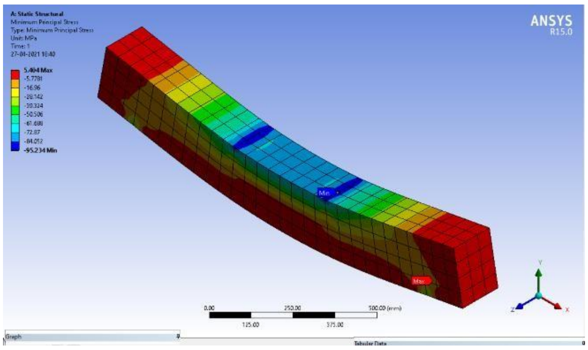


Fig 8 Equivalent stress

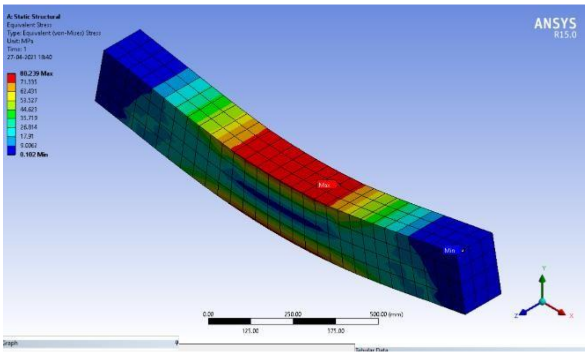


Fig 9 Maximum principal elastic strain

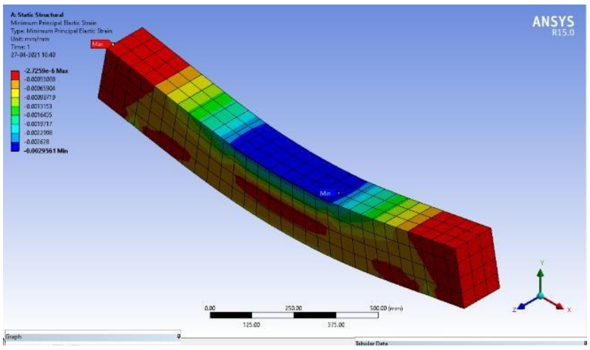
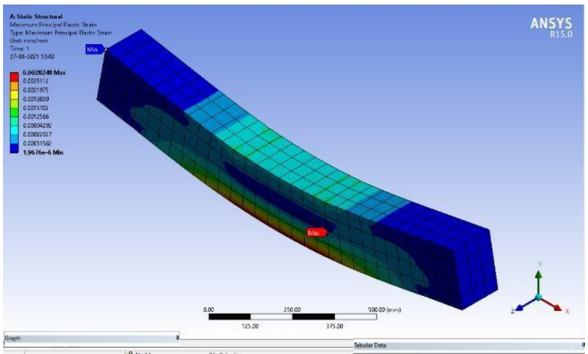


Fig 10 Minimum principal elastic strain



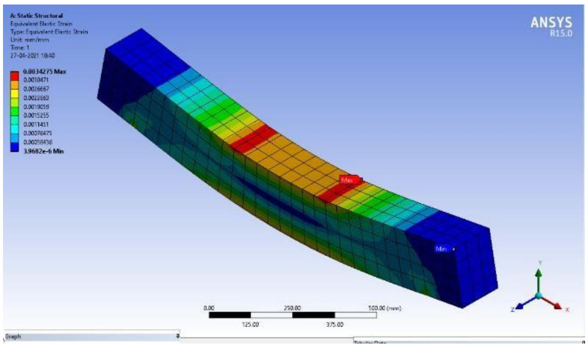


Fig 11 Equivalent elastic strain

10. CONCLUSIONS

1) UHPC using geopolymer as high strength binder was successfully developed and the influences of different fiber content, have been studied.The flowability decreased with the increase of fiber dosage..
2) The increase of steel fiber content could improve the mechanical and fracture properties of UHPGC including the compressive strength, elastic modulus, splitting tensile strength, flexural behavior, fracture energy and stress intensity factor.
3) Increasing steel fiber dosage resulted in the decrease of workability of UHPGC. The workability could be improved with the incorporation of 10% silica fume,

4) Minimum maintenance due to superior durability (providing immediate savings in costs for repair and rehabilitation)
5) Reduction in overall CO2 emissions, embodied energy in material consumption for UHPC and total elimination of the use of Portland Cement for UH
6) Saving in the total life-cycle cost, which helps to relieve the future national economies.
7) The test results shows that the UHGPC with steel and polypropylene fibre provide higher compressive, flexural and split tensile strength.The investigation results shows that UHPC with steel and polypropylene fibre possess high flow value.
8) The analytical flexural behaviour of UHPGC beam is obtained by Finite Element Method (FEM) modal software (ANSYS).

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